Study Of The Wind Speed, Rainfall And Storm Surges For The Scheldt Estuary In Belgium

Mohammad Abul Hossen, Farjana Akhter

Abstract: The Belgian coast and the Scheldt estuary are important for the Belgian economy. Coastal flood risks tend to increase due to climate change. This study was set out to investigate the wind speed, surges and rainfall in the Scheldt estuary. The study explored the changes in mean and extreme winds according to the recent ENSEMBLES climate models and examined the dependency of extremes between surge with wind speed and surge with rainfall. The dependence analysis between surge and wind speed aimed to investigate whether climatic changes in wind speed can be transferred to changes in surge, while the existence of dependence between surge and rainfall would require climate scenarios for rainfall upstream in the Scheldt basin to be correlated with climate scenarios for the downstream surge boundary. A special dependence measure χ, developed by Buishand (1984) and Coles et al (2000) was followed. Data was extracted and processed using Matlab and CDO. The analysis of wind speeds showed that future wind speeds in the estuary (based on the climate models) will remain stable in comparison with the past wind speeds. Also, wind direction will be mainly from 180°-300°, although slight shifts might appear towards more frequent south western winds. From the study of dependency, there was no significant dependency between sea surge at Oostende coast and rainfall at different stations. The definition of significant dependency is strong or conservative. Above all, the extremes events are more or less dependent. While the study has not found significant changes in wind speed and only slight changes in wind direction, it is important to further investigate the impact of these changes on the Scheldt estuary using hydrodynamic models. The assessment of changes in extreme rainfall and sea surge need to be further studied.

Index Terms: Climate Data Operator, Global Climate Models, ENSEMBLES climate models, IPCC, MATLAB, Regional Climate Models, Royal Meteorological Institute.

---

1 INTRODUCTION

COASTAL populations around the world are increasing significantly. It was estimated in 2000 that, 10% of the global population lived on 2% of the Earth's land area adjacent to the coast, which is less than 10 m above mean sea level (McGranahan et al. 2007, cited in McInnes et al. 2009). The Scheldt estuary and Belgian coast are important not only for housing and industry but also for trade and commerce. Due to climate change, coastal flood risks tend to increase because of an increase in the frequency and/or level of storm surges. The difference in water level between the observed sea level and the predicted astronomical tide is termed as sea surge. The storm surges are related with the changes in the wind climate (pressure, wind speed and wind direction). After extensive scientific research of the effects of increased greenhouse gas concentrations the focus is shifting to changes in the statistics of weather extremes on regional or local scale. Besides changes in temperature and precipitation, a burning question is whether the storm climate changes or not. Although the determination of a definite forecast in wind climate is not possible, it is wise to investigate the impact of these extremes on society, for instance flooding of low-lying countries like the Netherlands and Bangladesh due to storm surges. This study explored the changes in mean and extreme winds according to the ENSEMBLES climate models at the Scheldt estuary and addresses the question whether storm climate changes (according to these models) or not. Then we tried to find the relationship between surge with wind speed and surge with rainfall.

- *Mohammad Abul Hossen is currently working as sub divisional engineer in Bangladesh Water Development Board (BWDB), Bangladesh, PH-008801718154748.*
  E-mail: engr_mohammadhossen@yahoo.com
- *Farjana Akhter is currently working as an assistant engineer in Public Works Department (PWD), Bangladesh, PH-008801710646226*
  E-mail: farjanasony01@gmail.com

Study Area

The study area is the Scheldt Estuary, Belgium. The study of wind and surges are important for analyzing the hydrodynamic impacts along the Scheldt, which is vitally important for the Belgian in terms of social and economic aspects. It falls within 51 to 52 degree north and 3 to 4.5 degree east. The river Scheldt (Figure 1) is a lowland river, which takes its rise in the northern part of France (St. Quentin), covers parts of France, Federal Belgium, the Flemish Region, the Walloon Region, Brussels' Capital Region the Netherlands and falls into the North Sea near Vlissingen (the Netherlands).

Fig. 1. *Study Area, Scheldt Estuary [Source: Google Earth, 2009]*

The total catchment area is 22000 km^2, the total length of the river is 355 km, average flow is 115m³/s, the fall over the total river length is at most 100 m and the mean depth of the Scheldt estuary is about 10 m (Bayens et al, 1998). Approximately 7 million people live in the total river basin of the Scheldt. Urban areas with population densities of over 1000 inhabitants per km^2 are found near Lille (France), Gent, Brussels and Antwerp. The largest industrial areas are concentrated near Lille, Antwerp, along the canal from Gent to Terneuzen, and near Vlissingen. The river Scheldt and its tributaries are used as a major drain for industrial and domestic wastes.

Objectives
The main objective of this paper is to find out the changes in mean and extreme winds according to the ENSEMBLES climate models at the Scheldt estuary and addresses the question whether storm climate changes (according to these models) or not.

2 Methodology

Available Data
Wind speed data from 19 climate models were available from the ENSEMBLES project and the 6 h data were available at World Data Center for the climate (WDCC) CERA database. Precipitation data for Uccle from 1925 to 2005 and for Vlissingen from 1925 to 2010 were also gathered. The precipitation data for Deurne, Eeklo, Essen and Stabroek were obtained from 1976 to 2005 from the Royal Meteorological Institute (RMI) website (http://www.meteo.be/).The data were secondary data. That means, data were collected from Hydraulic section, Katholieke University Leuven (KUL) and KUL got the data from RMI. The data was in NetCDF (NC) format. Matlab was used to read NetCDF data.

Processing 6h data
There are only two climate models where 6 h data are available, called CLM. These models contain much information. Therefore, only the relevant data were selected for further processing. The dimensions of the original climate models were a 4D matrix. The climate models do not provide absolute wind speed, but a u-, v-component of wind speed. Thus, the u-component wind speed corresponds to the location by latitude and the v-component according to the longitude. The absolute wind speed could easily be calculated using the Pythagorean rule.

Study method of wind speed and wind direction
The objective was to analyze the wind speed for the Scheldt region to determine the potential future changes in the extremes. Therefore, models from the 16 ENSEMBLES projects were first analyzed at a daily scale to establish the range and direction of future change. The data was available from 1951 to 2100 for most of the simulations. The data was divided into different decade (for every 10 years) after which the extreme values for the wind speed were calculated. The values above a threshold (99th percentile) were termed as extreme values. Different percentile thresholds were analyzed to examine whether the extreme changes with intensity. At first the historical variability and trends were analyzed. Then future trends were projected.

Identification/quantification of dependencies

First, the extremes were extracted for all the variables using Matlab. For dependency analysis, the 90th percentile was set as the threshold value and the values above threshold are termed as extreme. Then the dependence between high sea surge, wind speed and precipitation was studied using a measure of dependence for dependency of extremes. The dependence was investigated for:

i. Wind and Surge
ii. Precipitation and Surge.

At first, the dependency between wind speed and surge was studied. Then the dependency between precipitation and surge was also examined.

3 Illustrations
The values above 99th percentile were termed as extreme values for wind speed analysis; therefore, the 99th percentile value was first identified. The monthly analysis is essential for understanding seasonal variability. So the percentage of extreme values was calculated for each month. The results from the full range of 19 model simulations were analyzed. The list of models can be seen from Table 1.

TABLE 1
List of Models Run

Sl No.	Name of the Models
1	C4IRCA3_A1B_HadCM3-e1_DM_25km
2	CLM_A1B_1_D3_dm_WIND_SPEED_20km
3	CLM_A1B_2_D3_dm_WIND_SPEED_20km
4	CNRM-RM5.1_SCN_ARPEGE_DM_25km
5	DMI-HIRHAM5_A1B_ARPEGE_DM_25km
6	DMI-HIRHAM5_A1B_ECHAM5_DM_25km
7	ETHZ-CLM_SCN_HadCM3Q0_DM_25km
8	ICTP-REGCM3_A1B_ECHAM5_r3_DM_25km
9	KNMI-RACMO2_A1B_ECHAM5-r1_DM_50km
10	KNMI-RACMO2_A1B_ECHAM5-r2_DM_50km
11	KNMI-RACMO2_A1B_ECHAM5-r3_DM_50km
12	KNMI-RACMO2_A1B_MIROC3.2-hires_DM_50km
13	MPI-M-REMO_SCN_ECHAM5_DM_25km
14	SMHIRCA_A1B_ECHAM5-r3_DM_25km
15	SMHIRCA_A1B_HadCM3Q3_DM_25km
16	SMHIRCA_CTR_BCM_DM_25km
17	SMHIRCA_CTR_ECHAM5_DM_50km
18	UCLM-PROMES_A1B_HadCM3Q0_25km_DM
19	VMGO-RRCM_A1B_HadCM3Q0_DM_25km

The monthly average values of the extremes were computed for different decades. It is seen from Figure 2 that in all decades, the averages of extreme values were higher from October to March and it was very low, sometimes zero, from May to August. The result of other climate models is similar. That means the wind speed is very high from October to March. Therefore, winter storm events are more important for this area and should be given more attention. The average wind speed of these six months (Oct- Mar) was determined. Then average of 1961-1990, 2010-2040, 2040-2070 and 2070- 2100 for the six months was calculated. The result is presented in figure 3. From Figure 3, it is not possible to see any clear inclination of the lines.

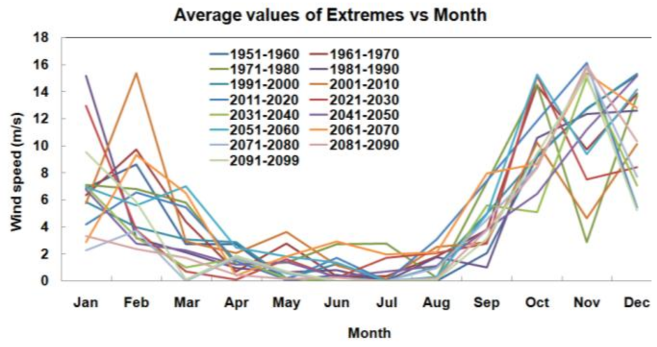

Fig. 2. *Average values of extreme wind speed vs month for each decade from 1951 to 2100 for the model DMI-HIRHAM5_A1B_ECHAM5_DM_25km*

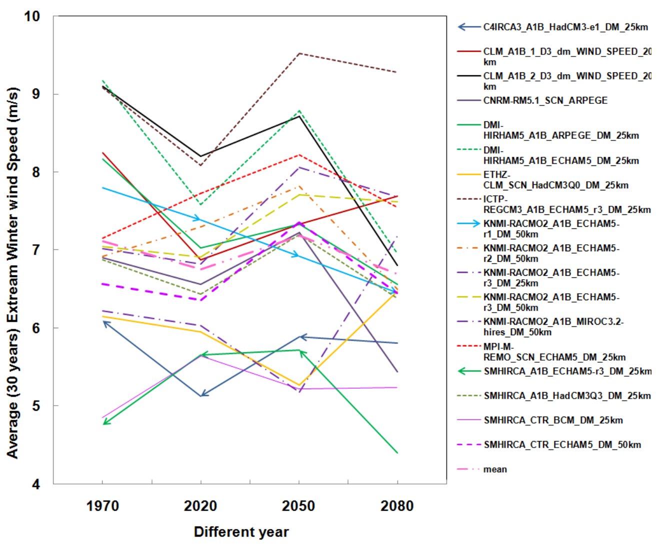

Fig. 3. *Average extreme winter wind speed (for 30 years) of all models*

According to some models wind speed will increase in future. On the other hand, some models are showing decrease of wind speed. Moreover, the variation of wind speed is also very high, which indicates high uncertainty. The whole procedure was done for 90th percentile and 80th percentile. Then, comparison was performed between models. An assessment was done between higher resolution and lower resolution. It can be said that smaller resolution may give higher value. Next to the wind speed, the wind direction was assessed to establish how the wind direction in the Scheldt changes. This time 6h data was taken. Data from only two CLM models was available. The data was found for the following time series.

History 1981-2000
Near-Future 2016-2035
Mid-Future 2046-2065
Long-Future 2076-2095

The wind direction was defined as the direction from which the wind blows (Figure 4).

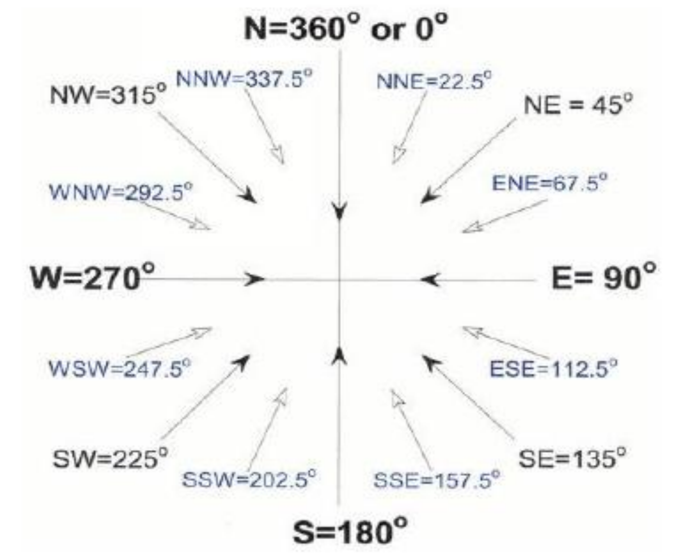

Fig. 4. *A wind rose showing the different directions from which the wind may blow*

The percentage of frequencies versus wind direction plot (Figure 5) shows that wind blows most of the time from 180°-300^0 which means from west side mostly. The western wind direction will increase the risk of flooding as the coast is lying in this side. For this reason, it is assumed that only the wind direction between 180^0 and the 300^0 (Figure 4) would be taken for further analysis. The future wind speed change with respect to past can be determined from the figure. The highest change occurs for a wind direction of 255° (Southwest). This wind direction increases by about 1.5%. The frequency of other wind directions (mainly East – Northeast) consequently decreases. The significance of such an increase can be determined from the use of a hydrodynamic model, which determines the water level along the Scheldt.

Does the number of storms increase? There is still a debate whether or not the number of storms and their intensity will increase due to increase of greenhouse gas concentration. For instance, Lambert and Fyfe (2006) reported that almost all models used for the IPCC Fourth Assessment Report (AR4) exhibit a significant increase of the number of extreme storms. Also, Leckebusch et al. (2006), driving multiple RCMs with different GCMs, reported an increase of the number of extreme storms for the European region. On the other hand, Bengtsson et al. (2006), who used an advanced storm tracking algorithm, did not detect an increase in the number of extreme storms in the MPI-ECHAM5 model. From the analysis of wind speed and wind direction, it is not possible to make any firm statement whether wind speed/storm will increase or not. There was no significant change in wind speed. This study is also consistent with the study by Brink and Hurk (2007). According to them, combined with the considerable bias in the distribution of extreme winds of the GCMs, it is hard to make any statement about changes in extreme wind behavior with the current knowledge.

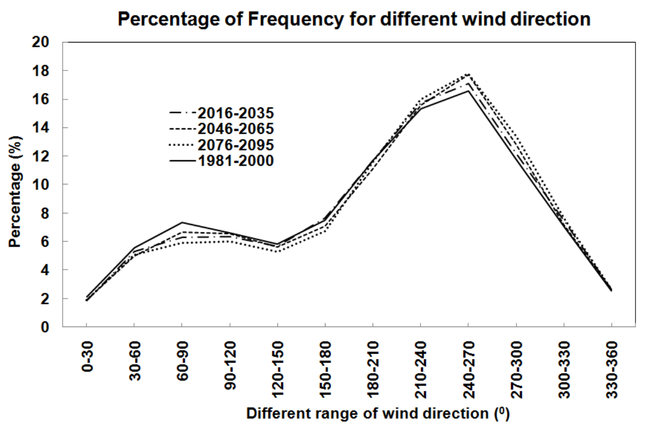

Fig. 5. *The percentage of frequency of wind direction for CLM1 model*

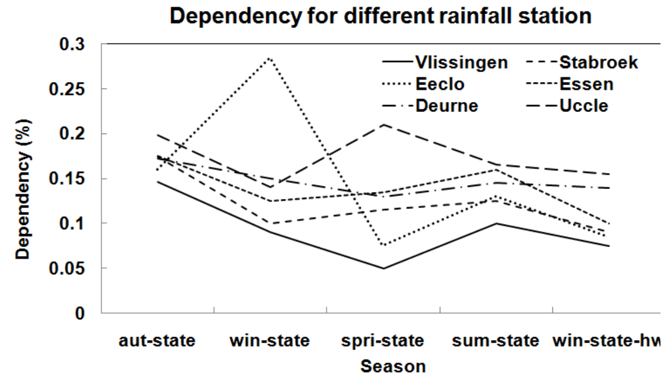

Fig. 6. *Comparison of dependency of extreme rainfall of different stations with extreme surge at Oostende*

Then the dependency between wind speed and surge was studied. It was observed that the relationship is stronger for winter than other seasons. After that the dependency between precipitation and surge was also examined. There is no noteworthy dependency. Then the dependency was calculated for rainfall at Uccle station and surge at Oostende. Again, the dependence in autumn is stronger than other seasons. This may be due to faster runoff in autumn. It is also observed that the dependence is stronger between surge and rainfall at Uccle compared to the surge and wind speed at Vlissingen. This means, there is a low chance that high wind speed at Oostende coast occur simultaneously with high inland rainfall at Uccle. After that, the dependency was determined for other precipitation stations. This time the dependency for other seasons is higher than winter. This may be because of other factors that affect surge. It is mentioned before that surge depends not only on precipitation but also wind speed, atmospheric pressure, flow etc. So if winter precipitation has weak relationship with surge it does not imply that precipitation is small in winter or precipitation extreme has no relationship with surge. It may happen that the other factors are weaker in winter. Then dependency of different rainfall station was compared (Figure 6). It can be said that Oostende station has more dependency with Uccle station. It is noteworthy that the Uccle station is the most southerly station indicating that the dependence may increase in the south direction. It is observed that the most northern station (Vlissingen) has the lowest dependence. From the above tables and figures it can be said that the dependency of extreme precipitation versus extreme surge is not significant. This may be for the following reasons:

- **i.** We had some limitations. First, there was not enough data to establish the relationship. Second, the surge data at Vlissingen is not available. It was assumed that surge at Oostende will be equal to surge at Vlissingen. But the Oostende coast is about 100km from Vlissingen. So the surge at Oostende may not be equal to surge at Vlissingen.
- **ii.** Usually precipitation affects surge after some time, which is called lagged time. In this present study the relationship is measured for the same time. If we can co-relate precipitation data and corresponding surge data for some lagged time, we may see stronger relationship. It happened in eastern Britain coast (Svensson and Jones, 2002). There the number of station pairs with significant dependence between precipitation and daily maximum sea surge is the largest when precipitation precedes the sea surge by one day.
- **iii.** Probably a large portion of the runoff from the rainfall stations may not pass through the Scheldt River. If that runoff does not increase the flow of the Scheldt, the surge at Vlissingen or Oostende is not expected to increase.

4 Conclusion

The analysis of wind speeds showed that wind speeds in the estuary will remain stable in comparison with the past wind speeds. No trends were observed for the 2020, 2050 and 2080s. However, wind speed alone was not adequate to explain the changes in surges. This was the reason for including wind direction in the analysis. Even so wind direction did not show large changes. While dealing with many uncertainties and there is no noticeable change, it is better to say wind speed may or may not increase. On the other hand, it can be said with more confidence that, wind direction will be mainly from 180^0-300^0. It was discussed before that wind direction has impact on wave and wave has direct relation with surge. So it can be predicted that this wind may increase surge height in the Scheldt estuary. The study of the dependency of extremes revealed one important finding that the dependency of extremes between the surges of inland rainfall varies spatially. The dependence of extremes was strongest for the Uccle station and weakest for the Vlissingen station. From the study of dependency we cannot forecast strong dependency between sea surge at Oostende coast and rainfall at different stations.

Acknowledgment

I wish to express my love and indebtedness to my beloved wife, who has encouraged me to finish this paper. Finally, I would like to thank all my well wishers for their inspiration and good wishes.

REFERENCES

[1] Baeyens, W., et al. 1998. General description of the Scheldt estuary. Hydrobiologia, 366, pp. 1–14.

[2] Bengtsson, L.B., Hodges, K.I., and Roeckner E., 2006, Storm tracks and climate change, Journal of Climate, 19(15), pp. 3518-3543.

[3] Brink, H.W., Hurk, B.J.J.M., 2007. Future changes in winter wind-climate over Europe. Climate Dynamic, 2007, pp. 7-8.

[4] Buishand TA., 1984. Bivariate extreme-value data and the station-year method. Journal of Hydrology, 69, pp. 77–95.

[5] Coles S, Heffernan J, and Tawn J.A., 2000. Dependence measures for extreme value analyses. Extremes, 2, pp. 339–365.

[6] ENSEMBLES, The ENSEMBLES project RT3, [online] available at http://ensemblesrt3.dmi.dk/ [accessed on 11/11/2010].

[7] IPCC, 2007. Climate Change 2007. The Physical Science Basis. Cambridge University Press, Cambridge, p. 940.

[8] Lambert, S., Fyfe, J.C., 2006. Changes in winter cyclone frequencies and strengths simulated in enhanced greenhouse gas experiments: Results from the models participating in the IPCC diagnostic exercise. Climate Dynamics, 26, (7-8). pp. 713-728.

[9] Leckebusch, G.D. et al., 2006. Analysis of frequency and intensity of winter storm events in Europe on synoptic and regional scales from a multi-model perspective. Climate Research, 31, pp. 59-74.

[10] McInnes, K. L., Macadam, I., Hubbert, G. D., and O'Grady, J. G., 2009. A modelling approach for estimating the frequency of sea level extremes and the impact of climate change in southeast Australia. Nat Hazards, 51, pp. 115–137.

[11] Sangireddy H. Reading NetCDF files in MATLAB and Analyzing the Precipitation Data. [online] available at https://webspace.utexas.edu/hs8238/www/surfacehydrology/surfacehydrology_Project.htm, [Accessed on 26/02/2011].

[12] Svensson C., Jones D.A., 2002. Dependence between extreme sea surge, river flow and precipitation in eastern Britain. International Journal of Climatology, 22, pp. 1149-1168.