Evolutions in Hydrography

Proceedings

6th - 9th November 2006

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Contents

Hydro 2006 - Innovations in Hydrography

As I write these words we just have finished celebrating the first (in history) international hydrography day at the 21st of june at the relocated Netherlands Navy Hydrographic Office in the Hague. I Started my career in the late 80's at this same office so I met on this special occasion, together with various HSB society members, former colleagues from that time. Many of these persons still active in the service, looking only a bit older but still exciting the profession and its evolution. A new ambiance but still the same spirit. This is what I can tell a global common feeling among many of us working as professional hydrographers in no matter what part of the profession. Embrace the changes of the future and preserve the good things from the past. That is just what grand leaders and so grand hydrographers of past and present time did and can do. They push forward the profession.

Passed this event, I am aware of the time pressure that is now becoming more sensible relating to the upcoming event in early November this year. As organizing committee we are aware that we have an obligation to host the international hydrographic community a truly memorable conference in 2006. An event that will not only present valuable and interesting stories from the members of our community but will also host an atmosphere in which we can feel ourselves comfortable in communicating on various levels in different directions. Meet old and new members, build relations and have good and memorable conversations perhaps with a beer (or two). And beer is one of the things the Belgians are famous for.

The international community has moved to new challenges since the federation was formally established during the last Hydro 2004 in Galway, Ireland. Contents and techniques are some of those challenges, however relations and beneficial cooperation require even more energy. The "initial five" are to be extended with other national societies and establishing strong relationship with other related societies. During the Hydro 2006 event the MoU with the IHO will be signed and formalized. This will result in forming a stronger global federation in which the profession of hydrography will be served to its best. "Find what unites us and learn from what is separating us". After all, we are a learning society.

It is therefore that the organizing committee is doing its best to establish all this. We are confident that we can do this. Perhaps in a different way as it was done in the past but nevertheless with the same objectives and sense of an "expected level of quality".

The party-chief and surveying crew of the Hydro 2006 which has just solved the question of the "Giant Druoon Antigoon Myth" will welcome you all at the 6th of November. We are looking forward to this event! Are you?
www.hydro06.com

Regards,

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Case Studies

Processing Methods For Single Beam Echo Sounders

Plough Marks And Sediment Characterisation In The North Sea

J. Janmaat, P.A. van Walree, M.A. Ainslie, D.G. Simons, and C.H. Harrison

Acoustical measurements by single beam echo sounders in the Cleaver Bank area of the North Sea are described. The water depth in the region of interest is about 35 m and the echo sounder frequencies are between 12 and 200 kHz. The data are processed in a number of different ways, each highlighting different features of the seabed. Regions of different morphology can be distinguished when the difference in travel time between two different echo sounder frequencies is plotted versus geographical position. This travel time difference is correlated with grain size, as determined by grain size analysis of available grab samples, which provides a useful clue for automated sediment classification algorithms. Maps of reflected energy or of echo duration show distinctive tracks of width up to 40 m and length up to 5 km. The tracks are not visible in bathymetry maps of the same lateral resolution. We hypothesise that the tracks are regions where the sediment is upset by some anthropogenic activity – such as beam trawler fishing. If this hypothesis is confirmed it may be possible to use similar maps to monitor the activities of the vessels involved in the activity.

Introduction

The present paper describes echo sounder experiments in the Cleaver Bank area in the North Sea. The acoustic data under examination were acquired with the HNLMS *Luymes*, a hydrographic survey vessel of the Royal Netherlands Navy, in December 2004. A triple-frequency echo sounder was used, operating at 12, 38, and 200kHz. The echo sounder bottom returns are processed in a number of different ways, each highlighting different features of the seabed.

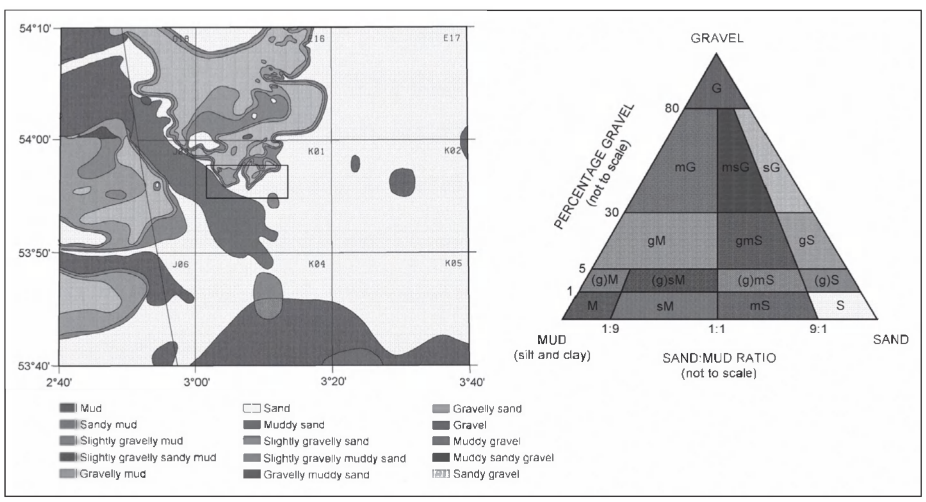

Figure 1: Survey area with Folk classification. The map is taken from [6].

The trials area is located in the Cleaver Bank, between 53°58' N, 003°01' E, and 53°55' N, 003°13' E, and is a popular acoustic survey destination because of its wide variety in sediment types [1]. It is one of the few areas in the North Sea where gravel is found; the Folk classification [2] for this area varies from sandy Mud to sandy Gravel. The area was previously surveyed in 2000, when grab samples were collected with Hamon and Van Veen grabs. Fig. 1 shows a historical geological map of the Cleaver Bank, where the black box indicates the 2004 trials area. The water depth in the region of interest varies between 30 and 60m [1].

Within the box, 45 east-west tracks, and 4 intersecting north-south tracks were planned. The east-west legs have a length of 7 nautical miles (nmi), and are separated by 120m; the north-south legs are 3 nmi long. The echo sounder was set to 200mW (electrical power) with a 1ms pulse length for the 12kHz transducer, 0.256ms and 100mW at 38kHz, and 0.256ms and 200mW at 200kHz. These values remained fixed for the entire experiment.

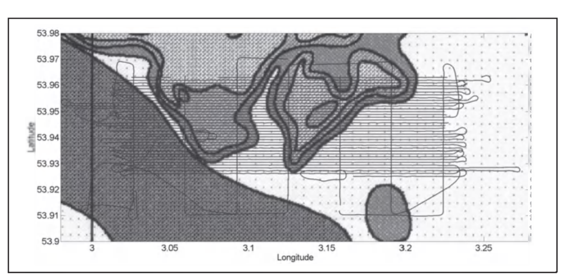

Figure 2: Tracks sailed during the 2004 survey.

Data Acquisition

The hydrographic survey vessels of the Royal Netherlands Navy are equipped with a wide variety of hydrographical sensors, including single and multi-beam echo sounders, motion sensors and standard meteorological/oceanographical instruments for maritime, meteorological and oceanographical observations. The sensor suite features a Simrad EA600 single beam echo sounder, which is the sounder that was used to obtain the echo signals studied in the present paper.

The EA600 consists of a PC with controller software, to which one or two GPTs (General Purpose Transceiver) are connected using a local area network. Each GPT features connections for up to two transducers. In the case of HNLMS *Luymes* there are two GPTs driving three transducers, operating at frequencies of 12, 38 and 200kHz. During operation these transducers all transmit at the same time. The controller PC is installed on the bridge, and parameters such as depth range, pulse length and power may be set through a graphical user interface.

The method of recording data is relatively novel for this sort of experiment. The EA600 (as well as the similar Simrad EA400) has a built-in facility for the recording of raw data on disk. With this feature enabled, an envelope of each bottom reflected ping is stored as a so-called 'datagram' in a binary file. This file will grow with every ping until an operator-specified size is reached, after which a new file is created and filled. Each datagram contains the power time series of a ping along with information such as time, frequency, pulse length, transmit power, bandwidth and sampling frequency (full specification in Simrad documentation [3]). In addition, every binary file begins with a configuration datagram containing general information: the number of transducers, their frequencies and some additional characteristics. Finally, a GPS providing data of the NMEA 0183 standard over a standard RS-232 line may be connected to the system (this was the case in the experiments); this information is incorporated in the raw data files as a separate datagram type.

Data Processing

The signals recorded by the EA600 are envelopes, stored in dB's [3]. Matlab was used to extract and process each individual ping. After reading a single time series, it is converted to acoustic pressure levels; the transmission burst is removed and the depth determined by locating the bottom reflection. Figure 3 shows an example of a time series for each frequency. The signal is then corrected for absorption and spherical expansion losses. Using the information in the datagram, a window is selected for further processing. This window starts 4 pulse lengths before the maximum of the echo, and ends 6 pulse lengths after the maximum.

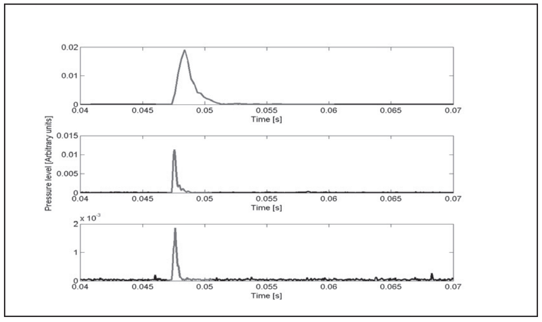

Figure 3: Example of coincident time series for the three echo sounders, recorded by the EA600; from top to bottom, the 12, 38 and 200 kHz echoes are shown. A window around the bottom reflection is marked in grey.

Since the survey legs are closely spaced, and since the number of echoes is large (7×10^5 at each frequency), it is possible to create feature maps with full seafloor coverage. To this end the relevant section of the seafloor is divided into 490 x 45 bins measuring 33 x 110m. Echo-to-echo fluctuations are mitigated by averaging quantities over all echoes within such a bin. Quantities that are described in Section 4 are the echo energy and the time spread, which is a measure of the temporal extent of the echo signal. The computation of these two quantities is detailed in [1]. Here we also consider the travel time difference between two sounder frequencies. When two or more sounders are operated simultaneously, minute differences in the arrival times of the bottom reflected pulse may reveal features of the seafloor. It is remarked that the criterion used to compute the depth can strongly influence the results. Various criteria (e.g. echo peak value, echo centre of gravity, accumulated energy threshold, etc.) can be considered.

Results

Plough marks

The echo energy is shown for the 38kHz sounder in Figure 4. It clearly shows that the lowest energies are found in the sandy Mud section at the left side of the figure. The highest energies are obtained in the triangular sandy Gravel area, which is predominantly red in the figure (echo energy between -6 and -4dB). More surprising is the presence of a large number of excess energy "plough marks", which appear to run in arbitrary directions. These strings are also evident in the time spread plot of Figure 5, at least in the sand region. One observes that the increase

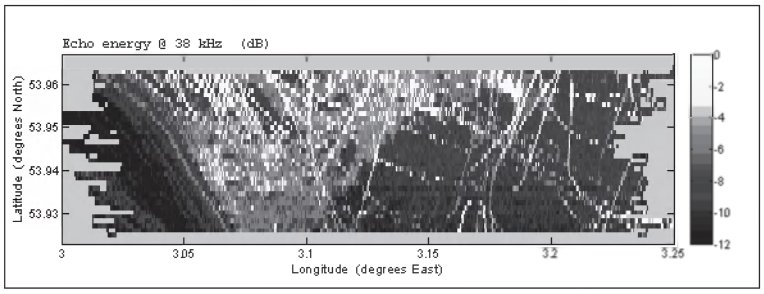

Figure 4: Echo energy for the 38-kHz sounder (in decibels).

in echo energy is accompanied by a decrease in the echo duration. Notice that the plough marks are manifest only because there is a dense grid and because the statistics are favourable with ~30 echoes per bin. Outliers in a routine echo sounder survey with widely spaced legs are frequently labelled as echo-to-echo fluctuations. The present maps, however, present a complete seafloor map and reveal that such fluctuations can have an underlying structure. The strings in Figure 4 and Figure 5 are also clearly visible at 200kHz (not shown), whereas at 12kHz (not shown) they are barely noticeable.

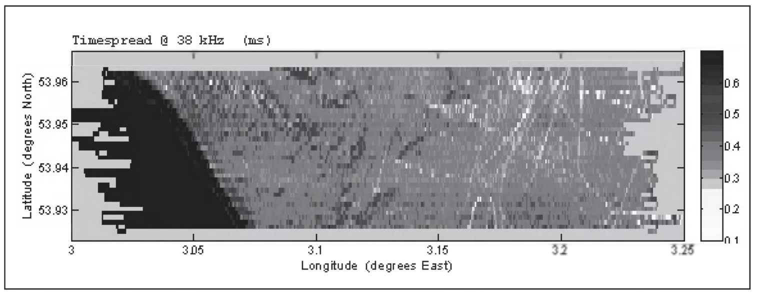

Figure 5: Echo timespread for the 38-kHz sounder (in milliseconds).

The designation "plough marks" follows from the hypothesis that the striking features are furrows caused by fishing gear dragged over the seafloor. A closer examination of the Cleaver Bank 38kHz data reveals that the echo energy in some furrows rises to as much as 10dB above that of the surroundings. The energy rise is also pronounced at 200 kHz, whereas it is only weakly present in the 12kHz data. Research on the physical effect of beam trawls on the seafloor has shown that the penetration depth in sandy sediments is typically of order 5cm [4]. Candidate physical mechanisms responsible for the pronounced acoustic fingerprint of the plough marks are discussed in [5]. The lifetime of the acoustically detectable disturbance is unknown. If it persists for a sufficiently long time, there is the prospect of monitoring the presence and impact of beam trawlers with simple echo sounders.

Travel time differences

The depth, or travel time, is determined by finding the maximum in a time signal after applying a moving average filter with a window width of 21 samples. For each of the three sounder frequencies the travel time provides information on the bathymetry of the survey grid. For a seafloor that acts as a perfect mirror these three bathymetries would equal one another, as a mirror is a frequency independent reflector. However, in reality the echoes are shaped by a combination of specular reflection, surface scattering, and volume backscatter. Any delay or smearing of the overall reflected energy caused by these effects is very small compared with the total travel time. However, when the travel times computed at two frequencies are subtracted from one another, the nominal water depth cancels out and a small, frequency-dependent, travel time difference remains.

This is shown in the bottom illustration in Figure 6 for the 38 and 200kHz sounders. The differential travel time map reveals particular features of the seafloor, the most important of which is presumably the penetration depth of the sound into the sediment.

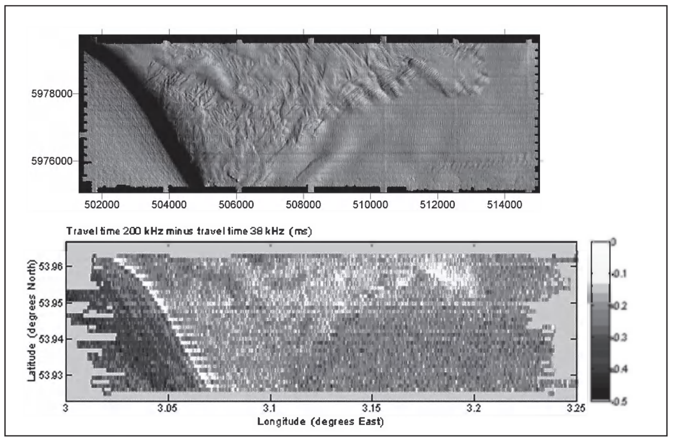

Figure 6: Top: Multi-beam echo-sounder image of the area. Bottom: single way travel time difference between the 200 and 38kHz sounders.

The top illustration in Figure 6 shows a multi-beam echo sounder image of the surveyed area. If this is compared with the lower map, it shows that single-beam data processed in this way can show morphological features not seen in conventional single-beam results. The rough-looking texture in the middle of the multi-beam image follows the yellow and orange of the differential travel time map (0.1 to 0.2ms), while the smoother texture corresponds to the red areas (0.2 to 0.3ms) to the lower right and small parts on the top. Comparing these observations with the geological maps in figures 1 and 2, it can be inferred that travel time difference between frequencies is a feature that might be used as a means of classification. Furthermore, it should be noted that the plough marks seen in figures 4 and 5 are absent here.

Travel time difference versus mean grain size

In the present subsection differential travel times are compared with available ground truth information. The travel times are computed from the echo centre of gravity, which yields slightly different values than the method described in the preceding subsection. The single-way travel time of the 200-kHz sounder is subtracted from the 38-kHz travel time, and the difference is converted to a distance via an assumed sound speed of 1500 m/s. The value thus computed is a measure of the penetration depth (difference) into the sediment. This penetration distance $D_{38\text{-}200}$ is compared with existing ground truth information. Specifically, the mean grain size [8] is considered of the grab samples acquired during the sea trials in 2000. The average $D_{38\text{-}200}$ is computed for all echoes within a search radius of 200 m from the grab sample positions, and plotted against the grab sample mean grain size in Figure 7. It appears that the penetration depth strongly correlates with the sediment type. A similar correlation

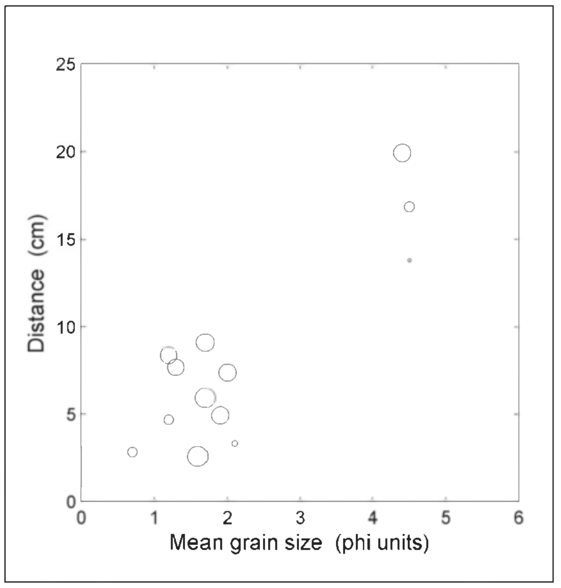

Figure 7: Penetration depth D38-200 versus the ground truth mean grain size. A sound speed of 1500m/s is assumed for the travel distance estimate.

between grain size and transition layer thickness is noted by [7]. Such correlations are potentially useful for automated seafloor classification algorithms. Specifically, travel times simultaneously measured at two sounder frequencies may be exploited for an acoustical prediction of the sediment mean grain size.

Conclusion

Echo sounder data have been processed in various ways. After determining the energies of bottom reflections, the results show "plough marks" that are presumably caused by the practice of beam trawling. A combination of travel times of echo sounders of different frequencies may offer a method for sediment classification.

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Coastal Zone Mapping: The Post Hurricane View

F. Saade, D. Millar, B. Richards, J. DaSilva Lage, C. Lockhart, and W. Gilmour

By October of 2005, work on post-hurricane mapping projects for five events in the U.S. was in process by Fugro Pelagos personnel. These included: Dennis along the Florida Panhandle; Katrina along Florida and several locations in Louisiana; Ophelia and Tammy along most of the East Coast; and Rita in southwestern Louisiana. Post-hurricane mapping work for Wilma has taken place in 2006. This paper discusses each hurricane and the technical requirements to achieve the required information. Each operation is discussed individually with the methodology and time-requirements to successfully conduct the field operations.

Introduction

With 28 named storms and 15 hurricanes, the Atlantic Hurricane season of 2005 was the most active in recorded history. Wind and water from the storms ravaged the coastline causing more than 100 billion dollars in damage in the United States alone. Fugro Pelagos, Inc. (FPI) under contract to the U.S. Army Corps of Engineers (USACE) and the National Oceanic and Atmospheric Administration (NOAA) completed the following post-hurricane surveys: Dennis along the Florida Panhandle; Katrina along Florida and several locations in Louisiana; Ophelia and Tammy along most of the East Coast; Rita in southwestern Louisiana; and Wilma along the Florida Gulf coast.

Each of the Tasks was unique to its event, requiring a variety of sensors, including airborne and vessel-based technologies. Data products and deliverables were customized to the goals of the engineers, scientists and researchers who required the information. All of the projects required rapid deployment of assets, occasionally simultaneously, and even the requirement to deploy safely and rapidly enough to collect pre-hurricane information. All of this added up to logistical, resources and personnel challenges to adequately support and ensure the quality of the data, accuracy of the surveys and responsiveness to the needs of the various data users.

Figure 1: Illustration of areas surveyed.

Objectives

The work for USACE was performed as part of the National Coastal Mapping Program (NCMP), a 4 year cycle of coastal mapping that provides data for regional coastal zone management. The objectives of these surveys are to provide accurate maps of the coastline.

The NOAA survey was performed on an emergency basis in order to identify any possible navigation hazards in the channel leading to Cameron and Lake Charles, Louisiana after Hurricane Rita passed through the area in late September 2005.

Methodology

Three different data collection systems were used to perform these post-hurricane surveys. The Fugro Pelagos commercial LIDAR (FPI LIDAR) was used for the Ophelia, Tammy, and Wilma surveys. The Compact Hydrographic Airborne Rapid Total Survey (CHARTS) LIDAR system was used for the Dennis and Katrina surveys. An emergency response hydrographic survey was completed post-Rita.

FPI Lidar Survey

A Beechcraft King Air A90 was equipped with a SHOALS-1000T Hydrographic and Topographic LIDAR System, to collect topographic LIDAR data from the waters edge inland 500m at 200% coverage, and hydrographic LIDAR data at 100% coverage from the waters edge offshore 1km, or to laser extinction dependent on water clarity.

The 1kHz hydrographic laser was used to collect hydrographic data at 5 x 5m laser spot spacing, flying at an altitude of 400m. For shoreline operations, the laser was switched to the 10kHz topographic mode and data were collected at 1.3 x 1.4m flying at an altitude of approximately 500m. In addition to LIDAR data, a DuncanTech DT4000 digital camera was used to acquire one 24-bit color photo per second.

GPS ground control data were acquired during LIDAR survey operations, such that the aircraft was never further than 30km from a base station during survey operations. GPS data were processed, often using multiple base stations, with Applanix POSPac software to provide a post-processed kinematic GPS solution and a refined inertial solution. All horizontal control for the project was referenced to NGS published monuments with a position quality of Class B or better. Vertical control was referenced to NGS benchmarks of at least First Order, Class I. Processed data were delivered in the NAD83 datum, with heights referenced to NAVD88. Conversion to NAVD88 was achieved using the Geoid03 model.

Flight planning, data processing and editing, quality control, and data export were conducted in the SHOALS Ground Control System (GCS) software, including POSPac and Fledermaus.

In house tools were created to automate the majority of final product generation. These tools made use of ArcGIS, Fledermaus and Leica's Photogrammetry Suite (LPS). Orthorectified mosaics were created using in-house utilities and LPS, while bare earth models were created with Terrascan and QT Modeler.

CHARTS Lidar Survey

Fugro Pelagos operates the CHARTS system for the Joint Airborne LIDAR Bathymetry Technical Center of Expertise (JALBTCX). The CHARTS survey capability includes an Optech, Inc., SHOALS-3000 LIDAR instrument integrated with an Itres CASI-1500 hyperspectral imager. CHARTS collects either 20kHz topographic LIDAR data or 3kHz bathymetric LIDAR data, each concurrent with digital RGB and hyperspectral imagery.

The post-hurricane surveys were completed as part of the NCMP. Survey specifications for the NCMP require that bathymetric data be collected from the shoreline to 1km offshore at 5m spacing. Topographic data are collected from the shoreline to 0.5km onshore at 1 m spacing and in opposing flight directions providing 200% coverage of the land portion of the survey. The surveys were flown at an altitude of 400m with a 4m x 4m spot spacing during hydrographic data collection and a 1m x 1m spot spacing during topographic data collection.

All data are positioned using post-processed kinematic GPS and National Geodetic Survey monuments. The RGB digital imagery have a ground resolution of 20cm per pixel and the CASI imagery have a ground resolution of 0.5 to 2m per pixel depending on the operational survey requirement. Both sets of images are georeferenced using CHARTS positioning and attitude sensor data. GIS products derived from these data include seamless bathy/topo grids, bare earth grids, building footprints, a NAVD88 shoreline vector, and RGB or hyperspectral image mosaics.

Hydrographic Survey

The survey was conducted in two phases using the R/V Seis Surveyor, which was equipped with an Edgetech sidescan sonar and Odom Echotrac single beam echo sounder.

A channel survey was conducted with 200% sidescan coverage and concurrent single beam bathymetry. Data were collected within a 250 metres corridor; the survey started with a center line and then parallel lines at 50 metres line spacing until the coverage requirement was met.

One hundred percent sidescan coverage with concurrent single beam bathymetry was collected in the safety fairway in the vicinity of the sea buoy. The survey started in the area east of the channel and proceeded west at 100 metres line spacing until the coverage requirement was met.

Results

The following table provides a summary of the post-hurricane surveys.

Dennis

Accurate forecast of the Hurricane Dennis landfall zone and quick mobilization allowed for acquisition of the pre-hurricane shoreline condition. The CHARTS system was mobilized prior to the arrival of Hurricane Dennis, so the USACE was able to complete a comparison of the shoreline area after the hurricane passed through.

Katrina

Hurricane Katrina devastated the Gulf coast from Louisiana to Florida. This survey consisted of 17 individual surveys ranging from the levees in Louisiana to the barrier islands in Mississippi and Alabama, and coastal Florida. There were approximately 1700 square kilometers of topographic data and 500 square kilometers of bathy/topo data. Hyperspectral imagery was collected in various areas.

Survey	Dennis	Katrina	Rita	Ophelia and Tammy	Wilma
Location	Alabama, Florida	Louisiana, Mississippi, Alabama, Florida	Louisiana	Maine to Florida	Florida
System	CHARTS LIDAR	CHARTS LIDAR	Echosounder sidescan sonar	FPI LIDAR	FPI LIDAR
Survey Area	200 km of coastline	400 km of coastline	70 sq km	2300 km of coastline	244 km of coastline
Distance on Line	16,300 km	21,182 km	932 km	45,000 km	14,000 km
Number of Acquisition Days	13	55	9	49	15
Total survey flight time	53 h 16 m	71 h 46 m	N/A	~250 h	54 h 54 m
Number of Flight lines			N/A	3500	492
Approximate number of Laser shots			N/A	> 5 billion	700 million
Temporary Field Offices	Home based	Home based	0	8	1
Data Storage Used			N/A	6 TB	554 GB

Table 1: Summary of post-hurricane surveys.

Ophelia and Tammy

Mobile field offices were established in Portsmouth, NH, Ronkonkoma, NY, Millville, NJ, Wilmington, NC, Myrtle Beach, SC, Brunswick, GA, Melbourne and Miami, FL. Seven personnel were deployed in the field at all times, including 3 ground control personnel and one airborne operator.

Project accuracy standards of +/- 30cm (2 sigma) for elevation and +/- 3m (2 sigma) for horizontal position were met. In general, flights were coordinated where possible to acquire topographic data at the water line within 2 hours of low tide and hydrographic data within 2 hours of high tide to allow for a seamless dataset at the land / water interface. Mission planning also reviewed dilution of position (DOP), to avoid flying when the PDOP would be greater than 3.0.
Final deliverables included ASCII XYZ files of all accepted elevations, DEMs in geotiff format of the Topo Last Return / Hydro data, bare earth DEMs, a NAVD88 zero contour depicting the shoreline in SHP file format, and orthorectified mosaics of the imagery in MrSID format. All deliverables were split into predefined boxes, each covering approximately 5km of shoreline. All files were accompanied by metadata compliant with FGDC standards and all work was carried out to comply with USACE surveying and mapping standards.

Rita

No hazards were located during this survey. A total of 104 sidescan contacts were noted, but most were observed as debris or tires less than 1.0 metre in height. The largest contact seen inside the channel and safety fairway area had a height of 1.92 metres, and a least depth of 43.1 feet.
No significant differences were observed between soundings shown on chart 11344 and this survey. The soundings generally agreed within +/- 1 foot. Minimum depth was observed to be not less then 38 feet inside quarter to inside quarter along the entire length of the channel, with most of the channel being 40 feet or greater in depth. The channel was cleared for navigation.

Wilma

Data collection for the Wilma survey has just been completed and post processing is in progress. The deliverables for the Wilma survey will be the same as detailed for Ophelia and Tammy.

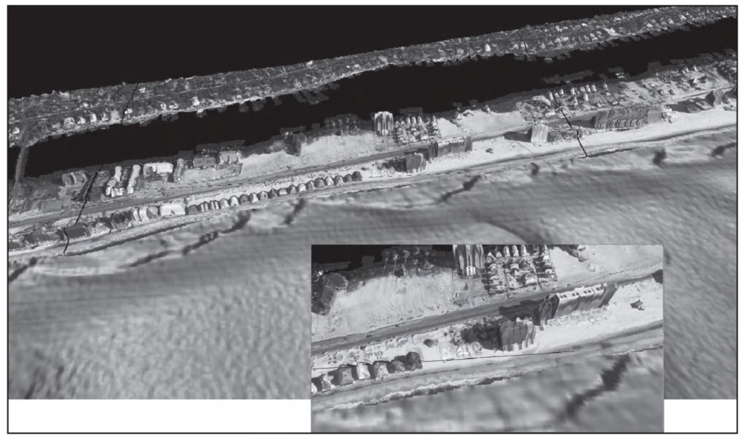

Figure 2: Example data product.

Conclusions

Fugro Pelagos was able to successfully mobilize personnel and equipment during and after the historically active 2005 hurricane season in the United States. The surveys ranged from ship-based hydrography to airborne LIDAR and provided the following:

- Post-Rita rapid response cleared the safety fairway leading to Cameron and Lake Charles, Louisiana allowing vessel movements to resume safely.
- All LIDAR Bathymetry and Topography data collection resulted in large-area detailed surveys of hurricane-impacted coastal zones, including aerial imagery.
- The capacity to cover regional areas quickly by high-productivity airborne LIDAR bathymetry will provide insights into coastal processes for short- and long-period time scales.
- Each area surveyed by LIDAR now has at least one full cycle of before / after hurricane data; the area around Dennis has four cycles going back to Hurricane Ivan in 2004. All data are currently under analysis by qualified coastal engineers.
- Fugro was able to simultaneously support two airborne LIDAR programs and a vessel-based operation to clear safety fairways, all in an emergency response mode. This was accomplished using three separate contract vehicles with three independent Agencies of the US Government.

Figure 3: Example of building footprint and bare earth.

Acknowledgements

USACE Mobile District
NOAA National Ocean Service
Joint Airborne LIDAR Bathymetry Technical Center of Expertise

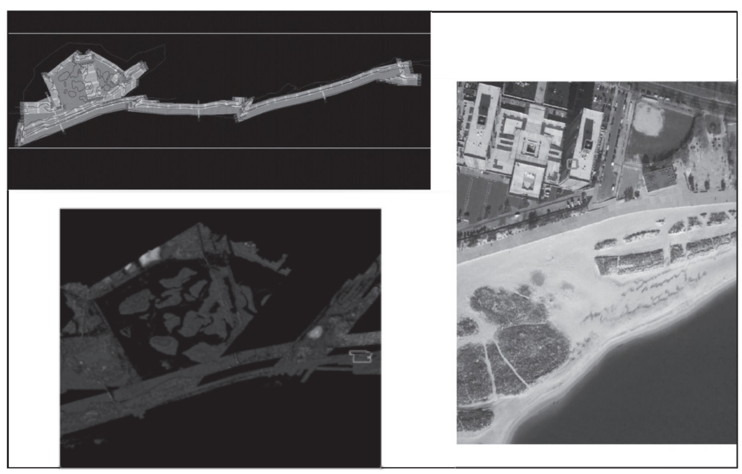

Figure 4: Example survey grid (top left), orthophoto (right) and LIDAR data product (bottom left).

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Environmental Monitoring During The Construction of The Jebel Ali New Container Terminal

M. Van Parys

Project

As part of a major expansion of Jebel Ali Port, Dubai, Stage 1 involves the construction of four container berths, dredging of a harbour basin to -14m DMD (Dubai Municipality Datum), the construction of protective breakwaters and revetments, the reclamation of approximately 350 hectares of land and the development of approximately 190 hectares of land. This new facility has been designed to service Super-post-panamax vessels with a length of 380m and a capacity of 12500 teu. An allowance has been made for future dredging of the basin to -18m DMD.

During the construction phase of the project the Contractor was committed to adhere to very strict environmental regulations. The implementation of a comprehensive monitoring program allowed measuring the effectiveness of the management measures which were implemented.

The initial dredging operations consist of dredging a trench of approximately 2,700 m length with a bottom width of 14.25 m on a depth of 20.20m DMD (see figure 2). During the first phase the Cutter Suction Dredger (CSD) *Marco Polo* will be dredging till approximately Chainage 1,400. This will allow the commencement of the Quay wall construction by others.

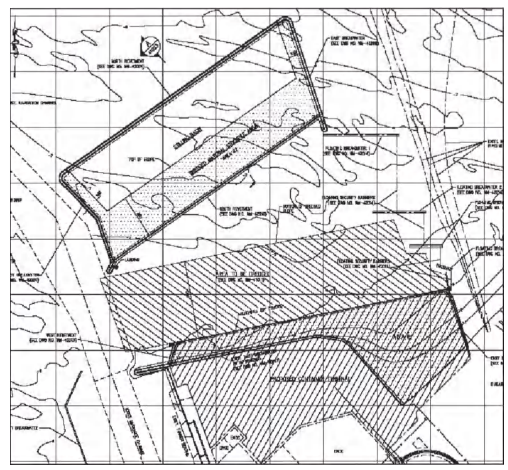

Figure 1: Project layout.

Monitored Parameters

Hydro-meteo parameters

The most important parameters that highly influence turbidity levels and the extent of the sediment plume are the hydro-meteorological conditions: current speed and direction, significant wave height, wave period and direction, seawater temperature and waterlevel.

Turbidity monitoring

Fixed monitoring stations

A total of 7 monitoring platforms transmit realtime turbidity values which can be accessed through a dedicated website:

- A row of 4 platforms is located eastward from the area to be dredged where 29 NTU was specified as threshold value.
- In the vicinity of 3 industrial plants with operational seawater intakes 10 NTU was specified as threshold value.

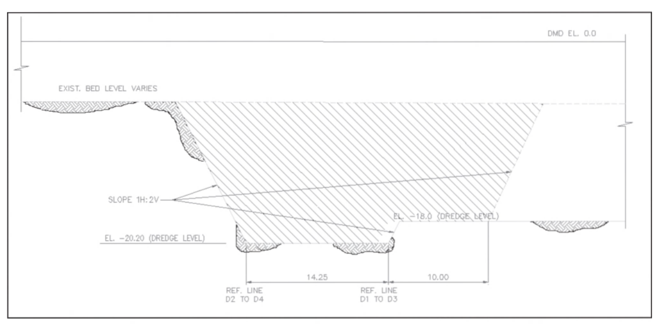

Figure 2: Trench design.

Synoptic monitoring at adjacent areas

The daily synoptic turbidity occurs at 10 locations:

- At 3 locations to the West of the project area synoptic monitoring was conducted at high tide and 59 NTU was specified as threshold value.
- At 7 locations to the North and East of the project area synoptic monitoring was conducted at low tide and 29 NTU was specified as threshold value.

Synoptic monitoring near the dredger

The dredging operations of the CSD Marco Polo are monitored at 150 m and 1000 m downcurrent from the dredging location. At 1000 m down current from the dredging location 29 NTU was specified as threshold value.

Synoptic monitoring near the relocation area

Near the relocation area the operations are monitored at 150m and 1000m downcurrent from the discharge locations. At 1000m down current from the discharge locations 29 NTU was specified as threshold value:

Mobile monitoring

Next to the contractual agreed upon turbidity monitoring, the Environmental Monitoring Team planned and executed additional surveys. The main reason was to gain further insight in the behaviour of the sediment plume originating from the 'Marco Polo'.

Fall velocity determination

In the initial Turbidity Monitoring Plan it was proposed to take 3 water samples at 150m distance downcurrent from the Dredger. However after a first laboratory test, it seemed that the watersample only had a very small amount of TSS. In order to have a better and more relevant understanding of the fall velocity of the dredged material the water samples were taken at the centre of discharge location from the barges.

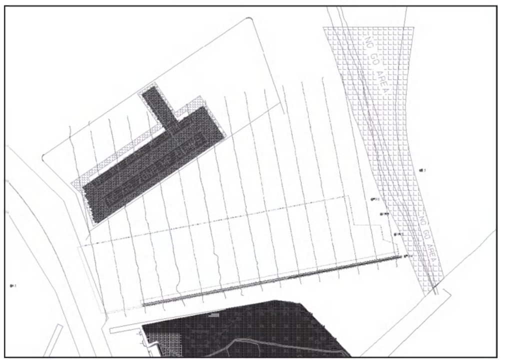

Figure 3: Turbidity survey grid.

Water quality analysis

Water analysis serves two goals, first the verification of the previously established conversion coefficients for the different turbidity sensors and second bio-chemical parameters to assess the dredging related impact on the coastal environment.

The following parameters are measured:

- Total Suspended Solids (TSS)
- Ammonia (NH_3)
- Nitrate (NO_3)
- Total Phosphorous (P)

Monitoring Setup And Working Grid

Hydro-meteo parameters

On the bottom of the seafloor next to 2 monitoring beacons Nortek AWACs are installed. This kind of current profiler uses the Doppler principle to measure current velocity by transmitting a short pulse of sound, listening to its echo and measuring the change in frequency of the echo. The system is also used to measure the wave amplitude, direction and period. An embedded thermistor monitors the seawater temperature.

Picture 1: AWAC sensor and its mounting frame.

Turbidity monitoring

Fixed monitoring stations

Fixed monitoring stations are used to monitor the suspended solids concentration at fixed locations and depths over longer periods at preset time intervals.

After activating the datalogger the system becomes an autonomous monitoring and registration system. The readings of all the connected sensors are broadcasted by the interfaced telemetry link at the set interval and at the same time all data is stored in the onboard datalogger. The receiver station at the office is interfaced to a processing computer.

Biofouling of turbidity sensors is a major concern in tropical waters and therefore regular cleaning of the sensors is of utmost importance. By applying antifouling as described in the manufacturer's recommendations per particular sensor the cleaning interval may be reduced.

Picture 2: Monitoring platform.

Synoptic monitoring and mobile monitoring

The survey launch (DN71) is used to conduct synoptic and mobile monitoring surveys and perform synoptic sampling. The equipment set up for mobile monitoring is identical to the synoptic measurements. The only difference lays in the working method. Synoptic monitoring takes places at several predefined locations and while measuring the DN71 stays on those locations. Mobile monitoring takes place at a constant speed of 2 knots along predefined survey lines

The OBS is attached to a cable on a winch operated by computer or remote control. The datasignals from the sensor are interfaced via the electro-mechanical cable through the winch to the survey computer and logged together with the easting and northing from the dgps-receiver and the seabed depth from the survey echosounder. NTU values are available in real time and are logged at the same time. Upon completion of the survey the data is processed at the office, where the recorded data is combined with other parameters.

Fall velocity determination

A Settling Tube is employed for sedimentation analysis. By measuring the elapsed time between corresponding measured turbidity values for the different sensors in the cylinder the settling velocity can be determined by dividing the distance between the sensors by the elapsed time.

Picture 3: survey vessel DN71.

Water quality analysis

Total suspended solids

For both Top, Mid and Bottom depth of the water column 1 liter samples are taken with the use of a peristaltic pump. The end of the tube is attached near the photo detector and signals are logged while sampling. A well-mixed 1 liter sample is filtered and the residue retained on the filter is washed and dried to a constant weight at 103 to 105°C. The increase in weight of the filter represents the total suspended solids.

Bio-Chemical analysis

Analyses to determine Ammonia (NH3), Nitrate (NO3) and Total Phosphorous (PO4) were executed by a local laboratory.

Results

Hydro-meteo parameters

Tidal currents

The tides in the study area are semi-diurnal and are the driving factor behind the relatively weak currents.

Two main directions can clearly be deducted for the lower part of the water column: mainly towards 230-240°, corresponding with high tide period and towards 50°, corresponding with low tide period. Near the surface, the current direction is more variable, going from the east towards the southwest. For both January and February a more outspoken different surface current was observed. Winds blow dominantly from the northwest throughout the year, however during winter are these winds noticeable stronger, the gale-force 'shamals'. The most of these shamal events occurred in January, which is also reflected in the continiously increased current speed.

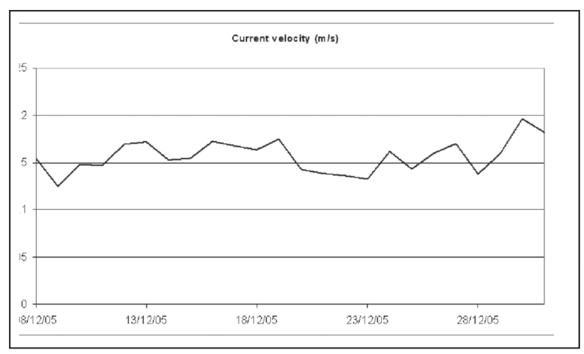

Figure 4: Current velocity for December 2005.

Wind and waves

The occurrence of 'shamals' is clearly reflected in the significant wave heights, both in their direction as in the significant wave height. The significant wave height exceeded several times 1m during this 3 month period. Each of these periods correspond with a shamal event and mostly were the dredging activities paused. Synoptic turbidity monitoring was also halted during these periods. The monitoring beacons measured a sharp increase in NTU values. Due to this extreme events one could notice numerous cloudy patches in the sea along the coastline of Dubai. These arose not specifically from dumped or dredged materials but from local shallow spots on the coastal terrace where the waves `touched` the seafloor.

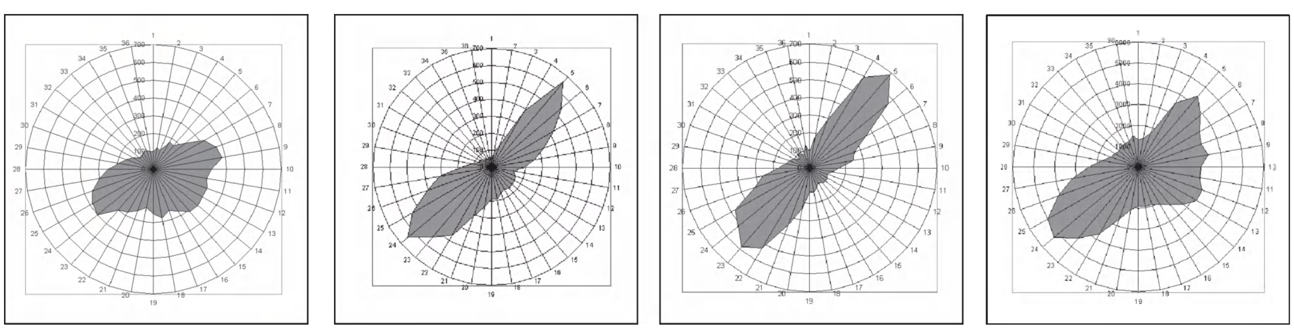

Figure 5: Prevailing current directions for December 2005 (A: at -1m below the sea surface, B: at mid-depth, C: at +1m above the seabed, D: monthly average for the three depths).

Turbidity monitoring

Fixed monitoring stations and Synoptic Monitoring

There are two main causes for elevated turbidity levels, both due to the natural environment in which the equipment is deployed : marine growth on the sensor and increased turbidity values after bad weather.

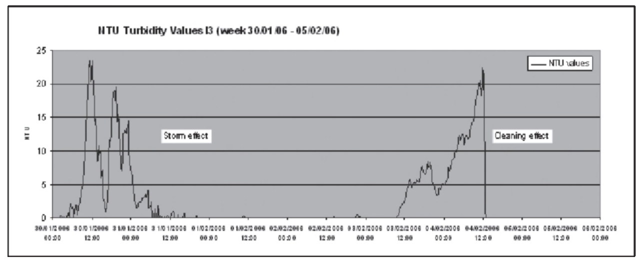

Figure 6: Influence of storm and biofoulding on turbidity.

The clear seawater in front of Jebel Ali port is characterized by a very low suspended sediment concentration, approaching 0-values. Compared to those normal background values, the above mentioned natural impacts cause a temporary but mayor increase in turbidity levels.
None of the occurrences of high NTU values could be related to the dredging and relocation activities.

Mobile monitoring

Next to the contractual agreed upon turbidity monitoring, the Environmental Monitoring Team planned and conducte additional surveys. The main reason was to gain further insight in the behaviour of the sediment plume originating from the '*Marco Polo*'. During a period of 3 months (Dec 2005 and Jan – Feb 2006) turbidity data was gathered in a survey grid covering the region of interest.

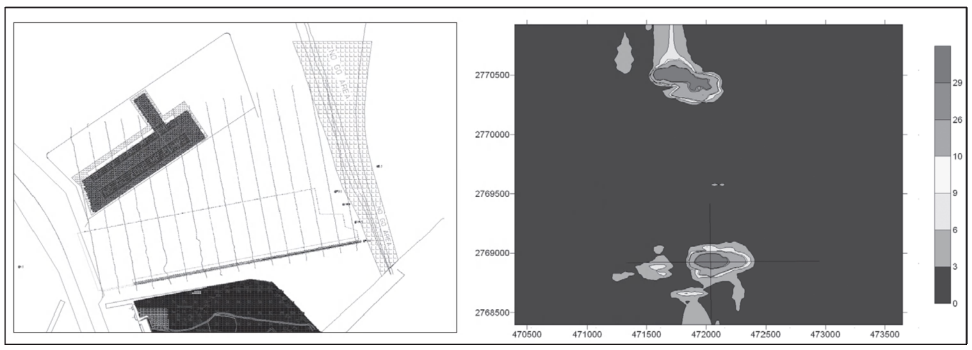

Figure 7: Example of interpolated turbidity map.

Statistical analysis gives the spatial extent in eastern direction of the *Marco Polo* sediment plume.

NTU alarm levels	29 E	26 E	10 E	9 E
Distance from Marco Polo (m)	**173**	**199**	**374**	**392**

Table 1: location of NTU alarm levels.

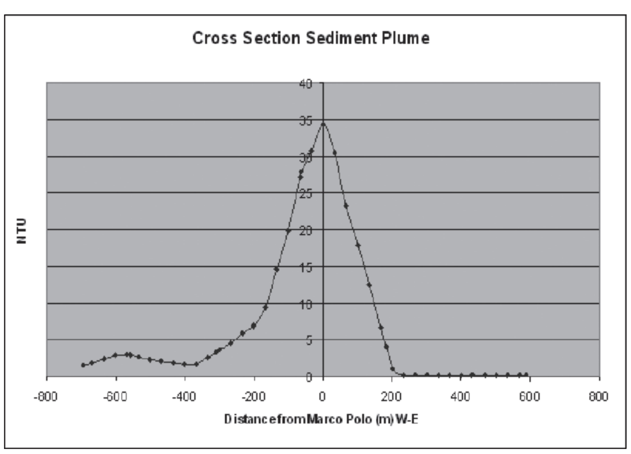

Figure 8: Plume extent.

Fall velocity determination

The fall velocity of the dredged material was determined during separate settling tests. From the log files an average settling velocity of 6.3 cm/min was determined.

Water quality analysis

Total Suspended solids

Beside laboratory determination of the ratio NTU – mg/L, in situ information was gathered during weekly TSS analysis from seawater samples taken in the dredging and dumping area simultaneously with the turbidity values. Taking all the measurements into account a conversion factor of 2.81 is obtained. When rejecting the average values increased or decreased with the standard deviation, a conversion factor of 2.43 is found, which confirms the initial value of 2.57 which was determined during the laboratory tests.

Nitrogen, Ammonia, Nitrate and Phosphate

The results of the chemical analyses, conducted on the samples which were taken during this phase of the project are listed in the table below.

2006	PO_4 (mg/l)	NO_3 (mg/l)	NH_3 (mg/l)	Methodology
Week 4	0.02	0.9	<0.01	AWWA/APHA
Week 5	0.13	0.6	0.04	HACH
Week 6	<0.1	0.1	<0.1	HACH
Week 7	0.04	1.3	0.12	AWWA/APHA
Week 8	<0.1	0.6	<0.1	AWWA/APHA
Week 9	<0.1	1.3	<0.1	AWWA/APHA
Week 10	0.1	0.6	0.1	AWWA/APHA

Table 2 : Results chemical analysis.

Summary And Conclusions

This report provides an analysis and evaluation of the environmental impact during the initial dredging stage of the Jebel Ali New Container Terminal (6/12/2005 – 10/03/2006). Methods of analysis include continuous turbidity monitoring, weekly water sampling for chemical and suspended sediment tests, and the set up of a hydro-meteo database. The dredged trench material is relocated a few kilometers further offshore, into the Reclamation Area and the Stilling Basin. The generated sediment plume is monitored both by mobile and fixed monitoring.

During the trench dredging, the turbidity remained well within threshold levels imposed by the client. However with the CSD *Marco Polo* moving up closer towards the fixed monitoring stations, it has to be kept in mind that the monitoring platforms, which had to be installed very close to the dredging area due to safety reasons (outside the pipelines corridor), will be situated within the influence radius of the sediment plume.
The chemical composition of the seawater showed no significant variance due to the dredging.

When the dredging activities were halted during bad weather conditions, it was noticed that the levels of turbidity around the fixed monitoring stations were much higher than while dredging works were going on. Due to the enforced action of wind, wave and current, the sediment is brought into suspension. So these natural actors also have an impact on the natural increased turbidity and were causing values of suspended sediment in the seawater reaching the threshold determined for dredging activities. Already can be stated that under influence of bad weather much higher turbidity values are reached than dredging works have done up until now. Unfortunately the rough conditions at sea make it impossible to execute a synoptic monitoring at the same time to check and verify the turbidity values at the other mobile locations.

Biofouling of the optical scatter instruments results into over-estimated turbidity values. Every sensor needs regularly cleaning. With increasing seawater temperatures the biofouling will speed up. One has to consider to apply anti-fouling agents in order to control the growth of bacteria and algaes.

In general it can be concluded that further detailed and thorough investigation is necessary seen the increasing importance of issues related to marine coastal environments, not only for this project, but also in other regions. The strict way in which this project is handled can be used as a model for future environmental monitoring programs and impact assessments.

M. Van Parys, Jan de Nul Group

Charting

Introduction Of Vertical Reference Level Lowest Astronomical Tide (LAT)

In The Products Of The Netherlands Hydrographic Service

I.A. Elema and M.C. Kwanten

Following international agreements, the Hydrographic Service of the Royal Netherlands Navy is in the process of changing the Chart Datum in its products from Mean Lower Low Water Spring (MLLWS) to Lowest Astronomical Tides (LAT). LAT is in general a level 2 to 3 decimetres below the level of MLLWS. As a result, depths in nautical charts will decrease. Tidal height predictions will increase with the same amount. The transition in the products is expected to take several years.

Introduction

The Hydrographic Service of the Royal Netherlands Navy (NLHS), executes hydrographic surveys and publishes nautical charts and other nautical information concerning the Dutch part of the North Sea and adjacent waters as well as the waters surrounding the Netherlands' Antilles and Aruba. The vertical datum used as a reference level in the nautical charts and tables is called Chart Datum. This is a low water level, thus revealing the critical depth for users of the charts. A Chart Datum situated higher than low water results in charted depths that are occasionally larger than the actual depth which in consequence might lead to a false sense of safety. Not every country is using the same level as Chart Datum. Due to the variety in tidal characteristics, a large number of implementations of Chart Datum exist. A Chart Datum is usually related to mean of low ocean surfaces, such as Mean Lower Low Water Spring (MLLWS), Mean Lower Low Water (MLLW), Mean Low Water (MLW), Low Water (LW), Lowest Astronomical Tide (LAT) or Mean Low Water Spring (MLWS).

Tidal predictions in tide tables of hydrographic offices show water heights relative to the same level as used in the corresponding charts. Until recently, all of the NLHS charts referred to Mean Lower Low Water Spring (MLLWS). This is the mean of the lowest water level of a month during a period of 5 years. During average meteorological conditions this MLLWS level is a surface which will seldom result in charted depths that are larger than the actual depths. In other words 'the value of the height of the tidal wave at any given moment, to be added to the charted depth to calculate the present water depth, is rarely negative'. Following international agreements, NLHS charts gradually will be transformed to LAT. LAT is the lowest water level that can occur as a result of the tidal effects of astronomical bodies and the local geographic circumstances. A water level below LAT can only occur due to meteorological circumstances. The LAT level is in general situated below MLLWS.

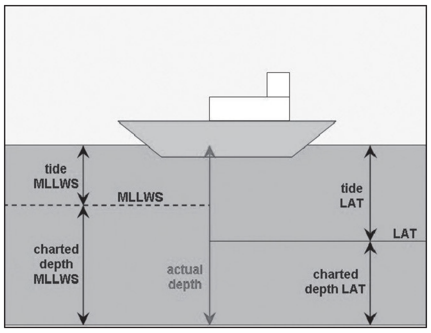

Figure 1. Relation between charted depth and actual depth.

Towards Standardisation of Vertical Datums

The IHO (International Hydrographic Organisation) and IMO (International Maritime Organisation) already stated in the early 1980's that states should consider adopting an astronomical level as Chart Datum. Following the IHO Technical Resolution A 2.5 Datums and Benchmarks, the Tidal Working Group of the North Sea Hydrographic Committee proposed during the NSHC-meeting (North Sea Hydrographic Conference) in September 1998 to adopt the Lowest Astronomical Tide (LAT) as Chart Datum as of January 1st 2000. At a later stage this was changed by the NSHC Tidal Working Group into 'at the earliest practicable opportunity'.

The transition in The Netherlands from MLLWS to LAT started in the second half of 2006. Germany (Bundesamt für Seeschifffahrt und Hydrographie (BSH)) started the transition in 2005, the UK and France have already adopted LAT and Belgium will follow after The Netherlands. In the near future the whole of the North Sea will be charted with respect to the same vertical datum. This has the advantage that no virtual vertical thresholds have to be passed when neighbouring charts of different hydrographic offices are used.

It will take some years to convert all NLHS-products to LAT, because nautical charts are not republished every year. LAT is generally a lower surface than the current Chart Datum referenced to MLLWS in The Netherlands part of the North Sea. This implies that a LAT-related chart in general will show depths that are more shallow than a corresponding MLLWS-based chart. This obviously does not have any consequence for the true depth, since the corresponding tidal heights in the tide tables will increase with the same amount. The differences between MLLWS and LAT depth values can be seen in figure 1. The average difference between MLLWS and LAT is about 2 to 3dm, but can be as large as 5dm near the amphidromic point. In a small area North of IJmuiden the LAT surface is above MLLWS.

Computation

The computation of the new LAT reference level has been performed in cooperation with the Netherlands Institute for Marine and Coastal Management (RIKZ) of Rijkswaterstaat.

The LAT matrix is based on 3 tidal models of RIKZ. Use has been made of the Dutch Continental Shelf Model and two more detailed models for inland waters like the Waddenzee and Westerschelde. Tidal models contain harmonic constants which are computed from tide gauge measurements, depth measurements and bottom roughness. RIKZ has computed LAT by predicting the tidal heights, for 19 years (the longest tidal period) using the tidal models, and determining the lowest water level in each point of a grid of the area of a model. The LAT values of the three separate tidal models are joined and regularly gridded by means of a linear interpolation by NLHS. The final LAT matrix for use in the production of publications contains differences in decimetres between MSL and LAT for positions in ETRS89. The grid cell size of the LAT matrix is 384m in longitude and 640 metres in latitude. This corresponds with 0.00576 degrees latitude and longitude. The values in the LAT matrix are rounded up. For example if the distance between MSL and LAT is 151cm, the LAT value in that location is 16.

LAT has also been computed for places where water levels are measured by permanent tide gauges. LAT values have been derived from these measurements by performing an harmonic analyses. The differences between the model LAT values and the measured LAT values are in the order of 5cm. The precision of the LAT level is expected to be in the order of 10cm. The differences with MLLWS (see figure 2) are between -1dm near IJmuiden (LAT surface is situated higher than MLLWS) and 5dm near the southern amphidromic point (LAT surface is situated lower than MLLWS).

The 5dm relatively large difference is caused by the apparent movement of the amphidromic point. The conversion moves it 25 kilometres in north westerly direction, when compared to the amphidromic point of MLLWS. The amphidromic point is defined as the centre of rotation of a tidal wave. In theory there are no vertical tides in an amphidromic point. In practice the amphidromic point represents an area with little vertical tidal movement.
The connection between the LAT values of the United Kingdom, Germany and Belgium and the Netherlands are in agreement.

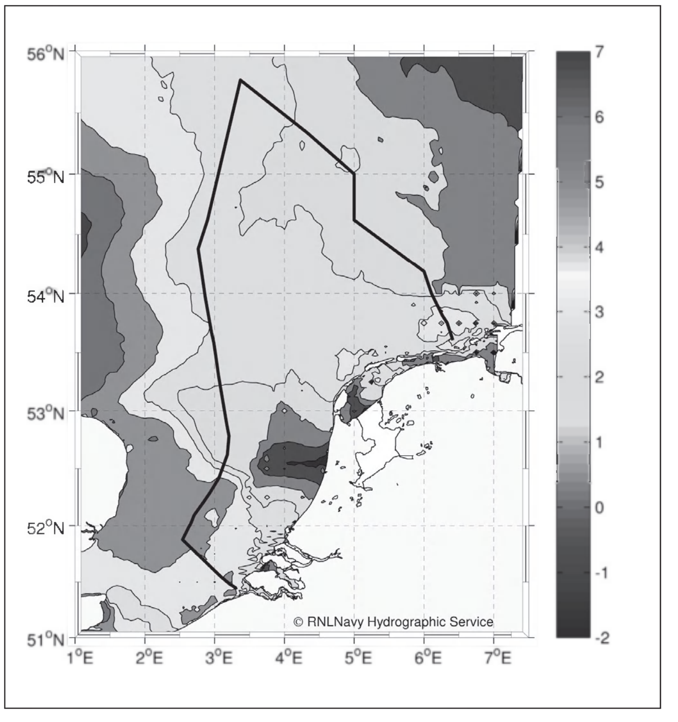

Figure 2. Difference in charted depth due to LAT transition.

The latest MLLWS matrix is the MTX88 matrix from 1988. This matrix was visualized in a Reduction sheet High and Low water 1988, which could be obtained from the NLHS. Next to lines with similar reduction values, co-tidal lines of High- and Low Water are presented. The lines are presented on two charts, one chart for High Water and one chart for Low Water.
Instead of a paper North Sea reduction chart, the digital matrix for LAT will be implemented in the multi-functional software program PCTrans. This program can be downloaded for free from the website of the NLHS www.hydro.nl. By using this software program, the user has more flexible access to the LAT values than on a paper sheet. It is possible to provide a position for which the program will show the corresponding LAT and MLLWS values. Other, non-tidal, functionalities of the program include datum transformation, direct and indirect geodetic problem calculations and area computations.

Introduction of LAT In The NLHS Products

The NLHS publishes a range of charts and other nautical publications. NLHS maps the Netherlands part of the North Sea, the sea around the Netherlands Antilles and Aruba and Suriname. Available products are listed in Catalogue HP7. The products have the purpose to serve SOLAS shipping as well as recreational shipping in order to maintain and enhance the safety of shipping. Furthermore half-products, (e.g. coordinates of platform location) derived from files used during the production of official publications, can be obtained.

Nautical charts

Nautical charts appear on various scales. The vast majority of the Netherlands charts are part of the IHO-INT program. Many charts are made in co-production with our neighbouring countries United Kingdom, Belgium and Germany under bilateral agreements. The nautical charts are meant for the international professional shipping and based on the "Chart Specifications of the IHO". These specifications specify format, topography, hydrography, aids to navigation, geographical naming and numbering.

The charts need to be corrected by means of Notices to Mariners (NtM), which are published weekly on paper as well on the internet (www.hydro.nl).

Figure 3. Survey ship HNLMS Snellius *during a recent survey in the Caribbean.*

As stated above, since the second half of 2006 LAT has been introduced in the products of the NLHS. Paper charts will be converted to LAT from North to South. The first two charts that are published in LAT are charts 1555 en 1460. These are charts of the north eastern part of the Netherlands. Second in line are 1456 and 1458 which will be published early 2007. New charts are announced in Notices to Mariners.

The LAT-matrix is implemented in the databases of NLHS. Firstly, existing depth figures relative to MLLWS are converted to LAT without operator interference. Newly measured depths are inserted in the databases relative to LAT. The two survey vessels of NLHS will be equipped with the LAT matrix in their surveying software.

In figures 4 and 5 the impact of the transition from MLLWS to LAT on depth figures and contours can be seen. The same data are presented relative to MLLWS as well to LAT. The area shown is situated north of the Frisian Island Schiermonnikoog. The figure on the left shows the depths with respect to MLLWS, the figure on the right shows the same area with the same data, but now with respect to LAT. The low water line (0-metre), the 2-metre line and the 5-metre contour line are dis-

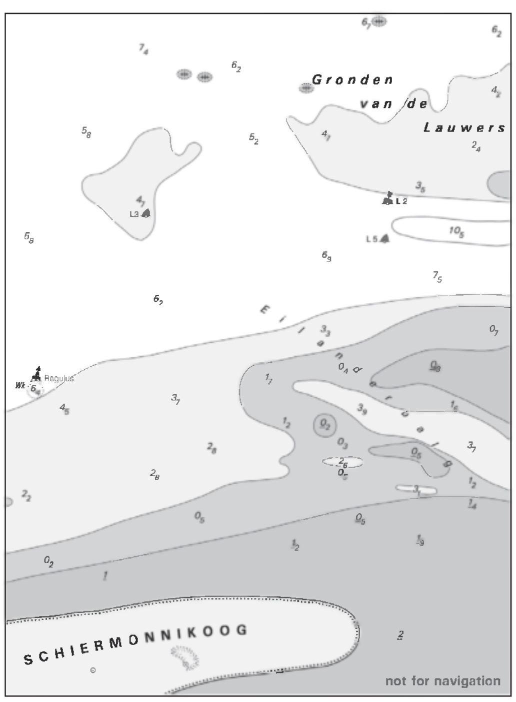

Figure 4. Depths with respect to MLLWS.

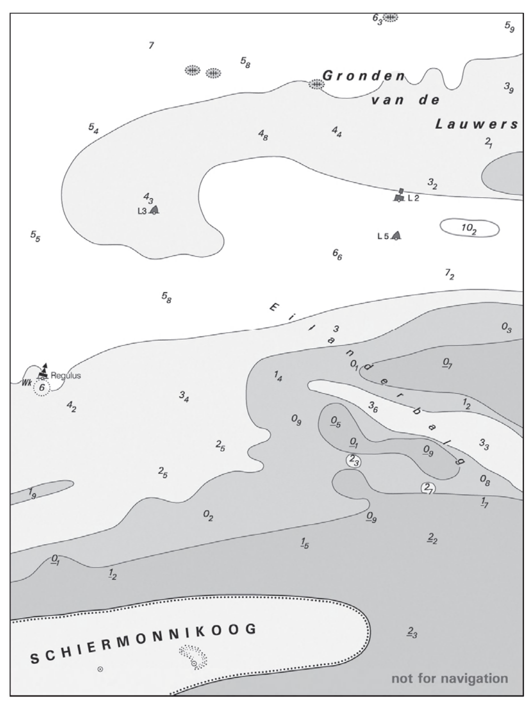

Figure 5. Depths with respect to LAT.

played. The depths in the figure on the right have decreased 3 or 4 decimetres. The patterns of the contour lines have also changed. Also note the change in depth above the two wrecks that are visible in the figures 4 and 5.

It will take a few years before all nautical charts have been transformed to LAT. The information on the charts will clearify which level is used as the Chart Datum. It is possible that the same area at one chart is shown in LAT and at another chart in MLLWS.

For the Netherlands Antilles the tidal range is not significant. A note will be put on the charts to state that the Chart Datum approximates LAT. Suriname will decide when charts of their charting area will change to LAT, since the Netherlands only have a cartographic role in the production of the charts.

1800-series

The 1800-series charts are officially issued nautical charts and serve as SOLAS publications. They cover the sailing routes near the coasts and the larger inland waters. The series contain 8 atlases with an average of 9 loose-leaf charts.
See figure 6 for coverage of the 1800-series. Yearly new editions of the charts occur. The charts can be corrected by means of NL-NtM's. The conversion of the 1800-series to LAT will take place in two phases. The 1800-series edition 2007 of 1811 and 1812 (of the north- eastern part of The Netherlands) will be published in LAT. The other charts will follow in 2008.

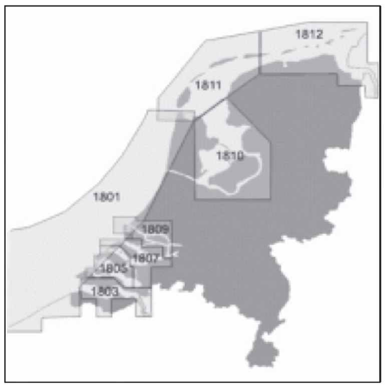

Figure 6. coverage of 1800 series.

Tide tables

Two tide tables are published by the NLHS. A paper product, HP33, and a digital product HP33D - NLTides. According to IHO publication M3, HP33 is of the category NP1, this means a printed paper publication. HP33D - NLTides is of the category NP2. This means a digital publication based upon existing paper publications. In the future tide tables will be published as a category NP3. This implies a digital dataset(s) fully compatible with ECDIS (Electronic Chart Display and Information System) that serve the purpose otherwise provided by NP1 or NP2.

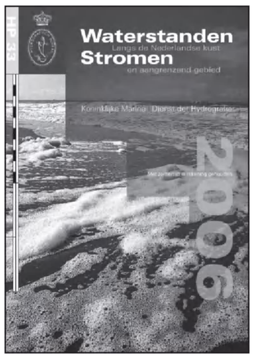

Figure 7. Frontpage of HP33.

The tide table of HP33 (Tidal Heights Streams along Coastal waters of the Netherlands and adjacent areas, see figure 7) presents the High- and Low Waters and the hourly values in decimetres for 2 Belgian and 15 Netherlands locations. For the HP33 there will not be a one step transition to LAT. Per year an inventory will be made which locations will appear on LAT referenced charts and which will not. Clear notes will indicate which level is used for the tidal predictions. For each location the difference between LAT and GLLWS will be provided.

HP33D – NLTides, launched in 2005, provides tidal height predictions for all significant ports from Nieuwpoort in Belgium to List in Germany and streams for the Southern North Sea, the Netherlands part of the Waddenzee, Scheldt, Tidal river area and main port approaches. Compared with the paper HP33, NLTides provides more ports, however the predicted tidal heights for the Netherlands ports and stream information are consistent. NLTides is an annual edition providing tidal predictions valid for that year. The program can perform Port Clearance calculations when information like draught and underkeel allowance of a vessel are provided.

NLHS issues the program NLTides as an official equivalent of paper tide tables in accordance with SOLAS V2.2. It may replace traditional paper tide tables

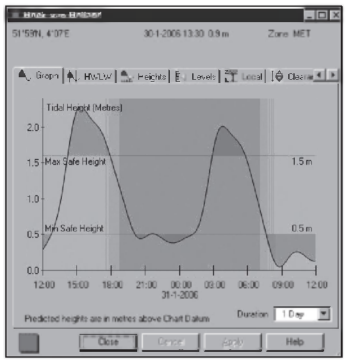

Figure 8. Prediction of tidal height in HP33D.

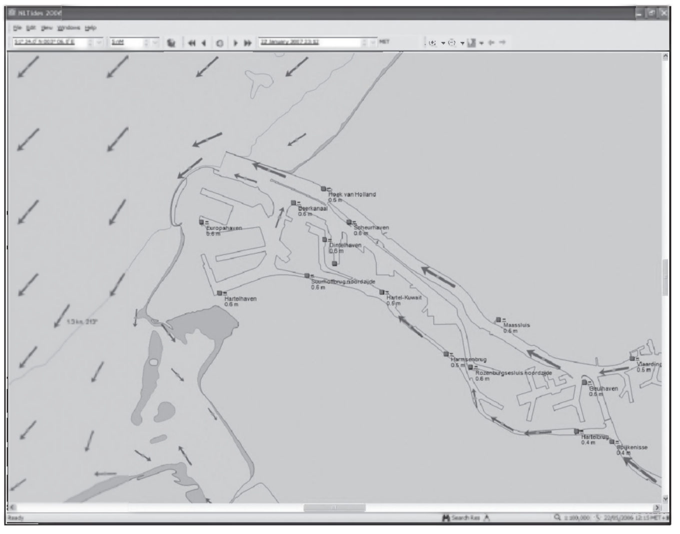

Figure 9. Prediction of tidal streams in HP33D.

provided that appropriate back-up arrangements are available (e.g. print facility or 2nd installed program).
In the future, during the transition, a choice can be made to which of the two levels the tidal heights will be referenced in the HP33D.

Electronic Navigational Charts (ENC's)

ENC's are being produced in the following usage bands:
1) Overview
2) General
3) Coastal
4) Approach
5) Harbour
6) Berthing

NLHS is in the process of finishing a complete set of NL-ENC's for the Dutch continental shelf. This process will be finalised in 2007, thus a complete set of ENC's will be available for the area of responsibility of the Netherlands, with the exception of the usage band 6, Berthing. ENC-coverage of the Caribbean waters, which are the charted by NLHS, will follow subsequently.
At this moment, it is not required that data of ENC's are defined with respect to LAT. If digital data used in ECDIS (Electronic Charting and Display Information System) are not in LAT, the used Chart Datum must be permanently displayed. When a paper nautical chart is published in LAT, the corresponding ENC-cell will immediately follow.

Remaining publications

In other publications, information changes as well, due to the introduction of LAT. E.g. wrecks will generally have less vertical clearance in the Wreck register HP39.

Other Consequences of Changing to LAT

In nautical charts a maintained depth is often shown in entrances to harbours. In the Netherlands the maintained depth is stated in a contract between port authorities and a dredging company with respect to Mean Sea Level or Normal Amsterdam Peil (NAP, The Netherlands land levelling system). This means the maintained depth figure in the chart will change, but in the established contract it will remain the same.

A change in depth figures implies the low water line (line of 0 metre) will change. A change of the low water line will have its influence on the maritime limits which have to be derived from the low water line, e.g. the 12 nautical miles outer limit which is used in defining the territorial waters. This low water line is also called the normal base line. The differences will be larger near coasts where the sea floor is sloping more gradually, e.g. north of the Frisian Islands. Already established maritime boundaries with neighbouring states will not change, of course. When neighbouring countries without an established maritime boundary are both transited to LAT, simplifies the negotiating process to establish a common boundary. The issue of choosing a common chart datum is not present anymore. There are examples of these kinds of problems, e.g. the maritime boundary between Belgium and France. One problem with computing a maritime boundary by using two different Chart Datums is thus overcome, although most of the maritime boundaries in the North Sea have already been delimited.

Having the same Chart Datum all over the North Sea has advantages for the user. No virtual thresholds have to be passed. Also, no negative values of predicted tidal heights in tide tables will appear. Although with MLLWS this was rarely the case.

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The Use Of ENC On Board Ships – Users Point Of View

Igor Karnicnik, M.Sc. Geod.

Today the electronic charts are already in use. There are several types of electronic charts systems on the market and different types of electronic charts. There has been questionnaire research survey made and the analyses of the answers received from users to the sent questionnaire are summarized in the paper. The analyses gives an overview of the benefits of electronic charts and what is also important, problems, difficulties and facts to which we have to be concentrated in the future in respect of using electronic charts, development of electronic nautical charts systems and production of ENCs. There are also most important standards of the International Hydrographic Organization (IHO) and conventions of International Maritime Organization (IMO) presented and some fundamentals are given about different types of electronic charts and electronic systems.

Introduction

The need for surveying and charting the sea and coast exists from the beginning of first attempts of sailing outside of known waters. With the development of compass and sextant the sailing was possible also behind the horizon, and the development of cartography gave the mariners the means to present the area where they are sailing.

Navigational charts were, are and will be most important navigational aid on the ship's bridge. The demands of modern navigation are such that it is hard to imagine navigating trough waters with dense traffic without electronic aids for navigation or integrated bridge system. To bring charts to the mariners on board ships, we use:

"**Hydrography**, the branch of applied science which deals with the measurement and description of the physical features of the navigable portion of the earth's surface and adjoining coastal areas, with special reference to their use for the purpose of navigation [1]."

Standards of IHO and IMO

There are many international and national regulations, conventions and standards that are dealing with the safety of navigation, preventing the maritime accidents, preventing pollution of the sea, hydrography and nautical charting. In the following section some of the basic conventions of the International Maritime Organization - IMO and International Hydrographic Organization - IHO are mentioned.

SOLAS Convention

Of all international convention the SOLAS - *International Convention for the Safety of Life at Sea*, is probable the most important and regulates all the aspects of safe navigation.

COLREG Convention

Convention on the International Regulations for Preventing Collisions at Sea regulates how the ships have to be equipped and what must be done in order to prevent collisions at sea.

SCTW Convention

International Convention on standards of Training, Certification and Watchkeeping for Seafarers regulates the level of knowledge for the mariners.

MARPOL Convention

International Convention for the Prevention of Pollution from Ships regulates the required measures in order to prevent the pollution from ships.

Special publication S - 44

IHO Standards for Hydrographic Surveys defines the minimum demands for hydrographic survey and required accuracy.

Special publication M - 4

Regulations of the IHO for International (INT) charts and Chart Specifications of the IHO defines how the nautical charts should be compiled in order to satisfy the uniform international demands for safety of navigation.

Special publication S - 52

Specifications for chart content and display aspects of ECDIS defines how the chart elements should be presented on the screen of electronic chart system.

Special publication S - 57

IHO Transfer Standard for Digital Hydrographic Data defines how the data should be coded for exchange between production authority and users.

Electronic chart systems and electronic charts

Many electronic chart systems were developed and are in use today on board ships. To distinguish among them we have to go to basic definitions. For commercial shipping and safety of navigation it is important to know and understand each system separately and to be aware of what can be used under SOLAS requirements.

Electronic chart systems can be divided in two main types:
- raster systems and
- vector systems.

According to the system used, there are raster and vector electronic charts, which may be divided, regarding what can be used as the basis for navigation under SOLAS requirements into:
- official (or what can be used under SOLAS regulations) and
- unofficial charts.

Electronic charts systems

Not all electronic chart systems have the same capabilities or the function in the same way. The primary difference between the various types of systems primarily relate to:
- format and content of the chart data,
- chart display,
- available navigational functions.

Based on these criteria, there are three basic types of systems:
- Electronic Chart Display and Information System – ECDIS,
- Electronic Chart System – ECS,
- Raster Chart Display System – RCDS [2].

Electronic Chart Display and Information System - ECDIS

To be called ECDIS (*Electronic Chart Display and Information System*) the equipment must do much more that just properly display stored chart data. ECDIS is a ship borne navigational device and it must support the whole range of navigational functions that make use of the characteristics of the chart data and their specific presentation. For this reason, the IMO developed a standard describing the minimum of functional requirements of an ECDIS - the Performance standard for ECDIS [3], and the definition for ECDIS as specified in ECDIS Performance standard is:

"Electronic Chart Display and Information System (ECDIS) means a navigational information system which, with adequate back up arrangements, can be accepted as complying with the up-to-date chart required by regulation V/19 & V/27 of the SOLAS convention, by displaying selected information from a system electronic navigational chart (SENC) with positional information from navigation sensors to assist the mariner in route planning and route monitoring, and by displaying additional navigation-related information if required."

To ensure that ECDIS equipment intended for onboard use is seaworthy, it must pass type approval and test procedures developed by the International Electrotechnical Commission (IEC) and based on the IMO and IHO requirements [2].

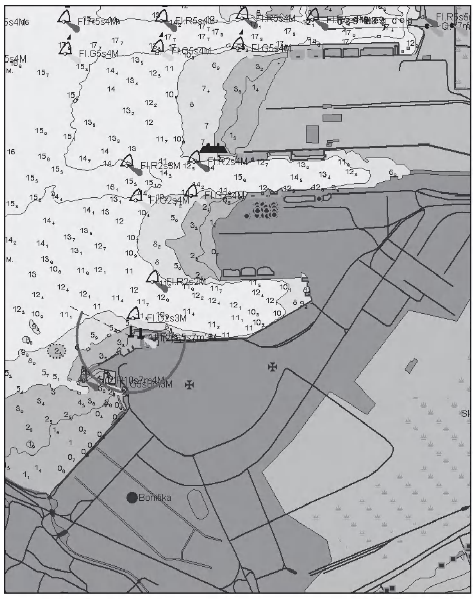

Figure 1: ENC Bay of Koper.

ENC (Figure 1) which is used in ECDIS contains the official chart data. The ENC is vector type of data presentation. In vector type of data, direct connection between two points is given either as two sets of co-ordinates (points), or by direction and distance from one given set of co-ordinates [1].

Electronic Chart System – ECS

In general, all the systems, which are not capable of meeting the ECDIS Performance Standard, can be generically designated as "Electronic Chart Systems (ECS)" [2]. There are two main reasons for this:

- this systems do not use official ENC data that has been issued by Hydrographic office or
- they have limited functional capability that does not meet the minimum requirements specified by IMO.

Raster Chart Display System – RCDS

Raster Chart Display Systems use raster charts for their prime source for presenting chart information on the screen. The raster charts used are called RNC or Raster Navigational Chart. By definition, RNC is a digital raster copy of official paper charts conforming to IHO Product Specifications and can only be issued by, or on the authority of, national Hydrographic Office.

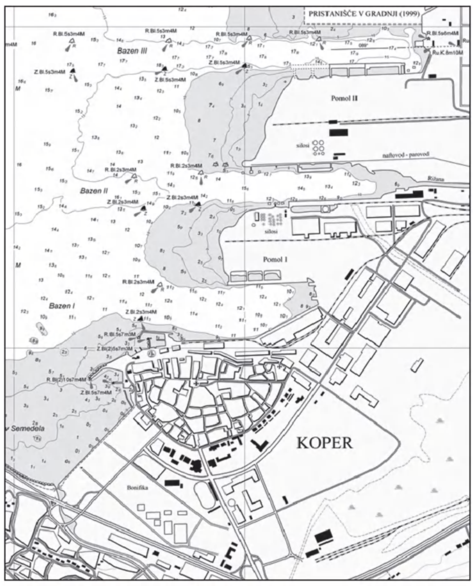

Figure 2: RNC Bay of Koper.

A RNC (Figure 2) is actually a digital copy of the same paper chart produced in a process of scanning. In this way RNC is an authentic copy of official paper chart and the authorities offer also regular updating of these charts. Some ECDIS can/may also perform in RCDS mode, but only when ENC of the same area is not available.

Questionnaire analysis – users point of view

A number of commercial ships nowadays use either raster or vector systems and introducing electronic chars into a mariner's world is not an easy task. Experts may develop electronic chart systems and many new electronic navigational tools, but they cannot be certain if this equipment will actually be useful when used by end users. In case of electronic chart systems and safety of navigation, the end user is primarily a mariner on board ship. To investigate how they see this new navigational tool, a research survey was carried out. The questionnaire was sent to officers on board ships to collect their opinion about ECDIS, ENC and RNC. There were 14 questions in the questionnaire, some required full answer, some required only to indicate most suitable answer. In total 351 questionnaires were sent out to varies institutions, individuals, hydrographic offices and shipping companies. There was 87 (or almost 25%) questionnaires returned, some were fully completed, some were partly completed and some only indicated, that they do not use electronic charts. Some questions required to write end user's own opinion, which proved to be most helpful source of information.

The majority of answers were from tankers, followed by container ships and RO/RO ships. Since the questionnaire was send also to the hydrographic offices, some 22% of answers were received from hydrographic research vessels (Figure 3).

ECDIS is navigational tool, which offers various tools such as route planning and monitoring, real time position fixing, setting safety alarms (e.g. anti-grounding alarm), radar and ARPA overlay, automatic updating of charts, etc. According to the responses from the users, the most welcomed benefit for the safety is real-time positioning, which saves them time plotting their position on paper chart.

A ship carries around 350-400 charts on board. To manually correct all this charts by Notice to Mariners (NtM) would take an officer up to five hours per week. ECDIS offers automatic updating and this shows as a drastic cut in the time absorbed by the navigator in chart updating to about 45 minutes a week [6]. Automatic chart corrections are second most welcomed advantage of ECDIS.

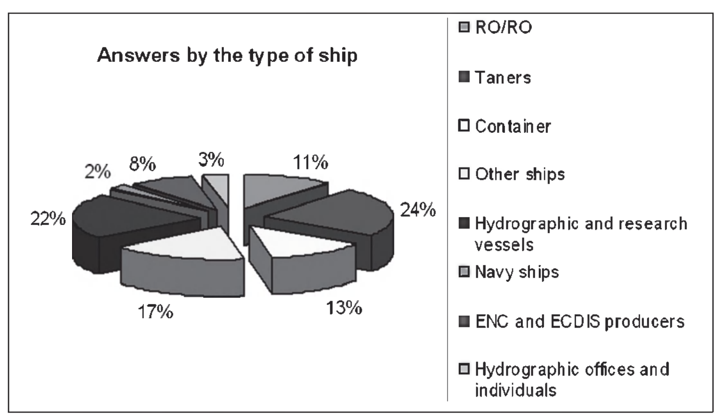

Figure 3: Answers by the type of ship.

Other big advantages, as it can be seen from the analysis, are built in warnings and alarms, for example setting the safety contour. Similar benefit can be seen from route planning and route check. ECDIS is playing central role in ship's bridge, all information mariner needs are in front of him. Navigator does not need to list through a stack of paper charts or nautical publications. Connection to other sensors gives him also other important information. Radar and ARPA overlay with electronic chart can improve situational awareness and reduce risk of collisions at sea, especially in confined waters or in conditions of restricted visibility (e.g. night, fog, rain).

ECDIS has many benefits, but one must be aware also of its limitations. At the moment, there are still many areas not covered by ENC, which represents substantial drawback. By the answers, this is what users are missing most. Then follows the problem, that user sees the ECDIS as too expensive tool, followed by costly updating of charts and maintenance of hardware and software as well. The need to upgrade the licence key every year is exorbitant. This can be discouraging to build portfolio of electronic charts.

What is also important and observed by users is that Officer Of the Watch (OOW) must still be alert to the situation outside the bridge. The operator must have the primary responsibility for the navigation. He must oversee the automation and exercise his informed judgement about when to intervene manually. With the constant use of ECDIS, OOW my "forget" to look outside the window and rely only to the electronic chart. Also, to rely and work only with ECDIS, may reduce the skills of young navigators, which my stop using and practice traditional navigational equipment.

Many users are experiencing the lack of training and education for the use of ECDIS. Mariners must be sufficiently trained for work with ECDIS. Not knowing all the benefits or using them wrongly can lead to disaster. ECDIS is electronic equipment and as such is subject to malfunction or loss of power supply. These are just a few of the aspects which still have to be considered using electronic systems as an aid for navigation, and the answers to the questionnaire are indicating mariners are aware of that.

Other aspect is the financial one. Some companies are reluctant to invest in ECDIS, since the investment is quite high, and than there are cost for charts and their updates. There was one comment to the question of availability of ENCs which should be mentioned: "ECDIS is fitted on board the ship, but the owner does not want to buy the ENC due to high price of them." Disturbing information. There are many benefits of ECDIS, which can result in saving time and money for ship operation and this should be presented to the investors.

Answers to the question, whether the users distinguish between ENC (Electronic Navigational Chart) and RNC (Raster Navigational Chart) need to be mention. We can conclude, that there is a high degree of confusion what is ENC and what RNC, what is ECDIS and what RDCS, what is official and what is non-official chart. And what is more important, what is the difference. All the involved parties, from ECDIS manufacturer, ENC producers and authorities need to present this difference to the users at all levels, form education to final operational use on board ship.

So far the number of ENC in the market is limited and not all the world's seaways are covered by ENC. IHO and other countries are trying increasing the ENC production, but the process of creating an ENC is very demanding and long. During a creation, ENC must go through several independent quality controls and validations. Only then an authority can guarantee its content and completeness so ENC becomes "official".

On the other hand, the production of RNC is faster and easier. The base for scanning is official and updated paper chart. With this also the RNC is official. At this point it is very important that users are aware of differences between these two systems. To point out such important subject, IMO prepared the list of differences between RCDS and ECDIS [4]. The IMO accepted the amendments that an ECDIS may operate also as RCDS, but only when ENC are not available.

The requirements for charts and publications to be carried can be fulfilled by:

1. carriage of official and up-to-date paper charts, or
2. carriage of a type-approved ECDIS, using official and up-to-date ENC together with an appropriate back up arrangement [5].

There are two aspects, which should be mentioned. Firstly which are official charts and secondly what is appropriate back-up arrangement. ENC issued by, or on the authority of a Government, authorised Hydrographic Office or other relevant government institutions are official and may be used to fulfil carriage requirements (provided they are kept up to date) [5]. All other charts are not official and are usually referred as private charts and are not accepted as a basis for navigation under SOLAS. Similar aspect is valid also for RNC. Official RNC is a digital raster copy of official paper chart and can be issued by, or on the authority of a national Hydrographic Office. Where official ENCs are not yet available, IMO regulations allow Flag States to authorise the use of official RNC with an appropriate folio of paper charts.

From the answers it can be seen, that majority of users, some 48% is already using raster charts, either only raster charts, or they are using raster charts where there is no ENC available. Related to this, some 10% of users support that ECDIS should work only with official ENCs, about 22% supports the idea that ECDIS should work in both modes, raster and vector. Majority considers that ECDIS should work with raster charts only until all ENCs are available (Figure 4).

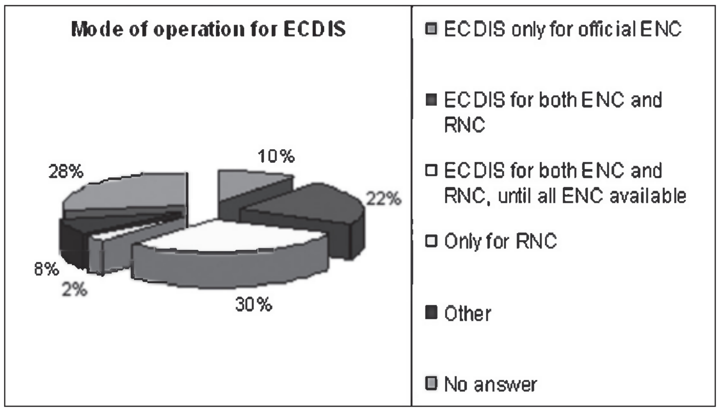

Figure 4: Users opinion about mode of operation of ECDIS.

Encouraging is, the about 1/3 of all replays considers ECDIS is ready for use and will be a great benefit for safety of navigation. Some 21% consider that ECDIS will contribute to the safety of navigation, but still needs some improvement. Luckily nobody thinks that ECDIS will not contribute to the safety at sea.

Conclusion

ECDIS is a great improvement for the safety of navigation. The majority of mariners are in favour of ECDIS and they see the benefits. Adoption for greater use among shipping companies has been slow and here we all should give some effort to increase it. Truth is, that there are still some concerns about ECDIS, which is shown mainly in power or software failure. As one of the users replied: "You can use paper chart with candle light!" Other greater concern among users is the confusion between ECDIS, RCDS, between ENC, RNC, ECS and what is official and what is not. This still needs some improvement and clarifications. We may summarise the findings into following points:

- ECDIS benefits are mostly seen in efficient and easy updating, route planning and monitoring, situational awareness, safety alarms, voyage recording, paper chart reduction which can all help in preventing accidents, loss of lives, ships and cargo and contribute to more precise planning of arrival time to port for more efficient use of ships time;
- Users should be aware of limitations of ECDIS and should be properly trained for their usage;
- ENC production must speed up in order to increase ENC coverage and give mariners the "food for ECDIS".
- Encourage shipping companies to install ECDIS on board their ships;
- Assure proper training of mariners at the naval colleges and maritime universities.

Electronic charts (be that raster of vector) are of a great benefit for safe navigation, although, ECDIS offers a number of additional functions and with this can be seen as superior to raster system. Correctly and consistently using the electronic chart during voyage from port to port can help preventing accidents, loss of human lives, ships and cargo and what is also important, prevent pollution and help preserve natural environment.

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Dynamic Bathymetric ENCs In Ports

SevenCs, Hamburg, Germany

Bohdan Pillich, Friedhelm Moggert

Most of the present day Electronic Navigational Charts (ENCs) are produced by digitising paper charts. This methodology leads to a considerable loss of detail of the bottom topography when compared with the source survey data. In addition, the delays in the chain of procedures leading from survey to a chart displayed onboard a vessel can be serious as well. This is particularly important in the areas where the bathymetry is likely to be changeable, either due to natural processes like storms or travelling sand waves, or to human activities, e.g. dredging. Ports and their approaches are the prime example of the latter. The new bathymetric data are often available on a much shorter notice than the standard ENCs are produced or updated. These high density data can be sent out by the port authorities and incorporated in the ENCs carried by the vessels by interleaving them with the other ENC data. The onboard software can then produce the required contour lines. Tests results indicate that this process is fast and can be carried out with minimal effort. It does not involve any changes in topography or in other existing chart information, only in bathymetry. The product has been thus given the name of "bathymetric ENCs". The availability of the bathymetric ENCs in the port environment applications will increase safety of navigation and the efficiency of the handling of vessel traffic and of the general management of port operations.

In addition, depth data, including bathymetric ENCs, can be dynamically presented and adjusted for tides and surges using either predictions, modelling or observational data supplied by in-situ transmitters. The creation of dynamic charts which include bathymetric ENCs thus permitting real-time display of the most up-todate depth data will enhance further the safety value of ECDIS. At present, regulatory restrictions preclude application of dynamic depths for the use in the official ECDIS, but these are expected to be lifted in the near future. These restrictions do not apply to the Portable Pilot Units or to other non-navigational applications, like port management information systems. Such systems can be based on the web and provide also the general public with access to this important information.

Introduction

Any chart, whether paper or electronic, is a snap picture of the marine world frozen in time. In reality all objects which make up a chart, man-made and natural, including coastlines and bathymetry, change with time at varying speed and frequency, and with varying level of predictability. For practical purposes, the cartographic objects are considered as constant while time variable navigational objects represent the dynamic variability of the real world surrounding the ships.

One can think of many types of time varying information that could be incorporated in ECDIS but, before considering any for inclusion, one most important question must be answered: is the information essential to safety of navigation?

Vital to safety of navigation is the depth of water which is not constant even if considered a cartographic object. The mariners must have this information, it must be up to date, and the data, usually providing much more detail than the official ENCs, are available from various sources, e.g. from port authorities. Hydrographic surveying is one of the daily tasks the port authorities have to fullfil. The bathymetric data obtained from these surveys provides the information not only for safe navigation buit also for port planning, dredging, construction work etc., especially since the size of the vessels using ports, the amount of cargo they carry and thus their draft are constanly increasing.

Present Day ENCs

Paper charts and ENCs are based on the same source data and at present, the depths shown in the ENCs are digitised from the paper charts, rather than obtained from the original source - the high density digital surveys. This reduces the accuracy of the bottom topography and remains the spurious ground for the present prohibition of dynamic depth display, where bathymetry is combined with tidal and other data influencing the water level (e.g. storm surges). In addition, any changes, including bathymetry, whether natural or man-made, take time before they make their way to the onboard ECDIS, the updating process being still rather slow and based on the same paper centred methodology.

Trying to integrate high-resolution bathymetry into paper charts would result in clutter and loss of readability so the cartographers have to generalize details, taking into account the final scale of the chart. This is why the official ENCs of a port area represent bathymetry in a very generic way despite the fact that the port authorities collect most accurate high density bathymetric data with full bottom coverage. These data don't make their way to the official ENCs. Basically it's the maintained depths that is represented in Harbour ENCs. Thus ENCs don't provide high resolution depth information that could be useful for route planning and/or high precision navigation. Tidal corrections (predicted or real-time) cannot be efficiently applied without high density bathymetry. Because of the low density of the underlying bathymetric data in the ENCs the IMO ECDIS performance standard prohibits the use of dynamic depth information.

The paper charts will always have to adhere strictly to the cartographic rules so the information is presented in a "human readable" format, meaning clearly legible. The situation is rather different with respect to the ENCs. Besides the display of information, it is stored in a machine readable format. This information held by an ENC is not limited to the features that are visually presented to the user. This additional information could be used for new functionalities much more sophisticated than what ECDIS is allowed to provide now. As long as the full potential of ENCs is not used, ECDIS won't be much more than an electronic display of a paper chart.

In the interim the bathymetric data still needs to br provided to the ships. Seven Cs developed a methodology to facilitate the incorporation in the ENCs of the new bathymetric data from various sources. It is descdribed below.

Bathymetric ENCs

Knowledge of the accurate depth of water not only improves the safety of navigation, but also shows clear economic benefits. Every extra centimetre of draft is worth thousands of dollars to the ship owner and also additional income to the port authorities.

The modern survey systems are capable of collecting bathymetric data in a short time with very high accuracy. There is not much left of this high resolution depth information in the ENCs, they contain ther least depth soundings and contours at relatively large intervals (e.g. 0, 2, 5, 10m, etc.). Harbour ENCs usually show the maintained depth withoud details.

The source data allows for the production of high precision ENCs containing depth contours at decimetric intervals. New bathymetric data can be made available on a much shorter notice than the standard ENCs are produced or updated. These data can be converted into S-57 format to be incorporated in an ENC and displayed in conjunction with other ENC data carried by the vessels. These amendments can be carried out with the minimal effort. Since this process does not involve any changes in topography or in other chart information we called the idea "bathymetric ENCs".

The bathymetric ENCs would facilitate drastically the incorporation of survey based depth information during the ENC production process. They don't have to be merged with data from other sources or incorporated in existing ENCs, their content being limited to the bathymetry data. The depth information is encoded by means of the S-57 object classes depth area (DEPARE), depth contour (DEPCNT) and soundings (SOUNDG). Meta objects are used to encode accuracy and quality information. The bathymetric ENCs, unlike the standard ENCs, do not necessarily have to be rectangular. The meta object M_COVR with CATCOV=1 is used to represent the geographic area containing data. It can overlap two or more standard ENCs cells. Although the bathymetric ENCs will be most likely used within geographically small areas, like ports or port approaches, there will be exceptions to this, e.g when large areas have to be resurveyed after a heavy storm (a usual occurence in the North Sea).

Converting survey data into S-57 to generate the bathymetric ENC objects can be done very efficiently. Merging these data with other information in an ENC is another matter. A bathymetric ENC must not be overlaid on top of the standard ENC to prevent obscuring navigational information. SevenCs uses a methodology called interleaving to prevent this from happening. Interleaving allows the bathymetric ENCs to be inserted above the original bathymetric data but below the layer containing the navigational information like navigational aids (buoys, lights), traffic seperation schemes, etc.. This information can be retrieved from other sources, e.g. the existing ENCs or other databases. Storing the bathymetric data separately in a bathymetric ENCs rather than incorporating it into the standard ENC will drastically facilitate the chart updating procedure. The regular ENC showing the maintained depths only does not have to be touched at all. Only the bathymetric ENC containing detailed depth data is replaced by a new edition.

Due to its limitation to bathymetric information, the bathymetric ENC would not comply with the Product Specification for ENCs which defines the chart contents, mandatory features, etc. in a very detailed fashion. To distinguish between a regular ENC and an ENC containing depth information only, we propose to introduce the "bathymetric ENC" as additional S-57 product. A dedicated Product Specification for bathymetric ENCs is required to define its content, data structure, topological requirements, meta information, the S-57 object classes (incl. attributes) necessary to describe the content, and the updating rules.

Defining an additional S-57 product by means of a product specification doesn't answer the question how it can be used in conjunction with other S-57 products. In the end it is the ECDIS or ECS application that must be able to properly handle different electronic chart products. Due to its limited content, the bathymetric ENC should not be used on its own since it provides only the detailed depth information that is not contained in standard ENCs. The current ECDIS/ECS Systems should have no problems loading and displaying a bathymetric ENC. Calculations that are needed for typical ECDIS functions like route planning, anti-grounding, etc. could easily take into account the detailed depth information of the bathymetric ENC in addition to the data provided by the standard chart.

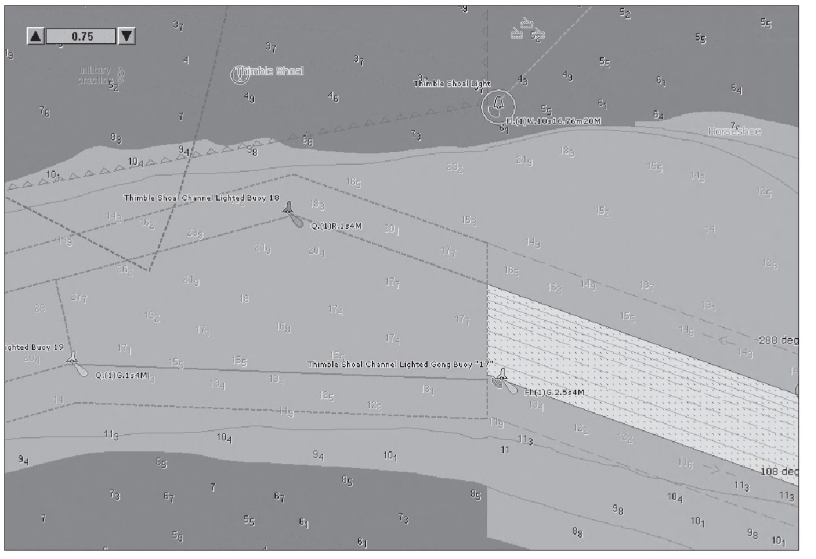

Figure 1: The original chart showing the approaches to the port (US5VA15M.000 US5VA19M.000).

Presentation of the data, interleaving

Recently, a new survey of the Hampton Roads has been conducted by the NOAA Ship WHITING. We shall demonstrate the interleaving using these data. The relevant part of an original ENC is shown in Figure1 above, the update data, kindly provided by the Centre of Coastal and Ocean Mapping (CCOM), is in Figure 2.

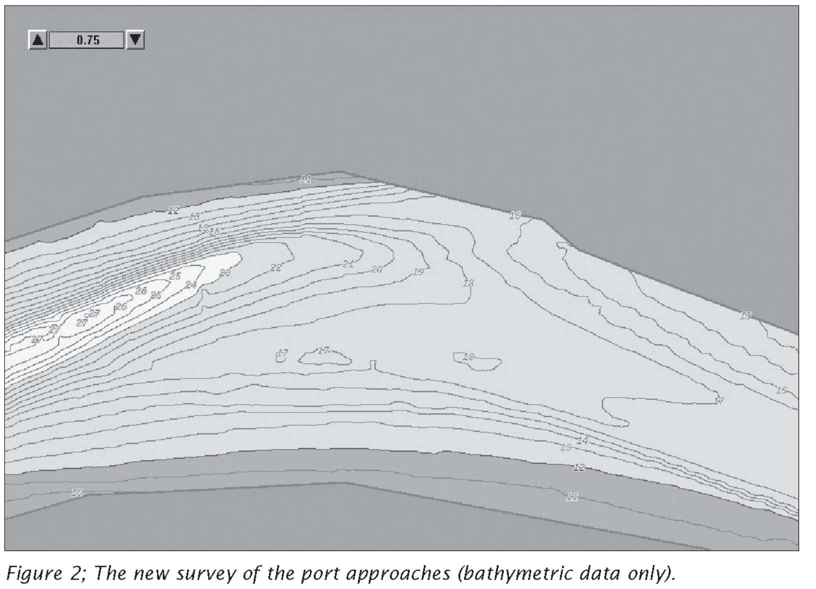

Figure 2; The new survey of the port approaches (bathymetric data only).

As can be seen in Figure 2 the survey does not cover the full width of the channel, only the part important to the deeper draft vessels. The bathymetric data, once converted into S-57, can be easily presented on the ECDIS screen, but simply overlaying it on top of an ENC (Figure 3, next page) obscures the navaids thus breaking the main rule of displaying the additional information on the ECDIS screen which requires that any such information must not obscure the navigational information

The interleaving methodology prevents obscuring, the results being shown in the Figure 4 (next page).

The use of bathymetric ENCs will be optional. However, it is expected that with the support of the port authorities, the usage of them will be widespread in the areas where the navigational waters are subject of frequent dredging or natural changes to the bottom topography (e.g. sand waves or storm induced changes). Applications using this approach should have the capability to switch on/off the bathymetric ENCs. The application should indicate when the function is turned on. When data query and anti-grounding alarm functionality are being used it must be indicated if bathymetric ENCs have been taken into account or not. It is expected that most of the presnt ECDIS systems will be able to handle the bathymetric ENCs.

The existing presentation standards for ENC and/or Inland ENC data (S-52) are sufficient to visualize bathymetric ENCs.

Data Distribution

From the technical perspective it wouldn't be much of an effort to introduce the bathymetric ENC as an additional S-57 product and utilize it. However there are also logistic and legal issues that need to be considered.

The question of the logistics of the distribution of the bathymetric ENCs may appear easy on the local level, but proper infrastructure must be in place once the distribution is to reach the vessels offshore or in the foreign ports. Chart and/or shipping agents may step in to fulfill the role of distributors. This is however, a relatively simple techological matter.

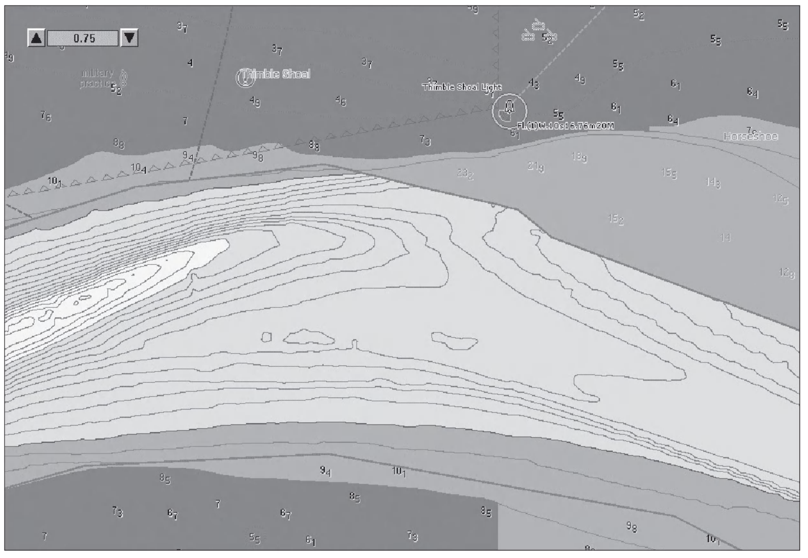

Figure 3: Survey data on top of the original ENC, navaids obscured.

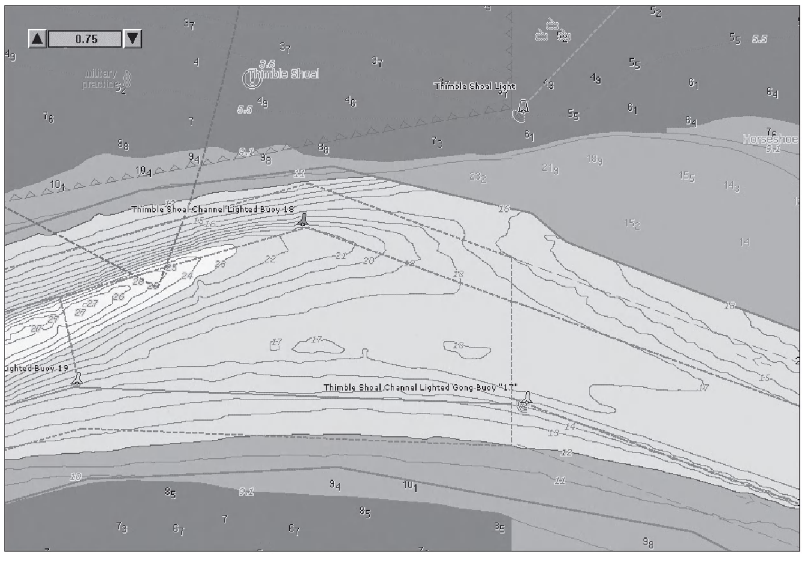

Figure 4: Survey data interleaved with the original ENC, all navaid information visible.

Much more complicated are the legal issues. Today the bathymetric products from the port authorities are not allowed to be used in ECDIS. The data are used for internal purposes and provided to the relevant Hydrographic Office for incorporation in the official ENCs. Hydrographic Offices are the only authorities to issue the official ENCs. In addition, there is no official S-57 product specification for the bathymetric ENC and until the IHO introduces it, the bathymetric ENCs do not have an official status.

Port authorities have the most reliable, most recent and most accurate depth data for their areas of responsibility. It is proposed that with respect to the bathymetric ENCs they could adopt the producer's role which the Hydrographic Offices have for standard ENCs. However, the issue of liability will have to be solved first. The HOs are liable for any inaccuracies in the official ENCs, but being supported by the national government, can carry this liability. Port authorities don't have the same national level back-up and may want to avoid the risk. At the same time however, ports are commercial organisations built for profit and producing bathymetric ENCs will increase their profit, so there is a possibility of arriving at a solution.

The port authorities would need to certify the official status of their bathymetric ENCs to be allowed for use in navigation, they could be then distributed and made available to the public via chart agents. ECDIS systems should be allowed to make use of certified bathymetric ENCs without violating type approval.

To guarantee consistency and completeness and to make sure that bathymetric ENCs can be handled by current ECDIS properly, a dedicated Product Specification is required. This should not be too restrictive and leave enough freedom for the individual situations in different ports. Some more questions need to be answered. Would the port authorities for example require approval by IHO or the national HO to introduce and certify bathymetric ENCs? Who would be the responsible authority for the Product Specification?

Future developments

The Navigation Surface Approach recently developed at the C-COM [1] proposes a new way of chart production. The Navigation Surface Database (NSDB) can be used to generate various cartographic products. Depending on the needs of the final product (e.g. bathymetric ENCs) the data are generalized to the requiered scale and stored in a product grid. Should a competent authority certify such a product grid as "safe for Navigation", (i.e. it obtains the status of a navigational product), it could be passed to the onboard software and used to create the dynamic bathymetric ENC on-the-fly. The onboard software could create dynamically the relevant contour lines on-the-fly directly from the product grid and tidal corrections applied to grid data.

Most of the marine variables are three-dimensional in their effect. Trying to represent them on an electronic copy of a paper map restricts us to the methods used by the paper print technology. ECDIS can free the user from these restrictions of the old technology. Innovative techniques for marine data conversion, display and modelling in ECDIS are being developed to accommodate the users' needs, e.g. three-dimensional displays. A 3D display lends itself to the dynamic depth information. The Chart of the Future project of CCOM [2] has already confirmed the concept of a dynamic 3D chart display.

Present computing capacities allow us to handle large data volumes without any problems. Modelling tools are available to generate DTMs which can be viewed from different perspectives, turned around and allow us to virtually fly through 3D scenes of the sea bottom. The three dimensional display of the will play a bigger role in the future, e.g. for docking situations or high precision navigation.

It is hoped that the ECDIS standards will keep track of new developments. S-57 Edition 4 (aka S100) is under construction, and its principal goal is: "… to support a greater variety of hydrographic related digital data sources, products, and customers. This includes matrix and raster data, 3D and time-varying data (x, y, z, and time), and new applications that go beyond the scope of traditional hydrography (e.g. high-density bathymetry, seafloor classification, marine GIS)" [3]. Bathymetric ENCs will hopefully be also included.

Summary

Bathymetric ENCs could be used to add high density bathymetry to standard ENCs with minimal effort. Introducing this idea will require support from port authorities in whose interest it is to provide the latest data to ships using their facilities.

The existing and forthcoming standards appear to be sufficient for the integration of the bathymetric and standard ENCs. A proposal for a bathymetric ENC product specification is available from SevenCs.

The legal issues must not be disregarded and should be discussed with all parties involved, i.e. port authorities, IHO, HOs, ECDIS manufacturers, etc.

Acknowledgements

Our thanks to the UNH for providing the charts and the bathymetric ENC data for the Hampton Roads

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Beyond ENC

S. Salter and A. Watkin

This paper discusses contemporary issues with ENC data and display systems. It identifies several areas where experience has exposed deficiencies in the use of ENC. We then go on to suggest several ways of improving cartographic data handling in the marine environment. Some of what we argue may seem counter-cultural since our experience of software development in the ENC context has given us an awareness of its limitations as well as its advantages. We want to see ENC continue to develop and for this reason we feel that it may be time to take a fresh look at some issues before they become needlessly ingrained in our collective consciousness.

There are a number of issues that fall into this category. In this paper we discuss just two: the importance of cartographic input to a charting system, and the potential advantages of a more dynamic and situation aware approach to symbology and standards.

Drawing Issues

Vector and Raster

Vector charts (ENCs) are generally considered to be an advance over raster charts (such as ARCS) and possibly even a successor to paper charts. However as they come into more common use several generic deficiencies are becoming apparent. Much has been said about the relative merits of raster and vector. Possibly too much since a large proportion of the voices have been driven by political and commercial concerns arguably to the detriment of the end user. However there remains an interesting technological issue which is seldom dwelled on; raster charts look better.

In our experience vector evangelists rattle out a litany of raster failings at this point, but the fact remains - raster looks better. It is clearer, suffers less from clutter, is better balanced and is totally familiar[1].

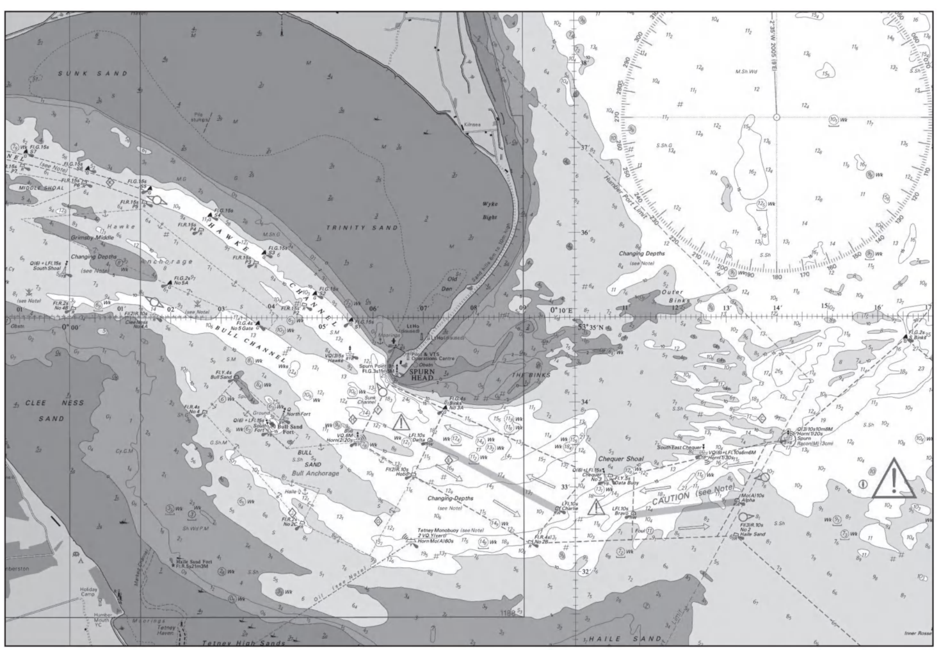

Figure 1: Typical raster chart. Clear understandable information which has carefully been compiled so as to be fit for purpose.

So what's going on? It seems obvious to us that the fundamental difference between raster and vector as implemented by ARCS and ENC is the contribution of the *cartographer*. While a good raster chart is an excellent facsimile of the chart a cartographer creates ENCs disregard much of the essential layout information since they try to recreate the chart dynamically, redrawing it from scratch (or very nearly). If we take a step back here it should be no surprise that this automated process is less effective than a cartographer's direct output. Good cartographers are highly skilled people who exercise professional judgement and experience in what they do. They can spend a day looking at an amended chart trying to assess whether it still retains the same value in terms of balance, content and clarity – and even scale and coverage. Everything we know about computer automation should have warned us that the deep human complexity of this process would be difficult to reproduce. Computers are dumb, don't learn from experience and have very little time in which to do the drawing. Substituting algorithmic complexity for cartographic expertise for the

[1] Neither is this article designed to be too one-sided in this particular aspect of the debate. CherSoft has worked very effecively with both raster and vector charts for 12 years.

most part fails miserably and our first thought for the future is that chart formats will need to retain more input from the cartographers.

Rendering

Rendering of ENC is comparatively slow and rarely gives satisfactory results when compared to a paper chart. Creating good quality charts from vector data will require adding cartographic information to the data set. There are some hints at this in ENC and a few more in VPF. The notion can be taken a lot further. Basically chart data should be designed for display at a particular scale.

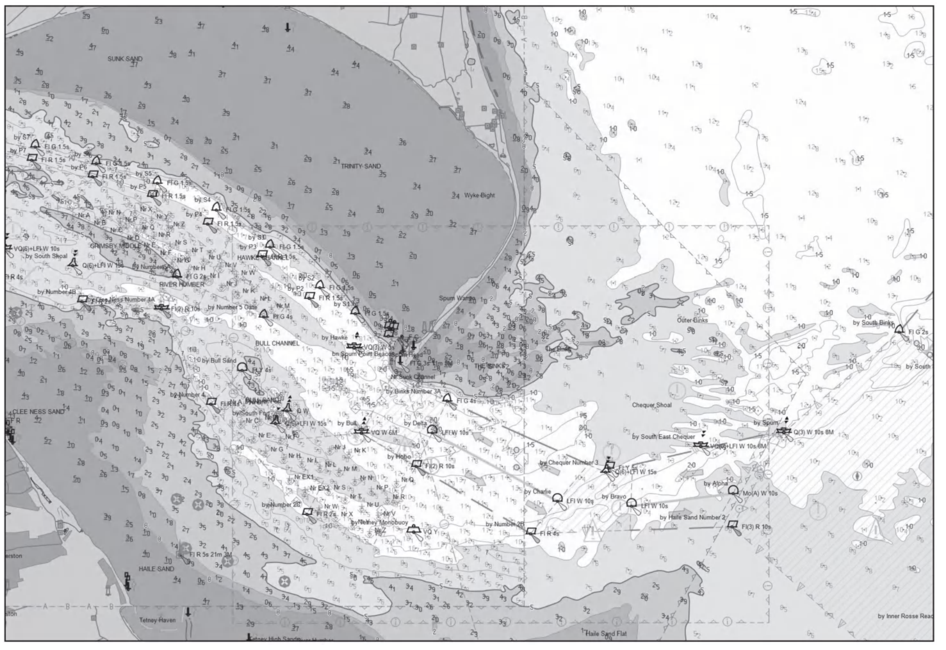

Figure 2: Vector data. Without the ability to zoom displays can easily become cluttered.

All good map or chart data is designed for display at a particular scale, the scale in turn chosen by the needs of the end-user. This is as true for hill walkers and car drivers as it is for mariners. Yet with ENC, a combination of the limitations of display technology and inside-out, feature driven development, has meant that the balance, usability, and at times safety of an ENC has been compromised. We cannot put a standard size chart on one inexpensive screen so we work around the problem by panning and zooming. Good cartography has been sacrificed in the temple of zoom.

Moreover, zoom is not necessarily the great advantage of vector charts that some would have us believe. It is closer to the truth to acknowledge that ENC actually needs zoom to help manage clutter. At anything like the information density of paper charts the ENC becomes dangerously cluttered.

Zoom is the obvious way out, but it does then dump unnecessary responsibility on the mariner. Instead of being presented with the right data in the right form and at the right scale, the mariner has to make additional decisions about what he wants to see displayed. Some may welcome this, although the safety implications are obvious.

The theoretical basis of S-57 is in the separation of geometry and attribution. This produces a (simple) model of the earth. Other mapping schemes use a database driven representation of a map. This has substantial cartographic information in addition to the model of the earth. Land map sales are more competitive than marine charts and so have maybe been pushed that bit harder. The lack of cartographic information in S-57 compounds the rendering problem so that the information density has to be kept down.

At an imaginative stretch you might find a use for 1:53,146 scale, or some other arbitrary scale, chart but for the most part knowing and understanding the scale of a chart is essential. Given a series of fixed scale charts the cartographers (remember them?) can be rolled out to turn the raw survey data into useful chart information. Their task involves aspects such as deciding what should be visible, how labels should be placed, what symbols should be used and so on. The chart has a purpose. Manipulating the data towards this end is highly skilled job. At the culmination of this we have another cartographic data set which tells us how to layout the chart at a certain scale. Great. Now the geeks can get involved. They will pre-process the data for display, optimise the rendering engines, cache off-screen images and support dynamic anti-aliasing. What ever all that means the end result will be fast, clear, reproducible chart images with all the benefits of an active data layer and the clarity or real paper charts.

Making Full Use of Available Data

Data Quality

ENC predicates better quality data than is actually available. Work is underway to re-survey many areas of the world but it takes time. Currently much ENC data is produced by tracing over existing raster charts. Because ENC cannot capture all the information and knowledge that goes into a paper chart it cannot make full use of the information actually available today. Paper charts used to be produced, in many respects, in isolation from other paper charts. The essential requirement being that the data was consistent on the chart – not that it should be consistent with adjoining charts. This data is still being used for ENC which is why you will often see discontinuities such as contours jumping at cell boundaries. On paper charts the Source

Data Diagram (SDD) is an essential consideration for the experienced mariner. ENC has the CATZOC attribute but this is of limited use. Rather than trying to hide issues of data quality it should be made an important aspect of the chart enabling the cartographer to make full use of the data to create a chart without misleading the navigator.

Projections

Although ENC claims to be projection independent this is not quite true. The path of a line between two points is not defined in ENC, although it is always taken to be straight line on a cylindrical projection. Co-ordinates are therefore defined on a two dimension grid (the surface of the cylinder) and so the ENC model is a flat, square world. Although navigators are typically comfortable with the distortion associated with cylindrical projections, these effects are really a hang over from paper based charts[2] and this is an odd juxtaposition with the notion that it is a good model for marine data. It is possible, but computationally intensive, to re-project ENC data, but other approaches to representing vector information might be more conducive to supporting general purpose systems such as would be essential for high latitude navigation. This is important since with the advent of global warming trans-polar routes are becoming increasingly feasible and we cannot ignore high latitudes to anything like the extent we once could.

Once we free ourselves from the limitations of paper charts the most obvious way to view the world is to look at it like a space man. Or a bird. This is what the world looks like if I were flying over it. Technically we call this a tangential projection. It is a natural way to look at the surface of the planet. By actually defining a straight line and using 3D coordinates a successor to ENC could power a new generation of chart viewers.

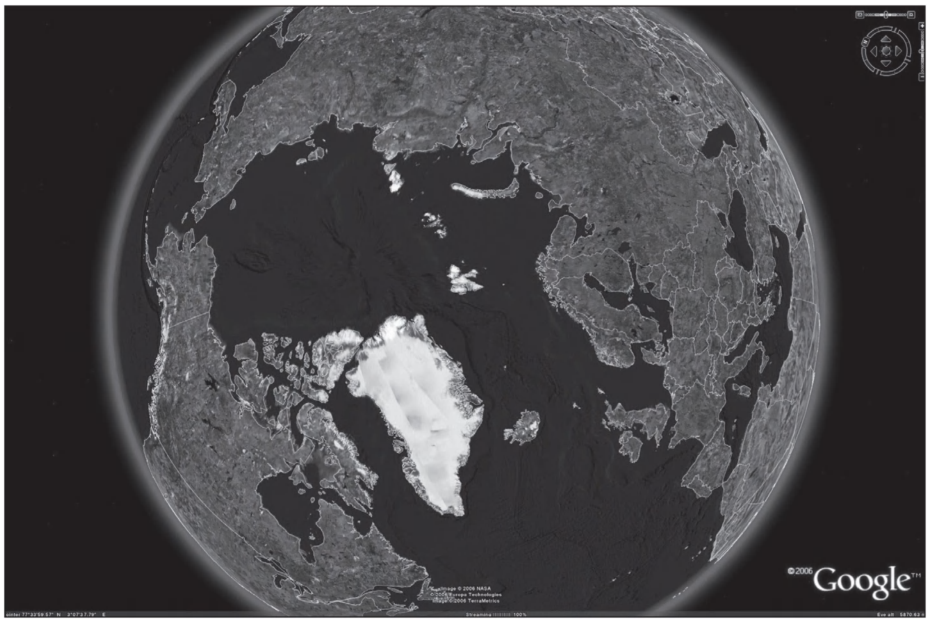

Figure 3. Google earth – a tangential projection which displays high latitudes as easily and naturally as equatorial regions.

Another type of useful projection is a variation on the bird's eye view where the direction of view is angled up towards the horizon. Again this is a very natural view in that it mimics common human perception. Objects in the distance, where they are less important, become compressed where as closer objects appear larger. Just like real life. This type of view is already commonly used in automobile satellite navigation systems – which of course have to be readily useable and understandable to untrained navigators.

Dynamic Symbology

The potential advantages are obvious if we think it through. While the main drive behind symbology in ENC is one of standardisation (one object, one symbol, everyone knows what it means), this makes much less sense when one considers the role of a chart in terms of situational awareness. For example, on a bridge system a nearby ARPA target heading straight towards you at 40 knots should slap you in the face. It is important, you need to be very aware of it, and quickly. Meanwhile another target at the limit of radar range doing 4 knots away from you is less of an immediate concern. A standard symbol cannot make this differentiation. Alarms on the bridge are almost useless because of the competition from all the other alarms, so an event like crossing a Safety Contour (a second very real example) needs to be signalled to the navigator in a more connected way. By this we mean that the symbology should help to show immediately what the problem is rather than just indicating that there is a problem somewhere.

The appropriate approach to situation awareness depends on purpose. In a passage planning exercise an interactive list of potential hazards is quite appropriate. However in a front-of-bridge voyage monitoring situation a more automated display that concentrated on immediate issues would be more useful.

[2] *ENC is still tied up with paper charts and so inherits a whole raft of issues including apparently strange behaviour at high latitudes.*

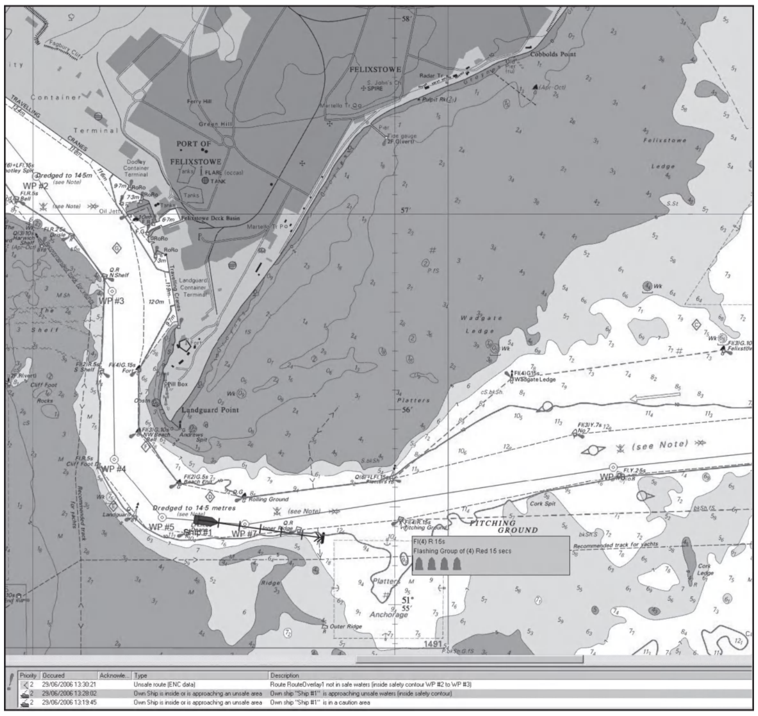

Figure 4: Simple dynamic symbology. The safety contour is an immediate concern to the vessel and has been high-lighted in red.

Facilitating a rapid appraisal of complex scenarios requires a much more dynamic approach to symbology. This does not just mean being able to switch layers on and off; it means variable size, colouring, transparency and even animation within the symbology. It means being able to manually mark objects for specific purposes, allowing dynamic input data (GPS, ARPA, RADAR), modifying the display and allowing the navigator to be able to interact by adapting symbols to suit his purpose. (The ENC safety contour is a step in this direction albeit a very small one).

To create real dynamic displays will require a rethink over the way standards are managed. Criteria will need to be phrased in terms such as 'is this situation clearly visible?' rather than the prescriptive testing for the appropriate static symbol. At the same time information such as display scale and source data information need to modify the drawing so as to create a feel for the quality of the chart information (back to the cartographic point). Contour lines and other symbols should be drawn using less precise edges where appropriate to offset the usual human tendency to assume that computer data is completely accurate.

Full situational awareness requires access to an open ended set of data and hence symbols. The full range of possibilities is large and growing: Radar, ARPA, AIS, tides and so on. To try and regulate all the possibilities would require an extraordinarily capable crystal ball. So if type approval is not intended to inhibit the development of these technologies then the approval criteria will need to be coined in terms of subjective usability.

There is a lack of stability in ENC caused by the number of parameters required to specify a view. For paper charts the only required parameters are chart number and update week number. This defines completely and reproducibly exactly what can be seen. However for ENC we need a list of contributory cells, zoom level, rotation, position, screen size, screen resolution and a hundred or more user configurable display options. The combination of these produces a chart display which can be disorientating and unpredictable. An incident investigation, for example, would want to ascertain exactly what chart information was being displayed. Easy with paper charts but very uncertain with ENCs. Much of this instability is an attempt to deal with clutter. The ability to switch layers off is really a de-cluttering control which then dumps responsibility as to what should be displayed onto the mariner. However the chart display should really be a tool not a process. Cluttering in charts is a combination of static symbology and lack of cartographic input. If these are dealt with appropriately then there will be far less need for operator intervention in creating a useable display. Charts will be more stable, more familiar, more useable and safer.

Summary

Computers cannot build good charts from raw survey data. Future chart information needs to include cartographic expertise.
Rapid situation awareness is a key issue in terms of the advantages of dynamic symbology and more intuitive projections.
Neither of these issues are new, but we should be examining them more closely in the context of ENCs. It is a mistake to think that the way ENCs are produced and regulated now will be fixed into the future.

Chersoft

CherSoft is a small UK based company that has been specialising in navigation systems with high performance raster and vector display kernels for the last 12 years. www.chersoft.co.uk

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Data Management

Datamanagement at Flanders Hydraulics Research

Koen Beys, Katrien Van Eerdenbrugh, Peter Viaene, Frank Mostaert

Flanders Hydraulics Research is a research centre of the Flemish Government. The centre provides consultancy services dealing with hydraulics, hydrology and nautical aspects to national and international public or private organisations. Within Flanders Hydraulics Research the Hydrological Information Centre (HIC) is a research group which provides scientific support for water level management on navigable waterways in Flanders. To achieve this, the HIC cooperates actively with the actual managers of these waterways and with other institutions involved in ground water, surface water and sediments.

An efficient functioning of the HIC requires powerful tools to load, store and validate data and to make them accessible for all users. For these purposes an application named HYDRA was developed. This article focuses on the setup, the use and the planned evolution of the application.

Services of the HIC

The services provided by the HIC are the following:

Measurements of hydrological parameters

The HIC measures water levels and discharges along navigable waterways in Flanders. Furthermore, it provides the operational management of gauging networks of other Flemish public authorities. Moreover, precipitation, groundwater and sediment data are measured in several locations. Of all these data, digital historical time series up to 30 years and longer are stored.

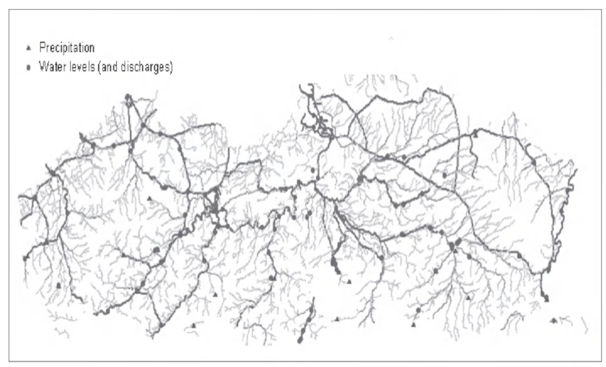

Figure 1: Network of hydrological measurements in Flanders (HIC).

Validation and processing of measured hydrological data

The measured data undergo a first, automatic validation process which removes obvious errors, such as spikes and gaps, before publishing on line.

Consequently, a second, more thorough validation is performed by a hydrologist, who examines the measurements over a longer period and corrects errors, shortages in data, etc. All information available, such as data of neighbouring measurement stations, is used in this second-stage validation.

Development of instruments for hydraulic and hydrological studies

Water level management today no longer chooses to prevent floods at all costs, but instead seeks to limit the damage. Also for

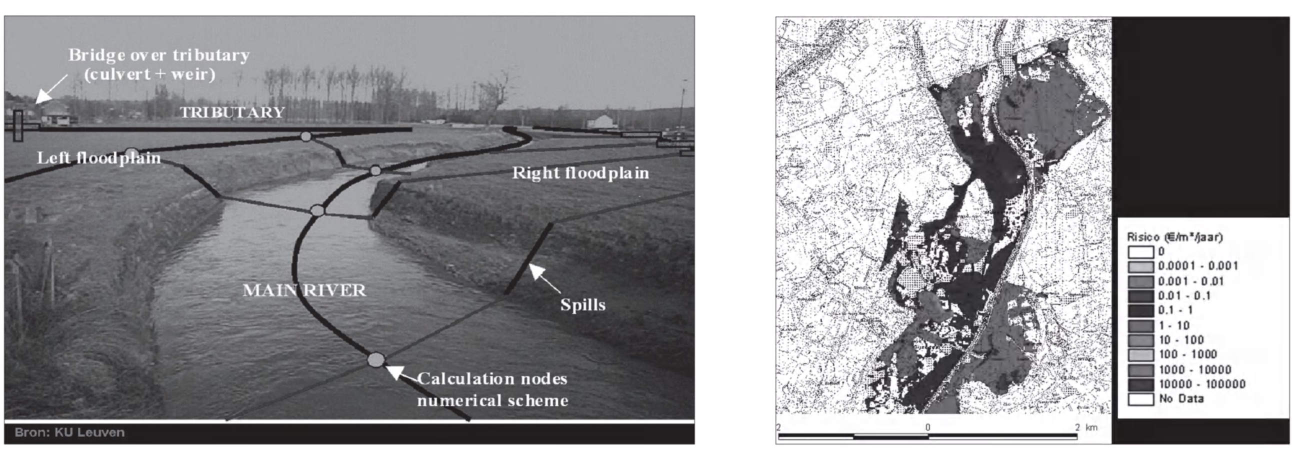

Figure 2: Schematisation principle of a numerical model and flood risk assessment along the river Dender.

low-flow periods, water managers want to minimise the amount of damage. The HIC has developed instruments to implement this risk approach for floods and for periods of water shortage. These instruments are numerical models that simulate the flow behaviour of the navigable waterways. They can be used to estimate the consequences of an intervention on the river's flow behaviour.

The HIC created a workable methodology to map the flood risk for all navigable waterways in Flanders. It offers a means to calculate the flood risk objectively providing policymakers with enough information to carry out a social cost-benefit analysis.

Moreover, a methodology to deal with acute low-flow problems is based on numerical models of the rivers and channels. It guarantees an appropriate evaluation of the proposed solutions and the best implementation strategy.

Both methodologies strongly rely on accurate time series of hydrologic parameters.

Daily hydrological forecasts

The HIC has been given the task of forecasting the water levels and discharges of navigable waterways in Flanders. Forecasts are made systematically: the models calculate the expected water levels for a period of 48 hours.
The river models are linked to the hydrological measurements. Based on these data and on weather forecasts, the HIC predicts water levels and discharges up to five times per day.

Publication of the measured data on web pages

Besides internal use by the researchers of the HIC, the measurements are also published online. The public can consult the measurements of the last 10 days by means of the following web link: http://hydra.lin.vlaanderen.be/. Registered users can obtain even more data such as historical time series, metadata and the rating curves of certain gauging stations.

Data exchange with other partners

Rivers do not stop at municipal or even national borders. The HIC collects all the hydrological data which are relevant to navigable waterways in Flanders. The data come from diverse measuring networks including other related Flemish organisations (RMI, Water, EM, Kust,…) and foreign parties (RWS, SETHY, DIREN,…). The Flemish data are also exported to some of our partners in neighbouring countries.

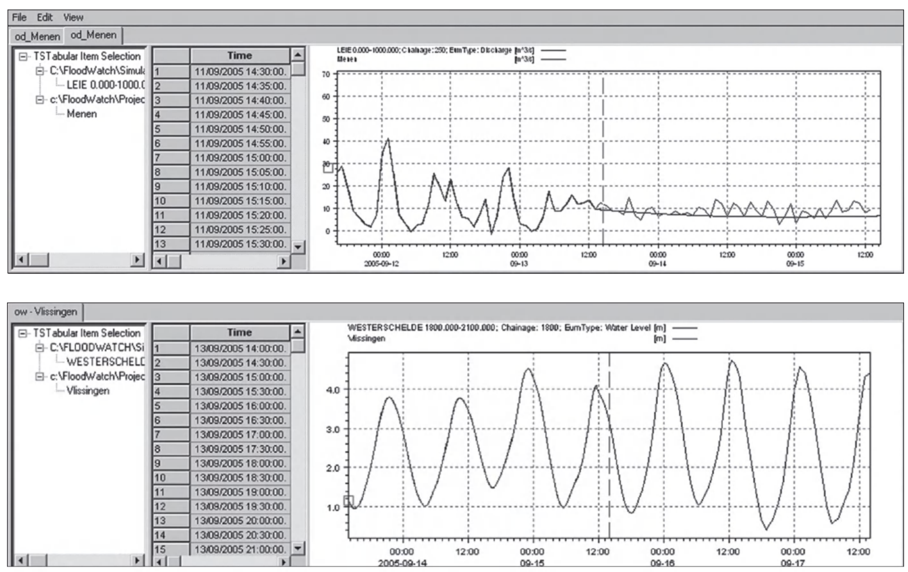

Figure 3: Forecasts for the rivers Lys and Scheldt.

Information centre

The HIC is the central knowledge and information centre for navigable waterways in Flanders. Questions about the surface water system in Flanders and about hydrological data are to be sent to hic@vlaanderen.be.

The HIC mainly works for water managers, policy makers and research organisations, but it also has also other customers.

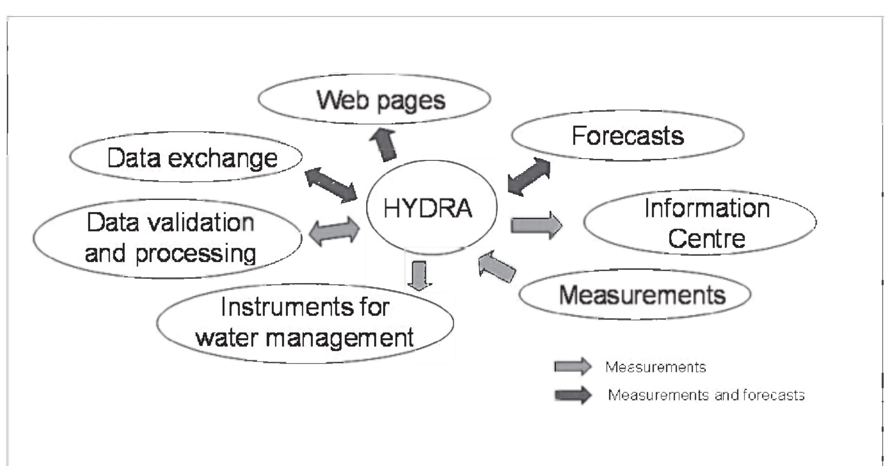

Figure 4: Use of the HYDRA application for different services of the HIC.

Specific requirements

To support all these activities, a hydrological database (HYDRA) was developed. In addition to the general properties of a database for time series, HYDRA needs to fulfil the following requirements:

- Two kinds of data must be stored: *calculated and measured data*. The calculated data include discharges based on rating curves on the one hand and forecasts on the other.
- Huge amounts of measured and calculated hydrographical, hydrological, sedimentological and meteorological data enter Flanders Hydraulics Research. The main variables that are stored are values for: water level, discharge, precipitation, water velocity, sediment load, bathymetry, wind velocity, temperatures and evapotranspiration. *Daily more than 20,000 files* are processed, containing about 500,000 measurements and 30,000 forecasts. As new measurement stations are added easily and frequently, and the number of forecasting models increases, the amount of data and the stress on the database increase constantly.
- *Several time steps* (1', 5', 10', 15', 30', 1h, 3h, 24h) need to be handled
- A *data versioning system* is needed. The goal of this data versioning is to store all changes made to a measurement, allowing retrieval of the different historical versions of a certain time series. Among others, this is important for the use of off-line computer models of the rivers. These off-line models are composed and calibrated with specific time series. If later on, changes to the model are needed, one has to be able to perform the calibration with the same version of time series.
- *Special environments* must be available for specific users: Data owners can work in their own environment with a personal configuration. Some data can only be viewed by a restricted public.
- An *overview of the status* of the measurement stations (normal, alert and alarm defined by thresholds) and the defects of the stations must be available on-line. A system to monitor the *quality of the stations* must be available.
- By means of *export routines*, measured and forecasted data are sent to external organisations (RWS, SETHY, RMI,…). Import of measurements and forecasts from these organisations must be possible.

The development of HYDRA is a continuing evolution. In the next paragraphs, the main steps in the setup of this database are described.

AREV, the first generation database

A first version of the hydrological database was built in 1990. This version was developed in Advanced REVelation. The database contained an internal system to query historical data and an application to validate data and to modify configurations such as rating curves.

Most of the measurements were only available on paper. These data were digitized and imported in the database. Some measurement stations were linked in a telemetry system: a central module called the stations regularly to load data and to realise an on-line availability. A preliminary internet application existed.

The system had restrictions for the planned evolution of the HIC. External time series could not be collected and stored. Other than hourly values could not be saved.

HYDRA, an important evolution

In 2000, the restrictions of the AREV system gave birth to a new database (HYDRA). Special attention was given on the following topics:

- Data exchange with *several data sources* had to be possible
- The different data sources created a need for different storing frequencies
- *A new telemetry system* was needed, resulting in a better availability of data during crisis situations
- It must be possible to query recent and historical data by means of *a web application*
- *Sufficient extension capacity was needed* to fulfil the expected growth of the database

At present the HYDRA application runs in parallel with the AREV application. The AREV system is used to validate the data. HYDRA contains the remaining functionalities.

HYDRA is based on an Informix database using the `time series' module. This module is very economical in comparison with a relational model. In a relational model, a timestamp and a value is saved for each individual measurement. In a 'time series' module, a timestamp and a value indicating the interval between two timestamps are stored only once. These are followed by all measured values. Thus more data can be stored and the expected growth of the database can be fulfilled.

Relational model	Time stamp 1	Value 1	Time stamp 2	Value 2	Time stamp 3	Value 3	…
Time series module	Time stamp	Δ t	Value 1	Value 2	Value 3	Value 4	…

Figure 5: Storage principle of a relational model and the time series module.

Measurements and forecast results are both processed. The forecasted data are used in flood warning and low-flow bulletins which are published on web pages.

Forecasted data	Time of forecast	Time stamp	Δ t	Value 1	Value 2	Value3	…

Figure 6: Storage principle of forecasted data.

The new telemetry system – which contains nearly all measurement stations – ensures that all data are available and thus published online with a delay of maximum 30 minutes during crisis situations.

By means of Export Transfer Load procedures (ETL) data are exchanged with 11 different data sources within and outside of Flanders. All data are stored in the HYDRA database, where they can be accessed by several applications such as the forecasting models.

The HIC researchers query the database thoroughly by means of a VB-application named 'Hydradownload'. For users within the Flemish community, an intranet application is available to download historical data. Due to development problems however, this application is not yet available on the internet. Until now external users must request the data by mail.

HYDRA contains a number of other applications being used by the HIC. An overview of the malfunctioning stations and of the exceeded alert and alarm levels is given on a web page. When an agreed alarm or alert level is reached, the HIC staff is informed by means of SMS and the first flood warning bulletins are published. Flood warning bulletins are published manually as it requires interpretation of skilled hydrologists, but large parts of the bulletin are compiled directly from Hydra.

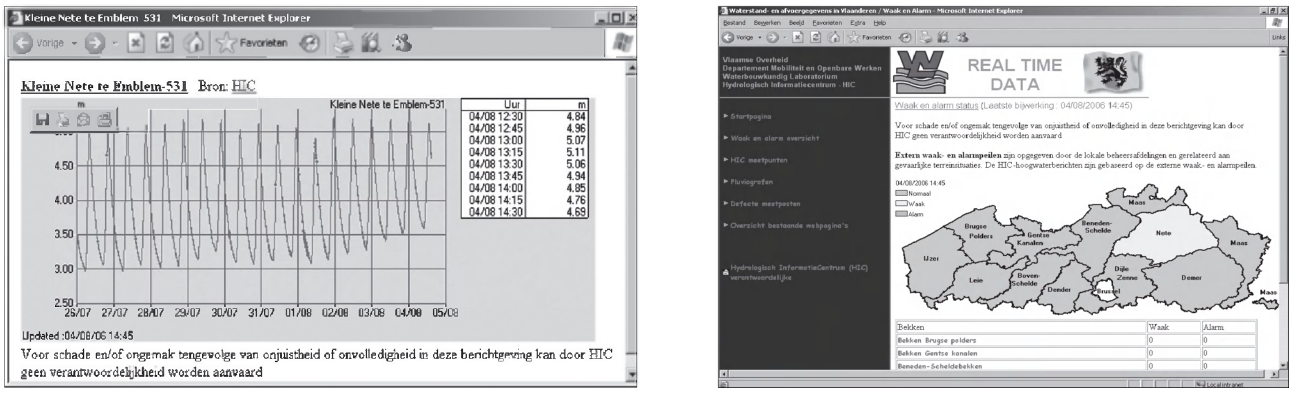

Figure 7: Web pages with recent measurements and an overview of the situation (normal, alert, alarm).

HYDRA+: optimization of the existing database

The principal shortcoming of the current system is the validation process, which still occurs in the AREV database. Moreover, the web application for downloading historical data should be more user-friendly. For these reasons a third phase has been started, which at present is in full development. Final results are expected by the end of 2006.

In the new set-up two databases, HYDRA and WIS (Water Information System), are active in parallel. The two databases functionally complement each other. The combination of both offers a set of functionalities which can't be offered by one of them. The incoming files are converted as quickly as possible and loaded into both the HYDRA and the WIS databases after an automatic validation. Once the data are stored in the database, they are immediately available for different applications and retrievable for scientific validation.

The WIS database is based on the software of KISTERS AG and offers a wide range of possibilities to visualise and validate data. It replaces all previous applications having the same objectives.

By means of a web application based on the WIS database, data can be retrieved in different layouts (charts, Excel, download CSV). Every user receives a login name, for which access rules define the retrievable data and the layout. For example, not everyone is allowed to consult the long-term minute values because this could overload the server.

Derived values are defined and also published on the internet. For minute values for instance, derived mean hourly values or maximum monthly values are made available. For tidal rivers high- and low-water values are derived.

Using access rules as described above, a special environment can be created for privileged users. Thus a specific water manager will be able to access and manipulate data for its region of interest.

Static maps serve as an interface for the web application. They are based on the data in the database. When a station in the database is added or deleted, the map is automatically renewed.

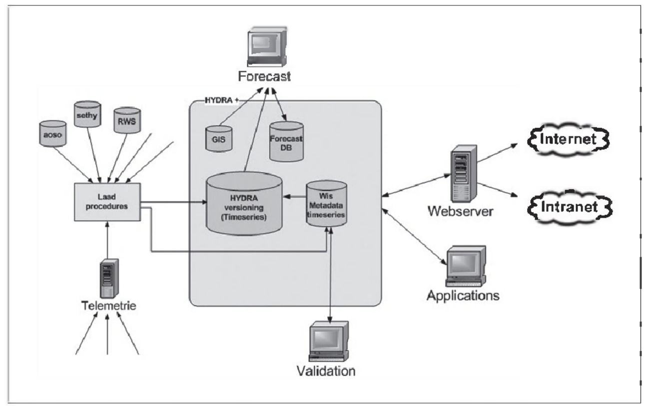

Figure 8: Schematic principle of the HYDRA+ application.

The WIS database only stores raw data and the most recent version of data, called the production time series. Whenever the production time series is changed, the new validated data are sent to the HYDRA database, where they are stored as a new and improved version. Former versions of the same data are also kept. This allows to reconstruct the historic data availability and thus to recalculate simulations that were made in the past identically. The HYDRA database also stores the different versions of forecast data similarly.
The forecasting system also works with data of the HYDRA database and makes use of the data versioning. The original forecasting application worked with several PC's, each running their own forecast model. The new system's forecasting software has its own central database, in which the model configuration is kept for each forecasting model.

In the development of the HYDRA+ system, an important effort was spent on the availability of the database system. For each part of HYDRA+, a back-up system is installed to minimise the probability of failure.

Future evolutions

Possible improvements to the HYDRA+ database include a further improvement of fail-over and security as well as extending the database with all available metadata. Furthermore is the improvement and extension of the internet site with additional information planned as well as modernization of the format of the yearly hydrological reports.

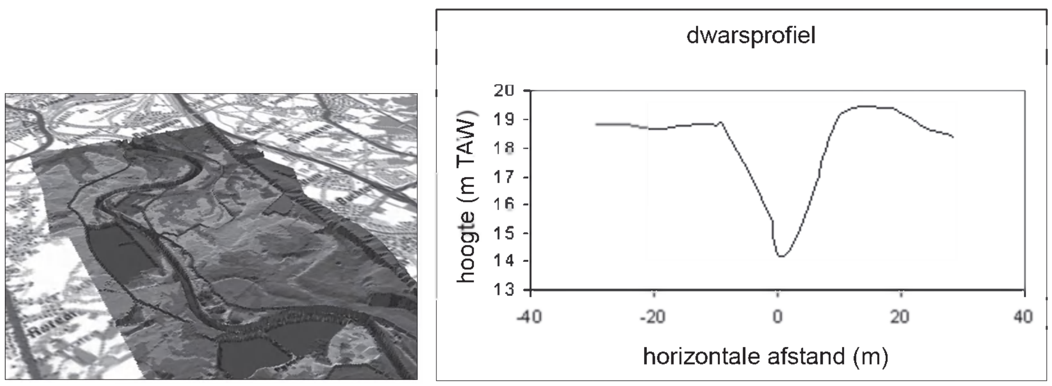

Figure 9: Survey data to be stored in a hydrographical database.

The database will be extended with a server using a versioning system for geographical data. These data will be stored in a Geographical Information System and are used for the website and the forecasting software.

Beside the hydrological database, a hydrographical database will also be created to store survey data of dykes and river banks.

A fileserver with a version management system for the numerical models will be installed. These models are to be fed automatically with versioned time series from the HYDRA+ database and bathymetry data from the new hydrographical database.

Conclusions

The HYDRA+ application is a powerful system for management and retrieval of extensive data sets. The current and future improvements guarantee an even better support. The configuration with two databases combines the best properties of two systems and offers Flanders Hydraulics Research and its clients an innovative, reliable and flexible multipurpose system.
By means of a versioning system, historic data availability can be reconstructed any time, which allows recalculating simulations that were made in the past identically.
Access rules make it possible to create a special environment for privileged users in order to access and manipulate specific data.
Its high availability and required security is an important support for the HIC in providing its main services.

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WADI: Datamanagement Of Hydrographic Information

N. Kinneging

Rijkswaterstaat is the Dutch government agency, which is responsible for the maintenance of the water infrastructure, the protection against floods and the quality of the main water systems. To perform these tasks a lot of information is needed and therefore many measurements are performed in the fields of physics, hydrography and ecology. Of all data types the hydrographic data represent the largest volume. To manage this huge amount of data Rijkswaterstaat has developed the WADI (WAter Data Infrastructure) database.

Introduction

Hydrographic data is used for many purposes, for instance the data are used for safety of the land against floods, for navigational purposes and for the planning and realisation of dredging projects. Rijkswaterstaat is responsible for these tasks and therefore collects hydrographic data on a daily basis using various single beam and multibeam systems. Rijkswaterstaat is a government agency with about 8000 employees, of which at the start of 2006 101 people were involved in hydrography, located at different parts of the country. A total of 18 ships are used to perform the hydrographic surveys of Rijkswaterstaat. For hydrography Rijkswaterstaat needs a yearly budget of over 20 million euros. These figures illustrate, that hydrographic information is a costly investment and should be managed accordingly.

Rijkswaterstaat has decided to make all measurement data centrally available in a uniform format and accessible through internet. Through international co-operation in projects like SeaDataNet the exchange of data with colleague organisations is facilitated. The WADI database plays a central role in the storage and management of information by Rijkswaterstaat. Of all the measurements stored in WADI in this paper the emphasis will be on the hydrographic data.

Work Flow

In order to organise the datamanagement the work flow around these data is essential. Previously the storage and archiving of information was a task to be performed at the end of each project. In the work flow of the information services of Rijkswaterstaat (see diagram in Figure 1) WADI has a central position. By using the central database local data storage can be avoided. This decreases the total costs for the organisation as well as the risks.

In the work flow a major distinction between the various stages of the process can be recognised. The scheme is demand driven, which means that for all data acquisition the information need of one or more end-users within the Rijkswaterstaat organisation is required. The data acquisition and validation results in data with a well defined quality level and format. Thus the need reconcile this phase later in the process in minimised. Data storage is now an integral parts of the work flow. Through the meta-data stored together with the measurement data a complete data set is stored and archived. Data processing and presentation is a separate part of the scheme, thus emphasizing the special skills needed for this work.

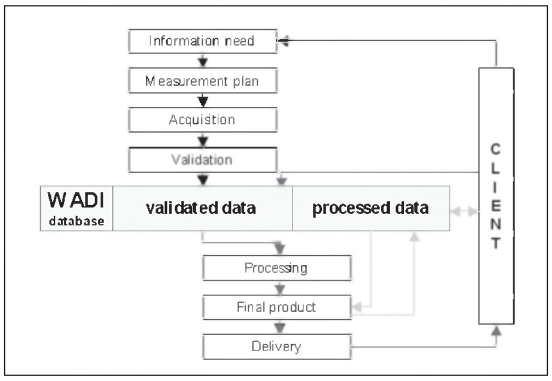

Figure 1: WADI's central position in the work flow of Rijkswaterstaat.

This description of the work flow has several advantages:

- There is a logical distinction in data acquisition and data processing.
- A better control of the data quality can be reached. The quality management system (QMS) ensures good data quality for WADI.
- Re-use of data is facilitated by this scheme. The database contains the validated data as well as processed data (e.g. after gridding).

Technical Design of WADI

It is beyond the scope of this paper to give a detailed technical description of WADI. All documentation can be found through the WADI-website (www.wadi.nl). In Figure 2 the structure of the WADI database is outlined.
Applications communicate with WADI through the web-api using SOAP (Simple Object Access Protocol). In this way the application is totally separated from the storage. WADI will provide a general application to search the database and retrieve data.

It is expected, that various specialised applications will connect to WADI in the coming years.

Within WADI a clear distinctions has been made between data and metadata. The user can find data in the database through the metadata only. A data model has been designed too describe the measurement data of Rijkswaterstaat. Metadata on e.g. location, parameter type, measurement time is stored. Furthermore user interface components are available to search and retrieve datasets. To structure the metadata WADI uses the RDF-technology (Resource Description Framework), one of the standards in Internet technology. By RDF the searching of the metadata is much more flexible than in standard database methods, where queries must be programmed for all possible searches.

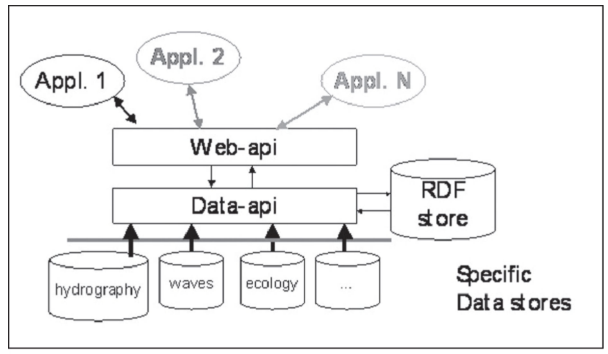

Figure 2: Structure of the WADI database.

The data itself can be stored in separate data stores, which can be tuned to the specific data characteristics. At this moment just one data store is implemented.

Example of Coastal Zone Management

One of the major tasks of Rijkswaterstaat is the protection of the Dutch territory against the North Sea. By law it is stated, that the coastline must be maintained at the position of1990. Every year sand suppletions are performed at critical zones of the coast to compensate for the erosion processes taking place. Each year the suppletion volume is about 6 million m^3 of sand. In order to plan these suppletions accurately a lot of knowledge is necessary of the morphological behaviour of the sea bottom near the coast up to about 20 meter depth. The yearly measurements of the coastal zone are stored in the WADI system.

In Figure 3 the user interface is shown for retrieving griddata from the WADI database. On the left the various elements of the metadata are shown, on which the search is done (location, time and data type) and on the right the possible locations are shown on the map of The Netherlands.

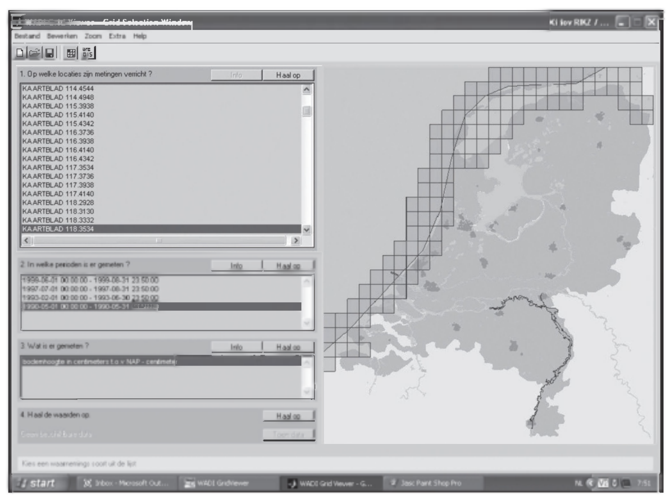

Figure 3: User interface for retrieving griddata from the WADI database.

In WADI coastal measurements over a long period in time are available. As an example in Figure 4 the sea bottom measurements for the same locations are shown for the years 1926 and 2001.

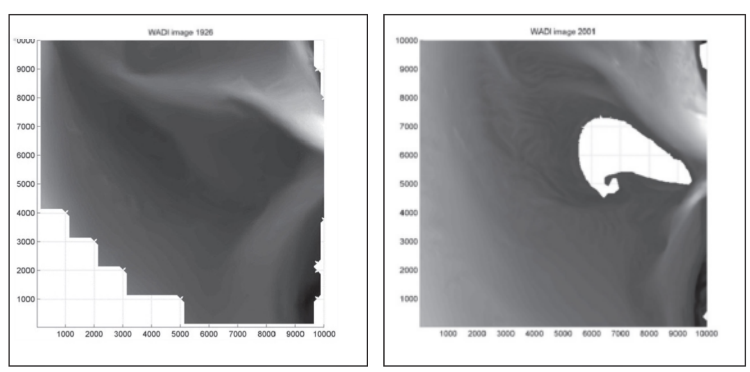

Figure 4: Examples of long term monitoring for morphological analysis of the coastal zone (same location for 1926 and 2001).

Conclusions

WADI offers a new data infrastructure for storage of all measurement data of Rijkswaterstaat. The system is built using leading edge technology in database development and web based programming. Thus a flexible system has been made, that can be easily connected to other databases. WADI is open to all users through public data portals and through dedicated applications.

References

Information and documentation on the WADI system can be found at the website www.wadi.nl. Information on coastal zone management at Rijkswaterstaat can be found at www.rikz.nl.

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Highest quality throughout all ENC product stages

Ensuring highest possible quality from chart to exchange sets

John K Klippen

Introduction

The term ENC Quality Control and Assurance is not limited to the production process for individual charts, but have to include the full ENC life cycle.

The life cycle for an ENC, with respect to source data assessment and verification, product compilation, validation and publication followed by product maintenance and eventually termination is a complex procedure where quality processes must/should be integrated.

The issuing Authorities responsibility is further extended to also include the distribution aspect, as a minimum limited to the data collection quality.

The term Quality Control is and cannot therefore be limited to S-57 encoding and successful testing stipulated by IHO S-58 "Recommended ENC Check list".
As a cartographer already is aware of, there are a variety of scenarios that cannot be detected by automatic testing and validation performed on ENC data, this is related to source data correctness, available Meta data, digitizing and product collection within IHO S-57 Exchange sets.
Further on, for the producer to ensure safety of their data it has been accepted within the hydrographic community that encryption of IHO S-57 data is required, and consequently IHO S63 have been issued in order to standardize the encryption of the data files.

It's also worth mentioning that the ENC term now a day's is even further expanded, with introduction of more product specifications/-standard based on S-57. Inland ENC and Additional Military Layers have been introduced and users have even further requests.

This paper focuses on all the aspects for quality control and assessment throughout the ENC product stages, from planning, compilation, production, distribution and maintenance to the ENC's termination.
The paper will not focus on production itself or the practical compilation of ENC's. Nor will it focus on any preferred production priorities defined by Paper chart driven or ENC Cell driven production.

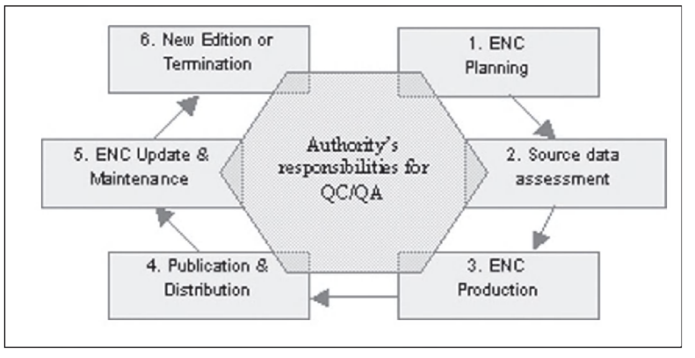


Figure 1: ENC Life Cycle.

ENC Planning

ENC Planning, is defined by "the establishment of a seamless and adequate ENC coverage within given usage bands, and assurance of source data quality required to enable safe navigation".

To allow an effective quality management for the planning process, the producer should have effective tools and technologies at hand enabling the operator access to all required source data (and their meta data) and have them visualized for easy comparison. The sources Meta data must hold enough information so that the operator may take qualified decisions.

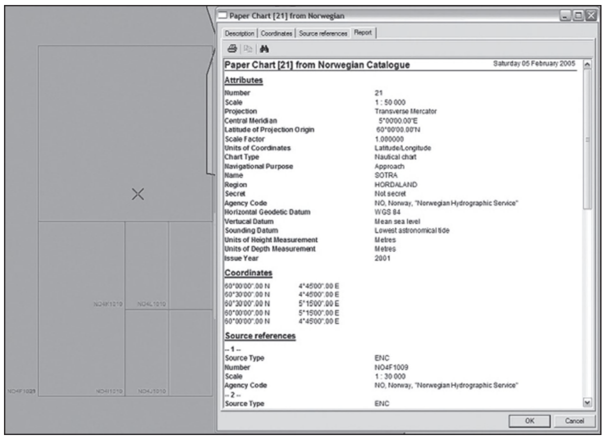


Figure 2: dKart Catalogue database.

Source data assessment

The source data assessment involves not only retrieval/collection of available/required source data for the ENC product(s), but with a primary goal to ensure highest possible quality for the chart coverage.

The producer need tools and technology to assess and fine tune the sources to meet the minimum requirement for ENC production, here implicit (not limited to) product dependant data cleaning/-collection, normalization and transformation of analogue sources where the quality aspect for the normalization is vital.

ENC Production

When the production is planned, sources are assessed and made available for the production unit and the product compilation is started.

It's however believed that a production tool should be consistent with respect to data formats, input, internal and output, to ensure and allow a highest possible quality throughout the production. Limiting the number of conversions to/from data formats will improve the quality of data and consequently the need for special attention to the operator in means of quality control.

HydroService has always focused on this matter, where as the internal format used is standard IHO S-57, and any data imported to the production tool is "directly", with assistance of controlled import routines, converted directly to S-57. This allows the users to validate the imported data on-the-fly allowing resources to be allocated with other more important processes within a production.

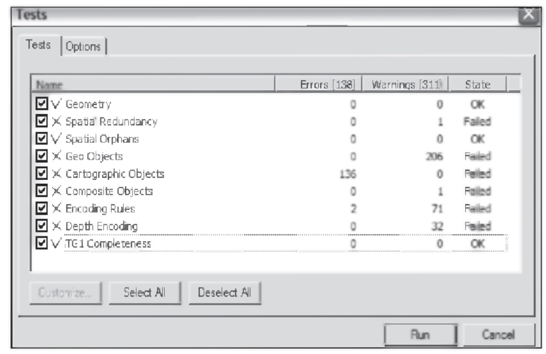


Figure 3: dKart Editor/dKart Inspector Test menu.

With the IHO S-58 standard the producer has been provided with a common platform for testing and validating the ENC's. This further improves the quality of the end product, but again to have an effective testing and resolution process the native format in production should be S-57. If it is, the user will have a WYSIWYG scenario and testing may be run on the fly when objects and its attributes are created or operator may at any time start S-58 testing on the data.

Even though the S-58 standard provides effective means to test and ensure the quality of an ENC, there are still a variety of important elements, which is not covered by the standard. This be correct presence of objects and attributes, positional accuracy etc.

An effective production tool must be able to provide secure and effective means to also quality assure these items.

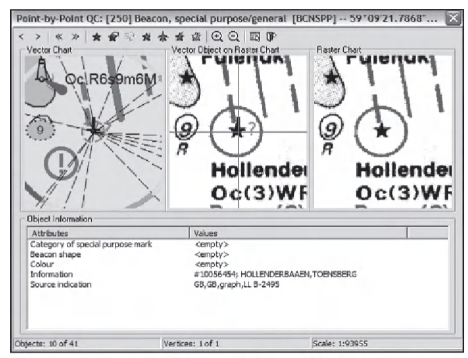


Figure 4: Point-by-Point QC in dKart Editor.

Point-by-point QC allows the user to validate that all objects from an analogue source have been encoded and positioned correctly. The user is guided through all, or queried, objects where visualization gives position, object and attribute values and last but not least each check object is "flagged" checked.

Window-by-Window QC allows the user to be guided through the entire coverage area and visual control on object digitizing and encoding is preformed.

These additional QC functions, integrated with automatic checking routines a comprehensive and controlled QC environment to the user, ensuring completeness and correctness to the cartographic work undertaken.

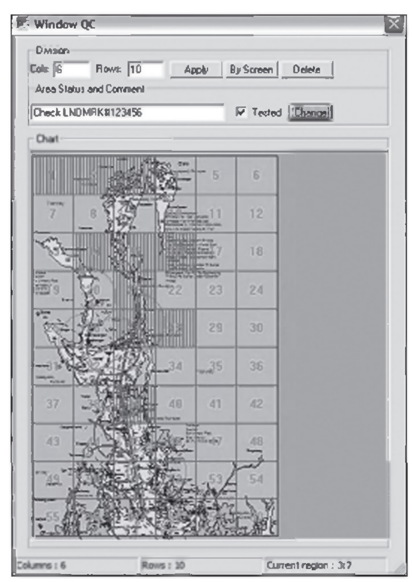


Figure 5: Window-by-Window QC in dKart Editor.

Publication and Distribution

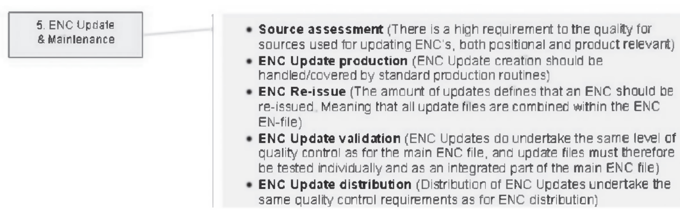
Following successful and accepted quality control and assurance routines, the ENC is ready for distribution to mariners. There are a variety of different ways to handle this, but the majority of released ENC's are distributed though bi-lateral and/or private channels on a commercial basis.

When the production of a S-57 cell is declared completed and approved, the "stamping" of the cell will "confirm" it, resulting in a "Published" ENC. Any changes made to/on a stamped ENC will automatically create a S-57 ER file (Update file).

Encryption of an ENC, or more correctly an ENC Exchange Set, is in practical sense a direct change of the data itself and quality assurance must therefore be performed on the encrypted data set. Validation and Quality assurance in this respect implies the ability to de-encrypt the exchange set, perform consistency checks and subsequent approval of the data set.
The complexity of IHO S63 is rather high, but nevertheless the user/producer must be capable of performing such validation to further ensure safe navigation for mariners. In most of the cases this validation resides within a RENC organization today (if this is used), but even for "internally" released ENC's such testing must be conducted.

Distribution will not be further discussed within this paper, as there already exists well known entities holding ISO type approved infrastructures for this.

ENC Update and Maintenance



"An ENC is an ENC only until next update".
If a maintenance program does not cover an ENC it is no longer an ENC. This is not limited to when an update is actually available for the chart, but to when an ENC was "Last checked" for updates.
To raise the quality of the maintenance process the source messages are fully integrated within the production line. This means that source messages for NtM's or general corrections are used for the update task and its quality control.

Only physical ENC update files are distributed.

The paper describes "a fully integrated NtM Source message handling for ENC Updating and Quality control".

Figure 6: Integrated NtM based ENC updating.

ENC Termination

When an ENC is defined as obsolete, for several reasons; new coverage/products available, obsolete products e.g., the operator must be able to validate and quality assure the decision basis for the termination process. In the same context the "Termination" process must be accessible only when given criteria are fulfilled and cancellation update must be created automatically (and distributed through standard distribution means).

From a quality control side a termination must result in a "locked" dataset, where no further corrections/changes may be applied.

John K Klippen, Project & Support Manager HydroService AS

Dredging Support

Side-Scan Sonar And Multi-beam Surveys in Dredging Projects

Are Both Techniques Necessary?

J. Lanckneus and E. De Jonghe, Belgium

Both side-scan sonar and multibeam have evolved from expensive and complex systems to user-friendly and affordable techniques. Although both systems are tools to describe the morphology and nature of the seabed, they have inherent differences with both their merits and demerits. Although some hydrographers start to question the use of a side-scan sonar in projects in which a multibeam is already being deployed, it must be stressed that both techniques produce complementary results and that the integration of both systems offers a synergy that increases highly the value of the obtained survey results.

Introduction

The dredging industry relies on a number of geophysical tools to visualize the seabed and to solve a number of problems frequently encountered such as the location of suitable sand for reclamation purposes, the identification of debris on the seabed and the mapping of rock outcrops.

The survey department of Dredging International has been using in particular dredging projects a combination of side-scan sonar and multibeam equipment to analyse the seabed characteristics.

This presentation will focus on the advantages and disadvantages of both techniques and demonstrate that in many projects the use of a side-scan sonar next to a multibeam increase significantly the quality and diversity of the obtained results.
Side-scan sonar has been for a long period the only available instrument for mapping seabed features on a broad scale. Side-scan sonar images consist of a series of lines, one per transmission-reception cycle, displayed perpendicularly to the survey track. On each side of the track, a single line segment represent the echoes received from the seafloor for a given ping as a function of slant range [1]. The side-scan sonar image reflects as well the composition and distribution of the seabed sediments as each sediment type absorbs and reflects a different amount of the acoustic energy produced by the sonar transducers. The resulting side-scan sonar image presents therefore different acoustic facies (from dark to pale) that can be translated in sedimentological facies by ground truth operations such as grab sampling [2].

Many hydrographers who have worked with side-scan sonar in the early days remember that although acquisition was straightforward, the processing of hundreds metres of paper roll was something of a nightmare. Patience of a monk was a primary necessity to translate the features visible on the paper recordings to a line drawing on a track plot. The raw side-scan sonar image suffered from numerous distortions and artefacts because of a number of reasons such as (i) the transversal scale, function of the slant range, was different from the longitudinal scale, (ii) the longitudinal scale would vary as it was function of the vessel's speed, (iii) the survey track was rarely straight and (iv) the attitude of the tow fish (heading, roll and pitch) was not constant. However in the last 20 years the digitalisation of the raw side-scan sonar signals and the development of new software programs made it possible to create fully corrected mosaic images similar to corrected aerial photographs, that can be superimposed on depth charts of arbitrary scale, datum and projection method.

Since the early 1990's the development of multibeam systems provided a new method for describing the morphology of the seabed [3]. Multibeam echosounders emit a fixed number of beams from a single transducer. Incident energy is emitted upon the seafloor and then either absorbed or reflected back to the transceiver. A multibeam system measures both the elapsed time and strength of the acoustic-electric signals being returned to the transceiver. This returned signal is converted into a digital depth calculation [4]. The received acoustic echoes contain as well information on the nature of the seafloor itself. By analysing the backscatter intensities of the received beams it is possible to make a classification of the seabed sediments [5], [6].

In the following case studies multibeam surveys were carried out together with side-scan sonar. We will comment on the benefits that the side-scan sonar results presented next to the ones obtained with multibeam.

Case Study Lulu Island, Bahrein

Dredging International, operating under the DEME group, was responsible in 2004 for the creation of an artificial island of 552 000 m² called Lulu Island located 200 m off the Bahrain Financial Harbour of Manama, Bahrain. The purpose of this reclamation was the creation of residential and leisure development, including hotels, shops marinas and leisure facilities.

Photo 1: Side-scan sonar fish fixed at the extremity of a steel pole. Note the echosounder transducer attached to the sonar fish.

Photo 2: Multibeam transducer being attached at the extremity of a steel pole.

The main objectives of the multibeam and side-scan sonar surveys were:

- to chart the access channels and to detect all obstacles between the sand borrow areas and the dumping site to provide a safe navigation for the dredging vessels as coastal waters are extremely shallow;
- to detect all obstacles that could hamper the dredging operations in the reclamation area in which a superficial muddy upper layer had to be removed;
- to map the presence of sandy sediments in the sand borrow areas.

A GeoAcoustics side-scan sonar system was used coupled to a digital TritonElics acquisition and processing system. As water depths were extremely shallow the tow fish was fixed to a pole. Such a fixed towfish deployment (photo 1) is the appropriate solution to survey shallow waters: (i) the exact position of the towfish and hence of all objects lying on the seabed is known with great accuracy as all offsets between the positioning antenna and the sonar fish are constant and (ii) the depth of the sonar fish is constant even during turns and sudden ship's manoeuvres what makes the side-scan sonar operation a less stressful activity than when using a towed fish.

All recordings were carried out with the 410kHz frequency and a slant range of 60 to 80m was used.
A Reson Seabat 8101 multibeam echosounder was used during the project. The transducer was installed at the end of a pool fixed on the ship's bow (photo 2). An Octans II sensor provided heading and attitude information. All acquisition and processing were performed with the help of QINSy software.

A significant advantage of side-scan sonar is that the slant range is independent of the water depth. This is particularly true when working in very shallow waters [7]. With a water depth of for example 5m, high resolution side-scan sonar images were produced over a width of twice 60m while the swath coverage of the multibeam amounted to twice 20m.

The advantage of being able to scan the seafloor with the side-scan sonar over a distance twice as wide as the multibeam track interval was made clear to the survey team during the first measuring day. The side-scan sonar recording revealed a small but nevertheless impressive coral reef (figure 1) that rose above the flat seabed. The reef, with a water depth at its summit of less then 1 metre, was positioned exactly on the next multibeam track. Without the detection of the reef with the side-scan sonar, the multibeam transducer positioned at the bow would have been crushed when sailing the adjacent track.

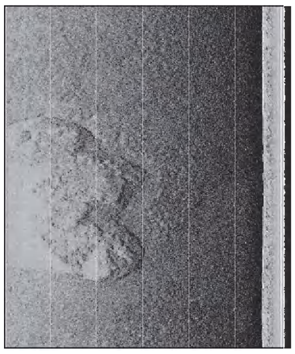


Figure 1: Port side-scan sonar channel of a small coral reef; slant range 60 m, distance between white lines: 10m.

Side-scan sonar therefore was used through the entire survey as a safety tool and was carried out along all multibeam tracks although a complete coverage would have been obtained with recordings every three multibeam tracks.

A problem encountered during most of the side-scan sonar surveys is that the processing time exceeds the processing time of multibeam data. However the project needs were such that one day of side-scan sonar and multibeam acquisition had to be processed in one day. Such a ratio of 1 to 1 is difficult to reach for side-scan sonar data, as a lot of time is lost during the bottom tracking. Digitising the exact position of the seabed is of capital importance for the creation of sonar mosaics and for the calculation of the correct positions of features on the seabed. The whole process of bottom tracking was eliminated by mounting a high-resolution shallow-water echosounder transducer on the sonar fish (photo 1). The height of the sonar fish was measured continuously by this transducer and was defined as the primary fish height in the acquisition software. As fish height data were of excellent quality even in turbid waters, bottom tracking was limited to a fast control allowing sonar mosaics to be created in a ratio of 1 day processing for 1 day of acquisition.

Having created the side-scan sonar mosaics, it became clear that they were an excellent tool for gaining insight in the sedimentological characteristics of the seabed sediments. This was of primary importance, as large quantities of sand were needed to carry out the reclamation work of Lulu Island. Figure 2 is a fragment of one of the side-scan sonar mosaics that were created. The large number of dredging marks on the seabed reveals the former sand dredging activities carried out in the framework of other projects. Figure 3 is the sedimentological interpretation of the mosaic shown in figure 2. These maps were used to detect the remaining presence of sand and to locate the presence of coral reefs that could damage the suction pipe of the dredger.

Case Study Weissebank, Germany

DEME Building Materials (a DEME subsidiary for winning, processing and supply of sea aggregates on the North-European market) extracts coarse sand and gravel on the Weissebank area located 45 miles off the North German coast. Extraction of the aggregates is performed with the 5000 m^3 trailing suction hopper dredger Charlemagne in water depths of around 25 m.

A multibeam and side-scan sonar survey was carried out in March 2005 to monitor the topographic evolution of the seabed and to map the remaining patches of coarse sand and gravel in order to assist with dredging planning.

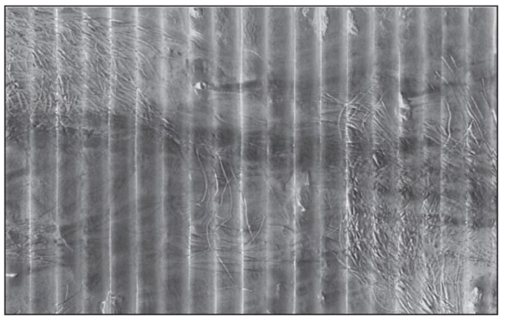


Figure 2: Fragment of a side-scan sonar mosaic (approx. 1200m by 750m). Note the numerous dredging marks.

A GeoAcoustics side-scan sonar system was used coupled to a digital Coda acquisition and processing system. As the survey was carried out with the dredger Charlemagne some logistic problems concerning the deployment of the equipment had to be solved.

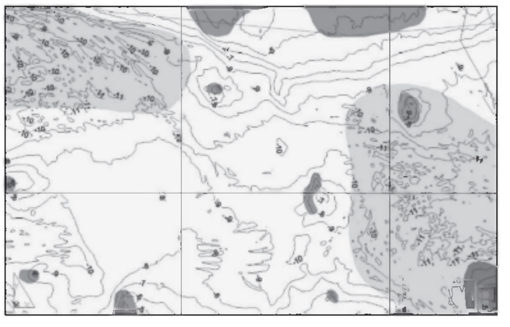


Figure 3: Fragment of the sedimentological interpretation (approx. 1200m by 750m) of the sonar mosaic shown in figure 2. Colours represent the sediment type.

The sonar fish has to be towed, as there was no possibility of using a fixed pole. Towing could however not be performed from the afterdeck due to the important ship's wake. The sonar fish was therefore towed on starboard with the help of a steel tube of 4m length. As the fish had to be lowered beneath the ship's hull in order to obtain good data on both channels, a lot of cable would have been veered out due to the impressive ship's draft. As this would not be a very safe option another deployment method had to be found. A hydrodynamic lead fish of 50kg was used to pull the sonar fish to a maximum depth with a minimum length of cable (photo 3). This method was used through the entire survey and gave excellent results.

All recordings were carried out with the 410kHz frequency. The sailed tracks had an interval of 150m. A range of 80m per channel was used during the side-scan sonar survey. This setting allowed a complete coverage of the seabed in order to produce a sonar mosaic of the entire area.

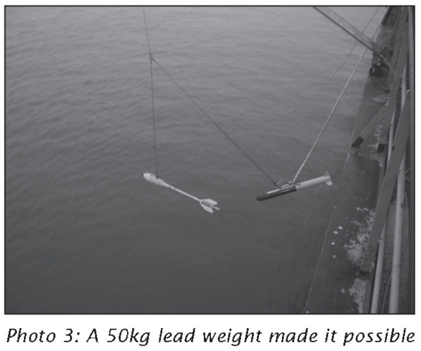


Photo 3: A 50kg lead weight made it possible to bring the sonar fish to a suitable depth while using a short length of cable.

A Reson Seabat 8101 multibeam echosounder was used during the project. The transducer was installed on a pole located on the ship's port side. The pole was attached to a steel plate that could move vertically allowing the transducer to be lowered under the ship's hull (photo 4). An Octans II sensor provided heading and attitude information. All acquisition and processing were performed with the help of QINSy software.

The acoustic facies visible on the sonar mosaic (fig. 4) could be used for mapping the different sediment types and for detecting the remaining areas suitable for aggregate extraction.

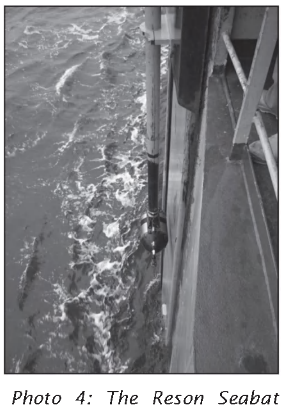


Photo 4: The Reson Seabat 8101 transducer attached to the extremity of a steel pole.

Case Study Tricolor

Side-scan sonar is still the most suitable tool when searching for debris lying on the seabed. A multibeam system can produce excellent results in this application only when positioned very close to the seabed. Magelas has been involved in the last 10 years in a large number of wreck removal projects in which both side-scan sonar and multibeam have been used simultaneously. In nearly all cases smaller debris could only be detected with side- scan sonar.

This is not surprising when the resolution of both techniques is compared. When working in a water depth of 30m, a Reson Seabat 8101 will produce one data point per 2m in a transversal direction while a side-scan sonar will have a transversal resolution of ± 10cm (while using a slant range of 80m).

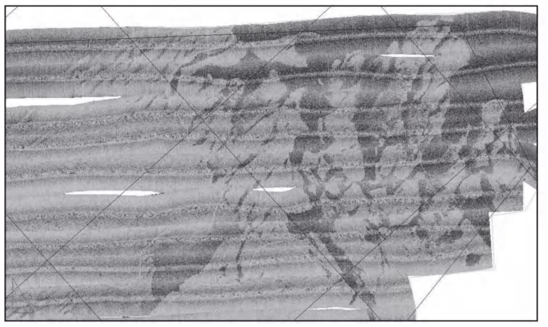


Figure 4: Section of a side-scan sonar mosaic (approx. 2.5 by 2.5km) recorded on the Weissebank area. The darker patches represent the coarsest sediment.

As an example of a debris survey, the case of the Tricolor is presented. The 1987-built Tricolor was lost following a collision with the container ship Kariba. The Tricolor was en route from Antwerp to Southampton and transported nearly 3000 cars. The vessel suffered severe damages and went down in less than half an hour. A multibeam and side-scan sonar survey was carried out to prepare the removal of the wreck and all debris.

A GeoAcoustics side-scan sonar system was used and all recordings were made with the 410kHz frequency. An Atlas Fansweep was used for the multibeam survey. All multibeam data was processed in a regular grid of 1m by 1m. Water depth around the wreck was around 30m.
Figure 5 gives an example of a section of the side-scan sonar mosaic on which several cars can be clearly observed.

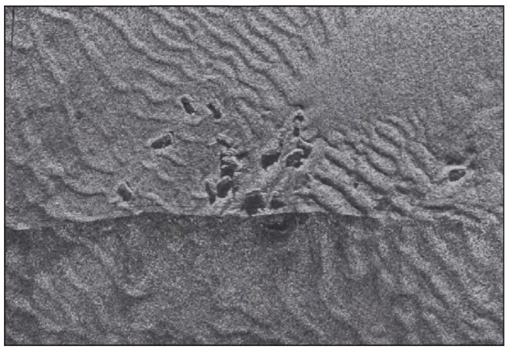


Figure 5: Fragment of a side-scan sonar mosaic (approx. 130m by 90m) showing multiple car wrecks from the Tricolor.

Multibeam data from the same seabed section was processed into several end products such as Shaded Relief Images and 3D images (figure 6). A careful analysis of these images reveals some seabed anomalies but a clear detection of the cars cannot be performed.

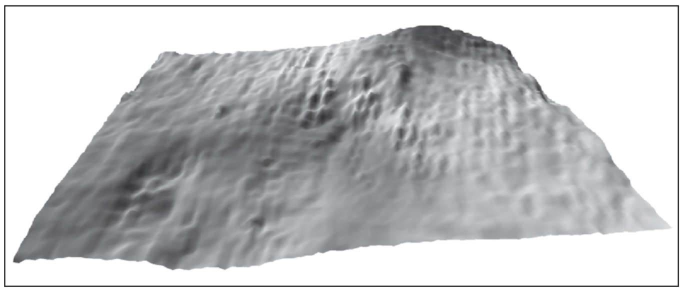


Figure 6: Fragment of a 3D surface (approx. 130m by 90m) based on a 1m by 1m grid derived from the multibeam recordings.

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Uniform Dredging Contracts Within Rijkswaterstaat

R. Perluka

Rijkswaterstaat is the Dutch Directorate for Public Works and Water Management. Core business is the protection of the Netherlands against flooding and maintenance of the waterways in order to provide safe and unhindered shipping. To provide safe shipping one of the instruments Rijkswaterstaat uses is dredging. This implies the use of contracts between Rijkswaterstaat and the contractor, a dredging company. In the last few years there has been some conflicts between a Regional Rijkswaterstaat Department and dredging companies. In some of those cases the Geo-Information and ICT Department was asked for an advise by the Regional Department. As general conclusion it appeared to be that the dredging contracts were ready for a quality improvement. In this paper we show our experience with the dredging contracts and how Rijkswaterstaat will improve the dredging contracts in the year 2006. The ultimate goal is to implement a standard hydrographical related paragraph in the Rijkswaterstaat dredging contracts.

Introduction

ECO (Expertise Centre for Contracting) is the authority within Rijkswaterstaat for optimal using the market by the departments. ECO has been assigned the task to anchor this expertise within the RWS. Besides developing and implementing, this means monitoring the experiences and developments by the government and the market to refine the policy in an adequate manner and to revise and implement the instruments. The input of ECO stretches itself from exploration up to and including realisation, management and maintenance.

The hydrographic paragraph does not live up to the quality standards necessary in the standard dredging contracts. The user writes this paragraph himself, without up-to-date knowledge of the risks involved in controlling the dredging process. Regional Departments are relative autonomous to each other, working together improved over the years but still is not a natural phenomenon. Bearing the organizational structure in mind, the hydrographic paragraph in the dredging contract is invented again and again throughout the organization. In the years 2003 and 2004 colleagues of the Geo-Information and ICT Department were asked to assist two Regional Departments in cases where there was a discussion between Rijkswaterstaat and a dredging company. In most of those cases the conclusion was that the dredging contract was unclear or incomplete on hydrographic issues. Thus leading to multiple interpretations.

Way of Thinking

In this paragraph the problem solving approach will be explained. Early 2005 there was no clear idea how big the problem was. Studying all dredging contacts is very time consuming. There are 10 Regional Departments, all dealing with dredging contracts. To reduce the complexity of the project the contracts of 3 departments have been analyzed.

The first step was to collect the relevant information regarding the hydrographic paragraphs in the dredging contracts and start comparing them [1]. Since the process of dredging is basically the same in every project (Figure 1), the expectation was that the hydrographic paragraphs would be the same as well. If not the result would be a list of hydrographic aspects ready for improvement. If so the second step would be to translate this into recommendations useful for both Rijkswaterstaat and the contractor.

Way of Modeling

Process flow schemes were made of the studies contracts. This proved to be a very helpful diagnostic tool. The scheme's helped us to distinguish a common mainline in de hydrographic paragraphs and the discrepancies.

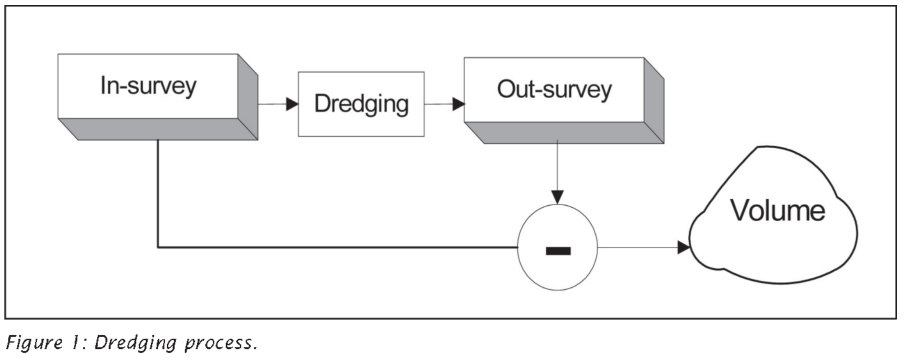

Figure 1: Dredging process.

Since the process is similar in (nautical) dredging contracts, the hypothesis is that the flow schemes are identical. Interpretation of the different flow schemes showed this hasn't been the case in the analyzed projects.

Way of Working

The Dutch policy towards contracts is changed. The change is from "activity prescribed" contracts (Dutch: RAW contract) towards "achievement based or performance-related" contract (Dutch: prestatiecontract). In activity prescribed contracts Rijkswaterstaat describes into detail every aspect of the project. In performance-related contracts only the matter of what is described. This gives the contractor (theoretically) more flexibility for instance for innovation. Dredging contracts are also subject to performance-related contracts.

The first conclusion indicated is hydrographic terms were used in different manners. In some contracts accuracy, precision and reliability were mixed. To solve this a uniform list of hydrographic terms was developed.

Figure 2 shows a diagram with quality descriptions. The term quality acts as an umbrella term that incorporates all the other terms. With this term one can globally judge data. Quality breaks down in several sub terms.

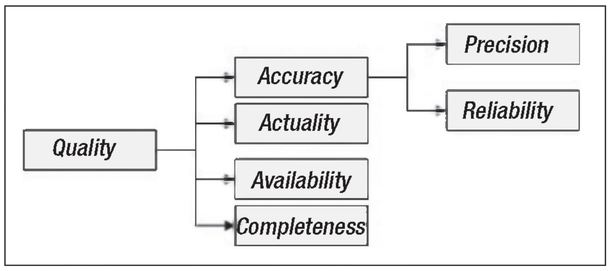

Figure 2: Quality descriptions.

Accuracy combines the terms precision and reliability. Two complete different definitions and regularly mistaken for each other. Precision describes the statistical occurrence of an event, i.e. described with a standard deviation. Precision governs random errors, or noise. The reliability will give a measure for the chance a certain error can be found. The reliability of an instrument for example is the chance it measures an outlier within a certain period. It is difficult to describe the reliability with a number. When a point is measured with different positioning methods (e.g. with an additional differential beacon) it will have an improved reliability but not necessarily a higher precision.
Figure 3 illustrates the distinction between both terms. For all cases a dart player attempts to throw his arrows in the bull.

In the first board the dart player throws the arrows in the board without high precision or good reliability. The arrows are distributed all over the board. The second board shows a series of arrows that are all clustered, hence a high precision. Unfortunately the distance from the bull is large, which indicates a poor reliability. A third attempt of the player results in a reasonable effort. Although the arrows are scattered a bit, which refers to less precision, the throws are consistent, thus a good reliability. Finally the dart player manages to throw all the arrows in or very near the bull. This indicates a high precision and good reliability.

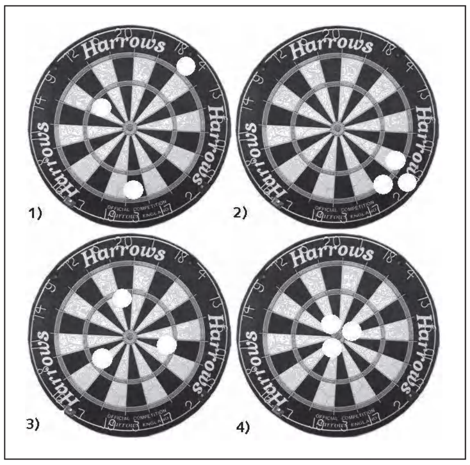

Figure 3: Example of the distinction between precision and reliability.

Secondly, we concluded that the content of the contracts varied. A government should act as a professional client, at least the contractors must know what to expect when a tender is put onto the market. In 2006 Rijkswaterstaat started a project to design a uniform dredging contract. The first scope in this project was to design a uniform strategy for drawing up the contracts.

Typically a dredging contracts contains the following content:

1. A project plan
2. A geographical project description
3. A set of performance demands
4. A set of general agreements

Together with project managers and the regional hydrographic surveyors a strategy has been developed for both project plan and a set of general agreements. In their quotation the contractor must indicate which hydrographic risks can be involved during the survey. The contractor, to whom finally the contract is submitted, must come up with a realization plan, as part of the set of general agreements. In here a set of hydrographic related questions must be addressed to convince Rijkswaterstaat the project will be carried out in a correct way. Both described topics are considered goods steps towards a uniform contract. Contractors now know Rijkswaterstaat expectations.

Finally we concluded that performance requirements are used in multi interpretable way. This had lead to discussions with contractors. Therefore a set of requirements has been defined [2]. The most important requirements are:

1. Functional specifications for geodetic control point

2. Functional specifications for the ships reference frame
3. Geographical definition of dredging areas
4. Definition of macro and micro tolerances

Requirements 1, 2 and 3 makes on objective comparison between two surveys possible, furthermore 1 and 2 put the focus on the reliability aspect of data quality. The fourth requirement reduces the error budget contribution of individual measured soundings.

Way of Controlling

The above mentioned improvements are implemented already in several dredging contracts. Rijkswaterstaat will evaluate the project- and realization plans late 2006. This evaluation can lead to improvement on the dredging contracts. Furthermore the hydrographic surveyors of Rijkswaterstaat dealing with dredging contracts will increase their effort in working together.

The Road to Uniform Dredging Contracts

The improvement of the dredging contracts will not stop here. Coming years Rijkswaterstaat will gain more experience with performance related contracts in dredging operations. At the end of the year a quality management system [3] for hydrographic surveys will be implemented. This format will play an important role for future dredging contracts.

Acknoledgements

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Using Fuzzy Logic Model For The Selection And Priorization Of Port Areas To Hydrographic Re-Surveying

Sebastião Simões de Oliveira, Flávio Joaquim de Souza and Flávia Mandarino

The establishment of a priority for hydrographic surveying, especially in countries with great coast extension, is essential due to the costs, time, navigation safety and political-economical conjuncture involved. Finding criteria that reflects the importance of re-surveying a given area is fundamental in this case. The traditional thematic classification has the limits and borders as crisps. However, reality shows that temporal, geo-biophysics and socio-economics data, that should be used to classify areas for re-surveying, can not be truly expressed in a crisp or Boolean way. The Fuzzy Inference System (FIS), based in the Fuzzy Set Theory, has been used successfully to deal with such kind of problems. In this paper an approach of the hydrographic re-survey priority plan in port areas problem is presented using a FIS.

Introduction

The International Hydrographic Organization (IHO) in its S-55 publication – *Status of Hydrographic Surveying and Nautical Chart Worldwide* – points that one of the actual major deficiencies is the difficulty faced by many countries in planning a prioritized survey program. That also involves routines of re-surveying, particularly to assure safe access to ports and restricted navigation areas [IHO, 2004].

The establishment of a priority for such re-surveys is not an ordinary task. In order to do that you must have a perfect knowledge of those areas reality. This includes not only the information of the previous hydrographic surveys performed but also data such as rate of variation of the seabed and volume of maritime traffic. Hydrographic Services must also establish, in accordance with the minimum standards of IHO S-44 [IHO, 1998] publication, what should be the technical needs of the hydrographic information in each region of this area. These indicators together must be combined in criteria, first to find where re-surveying is necessary, and then to support the decision where should it be made first. Therefore the degree of relevance of these data and their correlation must be expressed in the most realistic way.

One way to do that would be the classification of these indicators, establishing sets for each one in accordance with the necessity. These sets could be combined by logic and mathematic rules in order to achieve criteria for re-surveying.

However this methodology may be not as simple as it appears. Most of the data that would be used as indicators, such as the age of the survey, are expressed in continuous scales without a clear boarder of change from a set to another. Therefore a better alternative way must be used instead of the traditional thematic classification.

Furthermore the number of logic rules necessary to combine the number of indicators and their sets would be too many. Fuzzy Logic emerges as a successful way to solve these problems.

In the next pages an overview will be given of some of the most important indicators that can be used to establish criteria for selection and priorization of ports and surroundings areas to hydrographic re-surveying. In sequence, a brief explanation of Fuzzy Logic, and Fuzzy Inference Systems, will be made. Finally, a methodology that uses Fuzzy Logic and Spatial Analysis to combine the main indicators will be suggested.

Re-surveying Indicators

Data Preparation

When we look to status of the hydrographic surveys worldwide presented by the IHO [IHO, 2004] the first question that appears is how a Hydrographic Service can determine witch areas are or aren't adequately surveyed. The answer to this question, as simple as it seems, show us where to find the main indicators to establish the necessity of re-surveying an area: by comparing the existing area's surveys with a standard. This simple solution shows us that is impossible to kwon if re-surveying when we don't have the information of the preexisting surveys and consequently we don't have a standard to compare with it.

The creation of a hydrographic database that contains all previous, mainly bathymetric, information of the surveys made in a given area is still far away from the reality of most of the Hydrographic Services. This would demand not only a huge storing data capacity, but also large personal and time efforts to digitalize all past surveys made without digital processing and storage.

On the other hand the creation of a database using the surveys metadata is something easy to do in a short period of time, making possible to use them as indicators.

First of all to facilitate this creation is important to study and establish which kind of surveys, according to standards and age limits, can be used to determine the re-surveying necessity. This will save a lot of unnecessary work when inserting the information in the database. When digitalizing this existing metadata, from the surveys report, is also important to obey the standards established by the IHO in S-57 [IHO, 2000] to simplify its use and analysis.

The establishment of what should be the ideal, or minimum technical standards, applied to each part of the area is the second preliminary necessity to appoint the need of re-surveying. Is true that the IHO determine the minimum standards [IHO, 1998] for each Survey Order, but is indispensable that the Hydrographic Services appoint where are the geographic limits that each one should apply. As also clarified by the IHO in S-44, the Hydrographic Services should study the necessity to create areas where specific and more rigid criteria are used, due to their military, strategic, political or economic relevance.

Gather other information of the area and fix the geographic limits where they are applied is also important. Data such as rate of seabed variation, volume of maritime traffic, and classification of the area according to parameters as numbers of nautical accidents, or navigation safety relevance, are also important for the future establishment of the criteria. However, if we don't have in mind what kind of information will be used in our criteria gathering such data could be a waste of time.

Therefore, with the information of the existing reality of the maritime area, it will be possible to determine the firsts important indicators that should be used and, afterwards, combine them in criteria.

Age Indicator

Time is an essential element to consider. It is the main dimension used to vary some of the indicators and even the word "update" has the time notion inserted in its meaning. The age of the survey is, then, the most clearly identifiable indicator.

When we classify a survey by its age we insert notions of modifications in many physics and economics factors of the area. Furthermore, this indicator can also express the technical evolution of the equipments used to survey the area. Therefore, time is the great substitute for all the parameters that we can not use as indicators. As consequence we must stay alert to not oversize, or minimize, its relevance establishing its classification and weight according to the indicators present in the criteria.

Technical Indicators

These indicators can be obtained by the comparing the existing technical information of the surveys metadata with the standards established by the Hydrographic Service. The factors to compare are those expressed in S-44 publication: positioning precision, depth precision, line spacing and bottom coverage.

There are several ways to combine the metadata with the standards. The easiest way is to determine a ratio between the metadata and the specified standard. This mathematic number is easy to establish when we are talking about line spacing and bottom coverage, but it is not a simple task to do for the position and depth measurement problem. Considering old surveys if we don't have the complete information necessary to establish such data for instance the tide reference station information, and the sound velocity determination method, an exact number will not be achieved, making more difficult to use such information in a criterion. Although we can use some inexact information, as well as some technical reference that may facilitate its use, such as the table suggested in the IHO Manual of Hydrography Appendix 2 [IHO, 2005] it should be carefully considered to insert these kind of relevance in the age indicator. If we choose to do that the technical information evolution should be used to establish the survey age indicator classification.

Spatial Modification Indicators

The main reasons to re-survey an area are the changes that have happened in it. These changes can have appeared due to the human, or nature, action both over or under the sea. The establishment of a rate that measures these changes is also a difficult job to do. Although the land part is also important the most expressive modification that motivates the re-surveying is the seabed variation. There are several ways to measure it from comparing the bathymetric data, measured in different surveys, to methodologies with sediments profiling [ARGOLO, 2001]. If we dispose from such data is very important to use it in the criteria combining it with the age of the survey and the technical indicators to obtain the information of the necessity to re-survey a given area.

Priorization Indicators

After determine if a specified numbers of areas hydrographic/bathymetric information is actualized, or not, is also important to classify them identifying which are the most important areas to survey. Several relevance area indicators can be used to construct such criteria. Probably the most visible, and important, are the economic and the navigation safety relevance rates. To establish such rates many information such as port cargo or vessels traffic can be used. Hydrographic Services should choose them considering which are the data they dispose and the difficulty to combine their degree of importance into a rate.

Fuzzy Logic

Fuzzy Sets

The fuzzy sets Theory was conceived in 1960´s by Lofti Zadeh [ZADEH, 1965]. It is the base of the fuzzy logic and its main objective is to generalize the idea represented by the conventional or ordinary sets theory, approaching the imprecision and vagueness of human reasoning [Kosko B., 1992].

Unlike the conventional sets, where an element belongs or not to a set, in the fuzzy sets a given element is associated with a set by a degree of membership (μ) that varies from zero to one. This type of treatment turns possible that the transition between the conditions of belonging or not belonging to a set, do not occurs in a crispy, abrupt way, but instead of it progressively, as shown in Figure 1.

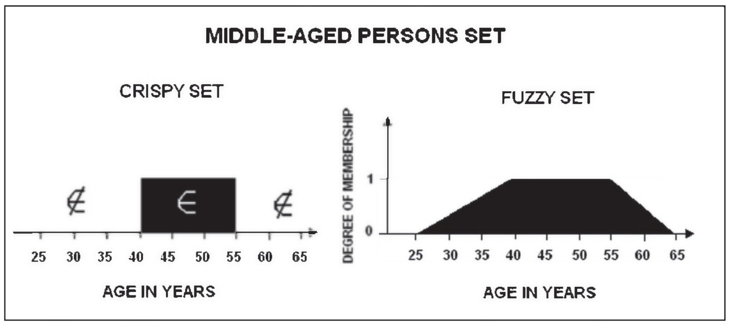

Figure 1: Middle-Aged Persons Set.

The "middle-age" concept is vague. A person is not young when it is 34 years old and suddenly in it 35th birthday it turns to be middle-aged. What happens in real life is a progressive change from a point that we are sure that the person is not in middle-age to the point that we are sure that it is. This kind of problem is also applied to other vague concepts such as near, far, big, small, and also for quantifiers as many and few. Therefore it can express in a better way the membership of some continuous scale numbers such as temporal, geo-biophysics and socio-economics data, where these concepts are usually present.

Like conventional sets there are specifically defined operations for combining and modifying fuzzy sets. Following the conventional fuzzy set operations, initially defined by Zadeh, the basic operations of two Sets "A" and "B" respectively with elements "x" and "y" are:

Intersection – $A \cap B = \min(\mu A[x], \mu B[y])$ (1)

Union – $A \cup B = \max(\mu A[x], \mu B[Y])$ (2)

Complement – $\sim A = 1 - \mu A[x]$ (3)

Since fuzzy sets are not crisply partitioned, in the same sense as Boolean sets, these operations are applied at the truth membership level. As a consequence of a fuzzy set's somewhat fluid characteristic function, deciding whether or not a value is a member of any particular set requires some notion about how the set is constructed, and manifold of the connecting surface [COX, 1994]. We can visualize this problem in Figure 2.

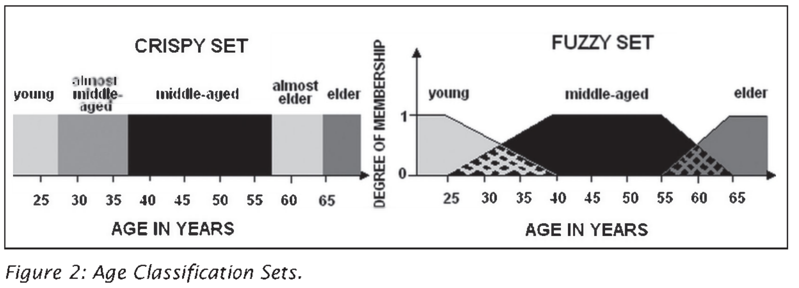

Figure 2: Age Classification Sets.

These set theoretic functions provide the fundamental tools of the logic. As in Boolean logic the intersection can be viewed as the logic operation "and", the union as "or", and the complement as "not". Therefore we can also apply logic rules for fuzzy sets as we do for the ordinary sets. This is named "fuzzy logic".

Fuzzy sets can classify the same phenomenon in a less numbers of sets than conventional logic as seen in Figure 2. Therefore, it usage becomes very advantageous when we have to combine a large numbers of antecedents into a predicate because it avoid the creation of many unnecessary sets that would raise number of rules and, as consequence, the complexity of the logic inference system.

For example if we want to combine the age classification sets in Figure 2 to determine the chances of a successful marriage the number of rules would be much greater if we use crispy sets (5 sets for husband X 5 sets for wife = 25 rules) instead of fuzzy sets (3 sets for husband X 3 sets for wife = 9 rules).

Fuzzy Inference System - FIS

Fuzzy Inference System (FIS), also named Fuzzy Logic Controller, is a technique that uses fuzzy logic for Decision and Support Systems and is based on the simple input, process, output flow concept as we can see in Figure 3.

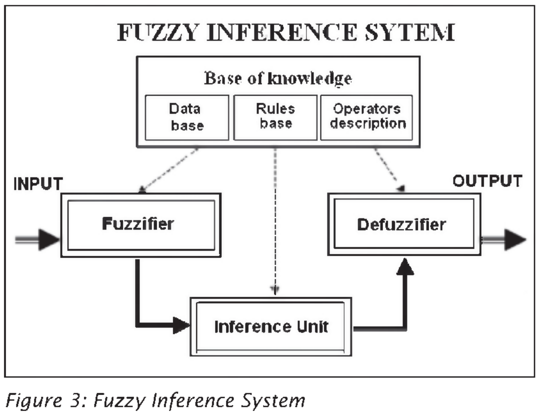

Figure 3: Fuzzy Inference System

It consists basically of inputs that are associated with a fuzzy set by a specific degree of membership in a process called fuzzification. The fuzzy sets are then combined in the inference unit through logic rules in order to generate the output inference fuzzy set. This information of the each fuzzy set is then combined in a process called defuzzification to obtain a single crisp value output. The defuzzification process can be made by many mathematic functions such as the centroid method. This method gives as answer the value of the abscissa of the mass center associated with the membership graphic obtained at the inference unit. There are several types of FIS models that are different in premise terms and control action's representation and in the operators for the controller implementation used in the "inference unit". The choice of what will be the best FIS model to be used depends of which type and precision of information will be used in the system. We suggest for the hydrographic survey selection/priorization problem, initially, the usage of the Mandani model for its simplicity and large implementation in the existent software.

Methodology Suggested

The methodology that is suggested for establish a selection and priorization of port areas to hydrographic re-surveying is shown in Figure 4.

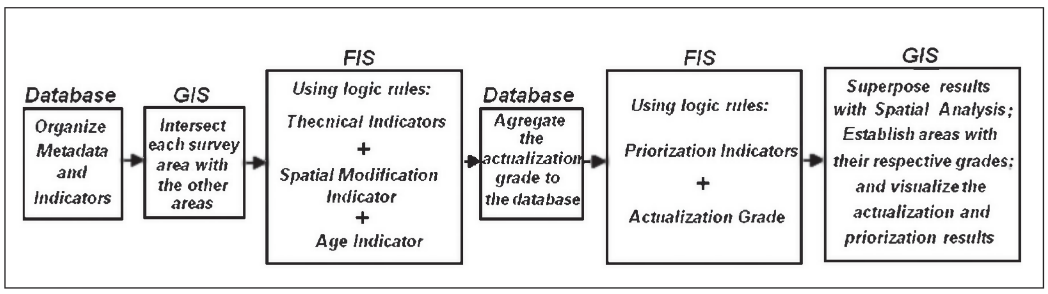

Figure 4: Methodology suggested for selection and priorization.

Initially all the areas of the previous surveys and their metadata must be clearly defined. It is also fundamental to have the areas of the other information that will generate indicators, such as the ideal or minimum technical standards, and the seabed variation rate, established. All these information should be kept in a database following, as far as possible, S-57 standards.

In sequence we must intersect the surveys areas with the others indicators areas. This intersection should be done in a Geographic Information System (GIS) to guarantee to a better visualization and a correct result. It is also important, as we have overlaying of many of the surveys, to make this combination individually for each survey in order to avoid errors mixing the metadata of different records. As a result, each new area corresponds to a specific record in a database with all the individual information necessary to establish its actualization and priorization grade.

After this it is necessary to use a FIS to select the areas that need survey actualization. This can be done by combining together the age indicator with the special modification and technical indicators. The number of indicators and sets, in each one, should not exceed four, otherwise the number of rules will be excessive, making difficult to establish and modify them, if necessary. If the number of indicators is higher we suggest first to group the correlated ones in a single indicator for technical specifications and/or special modification.

Accompanying the reality of the main metadata and information available we suggest to use for the criteria: the seabed variation rate as spatial modification indicator; as technical indicators the rate of line spacing and bottom coverage, obtained by comparing the metadata of the survey and the established ideal standards; and the age indicator, where the establishment of fuzzy sets must also consider other spatial modification and technical parameters, such as evolution in precision and measurement of position and bathymetric data through the years.

All the sets and rules used in the FIS must be established by the Hydrographic Service considering their ports and surrounding area reality. For instance, a country with ports that started to use a side scan sonar equipment in 1980 should not have the same sets and rules as other who started to use it in 1988. They must be revised periodically in order to accompany the modifications both in the Hydrographic Service and in the study's area reality.

After reaching a number, that express the actualization needs for each record, this information will be used together with the priorization indicators in a new FIS to establish the priorization of the area. It is also important that the sets and indicator's number are not too big. We suggest using as priorization indicators the economic and navigation safety relevance's rates which must be specified and established according to the disposable information and reality of each area in study.
At the end of the methodology is necessary to use a GIS again, in order to take away the superposition of information, and show

truly the need of actualization and priorization in the areas. To make it possible we must establish a priority grade, for plotting the areas in the GIS, overlaying the ones with greater actualization and priorization grades by those with the smaller ones. For instance, if we have two surveys that have an intersection in a specific area and one has no need to actualization, while the other has a small need of actualization, the intersection of them will accompany the more actualized and won't need an actualization. Therefore is important to determine, by intersection and priorization in spatial analysis, which are the coordinates of these new areas and what is going to be their actualization and priorization grade.

Conclusions

The usage of a FIS together with a GIS is a viable and easy way to treat spatial information and establish the necessary criteria to select and prioritize port, approach and surrounding areas for hydrographic re-surveying.
In order to do that is fundamental the knowledge of all metadata of the previous surveys existing in the area. These metadata should be organized as far as possible in databases according to S-57 standards.
It is also important to do preliminary studies, collect and spatialize the other necessary data to establish the indicators.
The indicators, sets and rules should be established considering each specific reality, revised as the situation in the studied area or the Hydrographic Service modifies and changed if necessary.
Only with this constant attention and preoccupation it is possible to know not only what to do, but where it should be done first.

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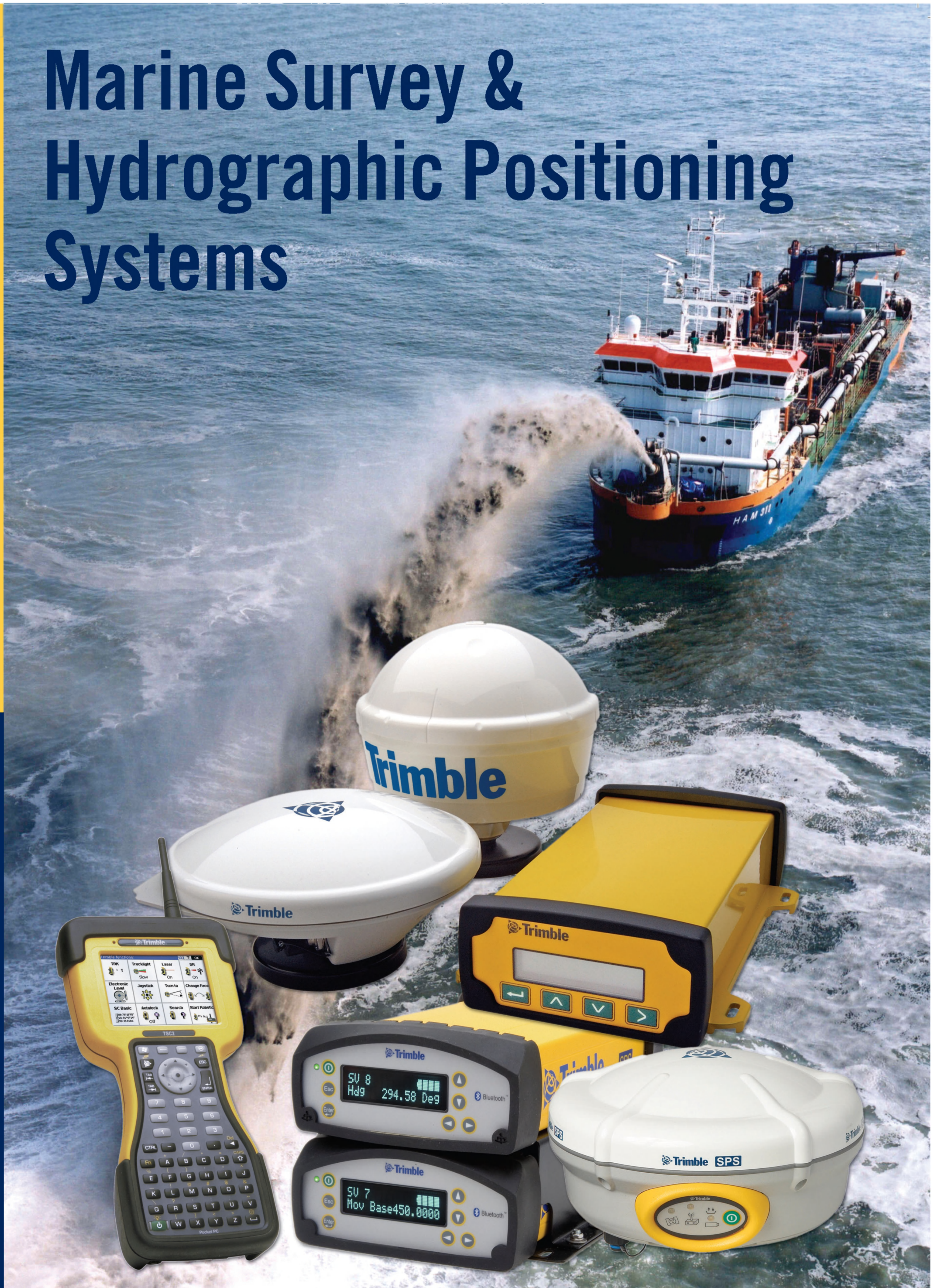
Marine Survey & Hydrographic Positioning Systems



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Multi-Beam

Monitoring The Sand Extraction On The Belgian Continental Shelf

Methodology, Results And Expectations

K. Degrendele and M. Roche

Within the framework of a sustainable exploitation of the mineral resources on the Belgian Continental Shelf, the Belgian government has established a surveillance and monitoring program of the extraction activities and the impact on the environment. The up to date results show a concentration of the activities on the Kwintebank, resulting in a strong but merely local impact of the extractions on the bathymetry and sediments of the seafloor. In the near future the governmental control will evolve to a real-time surveillance and a dynamic and three-dimensional monitoring program to assure the future sustainability of the economically important exploitation of mineral resources.

Legislative and economic framework

Numerous tidal sandbanks characterize the Belgian continental shelf. These sedimentary bodies stretch out over several tens of km. They reach a height ranging between 10 and 20m and are separated by parallel swales with a maximum depth of 40m. The extraction of sand on tidal sandbanks of the Belgian Continental Shelf started very cautiously in 1976 and is inventoried since 1979. The annual extraction has increased regularly from 370,000m³ in 1979 to 1,700,000m³ in the mid of the 90's. In 2001 the production exceeded the limit of 1,900,000m³ (or nearly 3,000,000m³ tons at a mean density for sand of 1.5t/m³). The last 3 years, however, the production has been around 1,600,000m³.

To assure a sustainable exploitation of the mineral resources on the Belgian Continental Shelf a legislative framework for the regulation of the exploration and exploitation of the aggregates was established in 2004 by the General Direction Quality and Safety of the FPS Economy. Within this framework, three control zones and one exploration zone are defined (Figure 1).

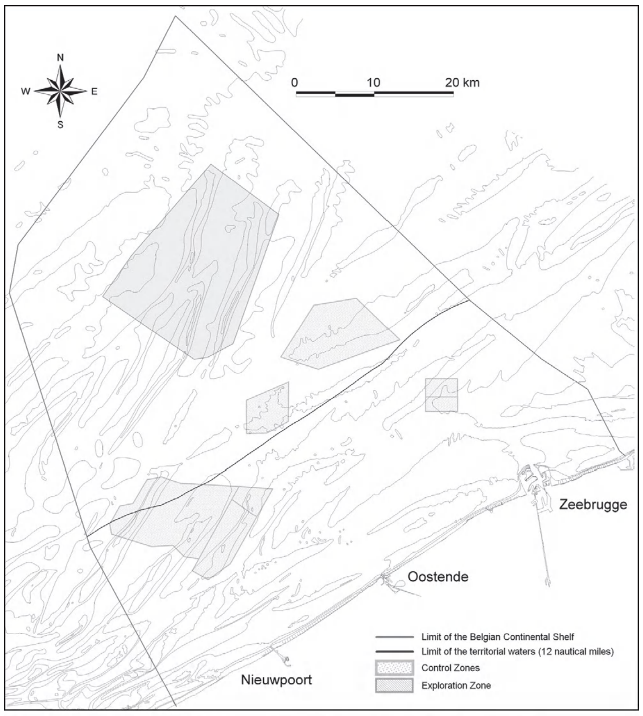

Figure 1: Dredging zones on the Belgian Continental Shelf.

Methodology and results

The governmental control is two-fold:

Monitoring of the extraction activities

- Each extraction vessel operating in Belgium has to be in possession of a register providing all relevant information on each extraction (vessel identification, date and location and discharging volume);
- A black box has to be installed aboard each exploitation vessel, This black box registers parameters entered by the crew before each journey (identification of the concession holder and reference number of the journey) and the automatically collected data (identification of the vessel; date and hour of the registration; position and speed of the vessel; status of the pumps and status of the extraction activity). All data are collected and analysed.

The analysis of the registers and the black-box records of the trailer suction hopper dredgers operating on the Belgian Continental Shelf reveals that, since the beginning of the extraction in 1976, at least 75% of the total extracted volume originates from only one sandbank, the Kwintebank.

On this sandbank the two most dredged areas are morphologically distinguished by two depressions: one in the central and one in the northern part of the bank (Figure 2). In order to limit the impact of the sand extraction on the bathymetry, the Fund for Sand Extraction has closed the central depression of the Kwintebank for exploitation in February 2003.

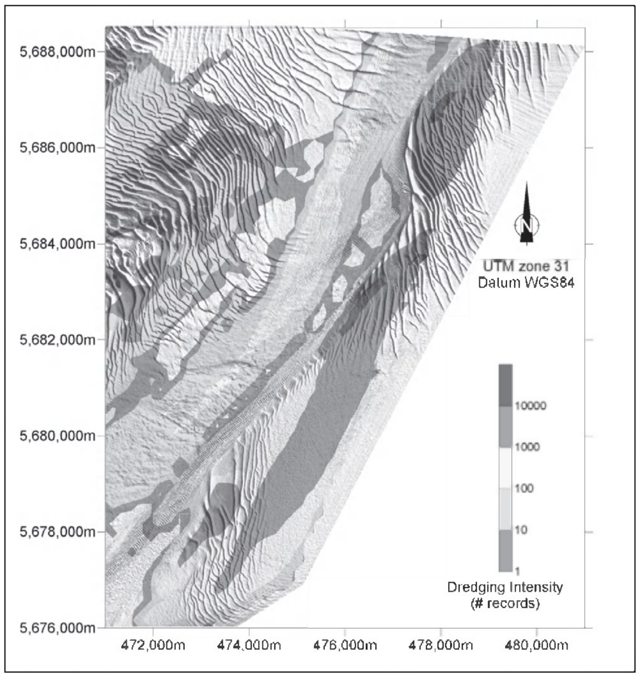

Figure 2: Superposition of the extraction intensity on the geomorphological model of the Kwintebank (number of dredging records from 05/11/1996 to 30/03/2005; each record represents 30 seconds of operation by a trailer suction hopper dredger).

Monitoring of the impact of the extraction on the seabed

In the framework of the follow-up of the marine extractions by the Fund for Sand Extraction, the Federal Public Service Economy acquired a Kongsberg Maritime 1002S multibeam echosounder. This system has been installed aboard the RV Belgica in summer 1999.

The EM1002 provides 111 beams of 2° (athwart) x 3.3° (fore-aft) width. It works at a nominal frequency of 95kHz with a ping-rate of around 4 to 6Hz. The data are real-time corrected for the roll and heave with a Seatex MRU 5 motion sensor and for the heading with an Anschütz Standard 20 gyrocompas. The geographic co-ordinates are provided by a Sercel NR103 (1999 until January 2003) and a Thales Aquarius 02 (since January 2003) GPS positioning system with a theoretical precision of respectively <5m and 10mm.

The soundings are tide-corrected using the specific M2 tidal reduction method for the Belgian coastal zone and referenced to the level of mean lowest low water at springtide (MLLWS).

The large amount of gathered data and the full-coverage capabilities of such remote system allow the construction of accurate terrain models of the seafloor. A global bathymetric error (2σ) of 0.35% of depth has been estimated on the basis of the variance between the resulting bathymetrical digital terrain models of four successive surveys of the same area within one tide cycle and on successive measurements on a stable wreck. This global error on the final product, the terrain model, is the combination of the independent errors of the EM1002 multibeam echosounder, the auxiliary sensors and the draught and tide corrections.

The processing of the backscattered acoustic signal through specific software packages results in the acoustic cartography of the seabed (seabed imagery). Despite the large amount of along-track artefacts, acoustic zones can be delimited (acoustic classification). The resulting maps partially reflect the real sedimentary nature of the seabed.

To evaluate the impact of the extraction in detail, several monitoring zones were defined: two in the active control zones (central and northern part of the Kwintebank) and one on the neighbouring bank to the east, the Middelkerkebank, situated outside the control zones (Figure 3). From November 1999 until the closure for extraction in February 2003 and the subsequent post-dredging evolution until June 2005, a total of 17 surveys were carried out on the central part of the Kwintebank (KBMA, Figure 4) and on a reference zone situated on the Middelkerkebank (R2), outside the dredging area. The resulting time series of digital terrain models (DTMs) and backscatter strength maps allow a detailed comparison of the bathy-morphological and sedimentary evolution of both monitoring areas.

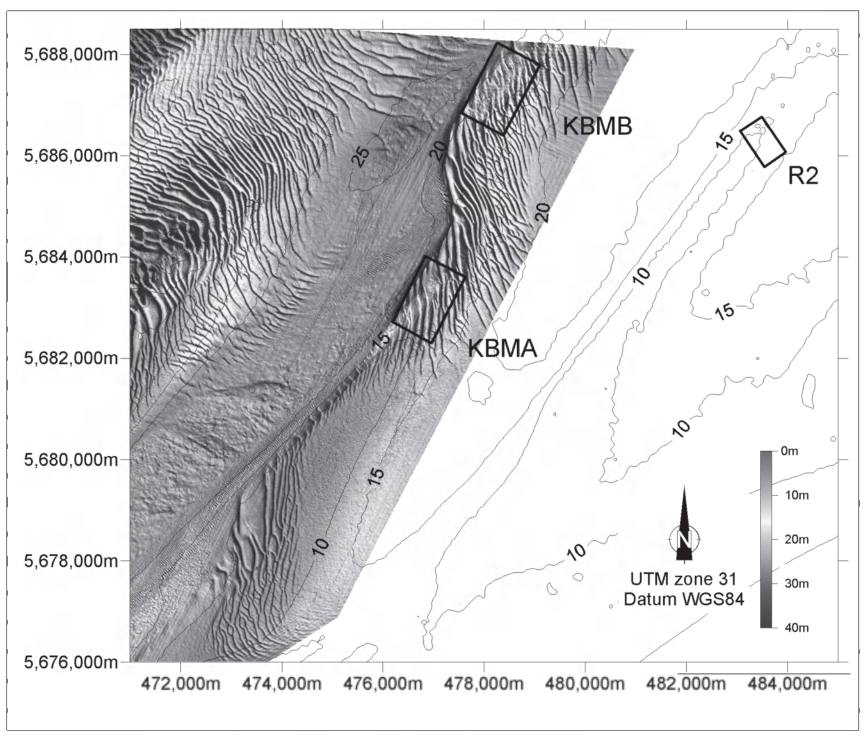

Figure 3: Location of the monitoring areas KBMA, KBMB and R2.

Since the start of multibeam monitoring in 1999, a global deepening of 0.5m of the whole KBMA monitoring zone is observed until February 2003. From that moment on, KBMA was closed for extraction and the bathymetrical trend on the central depression becomes less negative. The evolution of the KBMA can be considered as a combination of natural and anthropogenic factors. After the subtraction of the extracted volumetric component from the total volume evolution of the KBMA monitoring area, a close to natural evolution can be deduced and enables a comparison with the volume evolution of the R2 area outside the dredging area. This forms, together with the much smaller decrease since the closure of the zone for extraction and the lack of indications for cumulative effects on the bathymetry, a clear evidence of the merely local impact of the extraction. At the scale of the KBMA monitoring area, there is no indication of a change in natural processes. The volume evolution that was observed during extraction is reversed nor maintained.

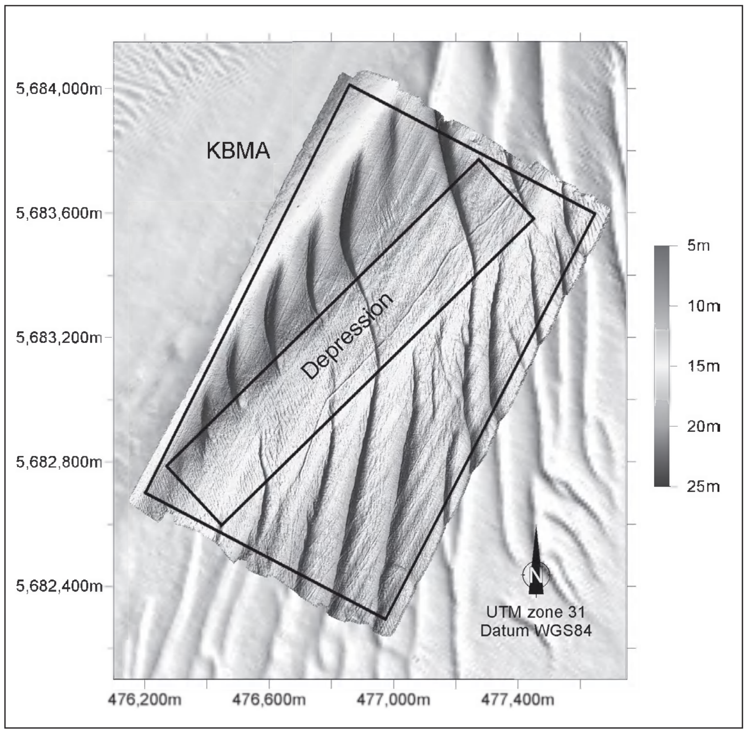

Figure 4: Detail of the monitoring area KBMA and the delimitation of the central depression.

The mapping of the backscatter values suggests a clear difference in sediments between the depression *sensu stricto* and the rest of the KBMA monitoring area. The central depression has a mean backscatter value of –24dB, which coincides with a backscatter strength mean value for medium to coarse sand. The mean of the backscattered strength values recorded on the east side of the KBMA area is up to –27dB, suggesting the dominance of very fine sand in this sub-area. The western side of the KBMA shows intermediate backscatter values, and is characterized as medium to coarse sands with grab samples. The focus of the extraction industry on this depressed part of the bank is explained by the presence of this medium to coarse sand. The backscatter strength values are fairly stable and do not show a clear evolution before or after the cessation of dredging. According to these data within the KBMA area, the sedimentary composition of the seabed at the water-sediment interface seems to be quite stable. However, the seabed classification indicates a minor tendency towards more fine and homogenous sand in the depression after February 2003. A similar stability of the backscatter strength is observed for the R2 monitoring area.

Expectations

The monitoring of the extraction activities is a control activity with a delay of a few months at best. The registers and black box readings are collected at regular intervals and processed. This constitutes an effective control of the extraction activities, but doesn't allow a real-time surveillance. Furthermore, the extracted volume for each dredging vessel and company is calculated based on the extracted volumes listed in the registers. These values are submitted on his word of honour by the exploitation vessel's captain. To establish a real-time monitoring independent of the controlled organisations the black boxes should be used to calculate the extracted quantities. The black box data should be collected as close as possible to real time to enable a direct response to infractions and a close follow up. For the latter, the use of AIS data can complement the information of the black boxes and provide a real time follow up of the extraction vessels and activities.

The monitoring of the seabed can still be improved on a few fundamental points. The important compensations for the draught of the vessel and the tidal height can be ameliorated and made available in real-time. Most important however, the use of a more adapted tool for the measurements, a very shallow water high frequency echosounder, instead of the by all means non ideal solution of a shallow to medium water echosounder, will greatly improve the accuracy, resolution and efficiency of the measurements. This will permit the researchers to refine and intensify the study of the impact of the extractions. Due to the limitations of the present system the monitoring is confined to small areas. The large-scale monitoring is currently executed by comparing the mapped sandbanks with recently sailed transects. With a more efficient system the re-mapping of large structures becomes a feasible option.

If the monitoring of the extractions activities can evolve to a near real-time surveillance, a dynamic monitoring of the impact becomes possible. The surveillance will enable the adjustment of the monitoring to the up to date information and provide a more adaptive, dynamic monitoring.

The monitoring of the seabed is at present a 2D evaluation of the surface of the seafloor. A real 3D evaluation of the mineral resources and present sedimentary bodies is necessary to establish the impact on the available volumes of sand and gravel and to develop a sustainable exploitation. From this point of view the Fund for Sand Extraction has launched a new project to develop and optimise techniques to transgress to a full 3D monitoring and cartography of the Belgian Continental Shelf.

Acknowledgements

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Processing And Filtering Of Multibeam Data

Grid Modelling Versus Tin Based Modelling

A. De Wulf, M. Hennau and D. Constales

Multibeam echosounder measurements serve to make a digital terrain model (DTM) of the seafloor. The Delaunay triangulation is a widely appreciated and investigated mathematical model to represent the relief of such a terrain and is highly efficient for building triangular irregular networks out of non-homogeneous data such as raw multibeam data. However, most multibeam systems deliver equidistant interpolated data, allowing faster processing to be achieved by using equidistant grid modelling. Both approaches yield their own advantages and drawbacks. More specifically, the filtering options of TIN and grid models are quite different. An analysis of both workflows will be worked out.

Introduction

Obtaining an accurate model of the seafloor is a major concern in dredging works. Nowadays' hydrographic surveying tools, especially the multibeam echosounder, yield a very dense sampling of the seafloor and this immense amount of data needs to be processed, according to some constraints imposed by the client, to form an accurate terrain model. Modelling can be performed in post-processing or in real-time, performing a real-time accountability which keeps track of the haul realised at some moment.

DTM software for hydrographic purposes must meet the following four requirements:

1. Fast model creation. The purpose is to create the model as fast as the data is gathered, so that real-time control and verification are possible;
2. Allow manual editing of the model: adding as well as deleting data points (vertices) in the model are both considered. When examining the theoretical model of a site, intervening directly in the model as it is displayed on the computer monitor by relocating, deleting or adding vertices is a prerequisite. It should also be possible to replace resurveyed areas with the new data and to update the existing model with this new information;
3. Reduce the large amounts of multibeam data to acceptable levels, keeping the seafloor model as accurate as possible;
4. The final result in the form of volume calculations should be as close to the truth as possible and certainly not farther away than acceptable, assuming that the acceptable quality level is realisable.

Grid models and triangulation models are the most frequently used models, offering different kinds of advantages and drawbacks. Both will be discussed with their advantages and drawbacks, with special attention to the filter-capabilities of each approach.

Grid Modelling

Principle

Nowadays, most multibeam systems offer equidistant grid data as default output of the on-line/on-board processing chain. The plane coordinate system used is generally a square grid with the axis parallel to the Easting- and Northing axis of the grid coordinate system used. Since the use of GPS equipment, the universal transverse Mercator system (UTM) in relation to the ETRS89 datum (referencing the global ellipsoid GRS80) has established itself as the standard grid system in Europe. This leaves the grid interval distance as the unique and most important user-defined parameter.

The use of equidistant points allows to store in computer memory only the depth values and not the Easting and Northing values, as these values can be computed out of the row and column number of each point, assuming (for instance) that the point storage is performed in a rowwise manner in the computer memory, using arrays of integer values that only need 2 byte for each depth or point.

Filtering

As the amount of data generated by a multibeam echosounder depends on the ping rate, which goes up to 30Hz, and the number of beams in the swath, typically between 100 and 300, incoming data flows can reach up to more than 30 million points per hour. It will be clear that reducing the data gathered by multibeam echosounding is indispensable because of the huge amount and because most of it does not contribute to a more detailed seafloor approximation anyway. Indeed, descriptions in literature are given of dataset reductions of scanned surfaces down to 5 or 10% of the original dataset size without significant loss of accuracy. An ongoing concern is therefore dataset reduction.

Dataset reduction can be performed by increasing the grid interval distance, either in the software of the multibeam manufacturer, or in the software used for the post-processing. While the first one often works as a black box without much control on the filtering parameters used, the second often offers a number of intelligent filter-processing options.

One obvious type of filtering is obtained by increasing the grid interval distance, e.g. an initial 1m by 1m grid is reduced to a 5 by 5m grid, yielding a reduction factor that is the square of the linear proportions, yielding a factor of 25 in this example. There is no need to use a multiple of the initial grid interval distance, though it may speed up the computation. For the filtering algorithm, different approaches are possible to compute the depth in the resulting bigger grid cell:

- The depth is the average depth of all depths of the initial grid points lying inside the resulting bigger grid cell.
- The depth is a weighted average of all depths of the initial grid points lying inside the resulting bigger grid cell, The weighting factor is usually the inverse of the distance between both, raised to the power n. Often, n = 2 is chosen, yielding an inverse quadratic distance as weighting factor.
- The depth can be taken to be the minimum of all depths of the initial grid points lying inside the resulting bigger grid cell. This can be motivated if the purpose is to determine the minimal sea bottom depth rather then computing an accurate volume, as can occur in dredging projects. Analogously, in reclamation projects, the maximum depth can be the most important characteristic of each resulting grid cell.

Advantages and drawbacks

The principal advantages are the simplicity of a basic grid model and the low memory requirements for the processing of the depth data, as planimetric coordinates are computed and not stored in memory. Hence, computations are fast and quite straightforward. In the case of homogeneous sea bottom coverage by a multibeam sensor, grid models are often the preferred data model for the bathymetric modelling of the sea bottom. Due to the less complex algorithms involved in the computational geometry modelling operations, real-time modelling is easier to implement using grid modelling than using TIN modelling.

An obvious drawback of grid systems is the loss of the initial measured bathymetric survey points. Their information is used to interpolate the depths of the grid points, yielding a planimetric shift of the data with depth information and resulting in a global smoothing of the digital sea bottom model. This can be particularly frustrating if a relatively small object with important depth variation was measured, for example a sleeve for pipe-laying projects. Typically the sleeve width has to be realised within decimetre range accuracy. If a high density grid model with an interval distance of 1m is used, the sleeve design will be highly distorted. This can be counteracted by the use of a heterogeneous model with different grid intervals depending on the area. Quadtree structures can be used for the modelling. However, heterogeneous models are complex, involving data manipulation routines that are difficult to implement and require significant higher amounts of computer memory and processing time.

Tin Based Modelling

Principle

It is common practice to use the Delaunay triangulation [1] to construct a TIN rather than other, less restrictive triangulations. In a Delaunay triangulation, the circumscribing circle of any triangle contains no other vertices [2].

Triangles whose circumcircle does contain another vertex are invalid and need to be replaced by another triangle by a process called *edge flipping*; this is shown in figure 1a and 1b. The triangles *abc* and *acd* are not Delaunay triangles as they contain *d* and *b* respectively in their circumscribing circles. After flipping the edge *ac* to *bd*, the triangles *abd* and *bcd* are created, which do not contain other vertices in their circumscribing circle. They therefore meet the Delaunay requirement.

Figure 1c represents what is called *edge completion*: when four points are cocircular, the resulting quadrilateral is (arbitrarily) split in two separate triangles. This constitutes a degenerate case as either of the two diagonals can be constructed.

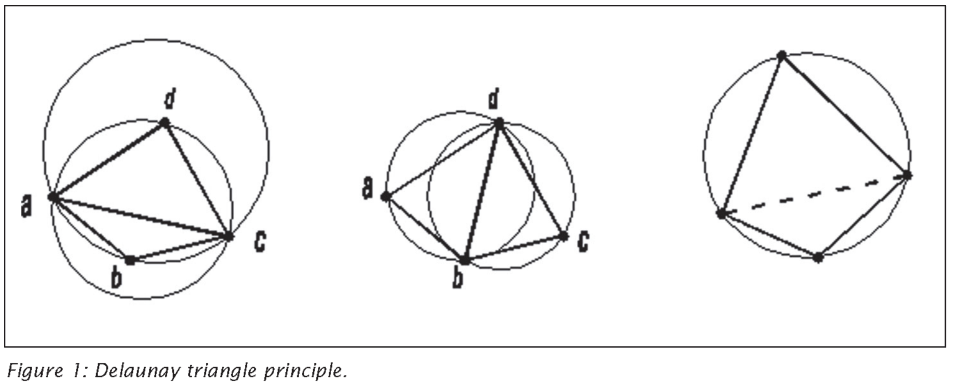

Figure 1: Delaunay triangle principle.

It can be proved that the Delaunay triangulation of a set of vertices is unique; this is an important quality asset towards the client as it allows him to repeat the calculations to verify the results independently.

Filtering

A necessary feature for a survey program is editing in order to optimize the digital terrain model. Two operations are comprised in editing an existing triangulation: it should be possible to add vertices and it should be possible to delete them. The latter is particularly important for filtering purposes, to reduce the multibeam data set to the most significant points.

Deleting points yields a retriangulation of the star shaped polygon that results when the vertex and its edges are eliminated. When deleting a vertex, the triangles containing this vertex become invalid and a hole is created around the removed point. The edges of this hole define a polygon. It has been shown by the authors [4] that it suffices to insert the conforming Delaunay triangulation of this polygon into the hole to obtain the updated Delaunay triangulation of the reduced dataset. The conforming Delaunay triangulation of the hole is in fact filling the hole with triangles that are Delaunay triangles for the updated triangulation also.

By extension, when deleting a group of vertices, a big hole is created, that can be filled with Delaunay triangles and reinserted to form the complete Delaunay triangulation of the reduced dataset.

Adding vertices one by one is easily done by the incremental algorithm as it is the basic operation of this construction method.

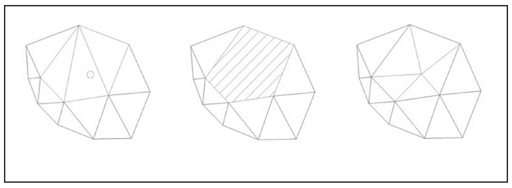

Figure 5: Vertex addition.

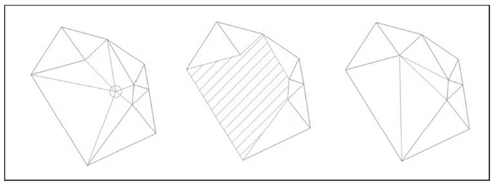

Figure 6: Vertex deletion.

A particular need for surveying at sea is replacing a part of an existing triangulation by newly available data. This means freeing the area of vertices of the original dataset where the new data are measured, in order to create a hole large enough to receive the new triangulation. Both triangulations need to be connected to each other.

An algorithm, based on the merge-step of the divide-and-conquer method for constructing a Delaunay triangulation, has been devised to join seamlessly both triangulated areas. The merging of overlapping triangulations requires determination of the overlapped area, deleting the influenced vertices and stitching together both disjoint triangulations.

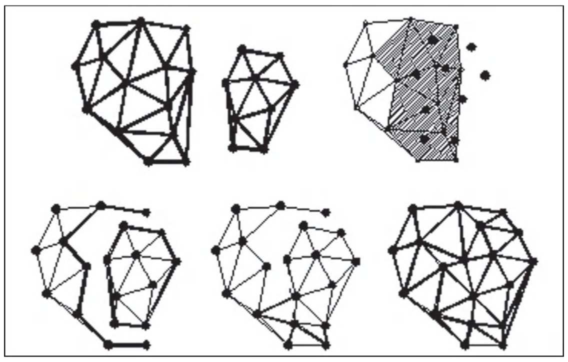

Figure 7: Merging two overlapping triangulations.

Advantages and drawbacks

It can be a requirement that the original survey points be in the digital terrain model from which the volumes are derived. This allows the client to check the results. Triangulated irregular networks (TINs) are a favourite scheme to construct a digital terrain model (DTM) from a seafloor measured at discrete spots. Overlaying the sampled points with a regular grid has three important drawbacks, compared to TINs.

1. It is generally impossible to have each sampled point in a separate regular grid position as the measurements are not on a regular grid but depend on the survey ship's survey system (equally spaced measurements or not) and attitude (roll, pitch, yaw).
2. Grid values do not reflect the actual measurements as gridding means either assigning interpolated values where the measurement density is inferior to the grid size, or resampling and loss of information where the measurement density is superior to the grid size; it introduces errors in the DTM.
3. The grid model is not adaptive. Whereas TINs will naturally represent areas with detailed relief information with a denser triangle pattern than areas with a smoother relief, grids will be far less flexible to cope with varied levels of detail.

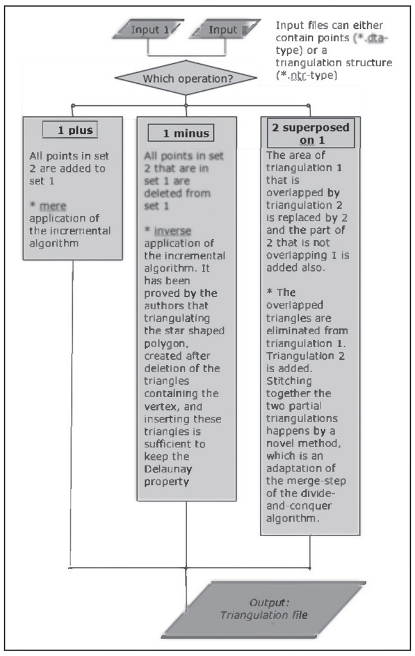

Figure 8: Merging two overlapping triangulations.

TINs do not have these drawbacks, but are more demanding towards computer memory and processing time, and the algorithms needed for geometric computations are more sophisticated.

Conclusions

Multibeam echosounder data impose some specific requirements to the processing. These requirements have been identified and the different aspects of DTM construction by grid modelling and by Delaunay triangulation have been treated in this context and opposed to each other as two alternatives, of which the advantages and drawbacks have been discussed.

The editing of the model is significantly more complex when TINs are used. As an example, the merging of two overlapping triangulation sets was demonstrated. The authors use an adapted merge-step in the divide-and-conquer algorithm to replace old data in an existing triangulation by newly available data. TINs are to be preferred when the surveyed area has a non-homogeneous coverage.

Equidistant grid models are less flexible, but offer higher speed, lower memory and easier implementation algorithms as most important assets, making them to be preferred when the surveyed area is homogeneously covered by a high-density multibeam survey. For heterogeneous covered areas, typical for singlebeam surveys, TINs are a priori the preferred option.

Acknowledgements

IWT project n° IWT990159 'Survey System for Dredging' (1999-2002) funded Ghent University, Department of Geography, as scientific partner in this project with Dredging International, Survey Department as private partner.

Ghent University was charged with the fundamental research in and the creation and implementation of an integrated mathematical model that will satisfy present and future needs with respect to real-time quality control in the mainly hydrographic surveying field. The present fundamental research fits in the larger, approved, international Eureka project 'Dredging Survey 2000 (EU203511)'. The three important research areas of interest in this project were: The development of algorithms for real-time construction of digital hydrographical charts, the development of algorithms for control and editing of digital terrain models, the development of efficient algorithms for adaptive reduction (filtering) of multibeam data.

We would also like to thank Gert Brouns who carried out during 18 months research work concerning the editing of triangulation models, within the frame of the aforementioned IWT (Institute for Science and Technology) project, funded by the Flemish Community.

Financial support from BOF/GOA 01GA0405 (funded by Ghent University) gratefully acknowledged for the research work of Denis Constales.

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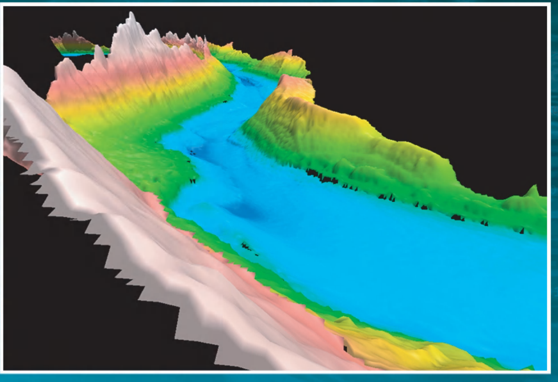

Evolutions In The IHO Standards For Hydrographic Surveys, S44

L.L. Dorst and C. Howlett

The fourth edition of the "IHO standards for hydrographic surveys, special publication no. 44" became available in 1998. Its principal aim is to specify minimum standards for hydrographic surveys. In 2004, the IHO decided to reconvene an S44 working group, which started its work in 2005. It aims to submit a draft new edition by the end of 2006. This paper informs about current S44 standards, it expresses some considerations about changes, provides an update on the status of the revision, and invites the hydrographic community to express their opinion about the current edition.

Introduction

The fourth edition of the 'IHO standards for hydrographic surveys, special publication no. 44' became available in 1998. Its principal aim is "to specify minimum standards for hydrographic surveys". This way, the data collected by hydrographic offices worldwide is "sufficiently accurate" and "the spatial uncertainty is adequately quantified" [1]. Following a letter of the Australian Hydrographic Office, the International Hydrographic Office (IHO) decided to reconvene an S44 working group (WG). The group contains 24 representatives from countries worldwide, it is chaired by Chris Howlett of the United Kingdom Hydrographic Office (UKHO), and Rob Hare of the Canadian Hydrographic Service (CHS) is vice-chairman.

The IHO recognizes the importance of the contributions of private companies and other interested bodies to its technical work [2]. Therefore, the WG organized a workshop immediately following Shallow Survey 2005, in Plymouth, UK, on 16 September 2005 [3]. A second workshop is planned immediately following Hydro06.

Contents Of S44, 4th Edition

Table 1 of the 4th edition is the most known part of the publication. It divides maritime areas into four orders, and specifies the required horizontal and depth accuracy for each order. Also, it recommends if a full bottom search is necessary, the minimal size of an object that a system should be capable to detect, and maximum line spacings. Table 1 is given in the Annexe.

However, it should be noted that S44 contains more standards than this table. For instance, Table 3 specifies accuracies for bathymetric models of the sea floor for each order. This table applies to surface approaches, that interpolate the measured depths to a continuous description of the sea floor. Also, S44 contains notes on sampling, tidal observations, stream observations, and elimination of doubtful data in a bathymetric survey, i.e. potential hazards to navigation. The S44 standard is discussed by various authors, like Wells and Monahan [4], Mills [5], and MacPhee and Hare [6].

It is most important to realize that the S44 standards are minimum standards. A hydrographic office can decide themselves to use their own, stricter standards. An overview of the existing standards is given by Wells and Monahan [4]. Also, IHO standards are voluntary for its member states, and therefore only contain recommendations. This is pointed out by e.g. Mills [5].

Evolutions In Hydrography And Their Influences On S44

Since 1998, hydrography has evolved on many aspects. This evolution was forecast by the IHO when they published the 4th edition, as it was planned to update S44 every five years.

The measurement aspects of hydrography have greatly evolved: nowadays, multibeam systems are in broad use, and remote sensing techniques have improved a lot, like airborne laser sounding, or SAR measurements from satellites. Also positioning technology has improved a lot: Selective Availability is switched off, LRK was introduced, SBAS systems like WAAS and EGNOS were developed. S44 does not intend to formulate standards for every measurement technique, but limits itself to describing the quality of the result, leaving the measurement methods to the individual hydrographic offices.

The documentation of hydrography has evolved as well. IHO publication S57 has specified Zones Of Confidence for nautical charting. It defines categories differing from the S44 orders. The IHO Manual on Hydrography, publication M13, was recently presented, that contains information on the same topics as S44.

The deliverables of hydrography have also evolved. The view of the sea floor as a surface that can be fully described by the combination of measurements and appropriate algorithms is gaining support.

Finally, the usage of S44 has evolved. Designed as a documents for the member states of the IHO, it has also found its way to the rest of the hydrographic world. S44 has aided the awareness of the limited accuracy of hydrographic surveys, and the discussion on its quantification. This broad support is appreciated, and we should be careful not to loose it by making radical changes. On the other hand, a standard that is outdated looses its value. Also, we should be alert that the standard is used properly by the hydrographic community. For instance, a single instrument in a survey suite can never be according to S44. S44 only applies to the quality of the resulting depths and their positions on the sea floor. These measurements involve many instruments.

Activities Of The S44 Working Group

The terms of reference of the WG include the consideration of all the evolutions mentioned above, but also contain recommendations to clarify the 4th edition. We consider if and when a full bottom coverage is required, how to give clearer guidance on feature detection, and specifications on survey resolution and density. Moreover, we discuss options for a better structure of the text: a short compliance standard followed by technical guidelines.

A standard cannot satisfy everyone, and we must make compromises. In order to do so, we need to have a clear view who uses S44, how they use it, and in which way they would like to change it. The opinion of every member of our community matters, and should be taken into account. During Hydro'06, the WG organizes a workshop to get insight into these opinions, to include them into the new edition. This way we can maintain the strong position of S44 in hydrography.

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ANNEXE: Table 1 Of S44, 4th Edition

Order	**Special**	**1**	**2**	**3**
Examples of Typical Areas	Harbours, berthing areas, and associated critical channels with minimum underkeel clearances	Harbours, harbour approach channels, recommended tracks and some coastal areas with depths up to 100m	Areas not described in Special Order and Order 1, or areas up to 200 m water depth	Offshore areas not described in Special Order, and Orders 1 and 2
Horizontal Accuracy (95% Confidence Level)	0.5 m	5 m + 5% of depth	20 m + 5% of depth	20 m + 5% of depth
Depth Accuracy for Reduced Depths (95% Confidence Level) (1)	a = 0.15 m b = 0.0075	a = 0.5 m b = 0.01	a = 1.0 m b = 0.01	a = 0 b = 0.01
100% Bottom Search	Compulsory (2)	Required in selected areas (2)	May be required in selected areas	Not applicable
System Detection Capability	Cubic features > 1 m	Cubic features > 2 m in depths up to 40 m; 10% of depth beyond 40 m (3)	Same as Order 1	Not applicable
Maximum Line Spacing (4)	Not applicable, as 100% search compulsory	3 x average depth or 25 m, whichever is less	3 x average depth or 100 m, whichever is less	3 x average depth

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Application Of Phase Measuring Bathymetric Sonars To Nautical Charting And Environmental Mapping

T. Hiller and P. Hogarth

The Phase Measuring Bathymetric Sonar (PMBS, often called interferometer) is becoming an increasingly popular tool for the shallow water survey community. Recent studies have shown that the bathymetric data quality in maps produced by the best PMBS systems compares with the best current beamforming multibeam echosounders. In shallow waters the PMBS advantages of high accuracy, wide swath bathymetric data, along with co-registered side-scan and texture mapped data products have proved attractive in many applications. The aim of this paper is to illustrate the capabilities of the PMBS sonar in the shallow water applications of nautical charting and environmental mapping, by looking at examples of the data products generated using a widely available commercial PMBS system (the GeoAcoustics GeoSwath Plus sonar). The emphasis is on application of best PMBS survey planning strategies, survey practice and data analysis methods in order to obtain useful survey data. Previous papers have described the theory behind the technology and the best processing methodologies to use when analysing the data. This paper concentrates on the best survey practice aimed at meeting survey objectives, and shows by example how well these objectives can be expected to be met using current PMBS technology.

Introduction

The Phase Measuring Bathymetric Sonar (PMBS, also called interferometric multibeam, or bathymetric side scan) is now part of the standard surveyors toolkit for shallow water hydrographic surveys. This paper illustrates the capabilities of the PMBS sonar in the shallow water applications of nautical charting and environmental mapping by using data examples, and describes how a PMBS system can best be used to meet the requirements of high quality bathymetric surveys.

The PMBS is a swath sonar which records a time series of phases and amplitudes on several receive transducer staves. Vernier deconvolution of the phases in the software gives a unique angle for each range, with the range calculated from the arrival times [1]. The advantages of such technology compared to standard beamforming techniques are the very high angular and therefore across track resolution, giving high resolution co-registered sidescan and bathymetry outputs over very wide swaths, and the relative simplicity of both hardware and software which leads to a lower cost and more reliable system.

Surveyors have noted that phase measuring sonars have a higher standard deviation (SD) of raw soundings than a beamforming multibeam, but that the feature definition in bathymetric images is equivalent or better. This excellent feature definition arises because the data collected has a very high density, which effectively compensates for the higher raw data standard deviation, resulting in mean bin soundings that are very accurate and repeatable [2]. Confirmation of the accuracy of commercial PMBS systems when surveying in the shallow water regime has been demonstrated many times by comparison with single beam and MBES surveys [3] [4] [5] [6] [7].

The Pmbs Sonar Technology

The PMBS uses phase comparison angle measurement. The sonar is typically configured with a port facing and a starboard facing transducer mounted with the boresight at 30 degrees down from the horizontal. Each transducer has one transmit stave and multiple receive staves. The transmitted pulse is similar to that used by side-scan sonar: very wide in the across track direction (greater than 150 degrees), narrow in the along track direction (about 0.9 degrees), and about 30 microseconds long (~7.5cm, although this can be usually be adjusted by the user). The beampatterns from the port and starboard transducers will typically overlap under the vessel, giving extra coverage in this area. Each sonar ping from the PMBS provides a range series of angles to the seafloor. A port and starboard ping together give the seafloor profile under the vessel, and a series of pings taken as the vessel moves along the survey track gives the swath of soundings. The amplitude of the sonar return is also recorded, giving a side-scan image.

The multiple receive staves are connected to electronics that measure the amplitude and phase of the sonar signals scattered from the seafloor. The relative phase delay between the receive staves is decoded to give the angle of return of the sonar signal. These relative phases allow the angle of return of the sonar signal to be measured to a fraction of a degree, and measurements are taken at very short intervals (the interval is user selectable, down to every wavelength). It is this rapid and accurate phase measurement that gives the PMBS its very high data density.

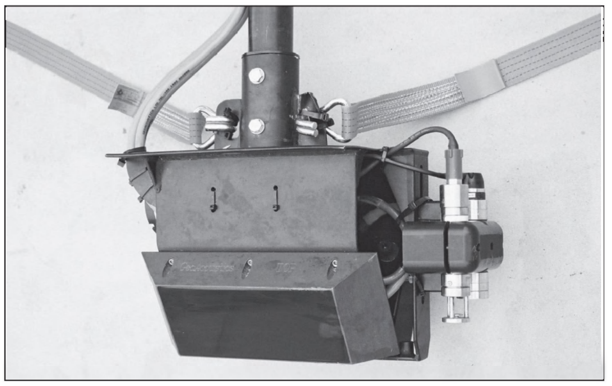

Figure 1: Sonar head.

Sonar analysis of the PMBS shows that the angle obtained from the phases will be distributed about the true angle to the centre of the ensonified sonar footprint, with a near normal distribution [2] [8]. The majority of the soundings for S/N above ~30dB will be normally distributed around the true centre, with a slightly higher standard deviation than the equivalent MBES. A consequence of the high data density in each bin is that the mean (or amplitude weighted mean) of the raw data distribution will be a good measure of the true seafloor depth in small bins (of the order of the sonar footprint size), providing outlier rejection and amplitude filtering has been used [2]. In a PMBS survey the smallest significant feature size, sonar footprint and bin size should be similar (1m or 0.5m bins). When this is the case a PMBS system can be used for shallow water surveying to IHO S-44 edition 4 Special Order and Order 1 specifications [9].

In this paper data from a widely used commercial PMBS system, the GeoAcoustics GeoSwath Plus [10], is used to illustrate PMBS survey results. This system has three frequency versions, 125KHz (for up to 200m water depth), 250KHz (for up to 100m water depth) and 500kHz (for up to 50m water depth, mainly deployed in ROVs and AUVs). The examples given here are from the 250KHz boat mounted system. The sonar head is shown in figure 1, with the two sonar transducers (35cm by 15cm by 6cm) mounted on a V bracket.

The survey examples shown here were carried out from small vessels of opportunity using side pole mounts, at speeds of between 5 and 10 knots. In shallow waters the maximum swath width will be up to 12 times water depth, up to a range limit of about 300m for the 250KHz system. The limiting factor on the swath width will be the noise in the phase determination caused by sea noise and the scattering characteristics of the seafloor, as described in previous papers [2] [4]. In an area of unknown softer bottom types it is prudent to design the survey to allow for 8 times water depth swath width.

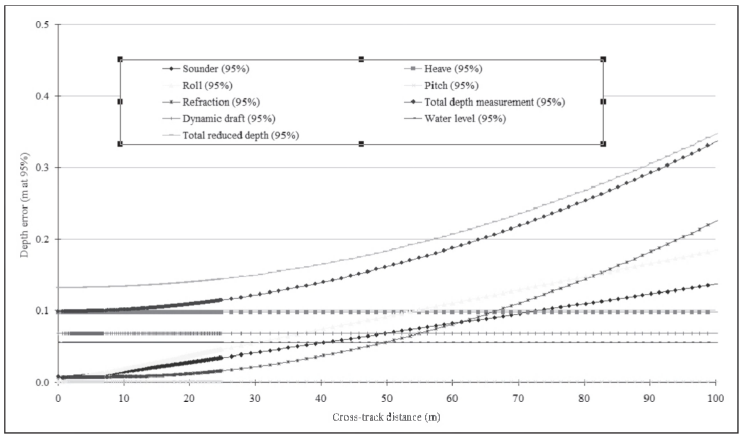

Figure 2: Example of standard deviation in shallow water.

The shallow water PMBS surveys shown here have a standard deviation in the raw data of about 7cm to 15cm (increasing at far range and in deeper water), see figure 2 for an example. After removal of outliers there will typically be over 20 data points in each 1m bin (up to several hundred). After binning the 95% confidence level of the bin depths will thus be better than 7cm, and often be better than 2cm. The chart accuracy will then depend mainly on non-sonar contributions to the error budget, as mentioned above. A PMBS error budget calculation is shown graphically in figure 3.

In PMBS data processing the raw swath data is filtered to remove outliers using amplitude and tracking filters [2]. Calibration parameters, sound velocity corrections, position, heading and motion data are applied, giving georeferenced, calibrated data files on a line-by-line basis. The data is then binned using small bin sizes (1m or 2m bins are typical, 0.5m is sometimes used in very shallow areas where the positioning accuracy is good enough). One depth is obtained from the data in each bin using a mean or amplitude weighted mean. After binning in small bins the data can be sub-sampled for charting using shoal bias techniques.

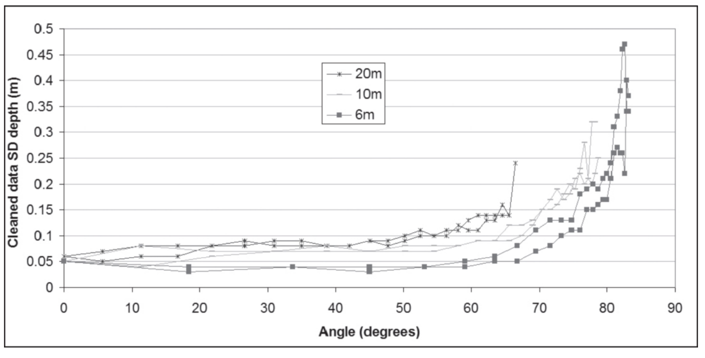

Figure 3: PMBS error budget calculation.

Surveying A Rocky Outcrop.

Figure 4 shows a survey of a rocky outcrop near a

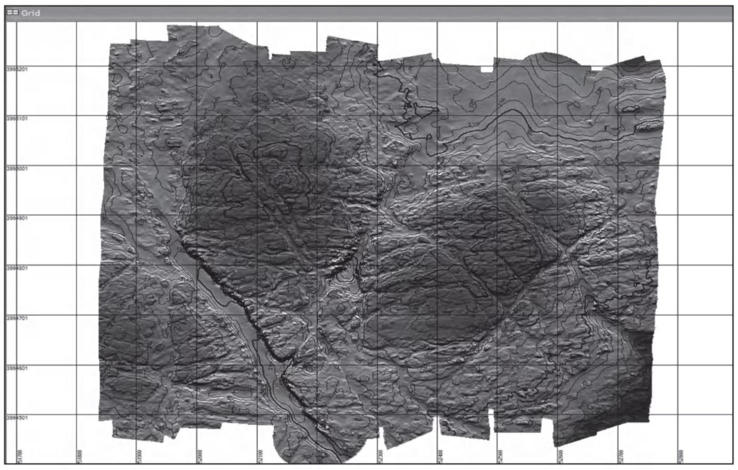

Figure 4: Survey of a rocky outcrop near a harbour entrance.

harbour entrance. Twenty lines were run at between 4kts and 5kts using an 80m swath width. This swath width allowed adequate coverage in the shallow areas (about 8m deep), while also allowing a fast ping rate along track. Lines were run in pairs in a side scan search pattern. This type of survey pattern uses >100% overlap on one side (port to port in this case), and ~10% overlap on the other. In this survey the line spacings were alternately 30m and 60m. This survey pattern gives a very high data density coverage, confidence of 100% ensonification, and good geometry for side scan detection of targets over all of the survey area.

The PMBS productivity for this survey was about 1 square Km in 3 hours, in water depths shoaling to 8m, running lines in a side scan search pattern, for collection of 0.5m binned bathymetry and co-registered side scan. Figure 4 shows the good definition of the rocky structures using a 0.5m bin size.

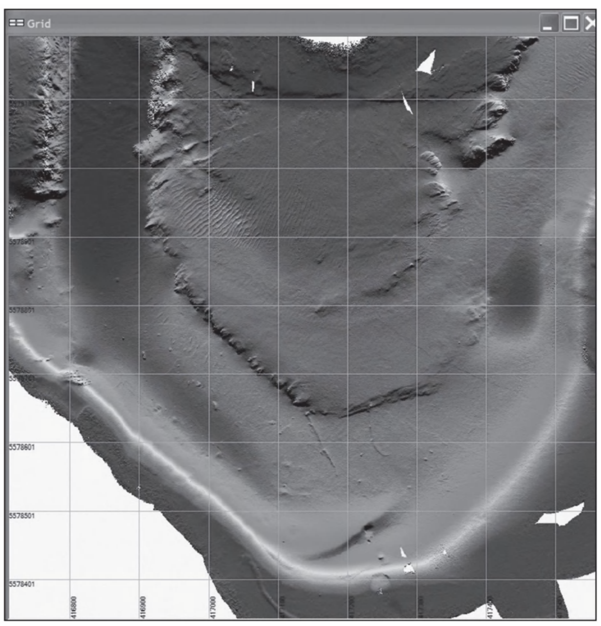

Figure 5: 1m bin data.

The Plymouth Data Set

In September 2005 the Shallow Survey Conference was held in Plymouth, UK. Prior to this conference sonar manufacturers were invited to collect a dataset of the bathymetry around Plymouth harbour. The survey areas covered were an offshore area south of Plymouth breakwater, and an inshore area around Plymouth Hoe. With the GeoSwath sonar a total of 6 hours was spent in the Barn Pool area, 6 hours in the Hoe, and 10 hours outside the breakwater.

Most of the survey was run at 5kts with swath widths set at 50m per side. Line spacing of 40 to 50m was used in the inshore sections, and a mix of alternate 90m and 40m spacing (side scan search pattern) in the outer sections.

At 1m binning the data needed no further processing, with the high data density per bin resulting in very accurate and repeatable mean depths. This can be seen in the resolution of complex small features in the survey areas. Figures 5 shows 1m bin data from part of the navigation channel. Figure 6 shows the extra environmental information available from the side scan data – here the side scan has been normalised using GeoTexture software [10], which removes effects of beampattern and incident angle from the side scan traces.

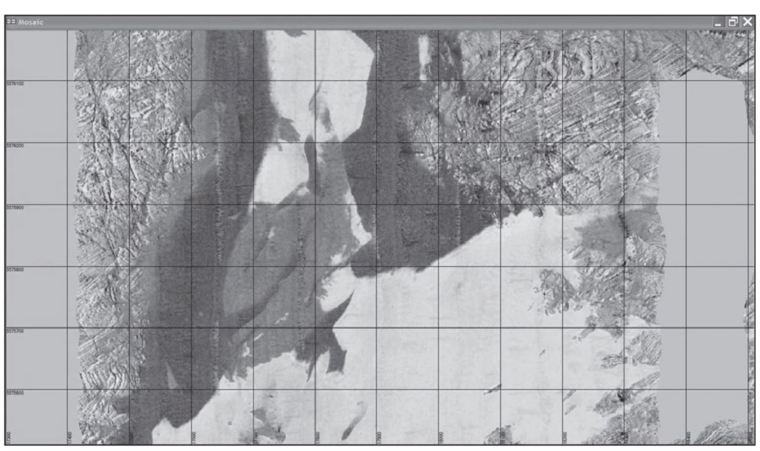

Figure 6: Extra environmental information available from the side scan data

Surveying A Pipeline Trench

A pipe trench can be a difficult acoustic environment for a sonar, with multiple reflections returning to the sonar head from the hard walls and the pipe. Figure 7 shows data collection being re-played (to check the survey geometry) from a pre-burial pipeline survey in 8m water depth. In this case a line was run either side of a pipe to give better definition of the trench walls and pipe, with enough overlap between the lines to give confidence checks of the sonar performance and positioning. This figure illustrates the use of the co-registered side-scan data, and shows the

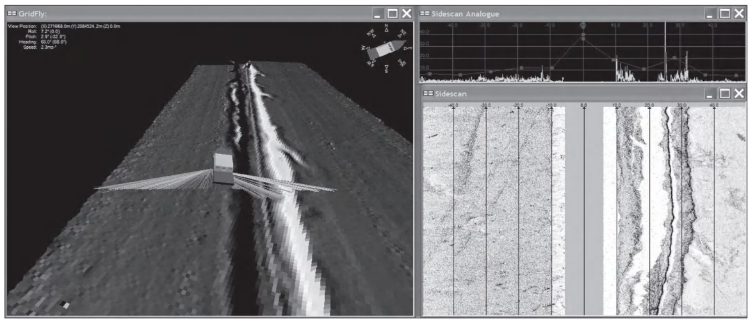

Figure 7: Data collection being re-played.

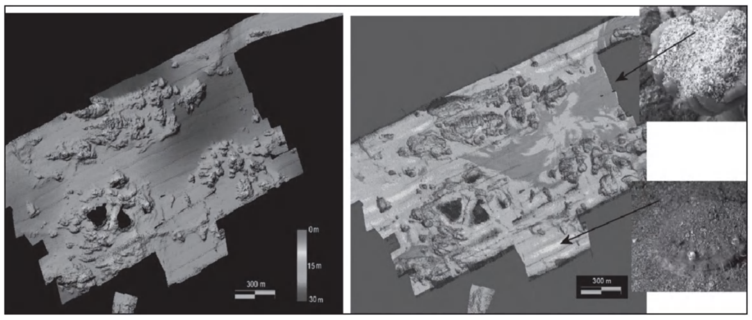

Figure 8: PMBS side scan data, normalised and classified.

object delineation capabilities of PMBS sonars at short ranges.

Environmental Mapping

The collection of high resolution bathymetry along with digital side scan data allows detailed classification of the sediments by sonar reflectivity and image texture. Figure 8 shows PMBS side scan data that has been normalised and classified using GeoTexture software [10], along with ground truth samples from these survey areas. The classified image is shown next to the bathymetry map of the area. This illustrates the ability to fully classify complex shallow areas, and combine the georeferenced side scan, classified side scan image, and bathymetry information.

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Conclusions

Phase measuring bathymetric sonars have been shown to provide accurate and reliable chart data for navigation and environmental mapping. The advantages of the PMBS over other sonar survey technologies in shallow water surveys are the wide swath width, co-registered side-scan, ease of deployment, robust transducers and low costs. Commercial survey sonars capable of the performance illustrated in this paper are now a standard option in the surveyor's toolkit.

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LITTO$_3$D

A Seamless Digital Terrain Model

Catherine Le Roux, Yves Pastol,
Laurent Louvart

The French National Geographic Institute (Institut Géographique National: IGN) and the French Naval Hydrographic and Oceanographic Office (Service Hydrographique et Océanographique de la Marine: SHOM) were tasked by the Prime Minister to join efforts to produce a seamless, precise topographic and bathymetric model, of the entire French coast. The Litto$_3$D ® project was then created to meet more than hundred requirements expressed by coastal managers concerned with the protection and exploitation of the littoral, and by users of geo-referenced data. An initial laser survey was conducted last summer in the Golfe du Morbihan, and was used to generate a precise Digital Terrain Model. This experiment enabled SHOM and IGN to develop a methodology applicable everywhere and by everyone.

Many Needs on Littoral

Coastal zone management is an essential objective to satisfy many needs: public maritime delimitation, littoral protection (e.g., change of coastline due to erosion, fauna and flora protection), risks prevention (e.g., floods, pollution, safety at sea, natural disasters), regional development (e.g., ports, tourism and industry), mineral and living resources concern, research and scientific studies, military needs (e.g., inshore patrol, search and rescue, amphibious operation, mine warfare). More than a hundred of applications have been registered.

Increasing population and coastal development justify a specific cartography of this area. Density of population on the seaside is twice and a half bigger than it is inland.

Littoral zone managers need a detailed and accurate very good description of the coast: dense everywhere, precise, at low cost, rapidly, open to everybody and fully shared. This applies to both civil and military requirements.

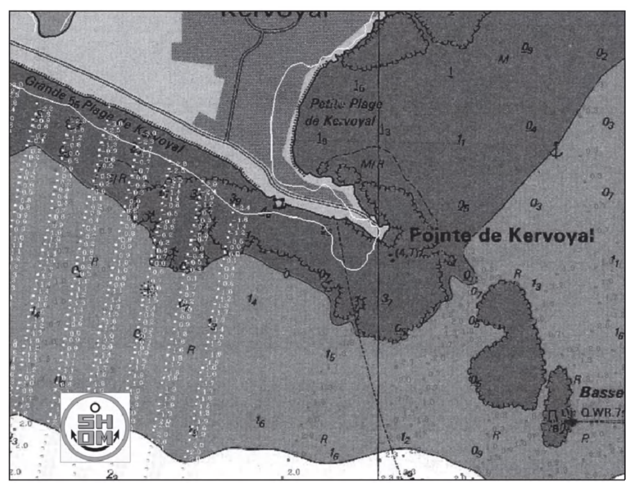


Figure 1: Printed sea charts depths (black) with bathymetric survey sheets (lighter).

Present Cartographic Deficiencies

Sea charts and nautical documents are not fully suited to satisfy theses needs as they are mainly used by mariners for safety-of-navigation. The information is focused on the navigation routes and ports. Moreover, for legibility reasons, information is less dense than what is contained in bathymetric surveys (Figure 1). Access to these plotting sheets is not easy and many people are not aware that hydrographic offices obtain much more information than is printed on paper charts or in a digital format. As a consequence, some people lose time and money digitizing charts and they get very poor (and even false) results if they use only charted information to describe and to model coastal phenomena.

On land, elevation (height) information is usually obtained by digitizing the topographic map contours (1:25,000 at most) and by photogrammetric interpretation. If density is good, accuracy is not sufficient to describe precisely the coast and to match with depths (Figure 2).

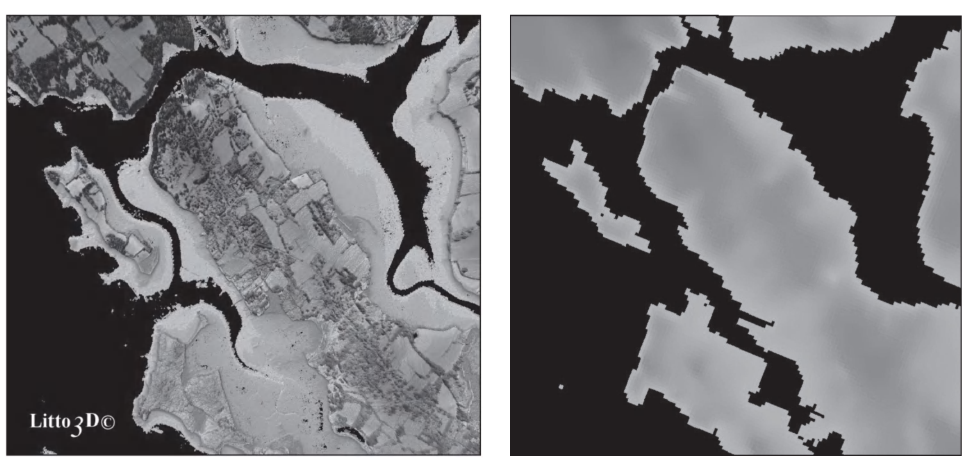


Figure 2: Laser altimetry model (cell size: 2m, σZ: 15cm) and IGN BDAlti® (cell size: 50m, σZ: 2m).

As a result, the inter-tidal area is not well described as it is very difficult to make surveys in very shallow waters (i.e., not enough water, too many rocks and breakers) and to get good photogrammetric restitution (wet and flat areas especially). This is why, in many places, there is limited data and no continuity between the sea and the land (Figure 3).

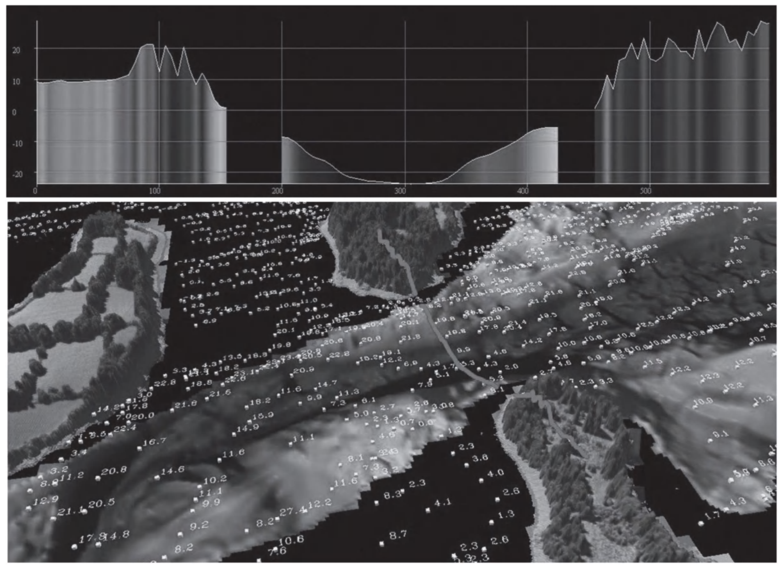


Figure 3: Limited data and no continuity between the sea and the land.

European Recommandation and French Response

M/V Erika (December 1999) and *M/V Prestige* (November 2002) disasters have pointed out the lack of critical coastal information. For instance, it was not possible to estimate environmental damages due to pollution without detailed information about coastal shoreline and the currents. Also, it was difficult to make a decision about which beach to protect or to evacuate, and which port of refuge should be chosen. On May 30th 2002, the European Parliament made a recommendation aimed to European members to start the inventory of the littoral, and to carry out an integrated coastal management. On April 29th 2003, the French National Council for Geographic Information (Conseil National d'Information Géographique: CNIG) and the Interdepartmental Sea Committee (Comité Interministeriel de la MER: CIMER) recommended that SHOM and IGN prepare this inventory, with a goal to achieve an altimetric continuous model for metropolitan coast and over seas French subdivisions. Using this model, all the different thematic layers will be based on and will constitute what is called RGL (Littoral Geographic Reference).

Preliminaries

During a preliminary study in Marsh 2003, SHOM and IGN evaluated the different issues to solve before getting a seamless database with continuous relief between water and land. In addition to the previous observations (§2), it appears that there is no difficulty to merge information since SHOM and IGN data can in most cases share the same geodetic reference level. Also, there are known correspondences between sea chart datum (LAT) and land datum.

These first results were reported to CIMER September 14th 2004. Within their present responsibilities, SHOM and IGN have all the necessary skills to contribute to this project, including bathymetric, geodetic and cartographic expertise. Notably, a French tide model has been implemented with a precision compatible with Litto$_{3}$D$^{®}$ requirements. An initial stage was to promote and to provide existing digital information through a new product called Histolitt (2006). Thus, a part of littoral requirements will be rapidly satisfied. Since a commercial policy is not yet defined as to who these data belong to (SHOM, IGN and others organizations) future agreements must be found before to make these data available to everybody.

Demonstrator in The 'Golfe du Morbihan'

Working together, SHOM and IGN must show that it is possible to achieve a continuous altimetric model in a small area, combining different, old and new acquisition means.

Thus, a laser airborne system was chosen since it provides an accurate, rapid, safe and cost effective method of surveying coastal areas. This system has been used by governments and commercial organisations over the last decade to conduct surveys for nautical charting, coastal zone management. It seems particularly suited to fill the gap between former sea charts and Litto$_{3}$D$^{®}$ (Figure 3 – cross-section).

Key objectives of the laser demonstrator are to:
- Know the performances and the limits of airborne laser survey,
- Compare and to merge MBES (multi-beam echo sounder) and laser data,
- Comply with the highest hydrographic and cartographic standards,
- Lay down standards to Litto3D$^{®}$ partners: data acquisition methods and qualification rules.

The Golfe du Morbihan offers a wide variety of relief and thematic. It is a good location for a demonstrator as it concentrates all difficulties: 0-50m depths, turbidity, currents, wide inter-tidal area, flat sandy beaches, and rocky coastlines are most representatives of the French littoral. This is also a highly used area for boating in the summer, and there is a need for SHOM to improve the types of nautical charting products. This survey took place in summer 2005.

Survey objectives

For the survey of the Gulf, each depth individually fulfils the S-44 order 1 requirements (absolute accuracy: vertical = 50cm and horizontal = 5m) and the area was incompletely surveyed, as shallow waters were not exhaustively detected. Spatial resolution is 1 measure every 4x4m laser spot spacing and there is 20% of overlapping between tracks. Data were processed in batch mode. The survey team was committed to survey the entire area (i.e., full coverage). But due to turbidity and hazardous meteorological conditions, the team had to do a best effort (Not full data).

Survey equipment

A bathymetric laser (SHOALS 1000-T) was mounted on a twin-engine aircraft (CESSNA 404) (Figure 4). This laser works with a near infrared (1064nm) and a green (532nm) light. There are two distinct working modes:

- Hydrographic and topographic mode at 1kHz frequency,
- Topographic mode at 10 kHz frequency.

The aircraft position was determined using three methods:

- Real time DGPS: For navigation and data pre-processing, OMNISTAR differential corrections were used. In case of lose of signal, inertial central data was also recorded.
- Batch stage KGPS: For data post-processing, both raw GPS data and inertial central data were computed in L1/L2 mode to get a Kinematic GPS location.
- Real time GPS-RTK: Ground stations provided differential corrections through GSM antenna. This third way is too dangerous for real-time navigation as there are some risks (data communications losses) but it was used for post-processing and quality insurance.

Figure 4: Aircraft and inside racks.

Survey strategy

While many strategies were explored, few of them are optimal. In water, tide and turbidity influence laser water penetration. On land, it depends on the height of the tide. In all cases weather is a key factor. This includes high-pressure condition, no rain, and light wind (<15 knots). The best weather period seemed to be summer, although July and August have to be avoided since there is considerable boating activity in the Gulf.

There were already MBES surveys in navigation channels, the deepest waters of the Gulf. So the strategy was to cover the unsurveyed areas rather than to penetrate deep water again: topographic laser mode in low water and bathymetric laser mode in high water at springs.

Turbidity is the conjunction of 3 factors: chlorophyll content, organic materials content and suspended sediments in water. The best period for chlorophyll and organic materials are summer and winter. The optimal period for sediments is the less turbulent current periods (e.g., slacks at neaps).

The general strategy was:

- Bathymetric surveys stood during slacks of high water at springs. Turbidity is not optimal but rather good at slacks. Deep depths cannot be reached, but there are some MBES surveys to fill in these gaps.
- Topographic surveys stood during slacks of low water.
- Flights took place nights and days in order to get best laser measure (i.e., no sun interferences), and not to waste slacks.

Flight tactic

Flight tracks were oriented perpendicular to tide propagation into the Gulf and followed the slacks. There is a tidal model of the Gulf with 143 tide harmonics every 200m. It was used to get predicted tide information all along tracks, and to follow the tide with the aircraft in real time (Figure 5).

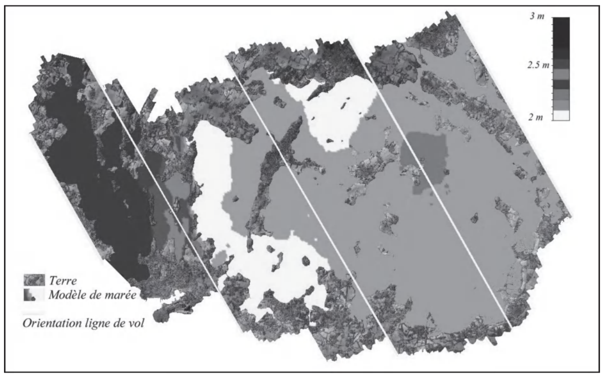


Figure 5: Evolution of tide height along flight tracks (heights in metres).

As a hydrographical rule, 10% tracks were perpendicular to regular survey tracks to permit error detection and S-44 qualification.

Quality insurance

Laser calibration (static and on the fly), GPS (Ground Control Point and levelling) and tide monitoring (SHOM) were carried out all along the survey.

Everyday, environmental information, geometric calibration measures and laser data were downloaded to a ground control system (GCS). GCS involves a signal processor to discriminate sea or land surface and sea bottom from the different signals. It contains automatic algorithms that calculate the exact location of laser signal from GPS and inertial central attitude data: X, Y, Z and a confidence interval is given for each measure. Doubtful signals are underlined and submitted to human control (Figure 6). Some video camera information was helpful to eliminate some artefacts in signals (e.g., birds, boats, shore breaking).

At the end of the process, data was converted into XYZ format and related to RGF93 datum. The same tide model used before for flight plan was reused in order to reduce laser data into depths. For the first stage, depths were relative to lowest astronomical tides (LAT), then to chart datum (CD) and at the end to land survey datum (IGN69). Tide model makes this possible as it contains differences models between all these vertical references (Figure 6).

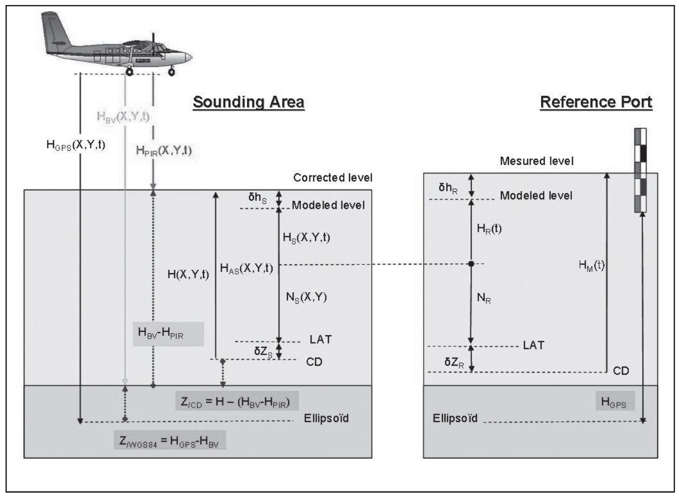


Figure 6: Propagation of tide observations at depth sounding area throughout model application

Laser data were compared to land surveys (e.g., laser and GPS levelling) and MBES surveys. Data were merged in accordance with the different accuracy and uncertainty of these different surveys. Many methods could be applied: GIS methods or geostatistical criteria (CUBE algorithms for instance).

Products

First of all, if some hazards to navigation were found out during the laser survey, they were automatically reported to SHOM and issued as Notice to Mariners.

The results acquired within this demonstrator allow SHOM and IGN to have a good idea of the feasibility, the costs and the real interest of laser. Results should be extrapolated quite easily to other metropolitan parts, within Litto$_3$D® project.
Validated data will be stored in SHOM and IGN databases for general public use. Most likely, the first customer of these data will be the different littoral agents of the Golfe du Morbihan and SHOM cartographers. As early as these basic products will be distributed, many modern and accurate by-products could be produced (Figure 7).

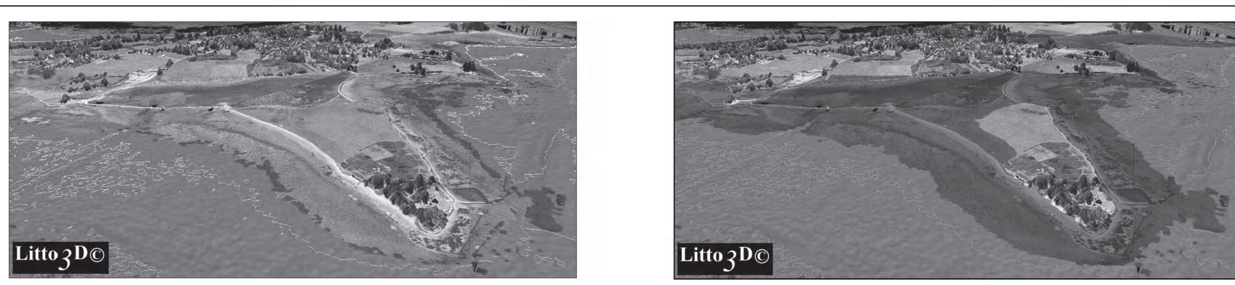


Figure 7: Golfe du Morbihan

Some Experiences

Should we fly at high or low tide?

One of the main issues with the bathymetric laser is the very shallow water. The measure of depths between 0 to 1m is problematical due to the difficulties to distinguish the surface from the bottom of the sea. We had to find a strategy to avoid this blind area. So we decided to organize two flights: one in the topographic mode and the other in the bathymetric mode. The purpose was not to have the very deep bottom but to have a seamless digital model between the land and the sea, with many overlapping areas. We organised two flights: bathymetric laser at high tide and topographic laser at low tide. This strategy has the advantage of having a high precision on the intertidal area.

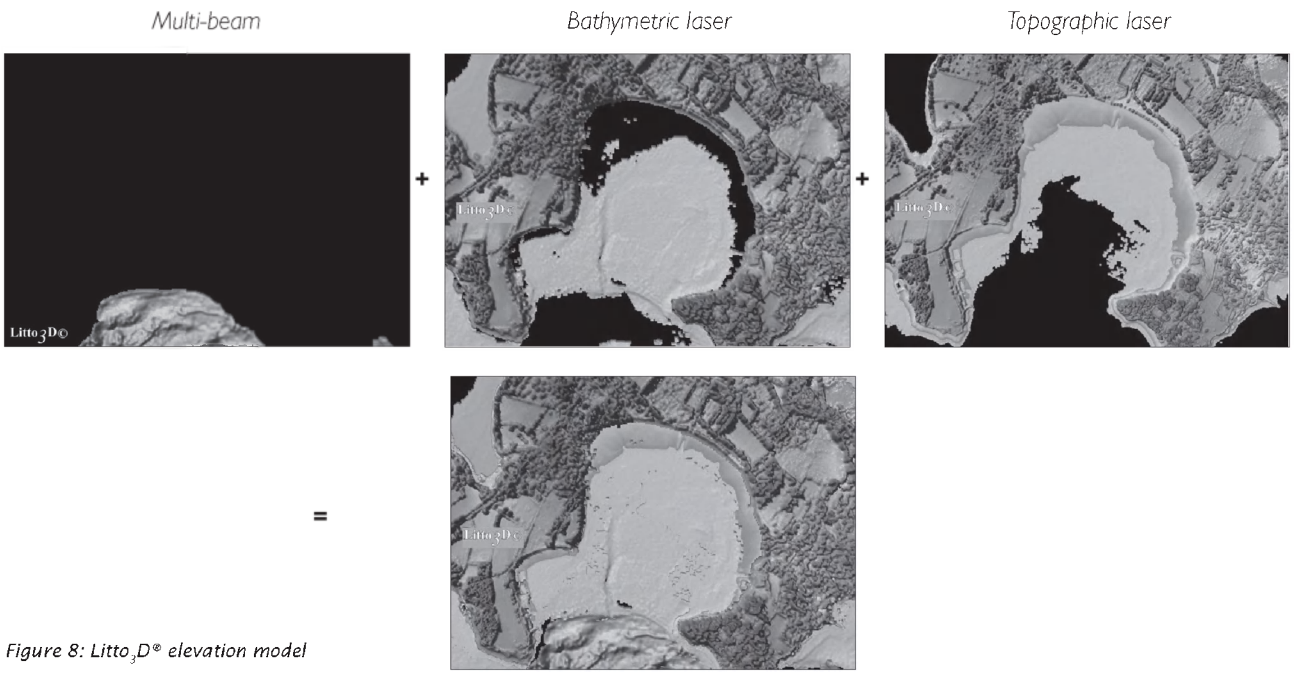
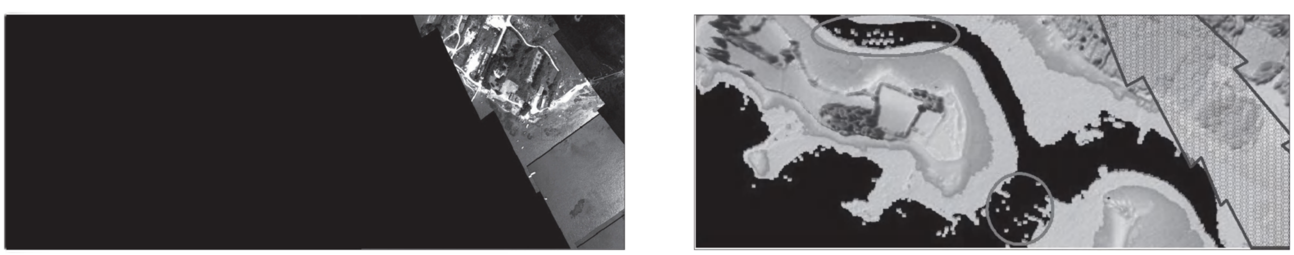


Figure 8: Litto$_3$D® elevation model

Should the multi-beam survey be done before or after the bathymetric laser survey?
In the Golfe du Morbihan we first conducted a multi-beam survey to have a flat area well described to be used as depth check (benchmark). But in hindsight, it seems that it could have been better to do the multi-beam survey **after** the bathymetric laser survey. At the end of the bathymetric laser survey, some areas were not detected (i.e., too deep, too turbid, boats, etc.). Thus, the strategy would have been better to conduct first the multi-beam survey of the calibration areas, then the bathymetric laser survey and at last the multi-beam survey of the areas not covered by the laser. Besides, it will be more efficient for the Hydrographer: the dangerous areas will be known for the ship survey as the shallow water limits will be well delimited. In this manner, you have the capability to survey the entire area with fewer risks.



Photos (by day), No photo (by night)

In the circle, spots to be accepted or rejected

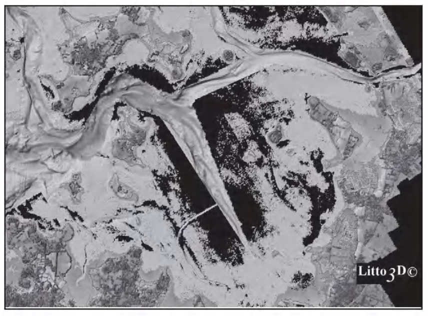
Figure 9: The utility of photos to validate data.

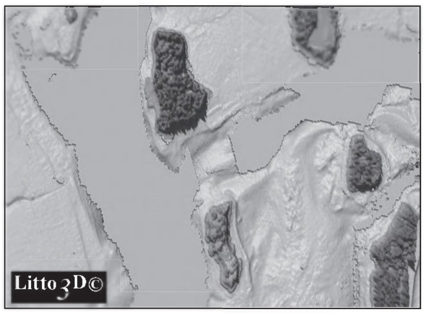
Should we fly by day or by night?
In the Golfe du Morbihan, the flights were conducted during both day and nighttimes. This gave us more time to do the survey and when the weather was fine, we could advance the survey very quickly. Although it is well known that laser performs best during the night, the cost is high due to the necessity to have two teams. Besides, when you are flying during the night, you have no photo of the ground. Consequently, it is difficult to choose the valid data and to reject the errors or the artificial objects such as boats, especially in the Golfe du Morbihan where there are a lot of anchored boats (more than 6000).

What about the turbidity?
The water in the Golfe du Morbihan is very turbid. Since a lot of areas are very shallow, tide, the river interferences, and human activities increase the turbidity. As such, the timing of the survey is very important. It is better not to work at spring tide. The turbidity increases considerably after bad weather (e.g., due to rain showers and wind). It is also essential to communicate with

the sea users. During the survey in the Golfe du Morbihan, the fishermen obtained permission to drag the clams; then it was impossible to find the bottom of the sea in this area. We have communicated our program to the official administrations but we did not contact the fishermen' associations. Next time we will explain to everyone the purpose of the survey.

Turbidity due to drag of clams





Less turbidity some days after

Figure 10: turbidity means no data.

Conclusion

The survey of the Golfe du Morbihan demonstrates the capability of bathymetric laser survey to improve the knowledge of the littoral. It also provides a means to accelerate the cartographic process, in addition to MBES surveys. With a combination of multi-beam, bathymetric and topographic laser, it is possible to generate a seamless sea/land coastal digital model. A recommendation has been written and will be useful for people who want to realise such a survey. This experiment enabled SHOM and IGN to develop a methodology applicable everywhere and by everyone.

Source: http://www.shom.fr/fr_page/en_act_litto3D/index_litto3D_f.htm

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Shallow – Shallower – Shallowest

Morphological Monitoring Walsoorden

Erwin Leys, Yves Plancke and Stefaan Ides

In 2001, an expert team appointed by the Antwerp Port Authority proposed a new strategy for disposing dredged material, as part of a strategy for managing the morphology of the Western Scheldt estuary. Extensive research carried out by Flanders Hydraulics Research – including physical scale-modelling, numerical simulations and field measurements – indicated that the proposed strategy would likely be successful. The final step to investigate the feasibility was the execution of a full-scale in situ test in view of modifying the shape of the 'Walsoorden' shoal. This paper describes the morphological monitoring program in detail. As far as known, the extreme project specifications were never realised before.

Introduction

The Scheldt estuary is the maritime access to several ports in Flanders and the Netherlands, the largest being the Port of Antwerp, located at some 100 km from the open sea. Until 1970, the navigation route required limited (< 5 million m³) dredging on the sills. During the 1970's a first deepening campaign was executed, resulting in higher (~ 10 million m³) maintenance dredging works. In 1998-1999 a second deepening was executed, resulting in a tide-independent draught of 38'.

Flanders and the Netherlands agreed in 1999 to cooperate closer for managing the Scheldt estuary and to set up a "Long Term Vision" (LTV), with attention for safety against flooding, accessibility of the ports and nature. One of the main objectives of LTV is the preservation of the dynamic and complex flood and ebb channel system in the Western Scheldt, the middle reach of the estuary.

An expert team appointed by the Antwerp Port Authority came to the conclusion that the morphological evolution results from both the natural changes (adaptation of the coastal morphology as a result of the Holocene sea-level rise) and human interfering in the natural evolution (land reclamation and "poldering", dredging and other river works). They proposed the idea of morphological management, aiming at steering the estuarine morphology in order to preserve the multi-channel system in the Western Scheldt. The proposed management strategy includes morphological dredging and disposal, modifications (removal, adaptation, construction) of the hard bordering to modify the erosion-transport-deposition processes.

To illustrate the management strategy, the Port of Antwerp Expert Team (PAET) proposed, as a pilot project, to dispose dredged material near the shoal of Walsoorden. The seaward tip of this shoal has been eroded during the last decades. Dredging works would be used to reshape this eroded sandbar, so that the flood and ebb flows would continue to maintain the multiple channels. Besides making the estuary ecologically and morphologically healthier, the reshaping of the sandbar would also improve the self-erosive capacity of the flow on the crossing and possibly reduce the quantity of material to be dredged. A diffuser-type device would be used to disperse the dredged material in a controlled way in shallow water along the sandbar edges.

In 2002-2003, the feasibility of this pilot project has been investigated by Flanders Hydraulics Research (Flemish Government). The research programme combined three tools: field measurements, physical scale models and 3D numerical models. The results of the research work confirmed the feasibility of the idea. However it was concluded that a real life (in-situ) disposal test was required to give final prove of the feasibility of this new dumping strategy.

At the end of 2004, 500.000 m³ of sand was disposed at the seaward tip of the shoal of Walsoorden using a diffuser. The main idea was to modify the morphology of this sandbar by disposing dredged material very precisely. The amount of 500.000 m³ was chosen because it is large enough to see an effect of the disposed sediment, while it is small enough to be reversible if something would go wrong. To evaluate the success of this in-situ test, Flanders Hydraulics Research set up an extensive monitoring programme, including bathymetric surveys (morphological monitoring), ecological monitoring, sediment tracing tests and sediment transport measurements.

This paper describes the morphological monitoring program in detail. As far as known, the extreme project specifications were never realised before. In order to meet the required specifications, EUROSENSE used the most recent survey equipment and software which was available on the market and used a small but fast survey vessel.

Project Specifications

- Multibeam surveys had to be performed up to a level of 1,0 meter NAP (equal to + 3 meter above low water).
- In addition to the very shallow water depths, an area (called "Area B") of approximately 11 km² had to be surveyed within a time limit of one working day. Once a month a larger area (called "Area A") of approximately 47 km² had to be covered.
- EUROSENSE had to determine how much of disposed dredged material remained in the disposal area; how much material moved and in which direction. Furthermore, the influences of the disposed dredged material on the bottom patterns and their movements had to be visualized.

Survey Equipment

In order to meet the required specifications; a survey system had to be chosen which was able to measure accurately and in detail the bed-forms. Since the river Scheldt is fully covered with LRK-GPS base stations (owned by the Belgian and Dutch authorities) the choice of a positioning system was simple. LRK-GPS gives an accuracy of centimetres in x,y and z. Therefore no tide gauges had to be installed. In order to get a high density of depth values, the SIMRAD EM3002 Dual Head was used. This system is able to measure up to 508 depths per ping and this at 40 pings per second. So, a maximum of 20.000 depths per second could be measured. In consultation with SIMRAD BV, a "MRU-5" motion sensor, combined with a "Seapath 20" heading sensor, was chosen for attitude measurements. However, soon after the first measurements, it was noticed that the "Seapath 20" did not meet the specified accuracies, especially not on a small survey vessel like "EB2". Therefore, the "Seapath 20" was replaced by the "Seapath 200" heading sensor. For the data acquisition and processing of all data coming from the various sensors, the "Qinsy software" was used.

Survey Planning

As mentioned above, "Area B" had to be surveyed within one working day. Within this area, 1,5 km² was located above low water level and also had to be fully covered with multibeam measurements. Being on the right place at the right time was crucial and therefore keeping track of the local tide was essential. Survey tracks on the shallowest parts of the Walsoorden shoal had to be planned very accurately. Also these tracks were surveyed at a speed exceeding 12 knots. As a result of high speed surveys in very shallow water, the vessel was stranded twice during the first month; resulting in damaged transducer heads, which had to be replaced.

Monitoring Results- Disposed Dredged Material

To visualize bed-forms, a common bathymetric depth chart showing depth values and contour lines was not usable. Bathymetric data had to be visualised in a different way. Therefore EUROSENSE used "sun illuminated" shaded views and coloured maps. By using this technique, bottom structures and patterns became visible. Figure 4, shows a "sun illuminated" shaded view, where riverbed structures are clearly visible. The red polygon on this figure shows the dumping area, where dredged material was disposed.

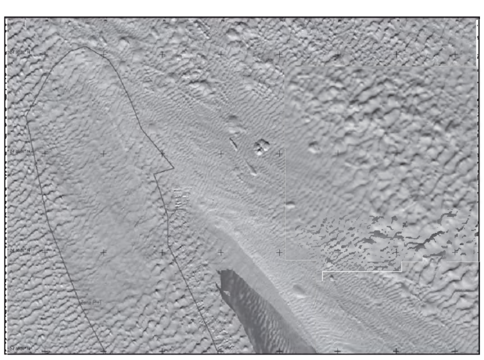

Figure 4: Sun illuminated shaded view.

The first survey was executed on November 2nd 2004. At this time, no material was dumped yet in the forseen disposal zone (within the red polygon). Soon after the completion of this survey, disposal activities started. Once a week the same area was surveyed in order to monitor the changes in morphology. At a very early stage, it was noticed that the bottom structure had completely changed. Due to the use of a diffuser (to dispose the dredged material) sand ripples disappeared and were replaced by a relative flat surface. On 'figure 5', one can clearly see the changes in bottom structure. The colours are indicating the depth. Red indicates the very shallow part of

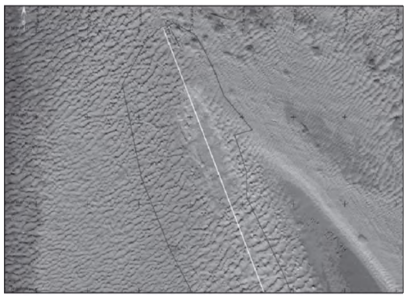

Figure 5 Changes in bottom structure.

the tip of the Walsoorden shoal and blue represents the deeper area. At this stage only 125.000 m³ of dredged material[1] was disposed.

Figure 6, shows a longitudinal section of the same disposal area.

The vertical and horizontal scales are indicated in meters. The black line indicates the original bottom structure. Sand ripples are still visible. The red line shows the profile after disposing 125.000 m³ of dredged material. The sand was disposed up to a level of NAP[2] –5 meter or +2,0 meter below low water. The time difference between the two surveys was 10 days.

The dumping of dredged material continued for three weeks. On December 22nd 2004, the out survey was executed. On "figure 7", one can see the total amount of disposed dredged material. Within a timeframe of one year (after the disposal activities), 20 surveys were executed. Figure 8 shows the result of the survey of the December 13th 2005.

It is visible that the natural dynamics restored the bottom structure. Sand ripples became visible again and the relative flat bottom structure, created by disposal activities, disappeared. Also, it became clear that the disposed dredged material was moved towards the tip of the Walsoorden shoal. This is also visible on the next longitudinal profiles (figure 9 and 10). Again, the black line indicates the original bottom structure. The blue line shows the results of the surveys of the December 13th 2005.

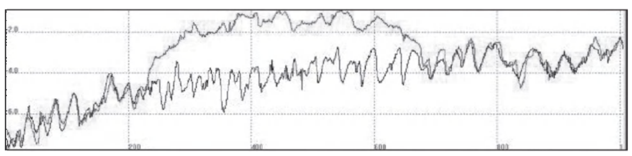

Figure 6: longitudinal section.

As part of the project specification, the amount of dredged material, which remained in the disposal area, had to be defined. Therefore volume calculations were carried out. It was noticed that only 425.123 m³ was found, instead of the 500.000 m³ measured in the hopper dredgers. This is mainly due to the difference in density of the dredged material in situ compared to the density in the hopper dredger. During the first two months, after the end of the disposal activities, the volume of sand in the disposal area increased. This is probably due to natural sand movements. However, the bottom structure gradually started to change and the amount of disposed material decreased. As already previous shown, a movement of sand towards the tip of the shoal was noticed. The volume calculations also indicated this movement. The amount of sand, which was lost in the disposal area, was moved towards the shoal.

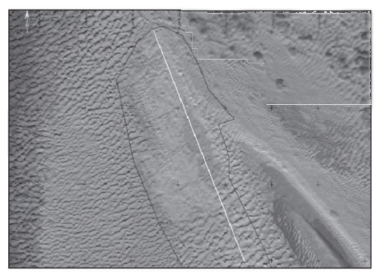

Figure 7: December 22nd 2004.

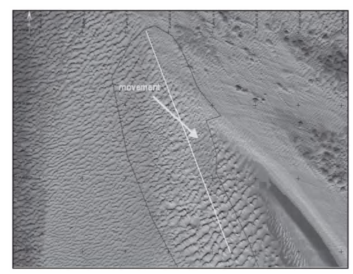

Figure 8: December 13th 2005.

The Detection Of Bottom Pattern Movements

During the course of the monitoring programme, it became clear that the river Scheldt has a very dynamic bottom structure. By making differential charts, the movements of sand ripples and sand dunes became visible. Yellow, indicates the areas were no changes in height were found. Red indicates a decrease in height and green an increase in height. Several changes can be seen. The green lines indicate old dredging tracks, which are filled-up again. The red-green pattern shows the movement of sand dunes. When a longitudinal profile is drawn over this pattern, the movement of these sand dunes

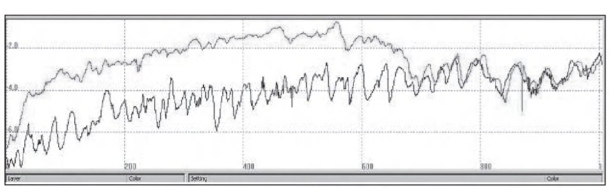

Figure 9: Longitudinal profile December 22nd 2004.

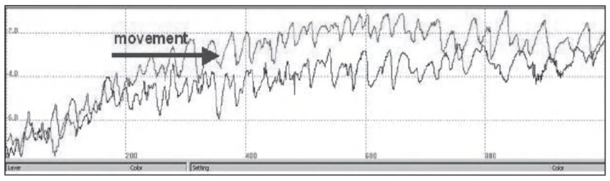

Figure 10: Longitudinal profile December 13th 2005.

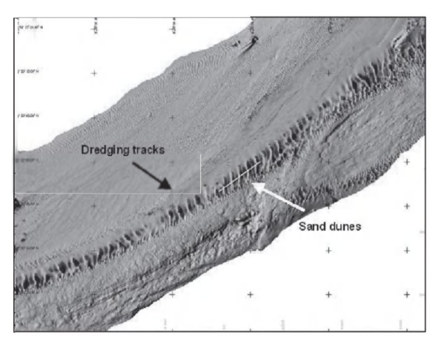

Figure 11: Bottom patterns.

1 Dredged material with a media grain size of ± 210μ.

2 NAP: Reference level in The Netherlands (± 2 meter above low water level).

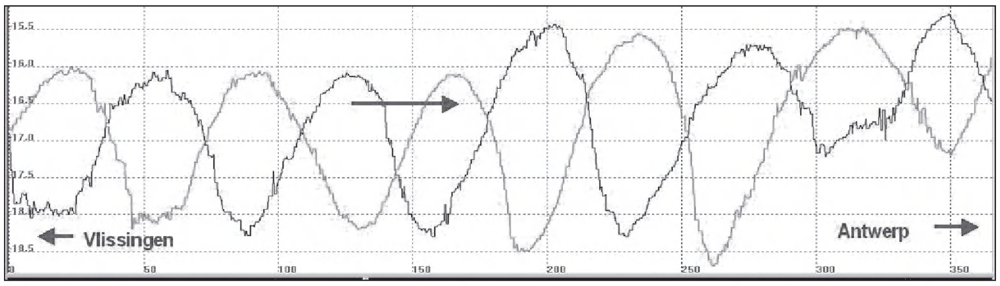

Figure 12: Bottom pattern movements.

becomes visible.
The red line is the result of the first surveys. The green line shows the second survey. The time difference between these two surveys is one month. From these profiles, we can learn that, in this part of the river Scheldt, sand dunes can be found with a height of 3 meters. The width at the bottom of these sand dunes is approximately 70 meters. The speed at which these sand dunes travel is 30 meters per month or 1 meter per day. Also, we notice that the sand dunes in this part of the river move up-stream towards Antwerp.

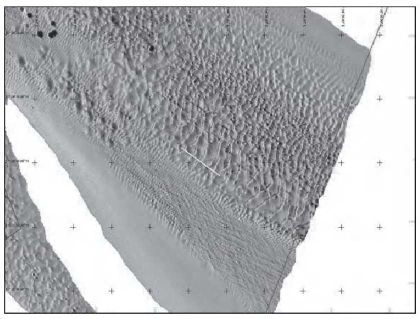

Figure 13: Bottom pattern.

When looking at other parts of "Area A", different patterns, sand ripples and sand dunes are identified. To show the differences in patterns, a profile was taken on the east side of the tip of the Walsoorden shoal.
Three successive surveys, with a time interval of one week, are shown below. First of all, we notice that the shape of the sand dunes is different, than those shown above. Furthermore, the height is approximately 1,5 meter and the width is 45 meter at the bottom. Also the travelling speed is only 3 meters per week.

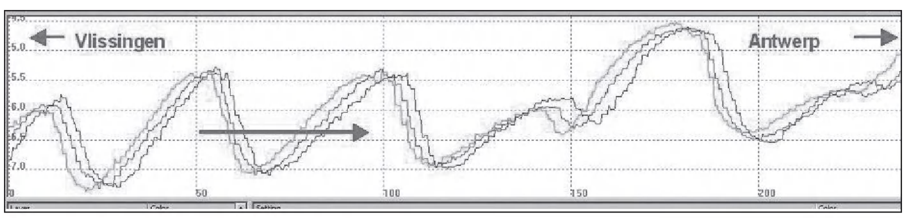

Figure 14: Bottom pattern movements.

Conclusions

EUROSENSE fully complied with the project specifications. Multibeam surveys were executed up to a level of 3 meters above low water level and an area of approximately 11 km² was always surveyed within one day. Furthermore, EUROSENSE determined how much disposed dredged material remained in the dumping area and in which direction this material moved. The influences of the disposed dredged material on the bottom patterns and their movements were visualized.
EUROSENSE also showed the benefits of using multibeam systems in very shallow waters. These benefits became clear during the execution of the morphological programme. As shown, it is now possible to determine the dimensions of sand ripples and sand dunes. Also the movements and the speed at which these sand dunes travel can be determined. However, it is important that time intervals between two successive surveys remains minimal in order to follow the changes of the sand dunes.
Since the end of the monitoring programme (2004-2005), another 500.000 m³ of dredged material was dumped on the tip of the Walsoorden shoal (January 2006). At this moment EUROSENSE is executing the continuation of the morphological monitoring programme. However, the "long term" impact of dredging works, which were used to reshape this eroded sandbar of the Walsoorden shoal is not clear yet. The continuation of the disposal experiment and the morphological programme will probably show this impact (if any).

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Improving Multi-Beam Echo Sounder Depth Measurements

Mirjam Snellen, Jeroen J.P. van den Ameele, Rebecca Biersteker and Dick G. Simons

An important research question is how to adequately correct multi-beam echo sounder (MBES) bathymetric data for refraction effects. This is especially relevant for survey areas, like the Maasgeul area off the Dutch coast, where the water column properties and thus the prevailing sound speed profile (SSP), are highly dynamic. Expensive, and therefore not widely applied, towed systems are available for performing SSP measurements continuously. Other options provide sparse SSP measurements only. Consequently, in practice, correcting for refraction is hampered due to insufficient knowledge of the prevailing SSP at the time of the MBES measurement. We present a new approach to correct for refraction. This approach requires and fully exploits the possibility of the MBES to survey adjacent swathes with overlap. Due to variations in the prevailing SSP and sparse SSP measurements, depths determined at overlapping points will in general differ. Here, a Monte Carlo search is used to find SSPs that minimize these depth differences. To this extent the SSP is parameterized according to a set of basis functions determined from historical SSP data from the survey area.

Introduction

Multi-beam echo sounder (MBES) systems are nowadays widely used for conducting bathymetric surveys. They allow for efficient surveying of large areas and offer the possibility of complete bottom coverage. With each ping, water depth measurements are carried out along a wide swathe perpendicular to the ship's heading. Due to the water sound speed varying with depth, the sound emitted in the oblique directions is subject to refraction. In order to correctly convert the travel time measurements to water depths, these refraction effects need to be accounted for.

In practice, refraction correction is hampered by insufficient knowledge about the sound speed profile (SSP) due to the availability of a limited amount of SSP measurements only. In principle, (towed) systems are available for performing SSP measurements continuously, thereby providing sufficient information. These systems, though, are not widely applied and often use is made of a conductivity-temperature-depth (CTD) device. When performing such a CTD measurement the ship needs to be stationary, making it a time-consuming process. As a consequence of this, in practice only a limited amount of SSPs is measured during a survey. While this is expected to play a minor role in environments that show little variation, it is expected to have large effects on the water depth measurements in highly dynamic environments. One such a highly dynamic environment is the Maasgeul off the Dutch coast at the port of Rotterdam, where the varying presence of salt and fresh water results in large variations in the SSP, both spatially and temporally.

It is standard practice to carry out MBES surveys with (at least a small) overlap between adjacent swathes. For a typical MBES survey the time between measuring two overlapping swathes amounts to several hours. Since bottom features only vary considerably on time scales of several days or weeks, we can expect the water depths as measured along two overlapping swathes to be the same at equal points on the seafloor (after applying the tide correction). However, for dynamic environments the measured water depths at equal points in the overlapping parts of the swathes will in general not be the same. A cause for this deviation often lies in the use of an SSP for the two-way travel times to water depth conversion that differs from the prevailing SSP at the MBES measurement epoch.

This paper is organized as follows. In section 2 a description of the Maasgeul MBES dataset is presented together with the Maasgeul SSP dataset. In section 3 an approach aimed at reducing the SSP induced bathymetry errors is introduced. In section 4 the results of applying this approach to the Maasgeul MBES dataset are presented. Section 5 considers the effect of a second error source, being the use of a wrong sound speed value in the MBES beamsteering. The paper is concluded in section 6.

The Maasgeul Environment

Since the Maasgeul is an important shipping lane, MBES bathymetric surveys are carried out regularly. With these surveys, it is current practice to have a significant overlap (~50 %) between adjacent swathes as illustrated in Fig. 1a.

Fig. 1b shows an example from the Maasgeul MBES dataset of measured water depths along eight of these partly overlapping swathes. For converting the measured two-way travel times to the water depths of Fig. 1b use was made of the best available information regarding the SSP, consisting of a single SSP only.

As mentioned, the bottom features can be assumed to remain unchanged for the time of surveying two overlapping swathes and one would expect the measured water depths at equal points on the seafloor to be the same (after applying the tide correction). In contrast to this, Fig. 1b shows significant differences in the water depths measured along the overlapping swathes, with differences sometimes exceeding 0.5 meter. This behavior is presumed to be caused by a mismatch between the SSP used for converting the two-way travel times to water depths and the prevailing SSP at the MBES measurements epoch considered here.

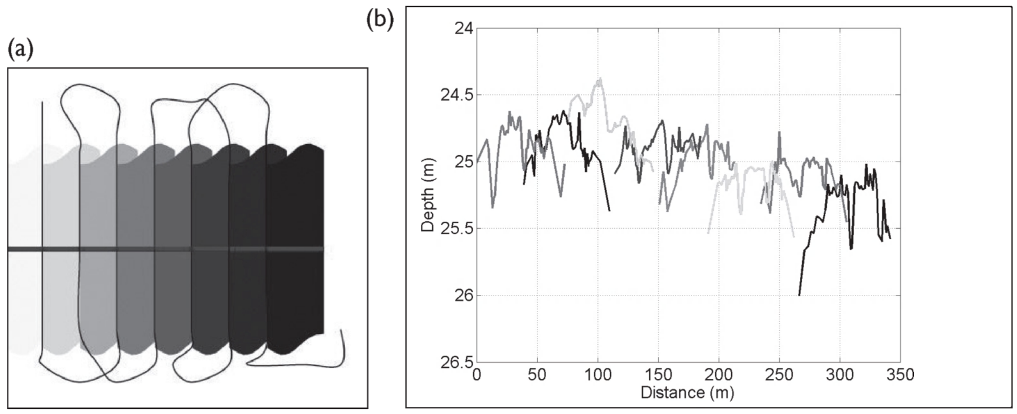

Figure 1: (a) An example of partly overlapping swathes (each in a different gray shade). The twisting solid line indicates the ship track. (b) Depth measurements as acquired along the horizontal line of the left plot.

In February of 2004, over the course of one day, a set of 83 SSP measurements was taken at a fixed location in the mouth of the river Maas. Here, we assume that this dataset is able to represent the total spatiotemporal variability of the SSPs occurring in the Maasgeul area. The consequences of this assumption are addressed in section 4.

A Method For Reducing SSP-Induced Bathymetric Errors

Contrary to many of the existing post-processing methods used to obtain a consistent estimate of the water depth from the results as depicted in Figure 1b, the method proposed here works on the measured travel times and not on the derived depth estimates. The method requires and fully exploits the availability of the redundancy in the measurements due to the overlap of two adjacent swathes. The steps taken are as follows:

- Assume new SSPs, one for each swathe. The SSPs are modeled according to a certain parameterization;
- Determine (using Snell's law) updated water depths along the swathes from the measured travel times and the assumed new SSPs;
- Determine the differences between the updated water depths along overlapping parts of adjoining swathes. A cost function is introduced for quantifying these differences.

This three-step process is repeated until the cost function is minimal. For illustration purposes we here present this approach using three swathes only. However, the approach can be extended to the complete measurement area.
In the following we consider the different steps in more detail.

Parameterization of the sound speed profile

A straightforward SSP parameterization consists of a sound speed at, for example, every meter of water depth. For a water depth of 25 meters, however, this would result in 25 parameters for describing the SSP. This implies a search for 25 unknowns per SSP when minimizing the cost function. In order to limit this number of parameters, we have considered a parameterization based on empirical orthogonal functions (EOFs). The EOFs are determined from the SSP dataset, i.e., they are the eigenvectors of the covariance matrix of the SSP dataset. The relative magnitude of each eigenvalue represents the fraction of the total variance in the dataset represented by its particular EOF.

	λ_1	λ_2	λ_3
eigenvalue	157.97	7.67	3.18
% of total variance	93.4%	4.5%	1.9%

Table 1: The first three eigenvalues, λ_i, i = 1, 2, 3, of the SSP covariance matrix and the percentage of the dataset's total variance represented by their respective EOFs.

In Table 1 the first three eigenvalues are listed together with the percentage of the total variance that is represented by their respective eigenvectors. From the table is seen that the first three EOFs together turn out to account for 99.8% of the total variance in the Maasgeul SSP dataset and are therefore deemed sufficient to represent the total SSP variability. With the EOFs denoted by v_1, v_2 and v_3 respectively, the mean SSP of the Maasgeul SSP dataset denoted by u and the depth denoted by z, the SSP is parameterized according to

$$c(z) = u(z) + a_1 v_1(z) + a_2 v_2(z) + a_3 v_3(z) \tag{1}$$

with a_1, a_2 and a_3 the EOF weight coefficients. These weight coefficients are determined by minimizing the cost function. The three EOFs and the dataset's mean SSP are plotted in Fig. 2.

Since the different swathes were measured at different times we can not assume one SSP to be valid for all three swathes. Therefore a different SSP is assumed for each of the three different swathes. This results in 9 unknown parameters for the parameterization according to eq. (1).

The cost function and its minimization

To quantify the differences in water depths along adjacent overlapping swathes, as seen in Figure 1b, a cost function is defined. This cost function is taken as the sum of the depth differences squared. As mentioned, we will apply our method using three swathes only, see Fig. 3a solid lines, but this number can easily be extended. In Fig. 3a, also the part of the data used in determining the value of the cost function is indicated.

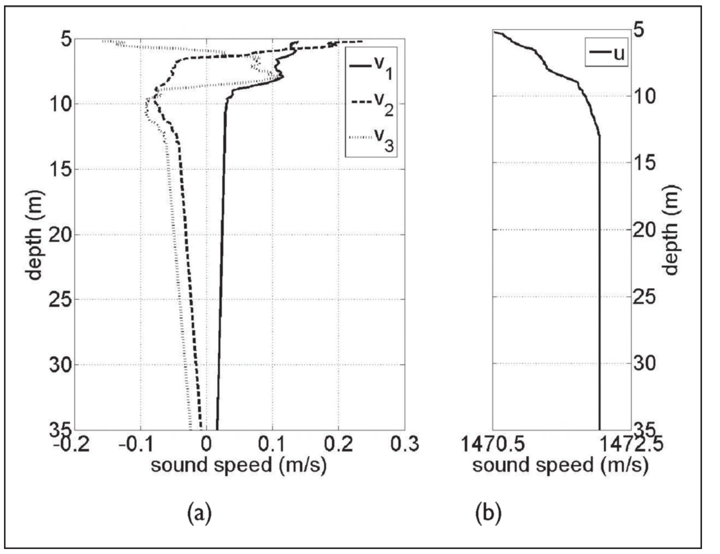

Figure 2: (a) The first three EOFs. (b) The mean SSP of the Maasgeul SSP measurement dataset.

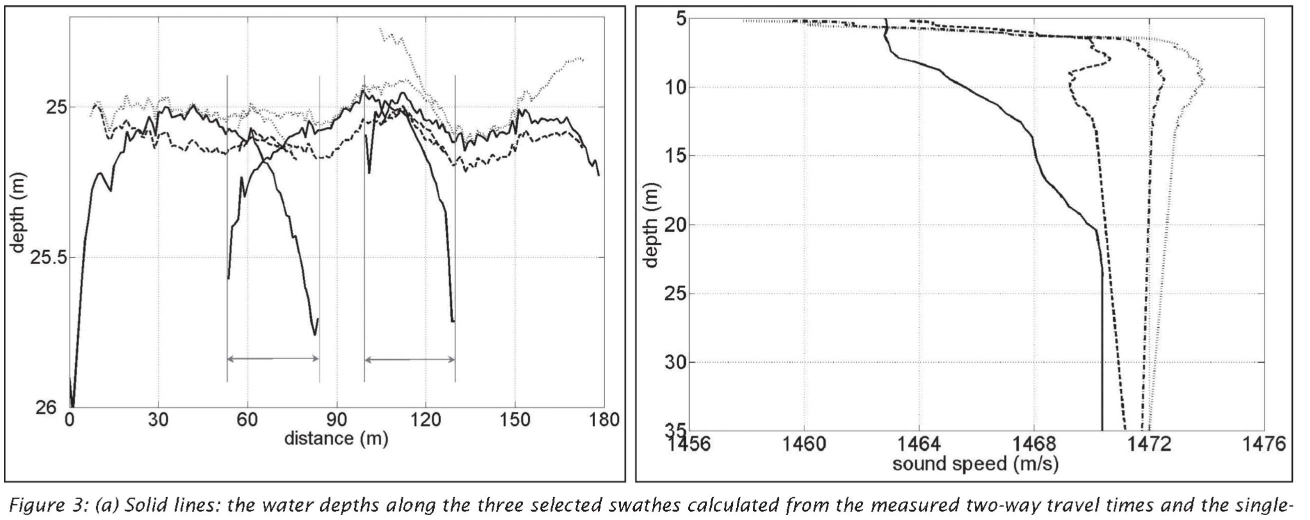

Figure 3: (a) Solid lines: the water depths along the three selected swathes calculated from the measured two-way travel times and the single-measured SSP. Dashed lines: the optimized water depths averaged over the 12 solutions. Dotted lines: the water depths calculated from the measured two-way travel times and single SSP but now with updated MBES departure angles according to a sound speed value at transducer depth of c_T = 1456m/s. The vertical grey lines indicate the parts used for calculating the value of the cost function. (b) Solid line: the measured SSP that was used in determining the original water depths from the measured two-way travel times. Dashed, dashed-dotted and dotted lines: the optimized SSPs for respectively the right, the middle and the left swathe, averaged over the 12 solutions.

The remaining step is to find updated SSPs, such that the differences in water depths are minimized. Or in other words, we need to search for those SSPs for which the cost function becomes minimal. We have employed the method of differential evolution ([1]), being a variant of the genetic algorithm ([2],[3],[4]), which is a nowadays relatively standard global search method for inverse problems. To further pin down the result of the global search we also employ the method of downhill simplex (DHS). Here the DHS algorithm as described by Nelder ([5]) is used.

In general, the above optimization methods are problem specific. A detailed investigation of the performance of the optimization methods for use in this type of underwater acoustic inversion problems in relation to the algorithm setting parameters and the derived optimal setting parameter values can be found in [6].

Application Of The Method To The Maasgeul Data

The method described in the previous section employs a Monte Carlo search, which implies a statistical behavior of the solution. Hence, in general, carrying out multiple independent optimization runs yields different solutions that are close to but different from the global optimum. It is therefore important to assess the precision of the method by comparing multiple independent solutions.

For the three selected swathes from the Maasgeul MBES dataset, 12 independent optimization runs have been carried out. The resulting water depths averaged over the 12 solutions along the three selected swathes are shown in Fig. 3a (dashed lines). From an analysis of the 12 solutions it can be concluded that the differences between the estimated water depths resulting from independent runs of the optimization procedure are below the precision level (~5cm) of the MBES system. In general it is clear that a considerable increase in agreement is obtained between the overlapping parts of the swathes. Also, the 'droopy'-like behavior, with water depths going down at the outer edges of the swathes, as visible in the original data, is no longer present. In Fig. 3b the resulting optimized SSPs averaged over the 12 solutions are shown as dashed, dashed-dotted and dotted lines. Also shown (solid line) is the measured SSP that was used in determining the original water depths from the measured two-way travel times.

Whereas the estimated water depths show little variation, an analysis of the standard deviation of the optimized SSPs of the 12 solutions shows that the resulting optimized SSPs, for all three swathes, do show considerable variation between repeated applications of the optimization procedure, i.e. several meters per second for depths up to 10 meters below the transducer. Analysis indicates that this variation is, at least to a large extent, caused by the presence of correlation, or parameter coupling, between the three EOF coefficient parameters that define the optimized SSP for a particular swathe.

From the figure it is seen that the three optimized SSPs are different. Also they do not match with the measured SSP. A possible cause for this deviation from the measured SSP is that the SSP dataset used for the determining the EOFs is not representative for the total Maasgeul SSP variability. This is for example indicated by the difference between the average of the SSP dataset (Fig. 2b) and the single SSP measured during the MBES survey (Fig. 3b, solid line). A second cause, however, might lie in the fact that, next to the SSP, additional error sources are present.

Other Error Sources – The Sound Speed At Transducer Depth

Apart from using an incorrect SSP there are other sources contributing to errors in the computed bathymetry. Examples are measurement errors in the ship's attitude due to sensor miss calibration and inherent limited precision, offset errors in the position and orientation of the transducer and possible variation of the SSP on a spatial scale smaller than the MBES swathe width contradicting the assumption of the SSP being only horizontally stratified. The most interesting at this point, however, are bathymetric errors arising from errors in the measured sound speed at the transducer. The transducer sound speed is required in the MBES beamsteering process and therefore has to be measured continuously during the survey. Wrong transducer sound speed values introduce, just like the use of an erroneous SSP, smiley or droopy-like behavior of the computed bathymetry (a too low sound speed value causes droopy-like behavior whereas a too high value causes smiley-like behavior).

Table 2 lists the values of the sound speed at transducer depth (= 5.16 meters) as used in the MBES beamsteering for the three selected swathes. Also listed is the value of the sound speed at the transducer according to the single measured SSP which was used in determining the original water depths (see Figure 3a (solid lines) for the water depths and Figure 3b (solid line) for the SSP). From Table 2 is seen that the values used to steer the beams for the left and middle swathe differ considerably from the value according to the measured SSP. For the right swathe there is good agreement between the MBES beam steering value and the SSP value.

In order to quantity the effect of using a wrong sound speed in the beamsteering, a simulation was carried out. This simulation indicates that for a flat bottom at 25 meters depth, an absolute error of five meters per second in the transducer sound speed used for MBES beamsteering, results in a maximum absolute bathymetric error of the order of one meter.

Value used for MBES beam steering			Value from SSP
left swath	middle swathe	right swathe	
1452 m/s	1457 m/s	1464 m/s	1463 m/s

Table 2. The sound speed value at transducer depth (5.16 meters). Listed are the values used for MBES beamsteering for the three selected swathes, and the value according to the single measured SSP.

As a second step an additional simulation was carried out. For this, the water depths of the three selected swathes were again calculated using the measured SSP and the measured two-way travel times, but now the MBES departure angles based on the sound speeds listed in Table 2 are updated according to a new transducer sound speed. This transducer sound speed is taken equal for all three swathes. Its value was varied over a range of transducer sound speed values with an increment of 1m/s. The cost function was again employed as a measure for the agreement between the overlapping parts of adjacent swathes. According to this simulation the value for the sound speed at the transducer that gives the best match between the different swathes is approximately 1456 m/s. The resulting bathymetry based on the updated MBES departure angles according to this value is plotted in Fig. 3a (dotted lines).

From this simulation it can be concluded that it is difficult to separate between effects caused by the use of an erroneous SSP for the two-way travel times to water depth conversion and the effects of using an erroneous sound speed for MBES beam-steering.

Conclusion

This paper introduces a new approach towards processing multi-beam echo sounder (MBES) bathymetric data. The method requires, and fully exploits, overlap of adjacent swathes, i.e. redundancy in the bathymetry measurements. Contrary to many of the existing post-processing methods, the proposed method does not work on the derived water depths as determined from the measured two-way travel times and the available information on the prevailing sound speed profile (SSP), but on the measured two-way travel times themselves. SSPs are determined such that differences in water depths between overlapping parts of adjoining swathes are minimized. Application to an MBES dataset taken in the Maasgeul shows a significant decrease of these water depth differences.

Simulations indicate that errors in the sound speed at the transducer, used in the MBES beamsteering, can give rise to errors in the estimated bathymetry similar to those resulting from the use of a wrong SSP. Consequently, either the sound speed at the transducer has to be known accurately or has to be determined in the optimization too. When determining new SSPs during the optimization process, the beam steering angles can be updated accordingly. We believe that accounting for erroneous transducer sound speed values will further improve the proposed method. Improvement is expected not only with respect to the agreement between the overlapping swathes, but also with respect to the validity of the estimated SSPs.

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Archaeological Object Detection Under Water

Seger van den Brenk and Bart van Mierlo

In 2006 the Valletta treaty (see appendix) has been implemented in The Netherlands. Since then, preservation of subacqueous archaeological heritage has become responsibility of the constructor. This requires a cost-effective procedure to detect and identify objects under water, in order to distinguish between archaeological and non-archaeological objects on the one hand, and between critical and non-critical obstacles to construction on the other.
The IMAGO project showed that there isn't one geophysical technique to achieve this goal, but that a combination of techniques is required. Moreover, a desk study is the most efficient way of planning the procedure to be followed.
The project of Barrages Grave and Sambeek was a test case of the IMAGO conclusions and it demonstrates that the strategy set out in the desk study was adequate. A combination of sidescan sonar survey, multibeam bathymetry and dive inspections was efficient. The result was 4 historical shipwrecks varying from mid-thirtheenth, through late sixteenth to early twentieth century.

Introduction

Detection and identification of objects is of major importance in marine construction industry. Objects on or below the seafloor may form dredging obstacles and can cause serious and costly delays in any construction operations. Therefore, these obstacles have to be mapped and removed before the start of the operations.

Apart from the 'common' dredging obstacles like recent shipwrecks, debris and ammunition from the Second World War, another type of obstacles is getting more and more attention over the past years. These are the archaeological artifacts on and directly below the seabed.

According to new legislation, derived from the treaty of Valletta (see inset), archaeological artifacts should be protected and conserved, if possible in situ. This is the responsibility of the disturber of the seabed!

The marine construction industry now faces a problem. On the one hand, obstacles need to be removed before operations start; on the other hand, if the obstacles have archaeological value, they are not to be disturbed and need to be protected. This raises the following question:

- How to distinguish between archaeological and non-archaeological objects?

And more in general the major question remains

- How can we efficiently detect and identify objects under water?

IMAGO Project

In order to answer these questions, the Ministry of Transport, Public Works and Water Management (Rijkswaterstaat) in the Netherlands carried out a dedicated project between 2001 and 2003. This project (called IMAGO, a Dutch acronym for Innovative Measurements of Sunken Objects).

The objective of this project was to develop an efficient measuring technique or developing innovative methods to detect and identify wooden objects larger than 1m in diameter up to 4m below the seabed. Wooden objects are difficult to detect in a marine environment, and therefore proposed the biggest challenge in optimizing existing techniques and methods. Several specialists companies and organizations were invited to take up this challenge and test their innovative propose techniques in both a laboratory environment and in the field.

The project led to the following conclusions:

- A single overall geophysical technique to detect and identify all types of underwater objects does not exist; a combination of several techniques is required.

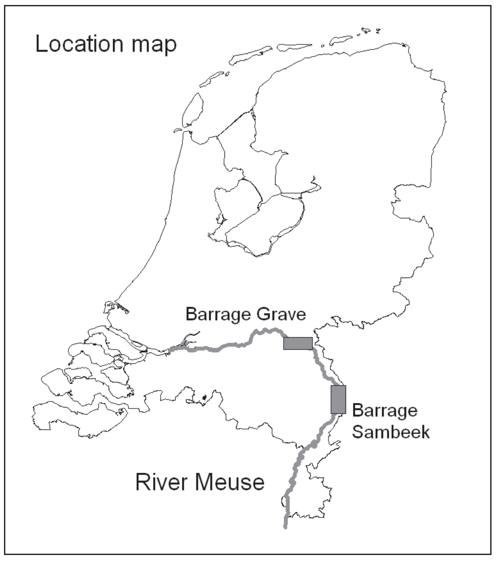

Figure 1: Location map of the research areas in the river Meuse.

- Bottom penetrating techniques in general are expensive in acquisition and processing. Interpretation and identification is difficult, hence raising more questions than supplying answers, therefore these techniques are less suitable for quick area scans.
- An extensive desk study including the acquisition of historical and geological information of the investigated area is a cost effective approach to reduce expensive and time consuming fieldwork.

PROJECT Barrages Grave And Sambeek, The Netherlands

The conclusions of the IMAGO project were put into practice in the first commercial archaeological assessment underwater performed in the Netherlands; the project 'barrages Grave en Sambeek' carried out in 2005 (see figure 1).

In order to improve flood protection, parts of the river Meuse in the south of the Netherlands are going to be deepened in the next few years up to 3m below the present riverbed. The plans for the Meuse are being drawn up and implemented by Project Organization 'De Maaswerken', in which Rijkswaterstaat, the Province of Limburg and the Ministry of Agriculture, Nature Management and Fisheries are co-operating.

Because of the high expectancy of the presence of dredging obstacles and/or archaeological artifacts, an extensive investigation was carried out following the conclusions and recommendations of the IMAGO project:

Step 1: Desk study (by Alterra) describing the history and geology of the research area, resulting in a number of archaeological expectancy maps.

Step 2: Combined side scan sonar and multibeam survey, carried out by the archaeological consultancy ADC Archeoprojecten in combination with Rijkswaterstaat. The multibeam data with highest possible resolution was only acquired at locations of interest derived from the side scan sonar survey, thus saving sailing- and processing time.

Step 3: Dive inspections: in order to identify the remaining locations of interest, derived from the side scan sonar and multibeam survey, dive inspections were carried out by the diving contractor ADT/Subcom supervised by ADC Archeoprojecten (See figure 2).

Figure 2: Unidentified features on the Scheldt River.

Results

Over a distance of 24.3 river kilometers a total of 222 features were marked by side scan sonar and mapped by multibeam. Despite the relatively low resolution of the multibeam system (Reson Seabat 8101, 100 beams), maximum resolution was obtained using the highest ping rate in relatively shallow water. After processing and interpretation, 58 locations were marked as possible archaeological value and selected for detailed visual inspection. For the diving operations a dedicated vessel with good positioning facilities was mobilized. Completing visual inspections of all 58 sites within 6 days, 4 locations were positively identified as important archaeological findings:

At the location Barrage Grave, the remains of two historical shipwrecks were discovered; samples were retrieved and dated 1596 AD ± 8 years (an oak board, see figure 3) and 1262 AD ± 5 years (several oak timbers).
At the location Barrage Sambeek two identical ferry boats in perfect condition, (dated early 20th century, see figure 4) were found in the vicinity of a recent car wreck.

Furthermore, 6 recent ship wrecks, 4 car wrecks, 1 ship anchor (see figure 5), 11 trees and various piles of debris were identified and marked as dredging obstacles.

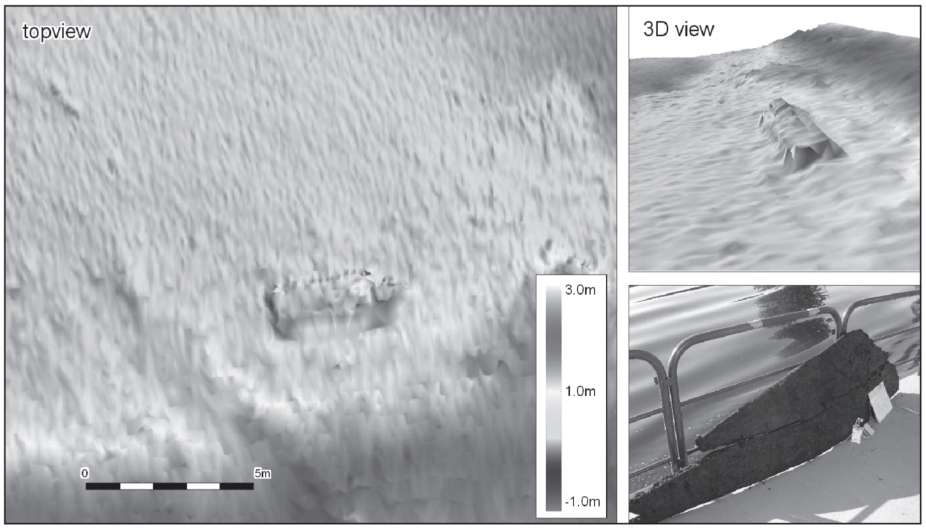

Figure 3: Multibeam record example of an object later identified as remains of a medieval shipwreck. Depths are relative to NAP.

Recent Developments

Beginning of this year the experience gained on several projects has resulted in the setup of a new company Periplus Archeomare BV. By compiling different geophysical and hydrographic data sets and putting them into an archaeological perspective the described approach to investigate marine construction areas has proven to be very successful. In two different projects, the Norned project (electricity cable from Norway to Groningen, Netherlands) and the Vespa project (new sluice complex at the Afsluitdijk, Netherlands), unknown and unidentified historical wooden shipwrecks were detected, of which the archaeological importance still has to be established.

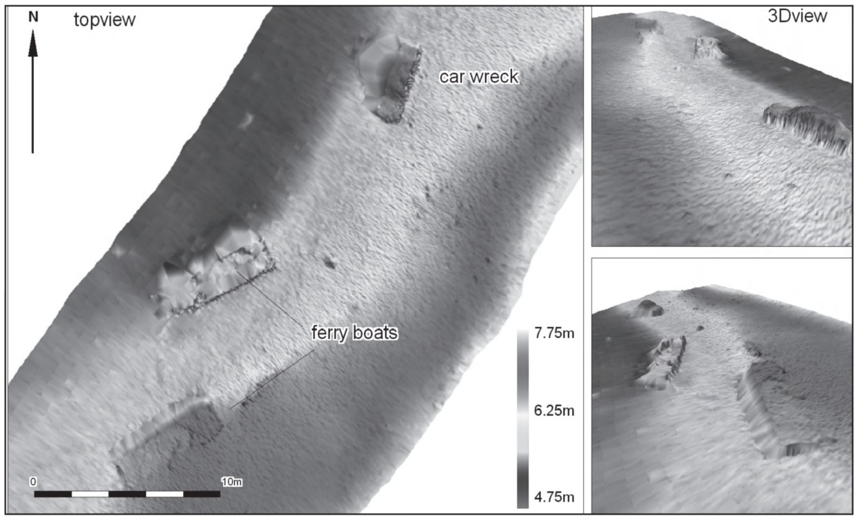

Figure 4: Multibeam record example of a location with a recent car wreck (brand BMW) and two historical ferry boats. Depths are relative to NAP.

Conclusions

Marine contractors should be well aware of the regulations enforced by the new legislation regarding archaeological heritage. Therefore they should implement the different steps of research at an early stage of a project, where bottom disturbance is part of the construction activities.

The practical approach derived from the IMAGO project has proven to be very efficient. The archaeological assessment of an area is based on similar geophysical and hydrographic data, as collected from an engineering point of view. Using the described approach will save the archaeological heritage without frustrating the execution of construction projects.

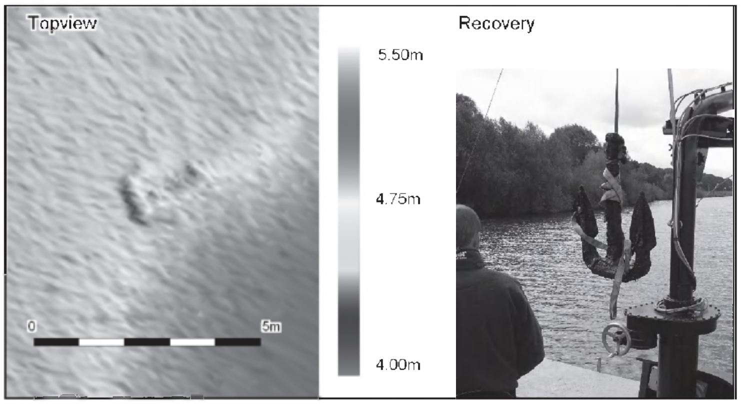

Figure 5: Multibeam record example of an object identified as a ship's anchor. Depths are relative to NAP.

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ANNEXE
Treaty of Valletta

In 1992, the European Committee signed a treaty concerning archaeological heritage.

The major points in the treaty are:
- To protect the archaeological heritage as a source of the European collective memory and as an instrument for historical and scientific study, whether situated on land or under water.
- Making provision for the conservation and maintenance of the archaeological heritage, preferably in situ or provide appropriate storage places for archaeological remains that have been removed from their original location.
- Making provision for the financing of archaeological research and conservation in the budget of projects in the same way as for the impact studies necessitated by environmental and regional planning precautions.
- Promotion of public awareness

The treaty was signed in Valletta, Malta in 1992 and implemented in national law in 2001 (UK) and 2006 (Netherlands).

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Positioning

Benefits of Using High Grade True INS for Hydrography

By A. Chapelon, E. Kammerer

Over the last number of years the hydrographic community has made intensive use of multibeam echosounders for deriving accurate subsea cartography. Consequently, as the processing of the multibeam data requires reliable attitude and position information, the use of precise motion sensors and positioning systems has massively increased. In this paper, we present how an integrated true Inertial Navigation System (INS) can be used to meet the hydrographic positioning requirements. We will present why and how a true INS can be used for hydrographic surveys. It can be used either as an autonomous inertial navigation system or integrated with GPS differential or RTK, or Doppler velocity log (DVL). In this paper, we will review hydrographic positioning requirements and we will explain how an INS was tailored to meet those needs. Moreover, we explain how an INS can cope with GPS dropouts or bad GPS data. We will give some field data and discuss the performance achieved for all parameters during dropouts of GPS data. Eventually, we present an interesting alternative for surveyors, independent from the GPS the joint use of DVL and an INS.

Introduction

In 1997, IXSEA developed an attitude and true heading sensor known as OCTANS [14] (today OCTANS uses 0.05 deg/hour FOGs (fiber optic gyroscopes). OCTANS was designed to meet the requirements of the marine and survey communities and provides 0.1 deg heading, 0.01 deg roll and pitch accuracy. Today, more than 700 OCTANS are now operating worldwide, primarily on survey vessels or underwater vehicles.
In 2000, IXSEA introduced PHINS, the first commercially available Inertial Navigation System, now a common navigation sensor in many AUVs. PHINS is a true INS. When started without external heading aiding, it can compute survey-grade heading, roll, and pitch with no degradation in both static and dynamic condition. When aided by external aiding sensors on surface (GPS) and subsea applications (USBL, LBL, DVL, …) it can provide a complete and suitable navigation solution to surface and subsea vehicle. In 2004, based on our experience with OCTANS and PHINS, we designed HYDRINS a true inertial navigation system for hydrographic surveys.

During survey work, HYDRINS is able to integrate information from any GPS and from a Doppler Velocity Log. The position drift using only DVL is less than 3 meters per hour at 2 knots and the heading accuracy is better than 0.02 deg. Moreover if for some reason neither GPS, nor Doppler velocity log is available for a while, HYDRINS is able to keep a good position in pure inertial mode in order to continue the survey work. To satisfy such requirements, HYDRINS relies on the highest inertial measurement unit (IMU) currently available on the commercial market, based on state of the art gyroscopes, the data of which are blended with external sensors data. IXSEA has been working on the fiber optic gyroscope (FOG) technology since 1987 and is now producing very high performance fiber optic gyros for space applications [13].

Positioning requirements for hydrographic surveys

Practical issues with using multibeam sonar: Attitude and time correction

Multibeam sonars use sound to measure ocean depth. They receive and transmit sound from an acoustic array. The transmit array is usually mounted parallel to the keel of the vessel and the receiver array is orthogonal to the transmit array. Such installation creates beams which are narrow in both fore-aft and athwartship directions. A series of narrow beams are generated and steered (acoustically or electronically) in the athwartship direction. This fan of beams is transmitted and received by the system (see [10][11]). This would be perfect in a static world, however practical limitations may apply. After bottom detection methods are applied to the incoming signals, a series of depths for each ping of the transducer are computed. The obvious issue is the movement of the ship as all these depths must be precisely georeferenced. Therefore, the position and orientation of the sonar at each transmit and receiver times must be known. Practically, on the survey vessel, this drives the need for the installation of sensors to measure horizontal positioning, orientation (roll, pitch, heading), elevation (heave and tide) together with the velocity profile of the water column. Obviously, the global accuracy of the survey is directly correlated to the quality of the different sensors individually as well as the quality of their integration onboard the ship.

A successful integration of these sensors requires a very precise knowledge of:

- The relative location of the sensors within the ship reference frame: full attitude data and the offset between the antenna and the transducer are needed to apply in real time a correction to the soundings.
- The location of the sensors with respect to the ship reference frame: roll, pitch, heave offsets will induce both vertical and

horizontal depth errors and small attitude biases can create depth and position errors.

- The time delays between the various sensors: time delay in the positioning sensor will result in an erroneous location and shift the attitude reduction of the data.

IHO regulatory minimum requirements

As described above, referencing the multibeam data is obtained by merging attitude information and earth relative position information. The main issue is defining the accuracy needed in attitude and position (see [15]). The international reference in terms of hydrographical depth measurements is described by the S44 standard, commonly named IHO standard by hydrographers (see [9]). The table below recalls the different accuracy thresholds.

Order	***Special***	***1***	***2***	***3***
Examples of typical areas	Harbors, berthing areas, and associated critical channels with minimum under keel clearances	Harbors, harbor approach channels, recommended tracks and some coastal areas with depths up to 100m	Areas not described in Special order and order 1, or areas up to 200m water depth	Offshore areas not described in Special order, and orders 1 and 2
Horizontal accuracy (95% confidence level)	2m	5m + 5% of depth	20 m + 5% of depth	Same as order 2
Depth accuracy for reduced depths (95% confidence level)	A=0.25 m B=0.0075	A=0.5 m B=0.013	A=1.0 m B=0.023	Same as order 2
100% bottom search	Compulsory	Required in selected areas	May be required in selected areas	Not applicable
System detection capability	Cubic features >1m	Cubic features >2m in depths up to 40m; 10% of depth beyond 40m	Same as order 1	Not applicable
Maximum line spacing	Not applicable, as 100% search compulsory	3x average depth or 25 m, whichever is greater	3-4x average depth or 200 m, whichever is greater	4x average depth

A = constant depth error, i.e. the sum of all constant errors
B = factor of depth dependent error

Murphy's law and the hydrographer: The most stringent requirements apply to the less easily practicable areas

Today, when it comes to meeting the IHO requirement, the critical problem that hydrographers are facing in order to meet the above requirements are as follows:

GPS outages in harbor areas

Unfortunately, the IHO special order case corresponds to the places where the GPS coverage is the less efficient even in RTK mode. This comes from numerous obstacles to GPS signal that can be found in harbors or rivers as a result of steep walls, cranes, bridges which cause shadows or multipath to the signal.

Precise altitude monitoring

The real time monitoring of the vessel altitude is also a critical issue. Both long term (tides) and short term (heave) variations are present in the altitude data. The critical areas mentioned above are also the areas where the hydrographers need the highest altitude accuracy. The best way to have a real time earth ellipsoid reference is to use the RTK GPS system. However you are still very dependent of GPS outages.

Synchronization of the different sensors

The most disastrous artifacts generated in the data acquisition are due to the inaccuracy of the time synchronization of the different sensors on board. Systems which integrate most of the sensors are best placed to cope with such problems.

INS

Principle

With the INS described in this paper, the heading accuracy is better than 0.02 deg and the roll or pitch accuracy is better than 0.01 deg. Moreover if for some reason neither GPS, nor Doppler velocity log is available for a while, the INS is able to keep a good position in pure inertial mode in order to continue the mission. To satisfy such requirements, the INS IMU is based on state of the art gyroscopes and the INS DSP contains a Kalman filter able to optimally integrate external sensor data from any GPS and from a Doppler velocity log.

Positioning solution

Taking advantage of the merging of GPS with inertial, the INS delivers a high rate (100 Hz) position. In fact, over a short period of time, the GPS is noisy but the INS is smooth, however over a longer period of time the GPS stays accurate, but the INS does drift. The Kalman filter is the optimal mathematical tool to take advantage of both inertial data and GPS data. The INS Kalman filter allows to have a smooth (no noise) and a non drifting position. Moreover the Kalman filter can also correct IMU errors like bias, to continuously improve the inertial performance.

For details on the theory of Kalman filters the reader can refer to [2] [4] [5] and for the applications of Kalman filtering in navigation the reader can refer to [1][7][12]. The goal of the Kalman filter is to use data provided by external sensor to correct inertial navigation errors.

Robust estimation and rejection of erroneous measurements:
During a long mission it is very likely that some external sensors will provide erroneous data from time to time. In a traditional Kalman filter, such erroneous data could lead to uncontrolled divergence of the estimations. Moreover the divergence of the Kalman filter would be proportional to the error of the external sensor. To cope with this problem we have implemented a robust estimation based on M-estimator in the INS Kalman filter (see [3][6]). The principle of robust estimation is to replace the linear response function of the Kalman filter by a non-linear response function (see Figure 1). Each measurement is compared to the corresponding expected standard deviation. If the measurement is in the expected range it is integrated as usual, if it is clearly not in the acceptable range it is rejected and if it is suspect it is attenuated.

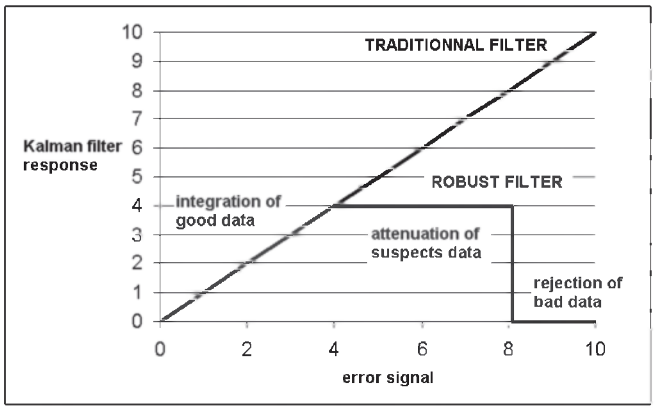

Figure 1: Principle of robust Kalman filtering.

Figure 2 at the left, we present the results from a typical survey in a difficult location. The vessel ran survey lines in a narrow estuary, passing under a bridge. It took place near Brest (west of France) on the Elorn river. In this situation, the corrections from the RTK GPS were poorly received, resulting in a 2-minute "patchy" GPS data set caused by multipath. However, thanks to its robust filter the INS continued to give accurate position with the inertial navigation

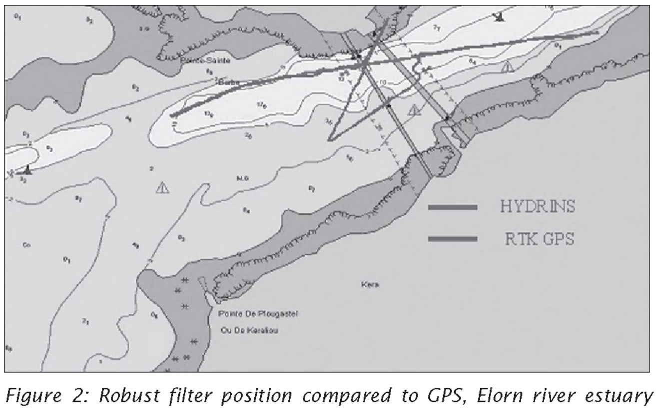

Figure 2: Robust filter position compared to GPS, Elorn river estuary (Brittany) survey 2 minutes multipath overcame by the INS.

Another way to improve the performance of an inertial system is to combine inertial data with speed sensor. The INS Kalman filter can also integrate Doppler Log Velocity information in order to improve the drift of inertial navigation. For example; the inertial navigation coupled with a DVL leads to a drifting posing less than 3 meters in one hour. This integration with GPS and/or DVL is performed in the INS; the user has nothing to do. The INS, thanks to its Kalman filter, does the entire job taking advantage of the 3 different sources of information: inertial, position (GPS), speed (DVL).

GPS outage

During a drop out of GPS, the INS computes a position using only the inertial data. However this position will eventually drift due to inertial sensor imperfection. The rate of the drift is depending of the IMU sensor, and of the initial error. To improve the results of inertial navigation, the INS Kalman filter makes a self-calibration of its IMU sensor. For drop-outs shorter than 5 minutes, the main drifting term is due to accelerometer bias. However, an accurate estimation of the accelerometer bias is impossible without a high class gyroscope (better than 0.1 degrees per hour), otherwise the Kalman filter can not sufficiently distinguish error coming from accelerometer or from gyroscope. In the next figure we give typical drifts due to either a typical accelerometer bias of 100 migroG only or a 0.01° initial roll error compared to HYDRINS drift.

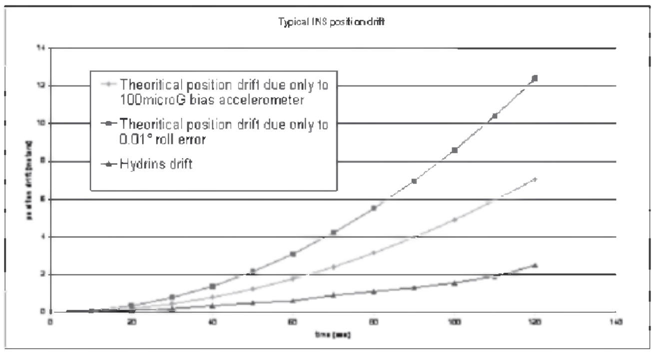

Figure 3: Typical INS position drift compared to HYDRINS.

Several trials have been done to validate the performance of HYDRINS, including laboratory trials (especially for attitude and heading), car trials, trials on specially calibrated tracks and sea trials using GPS RTK for comparison. In this section we present some of the results obtained during these tests. In Figure 4, we compare the temporal drift of different systems with respect to the IHO standards. We can observe that classical dual GPS antenna systems are very dependent on GPS outages which drift very quickly. Higher performance inertial systems like the HYDRINS stay for 100 seconds below the threshold of the IHO special order.

Special applications need centimeter positioning even during long GPS outage. For this case an inertial system alone can not maintain such performance. However, HYDRINS offers a solution with a speed sensor (like a Doppler Velocity Log) and as a result HYDRINS drifts only at 3 meters per hour without any GPS information.

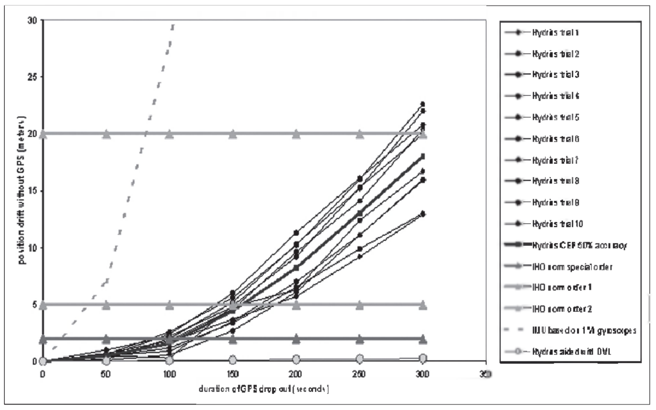

Figure 4: performance of position during GPS drop out.

Altitude

During a hydrographic survey, the altitude issue is a serious problem. The only way to have in real time a reference to WGS 84 earth ellipsoid model is to use the RTK GPS. The other solution is to take into account the tide elevation which most likely would result in post processing correction. Additionally, heave must also be addressed as one of the components of altitude.

Once again a smart integration of inertial data and RTK GPS altitude takes advantage of information from both. As can be seen in Figure 5, during the first 20 seconds there was higher waves, but the GPS RTK provides altitude position at slow frequency, so the hydrographer is required to do interpolation. However, using the INS altitude the hydrographer does not need to do interpolation, the INS altitude is suitable at 100Hz. The INS takes advantage of its inertial sensor to maintain an accurate altitude. In fact the inertial altitude gives true altitude even during long GPS drop out as seen in Figure 5.

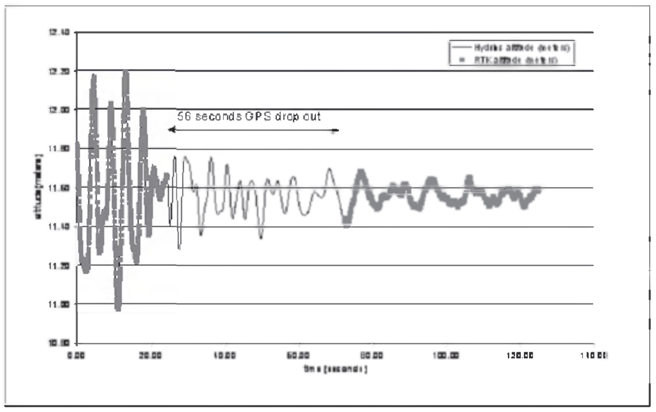

Figure 5 : example of HYDRINS altitude during GPS outage.

In case of longer GPS outage, the inertial algorithm cannot provide a geo referenced altitude. In a case like this HYDRINS is still capable of giving an accurate relative altitude (heave) by using a specific tuning free heave filter, called SAFE Heave (Self Adaptive Filtered Estimated Heave). This has been included in the HYDRINS for real time computing.

This filter is fundamentally a new heave filter concept using the latest progress in mathematical techniques to assess heave filter parameters in real time. As a result, the filter is always optimal, whatever the conditions and regardless of the type of vessel. This algorithm allows several turns without any built-up effect on the heave data as described in Figure 6 and 7. It can be seen on these figures that even when the vessel is changing direction (50 degrees heading changes on first part of the curve, and 720 degrees (two complete turns in a row) at the end of the curve, there is no spikes during or after turn on heave measurement: on that very calm day there were very small amplitude waves that does not change during turns.

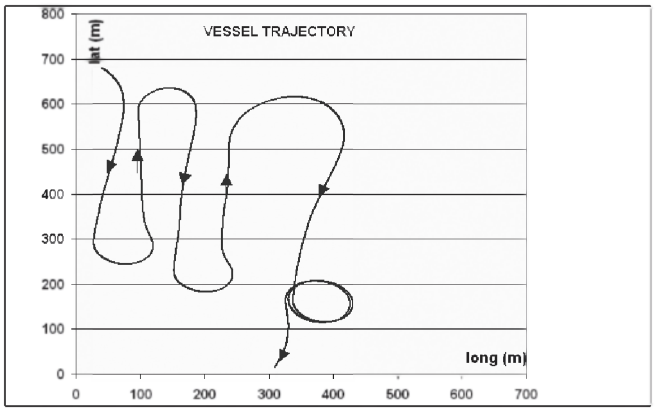

Figure 6 : Vessel trajectory during heave testing: survey lines followed by double turn.

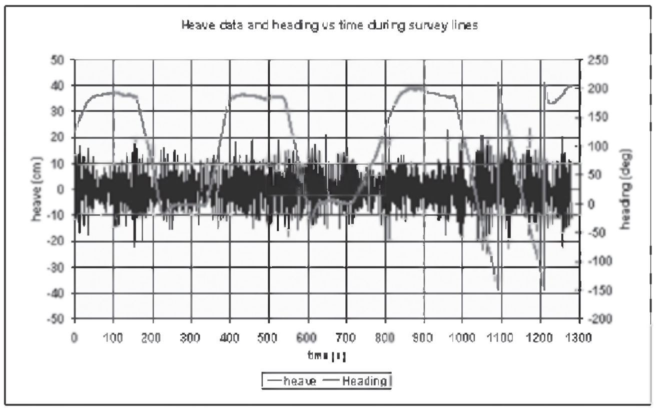

Figure 7 : Heading and heave versus time during survey lines.

Synchronization

For ease of integration, HYDRINS gives all the data useful for a multibeam acquisition system in real time with a time stamp that can be synchronized with PPS. HYDRINSsynchronizes itself with the GPS, therefore hydrographers have only one time delay to take into account between multibeam data and INS data (latitude, longitude, altitude, heave, roll, pitch, heading,, time stamping). This results in significant easiness for installation and use.

Conclusion

HYDRINS is the first high performance integrated navigation system based on fiber optic gyroscopes which is able to fulfill hydrographic requirements, even when GPS drops out.

The design of HYDRINS has been possible using IXSEA's experience in FOGs and inertial navigation systems. It is able to integrate optimally data coming from external sensor like GPS, and DVL using a specifically designed robust Kalman filter. Several tests have proved that HYDRINS achieves very high performances. Most importantly IXSEA offers a new approach for hydrographers to be independent of long GPS drop out.

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High Accuracy Integrated Subsea Positioning: Fugro's Finetrack

Kees de Jong

Fugro's Finetrack represents the next generation in subsea construction positioning systems. Utilizing state of the art inertial navigation and acoustic technology, Finetrack is tailored to ROV applications in the increasingly demanding deepwater environments (with depths up to 3000m) where reliability, availability, accuracy and efficiency are paramount. In this contribution an outline of the concepts underlying Finetrack will be given, with some examples of applications and results.

Introduction

The Global Positioning System (GPS) has revolutionized surface positioning in recent years, resulting in the discontinuation of virtually all existing terrestrial 2D radionavigation systems. Moreover, GPS made it possible, for the first time, to determine accurate 3D positions in a global, homogeneous coordinate frame.

Underwater not much has changed in the past 25 years. Since radio waves do not penetrate the water column, use of GPS is impossible and one has to revert to acoustic systems. Major error sources for acoustic positioning are uncertainties in the speed of sound, reflections and interference. In addition, acoustic technology is expensive, due to the time consuming calibration procedures required to position transponders on the seafloor. Finally, the low update rates of acoustic systems do not make them very well suited for e.g. visualization purposes.

A number of techniques exist or are currently under development to replace or complement the traditional acoustic systems for subsea positioning. Inertial navigation systems (INS) are very promising in this respect. They provide excellent short term stability, have high update rates and are independent of external references.

In the following sections an overview will be given of acoustic, inertial and integrated positioning. Next, Finetrack is introduced, with examples of applications and results.

Subsea Acoustic Position and Velocity Determination

Traditionally, the primary techniques used for subsea positioning are based on acoustic and pressure (to determine depth and tides) measurements. Observations from an acoustic positioning system consist of time differences, which are converted to distance after multiplication by the speed of sound. The speed of sound depends on depth, temperature and salinity; the latter two are hard to measure or predict and as a result, acoustic positioning accuracy deteriorates with increasing depths. Using acoustic measurements from a surface ship to a subsurface transponder and simultaneous GPS observations to position the ship, the transponder's location is determined in a global coordinate frame.

Most of the current technology is very expensive and, in particular for deepwater applications, often does not meet the accuracy requirements. For example, high accuracy LBL (Long Baseline) acoustic positioning requires arrays of acoustic transponders (usually 5-10 per km^2) to be precisely located on the seabed. Such arrays are positioned by a time consuming calibration procedure using a surface vessel, which may take several days per array, depending on water depth.

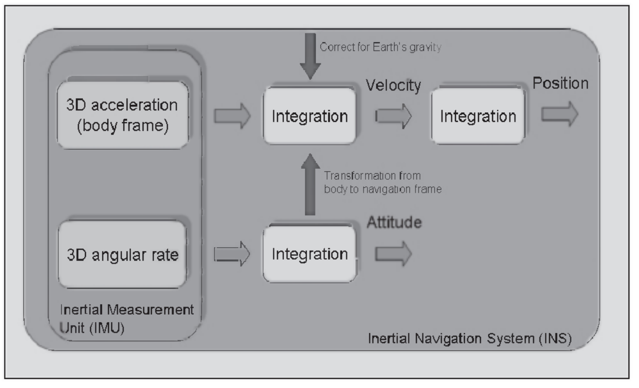

Figure 1: General concept of an inertial navigation system.

Another important limitation of current acoustic underwater technology is the low position update rate, resulting in low availability, which makes this technology less suited for visualization purposes. Reliability is poor as well, due to susceptibility to interference and multipath of the acoustic signals.

Velocity can be determined using a Doppler velocity log (DVL), provided bottom lock is maintained. Consequently, a DVL should be operated relatively close to the seabed.

Inertial Navigation

An inertial measurement unit (IMU) measures the 3D acceleration of a vehicle in the Earth's gravity field. Integrating these accelerations (after proper rotation from IMU body frame to navigation frame) once provides (change in) velocity, integrating again results in (change in) position. An IMU consists of a triad of accelerometers and gyroscopes to measure accelerations and changes in orientation; an inertial navigation system (INS) consists of an IMU and processing computer to derive position, velocity and attitude from the observed accelerations and changes in orientation, see Figure 1.

In contrast to GPS and acoustic systems, an INS is self contained. It does not depend on external references, such as satellites or transponders, or a medium for signal propagation. Although INS technology has been around for more than 40 years, only recent developments in strap down systems and reduction in price and size have made these sensors attractive for subsea positioning.

Integrated Positioning

An INS provides excellent short term stability and high position update rates (50 Hz or more). Long term stability is poor, however. GPS and acoustic systems have relatively poor short term stability and low update rates, but their long term stability is excellent. Therefore, INS on the one hand and GPS and acoustics on the other are complementary systems, which would benefit from integration. Other benefits are increased reliability and efficiency. Using an integrated system, the number of transponders on the seafloor can be reduced, since rather than full acoustic position fixes, sparse LBL ranges are sufficient to provide precise integrated positioning performance. As a result, shorter calibration periods are required. Shown in Table 1 are the characteristics for stand-alone conventional, inertial and integrated positioning systems. Figure 2 gives an impression of the error growth for different levels of integration.

	Conventional (acoustics, GPS)	Inertial	Integrated
Short term accuracy	+	+++	+++
Long term accuracy	+++	--	+++
Availability	+	++	+++

Table 1: Characteristics of various positioning systems.

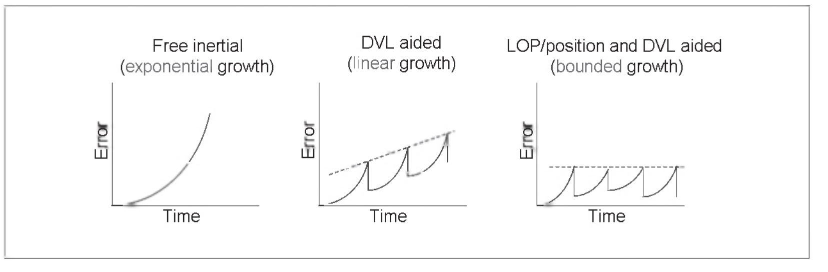

Figure 2: Error growth for unaided and aided inertial navigation.

Finetrack

Fugro's Finetrack is the framework featuring accurate real-time remotely operated vehicle (ROV) position calculations, based on a user selectable choice of integrated positioning calculation engines. These engines rely on various implementations of error state Kalman filters. For post-processing, Kalman smoothers are supported as well. The engines support both loosely (Finetrack L-series) and tightly (T-series) coupled scenarios, see Figures 3 and 4. Although primarily designed for subsea positioning, using acoustic and inertial measurement data, Finetrack can also be configured for surface applications, using e.g. GPS and inertial data as input. Applications of Finetrack include:

- Tethered ROV positioning applications.
- Setting marker buoys for offset wellheads or batch sets.
- Setting marker buoys for pile cluster installations.
- Suction pile orientations.
- Pipeline or umbilical as-builting a route using USBL or sparse LBL updates.
- Precise bathymetric surveys.
- Platform inspection.

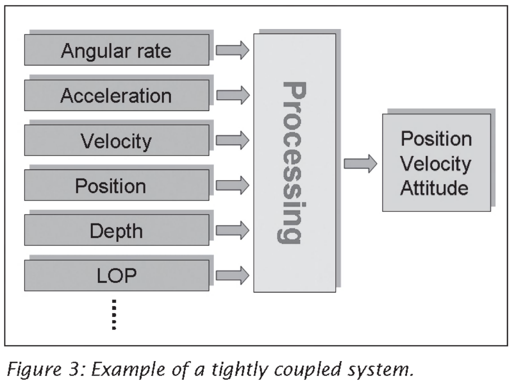

Figure 3: Example of a tightly coupled system.

Using advanced Kalman filtering and smoothing techniques, the Finetrack software was designed to accommodate a number of hardware configurations, such as navigation-grade inertial sensors, integrated with Doppler velocity log, depth sensor and multiple acoustic positioning systems. For surface positioning applications, GPS aiding is supported as well.

For example, Finetrack L200 is targeted as a cost effective INS solution. Hardware requirements consist of a good motion

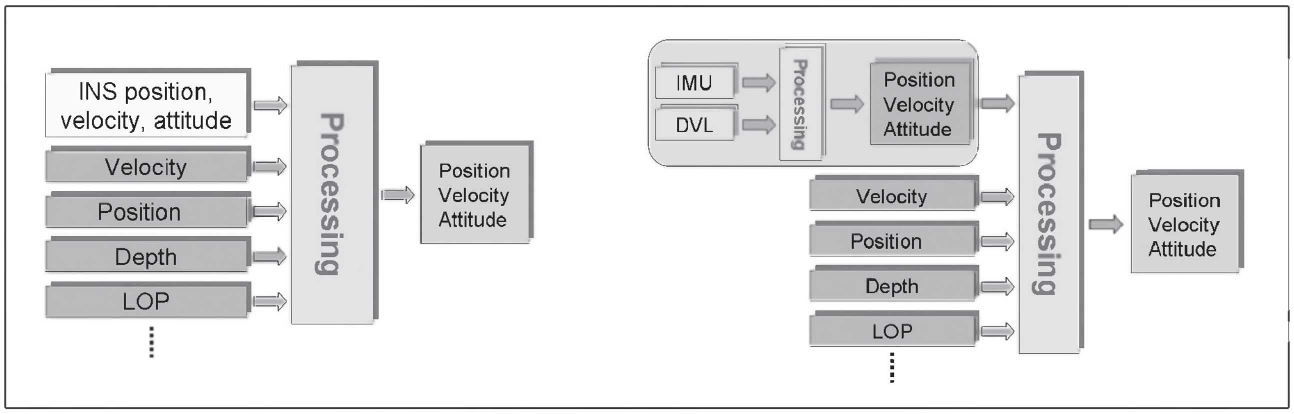

Figure 4: Examples of loosely coupled systems as used in Finetrack.

sensor to provide attitude (pitch, roll and heading), a DVL for 3D velocity, and positioning sensors, such as LBL. For surface or shallow water positioning, GPS could be used as well. Update rate is typically 4-5 Hz. Finetrack T100 targets the high end of the market and integrates a high-grade IMU with DVL and acoustic positioning systems; update rate of this system is 50Hz. With such update rates, real-time displays show fluid motion. True seabed scenes are built from multibeam data sets and 3D CAD drawings. The software architecture allows multiple windows configurations that can include dedicated ROV pilot and client requested information and real time QC data displays, see Figure 5.

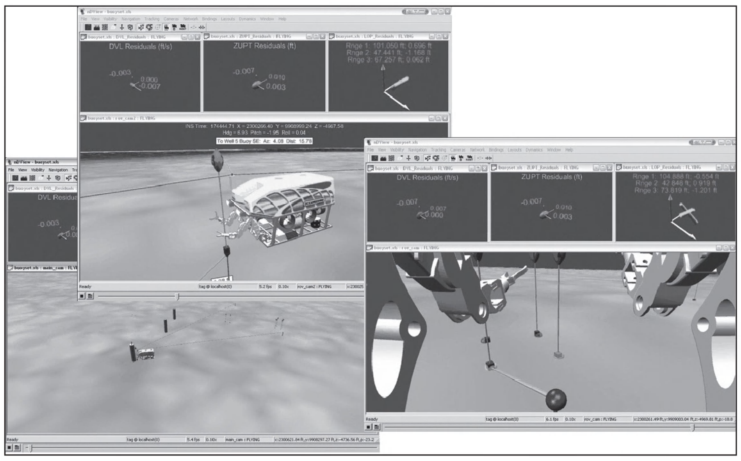

Figure 5: Example of real-time integrated (INS/DVL/LBL) positioning and QC visualization.

Applications and Results

Comparison of sensors

Since high grade IMU's are considered as strategic goods, they require an export license. For lower grade units, including motion sensors, such a license may not be required. Therefore one of the first trials conducted with Finetrack was an evaluation of three systems of different grade: Ixsea Octans (fiber optic gyro), CDL Minipos (Kearfott T16 ring laser gyro) and Kearfott SeaDevil (T24 ring laser gyro).

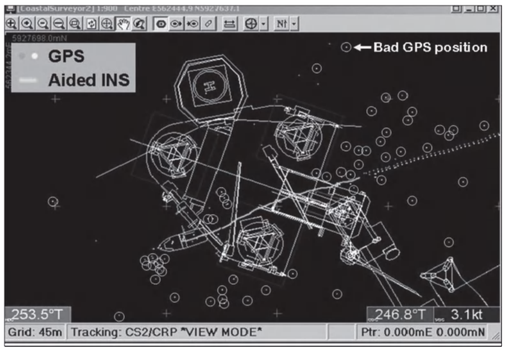

Figure 6: Positioning performance near a platform offshore the Netherlands.

The trials were conducted on a lake in The Netherlands. Aiding sensors consisted of a DVL (5Hz update rate) and Fugro's high precision GPS service, Starfix HP, which provides subdecimeter positioning accuracy (95%) worldwide. In post-processing mode, HP aiding positions were fed into the Finetrack filters with an update rate of 0.1Hz. The filter computed, among others, heading misalignment errors, scale factor, velocity biases and latencies. Using these estimated parameters, it was possible to compute positions at each epoch for which HP positions were available (1Hz interval) and determine the difference between the two. It appeared that for each of the three sensors considered, the horizontal positioning error (standard deviation) was within 2-4cm for Easting and Northing. The conclusion seems justified that, if sufficient aiding data is available, lower grade sensors may do the job equally well as high grade ones, with the additional advantage of not having to worry about export restrictions.

Platform inspection

A survey was performed where a small surface vessel had to sail under a platform. This time GPS positions were available not from Starfix HP, but from two Real-Time Kinematic (RTK) systems. Obviously, under the platform no GPS is available, but also in the vicinity of it GPS positioning may be bad, due to signal masking and reflections, even though the RTK system's quality indicators mark the positions as good. This type of environment shows the strength of an integrated positioning solution in terms of availability and reliability. If no GPS positions are available, navigation continues using the remaining sensors; if bad GPS positions are fed into the system, they will be identified as unreliable and not used. Figure 6 shows an example of GPS

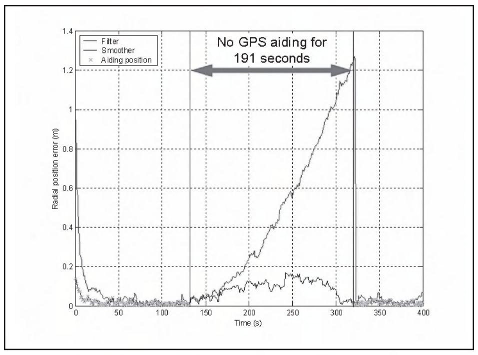

Figure 7: Finetrack filter and smoother performance for a period of 191 seconds during which no aiding data was available.

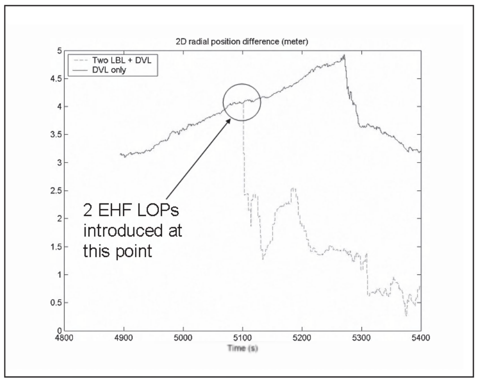

Figure 8: Tightly coupled horizontal positioning error with DVL only and DVL/LOP aiding.

positioning performance near the platform and integrated positioning results while under the platform.

Filtering and smoothing

Finetrack in post-processing mode allows for both filtering and smoothing of data. Filtering here means that at a specific epoch, all observation data up to and including that epoch are used to estimate the parameters of interest. For smoothing also observations from future epochs will be used for parameter estimation. As a result precision will be improved. Smoothing has proved very useful when there is no aiding data available during an extended period. An example is shown in Figure 7. Doppler and motion sensor data were integrated and aided using Starfix HP GPS positions. An artificial gap of 191 seconds was introduced, during which no GPS aiding was available. The position error for the filter increases rapidly. For the smoother the error is bounded and much smaller than for the filter. As soon as aiding data becomes available again, both filter and smoother show similar performance.

Sparse LBL aiding

So far only position aiding results were discussed. However, Finetrack also supports sparse LBL aiding. This means that ranges (usually derived from two way travel times) are fed into the filter as aiding data. It also means that instead of a full LBL array to compute positions, a smaller number of transponders needs to be positioned on the seafloor, resulting in a significant reduction of vessel time required for calibration. Figure 8 shows an example of a tightly coupled solution where at some point aiding data from two EHF (extra high frequency) LBL transponders became available. The immediate improvement in positioning accuracy (as compared to the case where only IMU and DVL data were available) is clear.

Conclusions

Integrated subsea positioning based on inertial and acoustic systems is an accurate, reliable and cost-effective alternative to the traditional acoustics-only approach. In addition to reduced support vessel and ROV costs, the integrated approach also reduces HSE (health, safety and environment) exposure time. Fugro's Finetrack provides a flexible framework, which is hardware independent, supports multiple aiding systems in loosely and tightly coupled scenarios and allows for both real-time and post-processing of data, based on Kalman filter and smoother implementations.

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The Use Of The Tidal Waterlevel And GPS

In Establishing A High-Resolution Digital Elevation Model Of A Sandy Beach

Stephan Procee MSc

In this study a stand-alone GPS receiver is used to establish the position of the shoreline at various tidal heights. Tidal heights are monitored simultaneously at 4 tidal stations. A tidal model is derived from these observations providing tidal height as function of time and position. The tidal model is coupled to the position of the shoreline resulting in a number of height contours. From these contours a digital elevation model is built. This model can be used to study the morphology of a sandy beach over a period of time, or it can be used for nautical Charting, i.e. establishing the drying contourline at the level of Chart Datum, and the coastline at the the level of mean High Water. For positioning a low cost hand-held GPS receiver is used in combination with a portable PC for data-storage. The proposed method can be carried out by a single person traversing the area by bike. This approach boosts cost-effectiveness and has little impact on the environment.

Explanation of the Proposed Method

Measuring height of terrain can be done in various ways. When the measurement is done manually, i.e. not by remote sensing, the choice for the sampling method is a balance between human effort involved and the amount of detail needed. Sampling each square metre provides sufficient detail but is not cost effective.

The scope of this study is to provide a local observer with a method of gathering unbiased data about the height of a beach and eventually the movement of the beach over the years.

Traditionally, measuring height is done in the Netherlands by way of beach profiling, thus measuring height along certain fixed profiles perpendicular to the coast with hundreds of metres in between successive profiles. Beach height is deduced from the interpolation between the profiles. One possible product from this method is the presentation of contour lines at given or fixed intervals. This way of gathering data is rather time consuming and involves at least two persons for levelling observations. Moreover the method of levelling requires a certain amount of professional expertise which 'local' RWS observers may not necessarily have at their disposal.

The proposed method in this study involves just one observer travelling along the actual shoreline at various tidal stages logging position data with a GPS receiver. During post processing these positions (latitude, longitude, time) are coupled with the tidal height at the moment of observation at that particular position. This combination of height and position and date is the basic data for input in a Geographical Information System (GIS). With the aid of a GIS, a Digital Elevation Model (DEM) can be built for a particular date. When these elevation models are built for consecutive dates, differences can be calculated. This enables visualising the growth or decline of the beach over time. A visualisation of the proposed method is shown in Figure 1.

Although limited to accessible shores, the advantage is that the surveying procedure can be done simultaneously with shoreline inspection which is part of the normal working procedure of local RWS staff. So the survey can be carried out without extra cost for labour or transport.

The infrastructure required for the proposed method is limited to a number of tidal stations around the area of interest providing observed tidal height. A reference beacon for the GPS observations is not necessary for improvement of precision and accuracy because standalone GPS in the Standard Positioning Service (SPS) provides sufficient accuracy (5-10m at the 95% confidence level) as is observed and explained in Chapter Four. However a differential beacon may offer higher reliability providing pseudorange corrections and SV health warnings in DGPS mode. This improves the integrity of the positioning system.

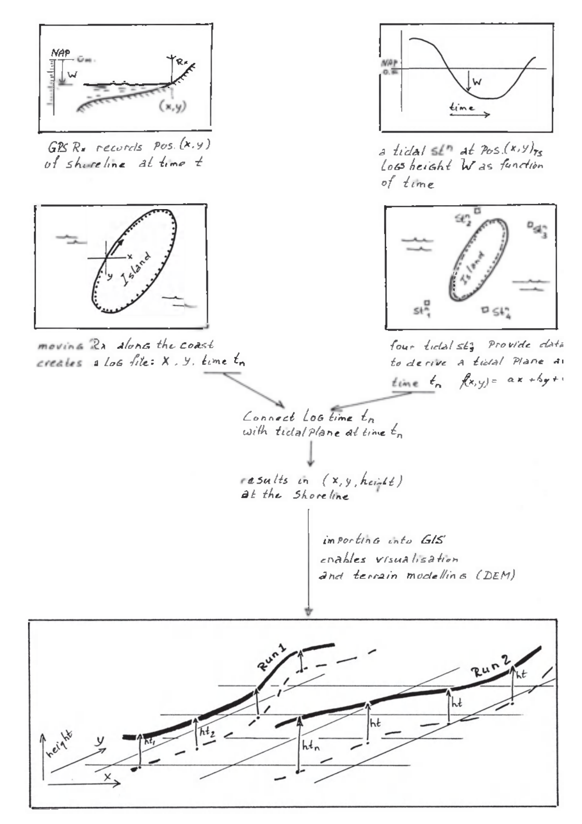

Figure 1: Visualising the growth or decline of the beach over time.

When carrier phase measurements are used a much higher (sub metre) accuracy can be reached. However, considering the scope of coastline surveying, the practical benefit of such a high accuracy is arguable. The shoreline observations on the *Noordvaarder*, which were carried out for this study, were all made with stand alone GPS Standard Positioning Service.
Observing the shoreline instead of measuring a profile perpendicular to the terrain slope yields the risk of losing terrain information e.g. undetected topography or coastal indents in between the observed shorelines. However, the space between profiles is not surveyed either.
A GIS is able to use a DEM for the production of the same product as was produced on the basis of the traditional beach profiling i.e. a map with contourlines at given or fixed intervals.

The Tidal Model

Tidal zoning

For the area of interest there are a number of tidal stations available (Figure 2). A general approach for interpolating between tides would be the method of Tidal zoning where a relation in time and height between tides at consecutive stations is assumed. However, testing this assumption with the aid of predicted tides leads to the conclusion that the model of tidal zoning is not suitable in this area. This is illustrated in Figure 3 where the difference in time of predicted HW between the stations West Terschelling (WTN) and Terschelling Noordzee (TNZ) is plotted. The difference in time of occurring HW varies between some 35 to 65 minutes over 90 consecutive tides, and the time difference between LW WTN and LW TNZ varies between 15 and 30 minutes. Even more striking is that the tidal period differs between the stations. It is shown in Figure 3 that from one tide to the next tide the duration of the tidal period differs some 17 minutes when comparing relatively nearby stations. Concluding, tidal zoning is not a suitable method for interpolating tides in this area because of the large and unpredictable irregularities.

Figure 2: Tidal stations.

The Alternative for zonal approach

An alternative and straightforward approach is to regard the local sea surface as a mathematical plane at a level that must fit at the location of the tidal stations (Figure 4). For this particular study in shallow water around Terschelling, the assumption is made that also for a larger survey area confined by a coastline and tidal flats the water level may be regarded as a plane. This plane is tilting in 2 directions and must fit through the tidal height at the position of the tidal stations. Control theory (LSA) is used to calculate the residuals of the plane at the position of the tidal stations, the magnitude of the residuals is regarded as an indication of the validity of the assumption. The magnitude of the residuals is also an indication of the magnitude of the error when interpolating in between the tidal stations.
For the sake of simplicity and ease of mathematical definition this plane is regarded as a mathematical plane (Z=aX+bY+c) in the 3-dimensional orthogonal space.

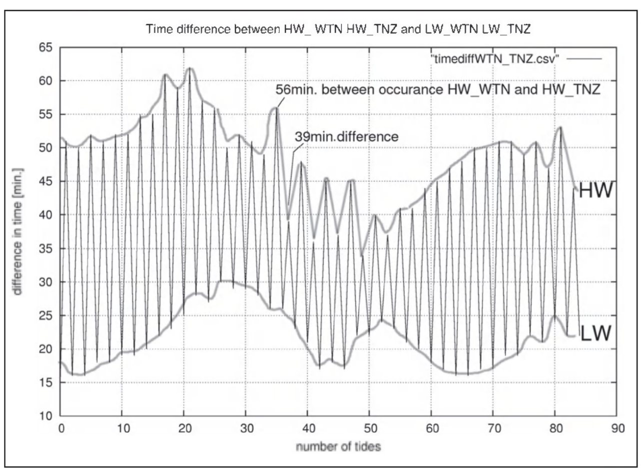

Figure 3: Difference in time of predicted HW between the stations West Terschelling (WTN) and Terschelling Noordzee (TNZ)

Linear interpolation of the tidal wave defining planar coefficients

The coordinates of tidal stations is defined in the Netherlands Grid *Rijksdriehoeksmeting* (RD-coördinates). The grid coordinates are rectangular where the Y coordinate is defined in metres according to a false Northing of 463000m and the X coordinate in metres according to a false Easting of 155000m referred to the central point of the National Stereographic projection in Amersfoort.
When the orthometric height is regarded as the z value in orthogonal 3D-space the plane representing the sea surface through the tidal stations can be defined:

$$Z = aX + bY + c$$

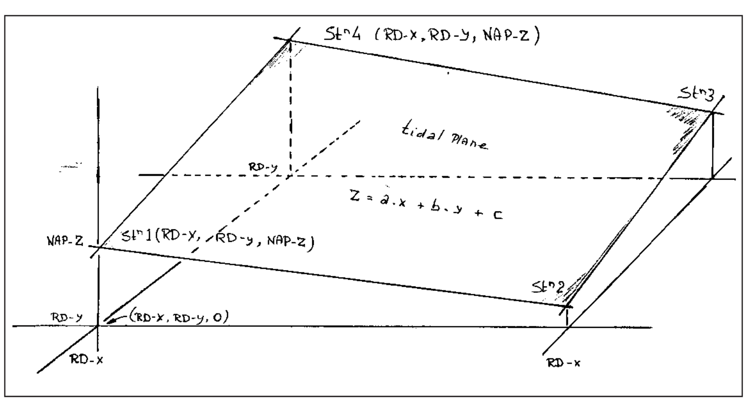

Figure 4: Mathematical plane.

For an observed height at 3 tidal stations the unknowns a,b,c can be solved as the coefficients for the plane. However, when more tidal stations are involved, the solution gets overdetermined. An

estimation of the best fitting plane is defined by least squares adjustment where it can be justified that the best fitting solution has a minimum sum of squared residuals. The difference between observed height at the tidal station and the planar height at the station is regarded as the residual v.
For each station with given X,Y coordinates and observed tidal height Z, we can define the equation:

$$Z + v = aX + bY + c$$

In order to test the assumption that the four mentioned tidal stations are related in time height and position, an experiment was set up to calculate the residuals for the predicted tides throughout the year 2001. The time and period of one year was chosen arbitrarily, i.e. not related to the position of the lunar-plane in its 18 year cycle.
As can be seen from the table, the majority (90%) of residuals have magnitudes less than 4cm. This means that the accuracy of 90% of the interpolated tide falls within a margin of plus or minus 4 cm around the true value. Considering the required accuracy in height this method looks valuable for use in tidal interpolation.

Position with GPS, Quality of Low Budget Receiver

Static Observations were directly logged from the NMEA formatted output of the GARMIN 12 receiver which resulted in one position sentence every 2 seconds. From a total number of observations of 327 the average was calculated resulting in differences not exceeding 5m. The reason for this good result may lie in the number of received satellites (up to 12 SV in view) and in the reduction of multi-path effects in this flat terrain with open horizon.
Mobile Observations were tested as well. To check whether the receiver is able to deal with changes in course and speed another trial was made by manoeuvring around a fixed landmark. A beach pole was used as a fixed reference mark and the receiver's positions were logged while approaching the mark and making a 90 degrees change in direction. The speed during this test was a modest 7km/h, which is normal for cycling on sand. This resulted in stable positioning within 8m distance of the reference track.
Concluding remark is that using a stand alone receiver with NMEA formatted output is suitable for low speed dynamic surveys with an accuracy better than 10m and an update rate of 0.5Hz. Integrity monitoring must be done with other means.

Magnitude	Number	Frequency (%
6cm and over	124	0,06
5 to 6	3504	1,66
4 to 5	17128	8,13
3 to 4	34919	16,57
2 to 3	37083	17,59
1 to 2	44678	21,2
0 to 1	73348	34,8
Summed	**210784**	**100**

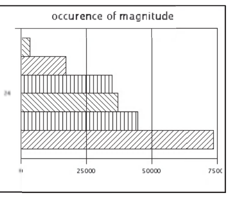

Figure 5. Recorded tracks.

Modelling the Terrain

During one tidal period four tracks were recorded cycling along the observed waterline. Two of these tracks are shown in figure 5. Visualising of the survey track in the GIS shows no apparent offsets in positioning or outliers in the transform-ing and reformatting of the coordinates. With regard to the backdrop topographic map, it is shown that differences exist between the survey lines of 13 October 2003 and the charted contours based on information from 1997.
A simple shell script was written to combine the GPS logged file (X,Y, time) with the tidal model (time, planar model) resulting in a file with position connected to tidal height equalling terrainheight. And with this (X,Y, Z) file the process of terrain modelling was started.
Connecting the tidal model to positioning results in a three dimensional survey file. In this file, containingng XYZ values, horizontal accuracy is equivalent to the horizontal accuracy of the GPS and vertical accuracy equals the accuracy of the tidal model.
In order to derive contours at user defined values, a method of interpolating between the surveyed heights has been found. Geographical Information Systems (GIS) are best suited for this spatial interpolation problem. The open software GRASS comprises a multitude of modules suitable for geo-spatial analysis. Defining a surface based on the XYZ points with the method of *regularised spline with tension* results in a realistic digital elevation model. The necessary setting of *tension and smoothing* parameters is a lengthy iterative process. Great care must be given to this 'tuning' because these parameters have a huge influence on the interpolated surface.
From a well balanced DEM, valid contours are derived at user defined levels. These contours are superimposed on an existing height model (AHN) from the Adviesdienst voor Geo-informatie en ICT (AGI) formerly known as Meetkundige Dienst. This gives an indication on the validity of the described method. Due to ageing, the respective DEM's did not co-locate in the most dynamic area of the beach; however, a satisfactory resemblance was shown in the stable leeward side of the survey area.
The superposition of the contour at the level of Chart Datum and mean High Water on the recent large scale Nautical Chart shows also a satisfactory co-location in the stable part of the

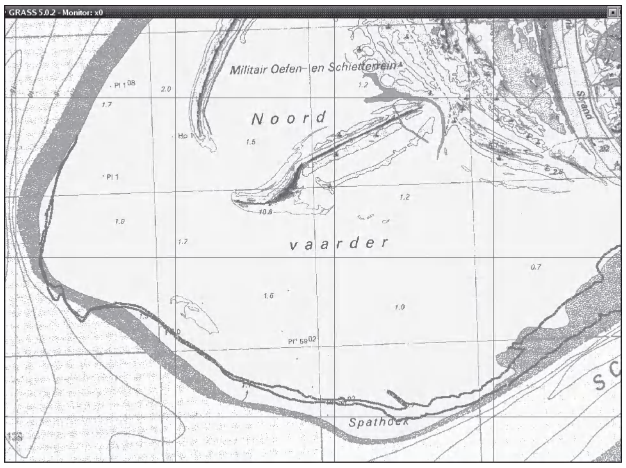

Figure 6.

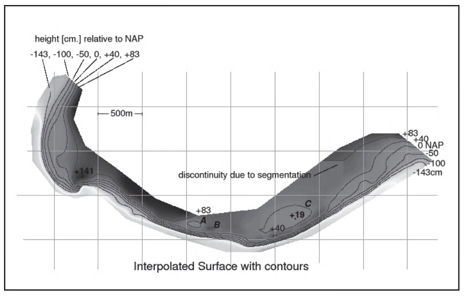

Figure 7.

survey area. From the hydrographic point of view the charted coastline and drying height contour should be shifted over a distance of 400 metres in the western part of the survey area. This difference in location of the respective contours is mainly due to the highly dynamic morphologic character of the terrain. It is suggested that a higher frequency of survey in this dynamic area, the extremity of the island, can increase the reliability of the chart during its lifetime. Revision frequency of small craft charts is once per annum.
Charts in the small craft series are revised into New Editions annually and updating by NtM is done weekly. However, correcting the coastline and contours by issuing block corrections is regarded laborious and expensive, and can only be applied a limited number of times on the same chart area in order to keep the Chart tidy and workable.

Conclusion

Working procedure

With regard to the procedure of survey, i.e. observing the waterline, the proposed method entails benefits and deficits. The workaround of travelling, by any means of transport, along the visual waterline of a sand beach doesn't require a huge budget or specialistic knowledge. Moreover, daily routine at Terschelling is that RWS staff carry out visual inspection of the beach, by car. Mounting a GPS receiver and a PC on the car and introducing a *'waterline inspection working procedure'* for the staff would be the sole requirement for data collection. A survey planner is needed for establishing times and routes depending on tide and daylight working hours. A data operator is involved afterwards to establish the tidal model from observed tidal heights during the survey, and makes the connection between position time and tidal height with the established tidal model. A quality check is made through both (human) visualising the DEM in the GIS environment, and calculating statistical properties of the DEM such as standard deviation of the difference DEM, and volume calculations.
There are limitations of the proposed method. One is that the surveyed area is limited to the intertidal area. Thus, creating a height model of dunes is not possible. A careful planning of the data gathering is absolutely necessary in order to be able to measure both High and Low water extremes on the same day. Only the hard and stable parts of the beach are suitable for survey by car. Results are only available after post processing, thus a quality check during the survey is not possible.

Cost per survey

The total cost per survey of Terschelling approximates €1060 when one survey is carried out per annum. When two surveys are carried out per annum the cost per survey is reduced as the fixed cost are halved resulting in €825 total cost per survey. The conclusion is that surveying the beach of Terschelling can be done at merely a fraction of the cost of traditional surveying.

Quality of the product

With regard to the accuracy standards as laid down in Special Publication number 44 by the IHO, the proposed method enables the determination of a natural coastline and the drying height contour for Order 1 type surveys areas and higher. The accuracy standard for Special Order survey is not met. As already explained in chapter 2, special order surveys are intended for areas where ships navigate with small underkeel clearance (UKC). This means that special order beach surveying would only be applicable when done for the purpose of planning amphibious operations, or near coastal fishery like shrimpers. The requirement of establishing 100% sonification cannot be met. However the traditional ways of beach survey, e.g. levelling, do not comply with this requirement either.

Why not use RTK ?

The cost per survey will increase drastically due to the increased value of the equipment and the increase of cost of labour, because operating RTK equipment requires a certain level of expertise which is not widely available throughout an organisation like RWS. Further limitation of RTK operations is the need for a 'line of sight' data link with the reference station. This limits its use in flat terrain surrounded by dunes 8 to 12m in height which block the data link. And secondly, the use of the reference station is limited to a distance of approximately 20-25km due to the possible difference in atmospheric conditions at the location of reference station and mobile receiver and also due to the limited height of the reference station antenna. This limitation urges the use of a second reference station at the expense of an increase in cost when the survey area exceeds 25km.

Acknowledgements

A word of thank goes out to:
- my colleague ir R. (Rob) E. van Ree for his detailed and in-depth commentary and support on the subject;
- the University of Nottingham for the use of their GRINGO and P4software package;
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- Meetkundige Dienst (RWS) for the use of the height reference data (AHN).

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Using ADCP Bottom Track for Surface Navigation

Jeroen van Reenen

Full cover hydrographic surveys by system integration

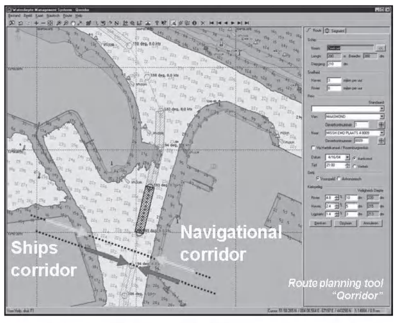
Port of Rotterdam of one of the busiest ports in the world. We have to deal with over 30,000 sea going vessels and 130,000 inland vessels coming in each year.

World Port Centre.

To control the involved ships movements Port of Rotterdam makes use of a state of the art VTS control centre situated in de city centre head quarters World Port Centre (WPC).

Controlling the ships traffic is a four dimensional job: Horizontal, vertical and time base vessel control. The VTS radar system is monitoring the horizontal movements, three hydrographic survey vessels are monitoring depth, current and sediment condition and the VTS operators are calculating time slots for vessel movements.

For ships route planning a special planning tool is used to guarantee a save passage to ships destinations within Port of Rotterdam. Yearly about 1000 incoming so called marginal draught vessels are tide based ships: they can only come in or go out at half or high tide.



Qorridor Planning Tool.

The planning tool "Qorridor" makes use of high density Electronic Navigation Charts (ENC's), predefined waypoint, actual and predicted tide information and a ships dimensions database. To calculate precise and effective time slots for incoming vessels the ENC's contains depths contours and areas every 10cm. Using this planning tool a time slot calculation can be made in advance of the arrival or departure.

To enable 4D route planning based on ENC's the hydrographic survey information is very important. The survey data must be reliable, up to date and full cover.

Multibeam survey vessel Dintelwerken.

To fix this survey job the Survey&Dredging department of Port of Rotterdam operates three multibeam survey vessels. Depending on the siltation rate of each port basin a yearly survey program is generated. According to this schedule surveys and dredging activities are carried out.

Each year about 5 million m^3 of siltation is dredged from the port basins and another 15 million m^3 from the fairways to and in Port of Rotterdam. The hydrographic surveys are presented by digital terrain models (DTM's) and converted to the various dredging operation systems. Also this data is used for the production of high density ENC's for the port planning tool and the portable pilot system (PPU).

To obtain the necessary full cover bottom information multibeam systems using GNSS-RTK positioning is not sufficient. Due to the port environment of container piles, cranes, big ships and other port constructions the GNSS positioning signals are sometimes blocked. Also the latest "all weather" indoor terminal developments are not allowing GPS positioning. If in near future Galileo will be added to the average 12 GPS and Glonass satellites, this will not solve the problem.

GPS Blocking Near Container Ships.

To fill in the none-GNSS position gabs Port of Rotterdam makes use of the ADCP bottom track navigation. For dynamic current profile measurements a RDI Workhorse Acoustic Doppler Current Profiler (ADCP) is build in two survey vessels. This ADCP can also be used for accurate bottom track output.

To combine the GNSS-RTK positioning and the ADCP bottom track we make use of the QINSy predicted positioning Kalman filter. This filter will become active as soon as one of the quality alarms of the GNSS-RTK positioning will appear. The last received "good" RTK position will be used as start point for the predicted positioning filter. The prediction filter is also reading the on-line bottom track and heading information. Due to this real time motion information the predicted position is very accurate (<0.5m) for al least three minutes. After two minutes the horizontal position will slowly drift to approximately 1.0m after five minutes.

Combining all available sensors on board of survey vessel will give you an effective full cover survey, including bottom information close and under moored vessels, under bridges and container cranes.

Biography

Jeroen van Reenen, graduated 1991 Nautical Collage Amsterdam, Hydrography (Hogere Zeevaartschol Amsterdam). Worked as hydrographic surveyor for Royal Boskalis during 1992 - 1999 on various dredging and marine construction projects world-wide. Since 1999 project manager for Port of Rotterdam, Survey&Dredging department. Responsible for hydrographic surveys, systems and special projects.

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Remote Sensing

AUVs, Hydrographic Vessels

Survey Challenges In Using Airborne Hydrographic Lidar To Survey The Gulf Of Morbihan In France

David Millar, Marc Lennon and Sylvain Lacombe

In June 2005, Fugro Pelagos, Fugro Geoid and Actimar SAS conducted an extremely challenging Airborne Hydrographic LIDAR survey of the Gulf of Morbihan for the Service Hydrographique et Océanographique de la Marine (SHOM) of France. The objective of the project was to validate LIDAR technology for hydrography and charting purposes and assess performances in detecting submerged objects.
The Gulf of Morbihan in Brittany was chosen by SHOM as the location for this technology evaluation, due to the diverse and complex conditions that characterize the coastal zone in this area. This paper will focus on the operational challenges that needed to be considered when planning and executing this survey. It will also demonstrate how LIDAR was used successfully in this very complex environment, when the risks were well understood and properly managed.

Project background

General

The French Government commissioned the Hydrographic and Oceanographic Services of the Navy (SHOM) and (IGN) to create a seamless topographic/ bathymetric model of the French coastal zone. The project, called Litto3D extends 10km inland from the land/sea interface and 6 nautical miles offshore from the same [1].
This project, entitled "Bathymetric and Topographic Survey By Airborne Laser of the Gulf of Morbihan", was a preliminary study for Litto3D and at the same time, served as a test project for submerged target detection. An RFP for the project was released in November 2004 and a team that comprised Actimar SAS, Fugro Geoid and Fugro Pelagos were awarded the contract in the winter of 2005.

Objectives

The primary objective of the survey was to provide a "life-size demonstration" of Airborne Hydrographic LIDAR Technology in the Gulf of Morbihan. SHOM wanted to test the limits of the effectiveness of the technology in various conditions characterizing the coastal environment. The Gulf of Morbihan was selected as the location for the survey, due to the complexity and diversity of its coastal environment. The Gulf of Morbihan contains beaches, lagoons, cliffs, turbid waters, strong currents and water depths less than 50m (Figure 1).

Figure 1: Oblique aerial photograph of the Gulf of Morbihan.

The Gulf of Morbihan is approximately 160km^2 and has a watershed that is approximately 800km^2. It is connected to the Atlantic Ocean by a 900m entrance, through which 400 million cubic meters of water flushes with every tide. This creates a very complex tidal regime, with time differences of more than 2 hours across the bay. At spring tides, currents can be as strong as 9 knots and the tidal range can be as great as 3.5m, which creates very turbid conditions and large areas of mud flats at low water. The gulf supports a vibrant aquaculture industry, with clams and oysters harvested in the bay. It also has a thriving tourism industry, with sailing, mooring, marinas and beaches.

Requirements

Specifically, the project was to provide an integrated topographic and bathymetric LIDAR survey of the entire gulf. While test-

ing the effectiveness of Airborne Hydrographic LIDAR in this complex coastal environment, the data would ultimately augment existing Multibeam Echosounder data, previously acquired by SHOM, for nautical chart production.
The survey had to meet IHO SP44 Order 1 Hydrographic Survey Standards. The absolute vertical accuracy was to be better than 50cm and the absolute horizontal accuracy was to be better than 5m. SHOM also specified a bathymetric sounding density of 4m x 4m.

Project planning considerations

Weather

The operation of Airborne Hydrographic LIDAR systems is subject to significant weather constraints. The presence of low cloud, fog and rain adversely affect the performance of Airborne Hydrographic LIDAR systems. In addition, high winds can also create flight safety issues and potential gaps in survey coverage.

The maritime weather in Brittany and the Gulf of Morbihan is extremely variable. The weather changes quickly and often. It is often windy, cloudy and rainy, though the best weather typically occurs in the summer months. After a thorough review of historical weather data, it was decided to conduct this survey in early June. This was reasonably favorable from a weather standpoint and also met some of the other project constraints, outlined below.

Water Clarity / Turbidity

The operation of Airborne Hydrographic LIDAR systems is subject to water clarity and turbidity constraints. Airborne Hydrographic LIDAR systems operating at around 532nm wavelength can typically penetrate 2-3 times Secchi Depth. The Gulf of Morbihan is considered turbid, with the turbidity primarily created by high tidal currents. However, research revealed that the sediments settle quickly when the currents are reduced or removed. As a result, a survey schedule was developed that had data acquisition occurring during slack tides (at both high and low water).

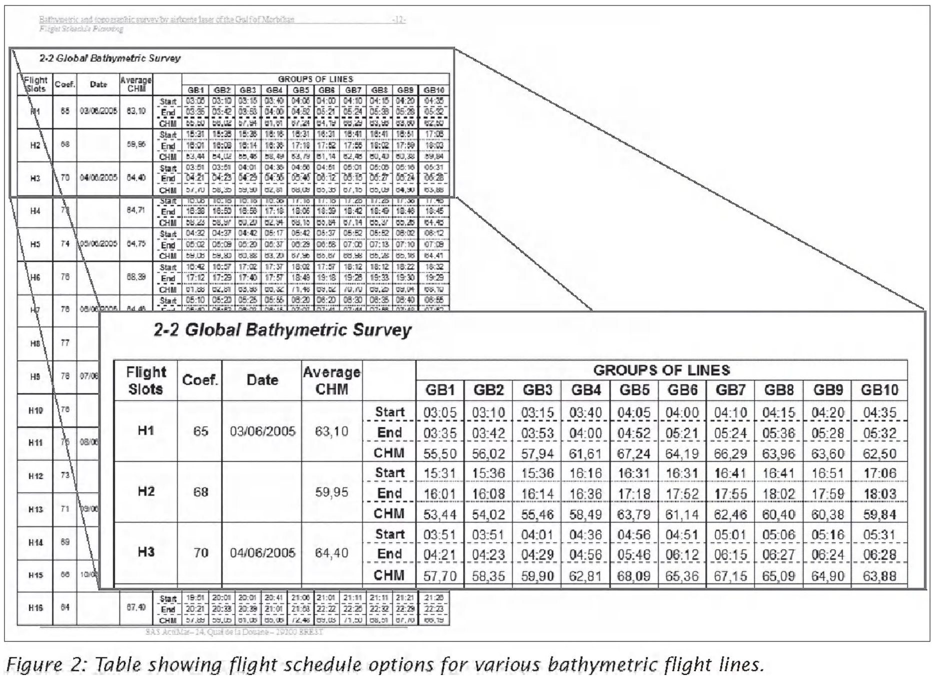
Currents / Tides

Closely related to water clarity and turbidity, described above, are currents and tides. The contract required that data acquisition occur during spring tides, when the tidal coefficient was greater than 70, in order to maximize the overlap between low and high tides in the intertidal zone. This condition created stronger currents and increased turbidity.

The Gulf of Morbihan is a very complex bay with many different tidal zones. The tidal range in the bay is on the order of 3.5m at Spring Tides. Currents at this time can be as high as 9 knots. The time delay between the mouth of the bay and the back of the bay is approximately 2 hours. As mentioned previously, to reduce the effects of turbidity caused by tides and currents, a survey schedule was developed that had data acquisition occurring during slack tides (at both high and low water).

Positioning

The contract required the use of three position sources, so that solutions based on all three sources could be compared and analyzed. Differential Global Positioning System (DGPS), Precise Processed Kinematic (PPK) GPS and Real-Time Kinematic (RTK) GPS were all required on the contract. Both PPK and RTK required the use of ground-based base stations. These stations had to be within 30km of the aircraft in order to meet the accuracy requirements of the project. In addition, the base stations needed to be close to the field office, in order to expedite processing. A portion of the survey was timed, so reducing travel time between base stations and the field office was critical. Furthermore, survey operations could only occur when the satellite constellation exceeded 5 satellites and the PDOP was less than 3.5. As a result,



2-2 Global Bathymetric Survey

Flight Slots	Coef.	Date	Average CHM		GROUPS OF LINES									
					GB1	GB2	GB3	GB4	GB5	GB6	GB7	GB8	GB9	GB10
H1	65	03/06/2005	63,10	Start	03:05	03:10	03:15	03:40	04:05	04:00	04:10	04:15	04:20	04:35
				End	03:35	03:42	03:53	04:00	04:52	05:21	05:24	05:36	05:28	05:32
				CHM	55,50	56,02	57,94	61,61	67,24	64,19	66,29	63,96	63,60	62,50
H2	68		59,95	Start	15:31	15:36	15:36	16:16	16:31	16:31	16:41	16:41	16:51	17:06
				End	16:01	16:08	16:14	16:36	17:18	17:52	17:55	18:02	17:59	18:03
				CHM	53,44	54,02	55,46	58,49	63,79	61,14	62,46	60,40	60,38	59,84
H3	70	04/06/2005	64,40	Start	03:51	03:51	04:01	04:36	04:56	04:51	05:01	05:06	05:16	05:31
				End	04:21	04:23	04:29	04:56	05:46	06:12	06:15	06:27	06:24	06:28
				CHM	57,70	58,35	59,90	62,81	68,09	65,36	67,15	65,09	64,90	63,88

Figure 2: Table showing flight schedule options for various bathymetric flight lines.

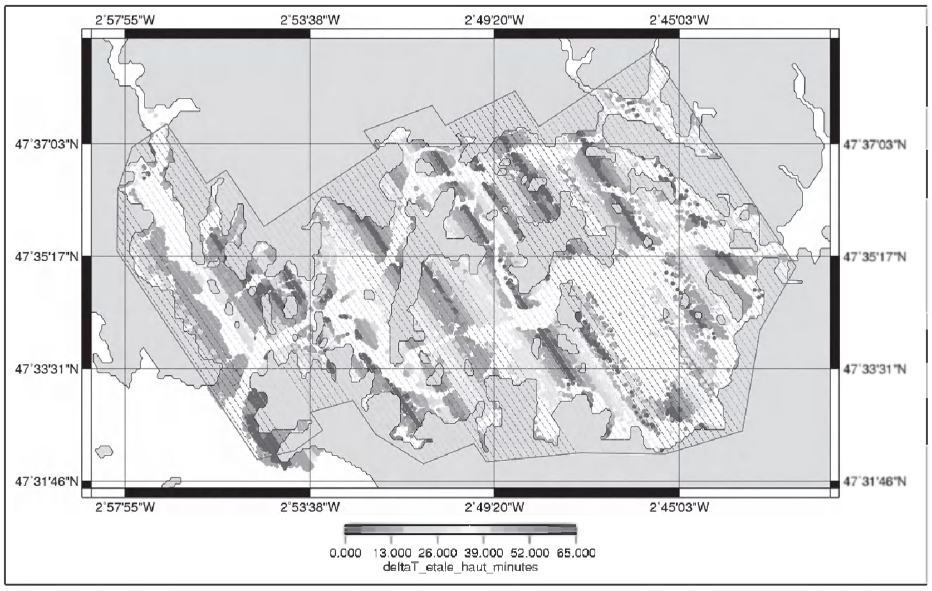


Figure 3: Color-coded shift between local slack time and real data acquisition time achieved during the survey. Colored legend is in minutes.

it was necessary to review the final flight schedule, which was driven primarily by tidal conditions, to ensure that the satellite constellation met the additional requirements outlined above.

Line Planning and Flight Schedules

As mentioned above, data acquisition had to occur during spring tides (coefficient > 70) in order to meet SHOM's specifications, as well as to provide maximum exposure of the foreshore. Given that turbidity is minimized during slack tides, High Sea Slack (CHM) was the target for bathy data acquisition and Low Sea Slack (CBM) was the target for topo data acquisition. Flight schedules were created using a dedicated flight planner developed by Actimar, which is able to optimize the flight lines planning by integrating changes in local tide conditions through a tide model. MASG$^{©SHOM}$, the tide model of the Gulf of Morbihan developed by SHOM, was integrated in the flight planner for this purpose. The flying window was planned to be 1 hour max before and 1 hour max after each local high and low tide. Shifting of local high and low tides through the Gulf with respect to time allowed the flight windows to be extended to more than 2 hours, while keeping the survey in the +/- 1-hour window from the local slack. With two high tides and two low tides per day, and by taking advantage of the tide shifting, up to 12 hours of data acquisition was possible. Operations were scheduled 24 hours per day. Figure 2 shows an example of flight schedule as optimized by the planner. Figure 3 shows the post-processed shifts between local slack time and real data acquisition time.

Aircraft Installation and Operations

The SHOALS-1000T is a portable system, so it was decided that the most cost-effective approach was to ship the system to France, where it would be installed on a suitable local aircraft. A French Cessna 404 was selected for the project. System mobilisation took place at Nangis Aerodrome, near Paris, in early June. The mobilized aircraft then ferried to the project area, where calibration verifications occurred and the project ultimately executed. Vannes Airport served as the base for air operations.

Ground Truth / Calibration Verification

Consistent with standard practices, calibration of the SHOALS-1000T was verified after mobilization and before commencement of the survey itself. The verification used previously established ground truth near or within the survey area. The ground truth consisted of two bathymetric areas within the survey area and two topographic areas, just outside the survey area. A coordinated peaked roof was also included as part of the ground truth. All ground truth was flown before the survey. In addition, one pass over ground truth was made on every sortie. It should be mentioned that "Power – Timing Test" were performed before, during and after every mission.

Project execution

Airborne Operations

As mentioned previously, the project involved an integrated bathymetric and topographic LIDAR survey of the Gulf of Morbihan. This involved a bathymetric LIDAR survey of the bay during high slack tide and a topographic LIDAR survey of the bay during low slack tide. Line plans and line schedules were established with this in mind. A summary of the parameters for the bathymetric and topographic surveys is presented in the following table:

Ground Operations

Survey Mode	Point Density	Flying Height	Flying Speed	Swath Width	Sidelap	Number of Lines
Bathymetric	4m x 4m	400m	126kts	215m	20%	108
Topographic	2m x 2m	900m	155kts	432m	20%	54

Table 1: Summary of parameters of bathymetric and topographic surveys.

The base of air operations was Vannes Airport, located north of the town of Vannes and north of the Gulf of Morbihan. A temporary field office was established in a farmhouse, located within 5 miles of Vannes Airport. The farmhouse provided both accommodations and office space during the project. A second farmhouse was used to provide additional accommodations for the 14-person team. The GPS base stations were also located within close proximity to the temporary field office. As mentioned previously, data acquisition and processing activities took place 24 hours per day.

Processing

Data processing took place in near real-time at the temporary field office that was established near Vannes. Two shifts of data processing occurred around the clock during data acquisition. The primary function of these data processors was to auto-process data, verify that accuracy requirements were met and verify that coverage requirements were met. After the data acquisition was complete, the data center was moved to Actimar's office in Brest, France, where a smaller team continued to process data, produce deliverables and write the final report.

As expected, data processing was very time consuming in this complex environment. Significant manual data cleaning and editing were required to remove boats, buoys and oyster bed structures. Through the team's careful research and meticulous mission planning, the depth of penetration was typically 8-10m.

Part of the project involved target detection tests. SHOM placed two "advertised" targets within the survey area. Their precise locations were not provided, however. Each target was a 1m x 1m x 1m cube with rough concrete faces. One target was placed in approximately 8m water depth, while the other was placed in approximately 10m water depth. Both "advertised" targets were detected by the SHOALS-1000T using a 2m x 2m sounding density with 200% coverage. In addition, an "unadvertised" target was found in approximately 5m of water. This target was a rock of 2m x 1.6m x 1.2m (LxWxH) dimensions and was unknown to SHOM. The data was subsequently used to update the appropriate nautical chart.

In addition to the XYZ point data mentioned above, the survey also involved the collection and processing of aerial photography. The SHOALS-1000T has a DuncanTech DT4000 RGB camera and this acquires high-resolution aerial photography at a rate of one frame per second. Ortho-rectified photomosaics with a pixel resolution of approximately 30cm were produced and delivered to SHOM.

Report and Deliverables

A comprehensive set of deliverables was presented to SHOM as a result of this survey. The extensive deliverables were required for SHOM to further analyze the dataset, so that they could better understand the capabilities and limitations of the technology and use these when developing specifications for future projects. A list of the deliverables included in this project is presented below:

- All raw LIDAR data, including waveforms
- All raw imagery
- The following digital products:
  - Integrated bathy/topo DEM in CARIS, DTED, GeoTiff, XYZ grid nodes
  - XYZ, time, water level, depth confidence in ASCII format for bathy data
  - XYZ of first pulse and last pulse, time, intensity in ASCII format for topo data
  - Ortho-rectified Photomosaics
- The following products in digital and hard copy format:
  - Profiles and cross sections for the "Beach Survey"
  - Slope map for the "Beach Survey"
- Metadata
- Survey Report in French

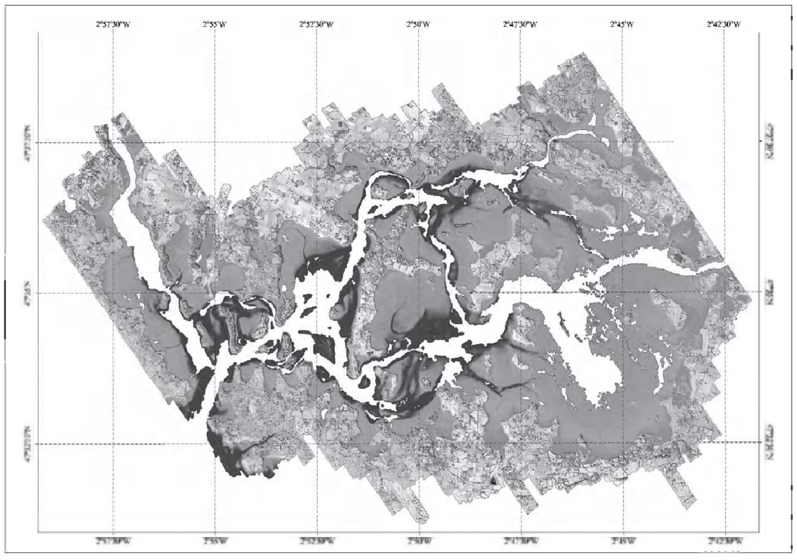


Figure 4: Color-coded elevations from integrated bathymetric/topographic DEM.

Preliminary conclusions

SHOM continues to analyze the data from this project. It is expected that a formal report with specifications will be issued by the fall of 2006. While this was an extremely comprehensive project that allows SHOM to evaluate the limitations and capabilities of the technology in numerous different regards, it is safe to say that the use of LIDAR (bathy, topo and aerial photography) for general hydrography was proven to be efficient even in a complex hydrodynamic environment. Furthermore, it may be possible to utilize LIDAR in the most complex hydrodynamic environments, if the environmental risks are well understood and properly managed.

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The authors would like to thank SHOM for having commissioned Actimar SAS, Fugro Geoid, and Fugro Pelagos to carry out this challenging survey, and for having provided the authors with their tide model MASG©SHOM. The authors would especially like to thank Laurent Louvart, C. Le Roux, Nathalie Debèse, and Yves Pastol, from SHOM, for having shared their long experience for assistance during the whole project.
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Operational Remote Sensing Mapping Of Estuarine Suspended Sediment Concentrations (ORMES)

Sindy Sterckx, Els Knaeps, Mark Bollen, Koen Trouw and Rik Houthuys

Within the ORMES project a service is developed which provides suspended sediment maps from remote sensing images in an efficient way. Our main test site is a part of the Belgian Scheldt Estuary near Antwerp. A reliable semi-empirical algorithm has been developed to derive near-surface suspended matter maps in an operational way. This algorithm is applied to a series of hyperspectral airborne data obtained at different stages of the tidal cycle. The produced TSM maps showed good agreement with known variations of the suspended sediment content over the tidal cycle: maximum turbidity around high water and gradual settling of the sediment in the succeeding slack water. The cross-river differences in TSM matched well the variation measured at previous field campaigns.

Introduction

Each year, dredging companies remove more than two million m^3 of estuarine sediment from the Scheldt River (Belgium). This is necessary to assure access to the harbour of Antwerp. International Marine and Dredging Consultants (IMDC) advises government agencies and dredging companies to help them carry out their activities. Information on the sediment concentration is essential if accurate advice is to be given. IMDC uses this information to select new salvage locations, to estimate possible movements of sediment clouds and to calibrate sediment transport models. At the moment turbidity meters and water samples can provide measurements of suspended sediment concentration. However, these types of analysis are time consuming and expensive. Furthermore traditional in-situ measurements performed at single points or along transects are insufficient to provide a complete view of the spatial variability of suspended sediments. A cost-effective way of providing this information is to use remote sensing data. These data can cover relatively large areas instantaneously at relatively low cost and are therefore ideal for this type of assessment.

For these reasons, IMDC relies on the ORMES project in order to develop a simple and robust procedure for near surface sediment concentration mapping from remote sensing images. The ORMES project focuses on the full capability of state-of-the-art airborne hyperspectral sensors but also looks into possibilities to monitor the turbidity and deduce sediment concentration on a more routinely basis by converting the operational methodology to UAV (http://www.pegasus4europe.com), micro-satellite platforms and to broadband multi-spectral satellite sensors (eg. SPOT HRV, FORMOSAT).

Within the ORMES project the Scheldt Estuary has been chosen as main study site mainly because of its dynamic complexity. If the developed sediment mapping procedure works fine here, it is expected that the algorithm can relatively easily be applied to other tidal regions abroad. In this paper we will present the results obtained within the ORMES project for the Scheldt test site using hyperspectral airborne data.

Background on remote sensing of suspended sediments

The colour of water is affected by certain constituents including suspended sediments and therefore it is possible in suitable circumstances to detect their presence in water and quantify their respective concentrations using remote sensing. Passive remote sensing uses the light coming from the sun which is transmitted, scattered or absorbed by particles or molecules in the water body. The scattered light may subsequently leave the water body. This water-leaving radiance can reach the field-of-view of a remote sensor. The sensor measures the scattered light in several wavelength bands, often, even beyond the range of human vision (ultra-violet, infrared, microwave). Suspended sediments increase the radiance emergent from surface waters in the visible and near infrared proportion of the electromagnetic spectrum [1]. Hence, satellite or aircraft remote sensing data can be used to study near-surface suspended sediment patterns. Still, to derive concentrations of suspended sediment, some additional surface water samples are usually needed to set-up a calibration relationship between remote sensing data and suspended sediment. The calibration relationship is influenced by the composition and grain size of the suspended sediments and the spectral characteristics of the remote sensor (i.e. number, width and location of the wavelength bands).

Test case : airborne hyperspectral data over the scheldt

Study Site

The Scheldt river finds it origin in northern France and flows through Belgium via Antwerp towards the North Sea. Our study site is restricted to a part of the Lower Sea Scheldt as illustrated in Figure 1. Although the open North Sea is about 60 km away from Antwerp, the Scheldt is an important shipping channel giving access to the vast port area of the city.

The Scheldt is a complex river system where concentrations of suspended sediment are highly variable in place and time. The concentrations are in the range of a few hundreds mg/l [2]. At this location, the tidal range is more than 4 m.

Airborne and field data

On June 15th 2005 hyperspectral airborne data were collected with the AHS Advanced Hyperspectral Sensor (SenSytech Inc) at different stages of the tidal cycle. The data was collected in 80 spectral channels, covering the 0.430 µm to 12.70 µm electromagnetical wavelength range. Although weather forecasts were optimistic and the sky was clear at the beginning of the campaign, thin cirrus clouds covered the study area gradually. The remote sensing data were atmospherically and geometrically corrected.

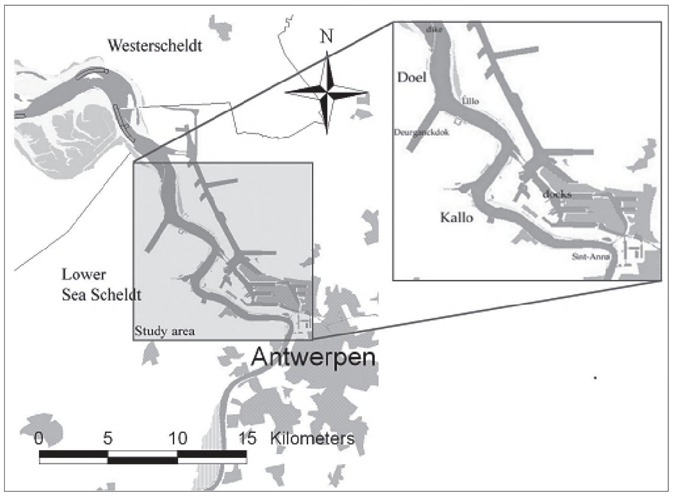

Figure 1: Study area.

Simultaneously with the aircraft overpasses, an extensive field survey took place. Two survey vessels were used at different stretches of the Lower Sea Scheldt to include some spatial variability. An extra vessel was deployed at the docks in the harbour of Antwerp. Several measurements were done on board of each vessel on predesignated locations at the time of airplane crossing over the study area. Four jetties served as additional fixed sampling locations. 150 surface water samples were collected and stored in 1 liter bottles to determine total suspended matter concentration. At one vessel in the Scheldt a turbidity sensor (Aanderaa RCM-9) continuously logged turbidity in the surface water layer. The location of the boats was continuously logged with a Trimble GeoXT GPS. Sun-photometric measurements were performed to estimate the aerosol content and water vapour in the atmosphere to calibrate the radiative transfer model used in the atmospheric correction. General atmospheric conditions were registered by taking photos of the sky at all the sampling locations of the boats.

Data processing

Field data processing

The TSM concentration was determined by filtering 250 ml of the water samples on pre-weighed 0.45 µm membrane filters. Filters were then dried and re-weighed. The measured TSM concentration in the Scheldt river and the docks ranged from 13 to 336mg/l and 7 to 12mg/l respectively.

To convert the continuous turbidity measurements in nephelometric turbidity units (NTUs) to TSM (measured in mg/l), the relationship between turbidity and TSM from water samples was statistically modeled for coincident points. A linear relationship was found with an R^2 of 0.83 and an RMSE of 35.2mg/l. This best-fit regression equation was then applied to all turbidity measurements.

Chlorophyll-a concentration was determined for six water samples following the ASTM D 3731-87 Standards [3]. The average CHL-a concentration was 4.4µg/l in the Scheldt river and 19,1µg/l in the docks.

TSM Algorithm

Reflectance spectra R(0-) were extracted from the hyperspectral images at the sampling locations. An average spectrum calculated from a 5 by 5 box of pixels (corresponding to an area of 20 m by 20m) was preferred to remove random noise. In the study area, the suspended matter concentrations and patterns change very rapidly as the tide fluctuates. The timing between airborne and in-situ sampling is therefore a critical issue. Hence, to calibrate as accurately as possible, only the samples taken within a few minutes of the airborne data recording were included. In total 41 samples were available to find a band combination which best predicts the TSM concentrations. The best fit with an R^2 of 0.83 and an RMSE of 15.53mg/l was found to be a log-linear line fit to a band difference:

$$\mathrm{Ln(SPM)} = 34.18 * (R(0-,833) - R(0-,1004)) + 3.16 \quad (1)$$

where R(0-,833) and R(0-,1004) are respectively the reflectance at 833nm and 1004nm.
The algorithm (1) providing the best fit was then applied to all the AHS data to map TSM concentration at different tidal stages. To predict how well the algorithm will perform for the entire dataset a leave-one-out cross-validation (LOOCV) is applied.

The RMSE of the LOOCV for our log-linear line model was 17.06mg/l.

For more detailed information on the data processing the reader is referred to [4].

TSM maps

The produced TSM maps (Figure 2 and Figure 3) are in good agreement with the known distribution of the suspended sediment content over different tidal phases. Figure 2a, taken at high tide, shows – compared to the other figures – high surface silt concentration. These general high near-surface TSM concentrations are mainly explained by high current velocities at high tide. The high concentrations are spread out over the whole cross-section, similar to the velocity distribution pattern observed by [5]. In the entrance channel of Kallo where velocities are much lower, lower silt concentrations at the surface can be observed.

In the succeeding slack tide high water (Figure 2b) the observed TSM concentrations are much lower. At this stage velocities are very low, which results in much lower surface concentrations of TSM, due to the sinking of the sediment particles [2,6].

A resuspension of sediment takes place at the onset of the ebb flow stage, especially at the bend-related shoals (Figure 2c). During ebb (Figure 3a-c) downstream velocities are observed, i.e. the sediment concentration is higher downstream of the inside of curbs which are shallower areas. Eroded sediment at the shallow area is dragged in the downstream direction. The distribution and concentration of the sediments remain relatively constant during these 3 successive tidal stages (Fig. 3a-c). The horizontal cross-section variation in TSM matches the variation measured at previous field campaigns. Surface silt concentrations are higher at the right bank than at the left bank [7]. A striking feature of sediment plume at this stage of the tide is observed at the Doel flow guidance dam, which emerges at low water. The submerged flow guidance dike clearly separates high silt concentrations west of the dike from low silt concentrations east of the dike. This dike is the border between a shallow area (resulting in high sediment concentrations at the surface) west and the navigation channel eastward.

Another known feature, well present in all the produced maps, is the low-TSM concentration in the harbour docks. Some sediment enters the docks near the access locks during sluicing operations. This sediment settles in the adjacent harbour dock. To verify these conclusions extra validation will be performed using a series of turbidity measurements along horizontal cross-section transects made by IMDC in the past at different stages of the tidal cycle.

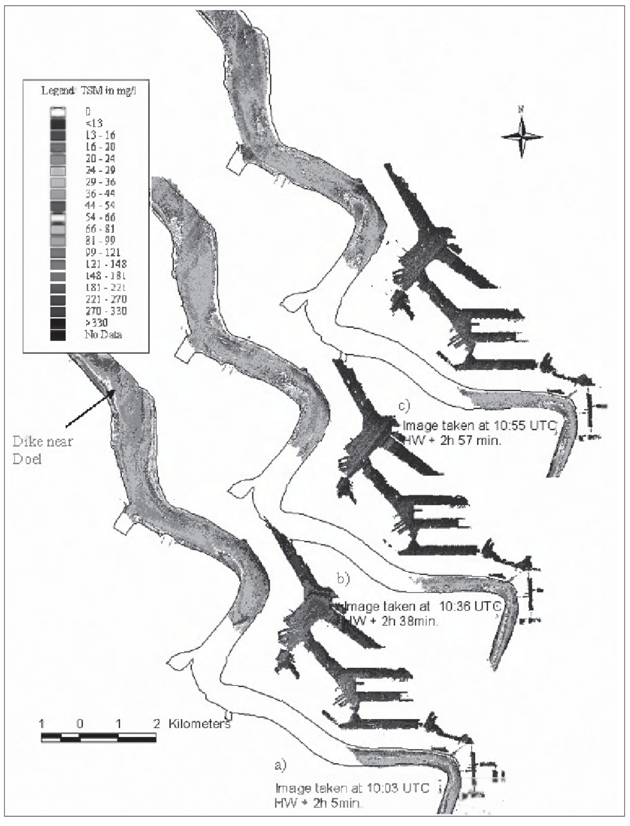

Figure 3: TSM maps for the Scheldt at 10:03, 10:36 and 10:55 UTC.

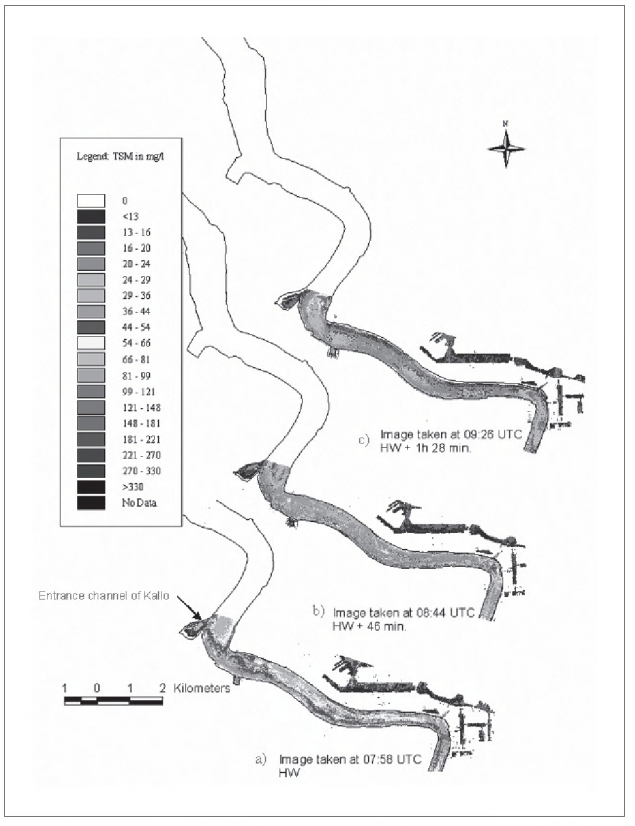

Figure 2: TSM maps for the Scheldt at 07:58, 08:44 and 09:26 UTC.

Conclusion

A calibrated regression model, that relates remote sensing reflectance data with field measurements of suspended sediment concentration, was applied to airborne remote sensing data. This procedure provided a detailed and synoptic overview of the suspended sediment fluxes and concentrations in the Lower Sea Scheldt near Antwerp at different stages of the tidal cycle. Even without calibration on the basis of in-situ data, remote sensing data complements traditional data collection techniques as satellite and airborne data can easily indicate the spatial pattern of suspended sediments which is not possible trough traditional measurement campaign. Remote sensing can provide high temporal coverage which is almost impossible by other existing techniques. However remote sensing will not fully replace the traditional field surveys as the measuring range is limited to the top few feet of the water column, especially in turbid waters [8] and cloud cover may obscure remote sensing data. Ideally, different techniques, i.e. limited field survey combined with remote sensing data and sediment transport models, should be deployed simultaneously as they complement each other.

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Unmanned Wavepiercing Vehicles For Hydrographic Survey

Hugh Young, Stephen Phillips and Daniel Hook

Unmanned wave-piercing vehicles (UWVs) combine many of the advantages of USV's and UUV's. They have the endurance, economy, speed, communications and positioning of USV's combined with the stability and much of the covertness of UUV's to give a new, adaptable, mobile instrumentation platform. If they are also stable at slow and zero speed they can deploy sensors to depth either from a winch or a daughter ROV or AUV. Autonomous Surface Vehicles Ltd have developed just such a vehicle and have recently received an order for a commercial variant for survey purposes. The applications of such vehicles to surveying in inland waters and shallow water are discussed, as well as applications to oceanography, seafloor mapping and remote sensing.

Introduction

The market for unmanned systems is developing fast, with well known and proven applications on land, at sea, in the air and in space. They have been shown to offer cost effective alternatives to manned systems engaged in activities involving significant danger, which are tedious or repetitive or where the optimisation of unmanned systems can provide significant commercial or technical benefit (for example by miniaturisation).

At sea, both underwater and surface unmanned craft have been developed and more recently, hybrids of the two have been discussed. Underwater vehicles clearly have the advantage of being able to dive to depth but suffer from lack of real endurance and speed, thus often have poor operational availability, unless serviced via a power umbilical. Likewise the transmission of data to and from the underwater vehicle is also very limited unless via a data transmission umbilical, thus real time communication and position fixing is particularly restricted.

Unmanned surface craft can operate with diesel power to give better operational availability and can use normal radio and satellite data communications for real time data transmission and position fixing. Traditionally, however, small surface vehicles have been very limited by their seagoing ability.

By the use of semi-submersible wave-piercing craft, this seagoing limitation has been significantly reduced, and the use of fully submerged daughter vehicles enables data from the sea bed to be transmitted in near real time. Autonomous Surface Vehicles Ltd (ASV) has developed a number of such craft, starting with small research vehicles to explore new ideas, progressing to a large, six metre, diesel powered prototype (code named the SASS 6M – Survey Autonomous Semi-Submersible) which proved the semi-submersible technology at full scale. The Company is now designing and building commercial unmanned wave-piercing vehicles for survey and visual surveillance.

Development of SASS 6M

Tests and trials with SASS technology have been extensive. Model tests and CFD undertaken by the University of Southampton were first used to establish the most appropriate water-plane area to displacement ratio of the semi-submersible design and the shape of low drag but practical hull forms. The aim was to provide a relatively small vehicle capable of operating in high sea states with adequate payload capacity, speed and endurance.

In 1998, a 2 metre, petrol engine prototype SASS was built under a research grant and tested at sea to establish the handling characteristics and the practicality of operation of the proposed SASS configuration.

On being granted a UK Government SMART award in 2001, the company designed, built and tested a 6 metre diesel powered SASS. Trials with this vehicle have covered the following:

a. General handling trials at sea (speed/power, manoeuvring and seakeeping).
b. Side by side comparisons with other unmanned surface vehicle concepts, investigating seakeeping and handling characteristics.
c. Surveillance trials using above water mounted cameras.
d. Below water survey using an S.E.A. SWATHplus Sonar and an Ultra Electronics Synthetic Aperture Sonar.
e. Above and below water noise trials (currently programmed)

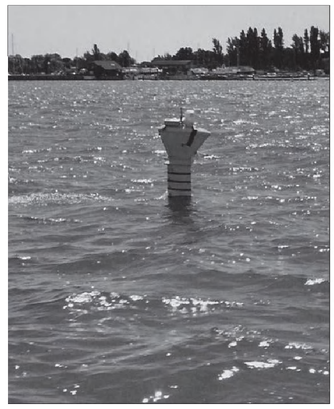
For very rough sea trials, ASV Ltd has had to resort to free running model tests due to the difficulty and costs involved in running such full-scale trials. Tests in sea-state 5 have shown no obvious limitations at surveillance speeds of 8 knots.

These latter tests have also indicated particularly low added resistance in waves such that the speed of the SASS in rough sea conditions can be as high as that of an otherwise much faster planing craft operating in similar conditions.

Launch, Recovery and Stowage

The use of the substantial vertical spar in the wave-piercing vehicles provides an ideal strong-point from which the vehicle can be secured for launch and recovery.

The primary recovery system for the SASS involves driving the SASS into a Vee channel formed in the stern of a RIB-like recovery craft, with both craft operating at a forward speed of about 5 knots. The RIB is towed behind the ship using a tow-line but also has a lifting line permanently secured to it from the ship's davit. Once the SASS has driven into the recovery craft, a mechanism traps the spar and inserts a lift-pin through the spar. The RIB/SASS combination is then pulled forward to a position under the davit and recovered in the normal way. The RIB tubes provide protection for the SASS in cases of impact with the ship's side during lifting. The launch procedure is simply a reverse of that used for recovery.



SASS 2M (2.0 metre) vehicle

SASS 6M (6 metre) vehicle

This system has been proven at model scale in head sea wave conditions up to sea-state 5 without any apparent limitations – higher sea-states were not possible to test at the time due to wave-maker limitations.

The significant advantages of this system are:
a. People are not required to operate near the water surface. This therefore minimises risk to safety.
b. Actual recovery of the vehicle is made away from the ship, thus minimising risk of damage to the ships propellers.
c. Launch and recovery can take place at forward speed, thus the mother-ship can maintain steerage.
d. The system is operable in high sea-states.

The efficient use of multiple unmanned craft is likely to require a more specific type of recovery system and to this end, ASV Ltd have designed a stern ramp arrangement which allows rapid recovery of multiple vehicles one after another.

Recovery of a 'dead' vehicle is at present undertaken by the release of a short cable from the nose cone which is then grappled from the mother vessel.

Regulation Development

It is recognised that the commercial market for unmanned craft cannot develop without adequate and acceptable regulation. It is also considered unlikely that international regulations will be developed in the near future. Thus ASV Ltd have developed an outline set of regulatory guidelines based on a Formal Safety Assessment (FSA) approach, which can be used by local administrations as a basis for the regulation of unmanned surface craft operations.

The FSA approach covers a number of activities; the primary steps being as follows:
a. Information gathering and definition of hazards
b. Assessment and ranking of associated risks
c. Development of risk control measures to give acceptable risk levels

Three primary risk control measures are proposed – the first is to set an (arbitrary) bound to the size of the unmanned craft considered (proposed 12 metres). Without a non-controversial size limitation it is expected that regulation of unmanned surface craft would become overly complex. The second is to propose that the operation of these craft be restricted. This is implemented by defining a number of Categories of Operation within which operational restrictions are aligned with specific secondary risk control measures (such as speed restriction against restricted areas of operation). The third is to provide a clear means of identifying such a novel vessel. For this a flashing light is proposed, possibly not yellow to disassociate it from hovercraft or surfaced submarines, which show yellow flashing lights. Such a measure is suggested to ensure that the entire marine community can identify an unmanned surface vehicle, since these are not covered by any national or international laws of the sea at present.

The proposed Categories of Operation are as follows:
Category A – Operation within 500 metres of mothership. This gives the ability to use these craft to give a 1 km survey swathe around a ship of opportunity. Vehicle monitoring and overall control is envisaged to be undertaken from the mothership.
Category B – Operation within a pre-determined and monitored area. This might be a buoyed off and patrolled area or possibly an area prescribed (permanently or temporarily) for operation of unmanned craft in which these craft can maintain an adequate lookout using optical and electronic sensors.
Category C – Temporary surface operations. This would cover the surfacing of underwater vehicles.
Category D – Autonomous operation within pre-determined area.

The details of the associated risk control measures for each category are at present of a proprietary nature.

Vehicle Designs

ASV Ltd provide the design and production of ship-deployable unmanned piercing vehicles for specific applications, including:

Low noise diesel-electric vehicles for fish-stock assessment

This vehicle has a transit speed of 10 knots on diesel engine and 5 knots on electric motor. The endurance at 10 knots is 2 days. The vehicle is fitted with a Kongsberg Simrad EK 60 sonar and features real time data-transmission to a mother-ship.

Coastal and environmental surveillance vehicle

The surveillance vehicles id fitted with above and below water sensors, covering 360 degree video cameras, SEA Swathplus sonar and WET Lab environmental sensors. The vehicle can remain on station for one month and has a transit speed 10 knots. A version of this design can also submerge for limited periods in order to avoid surface detection if necessary.

Rapid response vehicle

Similar to the coastal surveillance vehicle, this craft carries a small ROV for deeper water inspection. Transit speed 12 to 15 knots. Typically a small ROV, such as the Seabotix LBV 300, could provide acceptable performance down to about 100 metres in 2 knots of current

The company currently has a contract from C&C Technologies in the USA for the supply of a 5 metre unmanned wave-piercing survey vehicle based on the above mentioned surveillance vehicle.

Applications for Unmanned Wave- Piercing Vehicle

Both the civil and military applications of this technology are wide ranging, covering most of those using survey techniques. Applications involving long periods of loitering to gather data or those requiring frequent repetition are particularly relevant. The most usual is hydrography, but other examples are remote sensing, fisheries assessment and oceanography, and the interception of illegal immigrants or goods, or surveillance for the security of valuable assets such as oil rigs.

Remote Sensing

Remote sensing is an element in several other applications, such as hydrography and oceanography and, as mentioned above, for rapid response surveys where deployment of ships would take too long.

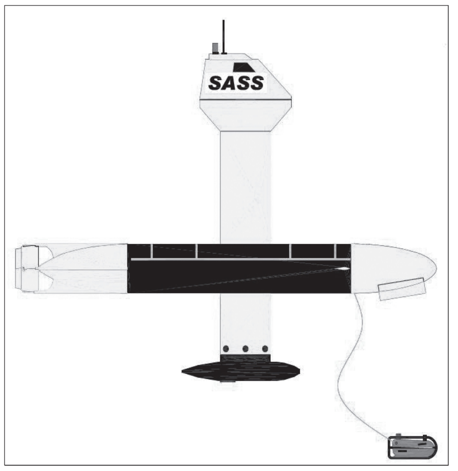
Because SASS vehicles can remain stable while stationary, they can deploy small imaging ROVs and relay the images via the umbilical by telemetry to shore or a mother ship. Small ROVs can carry visual identification sensors to depths of up to 300 metres. The Seabotix LBV 300 is one, with its own self-spooling winch for paying out the umbilical cable, and data profiles can be relayed directly ashore to radio ranges. Power for the ROV can be supplied from the SASS by running the diesel engine.

Drawings have been prepared to house the winch and ROV developed by Seabotix in the nose cone of the SASS prototype, and trials are planned as soon as funds are available. A schematic drawing of the arrangement is shown in the picture below:

Extending the idea of SASS vehicles as mother ship substitutes for ROVs, leads to the concept of a daughter AUV. All AUVs suffer from the disadvantage of limited speed, and power. For smaller vehicles endurance and range also impose severe limitations, and they are usually carried to an operating area by survey launch or ship. A SASS vehicle, however, can carry, launch and recover a small AUV.

The SASS prototype vehicle is not itself capable of carrying AUVs, but the basic SASS technology is flexible and concept studies are planned to develop suitable vehicles for deploying Remus and Gavia sized AUVs, possibly in pairs so that one can be on station while the other is recharged.
Alternatively the SASS need not actually carry the AUV. It can carry out another function of a mother ship by escorting the AUV, updating its inertial navigation system (INS) and checking that the sensor instrumentation is working without requiring it to

interrupt its task and come to the surface. It is planned to fit ultra short base-line (usbl) equipment to the SASS prototype to track a submerged AUV, and remain vertically above it so as to obtain optimum accuracy and the best acoustic path for communications. This also enables an operator to know exactly where the AUV is, as well as having assurance that sensors and positioning systems are correct. Thus an AUV and a SASS vehicle can enhance each other's performance by working together as a collaborating pair. This combination can in principal provide remote subsea data profiles of all types at long radio ranges.



Drawing of SASS + ROV.

Hydrography

SASS-type vehicles can carry virtually any surveying equipment that a ship can carry, either acoustic or electromagnetic sensors. For routine survey work swath bathymetry, side scan and synthetic aperture sonars are particularly applicable inwater depths down to about 50 metres. The S.E.A. Swathplus and a synthetic aperture sonar have been demonstrated in these waters. For deeper water swath bathymetry sonars are applicable provided the resolution required is not too great. If greater resolution is required remote sensing daughter ROVs or AUVs can be used. Routine and repetitive surveys are particularly relevant, such as shifting sand banks, or security surveillance. Current measurement for tidal studies, and wave form measurements are also possible at the same time as bathymetry.

Shallow Water and Inland Surveys

The SASS technology is flexible and capable of realisation in different configurations. One such version has a small keel and is suitable for shallow water applications. It can also be launched and recovered over the stern, which is sometimes a desirable alternative to alongside handling. The trade off versus the longer keel version is some slight reduction in stability; although this is not significant for inland water applications. Size can also be varied and designs to suit particular applications are encouraged due to the possibilities for optimisation for specific projects.

Oceanography

This is a wide-ranging subject, covering taking physical, chemical or biological readings or samples either on the move or at varying depths while stationary. The ability of SASS-type vehicles to remain in one position for long periods using GPS enables time sequences at several locations to be taken during a mission. Biological oceanography also extends to and overlaps with fish stock assessment, and quiet vehicles can be used to study undisturbed biological populations over extended periods. Daughter vehicles could also be used if necessary.

A further application of these vehicles is in air/sea interface studies, particularly relevant to climatology. Sensors can be fitted both above and below the surface and the resultant measurements are not distorted by the presence of a vessel.

Conclusions

Wave-piercing vehicles are a new development in the unmanned vehicle industry. They combine many of the advantages of UUV's and USV's for activities involving significant danger, which are tedious or repetitive or where the optimisation of unmanned systems can provide significant commercial or technical advantage. In particular applications they can act as ship substitutes, mother-ships for UUV's, and as mobile buoys.

A six metre prototype vehicle has been designed, built and demonstrated by ASV Ltd., who have also derived several variants for special purposes, and are currently designing such a hydrographic survey vehicle for C&C Technologies in the USA. Furthermore a regulatory environment for the operation of these vehicles has been developed: this being seen as essential if unmanned vehicles are to gain wider acceptance in the maritime community.

Practical, robust and cost effective unmanned vehicles are now in build at ASV Ltd – the potential market is very large and it is considered that commercial survey operations will benefit substantially from the use of these vehicles once operational procedures are better established.

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Sea Floor Mapping

Measuring High Concentration Benthic Suspensions (Hcbs)

Using A High Resolution Siltprofiler

M. Bollen, M. Sas, J. Vanlede,
T. de Mulder

Introduction

Background

The Lower Sea Scheldt is the stretch of the river between the Belgium-Dutch border and Rupelmonde, where the entrance channels to the Antwerp sea locks are located. The navigation channel has a sandy bed, whereas the shallower areas (intertidal areas, mud flats, salt marshes) consist of sandy clay to pure mud sometimes. This part of the Scheldt is characterized by large horizontal salinity gradients and the presence of a turbidity maximum with depth-averaged concentrations ranging from 50 to 500 mg/l at grain sizes of 60 - 100 µm. The salinity gradients generate significant density currents between the river and the entrance channels to the locks, causing large siltation rates. It is to be expected that in the near future also the Deurganckdok will suffer largely from such large siltation rates, which may double the amount of dredging material to be dumped in the Lower Sea Scheldt.

During the last years, the composition of the sediment dredged at the Sill of Zandvliet became more muddy, yielding since 2002 a strong increase in dumping volumes at the allocated dumping sites.

Many surveys have been carried out to increase the understanding of the dynamics of fine sediment in the Lower Sea Scheldt. Also, salinity and turbidity is measured continuously at Prosperpolder and Oosterweel. However, none of these measurements have been carried out in the lower 1 m of the water column.

It is expected that temporary layers of soft mud may be formed in this lower part of the water column, which may move independently of the tidal water movement, in particular during slack water. These layers may be remixed during accelerating tide, an indication for which is the observation of mud clouds at the water surface during maximum ebb and flood velocities. If such layers exist, they may contribute significantly to the siltation rate in the Deurganckdok. This would imply that measures (for instance passive constructions) to minimize siltation in the Deurganckdok can only be successful if such measures also affect the dynamics of these soft mud layers. Therefore, it is important to establish the role of these soft mud layers on the sediment dynamics in the Lower Sea Scheldt, both from a qualitative and quantitative point of view.

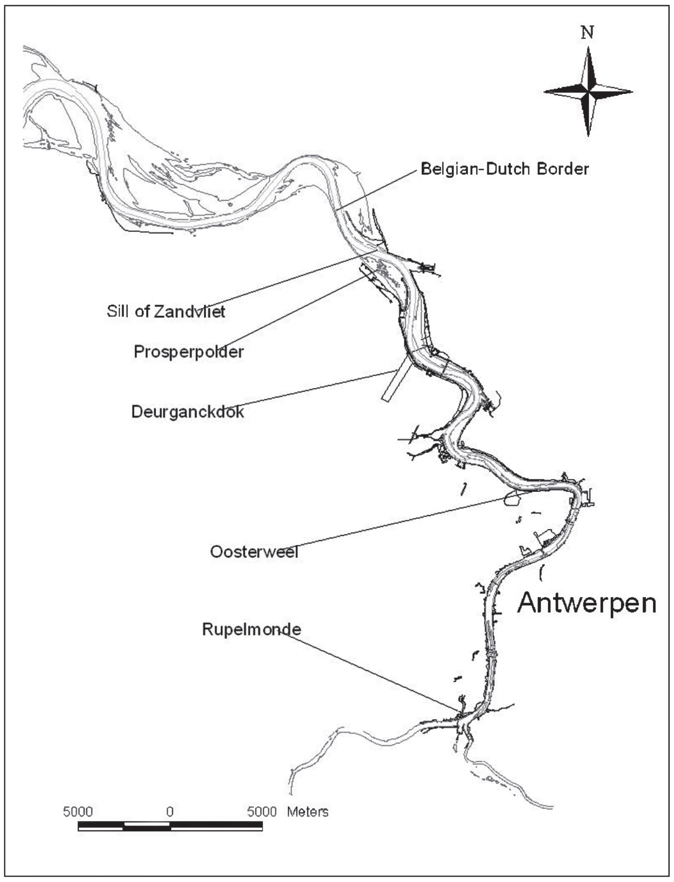


Figure 1: Overview of the Lower Sea Scheldt.

Survey Goals

The primary goal of the survey was to detect the occurrence of near-bed high-concentration mud suspensions (referred to as **high-concentration benthic suspensions - HCBS**), their dynamic behaviour and the conditions and locations of their occurrence.
The second goal was to establish fluxes of fine sediment in the river with the purpose to calibrate a numerical 3D fine sediment transport model of the Lower Sea Scheldt.

The third goal was to establish the sediment properties required for a sediment transport model.
Three surveys were foreseen. The first survey was carried out prior to the opening of the Deurganckdok on March 1, 2005. This survey was carried out on 16-17-18 February 2005. The second survey was conducted 21-24 March 2006 and a third measurement campaign is planned in September 2006.

Measurement Set-up

Equipment

During the HCBS measurement campaign in February 2005 several measurement techniques were combined to investigate the dynamic suspended sediment behaviour in the vicinity of Deurganckdok. ADCP backscatter intensity measurements were combined with a sampling strategy to calculate cross-section sediment fluxes. Arising from inability of the ADCP to discriminate in the lower 6% of the flow, and from the inability of conventional turbidity sensors to measure a wide range of suspended sediment concentrations and lutoclines, a profiling siltmeter was developed to measure near bed suspended sediment concentrations: the SiltProfiler.

The SiltProfiler (Figure 2) is equipped with multiple turbidity sensors to cover the entire range of 0 to 35000 mg/l suspended solids (silt). A conductivity, temperature and pressure sensor were also integrated.

A vertical gamma density profiler and the SiltProfiler were used to collect suspended sediment concentration profiles, from a few mg/l near the water surface over more concentrated concentrations near bed layer to recently deposited silt layers (up to 1.4 ton/m^3). Simultaneously long term measurements were carried out with a DON frame containing various instruments to monitor suspended sediment concentration, velocity and sedimentation/erosion dynamics.

Figure 2: SiltProfiler (left) & close up (right) of both transmittance extinction turbidity sensors.

Survey location and set up

Siltprofiler measurements were carried out near Deurganckdok on 17 February 2005. During a whole tidal cycle Siltprofiler measurements at both banks (right and left bank) were combined with ADCP transect sailing to measure sediment fluxes.

From the survey vessel a measurement cycle was completed every half hour. Every half hour on the hour and at 30 minutes past the hour velocity measurements were conducted. The vessel with a mounted ADCP sailed a fixed transect (Figure 3). Edge profiles were gathered to calibrate the ADCP transect measurements for temperature, salinity and suspended sediment concentration.

Two calibration profiles were collected for each transect:

- One before sailing the transect at the bank where the start of the transect was (Left bank during the flood; right bank during the ebb)
- One after sailing the transect at the bank where the transect ended (Right bank during flood, left bank during the ebb).

During these calibrations, a fish with a Navitracker density probe, CTD-OBS and watersampler was lowered to the bottom. The downcast was interrupted at two depths, one in the upper half of the water column (between 4 and 7 m from the watersurface), and one at 4 meters above the bottom. At these depths samples were taken for calibration, and are used as 'ground truth' for all suspended sediment concentration measurements (SiltProfiler, OBS and Sediview). The other instruments logged continuously during the downcast. Conductivity, Temperature and Depth was logged by the CTD-probe, while turbidity was recorded by the OBS. The Navitracker measured the density.

At the same time a SiltProfiler, a high resolution extinction turbidity meter, was lowered using a crane at maximum speed (0.6 m /s) to collect a high resolution turbidity profile on location. An echosounder logged hard (33kHz) and soft (210 kHz) bottom simultaneously.

After the measurement campaign SiltProfiler data was validated and screened for outliers. Raw data were filtered. Data-processing, -analysis and -visualisation were done using scripts and programs developed by IMDC in a Matlab environment.

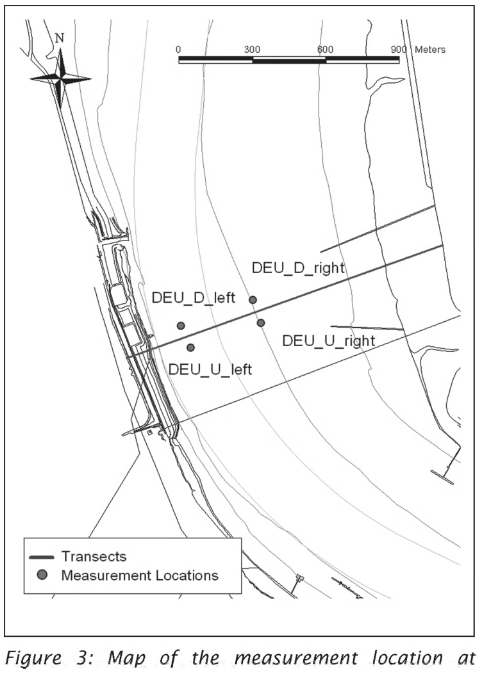
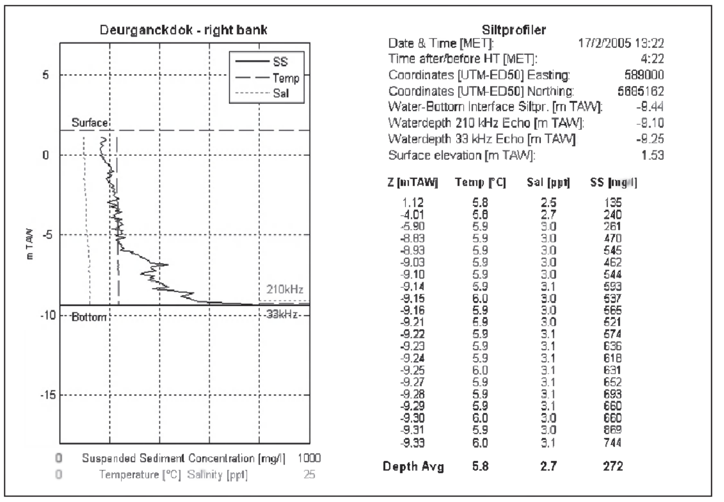


Figure 3: Map of the measurement location at Deurganckdok.

Results

A datasheet was produced that contains a plot showing the change in temperature, salinity and suspended sediment concentration versus depth. Apart from general metadata (date, time, time after HT, coordinates, surface elevation) the water-bottom interface is given as it was measured by the deepest position/ measurement of the SiltProfiler (Figure 4). A table is shown with values measured at various depths with extra detail for near bottom measurements. Also depth-averages are given for all parameters.

A time series was plotted to visualise the evolution of the SSC in the vertical profile for a whole tidal cycle. The time series for the right bank is shown in Figure 5. The bottom is marked by a black colour. High concentrations occur near the bottom both during the upcoming and outgoing tide.



Z [mTAW]	Temp [°C]	Sal [ppt]	SS [mg/l]
1.12	5.8	2.5	135
-4.01	5.8	2.7	240
-5.90	5.9	3.0	261
-8.83	5.9	3.0	470
-8.93	5.9	3.0	545
-9.03	5.9	3.0	462
-9.10	5.9	3.0	544
-9.14	5.9	3.1	593
-9.15	6.0	3.0	537
-9.16	5.9	3.0	565
-9.21	5.9	3.0	521
-9.22	5.9	3.1	574
-9.23	5.9	3.1	636
-9.24	5.9	3.1	618
-9.25	6.0	3.1	631
-9.27	5.9	3.1	652
-9.28	5.9	3.1	693
-9.29	5.9	3.1	660
-9.30	6.0	3.0	660
-9.31	5.9	3.0	869
-9.33	6.0	3.1	744
Depth Avg	**5.8**	**2.7**	**272**

Figure 4: Datasheet of SiltProfiler Measurement near Deurganckdok.

Conclusion

The intense deployment of the SiltProfiler during this measurement campaign allowed for a quality analysis of this instrument.

The high measurement frequency supplied a very high resolution image of the suspended sediment distribution in the water column. Figure 4 shows a clearly visible lutocline. The near bottom information provided by the SiltProfiler was crucial for sediment flux calculation in Sediview. The wireless bluetooth connection allowed for a very fast routine of profiling, including data-readout and quality control. All these features give the SiltProfiler an advantage for profiling suspended sediment in dynamic environments like estuaries, coastal zones.

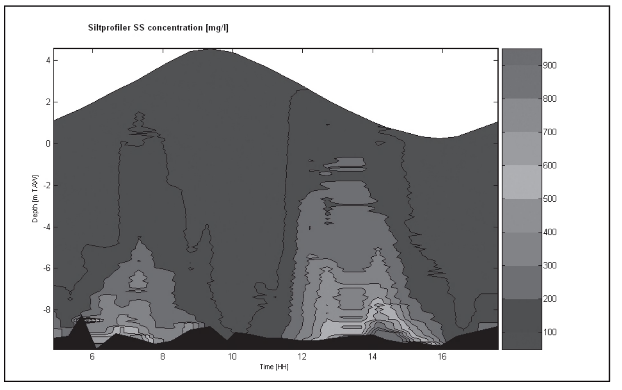


Figure 5: Time series of a through tide measurement at the right bank measurement point.

Simultane turbidity measurements with an optical backscatter sensor showed that the extinction turbidity sensors on the SiltProfiler were less proficient to measure low SS concentrations in the Lower Sea Scheldt (0-500 mg/l). For this reason a post calibration was performed. A Seapoint turbidity sensor has been installed on the SiltProfiler to account for the measurement of these low suspended sediment concentrations in following measurement campaigns. Other small adjustments to facilitate the measurements were done in the SiltProfiler software, allowing fast adaptions to measurement routines during field campaigns.
During this measurement campaign high concentration benthic suspensions were not encountered.

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Evaluation and combination of techniques used to determine the Nautical bottom

A call for rheology based instruments.

Stijn Claeys

The rheology properties of the underwater sediment will influence the possibility of navigation through it (or just above it). The rheology of the fluid/partially consolidated mud is a very complex issue. Most of the techniques to determine the nautical bottom are based on density information because of the relatively easy way of measuring. The problem is that the relation density - rheology can not be used as such. More correct and direct ways to relate the rheological parameters to the sludge are: in-situ sampling (of disturbed and undisturbed samples) combined with performing laboratory rotoviscosimeter tests on these samples or direct in-situ rheological measurements with body-profiling rotoviscosimeter. Relating this information to the structural information from the acoustical profiling methods is a step forward, but because of its complexity, it is seldom used. An accurate and easy to use online rheology properties measuring instrument (measuring shear-strength (rigidity and viscosity)) is still to be designed.

The influence of deep and shallow water on ship behaviour.

A ship experiences a large difference in sailing behaviour when it navigates in either shallow or deep waters.
In shallow water, meaning a keel clearance of about 10-15% of ships draft, a ship experiences completely different behaviour compared to when sailing in deep water.

Deep water is defined as being: more than a few times the draft of the vessel.

In shallow water the maximum allowed sailing speed will be much lower with the same power, and the turning circle for a given speed will need to be considerably larger.

Ship trials on new vessels are carried out to determine their sailing characteristics, and typically amongst other factors attempt to establish the maximum speed and the turning circle (at maximum speed). Normally these trials are performed in "deep water". This can be a source concern in terms safe operation in shallow water, where expectation are based on trial data from deep water. Typically, a ship operating at high speed in shallow water will experience significant and irregular vibrations and other dynamically navigation hazards.

The problems of muddy bottoms in navigation

In addition to the phenomena resulting from shallow water sailing, is the further influence of bottom type.

In "hard" bottom conditions (e.g. sandy bottom) navigators find that they have better control over the 'shallow' situation insofar as the behaviour is more predictable and less safety problems arise.

Theoretically, one would anticipate, that fewer problems should arise when sailing over fluid mud compared with a hard bottom. In fact the opposite is true.

The speed of the vessel is the determining force in maintaining the control over the vessel (i.e. reduced speed will reduce shallow bottom affects). However, because of the presence of currents (e.g. tidal and littoral), reducing speed is not always a safe possibility. In the example of the high sideways-on tidal currents, at the entrance of the Belgian harbours, vessels do not have a choice other than to use potential unsafe speeds to enter these harbours (see currents Atlas of Zeebrugge harbour published by the Flemish Government, made by Gems International).

If we don't take into consideration the effect of the mud level, it is inevitable that ships will encounter critical speed situation problems whilst sailing above muddy bottom during in and out manoeuvring of the harbours.

The solution

Ongoing maintenance dredging is the principal tool to solve these problems.

But at what economic level do they need to dredge out?

The top layer of the fluid mud can be detected with a single frequency of around 100 kHz. This acoustical top-level, unfortunately, is very difficult to handle by dredging. Removing only the effective zone of the "muddy bottom", and where that level is influence lies is still only a manner of speculation.

Influences other than the means detecting and determining the economic level of treatment (dredging), are the spatial and time variance triggered by weather, tidal and anthropogenic forces.

Therefore a nautical depth has been determined, that lies somewhere between the top of the fluid mud and the hard bottom.

The debate as to what is the correct level to dredge is based on:
- marine/mariner experience (at best poorly recorded)
- dredger trials (largely uncorrelated); and
- Laboratory scale tests

Moreover, the correct rheological model (and instrumentation) to efficiently determined the depth have yet to be designed.

Nautical bottom

The nautical bottom is defined as the level of a muddy sediment at which the vessels experience no difficulties when sailing at or above it. Below that level navigation problems could occur. The sediments lying above this level, therefore, have no important effect on the navigation of the vessels.

Only the rheology properties of the sediments will influence the possibility of navigation through the muddy layer (or just above it).

The rheology of this fluid/partially-consolidated mud is very complex and there exists of at least seven parameters/sets of influences that define it. These include:
- hydrodynamic and electrostatic forces;
- strength of inter-particle action;
- visco-elasticity;
- viscosity (zero shear and maximum viscosity of the fluid phase preventing sedimentation);
- size and shape of the particles;
- creep recovery.

The determination of these parameters and influences, and their relative importance to the nautical bottom model is difficult and complex. Measurements, of such rheological properties, even on laboratory scale is equally so. Another problem is that the laboratory circumstances do not always reflect the in-situ reality.

For decades now research have been carried out into "nautical bottom" these have included:
- laboratory and in-situ tests;
- scaled and normal size simulations; and
- use of natural and artificial mud.

But still no effective models or rules of thumb exist for determining "nautical bottom" for particular circumstances.

Density

Most of current techniques used to estimate "nautical bottom" are based on density instead of a rheology, mainly because of the relatively ease of measurements. So the following techniques are in common use:
- Type 1: acoustical density profiling based on acoustical impedance transitions (e.g. Silas; Innomar Sonar); Because every beam travels through the mud column during transit (without physically profiling sensors), we can consider these as a means of "underwater remote sensing".
- Type 2: body-profiling absolute gamma-ray point measurements for direct sludge-density measurements (e.g. Navitracker; Dophin);
- Type 3: body-profiling tuning-fork-based point measurements (e.g. Admodus USP; Densitune; Mudbug and XL4 Density probe).

All these density based techniques can be used in towed or vertical profiling mode.

In the table 1 on the next page, the 'pro' and 'contras' of Type 2 and 3 are compared.

	Absolute density systems (gamma-ray) (type 2)	Tuning fork density systems (type 3)
Radioactive source	Disadvantage: - long procedure to get licence for transport, operation and storage - safety qualified personnel	Advantage: not radioactive
Weight/operation	High weight (200 kg): - advantage: good penetration into the high resistance mud - disadvantage: no handprofiling	Advantage: Depending on setup, but mostly too light and sensitive for penetration into high resistance mud
Repeatability	advantage: High repeatability	- disadvantage: Direct contact with mud is needed (action-reaction) =>; good refreshment of the contact surface is needed => medium repeatability - advantage: not radioactive
Sample volume	Big sample volume: - advantage: distance between the legs is large: a representative mean density value of the sludge can be obtained	Small sample volume: - disadvantage: Local errors occur because contact surface is small. Could give less representative values, no mean value compensate the local disturbance
Amount of profiles/time	Equal	Equal
Sticky mud	The error caused by the amount of mud that sticks to the legs of the sensor will be negligible because of the averaging of the big amount of measured volume of sludge	Can give wrong readings

Table 1: This table present the 'pro' and 'contras' of Type 2 and 3 density instruments.

Both type of systems are used together with acoustical information from echo sounders. Different information coming from the echo sounders can be used:

- Classical bathymetry: given by the time to reflect at a certain boundary =f(profiling depth of the sound of a chosen frequency)
- Backscatter information of the reflected waves on strong impedance transition in the sludge.

The backscatter information is used more and more to give an image of the structure of the sludge. These images are created by acoustical impedance transitions, and gives (again) an idea about the density structure of the sludge (type 1).

Because every beam travels through the mud column during transit (without profiling sensors), we can consider these as a means of "underwater remote sensing". The resulting picture gives a contour plot. The given image cannot, however be directly interpreted.

Other sensors are used to look for a relation between the visualised structures and the collected parameters. Examples of parameters that are tried to fit into the picture are:
- density profiles;
- drilling information (sediment types), and
- rheology information.

Returning to the importance of the rheology properties in defining the "nautical bottom": We believe that there is a trustworthy and repeatable relationship between a defined acoustical structure, and the collected rheological information. This relation can have a direct connection with visual structures or a repeatable offset of this structure.

Combining the acoustical contour plots with density is a commonly used method, but with the processing capacity of the new electronics, very detailed structures can be obtained (see fig. 1, which shows a possible combination of density measurements and Silas Software).

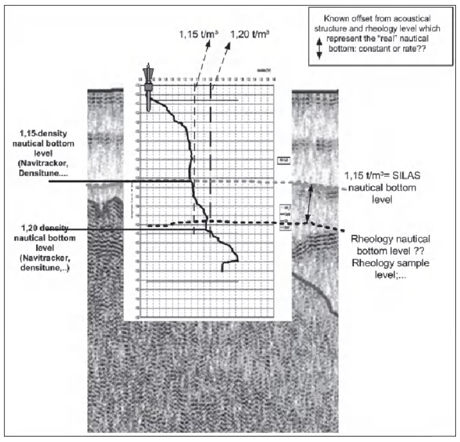

Figure 1: Combining acoustical contour plots with density to determine the nautical bottom.

More correct and direct ways to relate the rheological parameters of the mud need also to be further investigated:

- in-situ sampling (of disturbed and undisturbed samples);
- performing laboratory rotoviscosimeter tests on samples;
- direct in-situ rheological measurements with body-profiling rotoviscosimeter.

This information could be used directly for nautical bottom determination, but not as a stand-alone method, as they are time consuming and it is difficult to achieve repeatable results.

Relating this information, however, with its benefit of reduced amount of sampling, to the structural information from the acoustical profiling methods is a step forward. But because of its complexity, it is seldom used.

Research

Online and accurate rheology properties measurements for shear-resistance is still a thing for the future. Combining such information with the structural data derived from, the relatively easy to gather, acoustical profiling results, could significant improve determination of the "nautical bottom".

Before this kind of instrument (or combination with the acoustical contour plots) would be used, much research effort is needed (in-situ and laboratory simulation) to relate other available studies (mostly density-rheology based) in order to evaluate the new in-situ methods. These researches need to be done thoroughly to prove the efficacy of the results, and to convince the shipping and navigation industry.

The Flemish Government (Flanders Hydraulic Research, Division Maritime Access) had already invited GEMS International to test new in-situ methods. This project will be executed together with specialist from the university of Leuven and Gent.

This paper calls for other parties to join the test programme, and bring with them their innovated techniques to determine the in-situ rheology.

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Innovative Dredging in the Port of Rotterdam

Sander Cornelissen

A large part of the maintenance dredging costs in the Port of Rotterdam is determined by the long transit time between the dredging site and the disposal site at sea. The Port of Rotterdam Authority has been looking at several innovative methods of maintenance dredging, with the intention of cutting down the necessary transport volume. One of the methods considered is agitation dredging. Dredged material is released from the dredge hopper during favourable tidal or river flow, with the intention of transporting the material on the currents away from the dredge site toward sea. In cooperation with Environmental Tracing Systems Ltd the Port of Rotterdam Authority performed a silt tracer sediment transport study in order to determine the efficiency of the agitation dredging. The dispersion of dredged material was investigated by sampling the harbour bed and checking the amount of tracer per sample. Mass budget analysis of the retrieved tracer after 7 days shows that approximately 35% of the agitated material settled in the harbour. A remaining 15% of the released tracer was found outside the harbour entrance. The remaining part, adding up to 50%, is assumed to have left the area that was covered by sampling

Introduction

A large part of the maintenance dredging costs in the Port of Rotterdam is determined by the long transit time for transport of the dredged material to the disposal site at sea. A dredging cycle of a dredger can extend up to 4 hrs, while the effective time for suction and disposal is 30 minutes on average. Fig. 1 explains the long transit time to the disposal site.

The Port of Rotterdam Authority has been looking at several innovative methods of maintenance dredging, with the intention of cutting down the necessary transport volume. One of the methods considered is agitation dredging.
Agitation dredging in the Port of Rotterdam practice can be described as follows: Dredged material is released from the dredge hop per of a trailing suction dredger during favourable tidal or river flow, with the intention of transporting the material on the currents away from the dredge site toward sea. Hereby the dredger is utilised with the hopper doors left open to allow leakage and dispersion with the tide or riverine currents. This unconventional type of agitation dredging has been trialled in the Port of Rotterdam earlier. However up to now a remaining question was the reached efficiency of this method. In order to determine the efficiency of the agitation dredging the fate of the dispersed sediment has to be assessed. Where does the agitated material end up?

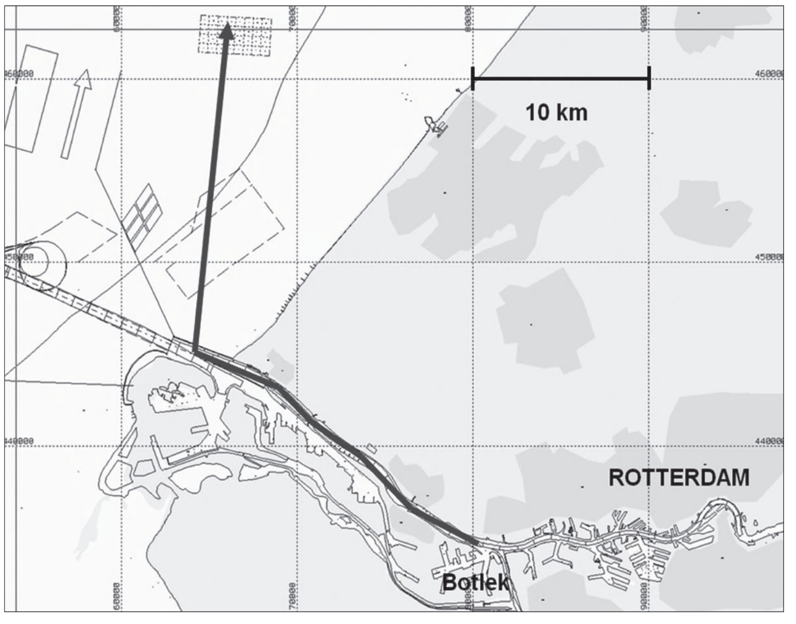

Figure 1: Shipping route from port to disposal site.

The Port Authority decided to undertake a silt tracer sediment transport study in cooperation with Environmental Tracing Systems Ltd. In this study silt tracer was added to the dredge material in the hopper during agitation dredging. The dispersion of dredged material was then investigated by sampling the harbour bed and checking the amount of tracer per sample.

The Botlek harbour basin was chosen as the study site to undertake this study (Figure 2). In this area a yearly average 1.7 million m^3 of dredged sediment is removed.
The main objectives for the study were:

a) Determine the main sinks of the sediment tracer particles in the survey area including highlighting whether sinks are temporary (1 tide) or longer (several tides)

b) Evaluate from ADCP data and the distribution of tracer concentrations the pathways and processes present
c) Calculate the mass budget of tracer particles accounted for within the Botlek compared with the total tracer particles released to establish the efficiency of the dredging operation in terms of particles leaving the dredge area into the river as a result of ebb tide agitation dredging

Study Results And Discussion

Study results

A silt tracer sediment transport study involves adding fluorescent silt tracer to the dredged material to be dispersed during the agitation dredging. The tracer can be monitored through laboratory analysis of bed sediment samples taken after the dispersion of the dredged material.

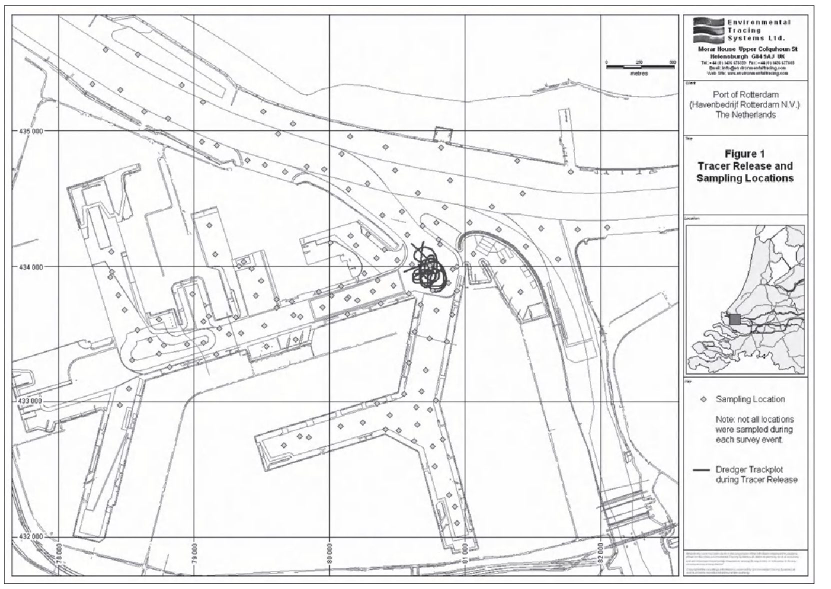

Figure 2: Layout of the agitation dredging site (Botlek turning circle) and sampling locations.

The main monitoring involved the following:

a) During dredge discharge, water column monitoring and sampling was carried out to measure and assess the dispersal and depth of advection for the dredged sediment and tracer particles.
b) Immediately after cessation of dredge discharge, bed sediment grab samples within the Botlek and the estuary channel were collected to determine the fate and pattern of deposition of tracer particles before the onset of the flood tide.
c) On the following day (and subsequently 1 week and more than 2 months later) bed sediment grab samples were collected over the same area over time to assess the effects of further transport and deposition. Rather than track the tracer particles in the main channel it was agreed that in order to establish the efficiency of the dredging process more intensive sampling would be conducted in the Botlek basins to determine the proportion of material retained.

In order to carry out the study during typical conditions, in this case favourable ebb tidal currents running out of the Botlek, it was necessary to look back at historical tidal current information and look at tidal model predictions. These data and model predictions provided an approximate tidal 'window' to carry out the tracer release, however to confirm these conditions additional tidal current measurements were carried out 1 day prior to the proposed dredge study, using a vessel mounted ADCP.

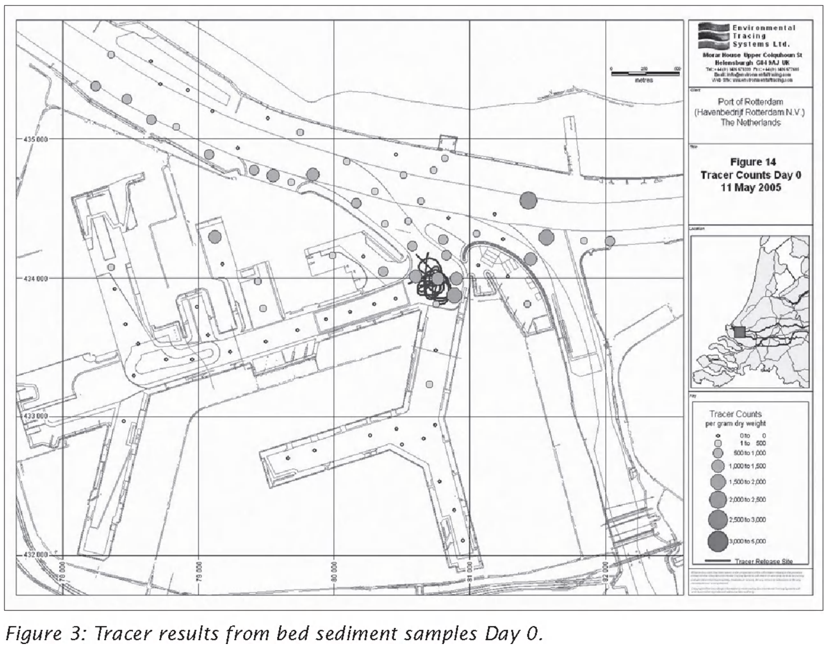

Figure 3: Tracer results from bed sediment samples Day 0.

The main dredge study and monitoring was carried out on the 10th to 12th May during spring tides, with the ADCP survey on the 10th May ready for the tracer release on the 11th May. The tracer release involved a 30 minute period of agitation dredging during which tracer was added in the suction pipe of the dredger. Fig. 2 shows the site with the dredger tracks during this 30 minutes of agitation dredging.

Figures 3, 4 and 5 show the results of the laboratory tracer analysis of the bed sediment samples that covered the Botlek area, on Day 0, Day 1 and Day 7 after the tracer release respectively.

General discussion

Based on the ADCP and salinity profile data, the dredge area within the Botlek Turning Circle is complex with continuing

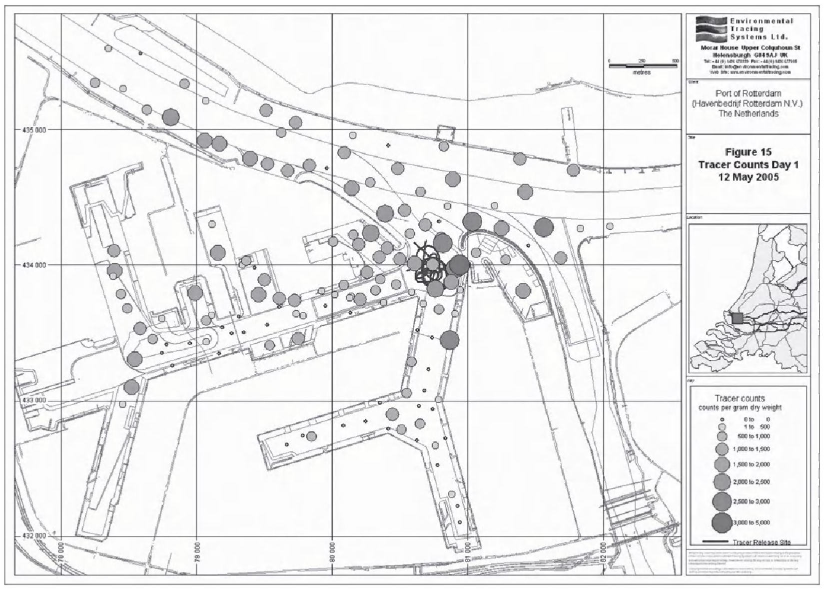

Figure 4: Tracer results from bed sediment samples Day 1.

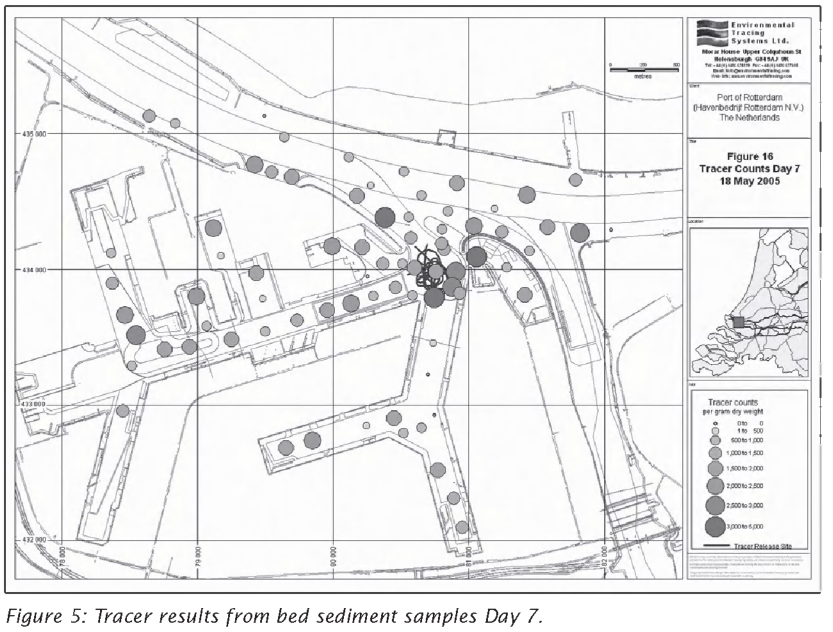

Figure 5: Tracer results from bed sediment samples Day 7.

flood tide (inward flowing) conditions and saline layers even during the main onset of ebb tide conditions. The tidal window for net ebb tide (seaward) currents suitable for effective agitation dredging is potentially very narrow. The sediment tracer study only assessed one 30 minute period of the ebb tide.

The sediment tracer released during ebb tide conditions in the mid and surface water column did clearly exit the Botlek Turning Circle, evident by the deposition pattern of tracer on Day 0. The main area of deposition was along the south side of the channel. During the initial few hours of the ebb tide, after the tracer was released, relatively high concentrations remained in the Botlek turning circle area in addition to some dispersal into the Botlek back basins. On the return of the flood tide (by Day 1) wider dispersal of the tracer particles took place leading to deposition in the central channel and on the north bank coupled with increased concentrations elsewhere. Increased concentrations were also measured throughout the Botlek basins possibly due to tracer particles present in the main navigable channel and in the Botlek Turning Circle being tidally pumped landward and into the Botlek as indicated by the increase of tracer concentrations for the Day 1 data. In addition, it is also likely that the effects of settling and consolidation of tracer particles and sediment over time led to further increases in measured concentrations over time.

Sediment sinks and sediment transport pathways

The Day 0 tracer particle data indicated that the short-term or temporary sinks created by the agitation dredging were located along the south side of the main navigable channel and in the Botlek Turning Circle. However, both locations became medium term sinks with tracer particles remaining for the duration of the monitoring up to 2 months. The data indicate that a proportion of particles released from the dredger never left the Turning Circle either due to circulatory currents and/or very weak ebb currents; it is also likely from the observed increase in concentrations throughout the Botlek basins that additional tracer particles entered the Turning Circle from the main navigation channel as a result of flood tide currents.

Over time there is clear net landward flood tide advection of tracer particles into the side basins of the Botlek. This is not unexpected given the regular dredging that takes place in these basins. The tracer particle data suggest greatest deposition and more long term deposition at the back of the basins and side basins.

By carrying out agitation dredging and releasing the dredged material in the mid- to surface water column the sediment is introduced into the ebb tide waters carrying much of the dredged sediment and tracer particles seaward out of the Botlek Turning Circle. The initial sediment pathway for the main dredge discharge appeared to be with the ebb tide out of the Botlek basin although the data clearly suggest that some of the tracer particles and therefore dredged sediment did not leave the Botlek Turning Circle during the first ebb tide.

One further sediment transport pathway that occurred during dredging at that time was the advection or entrainment eastwards upstream most likely to be due to a return gyre/eddy or circulatory path formed as a result of the two water masses (main Rhine and the Oude Maas) meeting and the ebbing tide.

Mass Budget Analysis

Given the Rhine estuary/main navigable channel is an open boundary system with particles potentially being dispersed over a wide area requiring a large quantity of samples to be collected, it is concluded it would be easier and more cost-effective to sample intensively in the Botlek basins and assume everything unaccounted for left. This approach was adopted to estimate the efficiency.

The mass budget estimates indicate a very low percentage (4%) of the total tracer particles released from the dredger was accounted for in the Day 0 samples collected from the Botlek basins. Subsequent to settling and consolidation of the tracer particles and dredged sediment over 24 hours for the Day 1 samples the proportion of tracer particles accounted rose sharply to almost 18%. Whether tracer particles were advected in to the Botlek on the subsequent 2 flood tides prior to Day 1 sampling is not known neither is the proportion, however obviously if settling through the water column and subsequent consolidation takes several hours as demonstrated by the difference between Day 0 and Day 1 data, then it is possible that any 'new' tracer particles introduced in suspension from the main estuary/navigable channel would not have had time to settle significantly by the time the Day 1 samples were collected. Based on the Day 1 results, it is proposed that the agitation dredging method is potentially c.80% efficient i.e. what remained in the Botlek basins at Day 1 is likely to be what never left at all estimated to be around 20%. Subsequent twice-daily flood-tide pumping with inward flowing tidal currents close to the sediment bed appears to have lead to a significant increase in tracer concentrations and more widespread deposition throughout the Botlek basins by Day 7, leading to an estimated mass budget of c. 32%.

Following provision of the data from the Day 7 survey, the Port Authority decided to carry out a further sampling survey approximately 2 months after tracer release After a relatively intensive conventional dredging campaign during these 2 months the overall mass budget is approximately 22% with a large proportion of this accounted for from areas that were not dredged in addition to the tracer particles that remained detected in the Botlek Turning Circle despite dredging.

Conclusions

In reference to the main study objectives mentioned in the introduction the following can be stated.

a) On the main sinks of the sediment tracer particles:
   - Approximately 24 hours after the tracer release, the tracer data tends to suggest that c.80% of the tracer particles released from the dredger had left the Botlek basins. Subsequent near-bed flood tides over several days up to the Day 7 survey appeared to lead to a re-entrainment of tracer particles from the main navigable channel into the Botlek basins. This transport back in to the area is likely to be due to flood tide pumping which lead to a peak in concentrations in the basins in the region of the one-third of the particles released. What is not known (and was not studied during this survey) is the natural contribution of sediment from the estuary into the basins to compare these data and determine the level of significance.
   - The tracer particle data did indicate that there was a steady migration of material towards the rear of the basins with advection and deposition perhaps concentrated in the side basins, shallower areas and regions where more quiescent conditions occur rather than in the main channels and notably the silt trap in the Botlek which saw only limited deposition over time. This creates a discrepancy between the relatively low deposition rates observed for the tracer particles in the silt trap and the fact that the Port Authority typically carry out the largest quantity of dredging in this basin each year.

b) On the pathways and processes present: Based on ADCP data, salinity data and the observed pattern of tracer particle transport it is believed that there is a very narrow time window of discharge for agitation dredging to ensure a high efficiency between the breakdown of the near-bed inward flowing layer and the onset of near quiescent ebb tide conditions throughout the water column. Further investigation is required to assess whether the tidal window is in fact wider without significantly affecting the efficiency of the dredging.

c) Mass budget of tracer particles accounted for within the Botlek compared with the total tracer particles released to establish the efficiency of the dredging operation: Mass budget analysis of the retrieved tracer after 7 days shows that approximately 35% of the agitated material settled in the harbour. A remaining 15% of the released tracer was found outside the harbour entrance. The remaining part, adding up to 50%, is assumed to have left the area that was covered by sampling.

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Assessing Nautical Depth Efficiently

In Terms Of Rheological Characteristics

Willem Fontein and
Jan van der Wal

A vital element of harbour services is the guarantee of save passage to and from the port facilities. When high siltation rates persist, adopting the concept of nautical bottom may reduce the significant maintenance costs involved with this service. In-situ density probes and acoustic methods are widely used for assessment of the nautical depth. New developments in tuning-fork systems are presented, that allow the direct measurement of deformation characteristics of muds, being the direct relevant parameter for navigation. This new technique is integrated in a existing survey scheme, allowing more accurate mapping of the nautical depth efficiently.

Introduction

A vital element of the harbour services is to guarantee the safe passage of vessels to and from the port facilities. For harbours where high siltation rates persist this service implies significant maintenance costs. These costs will increase exponentially when deeper access channels are to be maintained. The ongoing capacity increase of both transport modalities and harbours therefore trigger the need for maintaining safely navigable waterways in the most efficient way. In this perspective the nautical bottom concept was developed and implemented in several major ports. This concept is valid when the siltation material consists of fluid mud. In principle fluid muds have such low strength characteristics that it does not cause problems for navigation and even negative under keel clearance may be accepted[1]. The charted depth may be guaranteed without removing that material.

To assure the navigable characteristics of the channel knowledge on the in-situ mechanical properties of the upper waterbottom sediments is required (figure 1), instead of high frequency single- or multibeam echosounder information only [2]. The in-situ characterisation of mechanical properties did not prove feasible in the past. An indicator of the mechanical properties is the density of the harbourmud and nuclear density probes were available for in-situ measurements. These nuclear devices are now largely replaced by tuningfork systems, like the DensiTune. Figure 2 shows the relation of mud density with the shearstrength required to initiate permanent deformation for muds from several locations. From this figure it becomes clear that a density criterion is site specific. Muds from Guyana, South-America show very low strength values at densities as high as 1.5ton/m^3. North European harbours show significant strength increase at density levels varying between 1.15 and 1.25ton/m^3. Significant differences are notable between neighbouring harbours located only 50km apart.

The relation of nautical bottom to a density level has been a practical solution, but is a simplification of the problem and prevents efficient communication on acceptable levels for the nautical bottom. Rheology, the response to deformation, provides direct parameters, for instance shearstrength and viscosity, influencing ships navigation.

Rheological Characteristics of Mud

Not having a precise definition, fluid mud is generally described as a cohesive fine-grained sediment suspension with a concentration below that required for the formation of important soil structure [3]. The amount of particles in the suspension influences the density and the mechanical (visco-elastic) properties and can best be described as pseudo-plastic or plastic liquids, being a liquid with a yield point [4]. The main difference with fluids, like water, is the Non-Newtonian behaviour. These suspensions exhibit both solid and liquid behaviour. At low shear stress there is no or limited flow. The viscosity, the quotient of the applied shear stress with the strain rate, is infinite or high. When shear stress exceeds the yield stress the suspension will flow and the viscosity is gradually reduced to a constant lower level at high deformation rates (high shear viscosity). This decrease of flow resistance with increasing shear is referred to as shear thinning.

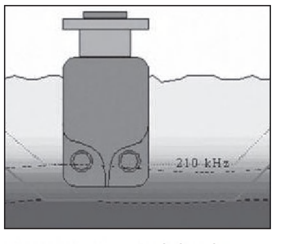

Figure 1: Nautical depth concept. Fluid, very soft mud is allowed within the nautical profile, provided safe shipping can be guaranteed. The assessment of the nautical depth can not be done by traditional survey methods.

The rheological parameters are not uniquely related to the particle concentration. The ability of the sediment particles to form bonds has an effect on its behaviour. This increase of yield-strength and viscosity with time is referred to as thixotropy. Figure 3 shows results of rheometric vanetests on three natural muds. The vane tests proved to be a practical method to provide very stable laboratory yield-strength data that could easily be obtained with minimal disturbance of the sample. It is apparent that the tests on consolidated mud, where the samples remained undisturbed, show higher shear strength values than completely remoulded samples of similar density. The dataset did not show this shift for the high shear viscosity of the muds. This parameter had a constant relation with the density.

Assessment of Rheological Characteristcs In-Situ

From the laboratory tests it was observed that the remoulded yield-strength and high shear viscosity remain unchanged with time and deformation history and can directly be related to mud density, provided the composition remains unchanged. This relation is established with roto-visco and vane tests. These figures provide a first order approach of the in-situ rheological values. It does however not account for the time dependent thixotropic behaviour. In-situ measurements of the yield-strength are required, as undisturbed samples are not easily retrieved from these sediments.

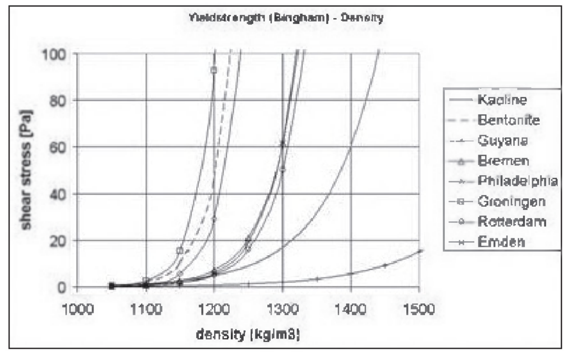

Figure 2: The relation of the shearstrength (Bingham) with mud density for several harbours. There does not exist a single nautical density applicable for any harbour.

Tuningfork density systems must be compensated for the visco-elastic properties of the muds to arrive at the density. The DensiTune tuningfork system has recently been improved to provide absolute yield-stress data independent from density measurements. The required correlations have been obtained from an extensive test series on natural and synthetic muds.

The proof of concept has been obtained in laboratory- and a field-test:

1. A very distinct bending point in tuningfork response can be observed at the transition of pseudo-plastic liquid to plastic liquid. This point marks the density where the mud can be characterised by the onset of the presence of a significant yield-strength. This phenomenon was first observed in several US harbours, where DensiTune data and rheometer data were compared, and also proved to be valid for other muds in the test series. In figure 4 the DensiTune response and yield-strength is plotted against the mud density. The transition point is density independent and may be mapped without further vane test calibrations. To arrive at an absolute yield- strength value site specific calibration data has to be retrieved.
2. A recent study in natural harbourmud has revealed a significant shift in a tuningfork response in mud with a known rest period after deposition. Harbourmuds had been dredged and redeposited in a deeper area with an initial thickness of 2 meters. At various moments DensiTune measurements have been performed at fixed locations to monitor the density. In the data a significant response shift with time was observed. This response shift can be addressed to the increased yield-strength of the mud with time (thixotropic behaviour).

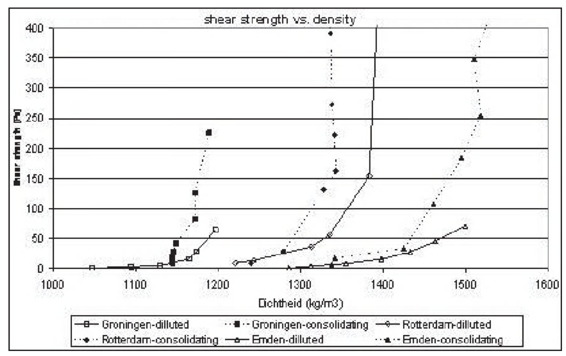

Figure 3: Yield-strength values of three mud types measured with rheometric laboratory vanetests. The diluted samples refer to completely remoulded material before testing. The consolidated samples refer to unremoulded samples that were left to consolidate for a certain period.

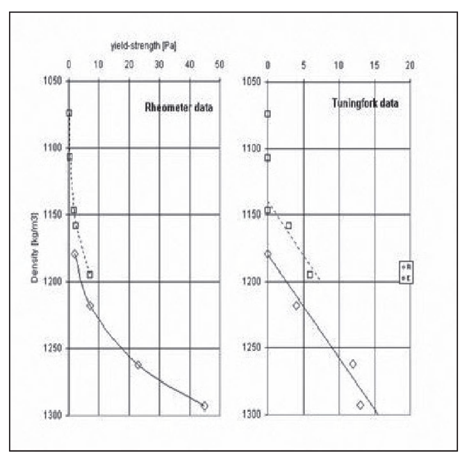

Figure 4: The onset of plastic behaviour in rheometer tests for various densities coincides with a sharp bending point of the tuningfork respons.

Mapping Nautical Depth Based on Mud Theology

Continuous survey techniques

Preferably depth levels are surveyed with profiling or area covering survey techniques. The transition at the water-mud interface is commonly mapped with high frequency echosounders. Density levels within the fluid mud interface can not be mapped with standard low frequency echosounders [5]. These systems are however capable of mapping density levels when the low frequency signal returns are combined with signal attenuation processing and calibrated with an initial set of in-situ-density measurements. The resistance to signal conduction for compressional sound-waves is related to density and sound propagation velocity. In this way continuous survey techniques are used to map iso-density levels (figure 6).

The mapping of rheological transitions can however not be obtained with acoustical profiling techniques alone. For retrieving adequately non density related shear-strength properties transversal wave transmission is required. Unfortunately only compressional waves can be transmitted through water. At present these mechanical properties will therefore have to be measured with in-situ probes as described above.

Critical levels for mapping

From the rheometric laboratory measurements is was concluded that mud density remains an important parameter for predicting the rheological state of the mud. The high shear viscosity was in the studied sediments directly related to the density. The yield strength was not uniquely related to the density, but for specific density trajects the relation of the yield-stress with a critical shearstrength can be unique. In figure 5 [6] this is schematically presented by defining two significant density levels, defining 3 types of density-rheology relations:

1. Densities with rheological properties that will never exceed the critical limits, the watercolumn and the very low concentration mudlayer.
2. Density levels that will develop strength after deposition (thixotropic behaviour) and will exceed the critical limits with time.
3. Density levels with rheological properties that always exceed the critical limits.

The transitions of these three units are based on density and can therefore be mapped with acoustical continuous surveying techniques. The critical density levels are calculated from the acoustic response and the relation of these two transitional levels to the nautical profile will allow the the decision of what actions are required. Positioning of direct in-situ rheological measurements on critical locations only, to verify whether the mechanical properties of the mud are still acceptable within the nautical profile. The amount of in-situ viscosity probes may be greatly reduced without increasing the risks for shipping.

Mapping of density will also have an advantage for planning of dredging resources. Based on the density maps a total TDS (tons of dry solids) to be removed or treated can be calculated. This will serve as a valuable tool for budgeting the dredging activities.

Conclusions

- Rheological parameters, as stated by the PIANC, are a more direct parameter for assessment of the nautical behaviour of harbourmuds than mud density.
- Tuningfork measurement methods, like the RheoTune, have become available to measure rheological parameters in-situ and simultaneously the mud density.
- Acoustic measurements in combination with in-situ rheometric measurements facilitate the efficient operation of the nautical bottom assessment and provide information for optimal use of dredging resources.
- This survey method allows the use of active dredging techniques (mud conditioning without removal) without endangering the safe shipping by adequately assessing the rheological/mechanical characteristics of the muds.

Acknowledgements

The measurements on mud characterisation and relation of tuningfork response with rheologic parameters have been realised by Vincent van Nesselrooij as part of his study hydrographic surveying at the Maritime Institute Willem Barentz.

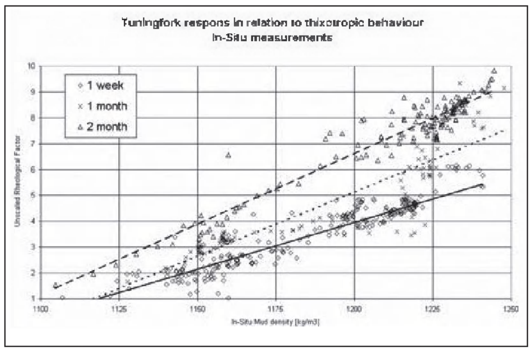

Figure 5: Tuningfork response in natural mud respectively 1 week, 1 month and 2 months after deposition. The tuningfork fork response shifts to values indicating higher yield-strengthvalues.

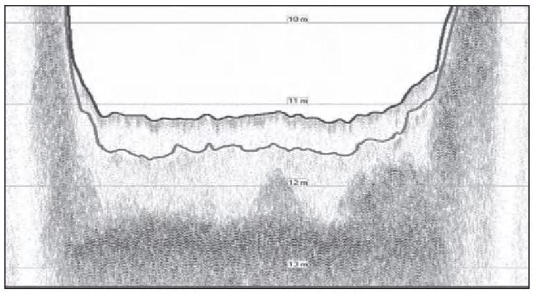

Figure 6: High resolution seismic profile obtained with the SILAS system, using a standard hydrographic 24 kHz echosounder as acoustical source. Iso-density level is calculated based on signal attenuation parameters.

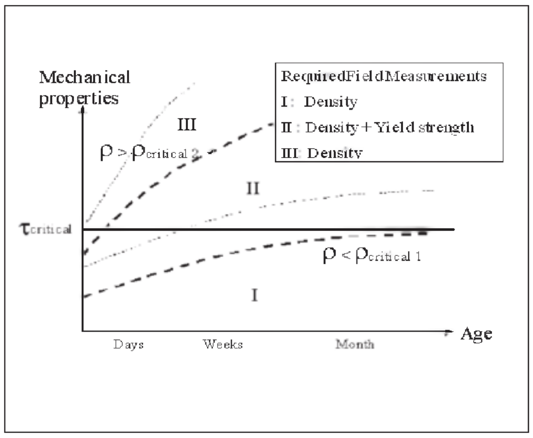

Figure 5: Lines of constant mud density are plotted in a yield strength against age (time at rest after deposition or deformation) diagram. In this graph three distinct zones can be identified: (i) The mud with densities lower than the critical density do not exceed the critical yield-strength at any time. (ii) The mud with a certain density will exceed the critical yield-strength limit at a certain age, but for a certain period of time it will be below this limit due to the non complete development of thixotropy. (iii) The third zone is obviously the range where the muds have such a high densities that it will always exceed the critical limit.

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3D High Resolution Sub-Bottom Imaging: 3D Chirp

M. Gutowski, J. M. Bull, J. K. Dix, T. J. Henstock, P. Hogarth, T. Hiller, T. G. Leighton

Chirp sub-bottom profilers are marine acoustic devices that use a known and repeatable frequency-modulated source signature to produce vertical seismic reflection cross-sections of the sub-seabed. Here a 3D Chirp system is described that operates in the frequency range of 1.5 to 13kHz, to produce a three-dimensional image of the sub-seabed with typical penetration of 10 – 30m and decimetric horizontal and vertical resolution. The design incorporates a rigid frame that contains the Chirp source array together with 60 receiver elements, with positioning provided by an integrated Real-Time-Kinematic (RTK) Global Positioning System (GPS) together with a GPS based attitude system. The array can be surface towed from a small survey vessel and applied to targets of marine geological, engineering, archaeological and defence interest. The capabilities of the system to image sub-surface structures and buried objects is demonstrated in two data-examples imaging a buried engineering object in the Port of Southampton, UK and a buried wooden ship-wreck in the river Hamble, Bursledon, UK.

Introduction

Seismic reflection methods use controlled acoustic sources to image the sub-surface. The hydrocarbon exploration industry has routinely used marine 3D seismic reflection methods for over 30 years to image geological structures down to kilometres depth, with vertical and horizontal resolutions of some tens of metres. However, near-surface high-resolution sub-bottom profiling typically still relies on single-channel 2D methods, producing 2D sections that have to be interpolated to give a pseudo-3D interpretation of sub-bottom structures. Consequently, the effective horizontal resolution of these data is controlled by the survey line spacing, and reflections originating away from the vertical sections make the data difficult to interpret.

In contrast to the 2D method, the 3D method produces data volumes that can be processed coherently across a site. These processed volumes can then be visualised and interpreted to reveal the true three-dimensional geometry of the subsurface with a horizontal resolution orders of magnitude better than 2D data, thus making it possible to detect small objects and reveal complex geometries. Further, by respecting the three-dimensional wave propagation during data processing, 3D seismic reflection data is of significantly higher quality.

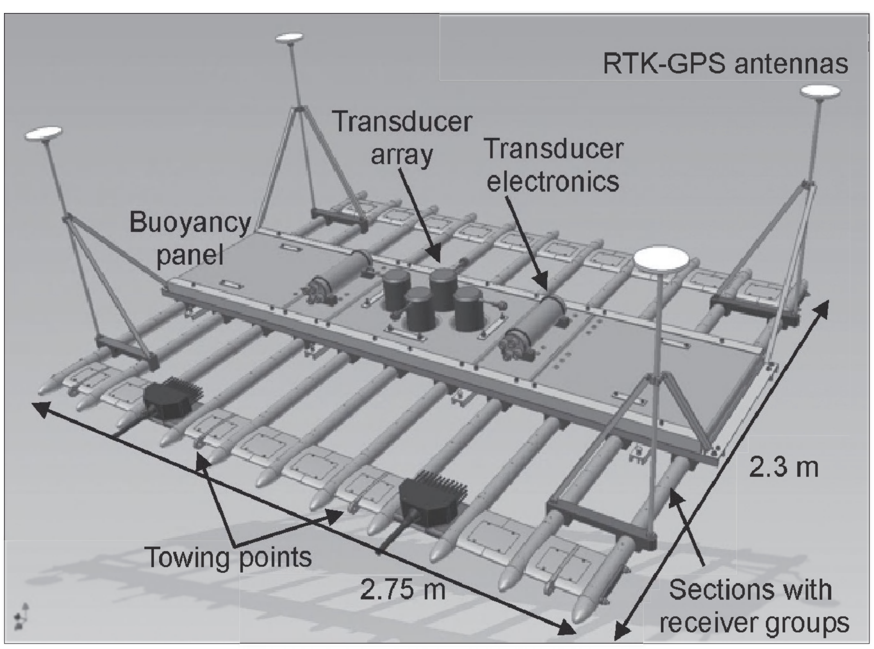

Figure 1: GeoChirp 3D: 3D high-resolution sub-bottom profiling system. The surface towed rigid 2.75m wide by 2.3m long frame holds 60 receiver groups in the longitudinal sections and a four-transducer source array on a central buoyancy panel. The transducers operate at a bandwidth of 1.5 to 13kHz. It is positioned using RTK-GPS and a GPS based attitude system with four GPS antennas attached to the frame.

There have been various projects over recent years aiming at down-scaling the 3D seismic reflection method to produce marine high-resolution 3D seismic data volumes by using high-frequency sub-bottom profiler sources. Henriet et al. [1] and Versteeg et al. [2] used boomer and water-gun sources with a frequency range of 1 kHz to 5 kHz and 100 Hz to 600 Hz respectively; Marsset et al. [3], Missian et al. [4] and Missian [5] used a boomer source with a frequency range of 100 Hz to 600 Hz; and Scheidhauer et al. [6,7] used a mini-airgun source with a frequency range of 50 Hz to 650 Hz.

In the downscaling from conventional to high-resolution seismics it is important that the receiver spacing is adapted to the frequency range to avoid spatial aliasing of the data, and to record adequately the absolute positions of the source and receiver elements during data acquisition. The design concept used in the 3D Chirp profiler described here, is to place all source and receiver elements on a rigid frame that is positioned using Real Time Kinematic (RTK) GPS technology (Bull et al. [8]). This is in contrast to the 3D high-resolution systems referenced above, which use lower frequencies and rely on individually towed and positioned source and receiver elements.

System Design

The 3D Chirp sub-bottom profiler, named the GeoChirp 3D, shown in Figure 1, consists of a surface towed array made up of longitudinal sections holding a total of 60 receiver groups, which are separated by 25 cm in both horizontal directions. The source array, consisting of four Chirp transducers operating on a bandwidth of 1.5 to 13 kHz, is positioned on buoyancy panels in the centre of the array. The source signatures can be chosen depending on the survey target [9]. The system is constructed from glass reinforced plastic and PVC foams making it a rugged, lightweight, overall neutrally buoyant system which is easily deployed and shows stable towing behavior. The array is positioned using Real Time Kinematic GPS positioning technology (Sagitta, Thales Navigation, CA, USA) together with a GPS based attitude system (ADU5, Thales Navigation, CA, USA) making it possible to determine the absolute position of the source and receiver elements with sufficient accuracy for 3D seismic data processing. The four GPS antennas are placed on the system and stay above the water surface during deployment. The construction concept makes it easy to expand the presently 2.75 m wide and 2.3 m long array by adding sections with additional receiver groups, which can be recorded by adding additional channels to the scalable custom-build acquisition system.

Data Acquisition And Processing

The 3D Chirp system is deployed from small survey vessels as shown in Figure 2. The survey area is generally covered by sailing closely spaced lines with a typical survey speed of 4 knots.

The seismic data is recorded with an integrated custom-built data acquisition system, which allows online survey planning, monitoring and data quality control. It combines the positioning and seismic data into the industry standard SEGY format online, which can readily be loaded into standard seismic processing and visualization software. Post-processing includes trace-by-trace seismic processing steps, such as filtering, source sweep correlation and computation of instantaneous amplitude (see for example [10]). The data are then combined into a 3D data volume by assigning the reflection mid-points of the traces, calculated from their associated source and receiver positions, to a regular bin grid with bin sizes as small as 12.5 cm and stacking the traces to produce the data volume. Alternatively a pre-stack 3D Kirchhoff migration algorithm can be applied. This algorithm is based on 3D wave propagation theory and repositions reflection energy to the correct subsurface position and enhances data quality and resolution. The output is a regularly sampled data volume (see for example [11]).

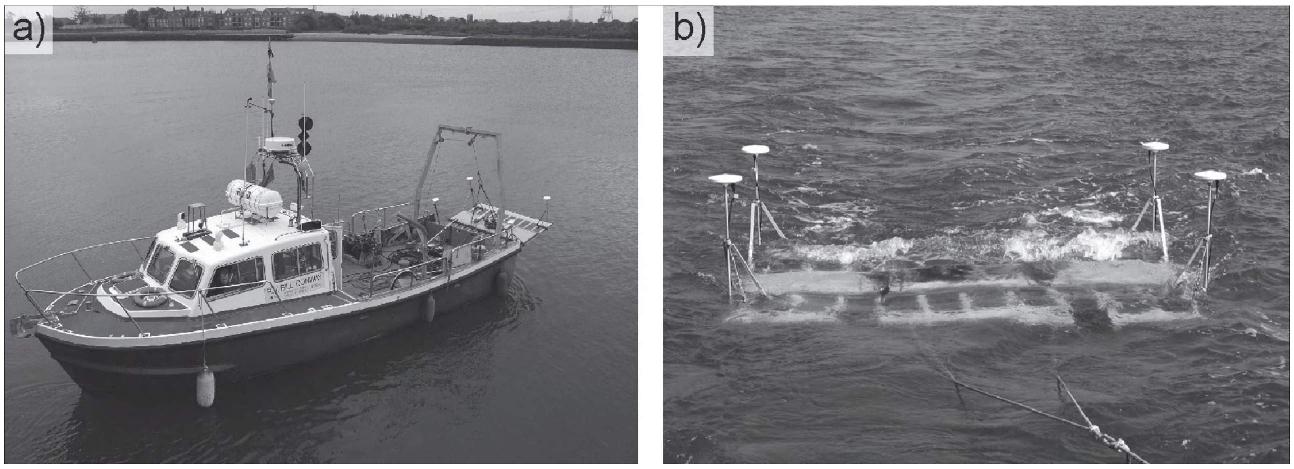

Figure 2: a) The 3D Chirp system is deployed from the A-frame of the 12m long R/V Bill Conway. b) Its lightweight open and rugged construction results in neutral buoyancy and assures a stable towing behaviour. The GPS antennas stay clear of the sea-surface during the survey.

Data Examples

Buried Engineering structure in the Port of Southampton, UK

In the 1970's the Prince Charles Container Terminal was constructed in the Port of Southampton. Prior to the construction of the quay walls a coffer-dam, formed with steel sheet piles, was constructed. This was subsequently toppled into a pre-formed trench and buried. Commissioned by Associated British Ports (ABP) Southampton a survey was completed to locate and image the buried coffer-dam.

The area was surveyed in 6 hours and a seismic data volume was produced for an area of 200 m by 25 m by applying the Prestack 3D Kirchhoff migration algorithm. The data volume is shown in Figure 3.

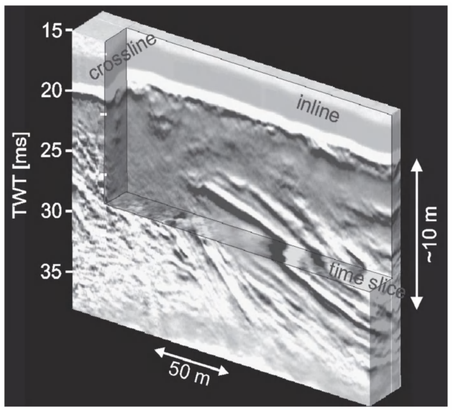

Figure 3: 3D Chirp data volume over the cof-fer-dam area. The data volume covers a 200m long by 25m wide area and images structures down to 15m below the seafloor. Note the vertical inline and crossline sections together with the horizontal timeslice. Dipping bedrock reflectors are apparent which are overlain by sediments and interrupted by a trench containing the buried cofferdam. See Figure 4 for a detailed interpretation.

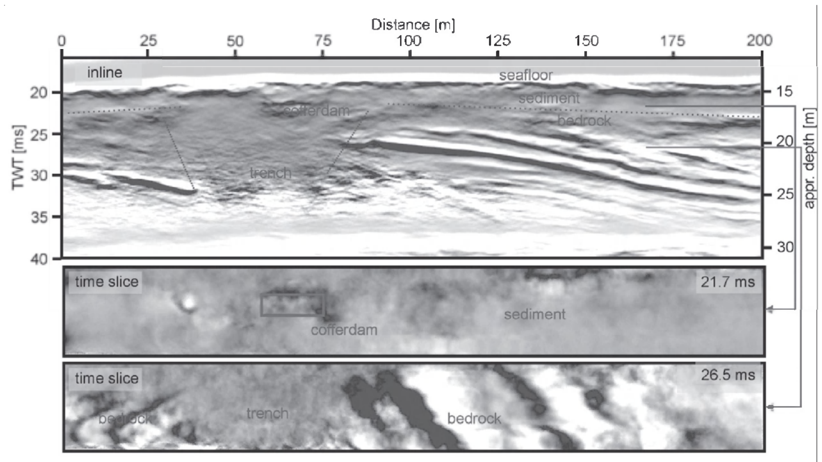

Figure 4: A vertical inline section and two horizontal timeslices from the 3D Chirp data volume of 200m length and 25m width (Figure 3). The seafloor is at c. 15m depth and the maximum penetration is equally 15m. The sections show dipping reflectors in the bedrock which are overlain by sediments. Between 25m and 85m a disturbed area is apparent that is interpreted as the trench which was dredged to hold the toppled cofferdam and then later in-filled. Within the trench the reflection from the top of the cofferdam with a length of 17.5m and a width of 6m is apparent which corresponds to the dimensions recorded in detailed construction drawings of the structure. Note that the true strikes of the bedrock reflectors are apparent from the timeslice at 26.5ms TWT. The timeslice at 21.7ms TWT images the cofferdam within soft surficial sediments (above bedrock).

Sections of the data can be viewed in any orientation, independent of the original survey direction. In Figure 3 vertical inline and crossline sections are highlighted together with a horizontal timeslice, representing the reflection amplitudes at a constant Two-way-travel-time (TWT). The seafloor is at 20ms TWT which equals approximately 15m water-depth and the sub-surface penetration is equally approximately 15m. The bedrock, which underlies a sedimentary cover, shows dipping reflectors whose true dip and strike can be easily deduced from their 3D representation. A disturbed zone that represents the in-filled trench containing the reflection of the cofferdam interrupts the sedimentary cover and the bedrock reflectors. Figure 4 shows an inline section together with two time slices at marked depths, in which the described features are highlighted. The reflection associated with the cofferdam is believed to originate from the top of the structure. Its width of 6m and length of 17.5m matches the dimensions of the cofferdam revealed in technical drawings.

A buried wooden ship-wreck in the river Hamble, UK

A survey was conducted to image a wooden buried shipwreck: the Grace Dieu, who was built in 1418 and has served as the

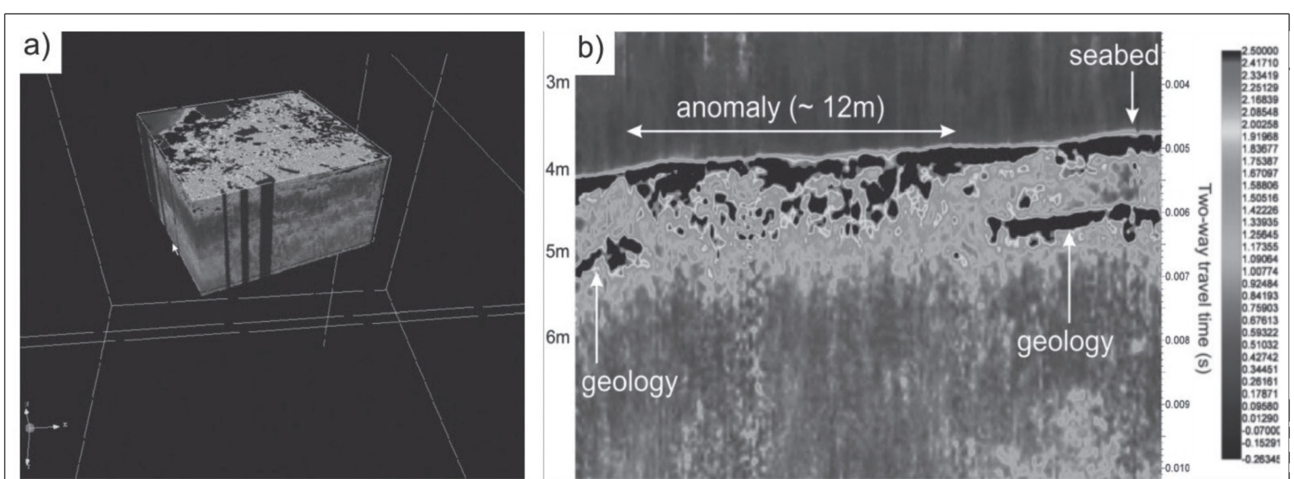

Figure 5: a) Data volume, stacked with a bin size of 12.5cm x 12.5cm, which images the Grace Dieu ship-wreck. b) a vertical cross-section through the data volume showing the seabed reflection at approximately 3m water-depth. The Grace Dieu ship-wreck is marked as anomaly, blanking the reflection of the local geology c. 1m below the seabed. The bottom reflection of the anomaly was interpreted in a 3D seismic interpretation software and is shown in Figure 6.

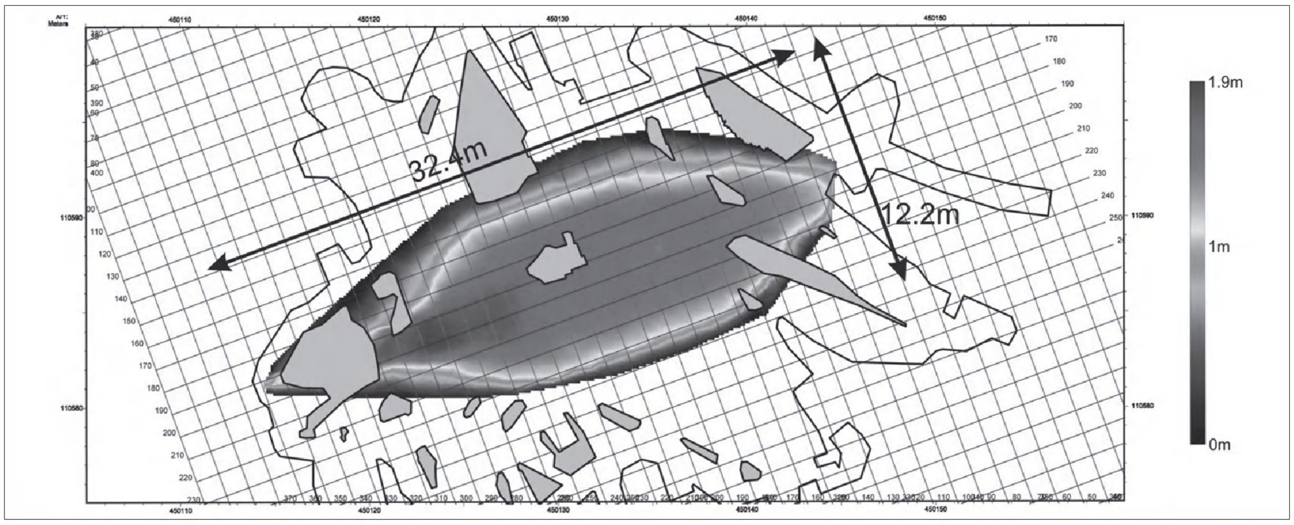

Figure 6: Isopach map showing the thickness of the anomaly representing the ship's hull with an overall length of 32.4m and a width of 12.2m.

'great ship' of Henry V's fleet. See Plets et al. [12] for details of this work. She was the largest ship ever built in England up to that time. Although the site has been studied for over 150 years by archaeologists, there is still very limited information on the basic dimensions and shape of the buried hull since it was never fully excavated [13]. Consequently, the data presented here not only demonstrates the capabilities of the system to image a wooden shipwreck in great detail but also increases the knowledge of this exceptional vessel applying this non-destructive method.

The situation of the survey area in a river bend made it impossible to navigate survey lines as described in the example in 4.1. instead the survey vessels was moored close to the side and the 3D Chirp system, equipped with floats for extra buoyancy, was pushed by divers to cover the 50m x 50m large area during a survey day.

In this case the data traces were binned on a regular grid with a side-length of the square bins of 12.5cm and stacked. Figure 5 shows the resulting data volume together with a vertical cross-section though the volume.

The isopach shows maximum dimensions of 32.4m x 12.2m and a maximum burial depth of 2m. It suggests well defined and pronounced longitudinal and lateral axial (keel) symmetry and indicates that the wreck is slightly tilted towards port side. A full 3D reconstruction of the remains of the hull of the *Grace Dieu* can be created. Additionally small, metre scale, objects are detectable in the data volume of potentially archaeological importance within and around the wreck.

Conclusions

The 3D Chirp system provides three-dimensional imaging of the subsurface for the shallow survey market. It three dimensionally images complex geometries and small objects in the subsurface with high resolution making it a valuable tool for marine engineering, defence, marine archaeology as well as general marine geology and geophysics applications. It is commercially available from GeoAcoustics Ltd.

Acknowledgements

The Chirp sub-bottom profiler was developed by the National Oceanography Centre, Southampton (NOCS) and GeoAcoustics Ltd. The initial project was funded by the EPSRC and GeoAcoustics Ltd. We are grateful to Gary Brown (ABP) for assistance and advice during the Port of Southampton survey. We are grateful to Ruth Plets for making the work presented as data example 4.2 available to us.

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Simulation, Detection And Prediction Of Sea Floor Dynamics

P. Menting, L. Dorst, R. Lindenbergh and H. Wüst

The Dutch part of the North Sea is mapped by two authorities. Both authorities predict the behavior of the sea floor by analyzing time series of bathymetric data. The Hydrographic Service determines parameters for sand wave dynamics from an area, based on deformation analysis. The North Sea Directorate uses a multivariate state space modelling approach to estimate, update and extrapolate trends per grid point. Here, both approaches are described and combined in order to obtain a prediction method that incorporates a sand wave propagation model. The new method is tested on two data sets of different characteristics.

Introduction

The Dutch part of the North Sea is being mapped by two authorities, the Hydrographic Service of the Royal Netherlands Navy and the North Sea Directorate, part of the Directorate-General of Public Works and Water Management. Monitoring the depth in the Southern North Sea is essential, because it is heavily used by shipping, but shallow. To ensure that main ports, such as Rotterdam, remain safely accessible, reliable depth information is needed. However, the depth is not constant in time, due to e.g. the development of sand waves. These are regular wave patterns, having amplitudes of several meters. These sand waves tend to grow and migrate, which may have consequences for the navigable channel depth.

As it is expensive to survey large parts of the sea on a regular basis, insight in the dynamic behaviour of the sea floor is required. Both authorities have developed their own method to monitor the sea floor by using time series of bathymetric echo sounding data. In this article, parts of both methods will be described and combined to a new method that benefits from both.

The Hydrographic Service is responsible for the production and upkeep of nautical publications, such as nautical charts. In order to make a more efficient planning of the bathymetric surveys used for the production of these charts, insight in the dynamics of the sea floor is needed. Therefore a method is developed, [1], for analyzing time series, based on geodetic deformation analysis. The core of this method is a testing procedure to determine if the sea floor is static or contains some kind of dynamics. Two kinds of dynamics are considered: outlying surveys and linear trends. This procedure can be applied at several scales, for single grid-points or for a whole area. The point-wise test results can be used for predictions. Furthermore, sand wave parameters are estimated within the area test. This method proves to work very good for the detection of dynamics, but the prediction results are not satisfying.

The North Sea Directorate is responsible for maintenance of the sea channels, like the Euro Channel to the port of Rotterdam. For this channel, a nautical guaranteed depth is defined: when the channel becomes too shallow it has to be dredged. To predict the moment when the depth in the channel will rise above a critical depth, a trend analysis model has been developed, [2], based on a state space model and Kalman filtering. In this method a linear growth model is attributed to every point of a fixed grid. This growth model consists of a depth part and a linear part which are updated when new measurements become available. Except for the actual depth and trend values, accuracy measures for these values are determined as well. These depths and trends, together with their accuracy, are used to make a prediction for the future sea depth. This method performs well for predictions up to five years ahead and also produces calibrated predictive uncertainty measures.

Both authorities have developed a grid-point wise prediction setup, but in both cases more complicated dynamics, like propagating sand waves, are not incorporated in the grid-point wise predictions. To overcome this shortcoming, a combination of both methods is proposed. First a deformation analysis is applied to detect outlying surveys and determine sand wave migration parameters. The detected outliers are used to correct the input data of the state space model. Furthermore, the model filter is extended with a local testing procedure and a sand wave propagation model, based on the parameters found in the deformation analysis.

This combined method is tested on two data sets of different characteristics. On the data set containing an obvious regular sand wave it proves to work well. The benefit of the new method on the other data set is less clear, because the mapped area is less dynamic and the sand waves are less regular. This demonstrates the importance of an efficient model snooping procedure that should select the most appropriate model for describing the morphology of a local sea floor surface and its dynamics. It should be noticed however that in e.g. the area monitored by the North Sea Directorate sand waves are either reported to move not at all, or at propagation velocities of at most 2m a year. Even in the latter case the improvements as obtained from the combined approach will still be limited.

In Section 2 the combined method is described in some detail, in Section 3 the prediction results on real data are presented, followed by conclusions in Section 4.

Prediction Methodology

In this section a method is described that allows for fitting a propagating sinusoidal sand wave model onto a regular grid of sea floor depth data for the purpose of predicting future grid-point wise depth values. First, an example is given that demonstrates the benefit of such an approach. Then, it is shown how to obtain initial sand wave parameters, and how to integrate these parameters into a state space model. The model can be used on the one hand to update the sand wave model with new observations, and on the other hand to obtain predictions of expected dynamics.

A simulated example

Consider a simulated propagating sand wave with an amplitude of 1m and a wave length of 300m. Every year, the crest is shifted 10m to the right. In Figure 1, left, the sand wave positions in the years 2001, 2002, 2003 and 2004 are shown. On the right, the analysis results of a deformation analysis per grid-point are given. Points on the left become deeper, while points on the right become shallower. From this simulation it is obvious that sand wave dynamics with a local growth model will result in a prediction accuracy that decreases with increasing sand wave propagation. Such predictions can be improved by incorporating a spatial area based sand wave model into the grid-point wise prediction method as this allows for modelling the sand wave propagation. The essential extension is that in this case a global model is used for predicting local dynamics.

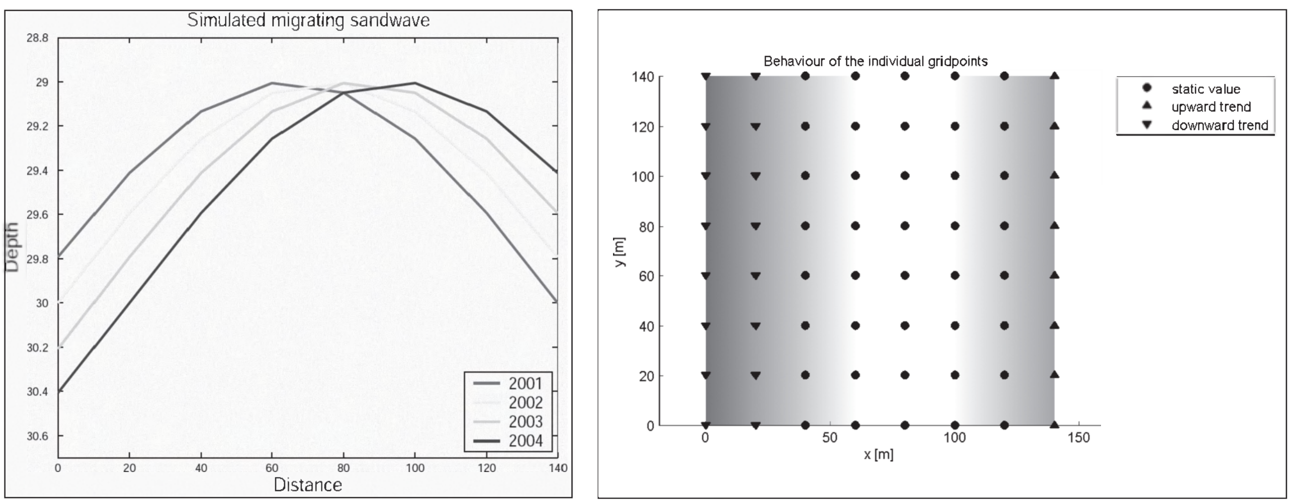


Figure 1: Left: profile of a simulated migrating sand wave. Right: depth predictions.

Experimental covariance analysis

The spatial continuity between neighbouring sea floor depth observations is traced by means of an experimental covariance analysis, under the assumption that the depth signal is stationary, [3]. This assumption states that the expected covariance between two depth observations is independent from the location of the observations in the signal. The covariance function is estimated by multiplying for any pair of depth observations d_i and d_j, the observation wise differences with the mean depth μ. The resulting numbers $c_{ij} = (d_i - \mu)\cdot(d_j - \mu)$ are now grouped with respect to the vector $p_i - p_j$ that denotes the difference between the observation locations p_i and p_j. By averaging groups of experimental covariances with similar difference vectors, an approximate, direction dependent experimental covariance function is obtained.

Covariance functions are used to describe the redundancy between depth observations in geostatistical interpolation methods, but in this case they are applied for obtaining an estimate of the average direction and length of sand waves, compare [1]. The direction of highest variability, αp_r, is assumed to correspond with the propagation direction of the sand waves and can be estimated by analyzing the gradients of the depth data. Along this direction, covariance values will be small at distances that correspond to half the sand wave length, but will be larger again at one sand wave length distance L. This parameter L is estimated from the experimental covariance function by taking an optimal fit parameter obtained from fitting a suited smooth function to the experimental covariance function.

Static sea floor model

After determining a suitable model of the sea floor, based on one epoch of data, the dynamics of the sea floor are determined in a deformation analysis procedure.

For modelling the sea floor, three scenarios are considered, the sea floor as a flat plane, the sea floor as a sloping plane and the sea floor as a sloping plane with sand waves. The latter model expresses the depth d_p at point p with horizontal coordinates (x_p, y_p) as

$$E\{d_p\} = (1, x_p, y_p, \cos(2 \cdot \pi \cdot x_p / L) - \sin(2 \cdot \pi \cdot x_p / L)) \cdot (d, \alpha_x, \alpha_y, u, v)^T, \qquad (1)$$

with α_x and α_y the mean slopes in the x- and y-direction, d the mean depth of the area and L the wave length of the sand waves. The wave length L is determined by a covariance analysis as indicated above. The remaining parameters, $u = A \cos \varphi$ and $v = A \sin \varphi$ describe a one-dimensional wave, with A the wave amplitude, and φ its initial phase via

$$A \cdot \cos(2 \cdot \pi \cdot x_p / L + \varphi) = \cos(2 \cdot \pi \cdot x_p / L) \cdot u - \sin(2 \cdot \pi \cdot x_p / L) \cdot v, \qquad (2)$$

In this way, the depth d_p at position p depends linearly on the estimation parameters ($d, \alpha_x, \alpha_y, u, v$). By the back substitution

$A = \ ,(u\text{^}2 + v\text{^}2)$ and $\varphi = \arctan v/u$, the sand wave amplitude A, and sand wave phase, φ, are recovered from the estimated parameters u and v.
Selection of the most likely sea floor model is made by a testing procedure, ([4, 1]). In such a procedure, the distance of the observations to an alternative model, that is, an extension of the current model, is determined in an adjustment step. The different distances to the alternative models are compared in a hypothesis snooping procedure that incorporates the number of parameters in each model, compared to the number of observations. Subsequently, the model is extended with the most relevant extension. This procedure continues until none of the remaining alternatives significantly improves the fit of the model to the data anymore.

Deformation analysis

Now it is assumed that the sloping plane with sand waves is tested to give the most adequate description of the sea floor as sampled by the observations in the first epoch, observed at t_0. The other epochs, k, observed at t_k are used to determine the dynamics of this sea floor model. Different scenarios for the sea floor behaviour in the area of study are compared: stability, a single outlying survey, trends in depth and slopes, and in amplitude and phase of the sand waves. The so-called null hypothesis states that the sea floor is static through time. If the null hypothesis is probable, that is, if the corresponding test statistic is below the critical value, the null hypothesis is accepted and the sea floor is considered static.
If the null hypothesis is rejected, the alternative hypotheses are considered: for all alternatives the quotient between the hypothesis wise test statistic (distance observations to model) and the critical value is determined. The alternative that has the largest quotient is selected. In case of the detection of a single outlying survey, all observations of the outlying epoch are removed and the procedure is repeated. As an example, the dynamic model of a trend in the sand wave is constructed by extending the current sea floor model with a term

$$\cos(2 \cdot \pi \cdot x / L) \cdot (t_k \cdot - t_0) \cdot \Delta u / \Delta t - \sin(2 \cdot \pi \cdot x / L) \cdot (t_k - t_0) \cdot \Delta v / \Delta t \qquad (3)$$

Adjusting the observations into this model will result in wave propagation parameters $\Delta u/\Delta t$ and $\Delta v/\Delta t$ that together describe a change in amplitude, ΔA, and phase, $\Delta\varphi$, of the sand waves in the study area.

Kalman filtering and the state space sand wave model

The dynamic area-wise sand wave model can be incorporated in a grid-point wise state space model. This model can be used to obtain depth prediction at grid points at arbitrary time t. The deterministic part of the model, [5, 2], consists of a state vector x_k containing model parameter values at time k and a transition matrix ϕ_{tk} that describes the change in model parameter values x_k at time k to the values x_t at time t, that is, $x_t = \phi_{t,k} \cdot x_k$. This step is called time update, as the state of the parameter values in the past is updated to current time, say. It is also possible that new measurements become available. Then a measurement update step is required that adjusts the (time updated) parameter values by incorporating the new observations at that time using the Kalman filter.
Besides a deterministic part, the state space sand wave model also contains a stochastic part. The latter part separately addresses the accuracy of the input observations and the growing uncertainty of the state space model predictions when evolving to future time steps.
Another way of error handling is by means of the so-called DIA procedure, [5]. DIA stands for Detection, Identification and Adaption. In the detection step it is tested whether the observations fit the null hypothesis model. If the distance between the observations and model is too large, the cause of the large distance has to be identified in the identification step. In this step several model extensions (alternative hypotheses) are considered, for example extensions that model an outlier in the, say, k-th observation. If e.g. an outlier is identified, the final step of the DIA procedure is entered in which the state vector is adapted in such way that the reported outlier does not influence the predictions anymore.
In order to express the above dynamic sand wave model in a state space format, the transition matrix $\phi_{t,k}$ and the state vector must be expressed in terms of the dynamic sand wave model of Eq. 1. The sand wave can only be modelled if sufficient spatial information is available at every Kalman filter update step. Therefore the model maintains local depths d_i, local depth trends Δd_i

$/\Delta t$ and the global sand wave parameter values u, v and Δu and Δv in a local grid around the prediction location. The positions in this grid are labelled from $i=1$ to $i=J$. The state vector is given by

$$x = (d_1, \cdots, d_J, \Delta d_1 / \Delta t, \cdots, \Delta d_J / \Delta t, u, \Delta u / \Delta t, v, \Delta v / \Delta t). \tag{4}$$

The transition matrix reflects the change in the state vector according to the dynamic model of above and has, with $A' = (A_0 + \Delta A)/ A_0$ and $Id_{J \times J}$ the identity matrix of size J, the shape

$$\Phi = \begin{pmatrix} Id_{J\times J} & Id_{J\times J} & & & & \\ & Id_{J\times J} & & & & \\ & & A' \cdot \cos\Delta\varphi & A' \cdot \cos\Delta\varphi & -A' \cdot \sin\Delta\varphi & -A' \cdot \sin\Delta\varphi \\ & & 0 & 1 & 0 & 0 \\ & & A' \cdot \sin\Delta\varphi & A' \cdot \sin\Delta\varphi & -A' \cdot \cos\Delta\varphi & -A' \cdot \cos\Delta\varphi \\ & & 0 & 0 & 0 & 1 \end{pmatrix} \tag{5}$$

A description of the full state space model for sea floor depth predictions with a state vector consisting of grid-point wise depths and linear depth changes is described elsewhere, [2]. The model presented here extends this approach, and maintains an area wide spatial model of the sea floor.

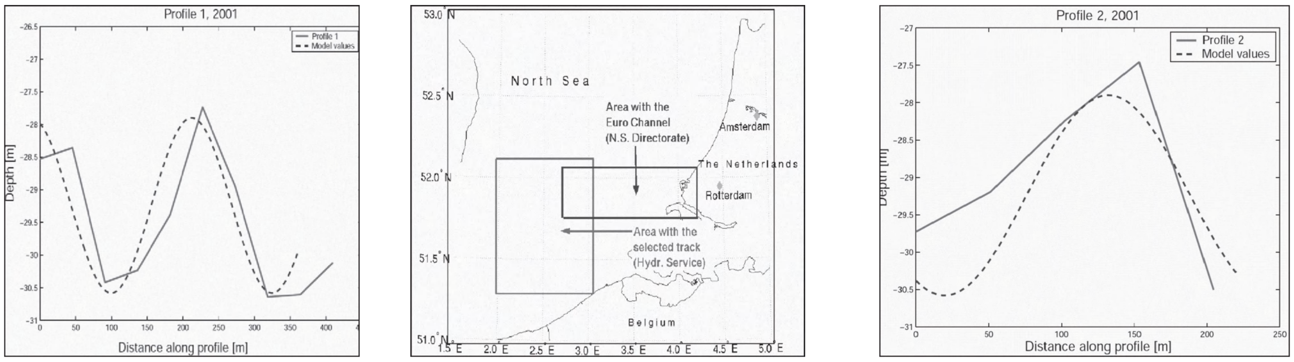
Final prediction algorithm

The steps leading to a grid-point wise prediction, as explained in some detail above, are summarized in the following algorithm.

Input: Data grid available in K epochs. At every grid point a depth value and a depth variance is available.

1. Determine sand wave length and sand wave direction from experimental spatial covariance analysis.
2. Determine sand wave velocity, sand wave amplitude and outlying surveys from a deformation analysis of all K epochs. Remove outlying surveys if found.
3. Run a state space model on the remaining data. At every Kalman filter update step, grid-point wise outliers are identified and eliminated by a DIA procedure.
4. Perform state space evolution step for a prediction at an arbitrary future moment.

Output: grid-point wise predictions.



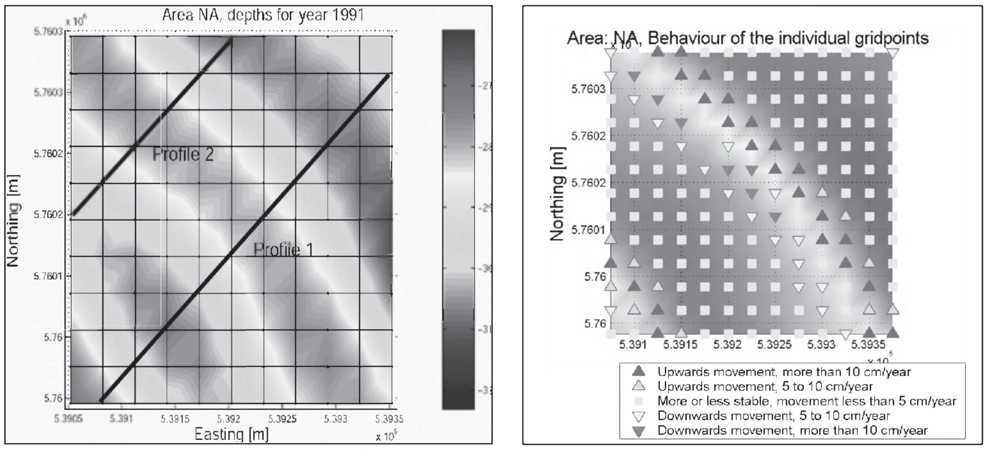


Figure 2. Data set A. Profiles of the modelled and the real sand wave are shown in the top left and right. The location of the profiles is indicated in the depth map at the bottom left. The position of this data set (right rectangle) and of data set B is indicated in the map at the top. At the bottom right, predictions are given based on the dynamic state space sand wave model.

Prediction algorithm results

Here the results of the new algorithm are given on two data sets. The first data set, A, features a regular sand wave. The morphology in the second data set, B, is far less regular however.

Data set A

Figure 2. bottom left, shows the depth of area A in 1991. Area A is located in the Euro Channel, indicated by the right most rectangle in the North Sea map in Figure 2. The presence of a sand wave in this data set is obvious. This area of 330 x 330m has been monitored by Multi Beam Echo Sounding in all years between 1991 and 2001, except for 1992 and 1998. The data are available on a 5m grid.

From the experimental covariance function a sand wave length of 225m was found and a sand wave orientation of 47 degrees East of North. Least squares adjustment to the dynamic sand wave model as described in Section 2, gives a sand wave amplitude of about 1.4m and sand wave propagation velocity of 1.6m/year. The amplitude growth is negligable. Two profiles, illustrating the sinusoidal sand wave model, are given in Figure 2, top left and right. From the depth plot it can be seen that the sand wave is curved. Therefore the modelled wave fits better in the middle (top left) than at the edges (top right).

Once all initial sand wave parameters were estimated, the state space sand wave model was run sequentially on the epochs of gridded observations. On the bottom right of Figure 2 the one year prediction for individual grid points is given. That is, the differences between the observations of the last survey and the predictions for one year ahead are displayed. Clearly, the motion of the sand wave in North-East direction is visualized by the pointed triangles, indicating upwards resp. downwards movements of at least 5cm. A validation of the prediction results is obtained by comparing predictions for e.g. 2001 to the actual grid wise observations. The mean absolute difference between prediction and observation is 12cm, with maximum values of +45cm and -12cm.

Data set B

The second data set that was processed is data set B, see Figure 3. This data set represents a part of the so-called `selected track', which consists of the seaway to the port of Rotterdam and the anchorages. The location of the selected track is indicated by the left most rectangle in the North Sea map in Figure 2. This data set is obtained by a single beam echo sounder in the years 1991, 1995, 2000, 2001, 2002 and 2003. This is a difficult area: although the area is clearly not flat, it does not have a regular sand wave either.

In this case a prediction is made without modelling a sand wave. Differences between state space predictions and measured depths are within -0.47m and +0.76m. No regular pattern or strong dynamics can be seen from the one year prediction map shown in Figure 3, right. It would only make sense to estimate the regular sinusoidal sand wave model, if the data set is subdivided into segments containing only sand waves with similar orientation. As in this case the area is not very dynamic anyway, gain, in the sense of more reliable depth predictions, would be limited.

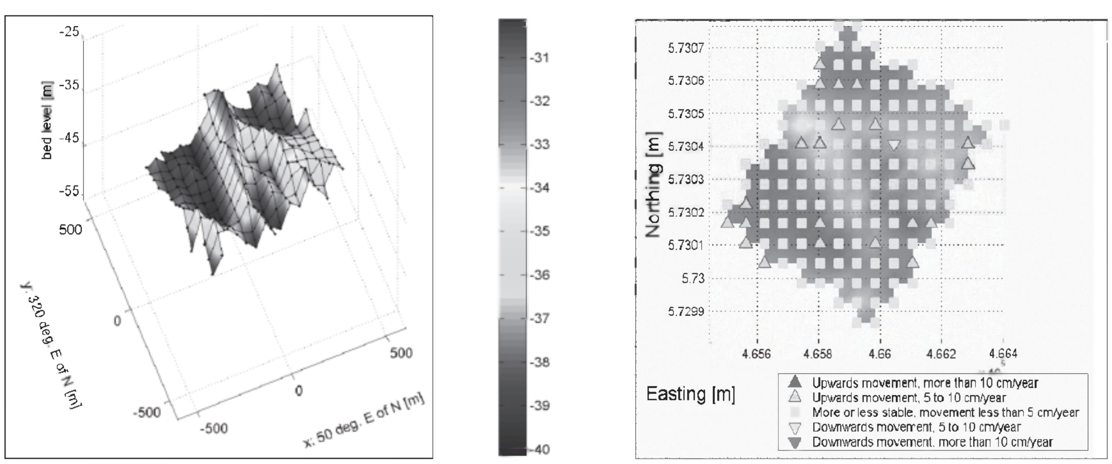


Figure 3. Left: interpolated depth map of data set B. Right: One year ahead state space model prediction without estimation of a sinusoidal sand wave model.

Conclusions

A method has been proposed to incorporate an area wide morphological sea floor model in a state space Kalman filter model for the purpose of grid-point wise change predictions. In this particular case a propagating sinusoidal sand wave was modelled. Test results indicate that on regularly shaped and moving sand wave areas more reliable and therefore more cost-effective predictions are obtained by using this state space sand wave model.

Dynamic areas with an irregular morphology can be automatically reported by the deformation analysis component as fitting badly to any tested dynamical model. In such a case the area could be segmented in more regular sub-areas.

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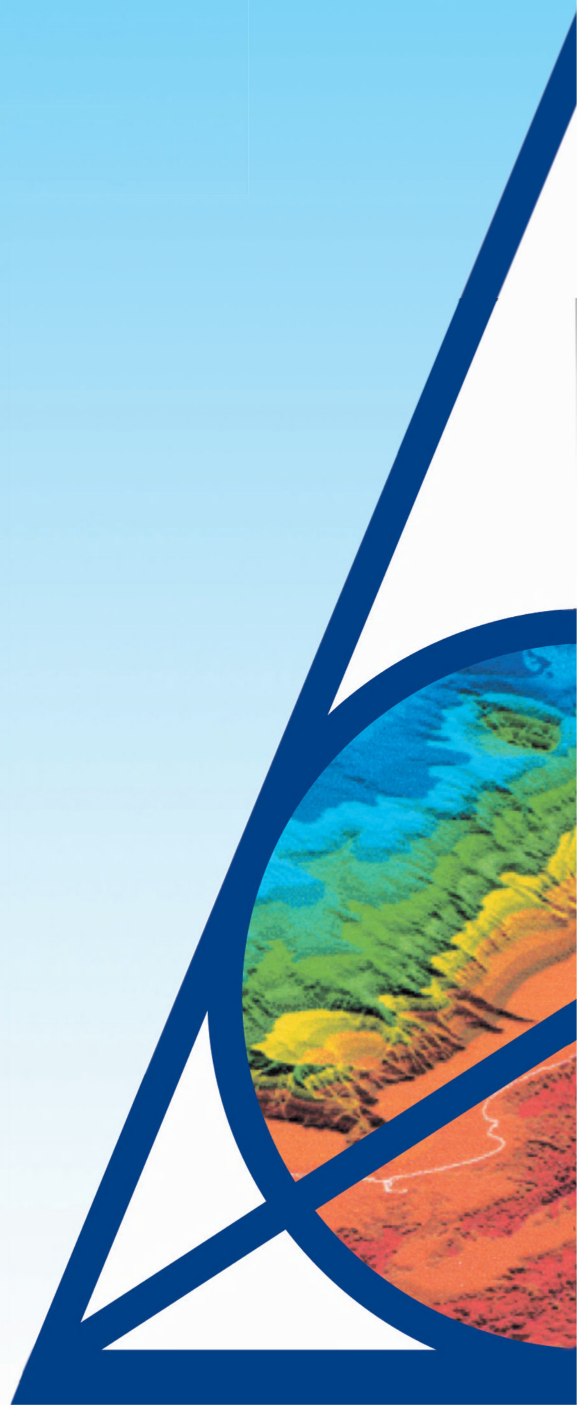

Posters

Quantification Of Sediment Concentrations And Fluxes From ADCP Measurements

Jeroen H. Aardoom

There are numerous reasons to measure sediment concentrations in the water column. It can be because a harbour is located at a tidal river, where sediment transport and deposition are major factors for maintenance of channels and harbours. Or it can be the local authorities that demand a strict control of the environment during dredge operations.
The first reason requires constant monitoring of the suspended sediment concentration (SSC), at least over tidal periods. For the latter one you must be able to intervene in case of unacceptable disturbances to the surrounding environment occur. For this reasons the monitoring results must be available in real time.
This paper presents a case study in which the sediment behaviour in the river Weser is monitored during a tidal period.

Introduction

Sediment transport in tidal rivers is a critical component to many coastal and waterway engineering problems: Examples include sedimentation in navigation channels, sand transport in the littoral zone and sediment re-suspension during dredging operations or due to natural processes. Sediment management tools are of fundamental importance for harbour and water authorities to reduce the costs for maintenance dredging and waterway building activities. This is underlined by the fact that the further extension of many navigation channels is planned in Europe and worldwide to meet the requirements of new (SuezMax) container ship generations. Reliable in situ data of sedimentation rates and suspended sediment concentrations (SSC) are a precondition to understand the mechanisms that control sediment transport. Regarding the measurement of SSC, both optical and acoustic devices have their pros and cons. In general, optical devices are successfully used for measurements of fine-grained sediments. They feature a nearly linear response to sediment concentrations spanning more than three orders of magnitude, which is advantageous in natural systems where concentrations can vary widely. However, optical measurements have to be regarded as point a measurement because of the strong signal decay with range and due to the nephelometer scattering, which restricts either the temporal or spatial resolution of the SSC measurement. Acoustic devices are capable of measuring SSC from a distance, at a high temporal and spatial resolution. Disadvantage of using acoustic devices is the dependence on sediment properties such as particle size distribution. The backscattered intensity from a homogeneous sediment suspension ensonified by an acoustic device is proportional to the product SSC⊠f2/a, where f is the particle form factor and a the particle radius (LYNCH et al. 1994). For particles that are small compared to the acoustic wavelength, the Rayleigh scattering law applies. Here ka « 1 (where k is the acoustic wave number) and f2/a reduces to a3 (RAYLEIGH 1945). For increasing particle size in the regime where ka is close to unity or larger, the sensitivity of the backscattered intensity to particle size decreases. Hence, the acoustic response generally grows more rapidly with size for smaller particles. Starting from the complementary characteristics of optical and acoustic devices we developed a software tool to complete a sediment monitoring system for real-time quantification of SSC. The software, VISEA-PDT⊠ (PDT stands for 'Plume Detection Toolbox'), is based on simultaneous ADCP and OBS measurements. Additional sensors can be hooked for additional information (e.g. GPS, STD, CTD, LISST, etc.). VISEA-PDT⊠ uses OBS and possible other input for real-time conversion of ADCP data to SSC. During post processing lab results of local samples (SSC and grain size distribution) can be used to validate the real-time calibration. On the basis of a case study in the river Weser the sediment monitoring system is demonstrated here.

Acoustic Formulation

ADCP backscatter of sound from suspended sediment can be modeled with the sonar equation (MEDWIN & CLAY 1998). It appoints a balance of the difference between emitted and received energy and the energy lost during the round trip of the acoustic pulse. Absolute calibration requires a complete characterization of the transmit and receive circuit of the instrument. This includes the parameters acoustic transmit power, transmit pulse length, transducer efficiency, acoustic receive sensitivity and temperature sensitivity. To quantify the relationship between these variables affecting the backscatter, a working version of the sonar equation in units of decibel was formulated (DEINES 1999):

$$S_v = C + 10\log_{10}\left[\frac{T_T R^2}{L P_T}\right] + 2\alpha R + K_c(E - E_r)$$

Herein, Sv is acoustic backscatter [dB], C is a constant [dB], TT is the temperature of the ADCP transducer [°C], R is the (slant) range along the beam to the scatterers [m], L is the transmit pulse length [m], PT is the transmit power [W], a is the attenuation coefficient [dB/m], Kc is a scale factor [dB/count], E is the relative backscatter equal to echo intensity [count] and Er is the received noise [count]. The values of C, TT, R, L and PT are recorded by the ADCP or provided by the factory. E is derived from the Received Signal Strength Indicator (RSSI) of the receivers. Its real-time reference level is denoted Er, the noise value when there is no signal present. It may be obtained from the RSSI at the end of a profile. A typical value of Er is 40 counts. The RSSI output is measured in counts that are proportional to the logarithm of power and can be converted to dB units by the scale factor Kc. This factor has values ranging from 0.35 to 0.55 and is typically 0.45 dB/count. The attenuation coefficient a is the sum of water absorption (aw) and particle attenuation (as). FRANÇOIS & GARRISON (1982a,b) summarized the empirical research on water absorption.

Particle attenuation is the spreading and absorption of acoustic energy by particles in the water. The attenuation by suspended sediment is parameterised by (URICK 1948). Using, the acoustic frequency [Hz], the sediment density [kg/m], the water density [kg/m], a particle diameter [m] and the kinematic viscosity of water [m2/s] according to VAN RIJN (1993). w is calculated based on salinity, temperature and depth according the well-known international equation of state of seawater (UNESCO 1981). All described parameters can be imported into VISEA-PDT™, either as a profile or fixed value. The result of the range and instrument normalization is Sv that is converted to SSC by means of reference measurements of SSC. Figures 2 to 7 exhibit the processing steps from relative backscatter to SSC.

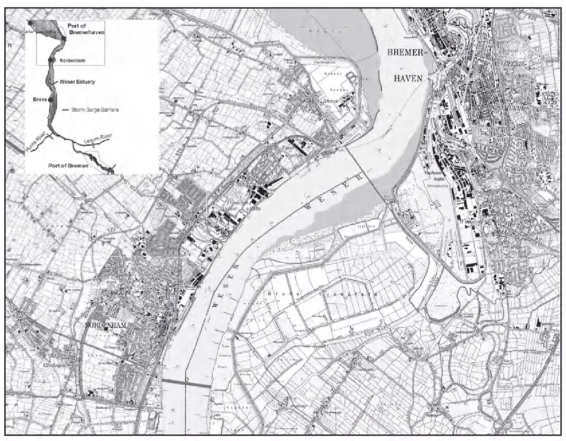

Figure 1: Overview of Weser estuary with measurement location near Nordenham.

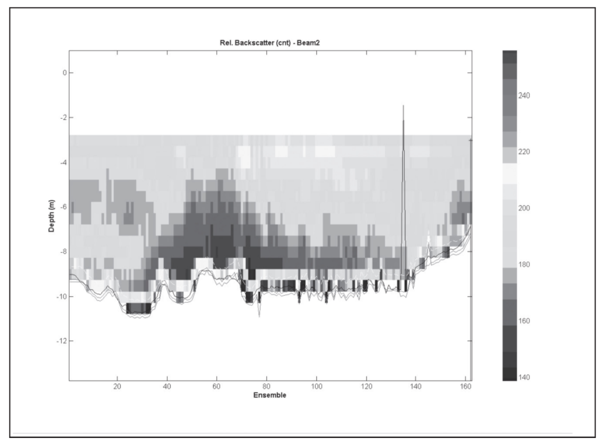

Figure 3: Measured relative backscatter expressed in counts, equal to E in equation (1). Although E reflects SSC in a certain way it cannot be straightforwardly transformed towards SSC.

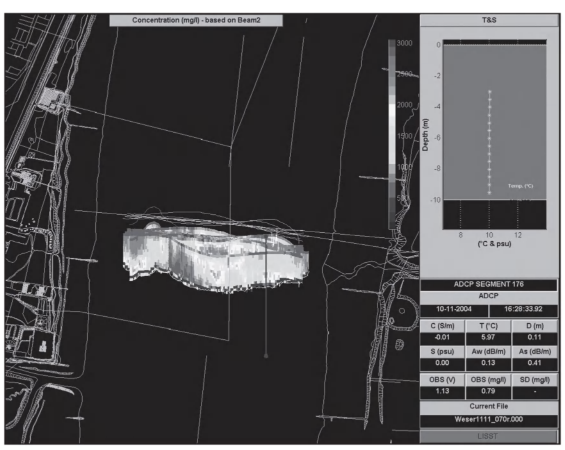

Figure 2: Three-dimensional SSC values in the main window of VISEA-PDT. The profile plot in the upper right hand corner shows data of T and S. Numerical information of relevant parameters are presented in the lower right corner.

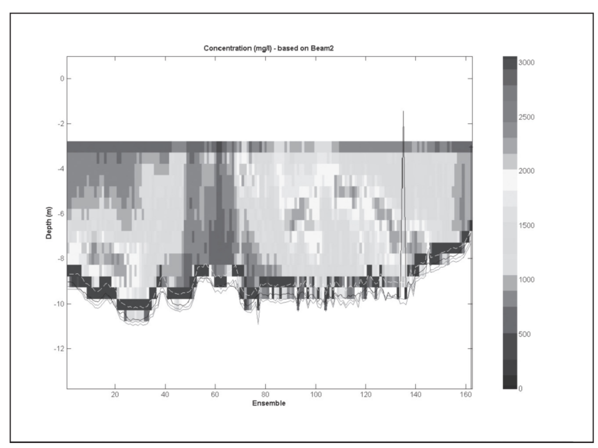

Figure 4: Resulting SSC as converted from Sv in real-time by means of OBS data. Note the difference with the uncorrected relative backscatter in Figure 1.

Weser Measurements

On 10 November 2004, a 13-hour SSC measurement campaign has been performed in the tidal river Weser near Nordenham. Figure 1 shows an overview of the measurement location in the river Weser near Nordenham. The test was organized by the coastal department of the German 'Bundesanstalt für Wasserbau' (BAW). VISEA-PDT™ was used for the real-time quantification of sediment concentrations and fluxes. Over a period of 13 hours, SSCs were monitored by moving boat measurements with

survey vessel 'TIDE' of the 'Wasser- und Schiffartsambt Bremerhaven'. The vessel was equipped with a 600 kHz ADCP of RD Instruments and a pre-calibrated multi-parameter probe for measurement of optical backscatter, conductivity, temperature and depth. Moreover a Laser In-Situ Scattering and Transmissiometer (LISST) instrument and an automated water-sampling pump were used. A total of 89 water samples were taken and analyzed afterwards in a lab to determine the SSC values and particle size distribution.

Calibration

The ADCP backscatter is processed and converted to SSC by means of CTD data and reference measurements of SSC. OBS data were used for the real-time calibration of the ADCP backscatter. During post-processing this real-time calibration is optimized by means of the lab results of SSC and particle size distribution analysis of the water samples. The lab results are the ground truth and used for the final calibration here. However, backscatter and therefore SSC is dependent on particle attenuation and particle attenuation is dependent on SSC. For this reason the SSC values have to be optimized using an iterative calculation procedure. VISEA-PDT™ starts from the absolute backscatter in the first ADCP bin and calculates SSC using a standard calibration relation. For calculation of absolute backscatter in the first ADCP bin, the particle attenuation is not taken into account. Acoustic loss is only based on acoustic spreading and water absorption. The resulting value for SSC is used for calculation of the particle attenuation. This particle attenuation is used to complete the range normalization and obtain a corrected absolute backscatter. This process is repeated until SSC is optimized. This SSC value for the first ADCP bin is used to calculate the sediment attenuation and SSC value in the second ADCP bin. This process is continued downwards for optimizing SSC values for the whole profile. The conversion process takes the influences on sound absorption by variable sediment concentrations in different layers into account. The calibration yields a relation between ADCP backscatter and SSC gained from calibrated OBS. Since the ADCP backscatter is dependent on sediment properties the LISST is used to measure grain size distributions. However, also other sediment properties (e.g. particle form) may influence the backscatter. Therefore a separate backscatter calibration is formulated based on the calibration measurements of 12 subprojects for each hour. The relation between the SSC results from the water samples and the ADCP backscatter (in dB) is presented for one of the subprojects in Figure 8.
The relation in Figure 8 can be formulated as:

$$10\log(SSC) = A \cdot Backscatter + B$$

In general, it can be concluded that A and B vary in time and that relations show a relatively good correlation (r [illegible] 0.8). In order to visualize the variation, A and B are presented in Figure 9 together with the measured water levels at the measuring site Nordenham. The figure shows the variation of A and B varies with the tidal phase. During the flood and ebb currents the values of A and B increase as a result of changing sediment properties at the measurement site. This observation justifies the separate calibration calculations for each of the subprojects.

Sediment behavior in the river Weser

For all transect measurements, SSC is calculated from the backscatter data according the correlation variables of each subproject. Moreover, the concentrations can be converted to sediment fluxes by making use of the simultaneously measured discharge.

Concentrations

Sediment concentrations of more than 1200 mg/l occur during the maximum flood current. At the end of the flood period the concentrations decrease to below 300 mg/l in the upper part of the water column and 600 mg/l in the lower part of the water column. At the beginning of the ebb period the concentrations decrease to about 50 mg/l near the water surface and 150 mg/l near the riverbed.

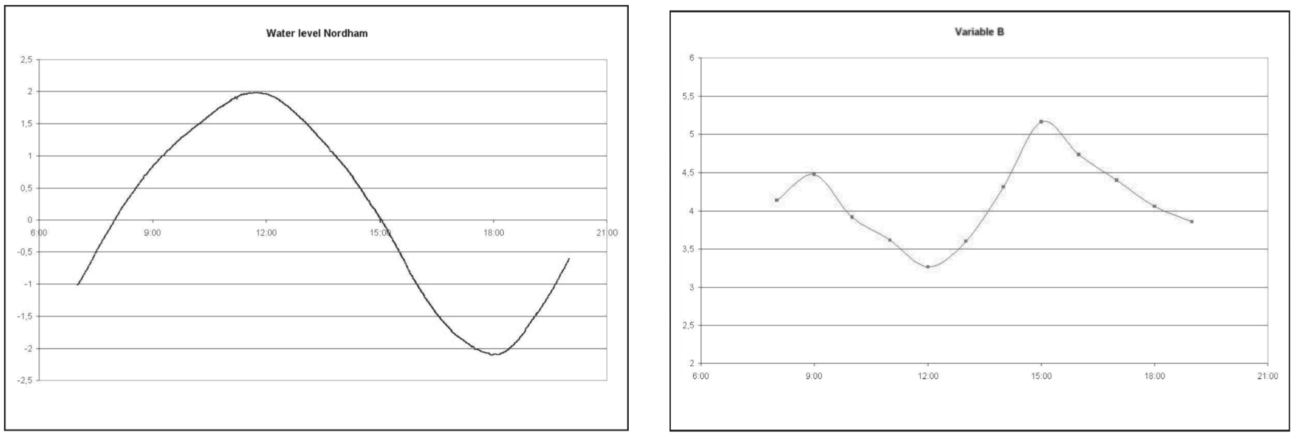

Figure 5: Variables A and B as a function of the tide.

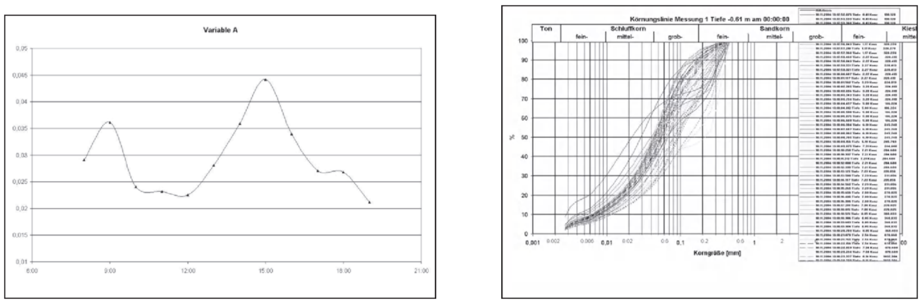

Figure 6: Grain size distributions of Weser sediments.

This situation remains relatively stable for the first half of the ebb period. Then the sediment concentrations increase at both sides of the river to approximately 500 mg/l. Within one hour the concentrations increase to more than 2000 mg/l near the riverbed. During the remaining part of the ebb period the high concentrations spread from the near-bed zone through almost the entire water column. The results consistently show that the concentrations in the middle of the river are lower than at the sides. This may be the result of the sediment being supplied from the riverbanks. At the end of the ebb period sediment concentrations higher than 2000 mg/l occur in the greater part of the water column. Within a relatively short period of half an hour the concentrations decrease to below 1000 mg/l at the beginning of the flood period.

Fluxes

During the maximum flood current sediment fluxes up to 2000 g/m2/s occur. Towards the end of the flood period the fluxes decrease to lower than 500 g/m2/s. After high tide the fluxes remain relatively low (<500 g/m2/s) until halfway the ebb period.

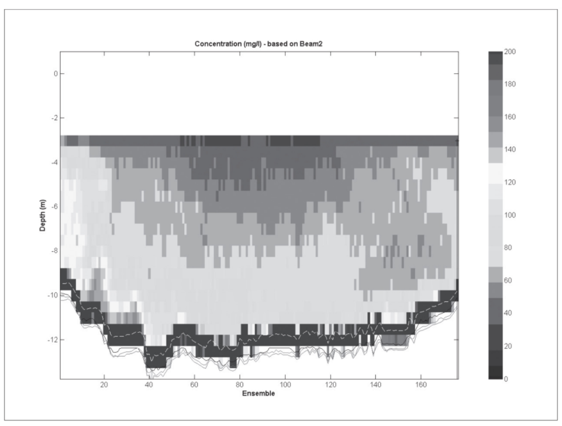

Figure 7: Concentrations at the first part of the ebb period

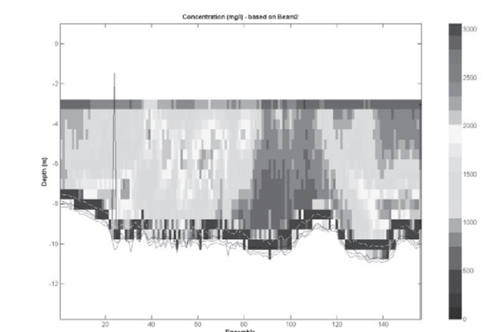

Figure 8: Concentrations at the second part of the ebb.

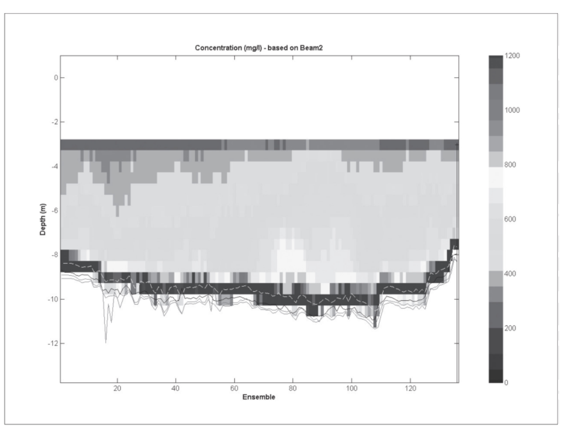

Figure 9: Concentrations at the first part of the flood period.

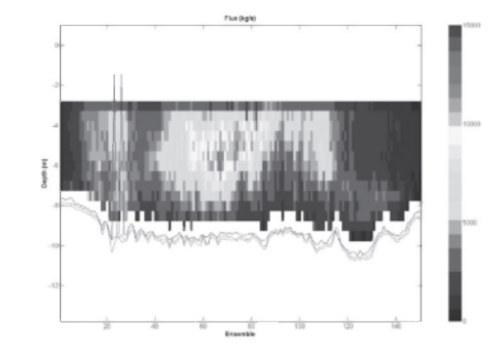

Figure 10: Sediment fluxes at the second part of the ebb

As a result of increasing velocities and concentrations fluxes increase up to 4000 g/m2/s occur in a small part at the east side of the river. During the remaining part of the ebb period the high fluxes expand over a greater part of the water column. At the end of the ebb period the fluxes decrease to 500 g/m2/s at low tide. In the first part of the flood period, fluxes of 1500 g/m2/s occur.

Discussion

The used methods for converting ADCP backscatter to sediment concentrations can only be applied in the Rayleigh regime. The use of a 600 kHz ADCP system limits the Rayleigh regime to grain sizes of 0-800 µm. Figure 10 presents typical grain size distributions of the suspended sediments in the Weser as measured with the LISST system. The grain size distributions show that the monitored sediment in the Weser meets the Rayleigh regime and that the used conversion method is valid.
Compared to optical devices, ADCPs have the advantage of yielding SSCs over the depth range that is ensonified, at a high temporal and spatial resolution. ADCPs are non-intrusive as the sediment suspension is being monitored at distance. The disadvantage of the acoustic approach is the dependence on sediment properties. In particular, irregularities of the grain size distribution restrict the accuracy of acoustic sediment measurements. For this reason grain size distributions were measured by the LISST system and used for post-processing the data. Applying the LISST data results in more accurate processing. In comparison with the default grain size distribution the sediment attenuation is lower as a result of the LISST grain size distribution. However, because the sediment absorption is a part of the total absorption, the results are not changed significantly by taking the LISST data into account. The resulting concentrations are slightly lower in comparison with the results based on the default grain size distribution. The correlation between the ADCP backscatter and the water sample results varies with time. From this can be concluded that changing sediment properties are of relevant interest and should be taken into account if possible. This study showed, despite the LISST input, a variable relation between the acoustic backscatter and the water samples. Most likely changing sediment shapes cause these variations. Unfortunately, there is not a simple instrument that can measure the sediment shape in real-time. Regarding the results of the Weser measurements the used method has been proven to be a fast and reliable method for SSC monitoring. During the measurement all used sensors showed their value. All the relations between the resulting backscatter and water samples showed a good correlation.

Conclusions

Because of its high temporal and spatial resolution, an ADCP is a very usable tool for measurements of sediment concentrations and fluxes. The additional input of grain size distributions from the LISST instrument did not change the results significantly. Variable sediment shapes probably cause the variable relation between ADCP backscatter and water sample results. The separate relations between backscatter and water samples have a good correlation.

Acknowledgements

The presented case study concerns a field measurement campaign that has been organized by the coastal department of the German 'Bundesanstalt für Wasserbau' (BAW). The authors wish to thank Mr. Christian Maushake for his cooperation and permission to present these results.

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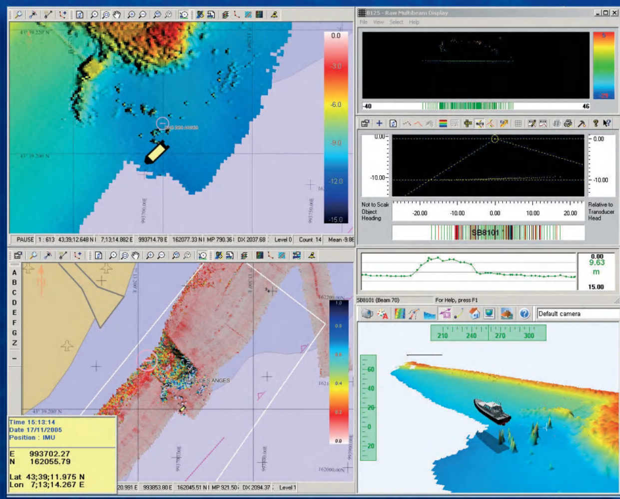

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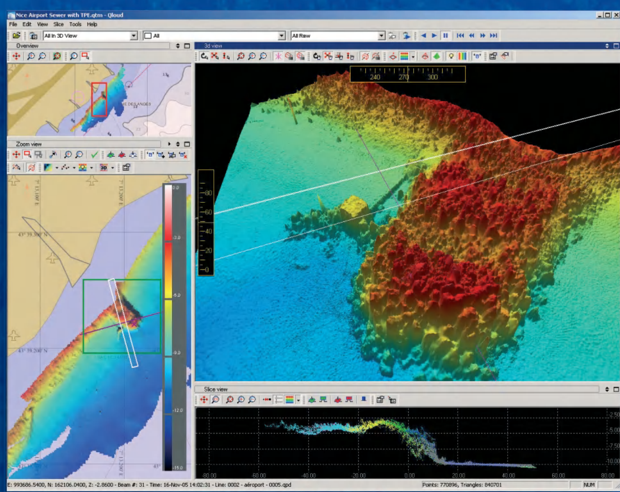

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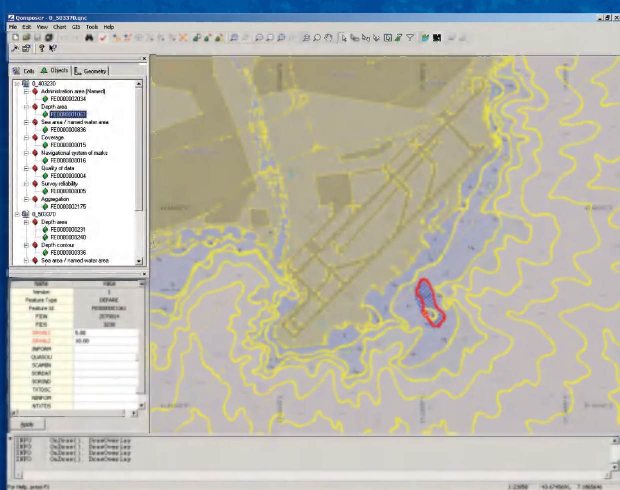

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Bathymetry Survey In The Iron Mine Dam

José Bartolomeu Ferreira Fontes

This bathymetric survey was performed in iron ore and pellet extracting industries, one of which located in the Southeast and the North of Brazil. The survey was accomplished with a single beam and a DGPS for real time positioning; the software was Hypack version 4.3a Gold. The TIN method was employed for a better understanding of the submerged features and of the superposition in the satellite image. The images were used for planning the survey lines, the real time sailing and the final plotting. The conclusion is that the use of a comprehensive amount of resources to perform hydrographic surveys provides better chances of obtaining precise results of dam monitoring and hydrographic follow-up, with the best possible precision ratio between the acquired and the presented data.

Introduction

The term "hydrography" has different meanings to different people in the ocean science community. Most of those attending Hydro 05, hydrography is primarily mapping the bottom of oceans, lakes, rivers, and other bodies of water – mainly the bathymetry – with a focus on safe navigation [1].
Survey Technology has always been driven by the desire for better results in particular applications, so a general survey specification will often play catch-up. The necessity of a pragmatic approach to specifications must be recognized; if a survey is useful then it is a good survey [2].
Along the last decades, technological advances in hydrography have grown rapidly. The applications of Bathymetry digital systems have acquired new directions, encompassing an ever diversifying area. With a growing number of equipment and technologies, the specificity of field surveys and results obtained, as well as data management are on the increase. Results are becoming more precise and adequate to every situation and field of study. Necessary equipment is chosen according to the object being studied and the time for conducting surveys. It is known that multi-beams do not replace single-beams and that they are different from sidescan sonars. The application of appropriate equipment to each situation requires technical and experiential knowledge of hydrography and of what is available in the market. Bathymetry's most frequent uses are port surveys for the mapping of channels and dredge control, identification and description of the bottom and sub bottom features, localization of submerged objects, and geological mapping. For each one of the above mentioned, several kinds of equipment can be applied in various operation frequencies. All of which with the intent of obtaining the most precise details of the submerged objects, providing information for projects and scientific researches, and a more effective management.
Technology in hydrography develops at the same rate as the resolution, speed, and range of data obtained in surveys. This paper covers the bathymetric survey in a very unusual environment, iron ore dams. The terrain, often rugged and mountainous, and obstacles such as tree trunks and mud make it difficult to sail. A high frequency single-beam transducer with DGPS was used, and the software for the data acquisition and processing was the Hypack 4.3a gold. The usage of satellite images in the survey planning and in the final plotting lead to a safer sailing and a better understanding of the results, and above all, of the bottom submerged features found in the area under study.
Another objective of this paper is to promote the quality and publishing of hydrographic mappings in various bodies of water.

Study Area

The bathymetric surveys were conducted in iron ore tailings dams. Tailings dams are defined as being structures built across a river to keep away tailings or sterile materials from mining or from other industrial processes [3]. These dams are intended to accumulate the heavy material, through a process of decantation, not allowing them to get in contact with the environment.
The first area is Dam 5 from Mutuca Mine and is located in the Southeast region of Brazil, Minas Gerais State, 340 km away from the coast, 999.815 meters above sea level, in a mountainous valley. The scale used was 1:2.000 in lines of 280 meters in length; spacing, at the dredge cut spots, was reduced to 1:1.000 with random longitudinal and cross-section lines to the axis of the cut. The triangular interpolation was of 50 meters (TIN Max size). The total volume of water is 396 000 m³. Construction work began in November 2004 and was concluded in March 2005. The surveys were performed on a weekly basis taking 5 hours each.

The second study area is the Geladinho dam located in Serra dos Carajás, North region of Brazil, in Pará State, about 670 km away from the coast, 214 meters above sea level. The survey started in July 2005 and is still being carried out on a monthly basis, with an average duration of 4 hours each. The survey scale was 1:2.000 in lines of 340 meters in length. The average temperature in both dams is 23°C, average turbidity is 1.07 μT, ambient temperature is 26°C, and ph is 6.16. The water is considered to be pure. Regarding weather conditions, the wind prevalent in most survey days was considered mild and the state of the water was bland fit for easy sailing.

Methods

Two vessels were used. The first one was a 5-meter fibre boat with a 0.50m draft and a 50HP motor, equipped with a hydraulic jack and center command. A transducer was mounted at starboard quarter, in addition to a 0.50m draft. The second vessel was a 6-meter aluminum boat, with a 15HP motor, a 0.30-meter draft, and a manual command. A transducer (120kHz) was mounted at port quarter in addition to a 0.30m draft. On both vessels, the DGPS antenna was mounted on the transducer axis (Figure 1). Digital topography data and satellite images for each area were used at the project's initial phase in order to determine survey sections. The images are made up of data with spatial resolution of 61cm in panchromatic and 2.5 meters in multi-spectral, providing images that are true to the actual terrain.

The preparation, surveying, processing, and final results are shown in Figure 2. The satellite image used is made up of spectral bands which correspond to the actual terrain (human eye). These collected data are used in the development of the survey project, as well as for the calibration of the DGPS equipment through the original image datum. This is done on site, loading the image onto the display and keeping a visible point in the image. Correction is done through X and Y delay in the software's geodetic parameters. A correction in the DGPS signal was done by the software in order to establish a reference in positioning with the satellite image previously provided by the mining company.

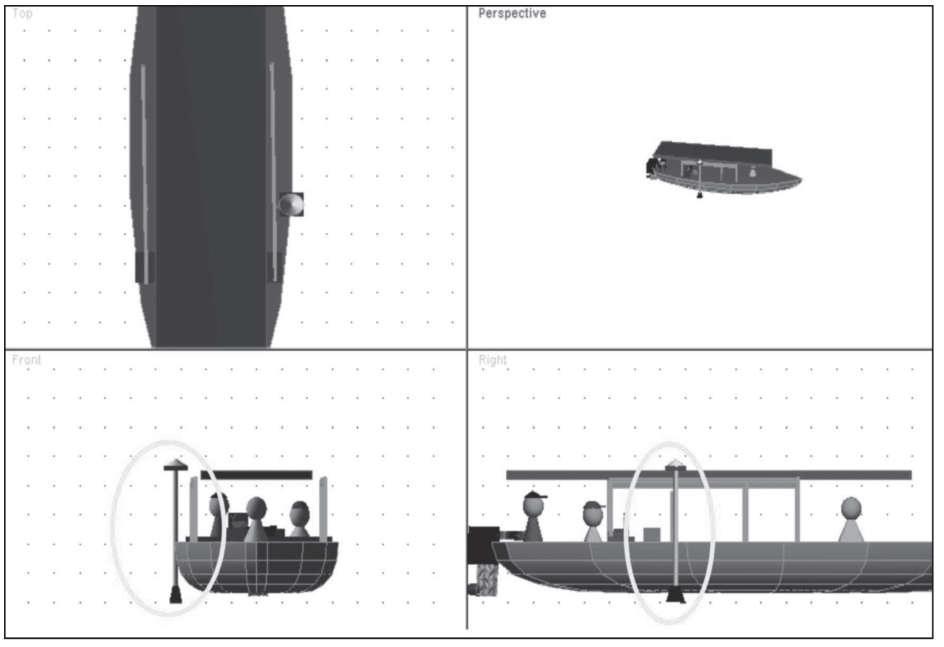

Figure 1: Transducer Positioning – 3D boat.

The image was loaded onto the survey display (Figure 3) so that corrections could be performed with local reference points. Correction was done through the software's datum configuration feature. Sailing was conducted with the satellite image and previous digital bathymetries (DXF), providing a higher safety and accuracy level in the survey so that volumes could be compared. During data processing, by the single-beam editor (SBMAX) program, the digital profiles were compared to the analogical profiles of the echo-sounder. Altered points were left out, as well as points that showed existing submerged vegetation in the area, so as not to distort volume calculations.

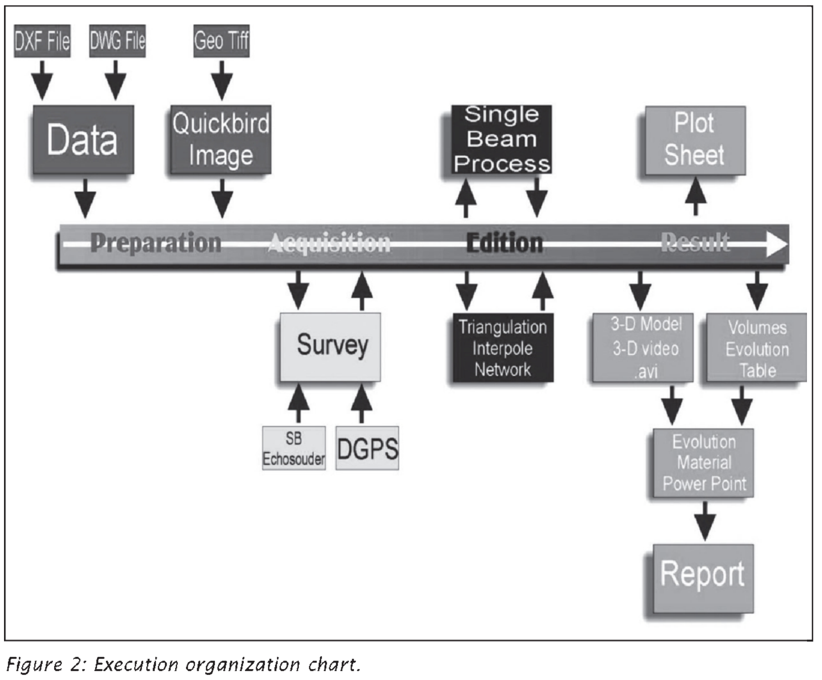

Figure 2: Execution organization chart.

Results And Discussion

Sediments that come into the dam are due to inflowing volumes and to solid waste, which are directly associated to human interference in the dam, which varies throughout time [4]. At these specific dams sediments are due to the ore washing process. The purpose of the bathymetric survey at Mutuca Dam was to follow up on the dredging of these materials. A main result of the bathymetry at Mutuca Dam was the perfect bottom feature and the accuracy in the dredging calculations.

At Geladinho Dam, the periodic bathymetric findings have provided the data necessary for keeping track of the dam's health condition. Those results were essential in allowing managers to have a higher control over deposited sediments. That control is mostly associated to the dam's structural safety. Within the International Commission on the large Dam (ICOLD), safety is defined as the ability of the structure, the reservoir, and the downstream area of the dam to fulfill behavioral requirements during the expected life of the dam, as far as environmental, structural, hydraulic, and operational aspects are concerned a safety control measure is applied to each of these aspects [5].

At Geladinho Dam, the main purpose was to follow up on the development of deposits of sediments and assess the inflow of solid wastes into the reservoir, also identifying places of release. As a result of the bathymetric survey, besides gathering data regarding the inflow of material, a depiction of the bottom features was also obtained according to the ore deposition, by means of tri-dimensional models. Through these models, measures can be taken according to material motion and deposits. Such measures determine whether sediments should be diverted or dredged. A greater amount of data and graphical resources can facilitate the bathymetric survey's accurate interpretation (Figure 4).

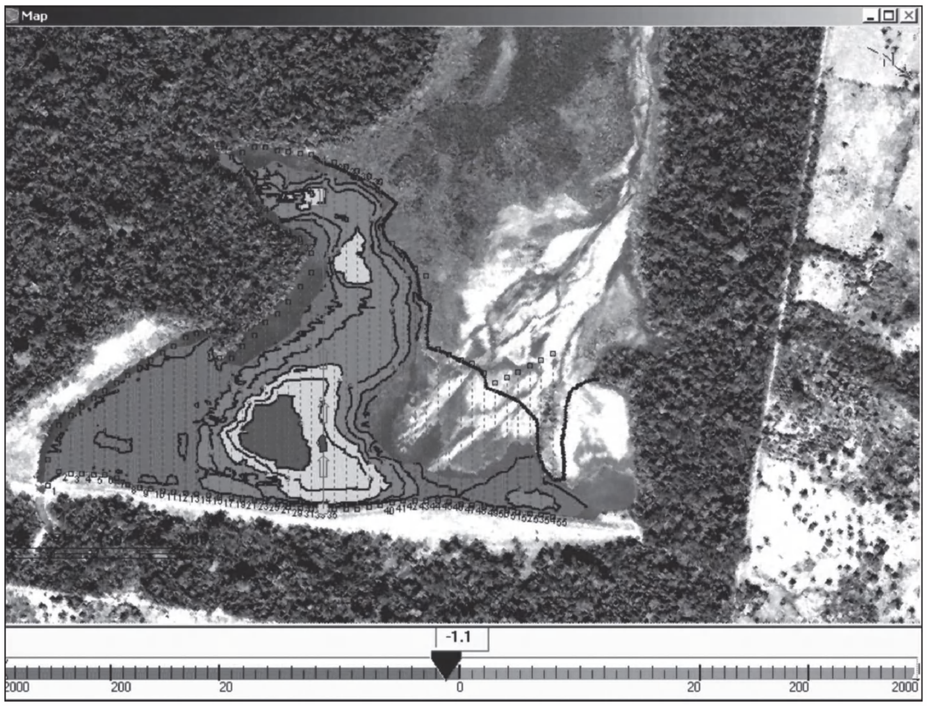

Figure 3: Survey Program Window with background image.

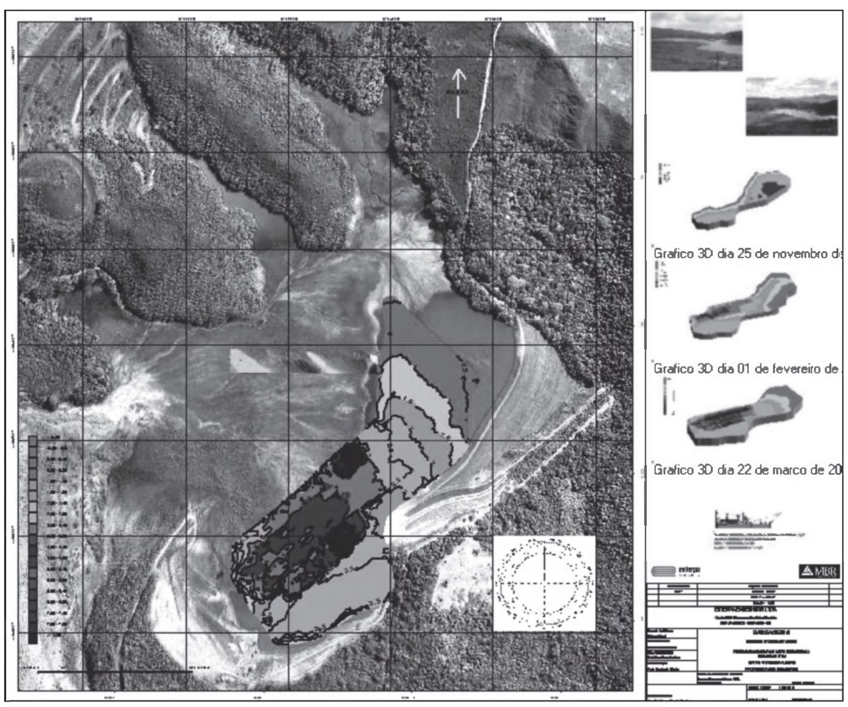

Figure 4: Plotting Sheet from Mutuca Dam.

Conclusions

At Mutuca Dam, bathymetric surveys that had been previously carried out were performed by means of a theodolite at sample points on the dam. That led to a higher demand of time and lower accuracy. After the first results from the digital bathymetry with the aid of satellite images, there was a significant improvement in control and management of the dam. The bottom of the dam was actually seen (Figure 5), along with the limits in the plotting, making it easier to manage data regarding water and sediment volumes.

At the second dam, a digital bathymetric system was already in place, though without graphic and tri-dimensional resources for the data analysis. The implementation of the sailing and surveying methods based on satellite images, and their respective results surprised the dam's managers. Unique field equipment and complex graphical resources and data processing were used to develop this work.

Since the conclusion of this work, more legible and understandable plotting sheets have been created, which today can be analyzed by people who are not familiar with the area. The plotting sheets truly represented, to the highest possible degree, the actual situation of both submerged and emerged features yielding a large amount of data, in addition to creating a standard segment of survey in mining areas on a global scale.


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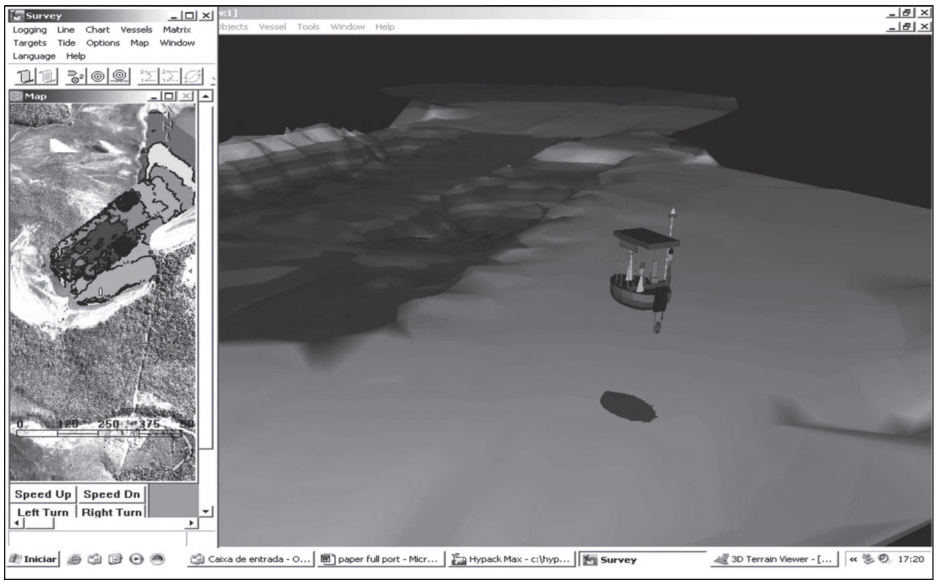

Figure5: Navigation Simulation 3D and Satellite Image below survey area.

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Spatial And Temporal Variation Of Water Salinity In The Curonian Lagoon

Inga Dailidienė, Lina Davulienė and Benediktas Tilickis

The Curonian lagoon is an estuary, connected to the Baltic Sea through the narrow Klaipėda Strait. The global climate change followed by the rise in water level could cause the change in salinity of estuaries and influence water ecosystems. The growing problem is more intense anthropogenic activity and its influence on the natural environment. The distribution of salinity in the Curonian lagoon and its variation in the course of time and determine reasons for the variation was analyzed. Long-term (1961–2005) changes in water salinity in the Curonian lagoon indicate the increase in the salinity in the northern part of the Curonian lagoon. This process is found to be connected rather to a number of factors and not only with the dredging carried out in the harbor area in the Klaipeda Strait.

Introduction

The global climate warming, the rise in water level can condition the increase in salinity of estuaries and influence water ecosystems. From a hydrological point of view the Curonian water body is an estuary of a lagoon type, separated from the Baltic Sea by a narrow spit. The Curonian lagoon ecosystem is influenced by fresh and saline water masses. Water salinity fluctuations in the lagoon are mostly linked with the inflow of more saline water from the Baltic Sea.

The main feature of it is the same as of other estuaries i.e. quite high bioproductivity and distinctive changes of saline marine and fresh river water. Every year rivers carry into the Curonian lagoon the amount of fresh water about 3.6 times bigger than the amount of water in the lagoon itself. A natural horizon incline of the water surface towards the sea is formed, therefore flowing fresh river water is dominant in the lagoon. Water salinity in the lagoon is mostly linked with the inflow of more saline water from the Baltic Sea. Therefore the Curonian lagoon is a transitory freshwater basin and the average water level in the lagoon is mostly higher compared to the sea level and water from the lagoon flows into the Baltic Sea.

Analyzing the questions of water ecosystems one of the main tasks is the determination of chemical regime and practical solutions of its forecasts in respect with variation and spread tendencies. The problem of our time is more intense anthropogenic activity changing the natural environment. The features of climate warming became more significant in the end of the 20th century. Scientific cognition of variations in physical-geographical factors becomes therefore important.

The water exchange between the Curonian lagoon and the south-eastern part of the Baltic Sea occurs through the Klaipeda strait. Natural and anthropogenic factors may have influence on this transitional water system. There were many reconstruction and dredging works carried out in the Klaipeda during the last decade of the 20th century in order to fit the growing needs of the only Lithuanian harbour located in the strait. However the influence of these changes on the water salinity in the Curonian lagoon will be not discussed in this paper.

Research, materials and methods

The Curonian lagoon is a large shallow coastal water body in the south-eastern part of the Baltic Sea. It is connected to the Baltic Sea through the narrow Klaipėda Strait Total area of the lagoon is approximately 1584 km^2 [1]. The lagoon volume is 6.3 km^3, length - 93km, width - 46km, mean depth is approximately 3.8m, the maximum depth - 5.8m [2]. Characteristic feature of the Curonian lagoon is high bioactivity and distinctive salty marine water and fresh river water mixing regime. Depending on the average water salinity Curonian lagoon is divided into four parts: Klaipėda Strait, northern, central and southern parts. The southern and central parts of the lagoon contain fresh water due to discharge from the Nemunas River and other smaller rivers (in toto 24km^3/year). Annual fresh water discharge due to Nemunas River is about 23 km^3 [3]. This makes 3.6 times of the lagoon volume, which is about 6.3km^3. Therefore the Curonian lagoon is a transitory freshwater basin and the average water level in the lagoon is mostly higher compared to the sea level and water from the lagoon flows into the Baltic Sea.

Systematic water salinity observations have been performed in the Lithuanian coastal Baltic Sea and in the Curonian lagoon since the beginning of the 20th century. The water salinity data of the Curonian Lagoon were retrieved from the national monitoring data for the period of 1961-2005. These data are available from the Marine Research Centre at the Ministry of Environment of the Lithuanian Republic. We used data from four coastal stations: Klaipėda Strait, Juodkrantė, Nida and Ventė, where the salinity of the surface water in the Curonian lagoon is measured daily at 6PM UTC (Fig. 1). Measurements of salinity during field survey are also carried out in the lagoon 1 or 2 times per month.

The long-term variations and trends of salinity were analysed. The monthly mean, maximum and salinity were found for the period of 1992-2005 for different stations. Also salinity trend for the recent and the previous decade was composed. The changes in salty water intrusions from the Baltic Sea into the Curonian lagoon and their influence to the salinity variability in the indifferent parts of the Curonian lagoon were discussed.

Results

The mean annual salinity decreases along with the increasing distance to the Klaipéda strait going from the northern to the southern part of the lagoon (Figure 2). Depending in the meteorological conditions and river discharge the salty water intrusions from the Baltic Sea into the Coronian lagoon may occur. The marine water is mostly observed in the northern part of the Curonian Lagoon up to the Juodkranté town and does not reach the southern part. Most often marine water penetrates into the northern part up to 25km. However, under particular meteorological conditions saline water can spread even 40-50 km into the lagoon and reach the central part of the lagoon.

The intrusions of saline water from the Baltic Sea into the lagoon are mostly conditioned by meteorological conditions. In the period of strong western (SW, W, NW) and northern winds a water pileup evolves at the southeastern coast of the Baltic Sea, and marine water starts flowing into the lagoon through the Klaipeda strait. Water salinity in the northern and central parts of the lagoon fluctuates between 0.04 and 7.35‰ (Table 1).

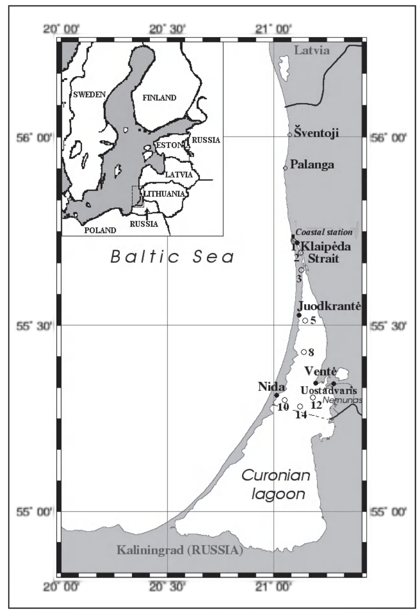

Figure 1: Locations of coastal and off-shore monitoring stations in the Curonian lagoon.

The annual mean salinity, its standard deviation and the extreme values of the measured salinity were found in order to asses the mean spatial salinity variation in the Curonian lagoon in the period of 1992-2005. In general, the mean annual salinity increases towards the Klaipéda strait going from the southern to the northern part of the lagoon (Figure 2 and Table 1).

Station No.	Salinity [‰]	Depth [m]	STD [‰]	Max [‰]	Min [‰]	N
1	2.49	0.0	2.54	7.23	0.04	192
1	4.69	9.2	2.54	7.35	0.04	162
3	1.76	0.0	2.33	7.15	0.04	193
3	2.67	7.5	2.65	7.17	0.04	162
5	1.07	0.0	1.84	7.12	0.03	195
5	1.31	2.2	2.07	7.02	0.04	104
8	0.29	0.0	0.68	4.57	0.04	151
8	0.41	1.7	0.93	4.64	0.04	99
10	0.1	0.0	0.14	1.57	0.03	181
10	0.1	2.5	0.19	1.63	0.04	104
12	0.08	0.0	0.13	1.1	0.02	181
12	0.1	2.4	0.19	1.46	0.02	105
14	0.09	0.0	0.12	0.92	0.03	148
14	0.1	3.8	0.18	1.84	0.03	148

Table 1: The annual mean salinity, its standard deviation and the extreme values in the Curonian lagoon in the period of 1992-2005.

The mean water salinity in the near bottom water is higher then in the surface water at all analysed stations of the Curonian lagoon (Tables 1). The largest difference between the salinity in the surface water and in the near bottom water, about 2.2 ‰, was obtained at the stations located in the Klaipeda strait. This difference decreased towards the central part of the lagoon.

Seasonal salinity variations are sensible in the whole Curonian lagoon. They depend on the Nemunas river runoff (Figure 3) and on the salty marine water intrusions. The increase in the Nemunas river run-off during spring strengthens water outflow from the Curonian lagoon into the Baltic Sea and therefore prevents salty water intrusions into the lagoon. This is one of the reasons why the salty water intrusions are mostly observed during the cold period of the year. This process connected with seasonal variation of Baltic Sea level and seasonal domination of air masses. Seasonal mean salinity in the central and northern parts of the Curonian lagoon and in the Klaipeda Strait has maximum in summer and autumn (Figure 2, Figure 3).

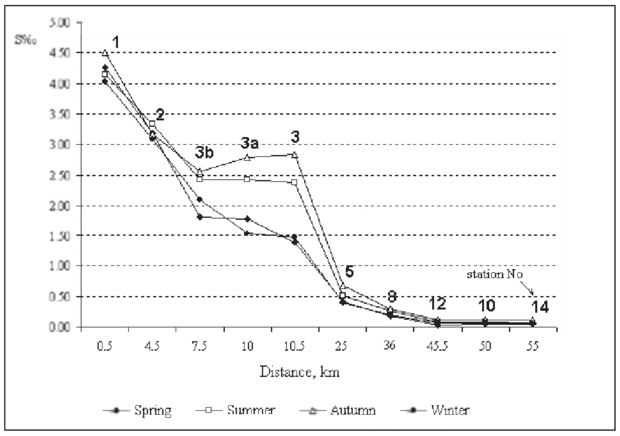

Figure 2: Distribution of long-term seasonal mean salinity in the Curonian lagoon starting at the Klaipeda strait (station No. 1), in 1992-2005.

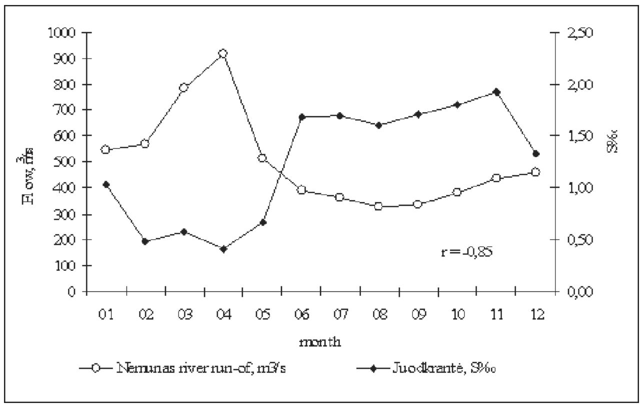

Figure 3: The Nemunas river runoff and mean monthly salinity in the Curonian Lagoon at the Juodkrante station, 1984-2005. "r" is a correlation coefficient.

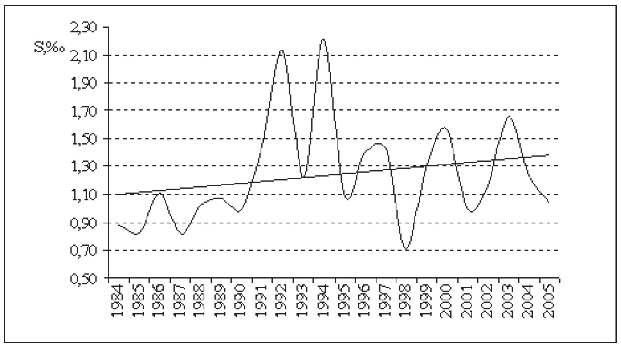

Figure 4: Annual mean variation of the water surface salinity in the lagoon near Juodkrante, 1984-2005.

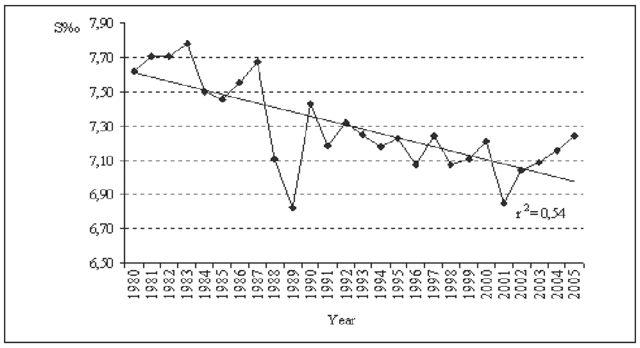

Figure 5: Long-term mean surface water salinity in the Baltic Sea and its trend in 1980-2005 at the monitoring station (No. 46).

Long-term annual mean salinity is increasing. This is sensible in the northern part of the Curonian lagoon. Long-term annual mean data series show salinity increase in the northern part of the Curonian lagoon near Juodkrantė town in 1984-2005 (Fig. 4). During last 15-year period salinity increased approximately 10% in the Klaipeda strait and approximately 20% in the northern part [5].

However, the mean long-term salinity in the coast of south-eastern part of the Baltic Sea decreased during the same period. Lithuanian monitoring station, 46 (N56°01'20", E19° 08'18", that is located furthers from the Lithuanian coast and is least influenced by the river runoff. Here surface water salinity is decreasing in 1980-2005 (Figure 5). However, salinity in the near bottom water layer (115m deep) is increasing starting from 1991 (Figure 6). This is due to the salty water intrusions from the North Sea [6].

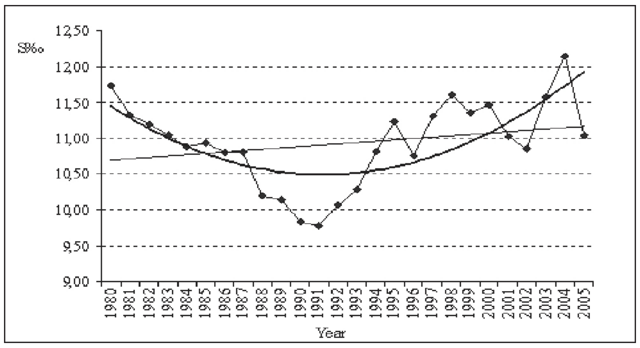

Figure 6: Long-term mean bottom water salinity in the Baltic Sea and its linear and polynomial trends in 1980-2005 at the monitoring station (No. 46).

Which processes cause increase in salinity in the Curonian lagoon? The increase in long-term mean salinity in northern part of the Curonian lagoon is caused by the several natural and anthropogenic factors. One of the most important factors is the change in atmospheric circulation, the increased frequency of westerly air masses occurrence in the North Atlantic region along with increased probability of stormy westerly winds during the cold period of the year in the Lithuania Baltic Sea coast region [2, 7, 8, 9]. It is important to note that westerly winds cause affluent along the south-eastern coast of the Baltic Sea followed by the salty maritime water intrusion into the Curonian lagoon. The increase in long-term mean salinity in the northern part of the lagoon could be also related to the mean sea level rise [10, 11] in the Baltic Sea due to the global increase in sea level [12, 13, 14]. The increase of water level is associated with changes in atmospheric circulation in North Atlantic region that indicated correlations with NAO index [11]. The water level fluctuations in the southeastern part of the Baltic Sea and Curonian lagoon are caused by variations in air masses dynamics in the North Atlantic areas. The increase in long-term mean salinity in the northern part of the lagoon could be also as well as to the long-term trend of the Nemunas river run-of to decrease [3, 11].

The factors: 1- winter NAO index, 2- air temperature, 3- water level (in strait), 4- precipitation, 5- depth of strait, 6- salinity of the Baltic Sea near Nida, 7- run-off of the Nemunas river.

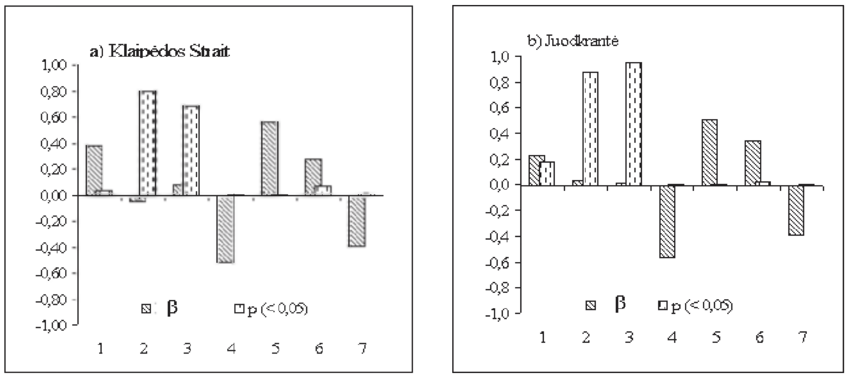

Fig. 7: Multiple-regression analysis for the dependent variable of factors influencing the water salinity increase in the Klaipeda strait, 1961-2005.

One of the most important anthropogenic factors - the continual dredging of the Klaipėda harbour that is situated be the strait connecting the Curonian lagoon and the Baltic Sea (Figure 1). The dredging in the Klaipeda port has been carried out since 19th century. However the action intensified after the World War II, the harbour has been deepened from about 10 to 14m. In some parts of the port water area the depth increased even by 6m. Till 1999 the hydraulic conductivity of the strait had increased by 12-15% [15, 16]. Higher hydraulic conductivity of the strait is responsible for greater annual intrusions of marine water. Therefore the increase in sea water volume penetrating into the lagoon through the strait is expected. The invasion of salty water into the Curonian lagoon could be also related to the slowly changing the ecosystems in its northern part.

Multiple-regression analysis for the dependent variable of factors influencing the water salinity increase in the Klaipeda Strait (1961-2005) shows that the factors having the substantial influence on the salinity increase in the Klaipeda Strait are increase the depth of Klaipeda Strait, precipitation, decrease in the runoff of the Nemunas river, and winter NAO index variation in the North Atlantic region (Figure 7).

Conclusions

In general, the mean annual salinity decreased along with the increasing distance to the Klaipéda strait going from the northern to the southern part of the lagoon. Seasonal salinity variations are sensible in the whole Curonian lagoon. They depend on the river discharge and on the maritime water intrusions in estuarial that connected with seasonal Batlic Sea level and air masse seasonal variability.

Long-term annual mean data series of salinity decreasing in Klaipéda strait and north part of the Curonian lagoon. The increase in salinity of the Curonian lagoon water is caused by the several of natural and anthropogenic factors.

One of the most important factors is the changes of hydro meteorological conditions, and intensification of westerly air masses transportation in the North Atlantic region. The increase in salinity of the northern part of the Curonian lagoon could be caused by the long-term trend of the Nemunas River discharge to decrease, and the long term water level rise in this region. One of the most important anthropogenic factors is the continual dredging of the Klaipéda harbour that located in the Klaipéda strait. Long-term salinity increase in the northern part of the Curonian lagoon could influence water ecosystems of the lagoon.

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Tides From Fugro's Global Starfix Hp GPS Service

Kees de Jong

Precise GPS positioning combined with a mean sea surface model allows for the determination of tidal corrections. Trials have shown that such a procedure results in tidal heights which fulfill the requirements for IHO S44 special order surveys (0.25m, 95%).

Introduction

Traditionally, tides are obtained from observations at permanent or temporary tide gauges, from interpolation in cotidal charts or from prediction, based on astronomical tides and meteorological components.

The heights obtained from satellite navigation systems, such as the Global Positioning System (GPS) refer to an ellipsoid and therefore have no physical meaning. In order to derive tidal heights from GPS, the separation between Mean Sea Surface (MSS) and the ellipsoid is required.

Mean Sea Surface Models

Due to sea surface topography, caused by current fields in the oceans, the geoid and and MSS in general do not coincide, see Figure 1. Differences can be as large ±1 metre.

A number of global and regional MSS models are available, see Figure 2 for an example. From this figure we can see that the difference between ellipsoid and MSS can be as large as ±80 metres.

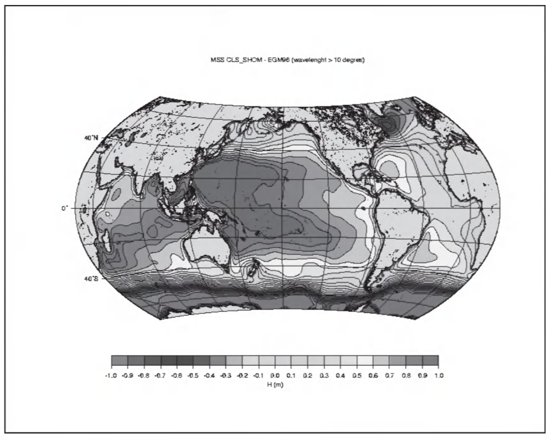

Figure 1: Difference between MSS (CLS_SHOM v98.2) and geoid (EGM96) (http://www.cls.fr).

Tides From GPS

GPS provides the height Hant of an antenna above a reference ellipsoid, see Figure 3. Using the ship's observed attitude (pitch, roll and heading), this height is reduced to the height Href of the vessel's reference point. Since the observed instantaneous heights are in general rather noisy, they are usually filtered to obtain the calm sea height HCS. This is still an ellipsoidal height. In order to obtain tidal height (or tidal correction) TC the separation NMSS between ellipsoid and MSS has to be applied.

GPS height Hant can be obtained from a GPS RTK (Real-Time Kinematic) solution or from Fugro's high precision Starfix HP service, which will be described in the next section.

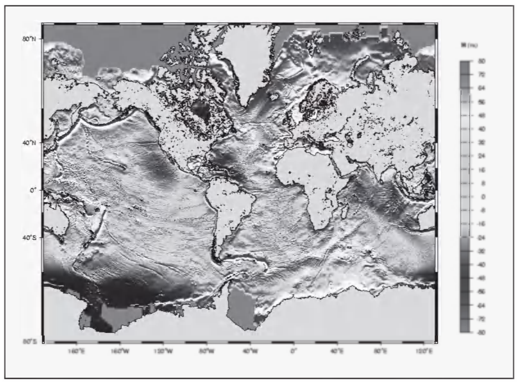

Figure 2: Example of a global MSS model (CLS_SHOM v.98.2, http://www.cls.fr).

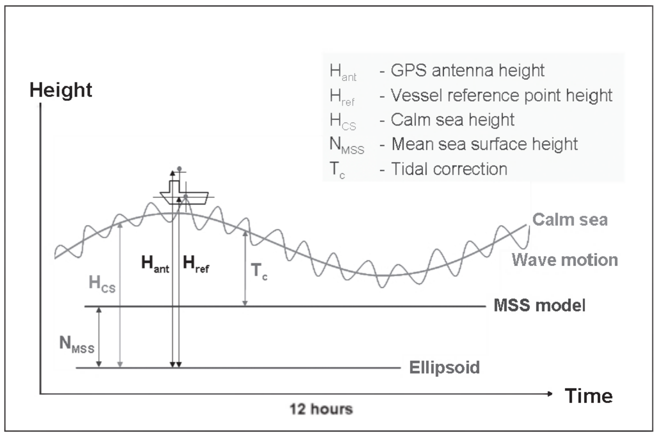

Figure 3: Height definitions.

Fugro's High Precision GPS Services

Fugro's Starfix HP and Skyfix XP are high-precision GPS services, which provide sub-dm three dimensional positioning accuracy worldwide. Starfix HP is a relative positioning service, based on corrections generated from a network of reference stations, shown in Figure 4. The corrections are transmitted to users of the service by means of satellite links. Starfix HP uses ionosphere-free code and carrier observations; estimated parameters consist of positions, tropospheric zenith delays and carrier ambiguities. Due to the long baselines involved, no attempt is made to resolve the carrier ambiguities to their integer values, as is done in RTK positioning.

Starfix XP is based on the principle of Precise Point Positioning (PPP), for which precise satellites orbit and clock parameters are required. These parameters are generated and provided in real-time by NASA's Jet Propulsion Laboratory (JPL). The corrections (difference between precise and broadcast (by the GPS spacecraft) satellite coordinates and clock data) are transmitted to XP users again using data links on geostationary satellites. Since the positioning algorithm of HP and XP are completely different (relative vs. absolute), the reference networks of Fugro and JPL share no common stations and the corrections are transmitted using different datalinks, both services are completely independent. A more detailed description of the HP and XP services is given in [1].

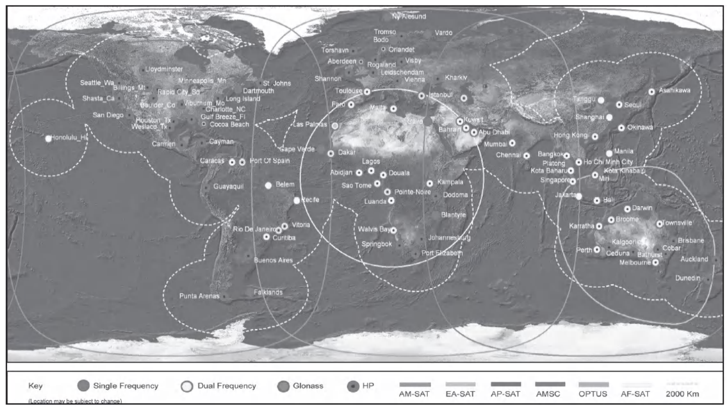

Figure 4: Starfix HP reference station network and service areas.

GNSS developments

A number of developments are going on in the field of Global Navigation Satellite Systems (GNSS). GPS is being modernized, resulting in a second civil signal on the L2 frequency (1227.60 MHz). The first satellite transmitting this signal was launched in 2005. From 2007, a third civil signal (L5, 1176.45 MHz) will be available as well. Eventually, all 28-30 GPS satellites will be transmitting these new signals. The Russian Glonass system is being revitalized. The current (mid 2006) constellation consists of 13-14 satellites. In 2008 (and probably even sooner) a constellation of 18 satellites will be in orbit; a 24 satellite constellation is expected in 2011. In 2005 the first test satellite of the European Galileo system was launched, with the first signals being received on 12 January 2006. In 2008 four satellites should be in orbit, with the complete constellation of 30 satellites operational in 2010. Signals on 2-4 Galileo carriers will become available, depending on the service. All in all, by 2008 there will be a total of about 50 satellites for precise positioning; in 2011 this number will have increased to about 80. Integrated use of GPS, Glonass and Galileo will not only result in higher reliability and availability, but also in rapid RTK-like positioning over extended distances. In particular the vertical component's accuracy will be improved, which is important for tidal height determination.

Trials

In February 2005 the Royal Netherlands Navy performed a series of trials in the North Sea, see Figure 5. Equipment consisted of a Starfix HP system, heave and attitude sensor, one permanent and two temporary tide gauges. Goal was to investigate the feasibility of using GPS and MSS models to determine accurate tidal heights. A detailed description of the trials and results can be found in [2].


Figure 5: Trial area, February 2005.

Figure 6 shows raw and filtered GPS heights, MSS separation and resulting tidal heights. For the North Sea the differences between MSS and geoid are marginal; therefore a local geoid model was used, which had an accuracy of 0.03 m. Note the completely different behaviour of GPS heights and tidal heights in the time series, which is due to the vessel moving in the trial area. This difference in behaviour shows that applying the MSS corrections is important and that one cannot simply ignore the variability in MSS, not even in relatively smooth areas like the North Sea.

Standard deviations GPS derived tidal corrections were found to be 0.12m. Main contributing factors were the errors in heave and draft compensation (0.06m) and MSS model, attitude and offsets (0.08m). The GPS vertical error was less than 0.07m.

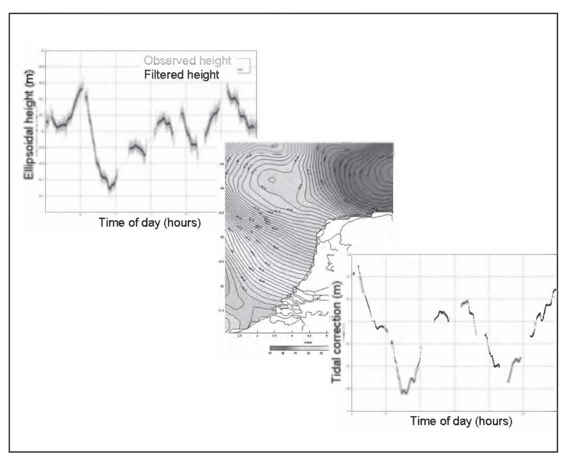

Figure 6: Ellipsoidal GPS heights (left), MSS model for the North Sea (middle) and resulting tidal corrections.

Direct Depth Determination

The above error can be further reduced by realizing that for depth measurements the draft compensation is not required, see Figure 7, which is based on [3].

The conventional way to determine depth CS is

$$CS = RD + D - T_C \quad (1)$$

where RD is observed depth, D draft and T_C tidal correction. The direct way is given as

$$CS = RD - H_{ref} + N_{MSS} \quad (2)$$

with H_{ref} the GPS derived height of the vessel's reference point and N_{MSS} the separation between ellipsoid and mean sea surface. This direct approach does not require any tidal or draft corrections and is therefore more precise than the conventional way.

Conslusions

GPS and MSS models are an efficient alternative to tide gauges. Trials have shown that GPS derived tidal corrections meet the requirements for IHO S44 special order surveys (0.25m, 95%, [4]). The direct approach to depth determination may further improve accuracy as will the availability of new and improved GNSS signals and systems.

Acknowledgements

Data from the North Sea trials was processed by Luc Thijssen en Dirk Voesenek.

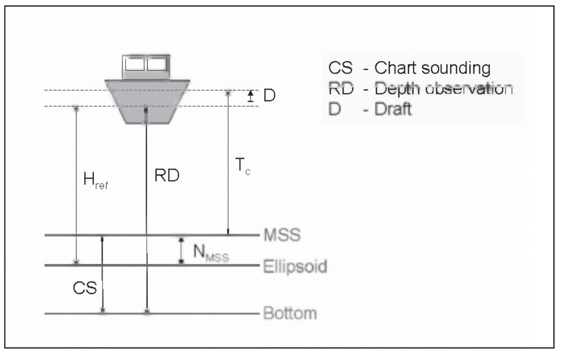

Figure 7: Direct depth determination from GPS and MSS.

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TIN-Based Digital Terrain Modelling Using Multibeam Data

A. De Wulf, M. Hennau and D. Constales

The latest bathymetric sounding equipment that is available nowadays, especially the multibeam echosounder, yield a very dense bottom sampling. When compared to the common singlebeam echosounder, an enormous amount of data is produced that needs to be processed in a correct and fast way. Grid-overlay (by local linear or more sophisticated interpolation and attributing values to individual grid cells) is not an option here as this method uses an interpolation of the measured values and hence will either cause accuracy loss or generate a still larger amount of data. A triangular irregular network (TIN for short), especially the Delaunay triangulation (Dt), does respect the actual measurements and will not generate new data. In literature, a number of algorithms have been developed that determine the Dt of a set of points (vertices) given in the plane.

Introduction

Many marine scientists and users of the sea take knowledge of the sea bottom's topography for granted; the consider is as a mere context to carry out research or deploy activities. Some disciplines do need more accurate bathymetric data than others, depending on depth values being background information or crucial information for their research or activities. In bathymetry, the representation of the sea bottom surface is the main objective and hence, this discipline will try to render the sea bottom relief as accurate as possible.

Multibeam Echosounder Calibration

A proper calibration of the geometrical setup of the echosounding equipment before taking off for a survey is indispensable [1]. The purpose of this calibration is to determine accurately the position of the hydrographical equipment, in casu the multibeam echosounder, with respect to the geometry of the vessel and especially with respect to the positioning antennae. This geometry is realised by means of a number of fixed reference points on the vessel for subsequent calibration measurements.

The calibration allows to refer accurately each echosounder measurement to the corresponding position and therefore to a plotted chart.

Rigorous processing of the calibration data by means of least squares adjustment [2] is necessary to obtain reliable calibration results and thus accurately georeferenced measurements.

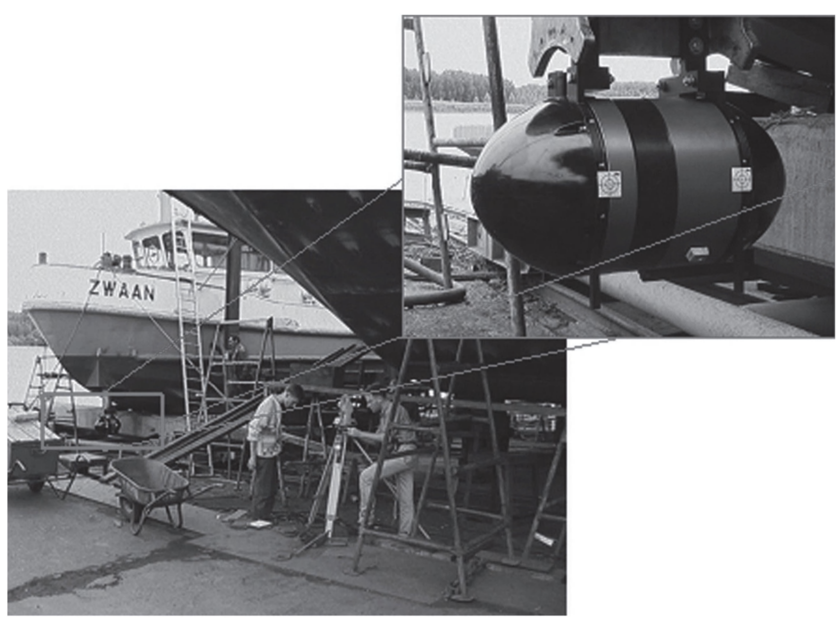

Figure 1: Pictures of the survey vessel 'Zwaan' during installation and calibration of the multibeam echosounder (magnified) in the docks in Rupelmonde, Belgium.

Creation of a TIN (Triangulated Irregular Network) Using The Delaunay Algoritm

Principle

It is common practice to use the Delaunay triangulation [3] to construct a TIN rather than other, less restrictive triangulations. In a Delaunay triangulation, the circumscribing circle of any triangles contains no other vertices of the triangulation [4]. Triangles whose circumcircle does contain another vertex are invalid and need to be replaced by another triangle by a process called *edge flipping*; this is shown in figure 2a and 2b. The triangles *abc* and *acd* are not Delaunay triangles as they contain *d* and *b* respectively in their circumscribing circles. After flipping the edge *ac* to *bd*, the triangles *abd* and *bcd* are created, which do not contain other vertices in their circumscribing circle. They therefore meet the Delaunay requirement.

Figure 2c represents what is called *edge completion*: when four points are cocircular, the resulting quadrilateral is (arbitrarily) split in two separate triangles. This constitutes a degenerate case as either of the two diagonals can be constructed.

It can be proved that the Delaunay triangulation of a set of vertices is unique; this is an important quality asset towards the client as it allows him to repeat the calculations to verify the results independently.

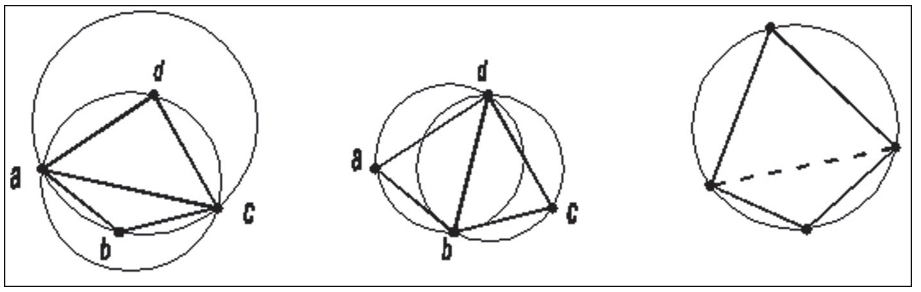

Figure 2: Delaunay triangle principle.

Exploitable Delaunay triangulation algorithms

Five algorithmic approaches exist to construct a Delaunay triangulation [5]. When looking closely at their conception and properties, two of them can be used advantageously for DTM construction in dredging works:

The divide-and-conquer algorithm is very apt for triangulating large datasets because of its calculation speed. The incremental algorithm on the contrary can be exploited to edit an existing triangulation. Both algorithms are briefly depicted.

Divide-and-conquer algorithm

The divide-and-conquer method [6] starts with the entire dataset, repeatedly cuts it in half until only subsets of two or three neighbouring vertices are left and recursively stitches together these partial triangulations. Some triangles near the edges are deleted in this process and new triangles gluing together both triangulations are created. Figure 3 clarifies this. Implementing this algorithm is rather difficult when compared to the incremental method, but it is well worth the effort as its calculation speed is far better than the latter's.

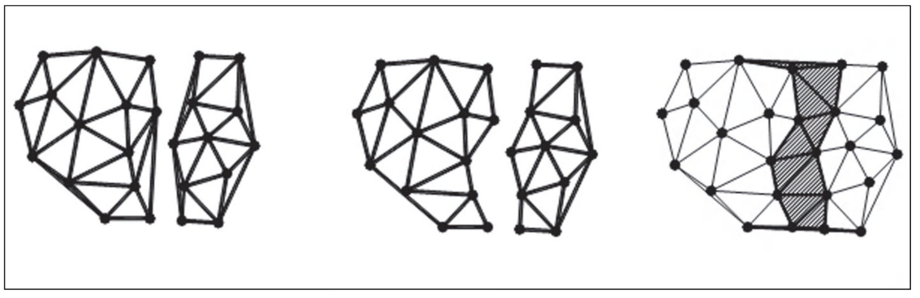
Figure 3: divide-and-conquer principle – merge step.

Incremental algorithm

The incremental algorithm is the most widely used because of its straightforward construction and implementation [7]. The principle is represented in figure 3:

- The triangle that contains the vertex is located.
- The triangles influenced by the new vertex are identified (these triangles contain the new vertex in their circumscribing circle)
- The triangulation is updated with the new triangles so that the Delaunay property remains valid for all triangles.

Because of its lower speed and its inherent decreasing speed for increasing dataset size (see Figure 5 and Table 1), it is not an adequate method to construct the Delaunay triangulation for the large datasets envisaged. It is, however, the ideal method to add vertices to an existing triangulation [8]. Where its application domain was previously 'constructing a TIN', it now shifts to 'editing a TIN'.

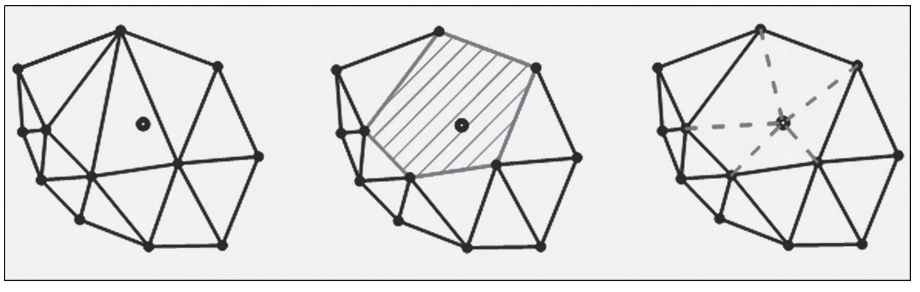
Figure 4: incremental algorithm principle.

Runtime comparison

A comparison has been carried out between the speed of the divide-and-conquer method and that of the incremental method. The following graph and table make clear that for increasing dataset size, the divide-and-conquer algorithm is increasingly faster when compared to the incremental algorithm.

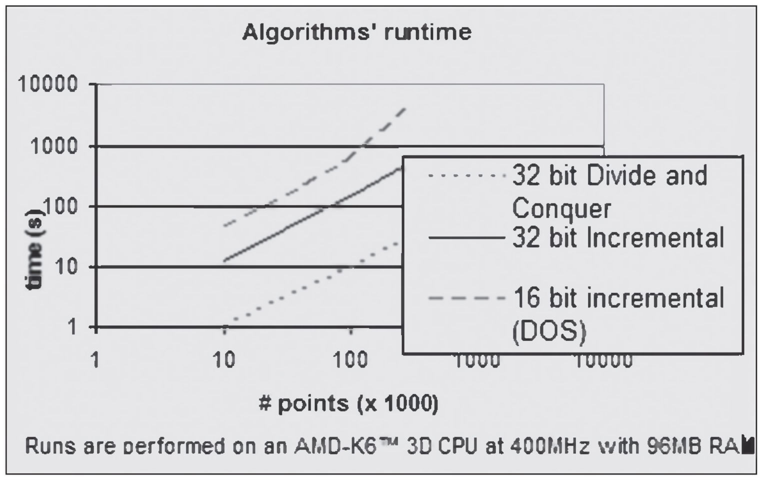

Figure 5: Performance of the different algorithms for different dataset sizes.

Multibeam Dataset Reduction

The amount of data generated by a multibeam echosounder is dependent on the ping rate, which goes up to 30Hz, and the number of beams in the swath, typically between 100 and 300, incoming dataflows can reach up to more than 30 million points per hour.

It will be clear that reducing the data gathered by multibeam echosounding is indispensable because of the huge amount and because most of it does not contribute to a more detailed seafloor approximation anyway [9]. Indeed, descriptions in literature are given of dataset reductions of scanned surfaces down to 5 or 10% of the original dataset size without significant loss of accuracy. An ongoing concern is therefore dataset reduction, either by *vertex decimation* (eliminating redundant data from an existing Delaunay triangulation) or by *greedy insertion or refinement* (gradually constructing the Delaunay triangulation by adding only those points that really contribute to the precision of the seafloor model).

Algorithm used / Number of points (x 1000)	A) D&C 32 bits	B) Inc 32 bits	C) Inc 16 bits	Ratio B/A	Ratio C/B	Ratio C/A
10	1	12	45	12,0	3,8	45,0
30	3	42	136	14,0	3,2	45,3
100	9	148	602	16,4	4,1	66,9
300	30	510	4235	16,8	8,3	139,9
1000	150					

Table 1: Performance of the different algorithms for different dataset sizes. Values are runtimes in seconds. Points are randomly distributed in a square.

Refinement (coarse to detailed) adds only those points to the triangulation that are, according to some selection criterion, necessary to obtain the required accuracy.

Decimation (detailed to coarse) requires a triangulation of all the input points and then eliminates redundant height points from it. The decimation method is the most promising for the application at hand, as it seems to keep the highest accuracy. It can be subdivided into:
- *vertex decimation*
- *edge contraction*
- *triangle decimation*
- *patch decimation*

The hole that results after deletion of a point, a triangle or a patch is subsequently retriangulated.

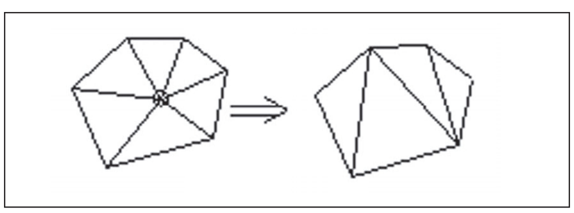

Figure 6 : Vertex decimation

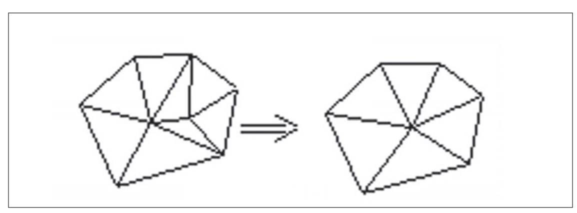

Figure 7 : Edge contraction

Almost all filtering algorithms described in literature use a height difference to determine whether or not to add a vertex or to delete one from the model. In case volume calculations are the final aim of survey, it is more useful to determine the generated volume difference between the two models. Hybrid models could combine the advantages of both.

Conclusion

In this paper, several aspects of terrain modelling by TIN modelling have been discussed. Starting with the proper calibration of a multibeam echosounder, the next step introduces triangulation.

Two interesting Delaunay triangulation algorithms have been indicated: the incremental method and the divide-and-conquer method. A comparison test between the speed of both algorithms has been presented, showing the better performances of the latter. Because of its runtime performance, the divide-and-conquer method can be exploited for the initial triangulation of the large datasets gathered by multibeam echosounding. However, the incremental algorithm is very adapted to editing an existing triangulation.

After this step or, as an alternative, prior to the triangulation, data set reduction can be performed, in order to reduce redundant information in the data file. The last step is the editing of the TIN, including operations as vertex addition, vertex deletion and merging of triangulated areas. Each of these aspects has to be executed with care and precision in order to obtain a valid digital sea bottom model.

Acknowledgements

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Ghent University was charged with the fundamental research in and the creation and implementation of an integrated mathematical model that will satisfy present and future needs with respect to real-time quality control in the mainly hydrographic surveying field. The present fundamental research fits in the larger, approved, international Eureka project «Dredging Survey 2000 (EU203511)». The three important research areas of interest in this project were: The development of algorithms for real-time construction of digital hydrographical charts, the development of algorithms for control and editing of digital terrain models, the development of efficient algorithms for adaptive reduction (filtering) of multibeam data.

We would like to thank Tom Van Herck and Stijn Van Maelsaeke who carried out the practical measurements of the survey vessel calibration in the docks in Rupelmonde.

We would also like to thank Gert Brouns who carried out during 18 months research work concerning the editing of triangulation models, within the frame of the aforementioned IWT project.

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Evolution Of The Hydrographic Network Of The Eastern Part Of The Vistula Delta In Conditions Of Strong Anthropopressure

Joanna Fac-Beneda

The decisive element for the determination of the evolution of the hydrographic network in the eastern part of the Vistula Delta were the changes introduced by man in historical times. The modern system of the hydrographic network of the Vistula Delta does not differ considerably from the one that was shaped during the intensified interference of man into water relationships, i.e. till the end of the 19th century. The long lasting and varying anthropopressure resulted in the fact that relatively natural processes occur only in the main channel of the River Vistula, while in the whole remaining area water relationships have been shaped by man and are under human control.

Introduction

River deltas are areas whose hydrographic network as a result of hydrological processes that occur within the very delta, a result of the hydrological impact of the whole drainage basin and the influence of the receiver. In the part of Europe covered in the Pleistocene by the accumulative operation of the Scandinavian continental glacier, river deltas had been built only by natural processes for several dozen thousands of years. Only at the end of the first millennium of our era they started being formed with a growing participation of man.

The Vistula Delta (Figure 1) is one of the most interesting and important geographical regions in Poland. It is a region where the interrelation between the natural environment and the one artificially transformed by man occurs to an extent rarely noted in other regions of Poland. This mainly concerns the hydrographic network which has been under strong anthropopressure since the 12th century. In such a specific geographic environment all the human activity has been conditioned by the regulation of unstable water relationships.

Methods of study

The evolution of the hydrographic network can be determined by the methods of hydrographic interpretation, which basically consist in the analysis of the material in terms of mutual spatial relationships of particular hydrographic elements. These methods include the interpretation of cartographic materials, of aerial photography, of hydro-graphic surveys and of non-geographic sources. In the paper the author applied the interpretation of cartographic materials (Henneberger's of 1579 y., Goth's of 1642 y., Schenk's of 1700 y., Endersch's of 1753 y., Maull's of 1862 y., Koppin's of 1811 y.) (Fac-Beneda, 1999) and the interpretation of aerial photographs from July 1989 y. The non-geographic sources found in the enumerated historical materials were used to verify the findings.

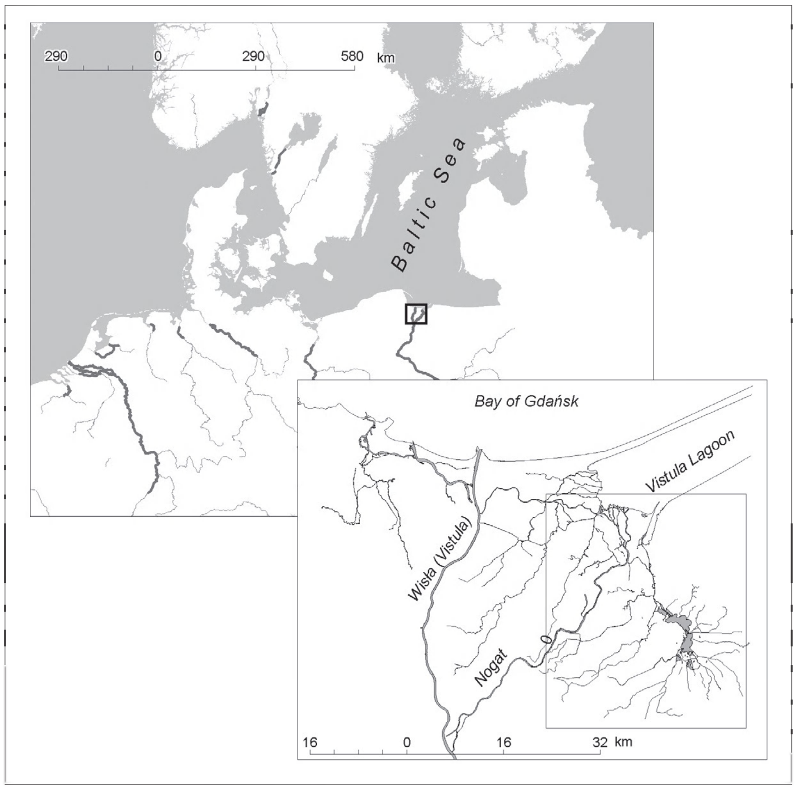

Figure 1: Area of study.

Recording of changes in hydrographic network in historical times

An attempt to determine which elements in a hydrographic network are natural and which result from human activity requires the determination of the initial state, i.e. the state of the hydrographic network from a period preceding human activity. Bertram's /1924/

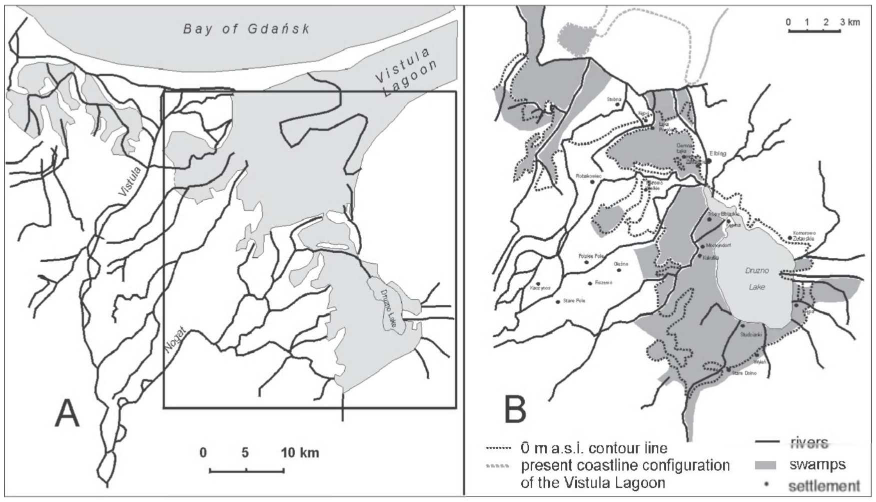

Figure 2 A: Reconstruction of the Vistula delta in 1300 y. (Bertram [1924], modified), B:Settlement pattern in the Vistula delta in the 13 c. (Długokęcki [1992], modified).

(Figure2A) and Długołęcki's /1992/ (Figure 2B) reconstructions are not fully satisfactory, as was shown by Fac-Beneda /1999/.

The furthest reaching attempt to question Bertram's reconstruction is the work by Długołęcki (1992), who as a historian based his work mainly on historical archive records and chronicles. Długołęcki questions the existence of a vast water territory, treated by Bertram as waters if Lake Druzno, in about 1300, i.e. in the pre-colonisation period. The author sees the main mistake of Bertram in neglecting historical sources concerning settlement. He localizes more than ten settlement sites existing at that time on swamps. In the light of the findings concerning hydrogenous settlement (Fac-Beneda, 1999) this location does not exclude the existence of a water territory. It is highly probable that this area was periodically flooded during floods. Human settlements were situated above the water level on artificial hillocks and the only communication between them was by water. Such a situation could have existed up to the late 14th and early 15th century when the area was drained and inhabited (Bertram, 1924). At the present stage of research, neither hypothesis can be unambiguously supported. It seems that Bertram's reconstruction shows a situation present during a humid period while Długołęcki's reconstruction illustrates the situation present at the same time but in a dry period.

The applied method of hydrographic interpretation supplied new findings concerning the transformations of water relationships in the eastern part of the Vistula Delta.

The decisive element for the determination of the evolution of the hydrographic network in the eastern part of the Vistula Delta were the changes introduced by man in historical times (Figure 3). The main transformations were then limited to changing the course and direction of natural watercourses and melioration canals. The analysis of the cartographically documented changes, additionally confirmed by written sources, as well as taking into account also the premises resulting from the hydrological conditions confirm the initial hypothesis that these changes must have been initiated by the hydrotechnical works performed in the early historical period in the area where the present River Vistula and Nogat split. As a result of the changes in the hydrographic network, performed by man in the period from the early Middle Ages to the present day, a new hydrographic system has been created.

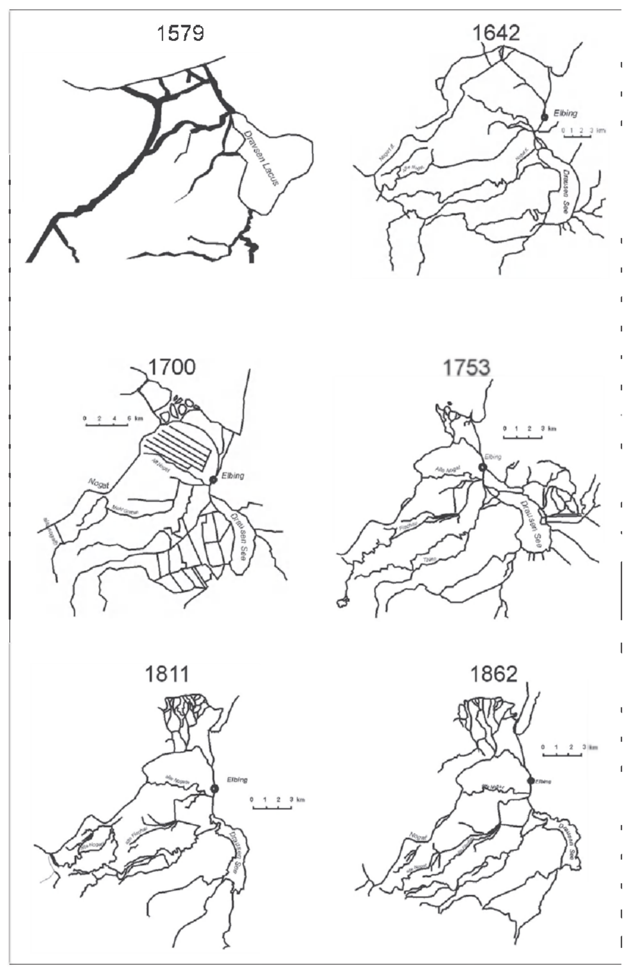

Figure 3: Hydrographic network of the eastern part of the Vistula delta on the maps dating from 16 to 19 century.

Interpretation of aerial photographs in prehistoric times

The state of the hydrographic network at subsequent stages of human activity, as it was already mentioned, is documented by cartographic records and information in written sources. On the other hand, the state of the network in prehistoric times can be determined by paleohydrographic reconstruction (Figure 4).

After the formation of the main draining base – the Baltic Sea and the simultaneous formation of the Vistula Sandbar, the Vistula Delta was built as an inner delta. The state of the hydrographic network at that time can be determined by paleohydrographic reconstruction. On aerial photographs various traces left by flowing water are visible. Some of them are

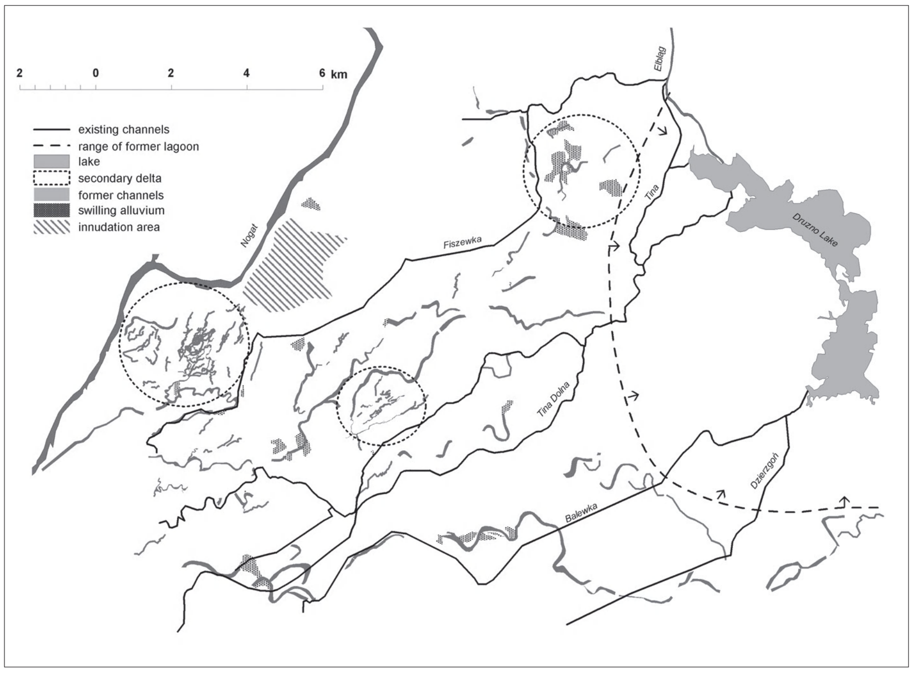

Figure 4: Paleohydrography of the south-eastern part of the Vistula delta after aerial photographs from July 1989.

traces left by water overflowing after breaking an embankment. There are also isolated traces of fragments of channels or washed away channels. Yet, the most interesting ones are long sections of channels of former streams, which in interpretation can be joined to form one sequence reconstructing the course of the stream. Equally interesting are small channels of flood streams forming characteristic fans. There are also clear places where the traces left by flowing water disappear in a way characteristic of sites of former occurrence of stagnant waters.

Present state of hydrographic network

Radical changes in relationships and therefore in the hydrographic picture of the delta, which started around the late 14th and early 15th century, took place due to successive management of the delta (Tab.1). South-western and western regions of the lagoon and marshes accompanying it were reclaimed for agriculture by draining and melioration. On the reclaimed terrain, communication, settlement and above all water network accepted a regular form.

The state of the present hydrographic network of the Vistula Delta (Figure 5) has been determined mainly by the geographic environment, especially by the natural hydrographic system and the needs of agriculture. To a smaller though visible degree the present hydrography has been influenced by the chronology of settlement events and hydrotechnology applied throughout centuries. The earliest to be meliorated were areas which were land at that time, hence the network of ditches and canals clearly corresponds to the natural network and even is dependent on the network. Areas situated below the sea level in 1300 (Bertram, 1924) show a network of strictly geometric pattern, which indicates conscious and organised melioration activity but performed at a much later time.

The final effect of the above presented changes is the radial incentric hydrographic system of the Basin of Lake Druzno /Drwal, 1991, Fac-Beneda, 2002/. At present the system constitutes a completely hydrologically separate unit, losing connection with the main watercourse of the delta – the Vistula River (Figure 5).

Period of rule	Period	Number of years	Events
Pomeranian	to 1308		simple protective dams, scarce settlements
Teutonic	1308-1454	146	embankments of the Vistula and Nogat, polderisation, German settlement, water legislation, floods
Polish with a Swedish episode	1454-1772	318	development of polders and embankments, confirmation of water legislation, Dutch settlement, Swedish flood
German with a French episode	1772-1920/ 1945	148/1737	development of polders and embankments, development of water legislation, floods, Vistula breach, Vistula cross-cut, /eastern part/
Free city of Gdańsk	1920-1939	19	modernisation of embankments and polders, development of water legislation, western and middle part
German	1939-1945	5	extension of embankments, German flood
Polish /Polish People's Republic	1945-1989	50	reconstruction of water system, drainage of delta, local floods, Polish settlement
Polish (Republic of Poland)	from 1989	7	beginning of the construction of a system of water quality protection, ownership transformations

Table 1: Outline of historical development of water system in Viastula Delta.

Conclusions

The continuous transformation of the environment lasting almost 700 years necessitated by safety precautions caused a disappearance of the natural landscape.

It has been replaced with an anthropogenic landscape with a characteristic geometry. Tracing the events within a period of about 1000 years adds emphasis to the fact that the present water system is an effect on the one hand of natural processes and on the other hand of human activity. The effects of these activities overlapped and brought about the present state of water relationships. Due to that, reconstructions of states of water relationships of the Vistula Delta in various periods of their evolution, despite obtaining new data, are still difficult.
However, in the light of the performed research it can be unambiguously stated that the use of various types of geographic interpretation and of various sources gives good results in the verification of evaluation of transformations of water relationships. Moreover, it can be stated that the obtained results do not question the previous reconstructions but significantly specify them.

Acknowledgement

I would like to thank very much prof. Jan Drwal for helpful discussions and important suggestions.

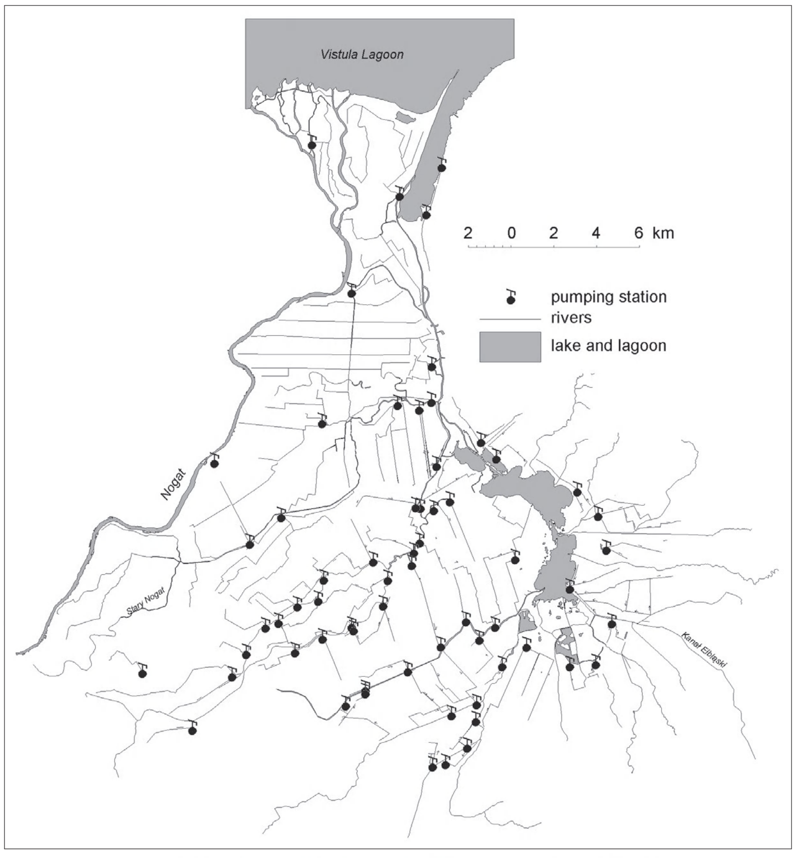

Figure 5: Present-day hydrographic network of the eastern part of the Vistula delta.

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NOAA Test And Evaluation Of Phase Differencing Bathymetric Sonar Technology

Caleb Gostnell, LT Jake Yoos and Steve Brodet

NOAA's Office of Coast Survey is seeking to ascertain whether current interferometric sonar technology is capable of meeting nautical charting hydrographic survey requirements for shallow water and nearshore survey work. Operational tests show that phase differencing sonar technology is capable of resolving ~1m^3 sonar targets on the seafloor and sloped and vertical features up to the draft of the instrument while improving coverage efficiency by better than two times that achievable with shallow water multibeam in waters shoaler than 10m. Preliminary results are promising enough that NOAA hopes to move forward with system integration and operational test and evaluation aboard a NOAA hydrographic survey vessel during the 2006 field season.

Introduction

NOAA spends a large portion of its overall nautical charting hydrographic survey effort obtaining bathymetric data in waters shoaler than 20m. Not only does it take more time and effort to survey a given amount of area in shoal waters relative to deeper waters, but these regions are also frequently the most dangerous areas that we require our hydrographic survey teams to work in. In the nearshore waters of Alaska both visible and submerged rocks are prevalent and currents can be strong. In the shallow and turbid waters of the Gulf of Mexico submerged pipeline terminations and other obstructions rising to within a few feet of the surface are common. Regardless of such hazards, waters of these depths are typically considered navigationally significant and must be surveyed in an accurate and methodical fashion.

While multibeam echosounders (MBES) are known to provide very accurate bathymetric information and are used throughout many the world's hydrographic offices, their data acquisition capability is typically limited to 3-5 times water depth when maintaining the rigorous data quality standards required for nautical charting. This does not become a major limiting factor until working in waters shoaler than 10-15m where it can be difficult to efficiently attain full bottom coverage. In many of these areas water turbidity or resolution requirements preclude the use of lidar and there are few alternatives for obtaining bathymetry in an efficient manner.

Interferometric sonar systems are one tool that may be capable of significantly improving the safety and efficiency of hydrographic survey operations in shoal waters. Interferometers, also referred to as phase differencing bathymetric sonar (PDBS) systems, provide high-resolution wide-swath bathymetry in shallow water with swaths of 10-15 times instrument altitude; a significant improvement over the typical 3-5 times water depth capability of MBES.

While the bathymetric data from phase differencing sonar systems has been historically of suspect quality, with bathymetric resolution limited to 2-3% of water depth [1], recent advances in electronics and phase deconvolution techniques and algorithms have markedly improved their precision and reliability [2,3,4]. These improvements, combined with NOAA's ongoing conversion to surface based nautical charting hydrographic survey deliverables [5], make the use of PDBS a potentially beneficial tool for NOAA's nautical charting survey program.

Preliminary testing conducted as part of a graduate level research project at the University of New Hampshire indicated that PDBS tended to produce data with higher standard deviation than that derived from MBES but that surfaces generated from the data were similar [6]. This similarity in surfaces is what would be expected based on high density data being distributed normally about the true surface as described by Hiller and Lewis [7]. It was also found that discrete features were reproduced with fidelity, that the average difference between PDBS and MBES surfaces was less than 0.1m and that PDBS was capable of accurately resolving sandwaves as small as 0.1m in amplitude [6]. Based on these findings a formal evaluation of interferometric technology was recommended to determine whether it is appropriate for NOAA to incorporate PDBS into the numerous technologies it uses for nautical charting hydrographic survey work. This series of tests is the result of that recommendation.

Methods

The goal of these tests was to ascertain the current state of interferometric technology to determine if it would be advisable for NOAA's Office of Coast Survey to integrate PDBS into the suite of tools used to acquire nautical charting hydrographic survey data. Several test sites were selected to test the capability of PDBS to accurately model features of known size as well as their ability to resolve sloped and vertical features and to more accurately estimate what, if any, real world efficiency gains are achievable.

Data were acquired with MBES, SSS, and each of three commercially available PDBS systems over the period of four weeks during the summer of 2005. MBES data were acquired with a Reson SeaBat 8125 while SSS data were acquired with a Klein 5500. PDBS data were acquired with each of the following three systems: GeoAcoustics GeoSwath, SEA SWATHplus, and Teledyne Benthos C3D. The first week was spent preparing the study sites and acquiring baseline data with MBES and SSS and then one week was spent acquiring data with each PDBS system. All data were acquired aboard the NOAA S/V Bay Hydrographer in and around the mouth of the Patuxent River in Chesapeake Bay, Maryland, USA. Water levels were obtained from NOAA's Solomons Island tide station (Station ID 8577330) in 6 minute intervals. Water column sound speed was measured at least every 4 hours during survey operations using a Sea-Bird Electronics 19 SEACAT CTD. Vessel motion correctors and position were provided by Applanix POS/MV V 4 except with the GeoSwath which employed a TSS DMS2-05 motion sensor at the sonar head.

Four study sites were developed to test specific system capabilities. The first site was developed to test the ability of PDBS to accurately and repeatedly identify small objects of known size and shape. This site was located at the mouth of the Patuxent River, measured 250m x 500m, and had a relatively flat bottom with numerous oyster beds to provide relief. The average depth of the area was approximately 7m. Sonar targets were constructed from 30, 55, and 85 gallon drums wrapped in wire mesh to create an irregular surface and encourage marine growth. The targets were connected at 10m spacing using polypropylene line and deployed in the southern portion of the area. In addition to a standard survey of the area, a tight search pattern was run over the targets; the same search pattern lines were used with each system.

The second site was designed to test the ability of PDBS to accurately resolve sloped features running up to the land water interface. This area was located adjacent to the East Patuxent Basin on the southern shore of the Patuxent River and measured approximately 300mx500m. The area was relatively flat to approximately 150m from shore, had a moderate slope from 150m offshore to 20m from shore, and had a steep incline from 20m from shore to the land water interface. Survey lines were run parallel to the shoreline and the same nearshore line was run with each system.

The purpose of the third site was to evaluate PDBS capability to resolve vertical features, something that interferometers have historically had difficulty with but which recent advances have worked to address [3]. The site was located under the Thomas Johnson Bridge, ranged from 20m to 40m in depth, and included two cylindrical bridge abutments with diameters of approximately 9m. Lines were run on four sides of the abutments to model their entire circumference.

The final study site was used to ascertain potential efficiency gains achievable with PDBS over MBES in waters shoaler than 10m. The efficiency test covered a baseline region of 1350mx500m over a fish haven. Six hours of acquisition were conducted with each system with a vessel speed of 5 knots and one sound speed cast conducted at approximately the 3 hour mark. Different line plans were run with each system to maximize coverage capability. Comparisons were made between the area covered with the MBES and PDBS systems in the allotted amount of time.

MBES data were fully processed within Caris HIPS/SIPS software package while PDBS data were processed within each vendor's proprietary or recommended software package. All data had vessel motion, sound speed, and water level correctors applied. Data were then imported into IVS 3D's Fledermaus data visualization package using similar conversion parameters for comparison and evaluation. All grids were created at 1m resolution using a weighted moving average and a weight diameter of 3. Point and surface PDBS data were then compared to MBES and SSS data covering similar regions and features.

Results

The targets were resolved by both MBES and PDBS and are clearly visible as shown in Figure 1. The cross section shown is over the largest target, which had a real world height of 1.04m. After binning, which tends to smear small, discrete objects [8], the target had a vertical presence of 0.34m in the MBES data and 0.18m in the PDBS data. In the sample datasets of the target area, the standard deviations of the unbinned data were 0.65 for the MBES and 1.32 for the PDBS. While there were small differences in the heights of the targets between datasets, other small features, such as 0.2m amplitude oyster beds, were similarly modeled in both.

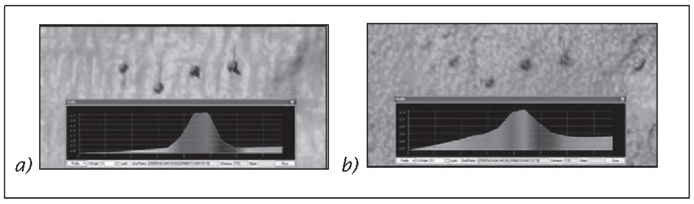

Figure 1: Sonar targets as gridded from a) MBES data and b) PDBS (GeoAcoustics GeoSwath) data. Note that the gridding process has reduced the height of the target in both datasets and that while the effect is more dramatic in the PDBS data the targets remain readily visible. Data are shown with a vertical exaggeration of 6.

PDBS appears fully capable of resolving sloped features up to a depth of slightly shoaler than the instrument itself. As shown in Figure 2, the PDBS captured an additional 20m laterally of the steep slope running up to the land-water interface while running the same nearshore line as with the MBES. In this case the systems were mounted approximately 2m below the surface and it is expected that bringing them closer to the surface would yield additional data (Figure 2).

Both MBES and PDBS resolved the 9m diameter bridge abutments at the appropriate locations and with the correct diameter. The MBES was able to resolve the abutments to a minimum depth of ~ 5.5m while PDBS was capable of resolving them to ~ 2.0m. The MBES provided denser, more regularly spaced sounding coverage on the features resulting in the gridded representations of the abutments appearing to have more significant vertical presence in the MBES data (Figure 3).

In six hours of operations at 5 knots the MBES provided approximately 0.44snm of coverage. PDBS yielded as much as 0.96snm in the same amount of time with the same vessel operating parameters; an efficiency gain of better than 100% in waters shoaler than 10m. MBES data had small gaps at the shoal end of the data due to reduced swath width while PDBS was acquired with 100% overlap leaving no gaps.

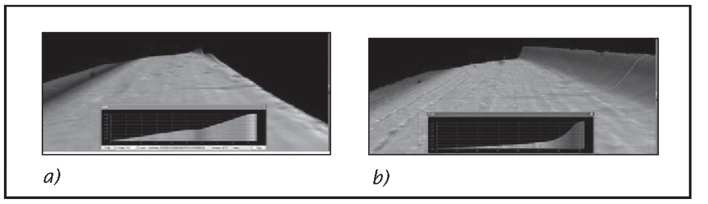

Figure 2: Sample data from slope area. Shown are a) MBES data and b) PDBS data (GeoAcoustics GeoSwath). Note that while the PDBS data is noisier than the MBES it still captures the small feature in the upper left portion of the data and the small depressions along the base of the slope. The along track artifacts are on the order of 0.1m in amplitude. Data is shown with a vertical exaggeration of 6.

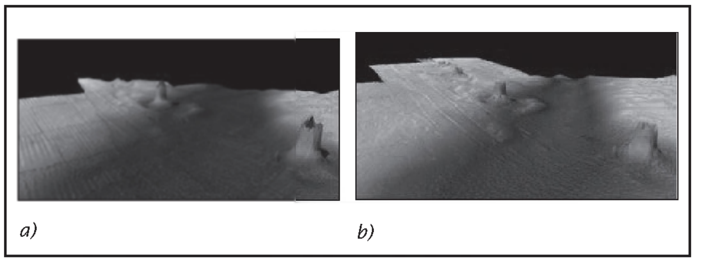

Figure 3: Shown are bridge abutments as modeled from a) MBES and b) PDBS (GeoAcoustics GeoSwath) data. Note the submerged cable trenches running parallel to the bridge and the remnant of a cofferdam at the base of the abutment in the lower right corner of each image. The motion artifacts clearly visible in the MBES data were the result of pole motion. Data are shown without vertical exaggeration.

Discussion

The sonar targets in this study were resolved by both MBES and PDBS, however, once the data were binned to a resolution of 1m the target heights in data from both technologies were significantly reduced from their acquired values. In the MBES data the targets appear slightly less than half their actual height and in the PDBS data they are reduced by half again. While a portion of this effect is due to gridding the data at a bin size greater than half the diameter of the targets [9], the point data from the PDBS did not tend to provide as dense a sampling of soundings on the targets as MBES did, and those soundings did not necessarily represent the shoal depths. In other instances PDBS did resolve similar features with fidelity, indicating that at least a portion of the problem may reside in the data filtering techniques applied and not necessarily with the technology itself. Over relatively flat areas, large objects, and areas of more gradual or consistent change this did not seem to be an issue and in general the soundings and surfaces vary little between MBES and PDBS.

PDBS technology appears quite adept at yielding quality data on sloped surfaces. As shown in Figure 2, the wide swath of bathymetry enabled significant additional data to be acquired along the representative slope than was feasible with MBES. In this example the PDBS provided a shoreward swath of 4-6 times as wide as that feasible with the MBES on the shoreward most line. This ability to acquire significantly more data affords the survey team several options; they have the ability to acquire additional data that they would not have been able to without PDBS or they can stand back farther off of dangerous features while still acquiring the same amount of data that would have been feasible with MBES.

The current evolution of PDBS appears fully capable of resolving vertical features (Figure 3). The use of multiple receive elements affords PDBS the ability to handle several simultaneous returns from different angles [10]. In this example, the PDBS resolved the bridge abutment to approximately 2m while the MBES was limited to ~ 65° off nadir (i.e., 65° to each port and starboard), yielding data to 5m below the surface. The MBES data was, however, more regularly spaced and denser on the vertical structure itself than was the PDBS data, resulting in the gridded feature appearing to have a more significant vertical presence. In the real time acquisition display the PDBS data appeared to be much denser than was realized after the data had been cleaned so it is feasible that the data were capable of supporting denser coverage over the abutments and that the sparse data were the result of the data cleaning process and that improved techniques may allow for more accurate data filtering.

Several years ago it would not have been feasible to consider using PDBS data for nautical charting because of the high standard deviation of the data. NOAA's move away from discrete soundings and toward surfaces as a final survey deliverable from the United States' domestic nautical charting survey fleet, however, makes the use of PDBS data feasible today. With a standard deviation approximately twice that of MBES, using discrete soundings from PDBS may not yet be advisable but may become possible as algorithmic advances are made and/or confidence is built in the technology through use over time. In the interim it will most likely remain necessary to continue to acquire development data over discrete hazards to navigation with MBES, vertical beam echosounder (VBES), or other proven means.
PDBS is capable of more than doubling the amount of area that can be covered in a given amount of time in waters shoaler

than 10m. The MBES data for this study were acquired using the maximum line spacing feasible while still achieving full bottom coverage resulting in small holidays within the inshore section of the data. Under real world surveying conditions it would have been necessary to tighten up the line spacing to ensure that no significant objects were missed which would have further reduced the amount of area covered. The PDBS acquisition, on the other hand, was run with a relatively narrow range scale and at a line spacing enabling better than 200% coverage to ensure that there was adequate coverage to demonstrate the viability of the technology. Under operational acquisition it is likely that the line spacing would be greater, and thus yield additional areal coverage.

The nearshore is one of the most challenging areas to operate a survey vessel, yet surveys are typically required in these areas because there is no accurate, up to date bathymetric data available. Navigating a vessel in such areas often requires the survey vessel to slowly work its way towards shore, navigating only in the waters which it has surveyed immediately beforehand. In the shallow waters typical to nearshore areas, multibeam echosounder systems are limited by their cross track range meaning that safely navigating shoreward can require survey line spacing of 10m or less. This often takes an inordinate amount of time and can be extremely difficult to execute when currents are present. While side scan sonar is capable of providing the required cross track range, it does not yield bathymetry, making it difficult to know where the water becomes too shallow for the vessel to safely operate. By providing wide swath bathymetry, PDBS appears to be a viable solution to this problem. Additionally, PDBS is also seen as offering a potential advantage for port and harbor surveys. Such surveys often require the survey vessel to acquire data in slips and along pier faces. The additional bathymetric coverage afforded by PDBS enables the survey vessel to stand farther off from submerged pilings and piers and other dangers, thus more safely and efficiently deliver full bathymetric coverage of an area.

Summary and conclusions

The NOAA hydrographic survey fleet spends a significant portion of its overall survey effort working in shallow and nearshore waters; areas that frequently contain dangerous rocks, wrecks, and obstructions making them particularly hazardous to work in. While multibeam echosounders (MBES) provide high quality bathymetric data, their limited swath width in shallow water makes them less than ideal for work in these areas. Interferometric, or phase differencing bathymetric (PDBS), sonar systems are capable of providing significantly wider swaths than MBES in waters shoaler than 10-15m, however, the technology has not yet been approved for use in NOAA's nautical charting hydrographic survey program. This series of tests was conducted to determine whether PDBS technology has advanced to a point where it is appropriate to integrate PDBS systems into NOAA's inventory of hydrographic survey equipment for operational test and evaluation.

Several study sites were designed to evaluate the current capability of PDBS to resolve small targets of known size, sloped and vertical features, and to ascertain achievable efficiency gains over MBES in waters shoaler than 10-15m. It was shown that PDBS technology appears capable of resolving ~1m^3 sonar targets on the seafloor and sloped and vertical features up to the draft of the instrument. PDBS was also shown to improve coverage efficiency by better than two times that achievable with shallow water multibeam in waters shoaler than 10m. While the noise levels inherent to PDBS technology make the individual soundings provided slightly suspect, NOAA's shift away from using discrete soundings towards a surface based deliverable makes the noise levels associated with discrete measurements less of an issue. Surfaces generated from MBES and PDBS data resolve small targets, slopes, and vertical features similarly making PDBS a viable candidate for use in acquiring nearshore and shallow water data. Preliminary results are promising enough that NOAA has begun to move forward with system integration and operational testing and evaluation aboard NOAA hydrographic survey vessels.

As binning at scales fine enough to identify navigationally significant objects but coarse enough to maintain the data at a manageable size tends to reduce the overall height of small, discrete objects, using surfaces is not the best method for measuring shoal depths over small obstructions to navigation. It is therefore advised that PDBS technology initially be used solely for charting generalized bathymetry and item detection with developments run over objects considered to be hazardous to surface navigation with vertical beam echosounder or MBES until additional advances and further testing has improved confidence in PDBS measurements over discrete objects.

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Smoothing Contour Lines Of Hydrographical Maps: An Optimised Approach

M. Hennau and A. De Wulf

Perhaps the most classic way to represent 3D-objects, like the DTM from a hydrographical survey, on a 2D medium is by generating contour lines. The sight of an unsmoothed contour map can be too rough and is often rejected by the map users, especially when a shelving surface is being represented. However, many users object to smoothing on grounds that smoothed contours do not honour the linear character of the source data. Therefore, the application of smoothing procedures for aesthetic purposes should be in respect with the geometrical properties of the source data. A popular method to smooth contour lines consists in smoothing each contour independently of the rest. A second approach engages the distillation of contour lines from smooth surface patches. An eclectic procedure has been worked by A. Christensen out to combine the advantages and minimize the drawbacks of both approaches. Furthermore we have refined the eclectic method by inserting optimisation algorithms into the procedure in order to smooth in an adaptive way and to increase the geometrical integrity of the contours.

Introduction

The quality of a cartographic product doesn't only depend on objective criteria. Although geometric accuracy is of fundamental importance, the possibility to offer fast and correct interpretation is one of the most important features which define the success of a chart.

Charting implies a certain degree of abstraction and simplification of the reality to be displayed. The goal is to help the end user comprehend instinctively the features displayed on the map. Although abstraction from reality can help the interpretation, it can also form a danger to the quality of the chart [1].

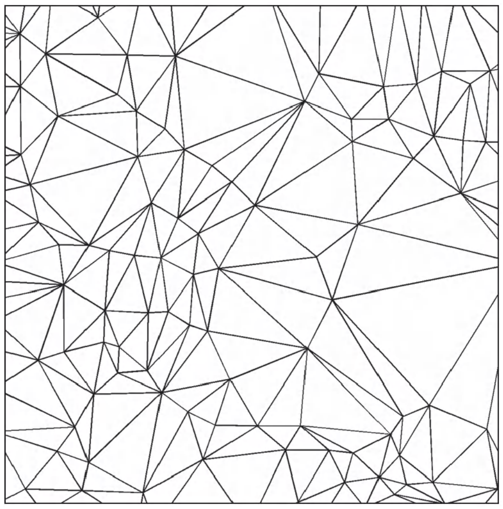

Figure 1: Triangular irregular network.

The primary objective of contour lines is to yield height information. The possibility to gain morphological information from the interpretation of a contour map depends on the quality of the charted contours.
One of the most classical ways to present the results of a bathymetric survey is to derive contour lines from a triangulated irregular network (TIN) of the source data. TINs (Figure1) can be applied to any terrain configuration.

This flexibility, however, can reveal itself as a weakness. Constant slope areas are covered with fewer, much larger triangles than those required to model more fractured areas.
Dense contours interpolated linearly from those large triangles expose the underlying TIN structure, thus looking so artificial that many users reject them (Figure 2).

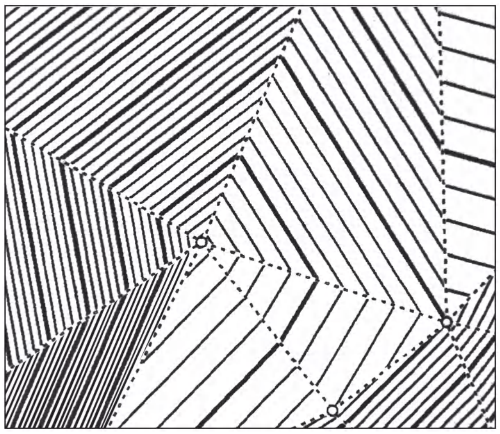

Figure 2: Linearly interpolated contour lines.

Smoothing can be effective in disguising the data structure and therefore facilitate the creation of appealing and easily interpretable maps (Figure 3).
There are however objections to smoothing on grounds that the linear character of the source data is not being honoured.

Smoothing procedures

Currently, there are two smoothing methods in use: Line smoothing and smooth patching [2].

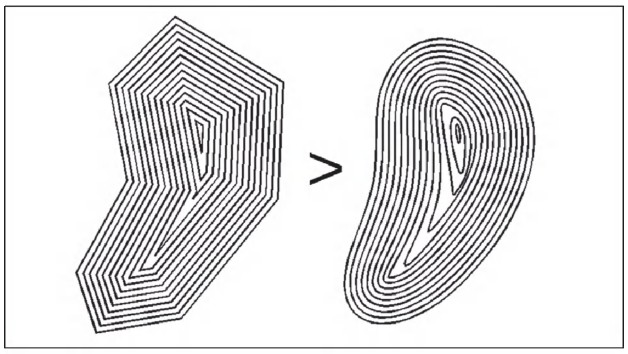

Figure 3: From raw to smooth contours.

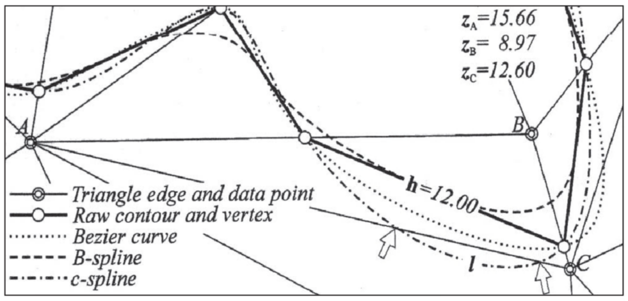

Figure 4: Errors (1) due to line smoothing.

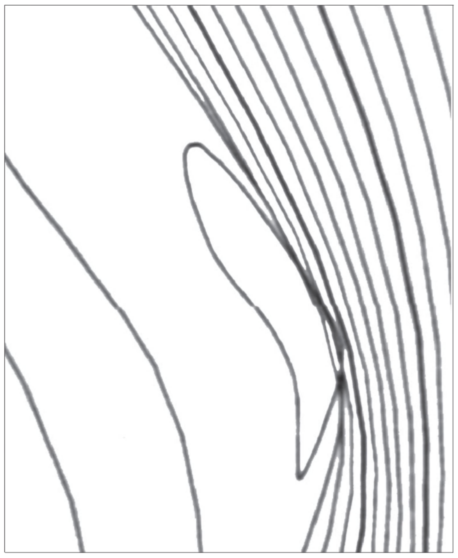

Figure 5: Errors (2) due to line smoothing.

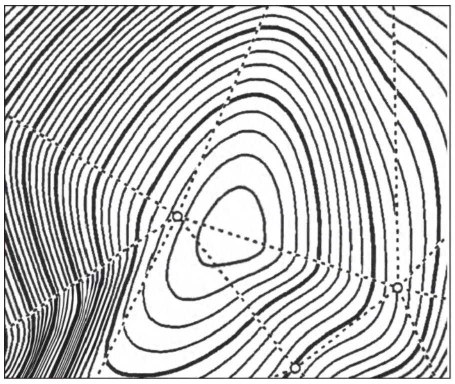

Figure 6: Errors (1) due to smooth patching.

Line smoothing

This procedure smooths each contour line independently of the rest. A continuous curve is determined across the sections of the raw contour. The major problems involved with the use of this method are:

1. the discrepancies between the linear model and the smoothed contours (Figure 4)
2. the crossing of contours (Figure 5)

Smooth patches

This method interpolates contour lines directly from smooth surface patches applied to the TIN structure. The major problems caused by the smooth patches are:

1. Planimetric shifts of relative orthometric maxima or minima can occur when the patches do not exactly fit the raw data (Figure 6 and Figure 2 represent the same area!) [3]
2. Smoothed contours are scourged by discontinuities when smooth patches are applied to triangles with very narrow angles (Figure 7)

Eclectic smoothing procedure

The eclectic solution proposed by A. Christensen comprises some of the characteristics of line smoothing and smooth patching and minimizes the deficiencies inherent to both procedures.

The raw contours are used as source data, thus imitating line smoothing (Figure 8). The smoothing of the contour at vertex V_i is performed by interpolating two consecutive quadratic parabolas (Figure 9).

The parameters of the parabolas are bound by the geometry of the triangles sharing the edge on which the vertex V_i was interpolated (Figure 8). The smoothing is linked to the underlying TIN, thus imitating smooth patching.

Furthermore, the smoothing of the contour at vertex V_i can be applied in a gradual manner away from the vertex in order to minimize the violations to the linear model (Figure 10).

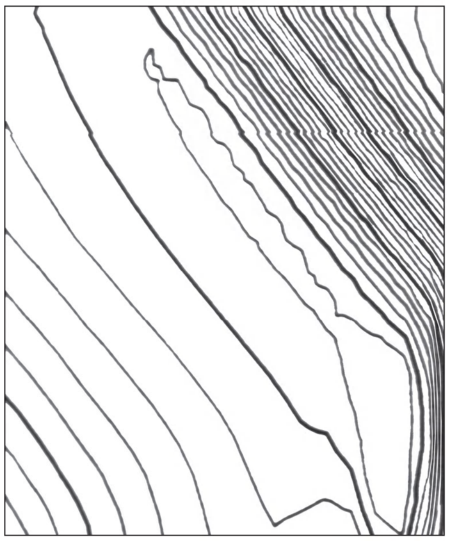

Figure 7: Errors (2) due to smooth patching.

P_k	: Source data
V_i	:Vertex of raw contour
C_i	:Triangle centroid
H_i	: Intersection of raw contour and median
J_l	: midpoint $[H_i,V_{i+1}]$ when f=1
K	: midpoint $[J_l J_{l+1}]$
$[D_m,E_l]$:	interpolated parabola segment
m	: number of segments to be interpolated

Further optimizations

Traditionally, the junction point K of the consecutive parabolas is arbitrarily computed as the midpoint of $[J_1,J_2]$ (Figure 10). This can lead to a loss of geometric integrity for the smoothed contour at some of her vertices. In a first optimization, the construction of the parabolas is performed in order to minimize the changes inflicted by the smoothing procedure to the geometry of the contour at each vertex. Therefore, the geometrical properties of the raw contour at vertex V_i are involved in the interpolation of junction point K, as formulated in equality (1).

$$\frac{D[J_1 K]}{D[K J_2]} = \frac{D[H_1 V_1]}{D[V_1 H_2]} \qquad (1)$$

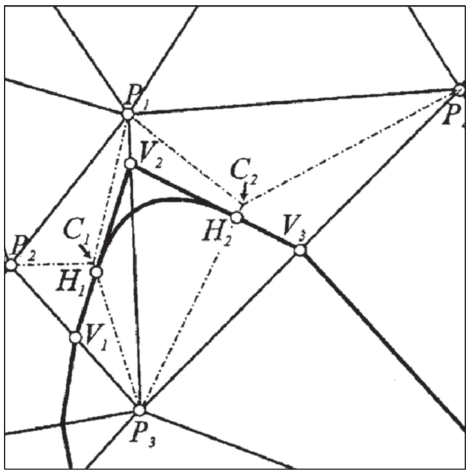

Figure 8: Eclectic procedure: basic configuration.

A second optimization is introduced to increase or decrease the smoothing according to the geometry of the raw contour at its vertices. The amount of interpolations used to perform the smoothing of the raw contour at vertex Vi is traditionally equal for all its vertices. This means that an acute angle formed by two consecutive contour segments is smoothed by interpolating two parabolas, which will be formed by the same number of segments as the parabolas computed for the smoothing of an obtuse angle from the same raw contour. Therefore, acute angles can appear as jagged as before. An optimization function (2), defining the angle formed by the consecutive parabola segments as the restriction parameter, is being presented to redress that shortcoming (Figure 11). This enables the procedure to smooth the raw contour at each vertex in an adaptive way.

I : iteration
A : maximal angle between consecutive segments to be tolerated
m : number of segments to be interpolated at iteration I (2)
S_m : parabola segment
$S_m \wedge S_{m-1} > A \qquad m_{I+1} = m_I + 1$

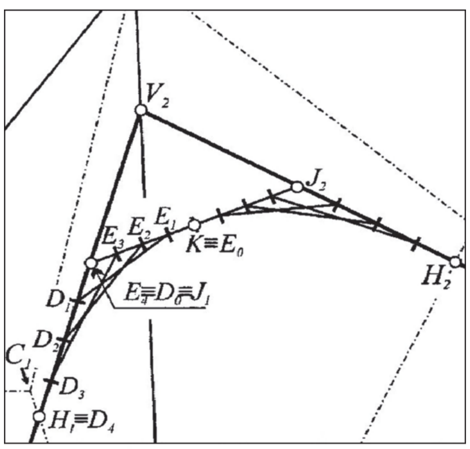

Figure 9: Eclectic procedure: interpolated parabolas.

Both optimizations can be easily combined, minimizing furthermore the violations to the geometry of the raw contours.

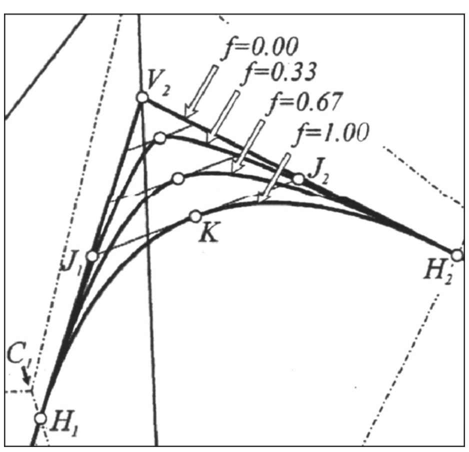

Figure 10: Eclectic procedure: degree of smoothing.

Acknowledgments

Parts of the optimized smoothing procedure have been added to the software implemented within the framework of the approved IWT project "A Survey System for Dredging" (n° IWT990159 "Hydrografisch Survey Systeem voor Baggeren", 1999-2002), a joint venture of the Flemish private partner and supervisor Dredging International, Survey Department and the scientific partner Ghent University, Department of Geography. The fundamental research fitted in the larger, approved, international Eureka project "Dredging Survey 2000 (EU203511)".

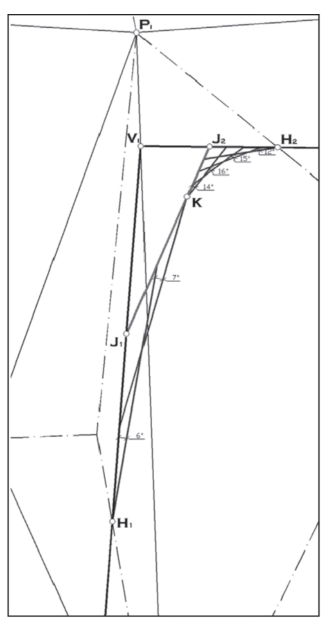

Figure 11: Optimised eclectic procedure.

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Water Level Forecasting In The Oder Estuary

In Relation To Passages Of Deep Low-Pressure Systems

H. Kowalewska-Kalkowska and
M. Kowalewski

A 3D operational hydrodynamic model of the Baltic Sea (M3D_UG), based on the Princeton Ocean Model (POM), was used to forecast storm surges in the Oder Estuary. Because of wind-driven back-up in the Oder mouth, a simplified operational model of river discharge was additionally developed, based on water budget in a stream channel. Linking the Oder discharge model with the Baltic Sea model into a single system made it possible to simulate hydrographic conditions in the Szczecin Lagoon and in the Pomeranian Bay. As the model adequately approximates the changes of water level in case of passages of deep low-pressure systems over the Baltic, it can be regarded as a reliable tool for storm surges forecasting.

Introduction

The Oder River forms one of major estuaries in the southern Baltic Sea. In its downstream reach, the Oder opens first into the Szczecin Lagoon. Then it drains into the Pomeranian Bay coastal zone through three straits: the Swina, the Dziwna and the Peenestrom. It is the region exposed among others to storm surges. Caused by deep low-pressure systems passing the Baltic Sea the storm surges are the result of wind activity and changes in atmospheric pressure on the sea surface, the so-called baric wave, as shown by Wiśniewski [1]. Wind and wave may be additive in their effects, i.e. they act in concert to increase or decrease the sea level on the coast, or their effects may be non-additive, as when one factor produces a sea level increase, while the action of the other results in a decrease. On the Polish coast, dynamic effects of the baric wave are more evident in case of passage of deep (below 980hPa) lows moving at a high speed. The wind effect is then less pronounced because of a relatively short time of the wind activity from a given direction. The wind effect prevails during passage of a shallow (above 980hPa in the centre) and slow (less than 30km/h) low-pressure systems.

The highest increases of sea level are recorded in the cases of the movement of deep depression with trajectory running close to the Pomeranian Bay coasts and strong winds from northern directions. In that case the Bay's brackish water can enter the Szczecin Lagoon and raise the water level throughout the estuary. As shown by Buchholz [2], the wind-driven water back-up forming in the Oder mouth may penetrate as high upriver as to Gozdowice (645.3km of the Oder River), The effect is particularly pronounced during autumn and winter storm surges under very strong northerly winds.

A reliable marine weather and hydrography forecasts are essential for the emergency centres and services responsible for coastal flood protection, especially for the protection of polders and zones adjoining river mouths. Therefore over recent years water levels fluctuations along the southern coast of the Baltic Sea have been the focus of numerous studies [3, 4, 5]. In the Oder mouth area the influence of atmospheric dynamics on water levels was described, i.a. by Buchholz [2] and Ewertowski [6]. An adequate approximation of the hydrographic conditions in the Vistula mouth area by a 3D hydrodynamic model of the Baltic Sea (M3D_UG), developed at the Institute of Oceanography, University of Gdańsk was an incentive for testing the behaviour of the model in the Oder mouth. This paper discusses application of the model to storm surges forecasting in the Oder estuary during the passage of low-pressure systems over the Baltic Sea.

Model Description and Its Performance

A three-dimensional, operational hydrodynamic model of the Baltic Sea (M3D_UG) is a baroclinic model that describes water circulation, with a due consideration to advection and diffusion processes. The model is based on the Princeton Ocean Model (POM), described in detail by Blumberg and Mellor [7]. Adapting the model to the Baltic Sea required certain changes in the numerical calculation algorithm, as described in detail by Kowalewski [8]. It was adapted then for the 60-h numerical meteorological forecast of ICM (Interdisciplinary Centre of Mathematical and Computational Modelling, Warsaw University). To obtain an adequate resolution and reliable output, two grids with different spatial spacing were applied: 5 nautical miles (NM) for the Baltic Sea and 0.5 NM for the other region, the latter comprising the Pomeranian Bay and the Szczecin Lagoon.

Because of wind-driven back-up in the Oder mouth there was developed a simplified operational model of river discharge based on water budget in a stream channel [9]. Discharge calculations are performed automatically on the base of water level data from gauging stations along the Lower River Oder published on the Institute of Meteorology and Water Management (IMWM) website (http://www.imgw.pl/wl/internet/hydro/biuletyn.jsp).

Linking the Oder discharge model with the hydrodynamic model of the Baltic Sea into a single system made it possible to simulate operationally hydrographic conditions in the Pomeranian Bay and the Szczecin Lagoon. Current results of the model may be viewed on the website (http://model.ocean.univ.gda.pl) as maps of 60-hour forecasts of water levels, currents, water temperature, and salinity.

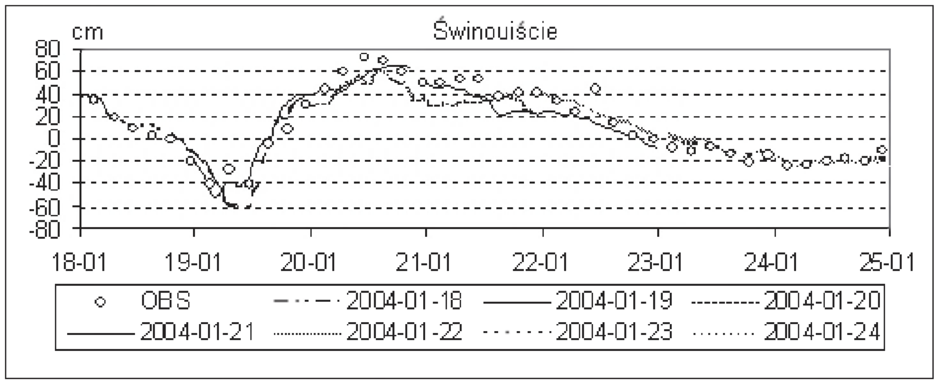

Figure 1: Observed and predicted water level changes in Świnoujście during the storm surge in January 2004; Legend: forecast of 18, 19,..., 24 January.

A preliminary evaluation of the model accuracy for the Oder Estuary was already presented by Kowalewska-Kalkowska and Kowalewski [9,10]. The best fit between the observed and modelled data were achieved for the water level and temperature. With respect to the water level series correlation coefficients between the observed and the predicted data sets higher than 0.81 for all the predictions were indicative of high statistical significance. For water temperature data the correlation coefficients between the empirical and the numerical data sets exceeded 0.98. The observed and the calculated salinity values showed a poorer fit; however, the relevant correlation coefficients were statistically significant.

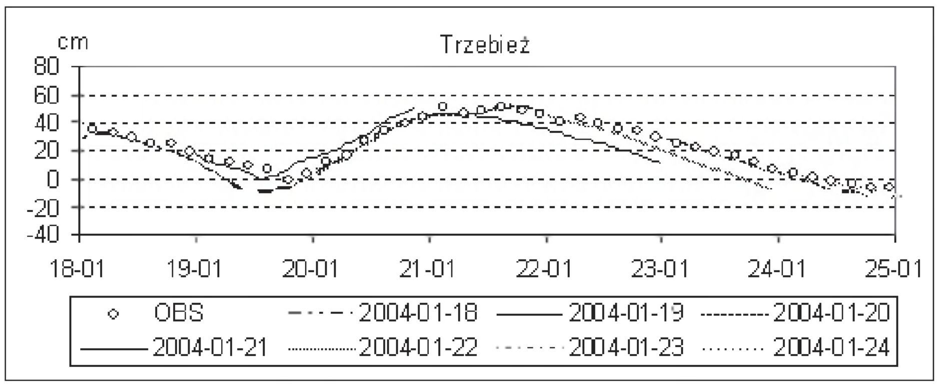

Figure 2: Observed and predicted water level changes in Trzebież during the storm surge in January 2004; Legend: forecast of 18, 19,..., 24 January.

Application of the Model to Forecasting Storm Surges

The good fit between simulations and observations in the Oder mouth area in the years 2002-2004 was an incentive for testing the applicability of the model to forecasting rapid water level fluctuations in case of passage of deep depressions over the Baltic Sea. Such temporal variations in water level, as approximated by the model, may be visualised for a case involving a storm surge between 19 and 25 January 2004. The storm surge was a result of a passage of a deep low-pressure system that moved eastward from the central part of Scandinavia, over the Gdańsk Bay, and further east. Initially, a decrease of water level at the Pomeranian coastal stations was observed. The 18 and 19 January forecasts of that drop correctly approximated its timing and extent (458cm in Swinoujście). Only the 18 January forecast underestima-

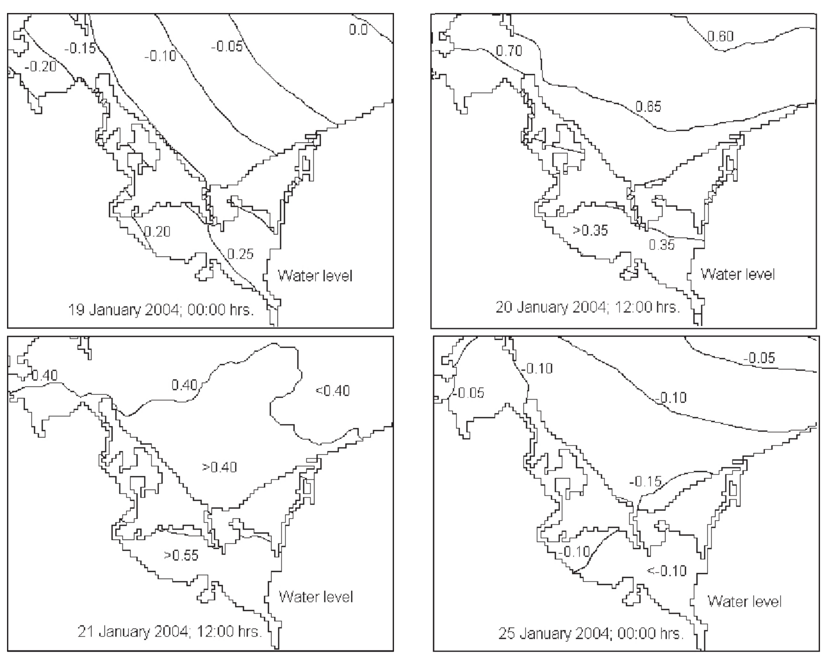

Figure 3: Water levels during the storm surge in January 2004, as simulated with the 3D numerical model (slope of the free surface of waters in metres).

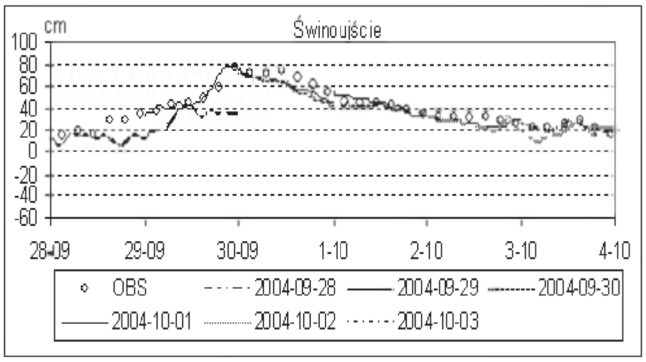

Figure 4: Observed and predicted water level changes in Świnoujście during the storm surge in September/October 2004; Legend: forecast of 28 September,..., 3 October.

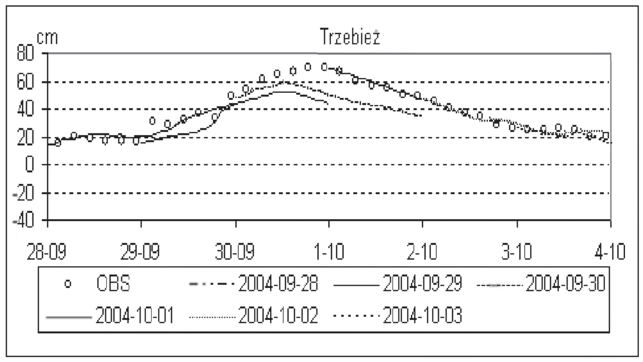

Figure 5: Observed and predicted water level changes in Trzebież during the storm surge in September/October 2004; Legend: forecast of 28 September,..., 3 October.

ted the minimum slightly (Figure 1). Beginning on 19 January, the sea level began to rise to reach the maximum on 20 January as a result of the low centre's fast shift over the Gdańsk Bay and strong (7oB) NE winds. The maximum value of 572cm in Swinoujście was also predicted with a high accuracy, although was underestimated by the model insignificantly. During the next few days, the ensuing decrease of water level was also accurately predicted by the model.

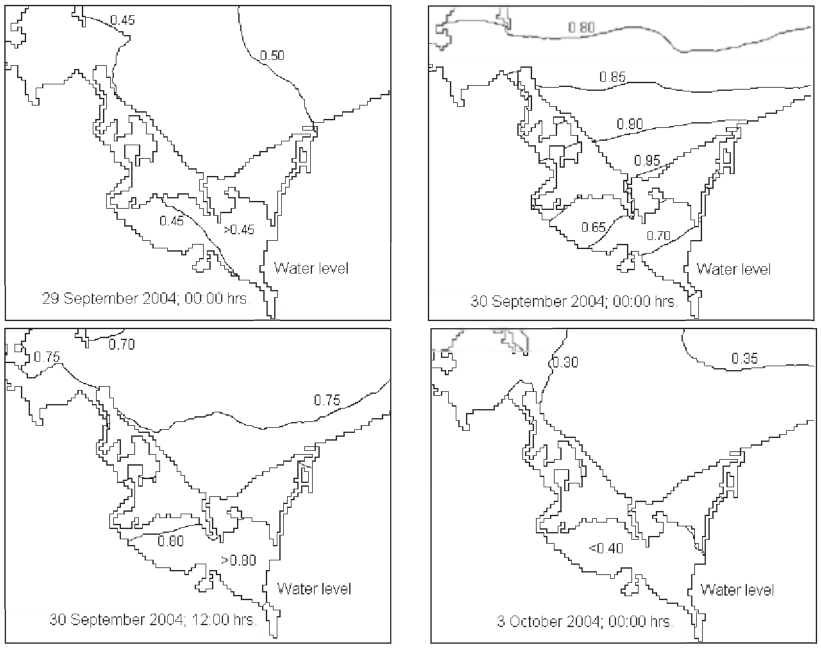

Figure 6: Water levels during the storm surge in September/October 2004, as simulated with the 3D numerical model (in metres).

During the storm surge discussed, the Szczecin Lagoon stations showed much weaker water level fluctuations that followed, with a time lag, changes in the sea level (Figure 2). From 19 to 21 January a constant increase of the water level until the maximum of 550cm (Trzebież) was observed, mainly as a result of NW winds. The forecasts very accurately predicted that phase of the storm in terms of the timing and the amplitude of the surge. The continuing drop in sea level over the following days was also accurately simulated by the model. Figure 3 illustrates the 3D numerical model simulation of water level changes in the Pomeranian Bay and the Szczecin Lagoon during the January storm surge.

Between 29 September and 2 October 2004, another depression passed over the Jutland Peninsula, along the southern Baltic coasts, the Gulf of Gdańsk and farther east. Along the Pomeranian Bay, it generated a system of 6oB force south-westerly winds. That shallow and slow low resulted in an increase in the sea level at the Pomeranian coasts. At the beginning, the 28 September forecast for Swinoujście underestimated slightly that first phase of the storm (Figure 4). Then, the subsequent increase of sea level until the maximum value of 576cm during the night of 29 September was very accurately approximated by the 29 September forecast. The continuing drop in sea level over the following days was also very accurately predicted by the model; only the 30 September forecast underestimated it slightly.

During that storm surge, water level fluctuations in the Szczecin Lagoon, following with a time lag the sea level changes, were mainly the result of the prevailing north-westerly winds. On 29 September the water level began to rise to reach the maximum on 30 September (569cm in Trzebież). The 29 and 30 September predictions properly reflected that increase, however produced some underestimates (Fig.5). The maximum value was underestimated insignificantly by the 30 September forecast as well. During the next few days, the ensuing decrease of the water level in the Szczecin Lagoon was accurately predicted by the model. Figure 6 illustrates all the storm phases as predicted by the 3D numerical model.

Conclusions

Following the adequate fit between the observed and predicted data, the application the model to forecasting storm surges in the Oder mouth area in the years 2002-2004 revealed its high usefulness. In case of passages of deep low-pressure systems over the Baltic resulting in significant water level variations in the estuary the model correctly approximated the changes of water level and reflected properly all the phases of the examined storm surges.

A quick website access to the hydrographic forecast (http//:model.ocean.univ.gda.pl) allows potential users to predict the day-by-day course of processes that may affect different areas of human life and activities, e.g., navigation, port operations as well as flood protection of coastal areas. In addition, the model may prove of assistance in studies on storm surges in the Oder Estuary.

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Survey Of Underwater Gas Pipelines On The Ob River With Parametric Sediment Echosounder SES

Oleg V. Levchenko

There are many different risks of damage for underwater pipelines, especially for their involuntary free spans over the shallow-water areas. The first SES survey on the Ob River in 2005 evidences high effectiveness and usefulness of this narrow beam parametric sediment echosounder for engineering monitoring of underwater gas pipelines. All free spans of the underwater pipelines both hung in water column and exposed on river's bottom were revealed very reliably, including very narrow scours by 5–10m wide and 4–5m deep. Pipes buried by sediments were revealed there sometimes in depth up to 5m beneath the river bottom. The collected SES data over the Ob River could be very important for scientific researches of topography-forming and sedimentological processes and subaqueous flow-transverse bedforms in rivers as well as for modeling of the after-effects due to anthropogenic intervention in natural regime of the rivers.

Introduction

A lot of underwater pipelines for transportation of gas, oil, fresh water etc are running through large and small rivers. There are many different risks of damage for the pipelines, especially for their involuntary free spans over the shallow-water areas. Predominant hazards are vessels, anchors and any trawling deep diving objects. The bottom morphology of the rivers is controlled by the sediment dynamics, and subaqueous flow-transverse bedforms are most peculiar features, which are formed in the natural flow channels. Free spans of pipes on the bottom of rivers with migrating dunes and ripples are usual and breakage due to bending of the pipes is other real hazard here. Divers and several acoustic technologies are used for inspection is a pipe buried within bottom sediments, laid up on bottom surface or hung above it in the water column. Sidescan sonar is most applicable one, but it provides no information about depth of buried pipes beneath rivers' bottom. Different linear sub-bottom profilers (sparker, boomer, chirp sonar etc) are used for measuring of the depth (Kalinin et al., 1999; Wille, 2005), but their vertical and horizontal resolution is often low for revealing underwater pipelines.

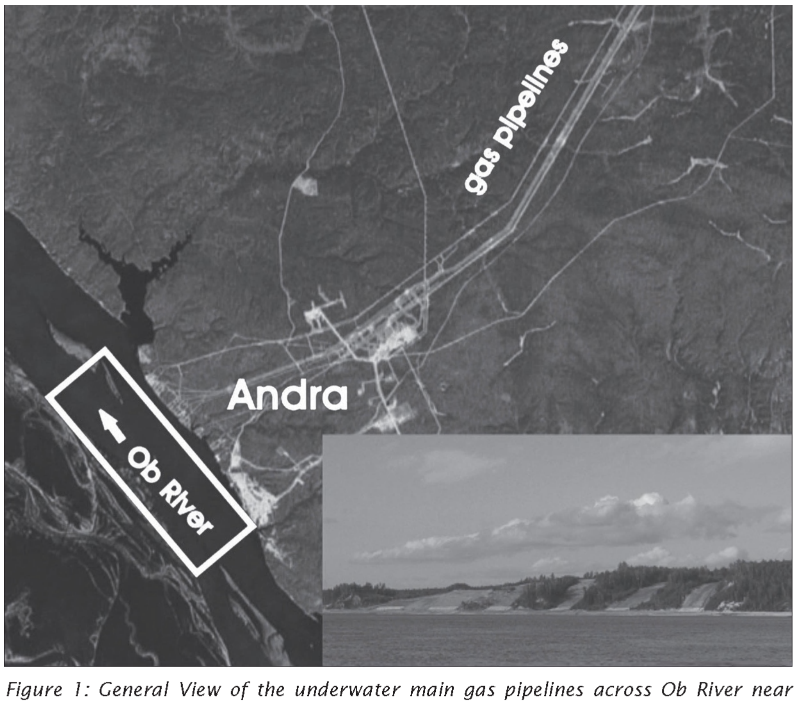

Figure 1: General View of the underwater main gas pipelines across Ob River near Andra, satellite image (http://earth.google.com). Location of the survey area is indicated by red box. Inset: photo of the pipes entry in the river.

Set of large pipelines was constructed some decades ago for transportation gas from Siberia to Europe and the main pipelines are crossing several rivers. The longest underwater part is the Ob River crossing from 2km to 4km wide in different seasons (Figure 1, 2). Very high-resolution seismic reflection profiling was carried out in summer 2005 here. Parametric sediment echosounder "SES-2000 compact" (Figure 3) was used firstly in Russia for survey over such water areas. The survey was conducted in the period 26 August to 31 August 2005 during systematic inspection of the underwater pipelines' technical condition, which is carried out yearly by engineering company "PODVODGAZENERGOSERVICE", AS "Gazprom". These routine works usually include echo-sounding and side-scan sonar survey only.

Nonlinear acoustics, narrow beam parametric echosounder ses, methods

Nonlinear acoustics

Company "Innomar Technologie GmbH" (Rostock, Germany) produces the SES family of sub-bottom profilers based on nonlinear acoustics (Hansen, Muller, 1999; Wunderlich, Muller, 2003; Lowag, Heuvel, 2004; Wunderlich et al., 2005). For nonlinear sound generation two signals of slightly different high (primary) frequencies are simultaneously transmitted at high sound pressures. Due to nonlinear interactions in the water column in front of the transducer, difference (secondary) frequency is generated. It is low and can be used for sub-bottom sediments profiling and embedded object detection. The high primary frequency signals may be used for the exact determination of the water depth (bathymetry survey). In comparison with linear echosounders, parametric systems have following advantages:

- Possibility to generate narrow sound beams at low frequencies with small transducers. Beam width is nearly independent of the sound wave frequency.
- Small and portable transducer and system dimensions allow the use for different applications and the installation on small boats too.
- High system bandwidth, which allows transmitting very short signals without ringing, gives high vertical resolution.
- Small beam width also at low frequencies and high pulse repetition rate result in high horizontal resolution.
- The directivity of the difference frequency has no side lobes.
- A narrow beam without side lobes and short pulses results in less volume of bottom reverberation and increases signal-to-noise ratio for detection of weak reflectors.
- Nearly constant directivities for the primary frequency and the different secondary frequencies at transmitting offer new possibilities refer to classification.
- The use of the parametric systems ensures bathymetry and sub-bottom survey results with high accuracy.

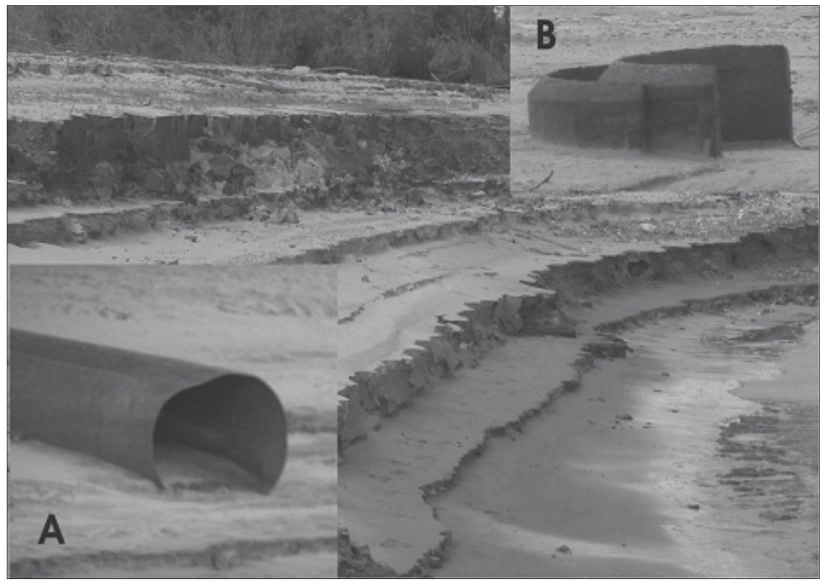

Figure 2: The river bank during summer water lowstand shows exposed part of bottom, which consists from alternating layers of mostly sandy to silty sediments. A- fragment of build pipe by about 1m diameter; B- sinking load on the pipe.

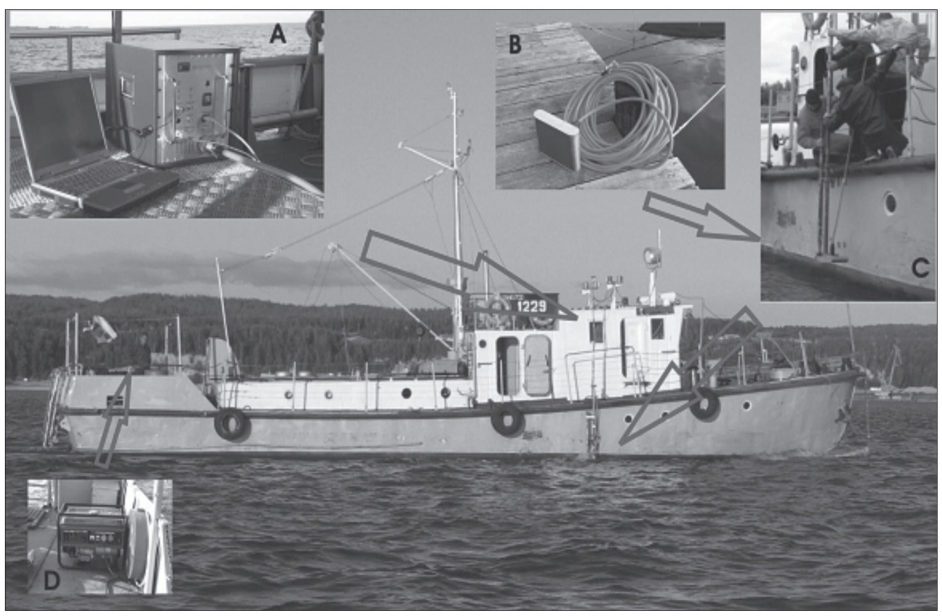

Figure 3: Diving vessel class of "Yaroslavetz". Red arrows show equipment position on board. Parametric sediment echosounder "SES-2000 compact": A- electronic block and notebook; B- transducer. C- installation of the transducer. D- petrol generator for electric power (220V, 50Hz) supply.

Narrow beam parametric echosounder SES-2000 compact

High resolution data of echosounders SES are ensured by narrow beam without side lobs, high frequency range and high pulse repetition rate of sounding signal. Main technical parameters of the used echosounder SES-2000 compact (Figure 3):

- Primary frequency: 100 kHz.
- Secondary frequencies: 5, 6, 8, 10, 12, 15 kHz.
- Beam width: ±1.8° at transducer size of 22cm x 22cm.
- Electrical pulse power: > 12 kW.
- Pulse width: 66µs up to 500 µs.
- Pulse repetition rate: up to 50 pulses per second.

- Water depth range: 1m – 400m.
- Operating range: 5m – 200 m.
- Penetration: up to 40m, depends on sediment.
- Layer (vertical) resolution: down to 5cm.
- Accuracy 100 kHz: 0.02m + 0.02% of depth.
- Accuracy 10 kHz: 0.04m + 0.02% of depth.

Methods

The 2005 survey over the Ob River underwater pipelines was conducted on board of diving vessel class of "Yaroslavetz" (Figure 3). All electronic equipment (Figure 3A) was installed in pilot cabin. The SES transducer (Figure 3B) was mounted on the side of the vessel using light metal pipe (Figure 3C) at a depth of 60cm. Petrol generator "Yamaha" by 3kVA output (Figure 3D) was used for electric power (220V, 50Hz) supply. Accurate positioning of the vessel was guaranteed by onboard differential GPS. Average speed of the vessel ranged from 14km/h (with stream) to 9km/h (against). Innomar's software tool ISE provides near real-time post-processing of the collected SES data and operation procedure could be corrected on-line. Several test profiles were surveyed to find the best system settings, first of all the adjustable low frequency. Acoustical signal by 8kHz and 2 pulses (signal length 250 µs) ensured best vertical resolution 10–15cm at acceptable penetration up to 5m. Oper-ating range by 6-8m depth was chosen to receive highest pulse repetition rate up to 30–40s^{-1}, hence excellent horizontal resolution. Bathymetry maps were compiled from collected primary (100kHz) frequency SES data, assuming average sound velocity of 1450m/s (Figure 4).

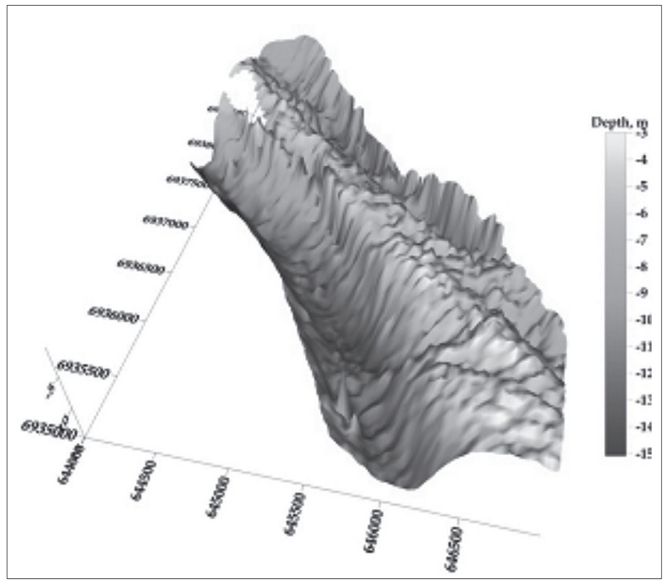

Figure 4: 3D Bottom topography of the survey area compiled from the collected high primary frequency SES data.

Results: detection of gas pipelines with parametric echosounder ses

Underwater pipes produce echoes in sub-bottom profiler's records in the form of typical diffraction hyperbolas (Kalinin et al., 1999; Wille, 2005). The SES survey over underwater gas pipelines across the Ob River revealed all free spans both hung in water column (Figure 5) and exposed on river's bottom (Figure 6) very reliably. Their height above the bottom is measured to within few centimeters.

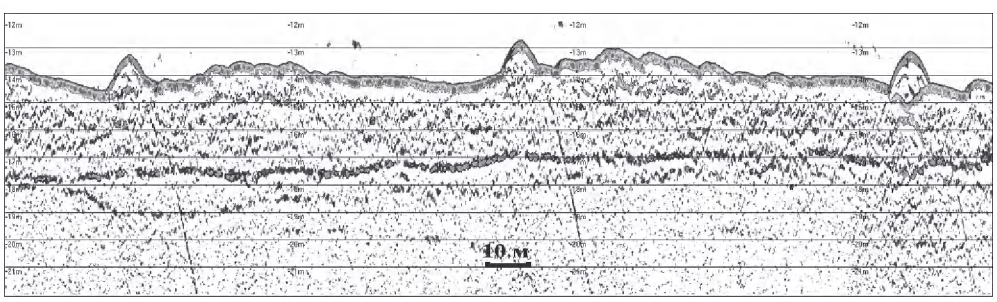

Figure 5: The Ob River, underwater gas pipelines within water column. Pipeline crossings. "SES-2000 compact" image.

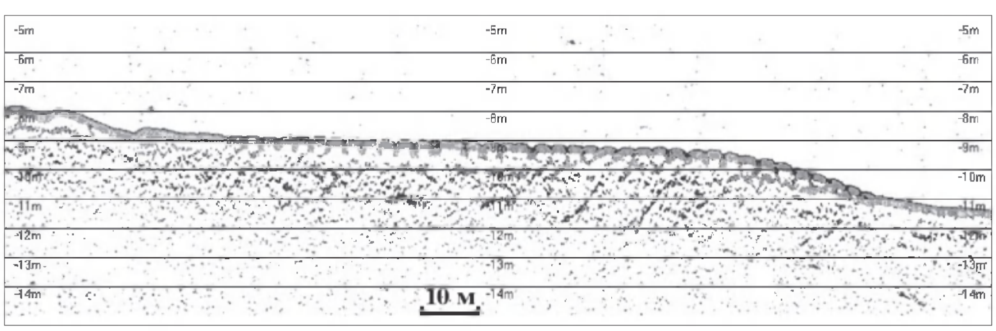

Figure 6: The Ob River, underwater gas pipeline on the river's bottom. Pipeline alongside. "SES-2000 compact" image. The distinct visible segmentation is caused by the sinking loads showed in Figure 2B.

Detection of buried pipes is difficult depending on bottom conditions: its topography, lithological and physical properties of bottom sediments and their structure. Besides, generation of present pattern of the river bottom was affected by anthropogenic activities. Deep trenches were dredged here first and pipes were laid inside then. These trenches filled up with soil are seen distinctly on the SES echoprints (Figure 7, 8). Gravels and large stones as well as strong artificial objects are scattered over their top for protection from erosion by currents. Such protection methods for underwater pipelines as fixing and burying them by casting shiploads of stones are usually applied everywhere (Wille, 2005). Unfortunately, the protective loadings could prevent from penetration of high frequency acoustic signals beneath and visible strong hyperbolic reflections seem to be generated sometimes by these hard heterogeneities but not by buried pipes themselves. In other places, one can see some parts of the trench but not the pipe inside.

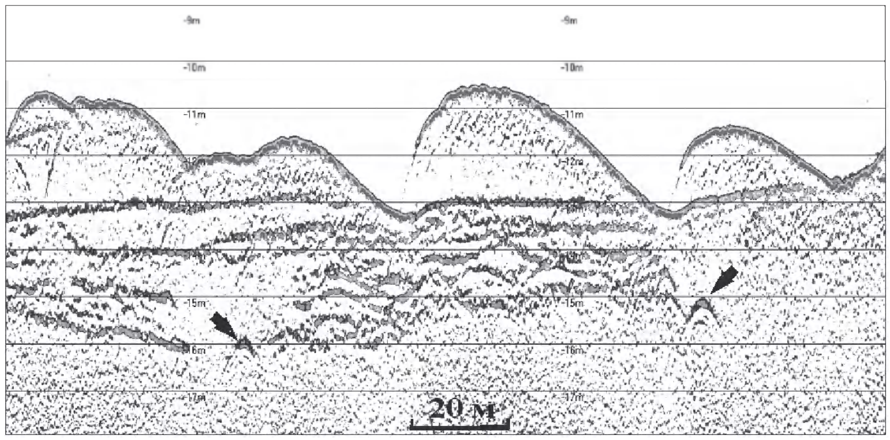

Figure 7: The Ob River buried underwater gas pipelines crossing.

In general, three natural morphological zones were distinguished in the Ob River cross-section: two deep near costal channels separated by shallow bottom zone (so-called "oseredok"). Each of the zones is characterized by individual bottom conditions therefore different capability of signal penetration for detection of buried pipes. The best conditions are near right eastern bank of the river, where bottom consists of soft silty and clayey sands. Buried pipes were revealed there in depth up to 5m beneath the bottom (Figure 7, 8). In two other zones, penetration was limited due to more compact or heterogeneous bottom sediments. Especially poor bottom conditions are over middle shallow zone, where natural erosion and sediments reworking processes are extremely active. Main free spans of the underwater pipelines are observed just here. Several other free spans are observed near eastern bank, particularly within narrow scour of stream which is flowing into the river. Exclusively, unique technical parameters of the narrow beam parametric sub-bottom profiler SES allows to see the small pipe by one meter in diameter in such scours by 5–10m wide and 4–5m deep (Figure 9).

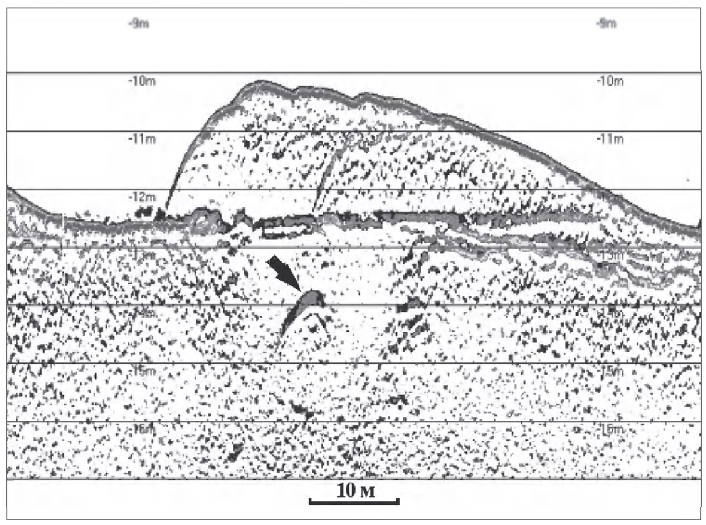

Figure 8: The Ob River buried underwater gas pipeline crossing.

The SES survey distinguished general small-scale local lateral changeability of bottom conditions over this area of underwater gas pipelines across the Ob River. Neighbour pipes closely spacing by 50–60 m are located on sites with absolutely different bottom topography and sediments structure. Therefore, various acoustical techniques would be testing for detection the underwater pipelines. The pipe will be "seen" by linear sub-bottom sediment profilers with wide beam under slant angles already earlier and still later indicated by longer mustache-like tails (Kalinin et al., 1999; Wille, 2005). However, location and depth of buried pipe can be determined from these data quite roughly. The diffraction hyperbola in the narrow beam parametric sub-bottom profiler SES records is very short (Figure 5, 7–9) since the pipe is "seen" very distinct under near vertical angle only, and that secures high accuracy of the determination. SES survey over embedded pipeline in a German lake showed similar results (Wunderlich, Muller, 2003).

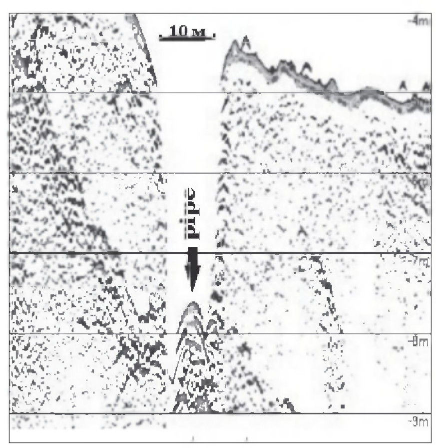

Figure 9: Crossing of the underwater gas pipeline in the narrow bottom scour.

The collected SES data over the Ob River could be very important for scientific researches of topography-forming and sedimentological processes and the subaqueous flow-transverse bedforms in rivers and especially in the Ob River. Most interesting could be migrating subaqueous dunes up to 1–2m high, their morphology and inner structure are seen very detailed on the SES records (Figure 7, 8). Usually, the records of the side-scan sonar and the echo sounder are used for determination of the dunes parameters (e.g., Francken et al., 2004). However they show pattern of current bottom topography only. These data do not make clear former features in bottom sediments, which document history of the paleoenvironments' development. Therefore, the side-scan sonar and echo sounder records could be supplemented essentially with the SES data showed distinctly structure of the bottom sediments. Besides water depth, current velocity and sediment composition are the main factors, which control the dunes' development. Therefore, the studies should be multidisciplinary including high resolution seismic survey as well as sediments coring and current measurement. Sites for the coring and measurement could be selected from the very detailed SES data. The data allow study anthropogenic influence on channel processes that is important for projection of any underwater engineering constructions. Prediction of the after-effects due to anthropogenic intervention in natural regime of the river can be modeling only and knowledge of topography-forming and sedimentological processes and migrating subaqueous flow-transverse bedforms is essential. Just bottom sediments dynamics is most difficult and least studied problem.

In general, the first results of the SES survey, 2005 on the Ob River evidence high effectiveness and usefulness of this parametric sub-bottom profiler for engineering monitoring of underwater gas pipelines. In our opinion now, the high resolution narrow beam parametric echosounder SES seems to be the best among all sub-bottom profilers for such work.

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Transformation Of Water Conditions Of The South Baltic Accumulation Coast

Caused By The Sediment Of The Young River Delta In The Environment Of Variable Human Pressure

Sylwia Magierska and
Roman Cieśliński

The work presents the results of researches made on the transformation of water conditions caused by the sediments of the young river delta. (Reda) as an effect of changing antophopressure. The Reda River with drainage area of 485,2km^2 and average annual discharge of 7,3 m3/s flows into Puck Bay (Gdańsk Bay, The South Baltic Sea). At the mouth of the Reda river there is delta, which in the last years has undergone significant changes as a result of the varying human pressure. This work aims to reconstruct the changes on the area of young, still sediment delta, which is the subject to changes and increasing influence of human activity. In the reconstruction of the above-mentioned changes the researchers used information technology integrating and analyzing the spatial information. The following image-data have been collected and analyzed: air data, data from archival topographic maps, DTN, soil maps, data about deployment of habitat fauna and flora and data obtained for hydro- chemical research. Registered phenomena have been analyzed in quantitative mode with the help of applicable models and algorithms used together with geographical information systems (GIS). Such systems enable to analyze any spatial data conditioned to numeral form and shaped in automatic mode. As a result of comparative analysis the changes, which generally are the result of delta natural development i.e. transformation of a principal tributary, lagoon formation and its destruction (eroding of the old delta by sea current) have been registered. Substantiated was also the transformation connected with human activity: land improvement, agriculture, polders, formation of past production dump and achievements connected with the protection of fauna and flora species.

Introduction

The research on the transformation of water conditions on the area of the Southern Baltic coast have been conducted since the 70's. The research works are restricted to the area of large old river delta (the Vistula), the small young river delta (the Reda), the estuary mouth of river from postglacial lake district, coastal lakes (Jamno, Druzno, Gardno) and wetland. The results of this research indicate that besides the transformation caused by natural processes which is the result of interaction between marine and land environments, also very important is the changes of pressure of human activity.

The work presents the results of research made on the transformation of water conditions caused by the sediments of the young river delta (the Reda), as effect of the antropho - pressure changes.

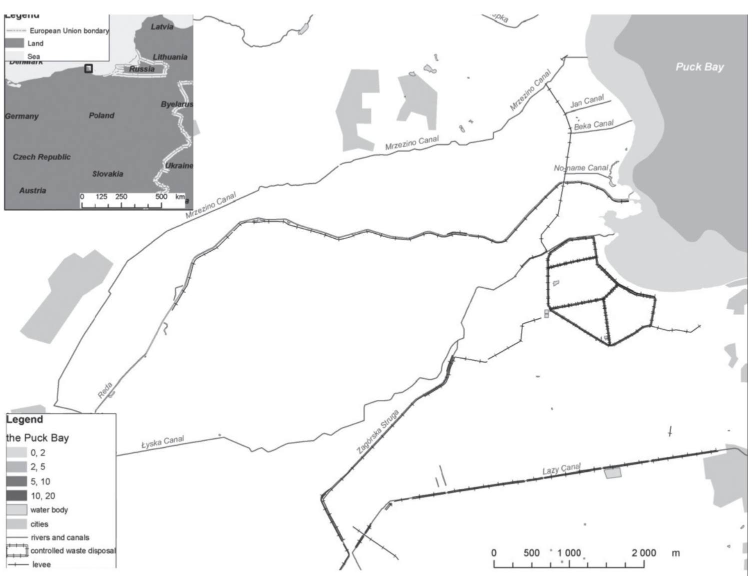

Figure 1: Localization area of the study

The Reda River with drainage area of 485,2km^2 and average annual discharge of 7,3m^3/s flows into Puck Bay (Gdańsk Bay, The South Baltic Sea). At the mouth of the Reda river there is delta, which through the past years has undergone significant changes as a result of the varying human pressure. The Reda is flowing across the postglacial stream valley Reda - Łeba, which was formed about 10 000 years ago by the waters of melting glacial ice. Near the mouth of Reda, one part of the valley - Kaszubian Meanderraises increases about a few meters over the sea level. From the north and from the south of this part are postglacial plateaus, which are raising 50 meters above the sea level. The riverbed is artificially modified and embanked in some places, but the mouth and its surroundings are still of natural character. The area, which has remained in a natural form, is very boggy in some places. The ground raises over the average

sea level, for about several centimeters. During the spring and autumn storms, the area near the mouth of the river is swamped by the salt sea water. Usually swamping of this area lasts from late autumn till March or April. At this time the saltwater infiltrates the sand ground and makes it salty. A large part of the area near the mouth of the Reda river is covered by the rushes of reed and by the salted meadow, where the high sedges dominate. Since 1978 these areas have been protected as a part of The Seaside Landscape Park and in 1988 "Beka" reserve has been established in this place.
This work aims to reconstruct the changes on the area of young still sedimentation delta, which is the subject of changes and increasing influence of human activity (Figure1). The area is a representative of the low accumulation coast of the South Baltic Sea.

Methods

The hydrographical interpretation as the basic method in this research has been used. This method depends on origin materials analysis with regard to the mutual relations of the particular hydrographical elements (Fac-Beneda 2005). The cartographical materials interpretation, teledetection imagery receiving and interpretation and non - geographical materials interpretation include in this method.
The integrated different technique has been used in research. It can be used in hydrographical interpretation of river sediment areas, fare well (Berendsen H.J.A., Stouthamer E,2000).
In this interpretation ArcGIS 9.1, as a GIS (Geographic Information System), tool has been used (education license for Department of Hydrology University of Gdańsk). This modernity tool enabled the origin material precision analysis and the result presenting.

In the reconstruction of the above-mentioned changes the researchers used information technology integrating and analyzing the spatial information. The following image-data have been collected and analyzed: air data, satellite images, data from archival topographic maps, DTN, soil maps, data about deployment of habitat fauna and flora and data obtained for hydrochemical research. Registered phenomena have been analyzed in quantitative mode with the help of applicable models and algorithms used together with geographical information systems (GIS). Such systems enable to analyze any spatial data conditioned to numeral form and shaped in automatic mode.

The archival cartographic materials descended from XVI and XVIII century, as well as contemporary multi-scale cartographic materials from XIX and XX century and descriptive material have been analyzed from the point of view of hydrological transformation. Sequences of air-photos from the years 1947 - 1997 and satellite images from 2006 have been investigated, as well (Figure 2). The researchers received the set of images presenting the state of water conditions on each stage of development.

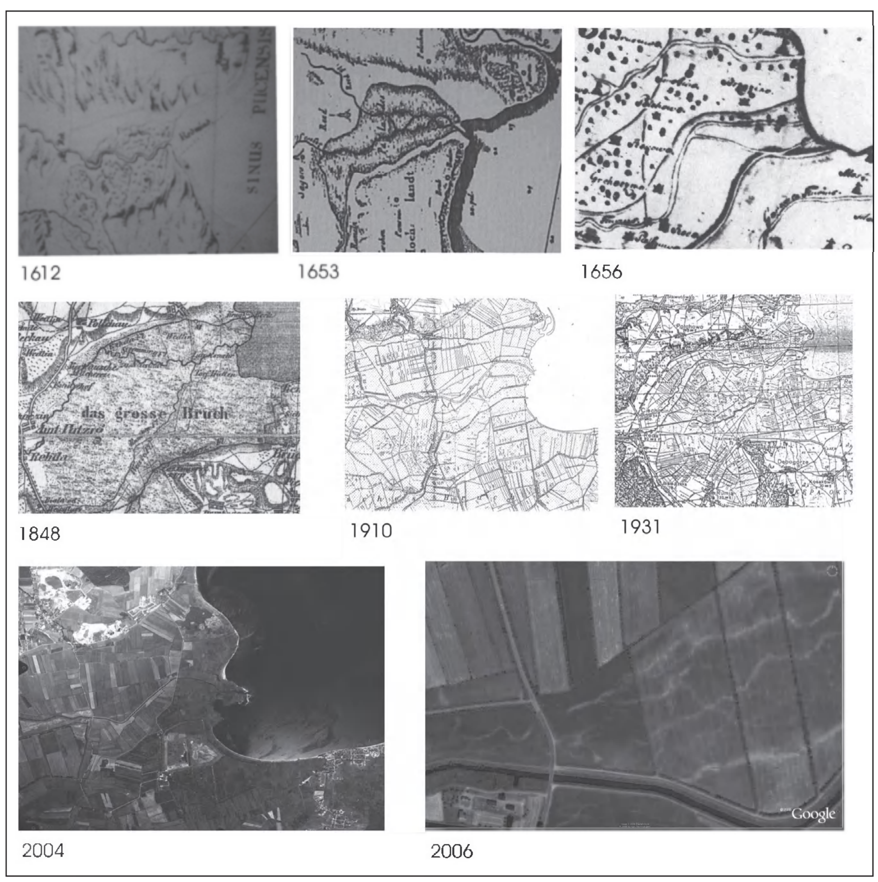

Figure 2: Fragments of origin materials

From XVI century to present map interpretation

In aim to reconstruction present water conditions situation was used the topographical maps, scale 1:10 000. It was scanned and rectified to WGS 84 projection (in force in Europe). The maps are as basic maps for digitalizing hydrographical object and its are the origin to nomenclature.

The archival maps was rectify to present maps - basic maps. In result of it, digitalisation the whole of map content elements can be possible. The same conduct can be funded in other researchers (Kijowski A., 1977, Jankowska M., 1996, Berendsen H.J.A., Stouthamer E,2000).

On basic cartographical materials it has been observed, the Reda river (Rheda) and the Zagórska Struga/ Zagórzanka river (Sagors) in the past was perform the main role in delta hydrographical development (Figure 4). Every of its was fulfil of ages space. The maps from 1796-1802, 1848 have been noticed the time of first human samples interference in natural delta ecosystem. The first meliorate ditches in this area on basic of this data have been reconstructed. Its course was continue to our times. The first paces of peat extraction (Torf Hutting) was organized there. The period 1920-1930, it was the time of next meliorate works and the Reda river water redirect from it main northern river bed to other south one (Strzemień). In 1950-1960 years the protective dike was created. It course was built on the course of past way. The Reda river regulation, land melioration and a lot of hydro - technique objects was realized (sills, weirs, culverts, bridges etc).

The 1960-1970 it was a period, when the industrial dump built began. This area was completely cut off from past water circulation, and it has been created own system.

The cartographical materials (1848-2005) analyse can reconstruct many shore forms and it dynamics. The coastal changes was related to The Reda streamflow. At time, when the main of Reda distributary was on north, the cone was developed in this place. The regulation the Reda bed into south was influenced on this cone erosion and new one creations. In the 30's, accumulation in mouth of Kanał Lyski began. Present it is the mouth of the Zagórska Struga.

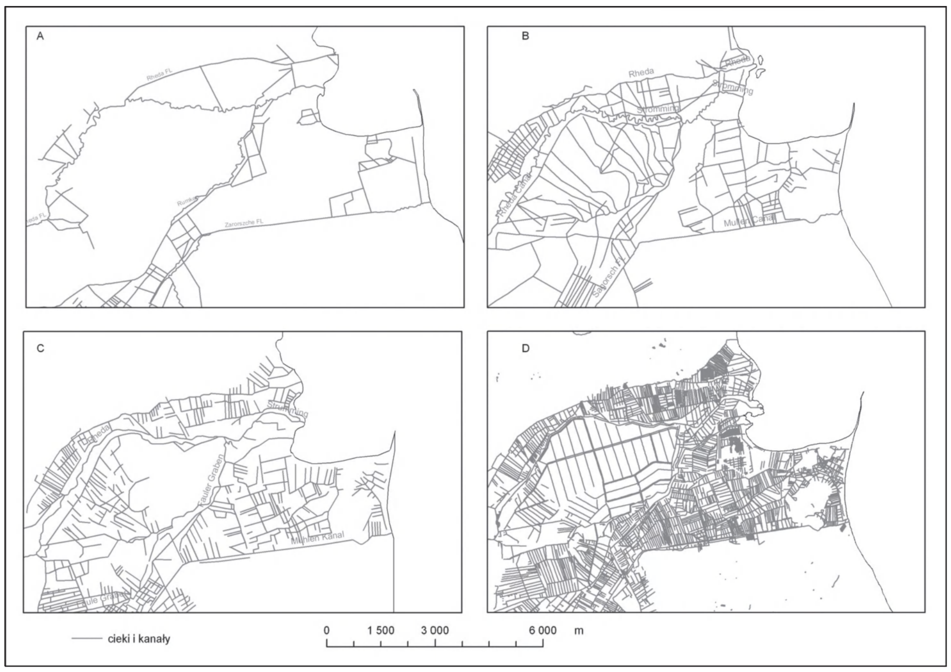

Figure 3: The development of delta hydrographical network A - 1848 y, B - 1910 y, C - 1931 y, D - 2002 y

Remote sensing materials interpretation

The air photos and satellite images in aim of old situation identification, which was remain in surface sediments, has been used. The information, which was interpretation from satellite images can reconstructed water conditions. There are the information about a area evolution, before the human was use the cartographical method.

Air - photos and satellite images compose material, it thanks which it was it been possible present geographical phenomena interpretation and "old view" reconstruct, which is "writing" in surface deposits (Tarnowska M., 1975, Furmańczyk K., Musielak S. 1975, Białousz S., 1977, Trafas K., 1977).

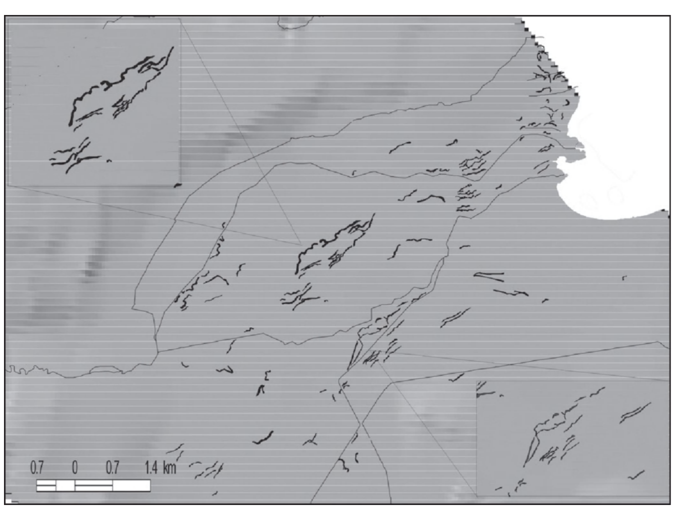

Figure 4: The interpretation of paleo riverbed.

The satellite images importing in maximal scale was rectified to basic maps. The whole material was put to the test under the filters of transformation of colours. Those receiving images are more expressive to interpretation.

Descriptive data interpretation

The materials, which confirmed data from other interpretations are hypsographical and archaeological publications. Its concern human activity in actual and past time. Practically all the archaeological discovers in-site are syngenetic to river activity. Because every water-course leave in landscape own mark for a long time (Louwe Kooijmans, 1974).

The first information about colonization in this place telling about the early iron age (650 - 500 b.p) - after Łużycka culture followed East - Pomeranian. The human from this age created the small settlements, especially at river valley. The next development stages was about decline old and new age i.e. at Wielbarska culture time. At this time colonisations was move in the Sea direction. It has been confirmed by village concentration from the Rumia to the Gdynia. The early - mediaeval colonisation (XVII - XII) was concentrate along the Reda river and at the seaside (Treder 1981). The first open and defensive villages was appeared along the Reda river e.g. Ciechocino, Pieleszewo, Reda. The XVI and XVII age it was the period of intensive wetland drainage and stump pulling. The result of this activity was a development in numbers of farms. Treder (1977) noticed development of colonisations, as follows - Figure 5.

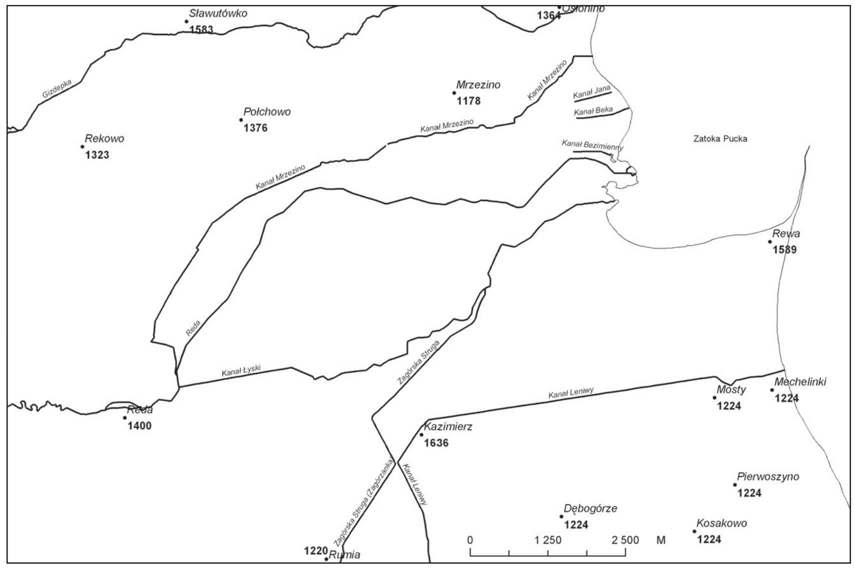

Figure 5: The colonisations development at The Reda delta plane.

Conclusion

The present water condition form of the accumulated river areas are the view of its changes in evolution time. That means for the natural sedimentation to the realization of different using strategy at new land surface. The retrospective tracing of the water conditions delta changes it makes possible, so indirectly the qualification of state of whole geographical environment on individual stages it development (Drwal, J 2001)

As a result of comparative analysis the changes, which generally are the result of delta natural development i.e. transformation of a principal tributary, lagoon formation and its destruction (eroding of the old delta by sea current) have been registered. Substantiated was also the transformation connected with human activity: land improvement, agriculture, polders, formation of past production dump and achievements connected with the protection of fauna and flora species.

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S57-Based Paper Charts Production

By Alexey Pirozhnikov

A modern HO is forced to consider ways of efficiently producing and updating both electronic and paper charts. One way of achieving this is to unify the respective production lines. This paper briefly outlines different approaches that can be used to combine production and maintenance of traditional paper charts and electronic charts. It also offers a deeper insight into dKart Publisher technology aimed at S57-based paper charts production and maintenance.

A Problem

In recent years, a number of relatively new "digital" chart products such as electronic charts (e.g. ENCs, Inland ENCs), thematic charts (e.g. climatic charts, ice charts), military charts (e.g. AML) were introduced to an HO's production routine. This change is supplemented with the requirements for higher quality and greater reliability of produced charts. There is also a constant demand for improvement in updating of cartographic products.

Is it possible to find a practical solution that may help the data producer cope with these problems?

Possible Solutions

It is commonly found that production and maintenance of traditional paper charts (navigational, thematic, military, etc.) and electronic charts (ENCs, AML, etc.) are run in parallel. The main disadvantage of such an approach is that it inevitably implies a doubling of resources, as most operations are duplicated and therefore the risk of data error and inconsistency is increased.

A possible way to improve the situation, saving on costs and gaining in quality, is to introduce a single unified production line. Within this approach a data producer may proceed in various ways, including:

- Produce and maintain electronic charts (ENCs, AML, Inland ENCs, etc.) based on paper charts;
- Produce and maintain paper charts based on electronic charts;
- Produce and maintain both products based on a unified database of source hydrographic information.

Note that the first and second options (electronic charts from Paper Chart and vice versa) may appear quite similar but only at first glance; these differences are quite significant and will be explained further in the article.

Digitizing

Let us begin with the first option that implies digitizing/attribution of paper charts and updating of the resulting electronic charts on the basis of traditional Notices to Mariners.

An obvious advantage of this approach is that it has a minimum impact on the traditional production line. It also helps to create the electronic chart portfolio quickly and inexpensively, so naturally this method has been used for the initial population of the electronic chart portfolio at most HOs. There are, however, significant drawbacks to this method:

- Typically, an electronic chart (e.g. ENC) is more informative than a paper chart, providing additional details taken from nautical publications, for instance, information from List of Lights. Therefore, in order to produce an electronic chart, one is forced to use additional sources of information, which in turn makes consistent updating very complicated;
- Positional accuracy of data derived from paper charts may be not suitable for modern cartographic applications due to various reasons (e.g. data generalization, imprecise positioning);
- Coverage of paper charts and electronic charts differs in general (e.g. in data limits and scales);
- Use of traditional paper-oriented updating routines (e.g. selecting and applying Notices to Mariners issued for paper charts) is not a simple and straightforward task (e.g. due to difference in data limits and content, a change to a paper chart may be not applicable to the relevant electronic chart or vice versa).

Unified Hydrographic Database

Considering the alternatives to digitizing, lets begin with the third option, which implies the use of a so-called "unified hydrographic database". This seems to be the most logical way of achieving consistency between paper and electronic charts. In the "unified" database approach a data producer creates and maintains one database containing all source cartographic features. Products such as electronic charts and paper charts become extracts from this database, matching applicable product specifications. This idea is ingenious in theory, but in practice, does have shortcomings.

The initial problem is creating a "unified" database that will embrace all possible aspects of the cartographic data use, including scale-dependence and generalization of data. Additional problems in the structure of the database and work management arise when the data producer maintains multiple formats and chart series (e.g. national and international charts).

In addition, if electronic and paper chart production lines already exist in an HO, combining them by introducing a "unified database" will most likely lead to a fundamental restructuring of the HO organization and infrastructure. A more preferable

solution would be to add a new component into one of the existing lines that will allow such a combination without shifting of the existing technology.
It may be concluded that the task of creating a “unified” database is extremely complicated even in theory; practical solutions do not really exist and its implementation would require extensive resources, money and time.

Making Paper Charts out of ENCs

Let us now approach the task from another perspective. In essence, electronic charts and paper charts are two different ways of expressing the same hydrographic reality. The main distinction is the difference in presentation of the cartographic data. To use these facts requires an understanding of the IHO S-57 standard for digital hydrographic data exchange. One of the basic principles and advantages of S-57 is the separation of cartographic data (i.e. information) from its presentation (e.g. for ENCs, S-57 Data Model is used to describe the information content of a chart, while S-52 guides the information display).

The production of paper charts from electronic charts can be described as a “simple” output of electronic chart objects according to “paper chart” presentation rules (e.g. INT1/INT2/M4 or national derivatives). This results in an S57-based approach to paper chart production and maintenance, where the starting point is an existing product, namely the S57 electronic chart (e.g. ENC, AML, Inland ENC).

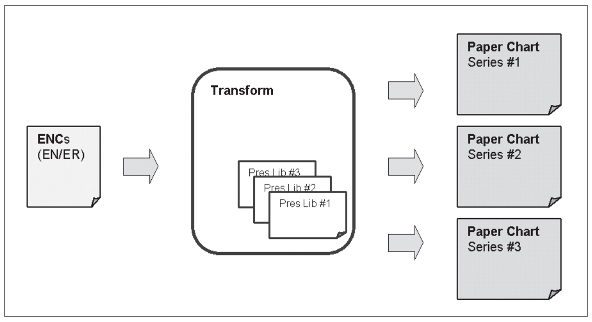

Figure 1: ENC-based paper chart production scheme.

A typical technological chain looks like this:

In this method, when a paper chart is produced and maintained on the basis of electronic charts, it makes the production and maintenance of traditional and electronic charts consistent, overcoming the difficulties of the “unified database” approach:
- Tools can be easily integrated into the existing production infrastructure as “add-on” components;
- The solution is easily expandable (the same electronic chart can be used to produce and maintain multiple paper chart products built according to different presentation rules);
- The solution is practical and necessary tools are already available on the market.

A Scope of Tasks

Let us review the typical tasks that arise in S57-based paper charts production and maintenance. They are:
- The presentation of the same cartographic information (objects) differs between traditional and electronic charts. Therefore one needs an intelligent converter equipped with specially designed libraries of cartographic symbols and line / area patterns.
- Paper and electronic charts may differ in scales, data limits and projections. There is also a growing demand for “Print-on-Demand” (POD) and “Chart-on-Demand” solutions where the end-user defines specifications (limits, scale, etc.) for paper charts.

There is, therefore, a need for automated data transformation/compilation tools.
- A data producer may simultaneously support several chart series that differ in presentation. The presentation may change with time. Its also a common understanding and rule that national specifications define national products, with reference to all the national variants of the INT1 standard.

Therefore both the presentation of paper chart and the transformation routines must be configurable.
- It is not possible to achieve complete automation of ENC to paper chart transformation. Factors such as text placement, smoothing and masking of lines cannot be formalized and therefore are subjects to reviewing and manual editing.

There is, therefore, a requirement for a manual cartographic editing tool.
- A paper chart usually makes use of additional information (e.g. tide tables, notes) provided either as files or as a separate database.

Therefore, there is a need to import information and to process data stored in an external database.
In order to be able to maintain a paper chart using digital updates created for the source ENC(s), the software should be capable of recognizing cartographic elements of a paper chart affected by the digital update (“ER-file”). The most logical solution would be to create a link between paper chart entities and the “parent” ENC object(s) during the transformation and to maintain this link automatically throughout the paper chart lifecycle.

The Result: Digital Paper Chart

Let us now take a look at the result of the operator’s work that is a digital paper chart. A digital paper chart is an electronic chart with defined borders, scale, projection and datum. The content of a paper chart is built in accordance with S-57 Data

Model, having the following implications:
- The information is divided into entities called "objects" ("an identifiable set of information"). An object has attributes that describe its presentational characteristics.
- As in S-57, objects are divided into two groups: paper chart objects (presenting cartographic data just like feature objects in ENC) and spatial objects (providing positional information). A paper chart object (or simply "object") cannot exist on its own, as it is always linked to a spatial object. Design elements, such as chart title, also have underlying geometry defining its placement on a resulting sheet, even though these spatial objects have no "cartographic" meaning. Several objects can be linked to the same spatial object. For example, a light buoy may be encoded as four objects (buoy symbol, topmark symbol, light symbol, light description string) sharing the same node but having different positional attributes (shifts, orientation, etc.).

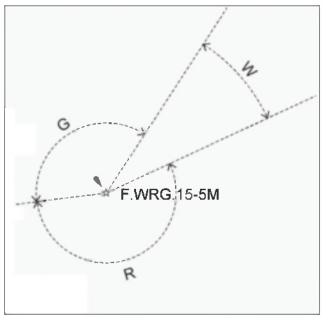

Figure 2: Sample of several objects (buoy, light flare, text strings) sharing one node.

- Each paper chart object belongs to a certain object class in accordance with a "paper chart dictionary". The dictionary includes all typical cartographic elements such as symbols, lines, sectors, images (raster pictures), etc. Additional object classes are introduced in order to link information on a paper chart with source ENC(s) and stipulate combining of different charts/insets on one paper sheet.
- Spatial objects are nodes, edges, lines and areas.

It should be noted that spatial objects define a "flat picture". In order to place objects relative to each other along the Z-axis (e.g. place a text on top of a region), a "priority" attribute may be used; in this way priorities create a layered picture.

It is easy to see that the selected way of storing/handling paper chart contents makes this solution compatible with S-57.

Creating Paper Charts Out Of ENCs

An automatic conversion from an S-57 data model to a digital paper chart will exploit the idea of the S-52 Presentation Library. The Presentation Library is a formal description of rules for cartographic information presentation, designed for and approved by the data producer. It includes symbols, fonts, color tables, patterns, etc. The program reads this library and builds the output according to cartographic rules for paper charts.

In brief, the process of paper chart production from an electronic chart requires the following steps:
- Source ENC(s) are loaded into the program;
- An empty paper chart of required datum, projection, scale and borders is created;
- Guided by the Presentation Library, the automatic conversion starts. During the conversion, the software creates a virtual ENC with borders as of resulting paper chart and contents taken from sources; objects within this virtual ENC are converted to paper chart objects;
- At this point the automatic conversion creates a draft paper chart that is subjected to validation. The operator also performs a final "make-up" of the paper chart that includes fine positioning of text and symbols (where results of automatic conversion are found to be unsuitable), manual or semi-automated masking of lines, adding text, pictures and tables from external sources, positioning insets, frames and other design elements;
- The resulting digital paper chart is saved in a printable file format (e.g. PostScript , PDF , DGN) or exported to a graphic file (e.g. TIFF/GeoTIFF).

Let us now consider some of the technical aspects in more detail.

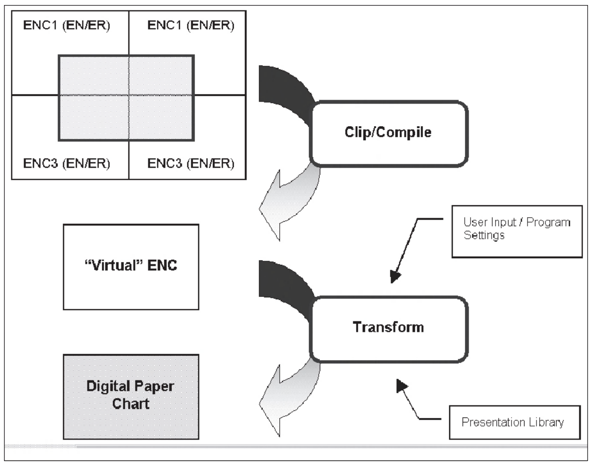

Figure 3: ENC to paper chart transformation layout.

Source Zones

As mentioned before a paper chart can be made from several ENCs, each having its own geodetic parameters and geographic extent, which may even overlap. Before conversion to the resultant chart, a cartographer has to define which part of the paper chart is to be taken from which ENC. To do this, the operator defines special areas ("source zone" regions) and associates them with source materials. This division is maintained and used during the whole life span of the paper chart (e.g., digital updates will be selected depending on source zone configuration etc.).

Transformation Routine

Generally speaking, the transformation routine can be described as follows:
- Source electronic chart(s) are loaded into the program
- An object of the electronic chart (set of logically related objects)

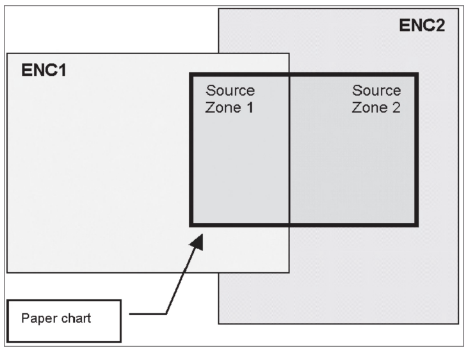

Figure 4: "Source Zone" concept. Note that a source zone is an intersection of the target paper chart and visible part of the source ENC.

is read;
- Presentation Library is loaded and applicable rules are selected;
- Paper chart object(s) are constructed;
- Created objects are placed according to the applicable rules;

At this stage, the program starts from the default object position (i.e. as described in the Presentation Library) and checks if this position is already occupied by another object. If it is, the software searches for another placement rule.
- Automatic testing of the resulting chart is performed and detected problems are rectified.

The transformation routine may be implemented as a Look-Up Table (direct analogue to S-52 presentation in the ENC) additionally enriched with procedural rules handling the complexity of the paper chart presentation (that is, compared to ENC, subjected to far more numerous regulations imposed by international and national standards). Procedural rules may be implemented as separate scripts written in a programming language (e.g. Java).
The important point here is that both the Presentation Libraries and the transformation scripts are "external" to the software and can be easily substituted/modified without re-designing or even re-installing the program thus facilitating the support of different final products (e.g. charts of national and international series, plans, inlets). The same scripting engine can be used to process the data stored in external files or in a database. A trained user might complete all the required customization in-house.

Let us consider an illustrative example.
The program takes a "lighthouse" that is encoded as the following ENC objects grouped into the "master-slave" hierarchy:
- LNDMRK
- 3 x LIGHTS

Having analyzed object classes and attributes the program creates the following paper chart objects:
- lights99 symbol for LNDMRK
- lightdef symbol for the light flare
- 3 different sectors with delimiting bearing lines and text strings indicating respective light colors for LIGHTS
• A light characteristic text string is created (note that the string reflects that more than 1 visibility range exists)
All objects are placed accordingly.

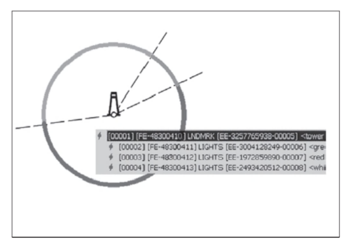

Figure 5-1: "Lighthouse" on ENC.

Cartographic Editing

Being a powerful and sophisticated tool, the automatic transformation may perform up to 90% of work necessary for ENC conversion ("typical" operations). Nevertheless, not all operations can be entirely automated and will still require manual editing.
For this purpose a cartographic editor should be implemented as an integral part of the program. When using the editor, the operator can edit objects either directly on-screen or with the help of precise coordinate input (table).
A typical editing session includes:
- Placement of complex text;
- Editing lines and symbols to avoid clutter in complex cases;
- Chart title, tables and picture placement;
- Combination of insets on one paper sheet;
- Frames, text outside the chart border, printing marks;
- Pre-print quality control.

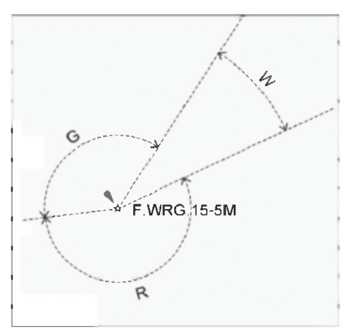

Figure 5-2: Result of automatic conversion.

Editing operations may be enriched with script-based tools that automate line masking, creation of flaps/continuations, frames and various design elements (e.g. compass roses, tide tables, etc.). It is also quite important that when "parent" links are used the operator can always get the necessary information on the ENC object related to the paper chart.
ER-Based Paper Chart Updating
An ENC is updated via digital updates (ER-files). The paper chart should also be updated accordingly. Direct use of digital updates for paper chart updating is the most promising solution ensuring maximum information consistency.
The algorithm for ER-based paper chart updating might be implemented as follows:
- The operator loads an update file(s);

- The software displays a listing of update instructions to the operator (supplemented with the textual Notice message if possible);
- Highlighting an update instruction in the listing automatically highlights affected object/position on the paper chart (this becomes possible since "parent" objects maintained in the paper chart allow linking of paper chart information with source ENC). This automation along with the textual Notice message aid the operator in identifying the affected object(s)/position(s);
- The operator then applies the ER-file instructions. The program automatically (or semi-automatically) updates the paper chart by re-applying the transformation routine only to objects affected by the update; all manual changes previously made by the operator to the "original version" are kept in the modified object.

As practice shows this scenario seems to be quite effective and reliable.

Commercially Available Answer

The approach described in this paper lies beneath the whole idea of the dKart Publisher software developed by HydroService AS. dKart Publisher provides all the proposed functionality for S57-based paper chart production and updating.

The software consist of:

- Intelligent and easily configured converter of S-57 data
- Clip/compile tools allowing the combination of data from several sources (electronic charts) into the single final product
- External, easily configurable presentation libraries
- Support of multiple converters and libraries defined by the end users product specification
- Powerful editing tools supplemented with QC routines
- Import/export facilities

The program can be integrated into any existing infrastructure or deployed as a part of dKart Office solution for a Digital Hydrographic Office.

Several Hydrographic Offices have already practically implemented dKart Publisher with positive results.

Conclusions

Presently a data producer faces a problem of simultaneous production and maintenance of both traditional paper charts and electronic charts (ENCs, Inland ENCs, AML), and therefore has to think about ways of restructuring the production process in order to minimize costs and sustain maximum quality. This can be achieved by the integration of processes into a single technological chain. The S57-based production and updating of paper charts seems to be a promising way of integration, since it achieves the highest quality of data with minimum impact on the existing production infrastructure.

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Biography

Alexey Pirozhnikov has a Ph. D. degree in Computational Physics from St. Petersburg State University, Russia. He has been working for HydroService AS since 1999 and currently holds a position of senior technical consultant.

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Circulation Patterns of South East Sector of the Mediterranean Sea

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An oceanographic survey were taken in the south east sector of the Mediterranean Sea during the period February 1999 to January 2000, covering 16 anchored current stations. From the current moorings, the circulation patterns as well as the wind effect on current system were studied. The maximum current speed was 0.89 m/s occurred in the winter months. The current regime appeared to consist of sustained periods of wind induced, easterly flow, when the dominant wind direction was from the north – west. Periods of consistent westward flow often occurred for several days and coincide with winds from the east, again indicating that the main driving force for the currents is meteorological. During periods of low current speed, diurnal rotation (clockwise) of the current directions was observed. These occurred in between periods of sustained flow when the current speeds tended to be higher. Such characteristics were often prevalent in the months between May 1999 and October 1999. At locations in deeper water the current flow varied throughout the water column, with current speeds often decreasing around mid – depth and then increasing near the bed.

Introduction

The original scope of the work comprised 12 current measurement stations, two wave stations, meteorological and water level station. Besides, conductivity, temperature and depth (CTD) casts at each station were also taken. The duration of the measurement program was from February 1999 to February 2000. Figure 1 shows the locations of the measurement stations in water depths ranging from 8m to 538m. The year long measurement program consisted of 7 scheduled sit visits; mobilization (February 1999), demobilization (February 2000) and five service visits (every two months). During the service visits, each mooring was

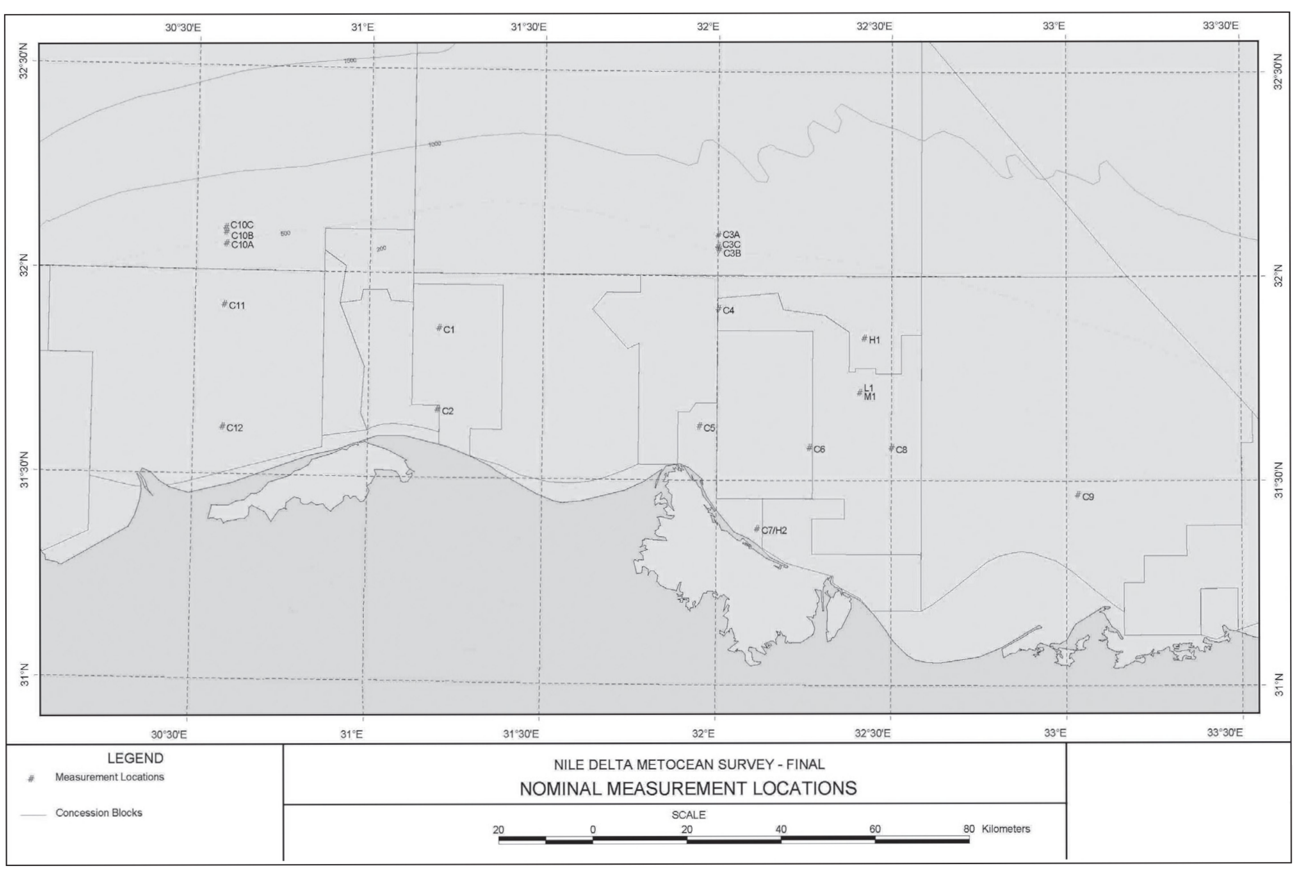

Figure 1: Nominal Measurement Locations.

recovered, inspected, component parts replaced as required and subsequently re – deployed. Current appear to be wind – driven with maximum events occurring near surface at times of increased wind speed. Consequently the currents were strongest in the winter months with the main current events occurring in January 2000.

Wave height was relatively low during the summer months (Hmo generally less than 2m) and higher during the winter (Hmo often exceeding 2m). The water column was well mixed at locations in shallow water depths. A seasonal thermohaline was observed at approximately 30 water depth at offshore locations.

Current speed and Direction Measurement

Locations C1, C2, C4, C5, C6, C7, C8, C9, C11 and C12 each comprised a self-contained RDI Workhorse Acoustic Doppler Current Profiler configured in upward-looking mode to measure current speed and direction throughout the water column. Instruments at C2, C5, C6, C7, C8 and C12 were deployed in trawl-proof frames approximately 0.4m above the seabed. Instruments at Locations C1, C4, C9 and C11 were contained in specially designed trawl-proof floats nominally 4m above the seabed. Locations C3 and C10 were situated in deeper water and each comprised a self-contained RDI Broadband Acoustic Doppler Current Profiler configured in upward-looking mode, approximately 160m above the seabed. In addition, two Aanderaa RCM current meters were suspended below the ADCPs to provide current measurements at 5m/15m and approximately 95m above the seabed. Mooring C10C comprised a self-contained RDI Workhorse ADCP 500m above the seabed, with three Aanderaa RCMs suspended below it. The mooring configuration is shown in Figure 2. All current meters recorded data at 10-minute intervals. The moorings were recovered by means of a Sonardyne acoustic release. Data were downloaded at each service visit and preliminary quality control of the data performed to check that the instrument was functioning correctly prior to re-deployment.

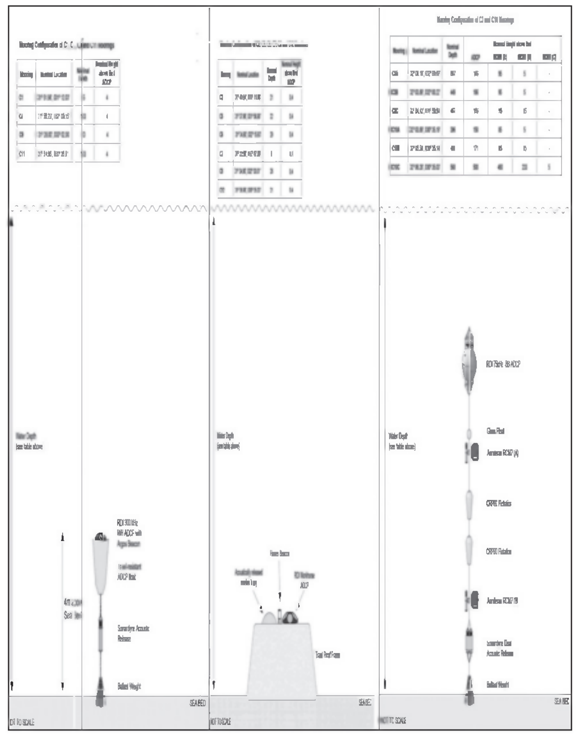

Figure 2: Mooring configurations.

Current Patterns In front of the Egyptian Mediterranean Coast

The current velocity during this survey reached a maximum value of 89cm/sec in the direction 97° recorded at location C9 at 6m below sea surface on 19 January 2000. High current speeds of 87cm/sec recorded at C2 and C7 on 18 and 27 January 2000 respectively. These current speeds in the upper water column of the south east sector of the Egyptian Mediterranean coast occurred during a period of strong wind from the west – north – west, indicating that the current is mainly wind induced. The bottom current regime in that area is quite reasonable during most of the year with values ranging from 20cm/sec (at depth 546m) and 2cm/sec (at depth 233m). The maximum current events occurred in the winter months (end of November to February). The current regime appeared to consist of sustained periods of flow predominately to the east, possibly wind induced during periods when the dominant wind direction was from the north – west. Periods of consistent westward flow often occurred for several days and coincide with winds from the east, again indicating that the main driving force for the current is meteorological.

The current flow at station C1 was mainly along the west – north – west to east – south – east axis with sustained flow over a few days occurring in both directions. Figure 3 shows the seasonally and total current rose and frequency distribution of current speed and direction at C1 (65m) at 07m, 33m, and 57m depth during 1999. The strongest current were toward the east – north – east and east – south – east and over 50% of all current speeds occurred in the east – north – east to south – south – east sector. The current event of 56 cm/sec flowing towards the east occurred on 18 August 1999. Maximum current speeds at locations lower in the water column occurred on 18 January 2000 and ranged from 53 cm/sec to 44 cm/sec through depth.

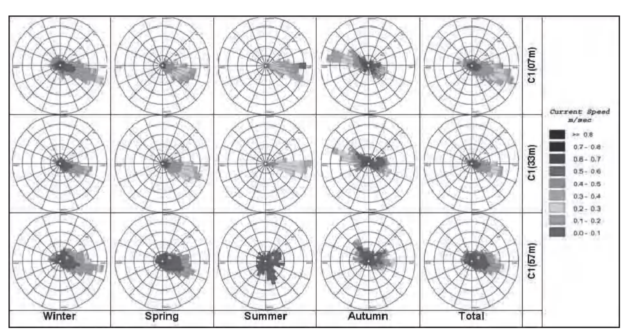

Figure 3, Seasonally and total current rose and frequancy distribution of current speed at C1 (65m) at 0,7m, 33m and 57m depth during 1999

At location C2 the current flow was predominantly towards the east – south – east and current speeds were relatively high compared to those measured at other locations. The strongest current speeds were towards the east – south – east with 50% of all currents observations occurring in the east to east – south – east sector for the upper depth as shown in Figure 4.

The measurements at location C3A, didn't last throughout the year as shown in Figure 5. The current speed at this location was predominantly towards the east – south – east in the upper water column at depths 141m to 237m. At C3B, the measurements didn't extend throughout the year as shown in Figure 6. The current flow at this location varied throughout depth with similar characteristics to these observed at location C3A. At location C3C, measurements covered only the period from 17 August 1999 to 15 February 2000 as shown in Figure 7. The current flow pattern at this location was very similar to that observed at the previous two locations C3A and C3B.

At C4, the maximum current speed is 59 cm/sec occurred on 18 January 2000 at 34m below sea surface during high winds from the west – north – west as shown in Figure 8.

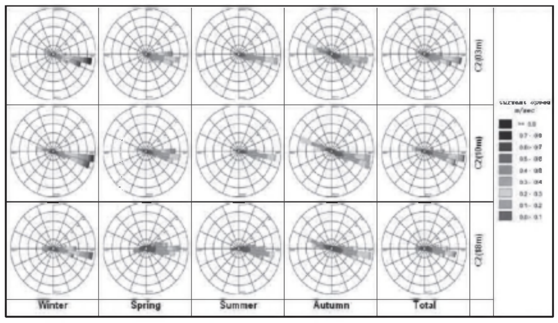

Figure 4: Seasonally and total current rose and frequency distribution of current speed at C2 (21m) at 03m, 10m and 18m depth during 1999.

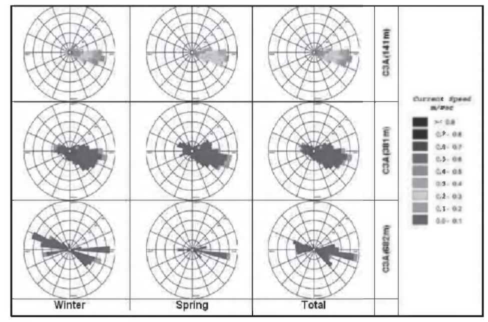

Figure 5: Seasonally and total current rose and frequency distribution of current speed at C3A (687m) at 141m, 381m and 682m depth during 1999.

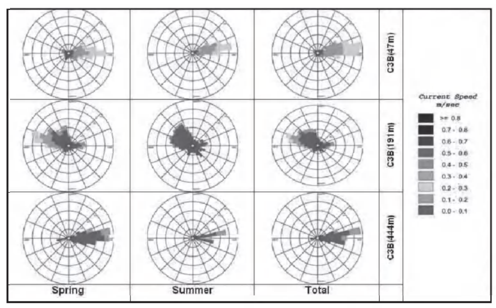

Figure 6: Seasonally and total current rose and frequency distribution of current speed at C3B (449m) at 47m, 191m and 444m depth during 1999.

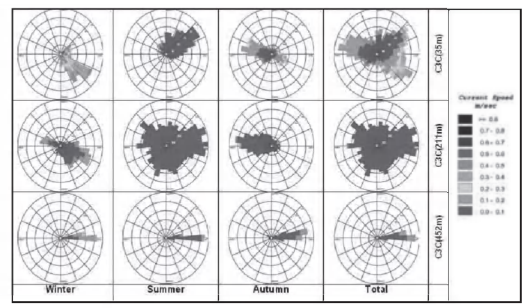

Figure 7: Seasonally and total current rose and frequency distribution of current speed at C3C (467m) at 35m, 211m and 452m depth during 1999.

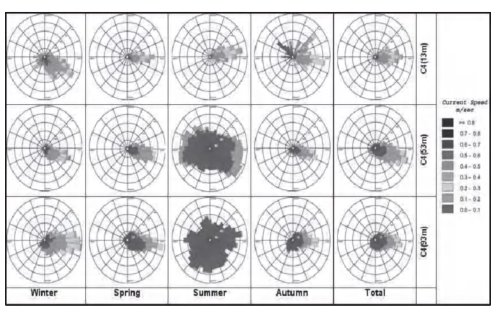

Figure 8: Seasonally and Total Current Rose and Frequency Distribution of Current Speed at C4 (103m) at 13m, 53m and 93m depth during 1999.

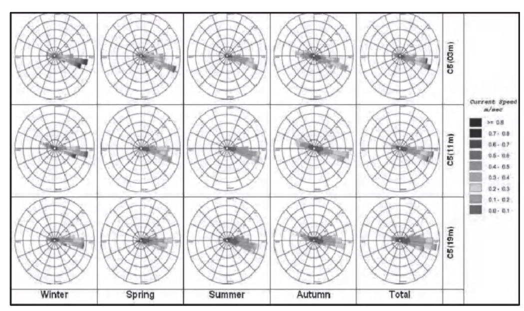

Figure 9: Seasonally and Total Current Rose and Frequency Distribution o Current Speed at C5 (22m) at 03m, 11m and 19m depth during 1999.

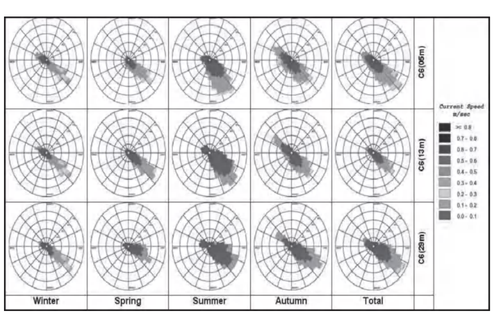

Figure 10: Seasonally and Total Current Rose and Frequency Distribution of Current Speed at C6 (29m) at 05m, 13m and 25m depth during 1999.

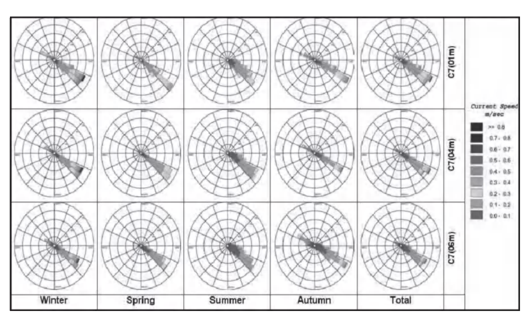

Figure 11: Seasonally and Total Current Rose and Frequency Distribution of Current Speed at C7 (08m) at 01m, 04m and 06m depth during 1999.

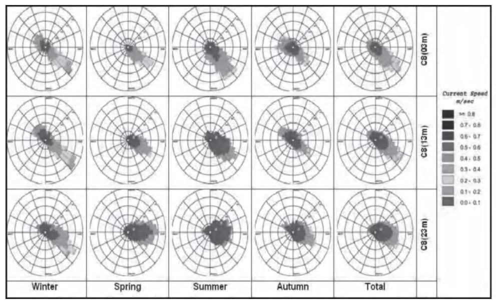

Figure 12: Seasonally and Total Current Rose and Frequency Distribution of Current SPeed at C8 (26m) at 03m, 13m and 23m depth during 1999.

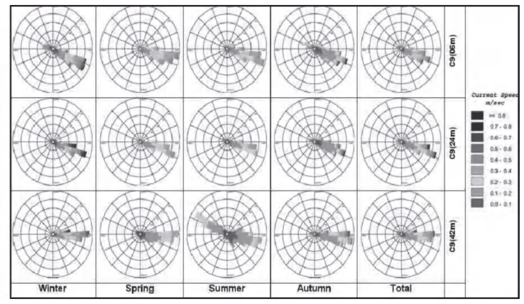

Figure 13: Seasonally and Total Current Rose and Frequency Distribution of Current SPeed at C9 (50m) at 06m, 24m and 42m depth during 1999.

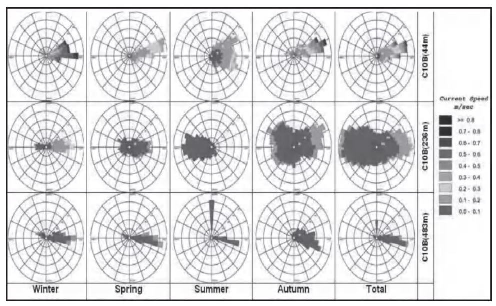

Figure 14: Seasonally and Total Current Rose and Frequency Distribution of Current Speed at C10B (498m) at 44m, 236m and 483m depth during 1999.

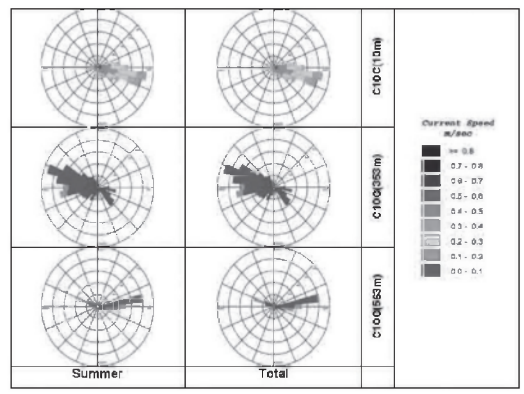

Figure 15: Seasonally and Total Current Rose and Frequency Distribution of Current Speed at C10C (568m) at 10m, 353m and 563m depth during 1999.

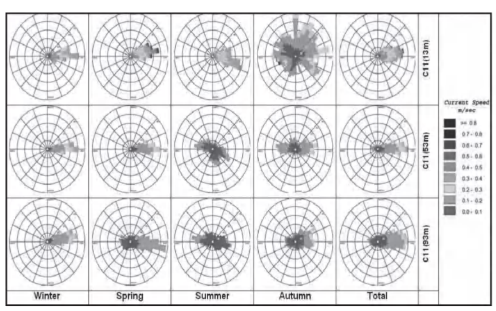

Figure 16: Seasonally and Total Current Rose and Frequency Distribution of Current Speed at C11 (103m) at 13m, 53m and 93m depth during 1999.

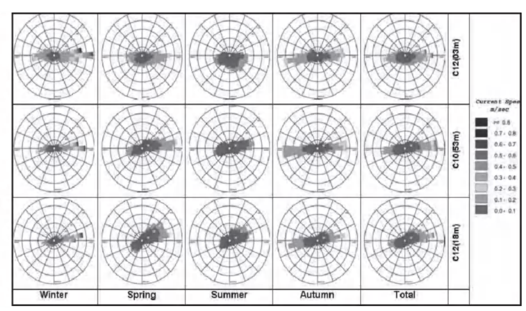

Figure 17: Seasonally and Total Current Rose and Frequency Distribution of Current Speed at C12 (21m) at 03m, 10m and 18m depth during 1999.

At times of maximum current speeds the flow was towards the east – south – east which is related to the wind flow from the north – west.

At station C5, the pattern of the current flow was strongly rectilinear as shown in Figure 9. The axis of current flow was along the east – south – east and west – north – west axes, with 42% and 16% respectively of all current speeds occurring in this sector. The maximum current speed recorded at this station was 82cm/sec on 5 January 2000. The maximum current speed recorded at station C6 was 50cm/sec on 19 January 2000 as shown in Figure 10. The current speed at this location were slightly lower than these recorded at other locations. There was a tendency for the flow to be directed more towards the south – east and north – west with 29% and 14% of all current speeds occurring in these sectors respectively.

At the shallow station C7, the current flow was directed towards the east – south – east and west – north – west with 52% and 13% of all currents speeds occurring in this sector as shown in Figure 11. Higher current speeds were towards the east – south – east with a maximum value of 87cm/sec towards the south – east on January 2000.

At C8, current flow at this station was directed towards the east – south – east and west – north – west with 28% and 11% of all observations contained in this sector respectively as shown in Figure 12. The maximum current speed of 53cm/sec occurred on 5 February 1999.

At station C9, the current speed was relatively high compared to the other locations, with a maximum current of 89cm/sec recorded on 19 January 2000 as shown in Figure 13. The current flow was mainly towards the east – south – east and accounted for up to 54% of all observations.
At station C10B, the measurements didn't extend throughout the year as shown in Figure 14. At C10B, the maximum current speed observed at this location was relatively high (77cm/sec) on 27 January 2000. The overall mean speed ranged from 18 cm/sec (at 45m depth) to 4cm/sec (at 484m depth). At station C10C, the maximum current speed was 44 cm/sec recorded on

6 July 1999 and the mean value for data collection period ranged from 19 cm/sec (at 10m depth) to 4 cm/sec (at 533m depth) as shown in Figure 15.

At location C11, the maximum current speed was 76cm/sec recorded on 29 June 1999 as shown in Figure 16. Mean current speeds ranged from 18cm/sec (at 13m depth) to 9cm/sec (at 93m depth).
At station C12, the maximum current speed is 74 cm/sec recorded on 18 January 2000 as shown in Figure 17. Mean current speeds ranged from 9cm/sec (at 3m depth) to 7cm/sec (at 18m depth).

Discussion

The metocean conditions in the survey region were seasonally influenced with the wind field providing the main forcing mechanism for current and wave regimes. The most dynamic period was in the winter months; most of the maximum wave, current and meteorological results were recorded in January 2000. Waves were predominately from the north-west as a result of wind forcing. However, a few periods of high waves were recorded from the east-north-east. The current regime appeared to consist of sustained periods of wind induced, easterly flow, when the dominant wind direction was from the north-west. Periods of consistent westward flow often occurred for several days and coincided with winds from the east, again indicating that the main driving force for the currents is meteorological. During periods of low current speed, diurnal rotation (clockwise) of the current directions was observed. These occurred in between periods of sustained flow when the current speeds tended to be higher. Such characteristics were often prevalent in the months between May 1999 and October 1999. At locations in deeper water (Locations C3 and C10) the current flow varied throughout the water column, with current speeds often decreasing around mid-depth and then increasing near the bed. A maximum current speed of $0.89ms^{-1}$ towards 104°T was recorded at Location C9, 14m below MSL on 19 January 2000. Overall the current regime was relatively benign during most of the year with mean values ranging from $0.20ms^{-1}$ to $0.02ms^{-1}$ throughout the survey area. Influxes of warm water appeared to result in increases in current speed at certain locations, indicating that other forcing mechanisms (beside the wind) have an influence. In addition, a series of peaks with a periodicity of around 24 hours in the current speed was observed at Location C9. Although the periodicity of these peaks is close to the inertial period at this latitude further work would be required to identify their cause.

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Data Base Centric Work Processes

Dr Dan Sherrill and Ole Berg

Abstract

The potential use of hydrographic information in the holdings of today's HOs extends much further than safety of navigation. The challenge is to continue to supply high quality, safety related information with an increased update rate, simultaneously with making new uses of existing information and establishing requirements for the acquisition and gathering of new data.

Evolving from Product Centric to Data Base Centric Work Processes is a way forward for an organisation that is seeking solutions to increase access to data holdings at the same time coping with an increasing amount of incoming source information and increased demands for higher update rates.

New tools for data analysis might yield new information from already existing data and in turn provide input into the planning of new surveys. A key requirement here is accessibility to information/data not to mention knowledge of the existence of the data.

The way forward to cope without a vast increase in the use of human resources is to change the internal processes in the organisation from the present product centric organisation to data base centric work processes and methods.

As is was

Hydrographic Offices (HOs) were established to provide mariners with the best possible information to ensure safe passage to and from ports. The classic information provision methodology was and is the nautical chart and the supporting nautical publications.

HOs have typically been organized in four main areas:
- Surveying
- Cartographic Production
- Publication Production
- Publishing

Surveying covers all activities at sea and includes post processing. Cartographic and Publication production takes over the post processed data, gathers supplementing information and produces the classic products: the still highly appreciated paper chart and the nautical publications. Publishing covers mass production; sales and marketing and distribution.

The organisation and work processes in the HOs have been tailored to ensure a highly controlled process aiming at publishing updated charts and publications and updating information at regular intervals.

If we focus on the charts, HOs have over time collected far more data and information than have ever been published.

A quick view at a sample post processed survey in form of a fair sheet compiled at 1:20,000 scale compared to the resulting nautical chart compiled at scale 1:50,000 will verify this. See Figure 1. To be borne in mind is that the compiled fair sheet is also a subset of the captured survey data, which is even more data rich. In the chosen example the fair sheet is compiled from a single beam survey

The compilation methodology including generalizations and cartographic editing to reach the end result in 1:50,000 scale has been largely manual.

The classical way leading to the actual updating process of a given chart is often this:
- Incoming information is logged and assigned an archive reference;
- The affected product (s) is physically marked with the geographic extent of the source information and annotated with the archive reference;
- The decisions to update (or not) is noted in the file folder;
- From time to time the individual products are scrutinized to assess if a revised edition is necessary;
- If a revised edition is required, the product materials and all relevant source information is gathered from the archive and the updating process is initiated;
- Similarly, a chart out of stock will initiate the updating process resulting in a revised print.

This is a time honoured system relying on file folders with documents held together by India tags. It is stable, secure and offers traceability. It is, however also slow and cumbersome to operate.

As it is

Much effort has over time been dedicated to improve data collection techniques to a degree where objects the size of an orange can be discerned on the seabed. The speed with which this detailed information can be gathered however, is still mostly linked to the speed of the gathering vessels. As a consequence the areas surveyed with very high accuracy is typically limited to the parts of the continental shelf where the commercial traffic is moving.

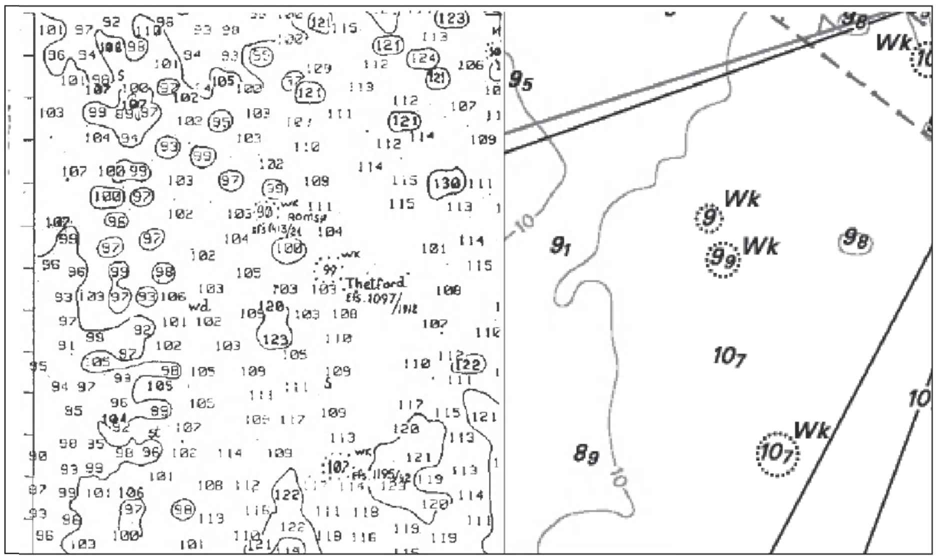

Figure 1: Fairsheet 1:20.000 - Chart 1:50.000.

Figure 2 shows a comparison between the data density in single beam and multi beam survey.

However, the resulting information published in the chart would still be comparable to the example shown in Figure 1 above.

Development in the production has in the past couple of decades been mainly focused on digital production methods. During the same time a new product has been introduced, the electronic navigational chart – or ENC. Electronic or digital chart products come in many shapes and forms, the one of major interest for HOs is the ENC as specified in the Product Specification in the S57 standard of the International Hydrographic Organisation (IHO).

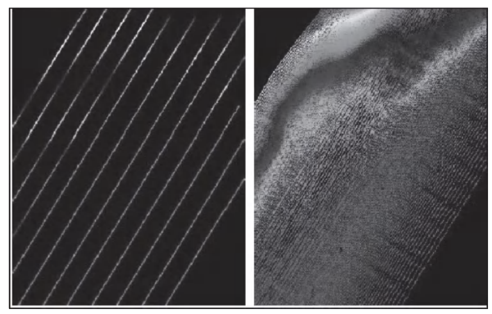

Figure 2: Comparison between data density in single beam and multi beam surveys.

The current situation for many HOs is still that the ENC is an added product to the collection to be updated and published. Most often the content of an ENC is sourced directly from the paper chart with some variations e.g. many HOs hold information on fixed and floating aids to navigation in separate registers or data bases and source the digital production of paper charts and the ENCs from the same data base.

The information on the seabed topography in most cases comes from the paper charts; even though higher density information can be easily accommodated in the ENC. Notably exceptions are amongst few others:

- Norwegian Hydrographic Office (NHS), which is carrying out a systematic resurvey of the entire coastal waters. The results are newly compiled paper charts and ENCs compiled from source data. Whilst produced in parallel the contents differ with the ENC as the most data rich.
- Australian Hydrographic Office (AHO), which is producing ENCs with higher depth contour density for particular important sea lanes.

In many cases the organisational structure and the work processes used in the updating process remains unaltered from the description at the end of the previous section – the only difference is that the information is now held and handled in digital form – or put another way, the well established work processes have been digitized.

Many HOs are experiencing an increased demand for access to their source data, in particular the bathymetry. The demand is mostly coming from other government agencies and academia but the knowledge of the products offered by NHS and AHO will spread to wider user circles probably sooner rather than later.

The pressure on HOs to provide access to their information is bound to increase. A number of possible courses of actions exist e.g.:

- Allowing private companies access to source information for generation of further customer specific products;
- Increasing the number of products published by themselves;

- Subcontracting private companies to produce and maintain products on their behalf; and,
- Probably numerous other variants and combinations.

Depending on the status of the published products and the liability concerns the HO will be more or less involved and this will lead to a requirement for increased productivity if this is to be achieved with the same quality standards and maintaining staffing levels. The latter is likely to be a firm requirement as Increase in public staffing levels appears to be very unpopular from a political perspective around the world.

How it could be

In order to achieve increased productivity and expand diversity of products published; productions tools and production processes needs to be examined.

The goal of the required re-engineering of the production is illustrated in Figure 3.

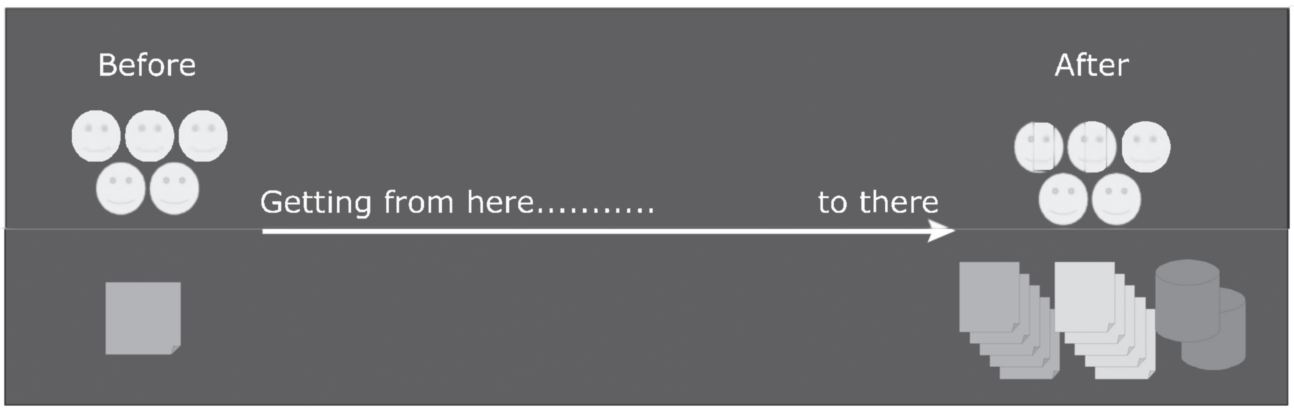

Figure 3: Production re-engineering goal.

If this goal is to be achieved and the quality standards maintained in order to ensure a continuous supply of up-to-date, high quality products and also supply incremental updating information, it is worth while to examine the procedures and processes used in potential high risk operations, for example operating aircraft and submarines.

In aircraft and submarines the crew are meticulously trained to hurry slowly. This is done through procedures established by careful examination of best practices, developing operational procedures for all actions to be taken and ensuring that procedures are followed.

One tool to achieve this is practice, practice, practice. Aircraft crews often do this in simulators, where standard and emergency procedures are trained to a level where the air crew will react to a given situation in a specific way utilizing the same mechanisms Pavlov discovered through his experiments with dogs.

The conditional responses are supported through established check lists where relevant. And make no mistake, even a highly experienced air captain with thousands of hours flying time,

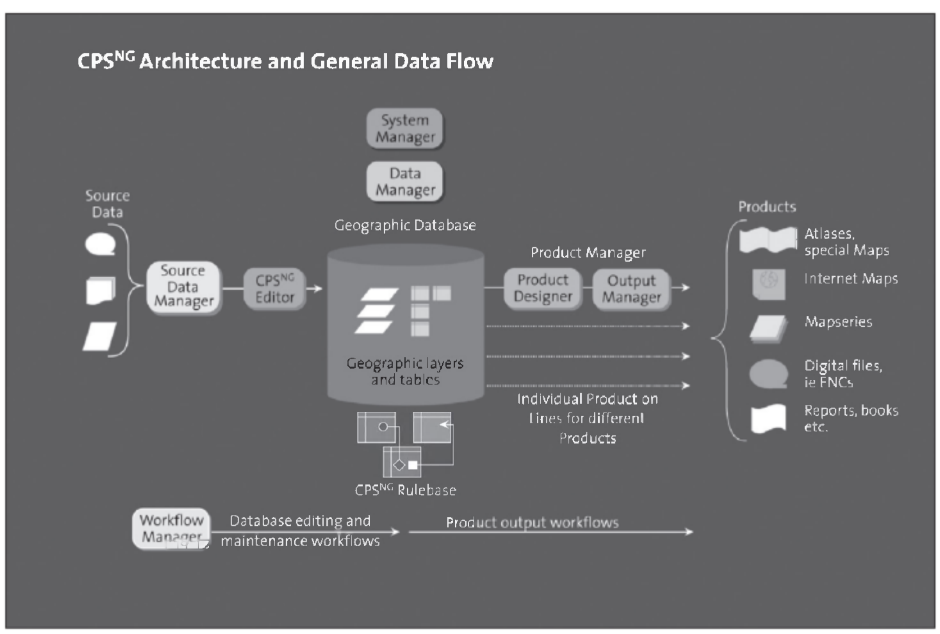

Figure 4: Data Base Centric Architecture and Tools.

does not take off with his aircraft without meticulously completing the prescribed checklists. When you want to do things quickly and safely, discipline and strict adherence to established best practices is the safest route.

It the desired goal: to increase productivity and diversity in offered products, similar processes are to be taken into use combined with the most efficient digital information handling tools available: GIS software, Relational Data Bases and dedicated production tools. In Figure 4 is illustrated a system architecture where the centre for the work processes is the geographic data base.

The geographic data base is structured in layers with different generalizations of the geographic features with geometry and describing attributes, linked together through the scale layers to support end enhance a rational updating process. It is the geographic data, often collected and refined through decades, which contains the true value of the organisation as a result of data collection, data capture efforts and analysis embodying centuries of knowledge.

In many HOs the geographic information is still held in the format of the end product be it digital or on paper. This limits the potential free use of the information as cumbersome processes are often needed to extract and reformat the information to make it fit for the intended use.

To achieve the goal of increased productivity and product diversity, the geographic data base must be structured to hold seamless geographic data open to viewing, analysis and extraction through numerous different applications from web viewing over GIS analysis to specific product generation. A key to achieving this is to separate product specific information from the geographic features to the largest possible extent. This is illustrated in Figure 4 through the Rule Base, which is data base tables held in a table structure separate from but linked to the geographic features.

The Rule Base contains all information necessary to enable 100 % automatic product output in the final format for end use. This includes things like symbology, data models, datum and projection parameters etc. In addition the Rule Base is the repository for all information necessary to manage system, data base, user access work flows etc. As such the Rule Base functions as the organisational memory of the organisation. Figure 5 below illustrates how different organisational roles can be defined and managed with individual access rights to the various system components

All work processes are governed by workflows, (comparable to advanced checklists) which provide access to centrally maintained work process descriptions in addition to the stepwise guide through the work processes associated with the individual tasks.

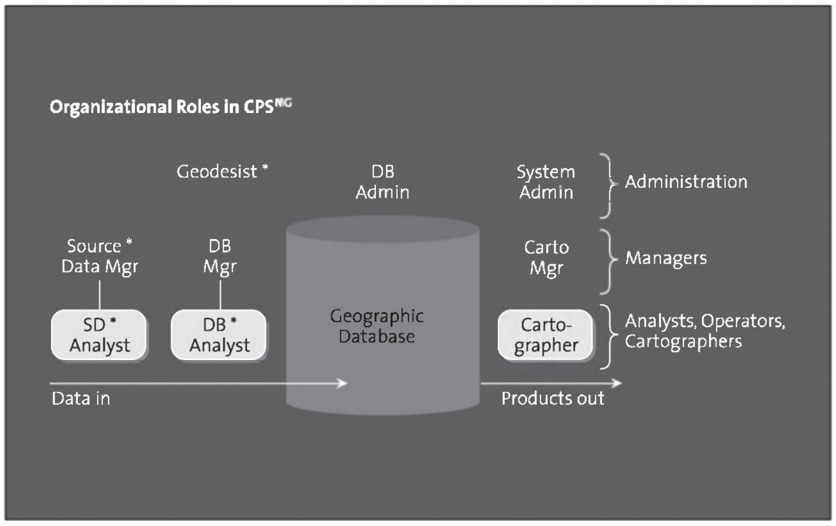

Figure 5: Organizational Roles in a Data Base Centric System.

The paramount difference between the Data Base Centric Work Processes and the classical updating work processes described in the previous sections is that the processes on the left hand side of the geographic data base (Source Data Management and data base editing) runs continuously. The Work processes on the right hand side of the geographic data base (Product Specification and product Output) run on demand and completely independently from the updating processes.

To achieve 100% automation in product output, a data base updating sequence needs to address generalisation through scale layers and cartographic placement decisions for affected products in one updating and QC loop. This is to achieve a situation where an individual data component is handled the absolute minimum of times. This can be compared to two different ways of handling physical products in a warehouse:

- Method one: First all items to be replaced are removed from the shelves and put on the floor. Then the items are picked up from the floor and put on a cart. Then new items are put on the shelves. Finally the supervisor checks that the right items are in the right positions.
- Method two: First Items to be replaced are removed from the shelves and put on a cart. Then new items are put on the shelves. Finally the supervisor checks that the right items are in the right positions.

Method two achieves the same result as method one but has one job step less than method one.

The Data Base Centric Work Processes has a huge potential to increase productivity and maintain a high consistent quality. To achieve this all work processes must be carefully scrutinized, reassessed and adjusted to achieve the absolute minimum number of job steps.

Organizationally this can be illustrated this way:

- Classical, hierarchical structure with fixed assignment of resources to the individual organisational elements illustrated in Figure 6 and
- Organic structure with controlled flow of resources between departments following the fluctuations in work load illustrated in Figure 7.

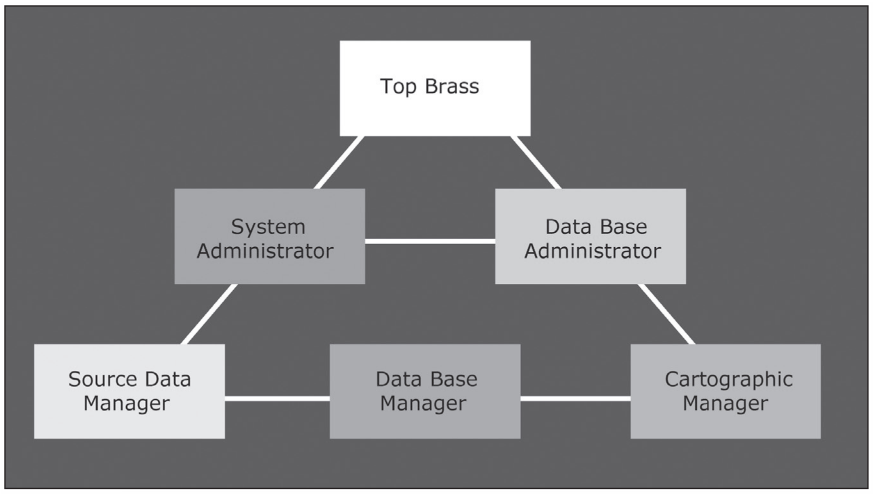

Figure 6: Classical heirarchical structure.

It can be argued that following predefined procedures leaves little room for creativity or individual expression. True to a certain extent, and the trick to maintain the creativity and utilize the ingenuity of human resources is to separate the day to day operations from creative sessions to discuss new products, changes to work practices, improvements etc.

Practical daily experience in a live, large scale production environment shows that Data Base Centric Work Processes are an efficient and rational way to achieve increases in productivity in the order of magnitudes compared to traditional production environments. Additionally the geographic data storages, with a seamless GIS enabled structure are opened up to access from other applications than the dedicated production environment. This means increased flexibility to adjust to future demands, offering increased service levels and product diversity with consistent quality levels.

In order to harvest the multiple benefits from the data base centric approach organisational evolution is essential.

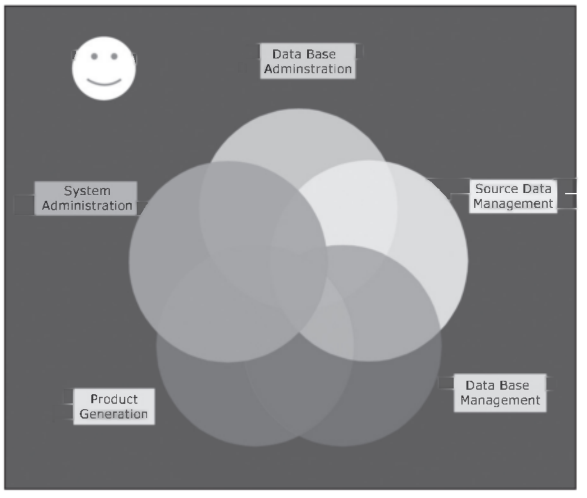

Figure 7: Organic structure.

Biographies

Dr. Dan Sherrill has a PhD in Geography from University of California-Riverside and a MA in Geography from San Diego State University. Dr. Sherrill has over 30 years of experience in earth sciences research applications for geographic information systems (GISs). He worked as senior consultant and program manger for ESRI from 1989 to 2000. He has been involved in the development of database design standards and has worked as a consultant on several international GIS projects. Dr. Sherrill works as Director of software development at T-Kartor Sweden AB and is the driving force behind the development of the database driven Cartographic Production System Software CPS NG.

Ole Berg is a former submarine Commanding Officer in the Royal Danish Navy. For 11 years, he has been Director of the Danish Hydrographic Office (Charting). He has been active in the international co-operation on the development of Electronic Navigational Charts and ECDIS, chairing the IHO CHRIS committee and the Primar Stavanger Advisory Committee. Ole Berg works with sales and marketing of Maritime Solutions at T-Kartor Sweden AB.

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New Advancements In Multibeam Echosounder Technology

B. Volberg and T. Meurling

The multiple beam echo sounding sonar (MBES) has become an important tool in oceanic applications such as seafloor mapping, sediment evaluation, sub-bottom profiling, surveys, fisheries research, mine countermeasures, and underwater inspections. Intense interest has been directed toward improvements in performance, and new concepts are being introduced at a rapid pace. Some of the new improvements include enhanced bottom coverage, new methods of sound velocity measurement and compensation for refraction, new methods of calibration, and flexible adaptation to the sediment as well as a new method to improve spatial resolution and signal processing.

Introduction

Intense interest has been directed toward improving the performance of Multiple Beam Echo Sounding Sonar (MBES), and new concepts are being introduced at a rapid pace. Some of the new improvements include enhanced bottom coverage, new methods of sound velocity measurement and compensation for refraction, new methods of calibration, flexible adaptation to the sediment as well as a new method to improve spatial resolution and signal processing.

Bottom coverage

The implementation of parallel sectors operating at different frequencies has provided a means of minimizing the non-scanned areas on the sea floor. With a single beam, the coverage pattern on the sea floor is not ideal. Rather, it exhibits parabolic shapes along the fore and aft borders of the coverage pattern, even when the beam is perfectly vertical. The shapes, in exaggerated form, are shown in Figure 1. To ensure complete bottom coverage, RESON utilizes "multi-ping technology" - a CW pulse train of 4 pings, each within a parallel sector that is in a slightly different direction along-track. The frequency separation of each pulse is 500 Hz.

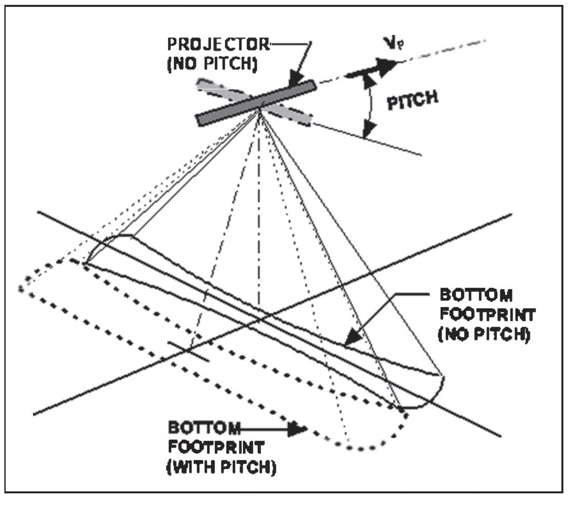

Figure 1: Exaggerated illustration of how the bottom coverage varies with pitch as the hyperbolic bottom patterns change shape, leaving areas that are not scanned.

With multi-ping, the simultaneous transmission of different frequencies in each of the separate steered sectors provides the necessary bottom coverage, and the merging of the multiple beam information is done in the post-processing.

One post-processing approach is referred to as Maximum Amplitude Detection (MAD). MAD is based on comparison between instantaneous amplitude levels received in the beams to determine the angular origin of the bottom backscattered signals [3]. To improve accuracy, the angular interval between each reception beam is made small. A high level of data is achieved because the calculation is carried out on each sample, but this high level is reduced to regular intervals between soundings.

Another example of innovation in the quest to achieve 100% bottom coverage involves the use of narrower, independently steered sectors that can be arranged to compensate for both pitch and yaw.

With bottom-looking sonar systems, a rather subtle effect can result in received signal fluctuation (as great as 40 dB) arising from sonar motion. A primary contributor to this effect is the continuous Doppler shift across the resolved bottom footprint. The resulting echoes add linearly, causing a beat or interference structure in the received signal. This beating effect results in a beat rate that is directly proportional to the transmitted frequency and platform speed, and is approximately equal to the difference between the maximum and minimum Doppler shifted frequencies in the resolved bottom footprint. Although the received beat envelope can be continuous with a long signal, short pulses will still follow the same envelope amplitude. This means that the beat rate is independent of the of pulse length. Increasing the bandwidth of the sonar is one way to minimize this problem, because the single frequency nulls in the envelope are filled in.

Sound velocity measurement and refraction compensation

In more complicated mapping missions, the MBES must provide accurate depth information which must be related to the georeferenced position of its transducer and the transducer depth with respect to the mean water level - even the changes in water level must be known. During operation, the vessel's kinematics, such as roll, pitch, heading, etc., must be available because they affect the MBES accuracy just as the need for SVP samplings. Under-sampling can cause serious errors, and a self-contained CTD or SVP profiler such as one of the Moving Vessel Profiler™ (MVP™) series can be used to collect data without stopping the vessel [3] [4]. Their recent equipment includes a winch and a computer-controlled deployment system that operates with a free-fall fish while the vessel is underway at speeds to 12 knots and depths of 800 m. No deck crew is required since the system is completely autonomous and the computer outputs a real time SVP profile during the fish free fall.

Having obtained the required SVP information, including the sound speed at the face of the transducer, the off-nadir refraction is computed with the assumption that the water column is horizontally stratified with new changes in SVP accepted with the next sampling. An onboard computer can accomplish the task, but a recently new approach for this purpose is the use of online computation. For the mapping scenario, this may be an advantage in view of the large number of information components involved.

Calibration techniques

There are many calibration techniques, such as field evaluation of sounding accuracy [5], calibration requiring the sonar to echo range on a calibrated target placed in the farfield [6][7][8][9], and a method that separates the sonar's projector from its hydrophone so that the two communicate with one another [10][11][12] as a means of using a system corrected chirp reference.

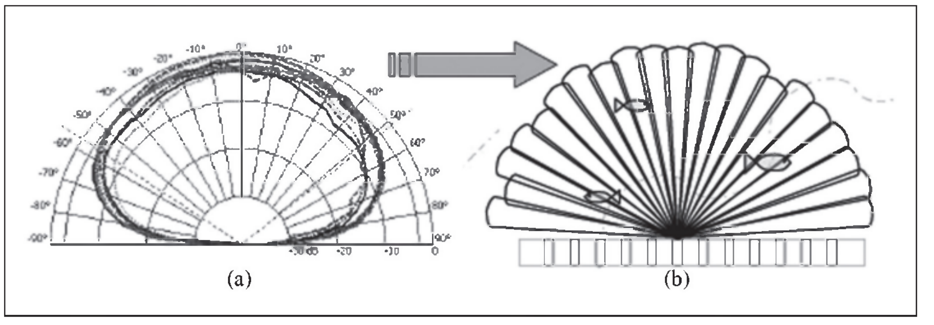

Figure 2: Unknown, but real acoustic array problems: (a). Measured directional responses for some channels of the same array; and (b). Resulting (unknown) beam magnitude and phase differences (RESON).

Since all array elements of an MBES transducer are not ideal, variations can be expected in their magnitude and phase characteristics. These variations translate to beams within a sector that exhibit magnitude and phase differences as shown in Figure 2. In view of this problem, P. Pocwiardowski of RESON has conceived a new transducer calibration method which provides a means of compensating the individual elements in an array so that smoothed and reduced sidelobe structure can be realized for the transducer [12]. In addition, beam amplitudes are made equal and the phase differences are compensated.

The technique calibrates every channel using complex directional responses to compensate for variations in the beamformer - an important factor in target strength estimation, classification, control of focusing, and some relaxation of the ever increasing precision required in manufacturing. Using the new RESON SeaBat 7125 MBES [13] for calibration treatment, some simulated beam patterns illustrate the differences between no compensation and the RESON compensation technique. Figure 3(a) shows the center beam without compensation while (b) shows the beam with compensation. Figure 4(a) shows the beam steered to 60° without compensation while (b) shows the beam with compensation.

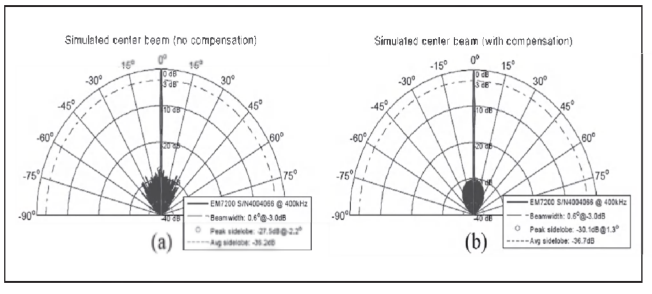

Figure 3: (a): Simulated center beam without compensation and (b): Simulated beam with compensation (RESON).

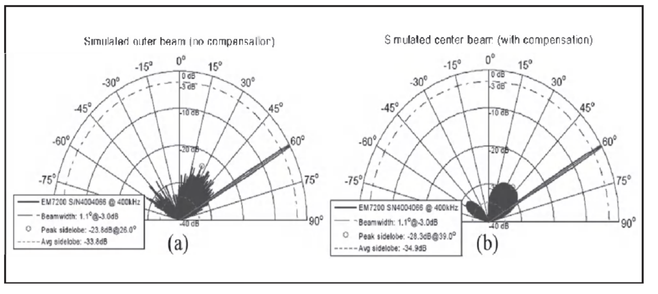

Figure 4: (a): Simulated beam steered to 60° without compensation and (b): Simulated beam with compensation (RESON).

With respect to phase calibration, RESON carefully observes frequency synchronization, time synchronization and spatial considerations for calibration. Without doing so, the rather senseless data in Figure 5(a) is obtained since synchronization is absent. However, with synchronization, Figure 5(b) presents phase responses as well-behaved linear functions leading to an estimated phase measurement accuracy of 1-2 degrees.

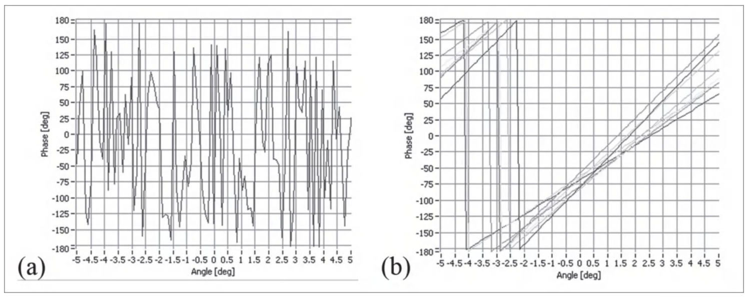

Figure 5: (a): Example of phase response done at one ping from – 5° to +5° with 0.1° steps with improper synchronization and (b): Relative phase done at one ping from - 5° to +5° with 0.1° steps with proper synchronization.

Normalization across-track varied gain (atvg)

Although not part of the propagation concerns, there are certain characteristics of the bottom sediments that have features in common. These features can be utilized to enhance the normalization of the return signals somewhat like Time Varied Gain (TVG). TVG provides normalization of signal amplitudes with respect to transmission losses so that all signals of interest fit within the effective dynamic range of the hardware. However, problematic effects involving variations in sediment backscattering and the strong return when viewing the bottom near and at nadir also require compensation. Shaping the projector response to reduce the strong return at nadir is a partial solution, but such an approach is rather inflexible, especially with respect to ship motion. Accordingly, the concept of "Across-Track Varied Gain" (ATVG) for the MBES systems was introduced [1].

ATVG actually simulates what would be desirable spatial filtering for the across-track projector response by compensating for generic characteristic of bottom backscattering as well as allowing for MBES mission changes. One advantage is that it resides in the software and can be easily adjusted for undesirable platform motion, unlike a projector designed to provide the desired pattern response.

ATVG is based on certain generic functions of bottom backscattering which can be explained by referring to Figure 6. For an MBES operating at 24 kHz, the backscattering coefficients, in dB/m^2 for several types of bottom sediments are shown versus the grazing angle in degrees [13]. Arbitrarily using a maximum sector of 110°, the dB range of variation in backscattering coefficient values and their corresponding mean levels using grazing angles from 35° to 90° are shown in Table 1. Note that the rather limited sector of only 110° used in this case may be cause for some changes in the application of ATVG described in the subsequent discussion when a larger sector is used.

Without the Rough Rock bottom, the mean change in dB from 35° to 90° of grazing angle is 18.16 dB using the data in Table 1. This leaves an error in the dB change of ±10 to ±11 dB for the extreme sediment cases, ignoring the Rough Rock bottom. If the foregoing mean change were not included in the ATVG, the maximum variation in dB across the multiple beams would be about 28 dB. The foregoing can be presented in a different manner as shown in Figure 7, where the mean backscattering coefficient is plotted as a solid curve versus grazing angle with the Hard Rock ignored. Taking the difference in dB for grazing angles from 35° to 90° yields the same difference as above. The figure shows the Hard Rock bottom backscattering coefficient as a dashed curve. For the sector width used here, there is not enough slope in the Hard Rock curve for normalization, but the level of the return will be strong.

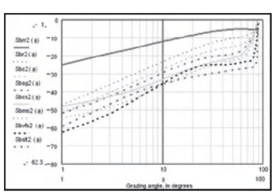

Figure 6: Bottom backscattering coefficients for approximately 24 kHz versus grazing angle in degrees. The uppermost curve is for Rough Rock. Along the left ordinate, from the top dotted curve to the bottom dashed curve are the backscattering values for the following sediments: Rock (dotted curve), Coarse Sand (solid curve), Cobble (dashed curve), Sandy Gravel (dot-dashed curve), Medium Sand (dotted curve), Silt (dot-dashed curve), and Very Fine Sand (dashed curve) [1].

Bottom Type	**dB change** from 35° to 90°	**Mean level** from 35° to 90°, in dB
Rough Rock	0.97	-5.67
Rock	6.78	-9.34
Cobble	10.43	-12.57
Sandy Gravel	14.29	-15.12
Coarse Sand	21.02	-16.36
Medium Sand	23.68	-18.33
Very Fine Sand	23.17	-22.09
Silt	27.73	-26.68

Table 1. Change in Backscattering Coefficients and the Mean Level for Grazing Angles from 35° to 90° using the 110° Sector of the Subject Sonar [1].

There are different ways to implement the ATVG concept. One of them is to take the mean curve shown in Figure 7 and adjust the gains of the formed receiving beams so that they provide the kind of relative compensating gain shape shown. This would result in a relative response that would exhibit the shape shown in Figure 8, and would be limited to the horizontal solid line which represents the 110° sector considered here. If a wider sector is used, the limiting horizontal line would have to be raised to match the sector width. This example applies to the case where multiple sediments are involved as described in Table 1, except for the Rough Rock.

Variations of the bottom types could be applied singularly or in combination following the previous example. However, it is essential that the null (dashed vertical line in Figure 8) of the normalization curve be maintained at the vertical (nadir) position by roll and pitch inputs from the platform motion sensor. In the event that the sector must assume an oblique angle the gains can be varied in consort with the curves in Figure 6.

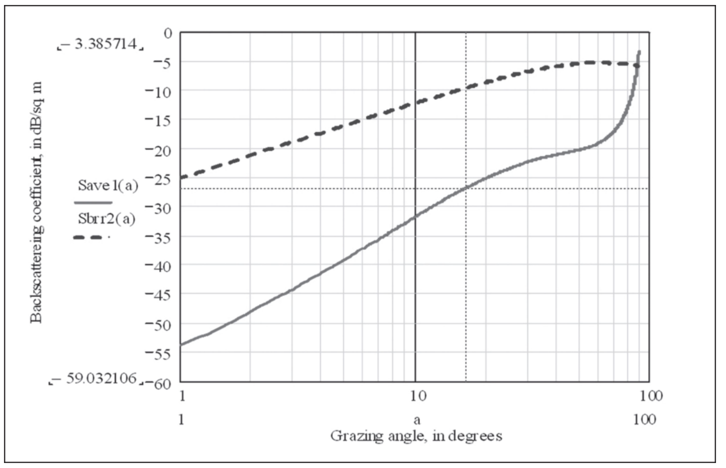

Figure 7: Solid curve is the mean backscattering coefficient in dB/m² versus grazing angle in degrees, for all sediments in Figure 6 except Rough Rock. The dashed curve represents the backscattering for Rough Rock [1].

Conclusion

While every new feature available for MBES sonars would be desirable, there are economic as well as technical trade offs that always limit final choices. It is important to consider the primary sonar application and mission objectives prior to making a decision as to which features will best meet stated requirements.

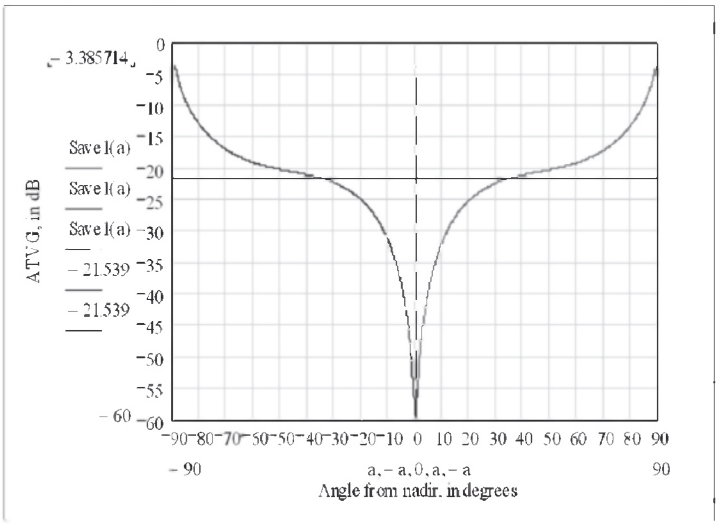

Figure 8: The shape of the performed beam gains with respect to beam steering angles from nadir to normalize for a multitude of bottom sediments described in Table 1, except for Hard Rock. Note that the application of ATVG need only by applied below the horizontal solid line because it sets the limits of the across-track sector considered in this example. Wider sectors would raise the horizontal line [1].

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