On the effects of climate change on the wave loads on the Dutch water defences

Plan of Approach

Deltares

On the effects of climate change on the wave loads on the Dutch water defences

Plan of Approach

Sofia Caires

1230042-010

Deltares

Title
On the effects of climate change on the wave loads on the Dutch water defences

Client	Project	Reference	Pages
RWS	1230042-010	1230042-010-ZWS-0004	22

Keywords
Climate Change, Wave Climate, Extra tropical storms, tropical cyclones, BES, climate scenarios, Water defences, hydraulic loads, morphology

Summary
Knowledge of the effects of climate change and variability on wave loads is paramount for the design and assessment of water defences, in particular for assessing future flood risks for the Netherlands, and the safety of maritime transport, in particular the safety in ports in the Dutch Caribbean islands. Both the safety of the Dutch primary water defences against floods as the safety of maritime transport in Dutch Caribbean islands are concerns of the Dutch Directorate General of Public Works and Water Management (Rijkswaterstaat, RWS).

The aim of this study was to identify knowledge gaps and define a Plan of Approach to determine the effects of climate changes on the wave loads affecting the water defences of the Netherlands and the safety of maritime transport on the Dutch Caribbean islands. The plan of approach is defined along five research lines dealing with 1) Assessment of the effects of climate change on the wave loads along the Dutch primary water defences, 2) Assessment of the effect of left overs of tropical cyclones on the wave loads along the Dutch North Sea, 3) Assessment of the effect of climate change in the Caribbean extreme wave climate, 4) Assessment of the effects of climate change on Dutch coastal sand dredging and suppletion and 5) Definition of climate change scenarios affecting the coastal waters of the Netherlands. For each research line the Why, What and How are specified.

References
Plan van Aanpak KPP 2016 project: Versterking Onderzoek Waterveiligheid. Deltares report 1230042, H. Wolters.

Version	Date	Author	Initials	Review	Initials	Approval	Initials
2	Nov. 2016	Sofia Caires		Marcel van Gent		Wiel Tilmans	

State
final

Contents

List of Figures

1 Introduction

1.1 Background

Knowledge of the effects of climate change and variability on wave loads is paramount for the design and assessment of water defences, in particular for assessing future flood risks for the Netherlands, and the safety of maritime transport, in particular the safety in ports in the Dutch Caribbean islands. Both the safety of the Dutch primary water defences against floods[1] as the safety of maritime transport in Dutch Caribbean islands[2] are concerns of the Dutch Directorate General of Public Works and Water Management (Rijkswaterstaat, RWS).

Climate change can in principle impact both the mean sea level and the storminess of a given region, which are the main factors dictating variations in coastal wave loads. Therefore, on order to assess the effects of climate change on the wave loads on coastal defences, the effects of climate change on the mean sea level and storminess need to be quantified. When studying changes in storminess relevant for the Dutch coastal waters one needs to consider not only extra-tropical cyclones, which are responsible for most of the storms reaching the North Sea and the Netherlands, but also tropical cyclones which are responsible for most of the storms reaching the Dutch Caribbean waters. Some of which can travel further, with its leftovers also reaching the North Sea and the Netherlands.

Future effects of climate change are generally determined by resorting to climate projections. C*limate projections* are inferred from simulations using climate models of certain scenarios with assumptions on future socio-economic and technological developments. They differ from *climate predictions*, which attempt to produce a most likely description or estimate of the actual evolution of the climate in the future.

One of the missions of the Intergovernmental Panel on Climate Change (IPCC) is to provide comprehensive scientific assessments on environmental consequences of *projected* climate changes. The IPCC's assessment reports are written by groups of leading scientists, who base their figures and findings on published analyses of climate model results using different emission scenarios. The most recent IPCC's assessment report is the Fifth Assessment Report (AR5, https://www.ipcc.ch/report/ar5/), which is based on the Coupled Model Intercomparison Project phase five (CMIP5) data (http://cmip-pcmdi.llnl.gov/cmip5/). The previous IPCC's assessment report was AR4 (https://www.ipcc.ch/report/ar4/) which was based on the assessment of the model results available in Coupled Model Intercomparison Project phase three (CMIP3) database (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php). There has been a change in terms of the scenarios considered in CMIP3 and CMIP5. In CMIP3 the baseline scenarios of the Special Report on Emissions Scenarios (SRES, (http://en.wikipedia.org/wiki/Special_Report_on_Emissions_Scenarios) played an important role, with the A1b scenario being generally considered close to the business as usual emission scenario. In CMIP5 the considered scenarios are Representative Concentration Pathway (RCP, http://www.wmo.int/pages/themes/climate/emission_scenarios.php) scenarios with RCP 6 to 8.5 (2071-2100, radioactive forcing of 6 to 8.5 W/m2 at the end of 2100) being those that come closer A1b.

[1] *http://www.helpdeskwater.nl/secundaire-navigatie/english/legislation/@29167/dutch-water-act/*

[2] *https://www.rijksdienstcn.com/en/infrastructure-and-the-environment/bes-maritime-management-act*

The IPCC reports contain an overview on the effects of increased emissions on different environmental variables and are therefore the official source for such figures. However, not all variables are computed by the climate models with results in CMIP databases, one of those variables being ocean waves. Furthermore, given that the applied climate model are global and need to be run for quite long, their resolution is often too coarse to capture local and small scale effects. The CMIP data need, therefore, to be downscaled to a certain region, as for instance the Dutch Coast, or variables, as for instance wave data, or small scale effects, as for instance tropical cyclones. The downscaling of climate model results can be carried out either dynamically, by running numerical models such as waves models and regional climate models, or statistically, by applying current climate statistical relationships between variables.

The Coordinated Ocean Wave Climate Project (COWCLIP, http://www.jcomm.info/index.php?option=com_content&view=article&id=275&Itemid=37) group has been pivotal in coordinating wave climate projection studies using as input CMIP wind and surface pressure data, with the AR5 entries on effects of climate change on the global wave climate having been based on publication by members of the group and providing the needed references for the AR5 data on wave projections. The available data are, however coarse, providing yet no projections of the effect of climate change on the wave climate along the coast of the Netherlands and the Dutch Caribbean islands.

The Royal Netherlands Meteorological Institute (KNMI) provides a translation of the global IPCC results to the Netherlands. Their latest translation, the KNMI'14-scenario's (KNMI, 2015) provide figures for sea level rise in the Dutch North Sea and changes of the wind climate in the Netherlands, but provide no figures for the effects of climate change on waves and wave loads.

1.2 Motivation

Sea level rise and increased severity of storms can lead to further increases in coastal wave loads. For instance, in extreme events the nearshore significant wave height is proportional to the water depth (between 30 and 60% of the local depth). A sea level rise of 1m means at a depth of 5 m a 20% increase of the depth; if the wave load for a given failure mechanism of water defences is taken to be proportional to the squared significant wave height (which is the case for many failure mechanisms and there are also mechanisms for with the wave load is proportional to powers higher than 2), then a sea level rise of 1m would in such situation lead to an increase of the wave load by 40%. Changes in storminess may also affect the nearshore significant wave height, mean wave period and mean wave direction affecting also the resulting wave loads in coastal defences and accessibility of ports and harbours. Furthermore, changes in the mean wave direction in particular may lead to changes in morphological development and affect sand dredging and suppletion needs.

1.3 Aim

The aim of this study was to identify knowledge gaps and define a Plan of Approach to determine the effects of climate changes on the wave loads affecting the water defences of the Netherlands and the safety of maritime transport on the Dutch Caribbean islands.

1.4 Approach

The approach followed in this study consisted on collecting and reviewing available studies and publications in order to inventorize what is presently known and define what still needs to be studied in order to determine the effects of climate changes on the wave loads affecting the water defences of the Netherlands and on the safety of maritime transport on the Dutch Caribbean islands (chapters 2 to 4). Having identified current knowledge gaps a plan of approach has been defined (Chapter 5). The plan of approach is defined along five research lines. For each research line the Why, What and How are specified.

2 Sea level rise

2.1 Fifth IPCC assessment

The AR5 figures on projections of sea level rise are based on the CMIP5 data and are given in Church et al. (2013). Figure 4.1 shows a reproduction of the projected global mean sea level rise and the regional percentage of the deviation from the global mean value. The global mean point estimates range from 0.4 m to 0.8 m depending on the scenario. For the North Sea and the Dutch Caribbean waters regional percentage of the deviation from the global mean value is about 10%.

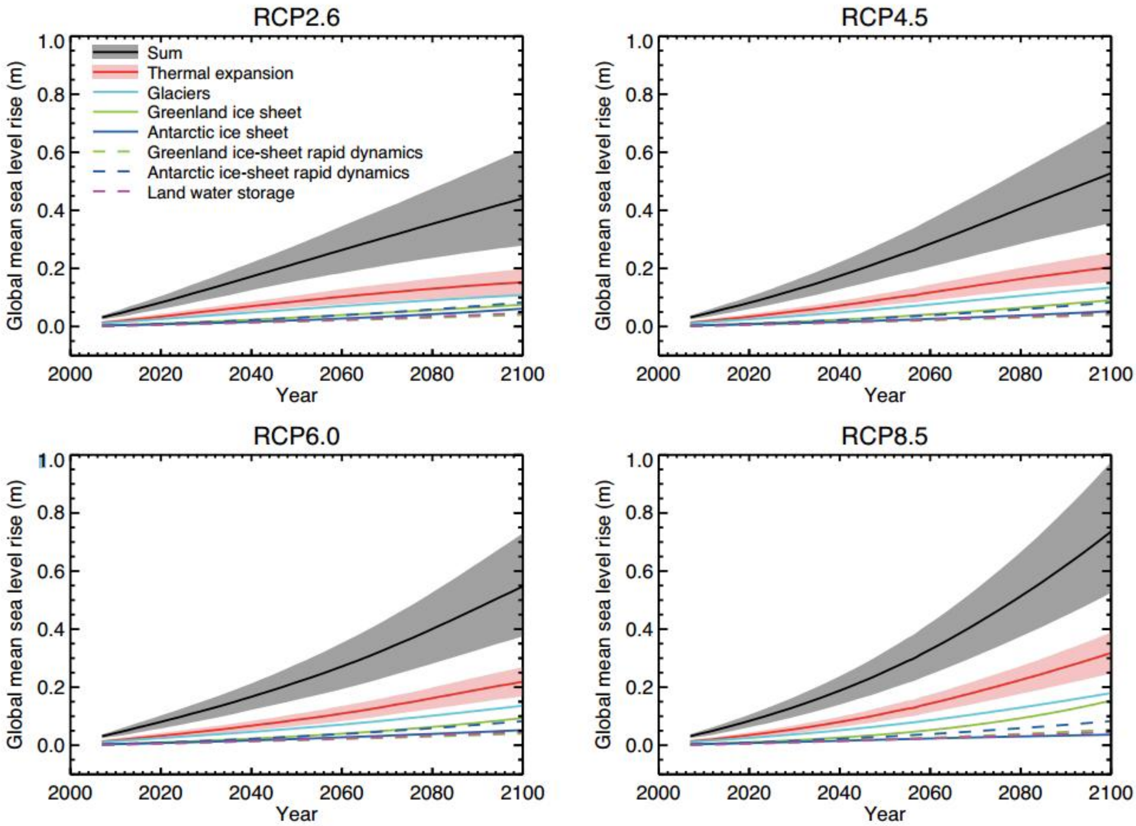

Figure 2.1 Projections from process-based models of global mean sea level rise relative to 1986–2005 and for the four RCP scenarios. The lines show the median projections. For global mean sea level rise and the thermal expansion contribution, the likely range is shown as a shaded band. The contributions from ice sheets include the contributions from ice-sheet rapid dynamical change, which are also shown separately. Taken from Church et al. (2013, Figure 13.11).

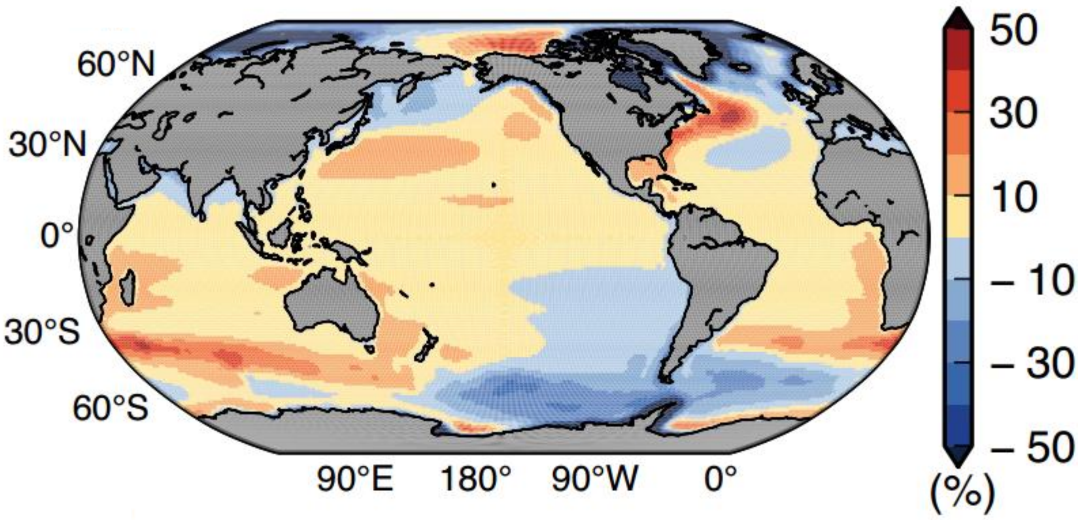

Figure 2.2 Percentage of the deviation of the ensemble mean regional relative sea level change between 1986–2005 and 2081–2100 from the global mean value. The figure was computed for RCP4.5, but to first order is representative for all RCPs. Taken from Church et al. (2013, Figure 13.21).

2.2 Post fifth IPCC assessment studies (recent and on-going studies)

The KNMI'14-scenario's are organized along two dimensions, one representing global-mean temperature rise, and the other regional precipitation/circulation change. Four scenarios are defined along these dimensions:

- G_L - moderate increases in temperature combine with low values of regional precipitation/circulation change;
- G_H - moderate increases in temperature combine with high values of regional precipitation/circulation change;
- W_L - large increases in temperature combine with low values of regional precipitation/circulation change; and
- W_H - large increases in temperature combine with high values regional precipitation/circulation change.

Figure 2.3 shows the sea level rise along the coast of the Netherlands according to the KNMI'14-scenarios. The upper bound of the values for the W scenarios corresponds to a sea level rise of about 1 m NAP by the end of the 21st century.

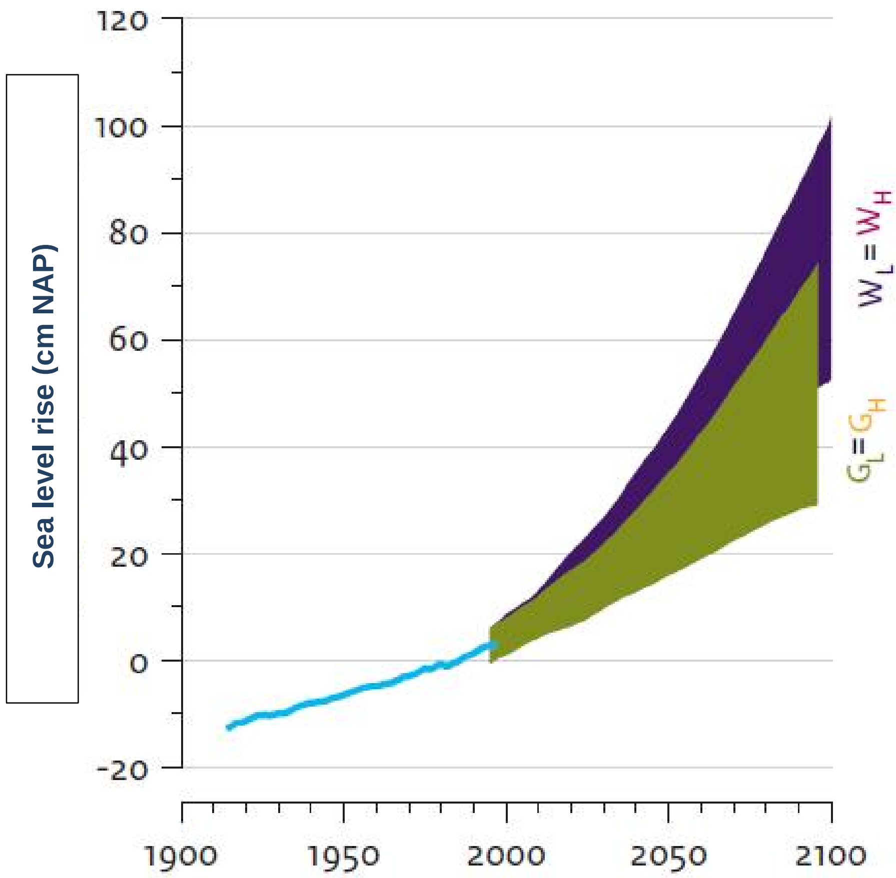

Figure 2.3 Projections of sea level rise along the coast of the Netherlands according to the KNMI'14-scenarios. Taken from KNMI (2015).

Church et al. (2013) state that only the collapse of the marine-based sectors of the Antarctic ice sheet, if initiated, could cause GMSL to rise substantially above the likely range given in Figure 2.1 during the 21st century adding that this potential additional contribution cannot be precisely quantified but there is medium confidence that it would not exceed several tenths of a metre of sea level rise. However, Pollard and DeConto (2016) report that the Antarctica has the potential to contribute more than a metre of sea level rise by 2100, if emissions continue unabated. That could imply a potential sea level rise of about 2 m NAP along the coast of the Netherlands by the end of the 21st century. The uncertainties associated with such figures are, however, large.

3 Surface wind

3.1 Extra-tropical cyclones

3.1.1 Fifth IPCC assessment

According to (Haarsma at al., 2013), in the present-day climate, the vast majority of west European storms originate from baroclinic instability in the midlatitudes, which is driven by the north-south atmospheric temperature gradient. In a warmer climate, due to increased concentrations of greenhouse gases, this meridional temperature gradient will decrease because the Arctic will warm faster than the equatorial regions, implying that baroclinic instability will reduce which can lead to reduced wintertime storms (in frequency and intensity). On the other hand, the increase of tropopause height and increased latent heat release can lead to an increase in the intensity wintertime storms. These two opposing effects may approximately balance, as it has been found that global warming only induces minor changes in the frequency and intensity of midlatitude storms. Furthermore, according to Stocker et al. (2013) the large variability on interannual to decadal time scales hampers robust conclusions on long-term changes in atmospheric circulation in many instances. Accordingly, the main conclusions of Christensen et al. (2013) and Collins et al. (2013) are that there is low confidence in near-term projections of the position and strength of Northern Hemiphere (NH) storm tracks. Natural variations are larger than the projected impact of GHGs in the near term. In the long-term mean sea level pressure is projected to decrease in high latitudes and increase in the mid-latitudes, poleward shifts in the mid-latitude jets of about 1 to 2 degrees latitude are likely at the end of the 21st century under RCP8.5 in both hemispheres, with weaker shifts in the NH. However, there is substantial uncertainty and thus low confidence in projecting changes in NH storm tracks, especially for the North Atlantic basin.

3.1.2 Post fifth IPCC assessment studies

De Winter et al. (2013) analyzed CMIP5 wind data from 12 models and of scenarios with RCP 4.5 and 8.5, they found no significant changes in extreme wind speeds and an indication that the annual extreme wind events are coming more often from western directions, compatible with a poleward shift of the North Atlantic storm track. More recently, Sterl et al. (2015) analyzed downscaled CMIP5 EC-Earth data using a regional climate model for the definition of the KNMI'14 scenarios. Their main conclusion is that global warming will not change the wind climate over the Netherlands and the North Sea beyond the large range of natural climate variability that has been experienced in the past. In conclusion, these studies indicate with a large degree of uncertainty that no large changes are expected in projected winds above the North Sea.

3.2 Tropical cyclones

3.2.1 Fifth IPCC assessment

According to Stocker et al. (2013) projections for the 21st century indicate that it is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged, concurrent with a likely increase in global mean tropical cyclone maximum wind speed. However, it is more likely than not that the frequency of the most intense storms will increase substantially in the North Atlantic under projected 21st century warming, see Figure 3.1.

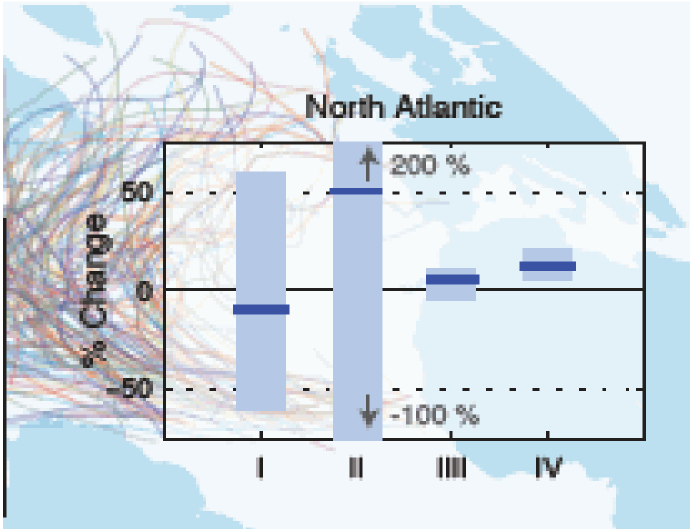

Figure 3.1 Projected changes in tropical cyclone statistics. All values represent expected percentual change in the average over period 2081–2100 relative to 2000–2019, under an A1B-like scenario, based on expert judgement after subjective normalization of the model projections. Four metrics were considered: the percentual change in I) the total annual frequency of tropical storms, II) the annual frequency of Category 4 and 5 storms, III) the mean Lifetime Maximum Intensity (LMI; the maximum intensity achieved during a storm's lifetime) and IV) the precipitation rate within 200 km of storm centre at the time of LMI. For each metric plotted, the solid blue line is the best guess of the expected percentual change, and the coloured bar provides the 67% (likely) confidence interval for this value (note that this interval ranges across –100% to +200% for the annual frequency of Category 4 and 5 storms). A randomly drawn (and coloured) selection of historical storm tracks are underlaid to identify regions of tropical cyclone activity. Taken from Stocker et al. (2013, Figure TS.26).

3.2.2 Post fifth IPCC assessment studies

Haarsma et al. (2013) used a very high resolution global climate model (~25 km grid size) with prescribed sea surface temperatures to show that greenhouse warming enhances the occurrence of hurricane-force (> 32.6ms–1) storms over Western Europe during early autumn (August–October), the majority of which originate as a tropical cyclone. Their results show that the rise in Atlantic tropical sea surface temperatures extends eastward the breeding ground of tropical cyclones, yielding more frequent and intense hurricanes following pathways directed towards Europe and which underway transform into extra-tropical depressions and reintensify after merging with the midlatitude baroclinic unstable flow. This leads to a clear increase in the frequency of severe winds (Beaufort 11–12, > 28.4ms–1) during autumn in the North Sea and Gulf of Biscay and a factor 5 increase of the probability of present-day extreme events over the North Sea. Further studies into the transition of tropical cyclones into extra-tropical cyclones are to be carried out by KNMI (Haarsma and colleagues) in EU Horizon 2020 project PRIMAVERA (https://www.primavera-h2020.eu/). It would be of interest to also study the effect of such transition in the North Sea wave conditions; however, there is yet no funding for such a study.

4 Wind waves

4.1 Fifth IPCC assessment

The AR5 figures on projections of ocean waves are given in Church et al. (2013), which have been determined by considering wave projections carried out by different member of the COWCLIP community in some cases by means of dynamical downscaling and other cases statistical downscaling of the CMIP5 winds and sea level pressures (Hemer et al., 2013). Figure 4.1 shows a reproduction of the projected changes in mean wave conditions given in Church et al. (2013). The figure shows a non-significant increase in the significant wave height and decrease in the mean wave period along the North Sea coast of the Netherlands. With relation to projected changes in extreme wave conditions and in the North Sea reference is made to Caires et al. (2008), Debernard and Roed (2008) and Grabermann and Weisse (2008) who report a 6 to 18% along the east North Sea coast in the significant wave height extremes.

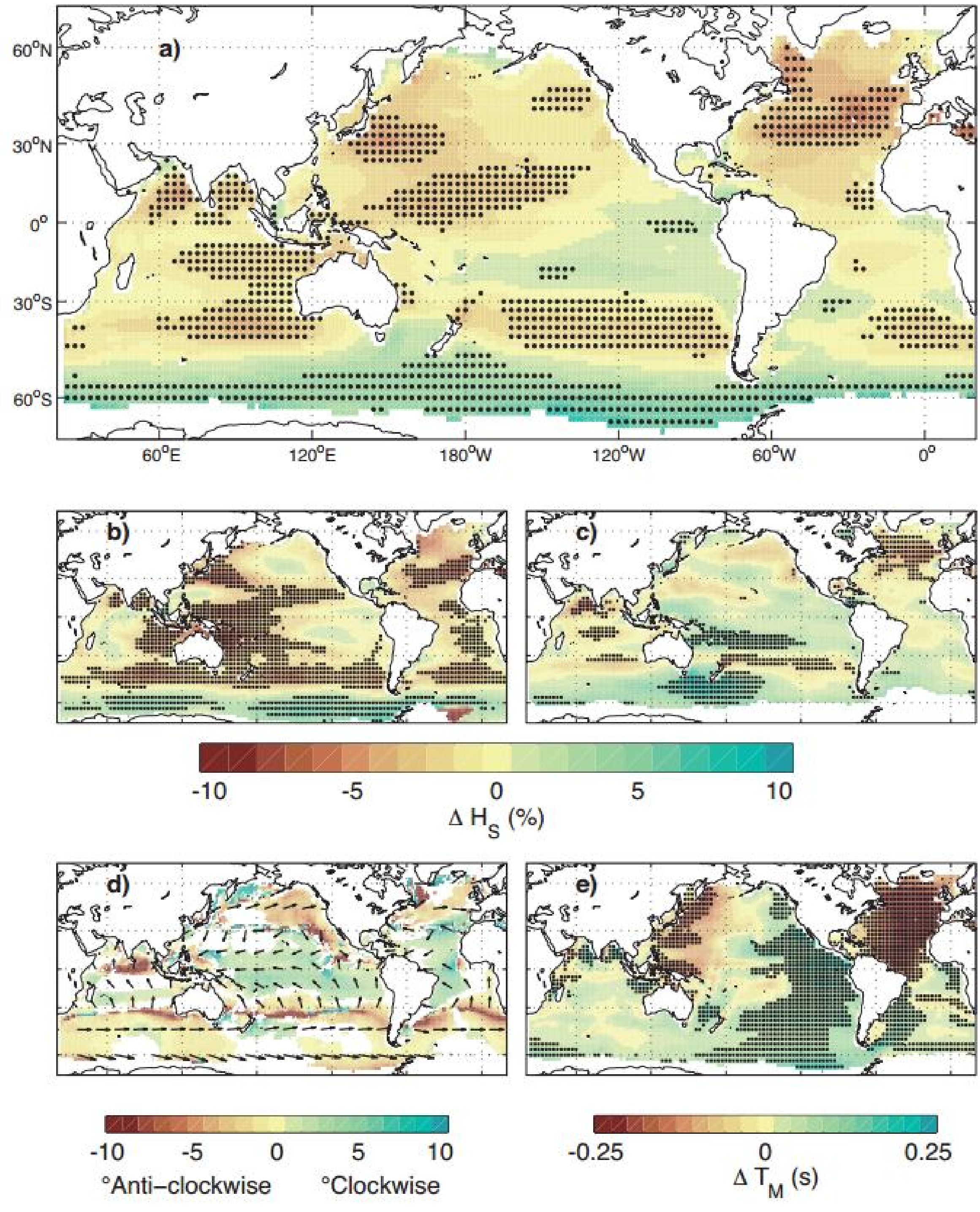

Figure 4.1 Projected changes in wave conditions (~2075–2100 compared with ~1980–2009). (a) Percentage difference in annual mean significant wave height. (b) Percentage difference in means of January to March significant wave height. (c) Percentage difference in means of July to September significant wave height. Hashed regions indicate projected change is greater than the 5-member ensemble standard deviation. (d) As for (a), but displaying absolute changes in mean wave direction, with positive values representing projected clockwise rotation relative to displayed vectors, and colours shown only where ensemble members agree on sign of change. (e) As for (a), but displaying absolute changes in mean wave period. Taken from Church et al. (2013, Figure 13.26)

4.2 Post fifth IPCC assessment studies (recent and on-going studies)

De Winter et al. (2012) investigated the change in wave conditions in the North Sea considering the SRES A1b scenario, wind data from the ESSENCE climate projections (Sterl et al., 2008) and the NEDWAM wave model (Burgers, 1990). They found between 1961–1990 and 2071– 2100 no significant changes in the means of the significant wave height and mean wave period, a decrease in the annual maxima of the mean wave period (by 0.3-0.6s), and a in the direction of the annual maximum wave conditions from north and north-west to west and south-west (induced by a similar shift in the direction of the extreme wind speeds). The model used got no boundary waves and reflects therefore only changes in the local wind. Furthermore, the considered locations are at relatively deep water with water level, in particular sea level rise effects not having been taken into account.

Currently the COWCLIP group is busy a Phase-II ensemble of wave climate projections (http://www.jcomm.info/index.php?option=com_oe&task=viewDocumentRecord&docID=17213). Phase-II aims at creating more confidence in wave projections with different groups planning both statistical and dynamical downscaling of the CMIP5 wind and mean sea level pressure data. Unfortunately, there is presently no planned downscaling of the CMIP5 wind and mean sea level pressure data to waves nearshore of the Netherlands nor around the Dutch Caribbean islands.

5 Inventory of project objectives, work packages and activities

5.1 Knowledge gaps

From the summary given above on the available data on the effects of climate change on winds, waves and water levels, it can be concluded that in order to determine the effects of climate changes on the wave loads affecting the water defences and maritime activity of the Netherlands and the Dutch Caribbean islands the following knowledge gaps need to be filled:

- Consequences of the projected changes in extra-tropical storminess and sea level rise along the coast of the Netherlands on the hydraulic loads in the Dutch primary water defences (dikes and dunes).
- Consequences of the projected changes in tropical storminess and sea level rise along the coast of the Netherlands on the hydraulic loads in the Dutch primary water defences.
- Consequences of projected changes in North Sea wave climate on the current sand dredging and suppletion needs for the safely of maritime activities and coastline maintenance.
- Consequences of the projected changes in tropical storminess and sea level rise on the maritime activity of the Dutch Caribbean islands.

The five activities described in the following sections have been defined aiming at fulfilling these knowledge gaps.

5.2 Activity 1: Assessment of the effects of climate change on the wave loads along the Dutch primary water defences

5.2.1 Why

There are no available figures on the consequences of the expected changes in extra-tropical storminess and sea level rise along the coast of the Netherlands on the hydraulic loads in the Dutch primary water defences (dikes and dunes). According to the current knowledge a sea level rise of up to 1 to 2 m along the coast of the Netherlands is possible and also changes in the North Atlantic storminess may affect the waves reaching the Dutch water defences. The quantification of such effects and associated uncertainties would allow a more accurate assessment and design of the primary water defences of the Netherlands.

The assessment of such effects would not only allow us to have the know how but also to contribute to international platforms as COWVLIP.

5.2.2 What

The goal of this activity would be to assess the effects of climate loads on the hydraulic loads along the Dutch primary water defences.

5.2.3 How

The following steps are to be carried out:

1. Selection of CMIP5 and other model wind and sea level pressure results.
2. Selection of sea level rise scenarios.
3. Dynamical and statistical downscaling of the wind and sea level data of 1. and 2. into hydraulic loads along a number of selected Dutch primary water defences.
4. Positioning of the uncertainties in the hydraulic loads of 3. with relation to other uncertainties relevant in de determination of hydraulic boundary conditions.

5.2.4 Links to other projects

The study would fall within the framework and contribute to the following project:

- COWCLIP – International community on the effects of climate change on waves.
- WTI – Dutch government program for the assessment of the Dutch primary water defences.
- HWBP (HoogwaterBeschermingsProgramma) – A joint Dutch government and water boards program for safety against flooding.
- NKWK – Dutch National Knowledge and innovation programme water and climate.

5.2.5 Budget and funding

This study should be carried together with KNMI and other COWCLIP members which may be able to provide downscaled wind and wave data.

The project is estimated to involve the following effort:

- Duration: 6 months
- Time allocation: KNMI 25%, Deltares 75%
- Total budget: 150K euros

Possibilities for funding from HWNBP are being sought.

5.3 Activity 2: Assessment of the effect of left overs of tropical cyclones on the wave loads along the Dutch North Sea

5.3.1 Why

It is expected that climate warming will lead to a poleward and eastward extension of the tropical cyclone genesis area and that the Dutch North Sea waters will be more frequently affected by post-tropical cyclones (Haarsma et al., 2013), which is of direct relevance for the water defences of the Netherlands.

5.3.2 What

Assessment of the effect of left overs of tropical cyclones on the wave loads along the Dutch North Sea.

5.3.3 How

In this study high-resolution climate, flow and wave models will be set up to study the effects of in tropical cyclone genesis on coastal hydraulic loads in the Dutch North Sea.

The study it to be carried out in KNMI and Deltares, with high-resolution climate and water level modelling being carried out at KNMI and wave and flow modelling being carried out in Deltares.

The relevant data will most likely be generated by the following models: EC-EARTH, ROMS, Delft3D-flow and SWAN.

5.3.4 Links to other projects

This activity has a clear link with the COWCLIP project. With COWCLIP partners a Marie Skłodowska-Curie Network (ITN) grant proposal on “Regional Waves, Marine Climate and Coastal Hazards” is being written with this joint KNMI and Deltares project as one of the tasks. If successful the Marie Curie grant can be used to finance one joint KNMI and Deltares PhD student for four years. For the cost of supervision of the PhD student matching found will be needed.

This activity is also linked with the European Horizon 2020 project PRIMAVERA (https://www.primavera-h2020.eu/) from which the wind data are to be obtained.

5.3.5 Budget and funding

This study should only go ahead if the proposed Marie Skłodowska-Curie Network (ITN) “Regional Waves, Marine Climate and Coastal Hazards” project is granted. Complementary funding of 10 days per year for KNMI and for Deltares will then be needed for the supervision of the student.

The project is estimated to involve the following effort:

- Duration: 4 years
- Time allocation per year: 10 days KNMI, 10 days Deltares
- Total budget: 20K – 25K euros per year

Possibilities for funding from have been sought from the RWS project “KPP Versterking Onderzoek Waterveiligheid 2017” with no success. Possibilities for funding of the Deltares contribution from Deltares internal R&D funds are being sought.

5.4 Activity 3: Assessment of the effect of climate change in the Caribbean extreme wave climate

5.4.1 Why

The frequency and intensity of tropical cyclones is expected to be affected by climate change. Changes in tropical cyclone intensity and frequency and expected sea level rise are of direct relevance for the hydraulic loads on the water defences of the Dutch Caribbean islands, the BES (Bonaire, Sint Eustatius and Saba) islands, and the maritime transport in the region.

5.4.2 What

Assessment of the effect of climate change in the extreme wave climate around the BES islands, accounting for sea level rise and projected changes in tropical cyclone activity.

5.4.3 How

The following steps are to be carried out:

1. Determination of current extreme wave climate by means of wave modelling considering historical tropical cyclones.
2. Determination of projections of extreme wave climate by means of wave modelling considering tropical cyclones with projected changes in trajectory, intensity and frequency and sea level rise.
3. Determination of the possible effects of climate change in the wave climate affecting the harbours of the BES islands.

5.4.4 Links to other projects

The study would fall within the framework and contribute to the following projects:

- COWCLIP – International community on the effects of climate change on waves.
- Maritime risk assessment of the BES islands - The Minister of Infrastructure and the Environment (IenM) in the Netherlands. Rijkswaterstaat (Directorate General of Public Works and Water Management - RWS) is responsible for establishing and managing the organization for responding to maritime incidents in the Territorial Sea and the Exclusive Economic Zone (EEZ) of the BES islands.

5.4.5 Budget and funding

This study should be carried together with KNMI and other COWCLIP members which may be able to provide downscaled wind and wave data.

The project is estimated to involve the following effort:

- Duration: 3 months
- Time allocation: KNMI 25%, Deltares 75%
- Total budget: 75K euros

Possibilities for funding from have been sought from the RWS project “KPP Versterking Onderzoek Waterveiligheid 2017” with no success. Possibilities for funding other RWS programmes are being sought.

5.5 Activity 4: Assessment of the effects of climate change on Dutch coastal sand dredging and suppletion

5.5.1 Why

Changes in the intensity of extreme storms, water levels and directionality of the wave climate can imply that the current sand suppletion and dredging programs for the Dutch coast and navigation channels need to be adjusted.

5.5.2 What

Study the effect of climate change in dune erosion and navigation channel dredging.

5.5.3 How

This activity should build from the results of activities 1 and 2, which the morphological changes being determined by means of sensitivity analysis studies resorting to the Delft3D and X-Beach models.

5.5.4 Links to other projects

The study would fall within the framework and contribute to the following projects:

- Kustgenese 2 (KG2) – A long term Dutch coastal research program that aims at providing by 2020 recommendations on policy of coastal suppletions.
- WTI – Dutch government program for the assessment of the Dutch primary water defences.

5.5.5 Budget and funding

This study is to build on the results from Activity 1. The project is estimated to involve the following effort:

- Duration: 6 months
- Total budget: 125K euros
-

Possibilities for funding from have been sought from the RWS project "KPP Versterking Onderzoek Waterveiligheid 2017" with no success. Possibilities for funding other RWS programmes are being sought.

5.6 Activity 5: Definition of climate change scenarios affecting the coastal waters of the Netherlands

5.6.1 Why

Klijn et al. (2015) defined projections of extreme discharges of the rivers Rhine and Meuse in the Netherlands and found the need to define a fifth scenario to complement the four KNMI'14 scenarios, which are local to the Netherlands. The fifth scenario, referred to as $W_{H,dry}$, corresponds to a situation in which there is dry weather over the whole European continent. A situation of relevance for the discharges of the rivers Rhine and Meuse. Such an assessment of the KNMI'14 scenarios in terms of hydraulic loads has not yet been carried out and it can also be that a scenario focussing on the North Atlantic storm track region, where the wind forcing is of relevance for the hydraulic loads along the Netherlands coast is of relevance. In the current KNMI'14 scenarios only changes in local (Netherlands and coastal North Sea) winds are considered.

5.6.2 What

Study whether the KNMI'2014 scenarios can be enhanced in order to account for changes in North Atlantic extra-tropical storminess and further traveling of Tropical Cyclones to the North Atlantic.

5.6.3 How

Based on the results of activities 1 and 2 a scenario of relevance for effects of climate changes on the coastal waters of the Netherlands will be defined.

5.6.4 Links to other projects

The study would fall within the framework and contribute to the following projects:
- NKWK – Dutch National Knowledge and innovation programme water and climate.
- Delta programme – Programme aiming at ensuring that the Dutch flood risk management and freshwater supply are sustainable and robust by 2050.

5.6.5 Budget and funding

This study should be carried together with KNMI and only if the need for it identified based on the results of activities 2 and 3.

The project is estimated to involve the following effort:

- Duration: 2 months
- Time allocation: KNMI 25%, Deltares 75%
- Total budget: 30K euros

Once the need for the study has been established possibilities for funding from the to be identified most adequate RWS programme is to be sought.

References

Burgers, G., 1990: *A guide to the Nedwam wave model*. KNMI Scientific Report SR-90-04, http://bibliotheek.knmi.nl/knmipubWR/WR90-04.pdf.

Caires, S., Groeneweg, J. and A. Sterl, 2008: Past and future changes in the North Sea extreme waves. *Coastal Engineering* 2008 (pp 547-559), Hamburg, September 2008.

Christensen, J.H., K. Krishna Kumar, E. Aldrian, S.-I. An, I.F.A. Cavalcanti, M. de Castro, W. Dong, P. Goswami, A. Hall, J.K. Kanyanga, A. Kitoh, J. Kossin, N.-C. Lau, J. Renwick, D.B. Stephenson, S.-P. Xie and T. Zhou, 2013: *Climate Phenomena and their Relevance for Future Regional Climate Change*. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: *Sea Level Change. In: Climate Change 2013: The Physical Science Basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner, 2013: *Long-term Climate Change: Projections, Commitments and Irreversibility*. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Debernard, J. B., and L. P. Røed, 2008: Future wind, wave and storm surge climate in the Northern Seas: A revisit. *Tellus A*, 60, 427–438.

De Winter, R.C., A. Sterl, J.W. de Vries, S. L. Weber and G. Ruessink, 2012: The effect of climate change on extreme waves in front of the Dutch coast. *Ocean Dynamics*, 62, 1139–1152.

De Winter, R.C., A. Sterl and G. Ruessink, 2013: Wind extremes in the North Sea basin under climate change: an ensemble study of 12 CMIP5 GCMs. *Journal of Geophysical Research: Atmospheres, 118, 1601–1612, doi:10.1002/jgrd.50147.*

Grabemann, I. and R. Weisse, 2008: Climate change impact on extreme wave conditions in the North Sea: an ensemble study. *Ocean Dynamics*, 58, 199-212, 10.1007/s10236-008-0141-x.

Haarsma, R. J., W. Hazeleger, C. Severijns, H. de Vries, A. Sterl, R. Bintanja, G. J. van Oldenborgh and H. W. van den Brink, 2013: More hurricanes to hit western Europe due to global warming. *Geophysical Research Letters*, 40, 1783–1788, doi:10.1002/grl.50360.

Hemer, M. A., Y. Fan, N. Mori, A. Semedo, and X. L. Wang, 2013: Projected future changes in wind-wave climate in a multi-model ensemble. *Nature Clim. Change*, 3, 471–476.

Klijn, F., M. Hegnauer, J. Beersma and F. Sperna Weiland, 2015: *Wat betekenen de nieuwe klimaatscenario's voor de rivierafvoeren van Rijn en Maas? Samenvatting van onderzoek met GRADE naar implicaties van nieuwe klimaatprojecties voor rivierafvoeren* (in Duch). Joint Deltares and KNMI report, September 2015.

KNMI, 2015: KNMI'14 klimaatscenarios's voor Nederland (in Dutch), http://www.klimaatscenarios.nl/images/Brochure_KNMI14_NL.pdf.

Pollard, D. and R.M. DeConto,2016: Contribution of Antarctica to past and future sea-level rise. *Nature*, 531, 591–597, http://dx.doi.org/10.1038/nature17145.

Sterl, A., C. Severijns, G.J. van Oldenborgh, H. Dijkstra, W. Hazeleger, M. van den Broeke, G. Burgers, B. van den Hurk, P.J. van Leeuwen, and P. van Velthoven, 2008: When can we expect extremely high surface temperatures?. *Geophys. Res. Lett*., 35, L14703, doi:10.1029/2008GL034071.

Sterl, A., A.M.R. Bakker, H.W. van den Brink, R. Haarsma, A. Stepek, I.L. Wijnant and R.C. de Winter, 2015: Large-scale winds in the southern North Sea region: the wind part of the KNMI'14 climate change scenarios. *Environ. Res. Lett.*, 10, 035004 doi:10.1088/1748-9326/10/3/035004.

Stocker, T.F., D. Qin, G.-K. Plattner, L.V. Alexander, S.K. Allen, N.L. Bindoff, F.-M. Bréon, J.A. Church, U. Cubasch, S. Emori, P. Forster, P. Friedlingstein, N. Gillett, J.M. Gregory, D.L. Hartmann, E. Jansen, B. Kirtman, R. Knutti, K. Krishna Kumar, P. Lemke, J. Marotzke, V. Masson-Delmotte, G.A. Meehl, I.I. Mokhov, S. Piao, V. Ramaswamy, D. Randall, M. Rhein, M. Rojas, C. Sabine, D. Shindell, L.D. Talley, D.G. Vaughan and S.-P. Xie, 2013: *Technical Summary.* In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.