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Quantifying the impact of climate change from inland, coastal and surface conditions

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ABSTRACT: The impact of climate change for the short, mid and long term horizons is investigated for an area along the Scheldt river, at the confluence with the Dender river. The downstream coastal boundary comprises of the sea level rise and storm surges from the North Sea while the upstream inland boundary comprises of rainfall and related runoff discharges. The third surface boundary comprises of wind speed and direction along the Scheldt. The climate change scenarios are based on statistical analysis of an ensemble of (at least 20) simulation results with Regional Climate Models (RCMs). The RCM results are provided by the CERA database, the EU-FP5 PRUDENCE and the EU-FP6 ENSEMBLES database. Outputs of precipitation, temperature, potential evapotranspiration, wind speed, wind direction and Sea Level Pressure (SLP) have been validated for historical periods and correlations are accounted for when quantifying future changes till 2100.

1 INTRODUCTION

There have been several efforts to quantify the impact of floods on the present state of society primarily because of the costly damages. Flood risks could have increased as indicated by the increased precipitation (Osborn & Hulme 2002, Ntegeka & Willems 2008, Zolina et al. 2010). Changes in flood characteristics are likely linked to climate change (Schiermeier 2011). To quantify floods, flood analysts have relied on various sources including paleoclimatic, observations and future projections. Each of these sources is, however, faced with uncertainties, which make the challenge of quantifying the flood impact more intense. Nevertheless, the tools involved in flood impact analysis have advanced as improvements in data availability, science and computational speed have made it possible to validate and project, with increased confidence, the flood impacts. There remain, however, questions regarding the quantification of future flood impacts. Future impacts rely on climate models which come in varying degrees of complexity. For one, climate models have different resolutions suitable for the scale of the processes being modelled. The General Circulation Models (GCMs) essentially model large scale processes such as atmospheric circulations. This means that GCMs perform better for variables whose spatial variability is low, for example, temperature. Regional Climate Models (RCMs) are built for local scale processes and include more detailed configurations such as topography and convective storm systems. Moreover, the future picture depends on whether one is looking at a global or regional scale. The Intergovernmental Panel on Climate Change (IPCC) has considered such uncertainties and accounted for them in the climate models. This means that climate models are credible tools for quantifying future changes.

Flood impact studies have not reached a consensus on how the future changes will evolve. Climate change flood studies in Europe have shown that there is no clear direction of change (Dankers & Feyen 2008, Veijalainen et al. 2010), that is, a mix of positive, negative and insignificant changes. It is for this reason that the multi-model ensemble approach is widely recommended. The approach posits that rather than relying on a few climate models, it is advisable to consider as many climate models as possible to better capture the future uncertainties. This study aims to quantify the future flood impact by making use of different climate models from the EU-FP5 PRUDENCE database, the EU-FP6 ENSEMBLES and the CERA database. The flood impact considers future projections in sea level rise, precipitation, temperature, potential evapotranspiration, wind speed, wind direction and Sea Level Pressure (SLP).

2 MODELS AND DATA

2.1 *Observed data*

For this study, wintertime SLP records from October 1925 till March 2000 were evaluated for the region [40°W–40°E & 30°N–70°N]. The data was available from the National Centre for Atmospheric Research (NCAR) database (http://dss.

ucar.edu/) at 1 PM UTC from October 1, 1925 to December 31, 1939 and at noon UTC from January 1, 1940 to March 31, 2000. The SLP data are not available at the exact time of sea-surge records, but the weather regimes are persistent large-scale patterns, and it is assumed that the one observed at noon or 1 PM is nearly constant all day long (Ullmann & Moron 2008).

Observed inland rainfall (central Belgium) data was from the Uccle rainfall station in Brussels (Lat 50.8°N, Lon 4.35°E, Elevation 100 m asl). The station data available for this study was for the period 1961–1990. Potential Evapotranspiration (ETo) was available at Uccle for the period 1961–1990.

The surge is estimated from the observed water levels at Oostende [02°54'E, 51°13 N] for the period 1925–2000. Oostende is located on the Belgian coast near the mouth of the estuary of the Scheldt river. The water level is measured relative to the altimetric reference, the Tweede Algemene Waterpassing (TAW). The surge is calculated as the difference between the observed water level and the astronomical tide.

Hourly wind speed and direction were available for the Vlissingen station [51.45 N, 3.60E] for the period 1960–2005.

2.2 *Climate model data*

Data was available from the PRUDENCE project (http://prudence.dmi.dk). The project produced climate change scenarios based on 12 RCMs (50 km) and 3 GCMs (150–250 km), and emission scenarios A2 (mainly) and B2 (Nakicenovic & Swart 2000), for the periods 1961–1990 and 2071–2100. The horizontal resolution of most RCMs is 50 km with a few RCMs at 25 km (RCAO and HIRHAM). The RCMs were driven with four GCMs with resolutions of 150 km (HadAM3H, HadAM3P) and 250 km (ECHAM4/OPYC, ARPEGE). The RCMs were: (1) Swedish Meteorological and Hydrological Institute (SMHI), (2) Royal Netherlands Meteorological Institute (KNMI), (3) Norwegian Meteorological Institute (METNO), (4) Danish Meteorological Institute (DMI), (5) Swiss Institute of Technology (ETH), (6) UK Met Office Hadley Centre (HC), (7) Geesthacht Institute for Coastal Research (GKSS), (8) Max Planck Institute (MPI), (9) Centre National de Recherches Météorologiques (CNRM), and (10) Universidad Complutense de Madrid (UCM). More details about these simulations can be found in Baguis et al. (2010), Christensen et al. (2007), Deque et al. (2007) and Jacob et al. (2007).

Additionally, model results from the ENSEMBLES project were also studied (http://ensembleseu.metoffice.com). ENSEMBLES produced results from 13RCMs (25 km), 6GCMs (100–300 km) with the A1B scenario. The GCMs are: (1) BCM (300 km) from the University of Bergen (Norway); (2) CNRM (300–100 km); (3) HadC (3 versions at 300 km) and (4) MPI (200 km). The results were also for longer transient periods, that is, 1950–2050 or 1950–2100. However, time slices for periods 1961–1990 and 2071–2100 were extracted for consistency with the PRUDENCE project results. It should be noted that ENSEMBLES RCMs are updated versions of the PRUDENCE RCMs.

The CERA database (Lautenschlager et al. 2009) provided high resolution data based on the CLM regional climate model. This was especially important for the investigation of future changes in winds. The model was bounded by the ECHAM5 (T63/L31)/MPIOM GCM. The simulations were for periods 1960–2000 and 2000–2100. The A1B and B1 scenarios were used for the future emissions. However, for this study only 2 simulations from the A1B were studied.

3 HYDRODYNAMIC MODEL DESCRIPTION

Because of its high importance for the region and its several functions and conflicts, the Scheldt estuary has been extensively studied. Recent studies have been directed towards the revision of the "Sigmaplan". The first Sigmaplan was designed shortly after the flood event of 1976. It comprised of dike heightening and strengthening, the installation of 13 flood control areas, and a storm surge barrier downstream of Antwerp. The aim of these measures was to limit the water level at Antwerp to 8.97 m TAW (10,000-year return period). The storm surge barrier was, however, never built. Half a century after that date, the responsible authorities decided to revise the plan given its limited safety level, taking into account the climate change trends. The current flood return period along the Zeeschelde is about 70 years, and 350 years after installation of the 13th flood control area (which corresponds with a water level at Antwerp of 8.24 m TAW). This is largely below the safety level (10,000-year return period) foreseen in the original Sigmaplan. The updated Sigmaplan, which was prepared in 2000–2003, substituted the storm surge barrier near Antwerp with additional flood control areas. Although the storm surge barrier would offer more protection for very extreme storms, it was found that a combination of dikes and floodplains had higher benefits at lower costs (De Nocker et al. 2004, RA 2005). With about 4000 ha of additional flood control areas, it is expected that the return period of flooding along the Zeeschelde can be increased to about 4,000 years (Meyvis et al. 2003, RA 2005, De Nocker et al. 2006, Broekx et al. 2011). Figure 1 shows the location of the potential flood control measures considered in that analysis.

Increased flood risks may occur along the Scheldt Estuary and the North Sea coast because of high sea levels. Flooding episodes within the Scheldt Estuary might also increase because of increased peak flows from the upstream fresh water rivers or because of the combination of the changes in the downstream coastal influence and the upstream river flow contribution. A quasi 2D hydrodynamic model was developed for the area of the Scheldt estuary that accounts for these factors. The main Scheldt river branch is represented as many detailed flood branches on the two banks of the river. The floodplains along the river are conceptualised by means of a network of 1D flood branches and spills (Fig. 2). The flood branches represent the topographical depressions; the spills the topographical elevations between these depressions (Willems et al. 2002). The model has been implemented in MIKESHE (Abbott et al. 1986) and has been validated based on water level and discharge time series at several locations along the river. Studies for the flood risk in the Scheldt section in Belgium have considered current climate conditions and a mean sea level rise of 60 cm at Vlissingen (Broekx et al. 2011). To the best of our knowledge, no increase in upstream runoff discharges due to climate change has been taken into account. In this study, changes in upstream runoff from climate change scenarios have been accounted for. Additionally, the correlation between upstream (inland runoff) and downstream (coastal) boundary conditions has been considered. For more upstream areas along the Scheldt, for instance the city of Dendermonde, both the up- and downstream boundary conditions interact and jointly control the flood risk. The flood frequency at Dendermonde is thus much higher than at Antwerp. Thus the flood risk impact has focused on the Dendermonde area.

Figure 1. Location of the potential flood control measures in the Scheldt estuary, as considered in the revised Sigmaplan (Broekx et al. 2011).

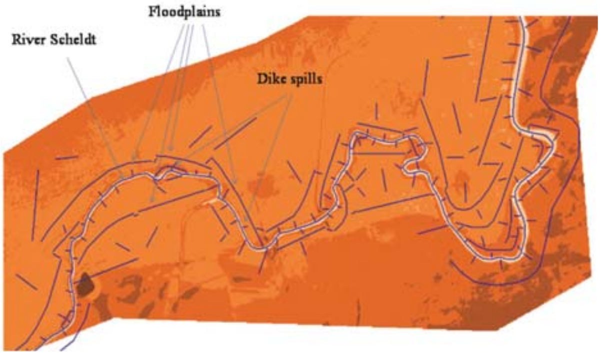

Figure 2. Quasi 2D hydrodynamic model of the Scheldt Estuary for the Dendermonde area.

4 HYDROCLIMATIC DRIVERS

To investigate the impact, the upstream hydroclimate drivers are taken as the upstream runoffs from Bovenschelde, Leie, Nete, Dender, Demer, Dijle, Zenne and other subcatchments. The downstream drivers are taken as the North Sea tide heights, which are influenced by the sea level rise due to thermal expansion, tidal wave propagation, and the storm surges arising from atmospheric circulation.

To quantify the impact of climate change on the flood extremes, several hydroclimatic drivers are required. Estimating the changes involves the use of diverse methodologies and models. One of the primary sources of data is the climate models whose output needs to be verified for suitability before projecting future changes. In this study, climate models provide future estimates of sea level rise, winds, mean sea level pressure, rainfall, and evapotranspiration. All the variables are extracted from RCMs bar the sea level rise as illustrated in Figure 3.

Other models involved in the analysis include the coastal surge, hydrological, and hydrodynamic

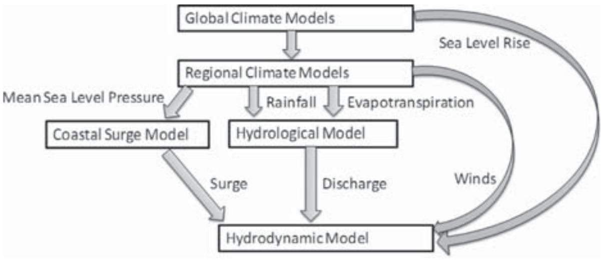

Figure 3. Impact analysis models and related hydroclimatic drivers.

models. Rainfall and evapotranspiration are used for estimating the runoff changes that are fed to the hydrodynamic model. Similarly, surge changes are estimated using the surge model and then fed to the hydrodynamic model. The changes in the winds and sea level rise are derived respectively from the RCMs and GCMs. It is noteworthy that the impact on waves was not explicitly simulated in this study. It was assumed that the changes in waves were inferable from the changes in wind characteristics. For the upper part of the Scheldt, differences in wave conditions should be very small (only locally generated waves and those are fully correlated with wind). For the lower (more seaward) part of the Scheldt estuary, main differences in wave conditions are due to differences in water depth. Therefore the differences in wave height lead to differences in wave propagation towards the dikes.

4.1 *Sea level rise—trend analysis*

Estimates on the sea level rise along the Belgian Coast have been proposed based on recent studies (Ozer et al. 2008, Van den Eynde et al. 2008). It was found that the sea level at Oostende has risen on average by 1.69 mm/year since 1927. This rise fits closely to the global average which the IPCC derived for the 20th century (1.7 mm/year). Measurement series which started later at the Belgian coast, show even higher values. This might indicate an acceleration of the rise in sea level, which is confirmed by regression analysis of the Oostende series of measurements: for instance a staged linear profile results in a kink in 1992. The increase was 1.41 mm/year on average between 1927 and 1992, but 4.41 mm/year between 1992 and 2006. Extrapolation of the historical trend shows a further rise in the sea level for the Belgian coast, depending on the relations applied, of 20 cm to 200 cm for the period from 1990 to 2100.

4.2 *Composite hydrographs and limnigraphs*

Given that different locations within a catchment are affected by different flooding extremes with different return periods, it is desirable to develop a method that would map the flooded zones for the same return period. With the composite hydrograph method, it is possible to derive hydrographs for the same return periods at different locations. The composite method and algorithms were developed for the hydrographs and limnigraphs for Flemish rivers by Willems et al. (2002). The method comprised of an extreme value analysis for a range of durations after which Discharge—Duration—Frequency (QDF) or water level (H)—Duration—Frequency (HDF) curves were developed. Willems & Rombauts (2004) derived the QDFs based on simulations of rainfall-runoff for several subbasins using the NAM rainfall runoff model (DHI 2004). The QDFs were then used to construct new hydrographs; the HDFs to construct new limnigraphs.

The composite hydrographs have the interesting feature that all flows for different durations have an identical return period. Given that the response time of the river to upstream rainfall runoff varies along the length of the river, composite hydrographs are desirable because, for a given return period, they have the advantage of simulating river states (water levels, discharges, …) at any location along the river with one single simulation (because they compose all response times in one single event). However, while the limnigraphs and hydrographs are defined for different points, wind speed is assumed not to vary (global) across the catchment. The Wind speed Duration Frequency (WDF) is assumed to be the same for all points in the catchment. Figure 4 shows the downstream "composite limnigraphs" at Vlissingen (coastal boundary) for return periods of 10, 100, 1000 and 10000 years, while Figure 5 shows the upstream composite hydrographs for one of the upstream rivers (Scheldt at Melle) for the same return periods.

4.3 *Surge quantification*

The projection of surges is achieved through the use of statistical downscaling that relies on the relationship between large scale circulation and local surge measurements. Ullmann & Monbaliu (2009) found that there is a connection between mean sea level patterns and surges at Oostende. They found that extreme sea surges ≥ 65 cm (99th percentile during winter for 1925–2000) were associated with a deep low pressure covering Scandinavia and high

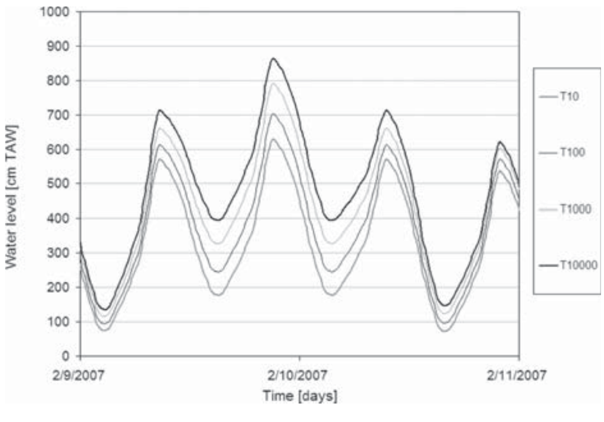

Figure 4. Downstream "composite limnigraphs" at Vlissingen (coastal boundary) for return periods of 10, 100, 1000, and 10000 years.

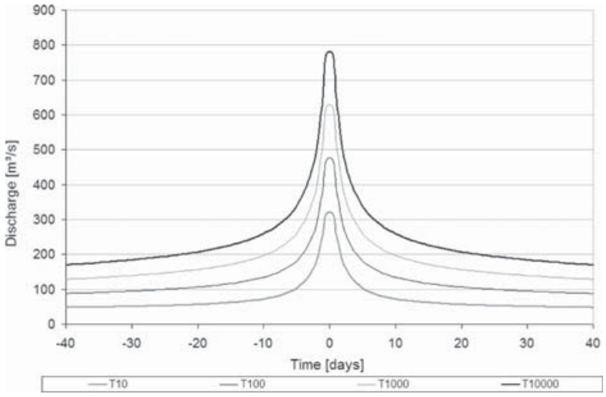

Figure 5. Upstream "composite hydrographs" at Melle (one of the several upstream boundaries) for return periods of 1, 2, 5, 10, 25, 50, 100, 500, 1000, 2500, 4000 and 10000 years.

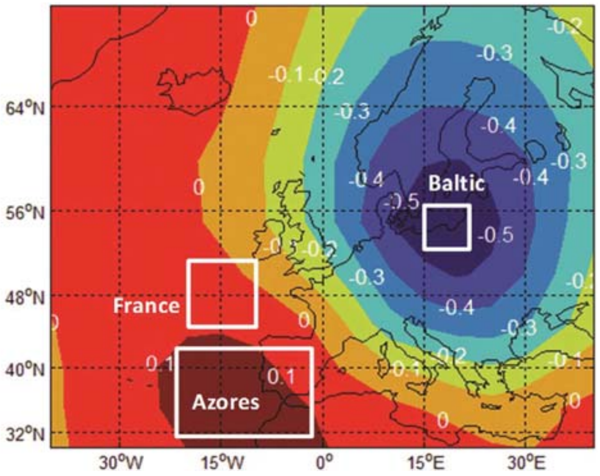

Figure 6. Mean correlation map of the surge with the SLP.

anticyclonic conditions over the near Atlantic between 30°N and 50°N.

This connection was further exploited to help in developing a regression model for estimating the surges. In this way, it is possible to quantify the changes in surges based on sea level pressure measurements alone.

By correlating the surges at Oostende with the SLP (NCAR) patterns, it can be shown that the SLP above Belgium does not have a strong influence on the surge. Rather, the low pressure above the Baltic Sea has a high correlation with the surges at the Belgian coast. Figure 6 exhibits the correlation for all the winter surges for the period 1921–2000. It is discerned that the Baltic Sea region has the highest correlation. Nevertheless, different combinations of regions were tested as predictors for the sea surges. The SLP at the tip of France, for example, was considered as a predictor because it was found to have high correlations for extreme surges (not shown).

For the empirical model development, regression analysis was applied for the period of 1980–1990 and verified for the period 1990–2000. The model fit was evaluated using the correlation coefficient to determine which source regions were important for the quantification of the surges. The regression equation takes the form of:

$$\hat{y} = b_0 + b_1x_1 + b_2x_2 + \cdots + b_kx_k \tag{1}$$

where k denotes the number of predictor variables x (SLP) with the corresponding coefficients b, and $\hat{y}$ is the predictand (surge).

After fitting the regression model, it was established that the Baltic region alone had a correlation of about 60.55% between the observed surges and simulated surges. Multiple regressions showed minor improvements in the correlation coefficients (Table 1). So the Baltic Sea region on its own was a reasonable approximation of the surges. Thus, the surges were estimated using the relation:

$$S = sc + b_1 SLP_{balticsea} \tag{2}$$

where S is the surge and sc and b_1 are constants and $SLP_{balticsea}$ is the SLP at the Baltic Sea.

5 QUANTIFYING FUTURE CLIMATE CHANGE

5.1 *Inland runoff scenarios*

The inland scenarios were based on climate scenarios that were previously developed for inland precipitation, temperature and potential evapotranspiration. Ntegeka et al. (2009) developed climate scenarios based on an ensemble approach after statistical analysis of the PRUDENCE RCMs and the IPCC AR4 GCMs. In that study, the following steps were followed:

- Validation of the RCM and GCM control runs (1961–1990) by comparison with historical data

Table 1. The correlation coefficient for the model for the modeled surges against the observed surges for the period 1990–2000.

	Azores	Baltic	France	Corr. (%)
Azores	X			19.6
Baltic		X		60.5
France			X	7.2
Azores	X	X		60.1
Baltic		X	X	61.5
France	X	X	X	61.6

at monthly and daily time scales: comparison of mean monthly and seasonal values and of the extreme value distribution

- Computation of change factors (called perturbation factors) from control run results (1961–1990) to scenario run results (2071–2100). Analysis of the monthly variations of the change factors and the monthly dependency between the change factor and the return period. For rainfall, change factors were computed for the monthly number of wet days and for the wet day rainfall intensities. Also the dependency was studied between the change factors of different variables (e.g. between rainfall and temperature/evapotranspiration).
- The change factors were then used to generate scenarios for the future by perturbing the historical intensities.
- The impact of the climate change on the peak flows was analysed and groups of models for high, mean and low conditions were identified. Through back tracking, the general rainfall and evapotranspiration seasonal variations were discerned. The derived rainfall-evapotranspiration relations were then used to generate representative scenarios ("high", "mean", "low"), which when simulated, mirrored the range of impacts from all the available scenarios.

5.2 *Runoff—surge correlation*

As this study aimed to combine the coastal scenarios to the inland scenarios, inland scenarios were compared with the coastal scenarios to establish relationships. A generalised lumped conceptual model based on the approach in Willems (in revision) was used for deriving the inland flow changes. The conceptual model requires only rainfall and evapotranspiration as inputs. The model structure comprises of 16 parameters, which means that the fitting of the model is faced with the equifinality phenomenon. However, in this research, only the climate model uncertainty was examined.

By studying the correlation of the future projections, it is possible to deduce how the coastal and inland changes will be combined. For example, it is vital to establish whether the occurrence high changes for surges coincide with the high inland changes for flows. It is therefore instructive to compare the surge at the coast for the same set of models with inland peak flow changes for the same catchment. This could then provide a basis for understanding the inland flow-coastal surge correlation and also help in developing future scenarios for the impact of the surge-flow changes on the Scheldt estuary.

As surge extremes tend to occur mostly during October to March, surges occurring in this season can act as a guide of understanding the future covariations in the coastal and inland areas. From the impact results from the Dender catchment (not shown), it was found that the future high impacts resulted from a combination of high surges with high peak flows. PRUDENCE models DMI-ECSC-A2 and SHMI-MPI-B2 showed this characteristic. Other models indicated that the mean surge changes in autumn would be combined with high, mean or low peak flow changes. Additionally, the low surge could be combined with a low peak flow change; model MPI-3006 displayed this characteristic. This low case would help to quantify the lowest impact on the floods in the Scheldt.

5.3 *Sea level rise*

The IPCC projections (IPCC, 2007) for global sea level rise fall in the range of 0.26–0.59 metres by the 2090s for their highest-emissions scenario. In this impact study, rises of 60 cm and 200 cm by 2100 compared to 1990 were selected based on the scenarios derived in recent sea level Belgian studies (Ozer et al. 2008, Van den Eynde et al. 2008).

5.4 *Wind changes*

Previous studies have analysed the wind speed from climate models and found that wind speeds will not change significantly in the 21st century. However, few studies have considered the analysis of the change in wind direction. This is perhaps explained from the low availability of high temporal resolution data that makes the wind directional analysis less useful. For this study, the Regional Climate Model CLM (Böhm et al. 2006) provided 6-hourly data for the analysis for two simulations (CLM_1 and CLM_2). The two runs differ in the initial anthropogenic conditions for the year 1860 used for running the control simulations for the period (1860–2000) after which the conditions for the year 2000 are used to project the changes for the period 2001–2100. Figure 7 shows the results

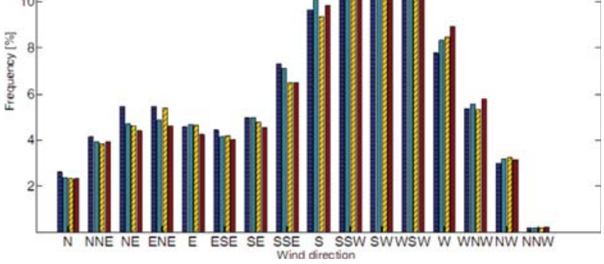

Figure 7. Wind direction percentages for CLM_1.

of one of the model runs (CLM_1). It is discerned that there is no clear increase or decrease of wind direction frequencies. There appears to be increases in southerly wind speeds but these are not important for surges in the Scheldt. Similar results are found for the second run (CLM_2). Recent studies (Ullman & Monbaliu 2009, Sterl et al. 2009) found that surge extremes at the Belgian coast are associated with winds from the northerly and westerly directions. Moreover, results from the two CLM runs were compared with wind speed outputs from models in the ENSEMBLE project which also applied the same scenario A1B. It was established that future wind speed changes for the future periods (not shown) are within the range of historical variability (1960–1990).

6 IMPACT ANALYSIS

The impact analysis to quantify the importance of the secondary sources for the Scheldt estuary is based on the hydrodynamic impact model results for three climate change scenarios, which involve combining sea level rise, surges and upstream flows (Table 2). The two high scenarios account for moderate and extreme high sea level rises, that is, 0.6 m and 2 m rise at the Belgian coastal area. The composite hydrographs are multiplied by the change factor of 30%, which was estimated from the high scenario. Similarly a surge of 21% was found to be the highest from the PRUDENCE and ENSEMBLES RCMs. The Sea Level Rise (SLR) is combined with high surges and high upstream flow increases. The third scenario combines the mean changes extracted from the PRUDENCE and ENSEMBLE climate models for the Scheldt area. In addition, the return periods of 100, 1000, and 10000 were studied for the impact. By preparing flood maps for the Dendermonde region (Fig. 8), it was possible to establish the risk factors, which were estimated by comparing the flood volumes for the present and future periods. For the short and medium periods (not shown), the factors were interpolated.

Table 2. Climate change scenarios for the 2080s.

	SLR	Surge	Upstream flow	Wind speed
S1:Extreme	2 m ↑	21% ↑	30% ↑	0%
S2:High	0.6 m ↑	21% ↑	30% ↑	0%
S3:Mean	0.6 m ↑	6% ↑	16% ↑	0%

6.1 *Ranking of the importance of the different sources*

The flood volume and the extension of the flooded area at Dendermonde were obtained from the flood hazard maps. This was done for each of the three scenarios (S1, S2, and S3) and for 2080s. The results were obtained for return periods of 100, 1000 and 10000 years. The evaluation of the risk multiplier is based on the comparison of the flood volume. It is worth noting that the scenarios refer to specific combinations of changes in mean sea level rise, storm surge and upstream flow. The difference in results between scenarios S1 and S2 gives an indication of the increase in the flood hazard due to the change from the mean to the high mean sea level rise change. The difference between scenarios S2 and S3 is due to the changes from the mean to

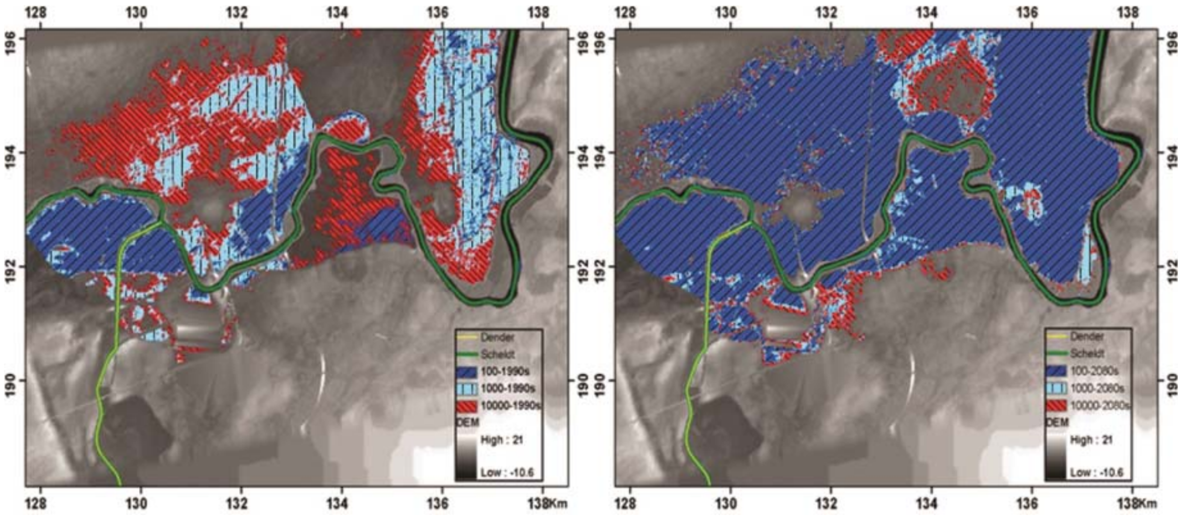

Figure 8. Flood hazard maps (1990s, 2080s) for return periods of 100, 1000 and 10000 years, after simulation of the correlated upstream composite hydrographs and downstream limnigraphs, for the Dendermonde area.

high changes in storm surge and upstream flow (Table 2).

Note that the risk factor is calculated as a ratio for present to future flood characteristic. It is higher for the lower return period of 100 years in comparison with the higher return periods. This is because the return period of flooding for the Dendermonde area is slightly lower than 100 years. A given increase in the Scheldt water level (although of same or lower absolute change) will lead to a larger relative change for the lower return periods. For illustrative purposes only, only results for the 100 year period and for the 2080s are discussed hereafter.

Next to the three scenarios S1, S2 and S3, which represent combined changes in mean sea level rise, surge and upstream flow, also the individual contributions from the each of the changes were estimated. Based on these results, the importance of the different sources (sea level rise, storm surge, wind characteristics and wave height, river flow) was established. For a 100 year flood S2 scenario, the upstream runoff climate change effect on the flood volume was the least important (1.03) followed by the sea level rise (1.71) and the surge (5.19). The combined risk factor was about 8. This means that the 100 year flood volume for the future 2080s is 8 times the current 100 year return period for the Dendermonde area. For the S1 scenario the order of importance from the highest to lowest is sea level rise (7.9), surge (5.19) and upstream (1.03). The combined risk factor is considerably high at 19.48. The combined risk for the S3 flood scenario is 3.78.

7 CONCLUSION

The impact of climate change on the Scheldt water levels has been investigated. The impact analysis of the hydroclimatic drivers along the Scheldt estuary is performed for flooding in the Dendermonde region. The quantification required the use of quasi 2D full hydrodynamic model, a regression model for the surges, a hydrological model and a set of climate models. However, the uncertainties associated with the models are not accounted for. This study only focuses on the climate change effect from the climate models to evaluate the relative importance of the different hydroclimatic drivers in the Scheldt region.

The quantification of the flood risk was made based on composite events developed for different return periods. For a detailed distributed model such events save on computational time. The flood volume climate change risk factors for the 3 boundary conditions imply that the sea level rise and surges are by far the most important factors when evaluating the flood risk in the Dendermonde region. It is clear that should the extreme changes for the three main Sources (mean sea-level, surge and upstream river flow) coincide, the impact would be disastrous.

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