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Adverse weather conditions for ship manoeuvrability

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Abstract

A definition of the severity or adversity of met-ocean conditions under which ships need to maintain manoeuvrability is a basis for formulating power and steering requirements for ships. Specification of such adverse weather conditions is one of the objectives of the SHOPERA (Energy Efficient Safe SHip OPERAtion) (2013–2016) project, funded by the European Commission in the frame of FP7. Three distinct situations requiring different adverse weather criteria are considered in the project: manoeuvring in the open sea, manoeuvring in coastal waters and low-speed manoeuvring in restricted areas. The purpose of the present study is twofold, first to investigate met-ocean climate associated with the three selected scenarios and specifying its main properties, second identifying critical met-ocean characteristics requiring sensitivity studies in numerical simulations and model tests. Both measured and hindcast data are used in the analysis. The North Atlantic deep water met-ocean environment and three coastal locations are considered. Seaway joint statistics for ship routes across the North Atlantic and in European coastal areas is supporting the investigations. It is shown that met-ocean conditions vary significantly in deep and coastal waters with regard to the likelihood of occurrence of sea states as well as their characteristics.

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Keywords: adverse weather conditions; seaway severity; ship manoeuvrability

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1. Introduction

The observed and projected climate changes have got a lot of attention in media, academia and the marine industry. Although significant uncertainties are related to projected climate changes a consensus has been reached within the scientific community that the observed climate changes are resulting from human activities (IPCC, 2007, 2013). Reduction of the greenhouse gas (GHG) emissions has become a concern of politicians, international organizations and society in general. The International Maritime Organization (IMO) has taken the initiative to regulate the greenhouse gas (GHG) emissions from ships by introducing the Energy Efficiency Design Index (EEDI) in the IMO Resolution MEPC.203 (62), being the first regulation in this respect. Introduction of the EEDI is a major step towards improving energy efficiency and reducing GHG emissions of shipping, however, it has raised serious concerns that some ship designers might choose to lower the installed power to achieve EEDI requirements and not account in a satisfactory way for ship safety by introducing innovative propulsion concepts. This could result in insufficient propulsion power and steering devices for maintaining the manoeuvrability of ships in adverse weather conditions. The issue has been highlighted by the International Association of Classification Societies (IACS). The investigations carried out by IACS led to development of first draft guidelines for consideration by IMO in 2011, IMO MEPC 62/5/19, which resulted in *2012 Interim Guidelines*, IMO MEPC 64/4/13, updated as *2013 Interim Guidelines* in 2013, IMO Res. MEPC.232 (65), where adverse weather conditions to be used in assessment of ship manoeuvrability are proposed. The aim of introducing the *2013 Interim Guidelines* has been to prevent uncontrollable reduction of installed power. However, the sufficiency of these guidelines has been disputed.

Steering and propulsion abilities of ships are challenged by the met-ocean (meteorological and oceanographic) environment in different ways depending on a ship type. A definition of the severity or adversity of met-ocean conditions under which ships need to maintain manoeuvrability is a basis for formulating power and steering requirements for ships. Specification of such adverse weather conditions is one of the objectives of the SHOPERA (Energy Efficient Safe SHip OPERAtion) (2013–2016) project, funded by the European Commission in the frame of FP7. The project is considering three distinct situations: manoeuvring in the open sea, manoeuvring in coastal waters and low-speed manoeuvring in restricted areas. These three scenarios require different adverse weather criteria. To identify their main characteristics for further investigations in numerical simulations and model tests both measured and hindcast data have been used in the present analysis.

The paper is organized as follows. Section 2 presents the *2013 Interim Guidelines,* in Section 3 selection of the adopted scenarios in light of met-ocean climate is addressed, Section 4 is dedicated to open waters, Section 5 to coastal areas while Section 6 to restricted waters. The paper closes with conclusions, recommendations and references.

2. Interim guidelines

The interim guidelines for adverse weather conditions given by MEPC 232 (65) were proposed in 2013. In order to determine them comprehensive ship assessments were carried out using numerical simulations (see MEPC 232 (65)). The North Atlantic scatter table from IACS Recommendation 34 (IACS, 2001) was used as a seaway climate in these calculations. Moreover, JONSWAP sea spectrum with the peak parameter of 3.3 was considered. The results of the comprehensive assessments were compared with the results of the statistical approach (Level-1 assessment). Consequently, the adverse conditions used for Level-2 assessment were determined taking into consideration both results of the comprehensive assessments and the statistical approach. The resulted adverse weather conditions are proposed for coastal waters and include the following met-ocean parameters: significant wave height, spectral wave period and mean wind speed, being all a function of ship length; see Table 1.

Table 1. Definition of adverse conditions as the following threshold value of ship size (MEPC 232 (65), IMO, 2013).

Ship length (m)	Significant wave height H_s (m)	Peak Wave period T_P (s)	Mean wind speed V_w (m/s)
Less than 200	4.0	7.0 to 15.0	15.7
$200 \le L_{pp} \le 250$	Parameters linearly interpolated depending on ship's length		
More than L_{pp}= 250	5.5	7.0 to 15.0	19.0

The *2013 Interim Guidelines* recommend using the JONSWAP sea spectrum with the peak parameter of 3.3 for coastal waters. They reflect the situation that the manoeuvrability in wind and waves are stricter in coastal waters where due to navigational restrictions the ship might need to keep a prescribed track irrespective of the direction of waves and wind. On the other hand, ships are not supposed to be in coastal areas in very severe weather conditions, and should leave to the open sea before the weather conditions become too severe. Thus, the weather conditions used in the assessment procedure can be relaxed in comparison with the worst possible weather conditions expected in unrestricted service. Therefore in the open sea, it has been adopted to be sufficient to keep a favourable heading with respect to wind and waves, and accepting some drifting with wind and waves.

The sufficiency of these guidelines, however, has been disputed. The adverse conditions specified in the *2013 Interim Minimum Power Guidelines* are validated in the SHOPERA project aiming at development of improved guidelines on ship manoeuvrability and their submission for consideration to IMO. Validation of the adverse weather conditions is also a topic of a new Japanese R&D project (MEOCC67/INF.22, 2014) with which the SHOPERA project is in communication.

3. Met-ocean description and scenarios considered

Steering and propulsion abilities of ships are challenged by the met-ocean environment. Wind, waves, current, sea water level, and in some geographical regions ice, defined this environment being geographic region and location dependent. A description of these met-ocean phenomena often employs a mixture of mathematical, probabilistic, empirical and statistical models. Physical models as well as field observations show that extreme wind, waves, current and sea water level within a large range of return periods are not occurring simultaneously. Random nature of these met-ocean phenomena requires use of joint probabilities to approximate properly their long term variations. Commonly, the following met-ocean parameters, or selection of them, are included in joint description: the mean wind speed, mean wind direction, significant wave height (total sea, wind sea, swell), spectral/zero--crossing wave period (total sea, wind sea, swell), mean wave direction (total sea, wind sea, swell), current speed, mean current direction and sea water level. A more complete met-ocean description requires also information about wind gustiness factor, wind spectrum, wind directional spreading and wave directional spectrum. The listed above met-ocean characteristics are used currently in assessment of loads and responses of marine structures.

An impact of met-ocean parameters on ship loads and responses, and consequently on ship manoeuvrability will depend on a ship type. The adverse weather conditions proposed in the *2013 Interim Guidelines* are limited to significant wave height, spectral wave period, the mean wind speed and the wave spectrum, and are proposed for coastal waters. They do not include recommendations on wind directional spreading, gust, wave energy spreading, wind sea and swell, tide (regarded by some researchers as a current component) and current, the met-ocean characteristics which may be of importance for ship manoeuvrability in some ocean regions, e.g. in the North-West Scotland presence of water tide and current need to be accounted for when assessing minimum propulsion and steering efficiency requirements.

Investigations carried out in the first phase of the SHOPERA project included data from deep water and coastal area as well as ship accident statistics, including investigation of accidents caused by insufficient manoeuvrability, and interviews of ship masters. They have shown that sea states being in the range of the adverse conditions of the *2013 Interim Guidelines* occur much more frequent in deep water than in coastal areas. Further, the proposed range of sea states may include combined wave systems (wind sea and swell). Some of the sea states are very steep and can trigger abnormally steep waves. Furthermore, current has impact on ships' manoeuvrability.

The first-phase SHOPERA investigations resulted in selection of three distinct situations requiring different adverse weather criteria: manoeuvring in the open sea, manoeuvring in coastal waters and low-speed manoeuvring in restricted areas. These three scenarios require different adverse weather criteria and to specify their characteristics both measured and hindcast data are used in the analysis. Coastal locations considered include: the coastal channels giving access to the port of Antwerp, Scottish waters and the port of Leixões, while deep water weather conditions are limited to the North Atlantic met-ocean climate. The investigations are supported by seaway joint statistics for ship routes across the North Atlantic and in European coastal areas. The aim of these investigations is to identify met-ocean properties for the three scenarios for sensitivity studies in numerical calculations and model tests.

The adverse weather conditions are not able to cover all location specific features of met-ocean climate which vary with geographic regions. Locations other than the ones considered by SHOPERA maybe characterized by different shallow-water aspects of wave and current shallow water dynamics and wind field, which may need to be considered when investigating ability of ships to maintain manoeuvrability in these regions.

4. Open sea

4.1. General

In the open sea, in most of situations it is probably sufficient to keep a favourable heading with respect to wind and waves. However, in the ocean areas with high density of ship traffic or near offshore installations in increasing storm severity maintaining manoeuvrability maybe an issue. Therefore ability of ships to maintain manoeuvrability in deep water met-ocean conditions in a developing storm requires also a manoeuvrability check, primarily for keeping heading against wind and waves. In the ocean regions with strong current present ability of a ship to maintain manoeuvrability needs to include apart from wind and waves, also current, if it is not possible to avoid it.

The North Atlantic wave climate has been regarded as most severe in the global ocean. This ocean region is characterized by intense ship traffic. The density of Voluntary Observing Ships' (VOS) reports collecting by the World Meteorological Organization (WMO) developed in SHOPERA is presented in Fig.1. It is interesting to note that the recent investigations of Cardone et al. (2014) based on GlobWave and GROW2012 data show that a vessel is more exposed to encounter dangerous sea states along mid and high latitude Northern Hemisphere routes.

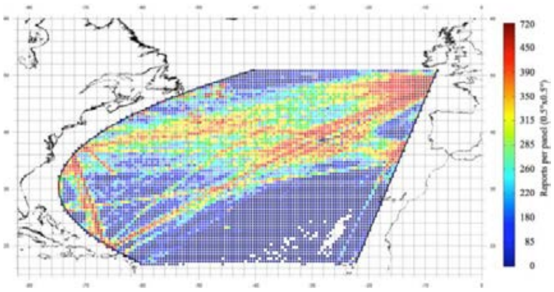

Fig. 1. Density of VOS reports on the considered area, *after Vettor and Guedes Soares (2015).*

Therefore the North Atlantic wave climate given in a form of a scatter diagram of significant wave height and zero-crossing wave period is recommended by IACS Rec. 34 (2001) as a basis for ship design. The IACS scatter diagram has also been used for evaluation of operation conditions of sailing ship. The IACS wave climate and associated with it wind climate is adopted herein as a reference climate for deep water. IACS Rec. 34 (2001) recommends using the Pierson Moskowitz (PM) spectrum (see, DNV, 2014) with the wave scatter diagram. The PM spectrum refers to a ‘fully arisen sea’, that is one which is in equilibrium with the local wind speed which is assumed to blow over a long fetch over a sufficiently long time.

4.2. Wind

Tucker and Pitt (2001) propose to use for the PM spectrum the relation between the significant wave height derived from the wave spectrum H_{m0} and the mean wind speed U_{10} (m/s) at a height of 10 m over the sea level:

$$H_{m0} = 0.0246 U_{10}^2 \tag{1}$$

For the JONSWAP spectrum, describing the developing sea, Tucker and Pitt (2001) recommend to use the relation

$$H_{m0} = 0.0163 X^{0.5} U_{10} \tag{2}$$

where X is the fetch in km and U_{10} in m/s.

An analysis of wave hindcast data from a few locations in the North Atlantic seems generally to confirm the above relations, but H_{m0} and U_{10} relations will be region dependent. An example of the mean wind speed for the West of Shetland (water depth of 500 m) is shown below. The West of Shetland hindcast data were generated by the Oceanweather Inc. for the period (1988–1998) and are sampled every 3 h (see Bitner-Gregersen, 2012 for details). The 10-minute mean wind speed given sea state severity has been fitted by a 2-parameter Weibull distribution following the model proposed by Bitner-Gregersen and Haver (1991), i.e.:

$$f_{U_w|H_s}(u_w \mid h_s) = k \frac{u_w^{k-1}}{U_c^k} \exp\left[-\left(\frac{u_w}{U_c} \right)^k \right] \tag{3}$$

where H_s denotes H_{m0} (or significant wave height derived from the 20-minutes' time series) and

shape parameter $k = c_1 + c_2 h_s^{c_3}$ (4)

scale parameter $U_c = c_4 + c_5 h_s^{c_6}$ (5)

The coefficients c_i, $i=1,2,\ldots,6$, are estimated from data. U_w refers usually to a 10-minute average speed at height 10 m above sea level although wind measured/generated at the other heights could also be used in the model.

The mean of the 2-parameter Weibull distribution is

$$\mu_w = U_c \Gamma(1 + 1/k) \tag{6}$$

The fitted parameters are listed in Table 2 and the fit given by the model shown in Fig. 2.

Table 2. Parameters of the conditional Weibull wind speed distribution, West Shetland.

Shape parameter	c_1	c_2	c_3	Scale parameter	c_4	c_5	c_6
	1.134	0.892	0.225		0.056	0.276	-0. 240

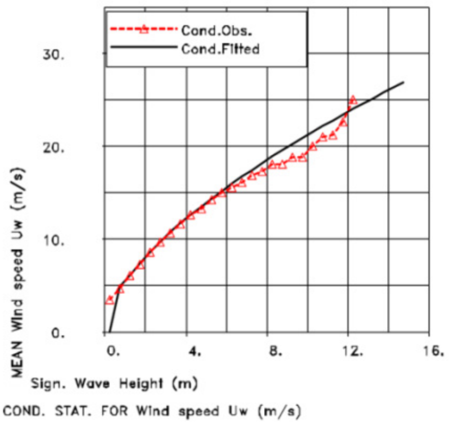

Fig. 2. Conditional mean wind speed U_w given H_{m0}.

4.3. Waves

The IACS scatter diagram of H_s and T_z has been established based on data collected by Voluntary Observing Ships in normal service in accordance with the guidelines of WMO with some correction introduced due to inaccuracy of zero-crossing wave period due to Bitner-Gregersen et al. (1995). The VOS data are summarized in a form of the Global Wave Statistics (GWS) Atlas by the British Maritime Technology (BMT, 1986). The data represent a sufficiently long observation history to provide reliable global climatic statistics over much of the global ocean. They include bad weather avoidance as ships try not to sail into storms; today weather forecast is sent to ships by meteorological offices. However, the GWS Atlas was published in 1986 thus the last 28 years including several severe storms are missing, what will impact extremes.

The accuracy of the visual observations been questioned in the literature, especially concerning the wave period (e.g. Guedes Soares, 1986; Bitner-Gregersen et al., 1995) and its effects on ship loads and responses as well as on fatigue damage have been demonstrated (Chen and Thayamballi, 1991; Bitner-Gregersen et al., 1995; Wing and Johnson, 2010). It was concluded that the GWS atlas should be used with care. Recent investigations of Grigorieva and Gulev (2006), including the VOS data up to 2006, have shown that the 100-year H_s is beyond 18–19 m in the North Atlantic, significantly higher than the GWS Atlas one, and the mean H_s has increased up to 4–5 m. Apart from uncertainties associated with the GWS data and missing the last 28 years, the limitation of these data is lack of information about directional wave spectrum which as shown have quite an unpredictable effect on the long term ship motions and loads (Wing and Johnson, 2010; Bitner-Gregersen et al., 2014).

The necessity of replacing that historic (essentially subjective) observations being a wave database for ship design with instrumentally collected (objectively measured) databases, or combination of numerical and measured data, has become a subject of increasing discussion within classification societies in the last decade. Large discrepancies between different databases predictions have not allowed reaching firm conclusions yet, as discussed by Bitner-Gregersen and Guedes Soares (2007) and Bitner-Gregersen et al. (2014). Recent investigations of Bitner-Gregersen and Toffoli (2015) have shown that a resolution of wave models in time and space has significant impact on hindcast data generated. A few meters lower extremes can be obtained when the resolution is coarse. There is an ongoing discussion within the shipping industry how to account in ship design for wave climate which sailing ships experience during their lifetime; can wave climate derived from ship motions and marine radar be utilized in this process? The technology for deriving wave heights from marine radars has not yet been demonstrated in a satisfactory approach. Improvement of accuracy of such approach is being under development within the JCOMM Wave measurement and EvaluaTion (WET) project (www.jcomm.info/WET).

Although H_s and T_z classes may occur with different frequency in different deep water met-ocean databases the ranges they cover are similar. Further, some numerically/instrumental databases give less steep sea states, however the IACS scatter diagram sea state steepness has been observed in nature and generated in laboratory tests. Therefore herein the IACS scatter diagram is suggested to be used for assessment of ship manoeuvrability in numerical calculations and model tests.

According to the joint model of H_s and T_z/T_p proposed by Bitner-Gregersen (for details see e.g. Bitner-Gregersen, 2012) the IACS scatter diagram wave data have been fitted by the 3-parameter Weibull distribution for significant wave height, with probability density function

$$f_{H_s}(h_s) = \frac{\beta}{\alpha}\left(\frac{h_s-\gamma}{\alpha}\right)^{\beta-1} \exp\left\{-\left(\frac{h_s-\gamma}{\alpha}\right)^{\beta}\right\} \tag{7}$$

where α = scale parameter, β = shape parameter, γ= location parameter, and the conditional (on H_s) lognormal distribution for peak wave period (or zero-crossing wave period)

$$f_{T_p|H_s}(t_p \mid h_s) = \frac{1}{\sigma(h_s)t_p\sqrt{2\pi}} \exp\left\{-\ \frac{(\ln t_p - \mu(h_s))^2}{2\sigma(h_s)^2}\right\} \tag{8}$$

where

$$\mu = E(\ln T_p) = a_1 + a_2 h_s^{a_3} \quad (9)$$

$$\sigma = Std(\ln T_p) = b_1 + b_2 e^{b_3 h_s} \quad (10)$$

the parameters α, β, γ and the coefficients a_i, b_i , $i=1,2,3$ are estimated from data for the actual location, herein the North Atlantic scatter diagram. The fitted parameters are given in Table 3.

Table 3. Parameters of the H_s and T_z distribution, the North Atlantic.

α	β	γ	a_1	a_2	a_3	b_1	b_2	b_3
3.075	1.505	0.626	0.7052	1.2638	1.3191	0.0940	0.0595	-0.0328

The mean value of the wave period follows

$$\mu_{Tp} = \exp(\mu + \frac{1}{2}\sigma^2) \quad (11)$$

4.4. Wave spectrum

Traditionally, the PM spectrum has been used by the shipping industry. Recently also other empirical spectra have started to be applied like the JONSWAP spectrum and a double peak spectrum (see e.g. DNV, 2014). For extreme sea states used in design a unimodal spectrum will usually be most representative but for evaluation of ship loads and responses in operational conditions a double peak spectrum including wind sea and swell maybe needed. Bitner-Gregersen showed in 2005 (for review see Bitner-Gregersen, 2012) for the location off West Shetland that beyond 50% of sea states included swell while Boukhanovsky and Guedes Soares (2009) have demonstrated that so high occurrence of swell is also present in other locations of the ocean.

The PM spectrum represents a special case of the JONSWAP spectrum with the gamma parameter γ=1.0. A sea state being under development will have different values of γ. Fig. 3 shows γ as a function of H_{m0} for the West Shetland location. As seen γ varies significantly with a sea state severity and sea type; as expected it reaches on average higher values for wind dominated seas. Further, low and intermediate sea states have higher γ compared to high sea states. Therefore effect of the gamma parameter on ability of ships to maintain manoeuvrability needs further investigations in numerical simulations and model tests.

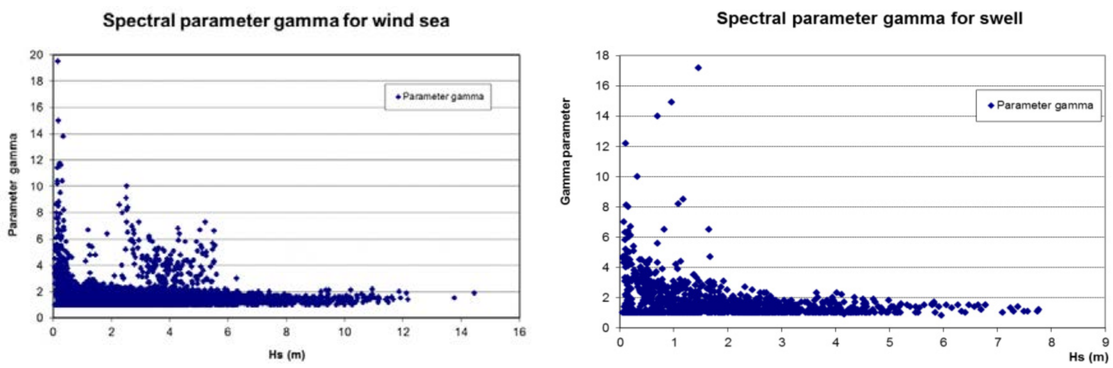

Fig. 3. The JONSWAP gamma parameter, left: wind dominated sea, right: swell dominated sea, West Shetland data (1988–1998).

Sea states with a narrow-banded wave spectrum, the gamma beyond 4, and the wave steepness $S_{Tz}=H_s/(1.56T_z^2)$ values higher than 0.067 (corresponding to $k_pH_s/2 \approx 0.10$, where k_p is wavenumber at spectral peak) have been proven to be able to trigger modulational instability responsible for generation of abnormal waves called also freak or rogue waves, see Onorato et al. (2009), Waseda et al. (2009). As shown by Bitner-Gregersen and Toffoli (2012) such sea states may occur in deep water. They are present in all sea states but are more frequent in the low and moderated sea states than in high sea states, Bitner-Gregersen and Hagen (2004). In a very steep sea state although H_s is not high a vessel may lose significantly the speed and it takes long time to build it up, as demonstrated by Guo and Vartdal (2015). Therefore sensitivity studies of these rogue-prone sea states, included already in the proposed adverse conditions, in model tests and numerical simulations need to be carried out.

5. Coastal waters

Met-ocean conditions in coastal waters are strongly location dependent. The range of H_s and T_p combinations proposed in the *2013 Interim Guidelines* may not occur in some coastal locations and occur with different frequency.

Long-term measurements of met-ocean conditions in the coastal waters of the Flemish Banks area in the Belgian zone of the Southern North Sea are available through the Flemish Banks Monitoring Network (http://www.meetnetvlaamsebanken.be/), which permanently monitors wind, waves (with both directional and non-directional buoys), tide and current. In this area, characterized by sand banks, the 40 nautical mile long dredged Scheur/Wielingen channel is the main access channel for deep-drafted ships to the mouth of the Western Scheldt estuary which gives access to the port of Antwerp. The measured data in the period (1984–2004) show that in these coastal waters the frequency of occurrence of sea states with H_s=4.0–4.5m and H_s=4.5–5.0 m, is 0.03% and 0.01%, respectively, while sea states with H_s values beyond 5 m were not recorded. Further, the corresponding zero--crossing wave period is in range from 4.5 to 7.5 s (corresponding T_p=6.2–10.4 s). Thus shorter wave periods than proposed in the *2013 Guidelines* are recorded and T_p up to 15 s have not been observed.

In the Scottish coastal waters being more open than the Flemish Banks area the wave hindcast data generated by the UK Met Office for the period (2000–2008) show that sea states with H_s =6.5 m can be expected and the wave period range for H_s=4.0–4.5 m and H_s=4.5–5.0 m is from 6.1 to 9.0 s while the occurrence of the sea states with H_s=4.0–4.5m and H_s=4.5–5.0 m is 1.2% and 0.5%, respectively. Both locations have different directional distribution of the mean wave direction. In the Scottish waters most frequent mean wave direction is SW and NE, while in the Southern North Sea the main direction is NW.

The port of Leixões placed in the East North Atlantic coast is not as protected as the Flemish Banks area and therefore is characterized by more severe wave conditions than the latter, and it is affected by swell.

The fitted joint (H_s, T_z) model parameters fitted to the data from the port Flemish Banks area, Scottish water and the port of Leixões are shown in Table 4. The fitted H_s distributions shown in Fig. 4 illustrate the different wave climate in these locations.

Table 4. Parameters of the H_s and T_z distribution.

Location	α	β	γ	a_1	a_2	a_3	b_1	b_2	b_3
Flemish Banks	0.673	1.129	0.370	0.0	1.349	0.225	0.065	0.417	-1.497
Scottish waters	1.369	1.594	0.777	0.0	1.678	0.117	0.050	0.283	-0.757
Leixões	1.219	1.428	0.392	0.0	1.888	0.201	0.075	0.183	-1.272

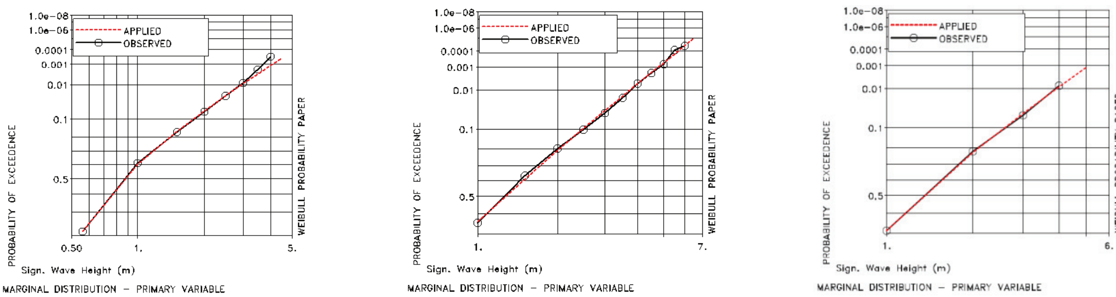

Fig. 4. Empirical and fitted distributions of significant wave height for the coastal access channel to Antwerp (left), Scottish waters (centre) and the port of Leixões (left).

Instrumental data collected near the Belgian coast show that the JONSWAP spectrum with the parameter γ beyond 3.3 can occur in these coastal waters (see Fig. 5) and that γ, similarly as in deep water, is a function of sea state severity. Different values of γ need to be investigated in numerical simulations and model tests as they may impact ship manoeuvrability. Expressions relating the zero up-crossing wave period T_z/peak period T_p and the mean wave period T_1 and the parameter γ are proposed in the legacy DNV RP C-205 (2014).

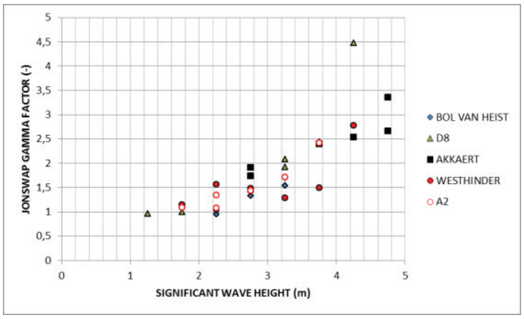

Fig. 5. The JONSWAP γ parameter resulting from average spectra near Belgian coast as a function of H_s (based on Truijens, 1992).

Recent investigations of Winterstein and Haver (2015) show that in shallow water the bottom topography will affect shape of the wave spectrum significantly. Following the DNV GL RP-C-205 (2014) in the finite water depth the TMA spectrum, for non-breaking waves, (the JONSWAP spectrum multiplied by a depth function, Bouws, et. al. 1985) is recommended to be used.

Due to the tide, the Scheur/Wielingen channel is not only characterised by water level variations, but also varying currents. Current velocities and directions vary along the channel (from open sea to the mouth of the estuary). The maximum magnitude at spring tide increases from 2 knots at the West side of the channel to 3.7 knots at the mouth of the Western Scheldt. As the flow roughly has the same orientation as the Scheur/Wielingen channel, no important cross currents occur for shipping traffic. Also the Scottish waters are characterised by presence of tide and current.

6. Restricted waters

Manoeuvrability at low forward speed in strong wind and, perhaps, current, is critical for ships with large windage area, such as container ships, cruise vessels and car carriers, but also for bulk carriers and tankers, during approaching to and entering ports. Therefore low-speed manoeuvrability criteria require specification of the wind speed and, perhaps, current (Papanikolaou et al., 2015). For example Quadvlieg and van Coevorden (2008) recommend wind speed of 20 knots for general use and 30 knots for ferries and cruise ships, as the wind speed at which the ship should be able to leave the quay. For tug operations, relevant for low-speed manoeuvrability criteria, IMO recommendations: significant wave height up to 5 m, wind speed up to 39 knots and current up to 2 knots as environmental limits for towing operations, could be adopted. These met-ocean conditions need still to be further investigated.

7. Conclusions

The analysis of hindcast and instrumental data have confirmed the earlier findings of the SHOPERA project, met--ocean conditions vary significantly in deep and coastal waters. Proposing three distinct situations: manoeuvring in the open sea, manoeuvring in coastal waters and low-speed manoeuvring in restricted areas, seems to cover all situations where maintaining manoeuvrability of ships need to be tested. The proposed *2013 Interim Guidelines* do not cover all critical situations; they are limited to coastal waters only. Further, the adverse conditions of the *2013 Interim Guidelines* may need also some revisions to reflect more satisfactory met-ocean climate.

Ability of ships to maintain manoeuvrability will depend on the ship type. Therefore further investigation of met--ocean characteristics identified in the present study in numerical calculations and model tests is needed to reach firm conclusions.

It should be noted that met-ocean environment is geographic region and location dependent. The adverse weather conditions are not able to cover all location specific features of met-ocean climate, particularly for coastal waters and restricted waters. Therefore apart from proposing adverse conditions a notation may need to be given requiring verifying met-ocean climate on a case by case basis to account satisfactory for shallow-water aspects of wave and current shallow water dynamics as well as associated wind conditions.

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