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Output Workshop 'Climate Scenarios Flemish Coast'

12 December 2018 – Flanders Hydraulics Research, Antwerp

INTRODUCTION

This document presents the output of the workshop 'Climate Scenarios for the Flemish Coast' which was initiated by the Flemish government.

The initiative originates from the common need in the projects Complex Project Coastal Vision (CPK) and Climate Resilient Coast (CREST), to have universal, scientifically accepted climate scenarios for the Flemish coast. CPK requires extreme scenarios to be able to design an adaptive coastal protection until 2100. Researchers from CREST require a wider perspective, including more moderate scenarios to refine their scientific models. As other research groups require similar scenarios, it is desirable to develop universal coastal climate scenarios, adapted to recent insights.

The workshop was held with national experts on the 12th of December 2018 at the facilities of the Flanders Hydraulics Research, Antwerp. Prior to the workshop, input documents were provided to all participants, which contained a summary of relevant research (MOW, 2018) and a set of proposed scenarios, which formed the basis of the debate. The output of the workshop was submitted for review and this feedback was incorporated in the report.

The following chapters present (a) the climate projections, to be used in CPK and CREST and (b) a summary with future research required to further elaborate on these projections according to the needs of potential users. The attachments present the list of participants and reviewers (Annex 1), a short introduction of CPK, CREST and CORDEX.be (Annex 2), the set of initial scenarios proposed prior to the workshop (Annex 3), a compilation of recent studies on global sea level rise (Annex 4), reflections on the initially proposed scenarios as discussed during the workshop (Annex 5) and finally feedback received on the output of the workshop (Annex 6).

Note that the final set of climate projections is based on current scientific insights, but as the future still holds a certain level of uncertainty, some parameters were derived through expert elicitation [1]. The projections are prone to change, according to future scientific insights.

Special thanks go to all participants of the workshop and the experts whose feedback significantly improved this document.

[1] The projections were not derived from one elaborate multi-model ensemble study. It is a compilation of several studies.

SET OF CLIMATE PROJECTIONS

Table 1 presents the final set of projections, which is an update of the scenarios initially proposed prior to the workshop (Annex 1). They consist of 3 climate scenarios and one set of extremes ('Extreme Situation') with high impact, but low probability of occurrence. The spread in projections represent the uncertainty envelope related to (a) future socio-economic development and related greenhouse-gas emissions, (b) model-uncertainty addressed in multi-model ensembles, (c) knowledge gaps w.r.t. physics and (d) uncertainties in observations and other evidence. The proposed set is in agreement with IPCC TGICA[2] guidelines (Nichols *et al*., 2011), who advise to consider a range of projections, including extremes.

The 3 climate scenarios are based on the emission pathways (Representative Concentration Pathways – RCPs) of the IPCC AR5 (IPCC, 2013): RCP2.6, RCP4.5 and RCP8.5 [3]. They represent the likely range of future climate projections. The parameters were derived as best estimates[4] for the respective RCPs.

The Extreme Situation (ES) was developed as some potential users require estimates beyond the likely range of the 3 climate scenarios, but within physical plausibility. It aims to aid contingency planning when a higher level of protection is needed. E.S. allows for sensitivity assessments and long term adaptation planning, particularly where assets with high value and long lifetimes are concerned, and where near-term adaptation choices could constrain the ability to up-scale adaptation responses at a later stage. These extremes do not represent an upper bound or maximum, but are derived from the uncertainty envelope related to RCP8.5. Note that it cannot be considered as one internally coherent scenario, because the uncertainty surrounding each parameter was handled individually[5].

Table 1: Climate Projections by 2100 w.r.t. base-year 1990 (5^{th}-95^{th} percentiles).

Parameter	RCP2.6	RCP4.5	RCP8.5	ES
Global air temperature	+1°C (0.3 - 1.7)	+1,8°C (1.1 - 2.6)	+3.7°C (2.6 - 4.8)	+4.8°C
Global mean sea level rise	+50 cm (38 - 73)	+60 cm (39 - 86)	+85 cm * (56 - 112)	+295 cm
Change in wind direction	No	No	No	No
Average wind speed	+0%	+0%	+0%	+0%
Average winter precipitation	+9%	+11%	+22%	-
Average summer precipitation	-6%	-12%	-30%	-
Extreme winter precipitation **	+5%	+8%	+18%	-
Extreme summer precipitation **	+6%	+4%	+2%	-

* The median of Le Bars *et al*. (2017), with the contested 'Rapid ice cliff failure', results in +184 cm.
** Daily extremes with an annual return period.

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[2] IPCC Task Group on Data and Scenario Support for Impacts and Climate Analysis

[3] RCP 6.0 was dropped because this lies within the envelope of other scenarios and is less represented in available research.

[4] Based on the median of a multi-model ensemble or – due to a lack of information – on expert elicitation.

[5] Hence the name 'Climate Projections' which include 3 scenarios and a set of extreme values.

Global air temperature

The global air temperature change was derived from IPCC (2013). The values now correlate with the respective emission scenarios, unlike the initially proposed scenarios which were based on CLIMAR (Van den Eynde *et al*., 2011). Table 1 provides the projections w.r.t. 1990. Hence, a global warming of 0.6°C by 1990 w.r.t. pre-industrial values was applied. For local temperature changes (including evaporation, tropical days etc.) one is referred to the Climate portal of the VMM. For the extreme situation the upper limit of RCP8.5 is chosen.

Global mean sea level rise

The global mean sea level rise of RCP2.6 and RCP4.5 is derived from IPCC (2018), where recent studies on global sea level rise were compared (Annex 4)[6]. IPCC (2018) does not focus on RCP8.5. Hence, for RCP8.5, it was decided to apply the most recent results of the UKCP18 (Palmer *et al*., 2018), who updated the IPCC AR5 projections to (a) the correct baseline period and (b) recent estimates of the contribution from Antarctic ice dynamics of Levermann *et al*. (2014).

The current climate models are too coarse-gridded to exactly simulate the Antarctic processes. Because the melting of the Antarctic ice sheet contributes greatly to the total sea level rise, so-called 'ice sheet models' were developed. These models have a large spread in their predicted sea level rise. Deconto & Pollard (2016) predict an accelerated sea level rise due to 'rapid ice cliff failure'. Their results were used by Le Bars *et al*. (2017) who performed a probabilistic analysis. However, the participants of the workshop hold some reservations w.r.t. their results[7], which is why they were not applied to the 3 scenarios. As an extreme situation, the 95th percentile of the most unfavourable ('Deep uncertain') scenario in Le Bars *et al*. (2017) was adopted. Note that if the median was applied as a best guess for RCP8.5, this would result in a significantly lower sea level rise of 184 cm.

The local sea level rise and changes in the astronomical tides need to be derived in order to enhance applicability. This was not carried out prior to the workshop, as first a consensus on the basis of the scenarios was required. The local phenomena will need to be further investigated. The global mean sea level rise is currently used instead of the local sea level rise.

Wind

The relevant researches focussing on the Belgian Continental Flat (MIRA, 2015; Sterl *et al*. 2015; Termonia *et al*., 2018b), do not find significant changes in the wind direction of the

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[6] The values of 2°C were applied to RCP4.5. The range represents the 5-95% confidence intervals, derived as the mean of the respective percentiles in each original paper. The 'best estimate' was derived as the mean of all percentiles from all studies. Note that this is statistically not correct, since the spread is not normal distributed. However, keeping in mind the related uncertainty, this method is redeemed sufficiently accurate. The baseline period was altered to the central year of 1990 by applying the method of UKCP18 (Palmer *et al*., 2018).

[7] Because there is no scientific consensus w.r.t. the 'rapid ice cliff failure'. The uncertainty w.r.t. Deconto & Pollard (2016) is underlined by the recent insights of Edwards *et al*. (2018). Note that this article was published after the workshop.

average wind climate. Hence, all projections assume an unaltered wind direction. This stands as well for the average wind speed.

During the workshop, Haarsma *et al*. (2015) was cited, who state that the impact of the Atlantic Meridional Overturning Circulation (AMOC) on atmospheric circulation patterns is underestimated in most CMIP5 models [8]. As the strength of the AMOC is decreasing (Caesar, 2018) and is very likely to further decrease (IPCC, 2013), this causes an increased uncertainty on changes in large scale atmospheric circulation and, hence, wind direction. At the workshop, there were no research groups present which thoroughly investigated the ocean-atmosphere coupling. As it is unclear how the global community feels about the statement of Haarsma *et al*. (2015), it was opted to maintain an unchanged average wind climate in all projections.

The workshop did not provide an output on changes in Extreme wind speeds during storms. The model-output produced in CORDEX.be[9] could be applied, but this dataset needs to be further investigated. It is proposed to continue research with an unaltered wind climate, until future scientific findings[10] indicate differently.

Precipitation

The goal of the projected precipitation in Table 1 is to communicate general trends to the broad public. However, researchers should not apply one value directly into their models. Perturbed time series are better suited, so one is referred to the Climate portal of the VMM or the perturbation tool of KU Leuven for these studies. Moreover, in order to study inland flooding, it might be more appropriate to directly apply changes in river discharge, as was performed in the Theseus project.

In the 3 climate scenarios, the median average and extreme precipitation[11] of the CMIP5 output was applied, as presented in Termonia *et al*. (2018a). It was chosen to apply the output of the global models because the Belgian ensemble of high-resolution regional climate models do not yet fully encompass the entire uncertainty-range of the global models. Note that the coarse resolution of the CMIP5 models does have consequences for modelling extreme precipitation[12]. It is suggested to further elaborate on the Belgian ensemble of high-resolution models.

In 'WCS CPK' of the initially proposed scenarios, the summer precipitation was derived from MIRA (2015) 'Low', while winter precipitation was derived from MIRA 'High. This led to discussions during the workshop and remained contested afterwards. It was decided to exclude values for precipitation in E.S.

[8] The above-mentioned relevant researches investigated or the output of CMIP5, or the output of regional climate models with CMIP5 output as a boundary condition.

[9] The High-Resolution CORDEX.be data is centralized at the RMI and can be provided upon request for further impact studies.

[10] E.g. from Climate Resilient Coast (CREST)

[11] Extreme precipitation is defined as daily extremes with an annual return period. Other return values can be found in Termonia *et al.* (2018a).

[12] To accurately model convection cells, a higher resolution is required (order of magnitude of 5 km).

FUTURE ELABORATION

The climate projections presented above, provide a base for future research, but they require some further elaboration. The following list summarize the needs of potential users, as discussed during the workshop.

1. The local sea level rise needs to be further investigated.
2. The future tidal change, needs to be derived based on insights in point 1. Future low water levels should not be forgotten, as this has an impact on freshwater discharge and, hence, inland flooding.
3. It is unclear how the community feels about the statement of Haarsma *et al.* (2015) regarding the ocean-atmosphere coupling and underestimated impact of oceanic on atmospheric circulation (and/or other teleconnections) in most CMIP5 models. This should be discussed with international research groups such as the ECMWF.
4. The model-output produced in CORDEX.be should be further investigated, to refine the perspective on future changes in local wind climate: wind direction and (extreme) wind speed. Insights of point 3 should be taken into account. Note that certain research groups require offshore wind climate (e.g. near Westhinder, not Oostende).
5. It is suggested to further elaborate on the Belgian ensemble of high-resolution models, as the coarse resolution of the CMIP5 models has consequences for the extreme precipitation.
6. Future wave conditions and currents need to be modelled, based on the parameters presented in Table 1. Insights of point 1, 2 and 4 should be taken into account.
7. The impact on storm surge should be included. Insights of point 1, 2 and 4 should be taken into account. The Theseus and CREST projects could provide valuable input.
8. Determine the return levels of future storm conditions accordingly, including confidence intervals.
9. Future sediment budget, morphological changes and if possible vegetation should be further investigated.
10. Including projections w.r.t. future water temperature could aid potential users, especially in the field of ecology. This can also have feedback loops to currents and oceanic circulation patterns.

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ATTACHMENTS

Annex 1: List of participants and reviewers

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Brouwers Johan	Flanders Environment Agency
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Vanneuville Wouter	European Environment Agency
Verheyen Bart	IMDC
Verwaest Toon	Flanders Hydraulics Research
Willems Patrick	KU Leuven

Annex 2: Summary of CPK, CREST, CORDEX.be and Theseus

C.P. Coastal Vision.

For the Masterplan for coastal safety a sea level rise of 30cm at high water by 2050 and 80cm at high water by 2100 was taken into account to guarantee coastal protection against a 1000 year storm event until 2050. As a continuation of this masterplan a projection on the longer term is needed, resulting in the start-up of the CPK which looks to the period 2050 -2100.

The Coastal Vision Project proposed two warm scenarios for the workshop; a best guess and a worst case scenario. Due to the large uncertainties, spatial planning requires a worst case scenario to be able to provide an adaptive design and because of great uncertainties.

CREST (Climate REsilient coaST).

The CREST project looks at coastal protection from a different angle. Often structures are over dimensioned because there are a lot of uncertainties regarding the involved processes. CREST looks at coastal processes itself and wants to minimize these uncertainties. They have different activities to achieve this, like model simulations, looking at coastal resilience and climate scenarios. Concerning the last topic, CREST mostly looks at the influence of climate change on wind climate, storm surges and waves through measurements and numerical modelling. CREST analyzed the results of eight different regional climate model and applied these to force storm surge and wave models.

Their modelling showed no differences in the number of storm events, nor in the average wind speed at the Flemish coast. An increase of extreme wind speeds was observed, but the maximum significant wave heights and storm surges do not change much in the simulations carried out in the framework of CREST (Van den Eynde *et al.*, 2019).

CREST looks at the coastline trend for the Flemish coast. It was found that the Flemish coast is accreting (8 ha over the past 35 years). This accretion originates from both artificial (nourishments) and natural feeding, where the latter is mainly caused by transport from the sea towards the dunes and for a smaller part by alongshore transport (Verwaest *et al*., 2018). The mechanisms behind this feed of sediment from the sea to the beaches and dunes is still unknown. Measurements are available but it is not yet possible to model this phenomenon due to the lack of knowledge on the driving mechanisms. CREST makes an assessment of the required amount of sediment necessary for different amounts of sea level rise. Above findings are temporary CREST results that will be further elaborated and quantified during the last year of the CREST research project (2019).

Most climate scenarios predict an acceleration in sea level rise. Through analysis of the measurements in the framework of the CREST project, an increase was found by Ozer *et al.* (2018). It is recommended to use a surtax on the sea level for short term design, but for the long term the uncertainties in the sea level rise are too large and would lead to an overdimensioning of structures. For the long term designs it is important to make an adaptive design.

The researchers of CREST determined which information was required to carry out certain assessments. For the verification of the sea defense, it is important to have information on the 1000 year storm, on the sea defense itself, and on the prevailing norms. To assess flood risk, there should be information about superstorms, the sea defense and for instance the land-use and level of the hinterland. For the monitoring of the coastal morphology it is important to have information on the topography, vegetation, nourishments and morphological trends of the coast.

CORDEX.be (Combining Regional climate Downscaling Expertise in Belgium).

CORDEX.be was a two-year project which is about COmbining Regional climate Downscaling EXpertise in Belgium. CORDEX.be starts from the IPCC scenario's and uses them as input for their high-resolution regional models. For the project the spatial resolution of conventional regional models was increased from the usual 12 km. Spatial resolutions of 3, 4 and 5 km were modelled specifically for the Belgium land area [13](LAM model). The models were validated through runs on the past (historical). The CORDEX.be models were found to give a more precise prediction than the usually used models for Belgium. All data (wind, rain fall, temperature) is openly available on request.

The CORDEX.be project had some important outcomes. An increase in extreme precipitation was found. For the Brussels urban environment an increase of factor three to four in the number of heat waves was found. Furthermore, a significant increase of heat stress for people living in the city of Brussels was found, up to twice as large as in the surrounding rural areas. The simulations showed an increased variability of biomass production and yields. Finally, an increase of 51% of biogenic emissions from isoprene were found.

The CORDEX.be results can be refined even further by the use of statistical downscaling. The climate scenarios for Flanders predict an average temperature rise of five degrees in winter and eight degrees during summer. The evaporation is predicted to increase 30% in winter and 22% in summer. The scenarios predict wetter winters and dryer summers. Overall, the precipitation intensifies. Based on historical storms, a fit was made for the prediction of extreme storm surges. Long-period oscillations were taken into account as well in the predictions.

THESEUS

Within the framework of the THESEUS project, the KU Leuven investigated the impact of climate change on inland, coastal and surface conditions (Monbaliu *et al.*, 2014). They hereby used the Scheldt estuary as a case study. Simulations showed no significant changes in wind speed, but a small increase in frequency of south-westerlies. Atmospheric circulation is important for the development of storm surges, so in order to predict storm surges in the Scheldt estuary, it is important to accurately predict changes in the atmospheric circulation. Their research showed that there is a correlation between storm surge and rainfall, which increases the risk of floods near the upstream part of the Scheldt estuary during storm conditions.

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[13] The local models are models for the Belgian (land) area. The Belgian coast was only modelled by RBINS, with the 12 km resolution input (see CREST).

Annex 3: Set of initially proposed scenarios

Table 2 shows the climate scenarios used as a starting point in the workshop. They contained 3 perturbed CLIMAR (Van den Eynde *et al*., 2011) scenarios: M, M+ and W++. These were combined with 2 scenarios developed by the team of Coastal Vision, who focus on the warm scenarios: 'Best Guess Scenario' (BGS) and 'Worst-Case Scenario' (WCS).

The reflection of the debate which led to the new set of climate projections (Table 1), is presented in Annex 5.

Table 2: Preparation of the workshop: Initially proposed climate scenarios by 2100

Proposal	**Scenario 2100**				
	M	**M+**	**BGS CPK**	**W++**	**WCS CPK**
Global air temperature	+ 2 °C	+ 2 °C	+ 4 °C	+ 4 °C	+ 4 °C
Related emission scenario	RCP2.6	RCP4.5	RCP8.5	RCP8.5	RCP8.5
Change in atmospheric circulation	No	Yes	No	Yes	Yes
Local sea level rise	+55 cm	+85 cm	+185 cm	+185 cm	+295 cm
Additional HW level rise	+3 cm	+5 cm	+10 cm	+10 cm	+15 cm
Average wind speed	0%	+4%	0%	+4%	+8%
Extreme wind speed	0%	0%	0%	0%	0%
Average winter precipitation	+9%	+11%	+12%	+22%	+38%
Average summer precipitation	-6%	-12%	-15%	-30%	-52%
Extreme winter precipitation *	+5%	+8%	+10%	+18%	+36%
Extreme summer precipitation *	+6%	+4%	+4%	+2%	+25%
Seawater temperature	+ 2.5 °C	+ 2.5 °C	+ 3.5 °C	+ 3.5 °C	+ 3.5 °C

* Daily extremes with an annual return period

Annex 4: Compilation of recent studies on global sea level rise

Table 3 (IPCC, 2018) provides a comparison of recent studies on global sea level rise.

Table 3 Comparison of recent studies on global sea level rise [cm] in 2100 by IPCC SR1.5 (IPCC, 2018) incl. 17-84% and 5-95% percentiles.

Study	Baseline	RCP2.6		1.5°C		2°C	
		67%	90%	67%	90%	67%	90%
IPCC (2013)	1986-2005	28-61					
Kopp *et al*. (2014)	2000	37-65	29-82				
Jevrejeva *et al*. (216)	1986-2005		29-58				
Kopp *et al*. (2016)	2000	28-51	24-61				
Mengel *et al*. (2016)	1986-2005	28-56					
Nauels *et al*. (2017)	1986-2005	35-56					
Goodwin *et al*. (2017)	1986-2005		31-59 45-70 45-72				
Schaeffer *et al*. (2012)	2000		52-96		54-99		56-105
Schleussner *et al*. (2016b)	2000			26-53		36-65	
Bitterman *et al*. (2017)	2000				29-46		39-61
Jackson *et al*. (2018)	1986-2005			30-58 40-77	20-67 28-93	35-64 47-93	24-74 32-117
Sanderson *et al*. (2017)					50-80		60-90
Nicholls *et al*. (2018)	1986-2005				24-54		31-65
Rasmussen *et al*. (2018)	2000			35-64	28-82	39-76	28-96
Goodwin *et al*. (2018)	1986-2005				26-62		30-69

Annex 5: Reflection on the initially proposed scenarios: minutes of the workshop

Table 4 summarizes the reflections on the initially proposed scenarios (Annex 3) and how this led to the outcome of the workshop. Feedback on the output can be found in Annex 6.

Table 4: Feedback on the initially proposed scenarios

INPUT	OUTPUT	COMMENTS
General remarks		
– It is impossible to implement all parameters with an important link to climate change, because it affects a lot of different parameters. – Furthermore, there is a correlation between different parameters, one is affected by the other. – The current scenarios use the latest insight from different sources, which makes them inconsistent with the physics at some points. This is a known fact, but since there are important recent developments in the field of climate change, it is deemed important to implement these in the scenarios. This way, it is possible to have one number to communicate with the public. – VMM refers to the documents on the climate portal as valuable information.		
Amount of scenarios		
– It is proposed to use the 4 emission scenarios from IPCC as a base and derivate the scenarios from there. – Furthermore, it was suggested to keep the terminology more simple. The worst case scenario aims to represent the worst case values within a 90% confidence band (so both the top and bottom 5% scenarios). – It should be stressed that the Worst Case Scenario is not a scenario, since the values physically cannot happen simultaneously.	– A consensus was made to have 4 scenarios, W++ drops out. – The IPCC scenarios (RCP) should be put in the first line.	– Three of these scenarios are 'normal' scenarios which more or less follow the IPCC scenarios RCP2.6, RCP4.5 and the RCP8.5. – The last column represents values that are extreme, but not impossible to occur.

Extreme values / storm conditions		
– During the discussion on extreme values and storm conditions, it was found that there is a general consensus on the subjects. – Other parameters not included in the current table are of interest as well. – A parameter that is not included in the current scenarios is the change of directional distribution of, for instance, waves and currents. Especially for morphology, a small change in direction of the current can induce a large change in sediment budget. – The mean values of wind and wave direction are already mostly included in the current scenarios. Extreme values for every scenario could be a useful addition. – Extreme minima (low water levels, low discharges) are also interesting, for instance when investigating droughts. – For decision makers and coastal protection it is important to know water levels with certain return period. This should be known for both the current climate and for different climate scenarios. When this is for instance known for the 1000 year storm, it gives insight in the change of the limit state conditions of the coastal defense. To give insight in the operational conditions, it is important to also know the change of occurrence of a certain water level. – During the discussion, it is stated that all scenarios are uncertain, so it is important that the scenarios are adaptive as well. Furthermore, the different scenarios do not have a specified chance of occurrence, they should be treated as equally possible scenarios (unlike the set of extremes).	– A consensus was made to add Wind direction. – Wave direction, tidal amplitude and return periods should be added to the table (when available). – A consensus was made that not all values can be presented in one table, but it is important that they are documented nonetheless because different areas of expertise need different parameters. It is suggested to add the change in tidal amplitude to the main table, because it is important in coastal morphology but also to design the coastal defense.	– See also the 3rd policy note of the Flemish Government which describes to minimize the risks of casualties for a RP1000 storm.
Sea level rise		
– The current table for the climate scenarios has a layout which suggests that the temperature is the base of the scenarios, since it is the first line. Since it was decided to use the IPCC scenarios as a base, these should be in the first line.	– A consensus was made to use the median value of the RCP2.6 studies for the M scenario, and the median value of the studies using two degrees temperature rise for the RCP4.5 scenario.	– The global SLR needs to be translated to local sea level rise. – For modelling it is important to know what the range (uncertainty) is. For

– The current table states a temperature rise of two degrees for the M scenarios. If you apply RCP2.6 and RCP4.5, the first one correlates with one degree. – The sea level rise is currently based on a combination of the most recent IPCC results and results from Le Bars *et al.* (2017). These are both global researches, so the corresponding sea level rise is global. The table now says 'Local sea level rise', this should be 'Global sea level rise'. – The current values for sea level rise are not consistent. It makes sense to use the most recent IPCC results, as well as the results from Le Bars *et al*. (2017). But for the M (RCP 2.6) scenario the median value for a global temperature rise of two degrees was used, and for the M+ (RCP 4.5) scenario the average of the 90th percentiles is adopted. It is suggested to use the median value of the RCP2.6 studies for the M scenario, and the median of the studies using two degrees temperature rise for the M+ scenario. – Another point of discussion is that there is no consensus in the scientific world about the results of Deconto and Pollard, on which the Le Bars *et al.* based their results. There is consensus between the participants on using the results for the Worst Case Scenario, but not for the Best-Guess Scenario. It is suggested to use a different model for the Best-Guess scenario and to add the sea level obtained by Le Bars *et al*. as a footnote.	– A consensus was made that the temperature rise is 1°C (0.3 to 1.7) for the M-scenario (RCP 2.6). – The local sea level rise based on the global sea level rise should be added to the table (using numerical models). – The processed results of Deconto & Pollard (Le Bars *et al*., 2017) are used for the Extreme Situation, but not for the Best-Guess Scenario (RCP 8.5). It is suggested to use a different model for the RCP 8.5. A consensus was made to add the 50th percentile of Le Bars *et al*. (2017) as a footnote with RCP8.5.	communication it is important to keep the table simple, but for some parameters (for instance sea level rise) it is necessary to give insights into the range.
Additional HW level rise		
– To make it understandable to the reader where the values are based on, it should be added that the increase is due to tidal change. – The additional high water also seems to be based on a worst case, it could be useful to add a mean value as well. According to the experts, it is possible to calculate the additional high water using a relatively simple model.	– A consensus was made that this will be further investigated based on the advice of the experts.	– Needs to be further investigated with numerical models.
Atmospheric circulation - *Circulation patterns*		
– The studies cited in the presentation do not find a significant change in wind direction. However, Haarsma *et al*. (2015) was cited, who state that the impact of the decreasing AMOC is underestimated in most global models. As these GCM's provide boundary conditions to the applied RCM's, this causes	– A consensus was made that the term 'atmospheric circulation' has to be changed to 'wind direction'.	– It is unclear how the community feels about the statement of Haarsma *et al*. (2015) regarding the ocean-atmosphere coupling

an increased uncertainty on changes in large scale atmospheric circulation and, hence, wind direction. The Coastal Vision Project suggests to use no change in circulation for best guess and to assume a change in circulation patterns as a worst case. – There were no research groups present which investigated the ocean-atmosphere coupling in-depth. More information needs to be requested at international research groups such as ECMWF or NOAA. – The debate lead to the conclusion that (a) 'atmospheric circulation' has to be changed in change of wind direction. As for now, most research groups did not find a significant change in the orientation of the average wind climate, no scenario should include a change. Even though every model run will provide a change. The discrepancy between all models (including sign) is too large to derive a trend. – The model-output produced in CORDEX.be should be used to further investigate the change in wind direction.	– Most researches did not find a significant change in the orientation of the average wind climate, so a consensus was made that no scenario should include a change.	and underestimated impact of AMOC on atmospheric circulation (and/or other teleconnections) in most CMIP-5 models. This should be requested with international research groups such as the ECMWF. – It is possible to further investigate the change of wind direction using the newly gained model-output produced in CORDEX.be. This could improve the scenarios.
Atmospheric circulation - *Average wind speed*		
– In the presentations it already came forward that most studies do not find significant changes in average wind speed. There is consensus between the experts present at the workshop to adopt no changes in the average wind speed in all scenarios, including the WCS. – The model-output of CORDEX.be requires further research.	– A consensus was made that for all scenarios no change in average wind speed (+0%) will be used.	– It is possible to further investigate the change of wind speed using the newly gained model-output produced in CORDEX.be. This could improve the scenarios.
Atmospheric circulation - *Extreme wind speed*		
– Because quantitative values on extreme wind speed are hard to find in literature, input was asked from the experts present at the workshop. – It was unclear which numbers to apply. The model-output produced in CORDEX.be could be applied, but this needs to be further investigated. – The duration of a certain extreme wind event might have an impact on the sea-state and needs to be taken into account when assessing which model output could be applied (GCM, RCM, high-resolution LAM).	– No output.	– The output requires further investigation of the model-output produced in CORDEX.be.

– The question was asked what duration is required for every phenomenon (e.g. storm surge, vs wind waves, vs swell). MDK stated to look at the output of 'Masterplan Kustveiligheid'. Instantaneous (e.g. 10 min) wind gusts could have an impact on the waves in confined harbors. However, for the average sea-state, the models used in CORDEX.be, should be sufficient. Here they applied their coarser (ca.10 km resolution) model, as the North Sea Basin need to be included.		
Precipitation		
– It is stressed during the discussion that combining the average summer and winter precipitation of the WCS are not physically correct. The values are based on MIRA results, but are a combination of the MIRA 'low' (5th percentile of CMIP5 output of summer precipitation) and 'high' (95th percentile of CMIP5 output of winter precipitation) scenarios. It is possible that any one of the values may occur, but not in such a combination. These outliers can be used for communication purposes, but should never be applied in models/studies. The Climate portal or the perturbation tool of KUL are better suited for researches. – For all other scenarios, one can apply the values of Termonia *et al*. (2018a), more specifically: the median CMIP5 values of the respective emission scenarios. One should not (yet) apply the output of the Belgian, high-resolution ensembles, as these 4 models do not encompass sufficient model-spread (read the entire uncertainty of all GCM's). – The Best-Guess scenario and W++ scenario have different precipitation numbers, according to the experts, the W++ values can best be adopted for the BGS scenario.	– In the 3 RCP scenarios, the (median) CMIP5 output, as presented in Termonia *et al*. (2018a), can be applied. – A consensus was made that the W++ precipitations numbers are used for the RCP 8.5 and hence the W++ is dropped out.	– The outliers from the initially proposed scenarios should not be combined into one physically correct, scenario. They represent worst case outliers for floods in winter and droughts in summer. – The values presented here are for communication purposes only. They should not be applied in models/studies. For this, one is referred to the Climate Portal of the VMM or the perturbation tool of KUL.

Annex 6: Feedback on output of the workshop

National and international experts, who could not attend the workshop were asked to provide feedback on the output of the workshop. Table 5 summarizes their reflections and how these were answered and/or incorporated in the report.

Table 5: Feedback on the output of the workshop

INPUT	ANSWER / COMMENTS	REVISION OUTPUT
General Remarks		
– Although this study looks at the coast, 4 out of 8 parameters are about precipitation.	– Precipitation is important for riverine floods or droughts near the coastal are and, hence, is considered a base parameter for specific studies. Due to the division in extreme, average and seasonal precipitation, 4 parameters are obtained.	
– For precipitation, it is mentioned explicitly that the Belgian high-resolution ensemble is not used. How, at least regionally, specific are the values for air temperatures and SLR?	– For a high-resolution prediction of local temperature changes, we refer to the Climate portal of the VMM. The change in global air temperature is mentioned in the table because (a) to the broad public, this is more informative than the RCP scenarios and (b) they clearly define the scenarios especially w.r.t. sea level rise. The local sea level rise needs to be further investigated.	
Sea level rise		
– The eustatic sea level rise and temperature will not be globally homogeneous under the different RCP scenarios.	– To calculate the local sea level rise, it is necessary to investigate	

	other phenomena such as: tectonic and isostatic component of the landmass (short summary in MOW, 2018), gravitational pull of ice-masses and changes in oceanic circulation. This goes beyond the set-up of this workshop. The local sea level rise is included in the Section 'Future Elaboration'.	
– The scenario WCS CPK should not be labeled as a scenario of lower probability of occurrence; the almost 3m SLR is essentially deep uncertainty and recently also criticised (Edwards et al., 2019, Nature). The extreme value is based on a single study by DeConto and Pollard (2016) in Nature and taken over by many other publications.	– The uncertainty related to DP16 will be rephrased.	– The uncertainty related to DP16 is rephrased.
– The cliff failure was not investigated by Le Bars. These authors took the values of DP16 and included them in a probabilistic analysis. An investigation on cliff failure was done by Edwards *et al*. (2019) https://www.nature.com/articles/s41586-019-0901-4, showing that cliff instability is not necessary to explain past high sea level stands (Pliocene, Last Interglacial) as was needed for DP16. The authors quantify ice-sheet modelling uncertainties for the original MICI study and show that the probability distributions are skewed towards lower values (under very high greenhouse gas concentrations, the most likely value is 45 centimetres). Even DP16 are revising their future Antarctic SLR estimates with cliff instability lower (not published yet). Furthermore, DP16 considered significant surface melting to make ice shelves collapse before 2100, which is contested in several other studies investigating surface mass balance and surface melt. Given the current discussion and the fact that also other countries are investigating this deep uncertain 3 m SLR by 2100 in their planning the scenario should not per se be omitted, but be called 'deep uncertainty'.	– The uncertainty related to DP16 will be rephrased. We will also look whether/how to incorporate Edwards *et al*. (2019) in the text – even though this was published after the workshop. – The naming is the fruit of long discussions, so we will not alter the names anymore at this stage. Based on your comments, we would like to clarify that E.S. stands for extreme situation and not a scenario.	– The uncertainty related to DP16 is rephrased. – The paragraph w.r.t. Le Bars is corrected. – The insights of Edwards *et al*. (2019) are incorporated.
– These high end scenarios (such as the 3m sea level rise) need a clear purpose as anybody skim reading this might – falsely – think that 3 m rise is as likely as the RCP8.5. Several international experts are quite skeptical of the values given in DeConto & Pollard (2016). So one could ask if we have	– These insights will be applied to improve understanding of how to apply the E.S.	– The uncertainty related to DP16 will be more clearly stated. – The goal of E.S. and how to apply it is rephrased.

overreacted to one paper with big numbers? It comes back to the purpose of the high end scenario and how it will be used. For London's defences, the H++ scenario was developed (Palmer *et al*., 2018). This scenario is applied for stress tests: to assess whether the adaptive plan works if such a high end scenario occurs. However, the defences are being built for lower estimations, close to RCP8.5. Through monitoring of the sea level, one will see what actually happens. Combining scenarios with observations is the sensible response to a slow onset phenomenon like rising sea level. Some of the footnotes to the Coastal Vision document imply similar thinking in Belgium. Moreover, it is important to note that the sea level rise will not stop in 2100, so one may well see 3 m or 5 m of sea-level rise. The question is when. Based on this information, it might be useful to think beyond 2100. Finally, Jason Lowe and others continue to develop the (extreme) H++ scenarios, for which they draw together all the lines of evidence that are available. However, they do not pretend to be probabilistic -- rather the users need to define their needs. This would be good for you to look at.		
Wind		
– As the output of CORDEX.be requires more investigation, but the projects need to progress. It is suggested to use no change in extreme wind speed for all projections. – While there is still discussion about wind (see for example https://www.eea.europa.eu/data-and-maps/indicators/storms-2/assessment), I'm surprised to see that no changes in direction and speed are included in the ES.	– This will be incorporated in the report. – Correct. This study was incorporated in the background report (MOW, 2018). It has been discussed during to workshop to incorporate a change in atmospheric circulation in the E.S. However, the majority of the participants decided that there is not enough consensus in the available literature and further research is required (e.g. currently being investigated in CREST). The local wind climate is incorporated in 'Future elaboration'. The outcome of this investigation might lead to an update of these scenarios.	– For the moment no change in extreme wind speed will be applied.

– Just as with precipitation, there are also the changes in extremes that define more adaptation actions than the wind averages. One could look at the general wind direction and average storm duration, but also a change in maximum wind speed and gusts.	– This will form the basis of future investigation.	
Precipitation		
– MIRA did not consider that kind of worst case scenario because their goal was different namely: riverine and urban flooding. It is suggested to use no values yet or – in models – to combine with the middle MIRA scenario instead of the high scenario for precipitations. When one wants analyse the impact of climate change on coastal safety, it is suggested not to calculate runoff and evaporation based on precipitation and temperature scenarios, but to directly apply changes in discharges. This is similar to the approach carried out in the Theseus.	– This will be incorporated in the report. Values will be adjusted.	– As the precipitation in the E.S. remained controversial, no values will be provided. – The method applied in the THESEUS project is mentioned.
– How comparable are these scenarios with the CCI-HYDR scenarios (or other Belgian climate scenarios), for temperature and where relevant precipitation?	– The values incorporated in the proposed projections show a trend of wetter winters, drier summers and more severe extreme events. This is in line with the current Belgian consensus (including the CCI-HYDR scenarios).	
– For precipitation, I don't know how to understand "for communication purposes only". Or the detailed numbers make sense scientifically, or a different way of presenting them should be used.	– Researchers should not apply one value directly into their models. Perturbed time series are better suited. The goal of the projected precipitation is to communicate general trends to the broad public. Researchers will be referred to the available tools.	– This is better phrased in the report.
– In addition to annual return periods, it makes sense to look at decadal or higher return periods as well as trends, as these can become stronger, weaker or completely change.	– The annual return levels were taken from Termonia *et al.* (2018a). They present other return levels as well.	– A footnote is added where other return levels can be found.

Future elaboration		
– Water temperature as an additional parameter (as suggested for further elaboration) makes sense as this can have feedback loops to currents. – If waves are seen as secondary and outside the scope of the study, vegetation is tertiary.	– The determination of future wave characteristics has a higher priority. Vegetation will be important to predict future morphological changes.	– Feedback loop is mentioned.