REQUEST FOR A SPECIAL PROJECT 2021–2023

MEMBER STATE: Netherlands

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Project Title:

Downscaling extreme sea-surge events from climate models using Harmonie

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ___________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2021	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2021-2023: (To make changes to an existing project please submit an amended version of the original form.)		**2021**	**2022**	**2023**
High Performance Computing Facility	(SBU)	20M	20M	
Accumulated data storage (total archive volume)[2]	(GB)	5,000	5,000	

Continue overleaf

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.
[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.

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Abstract

The coastal defence of The Netherlands is designed to withstand extreme sea surges that occur on average only once in 10,000 years. Insight into the meteorological circumstances that causes these extreme events can be gain from long simulations with climate models. However, the spatial and temporal resolution of these models are too coarse to take all relevant aspects into account.

In this request we propose to downscale the relevant cases of extreme surges with the non-hydrostatic Harmonie model. Ideally, the Harmonie runs serve to translate the long-record but low-resolution outcomes of the climate models to high-resolution and reliable results that can be used to calculate the design heights for the sea dikes in The Netherlands.

1 Introduction

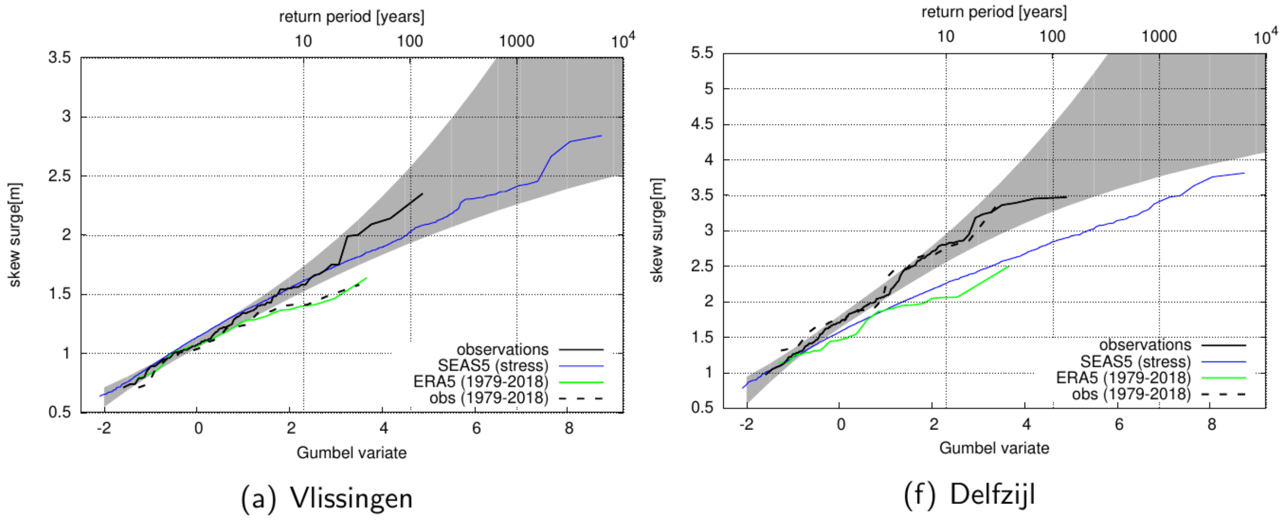

Figure 1: Gumbel plots of the skew surge in Vlissingen (a) and Delfzijl (f) for the observations (black) and SEAS5+DCSM5 (blue). The shaded area indicates the 95% uncertainty in the extrapolation from the observations. The green line shows the results for ERA5+DCSM5, and the dashed line the observations for the same period as ERA5 (1979-2018).

The sea dikes in The Netherlands have to withstand the water level that is exceeded only once in 10,000 years. This level is determined by astronomical tides, waves and surges. As both waves and surges are wind-driven, a thorough understanding of the extreme wind conditions over the North Sea is crucial in the derivation of reliable design heights. Historically, the design heights are derived from statistical extrapolation of observational records. This approach has several disadvantages. First, the observational records are relatively short (i.e. ~ 100 years) which requires statistical extrapolation over two orders of magnitude. Second, statistical extrapolation only results in a number for the 10,000-year return value, without any information about the spatial and temporal development of the meteorological situation that causes the event. Third, no information about the interaction with other phenomena, like astronomical tide, waves, possible resonance effects, etc. is obtained from a statistical analysis. Fourth, the statistical approach only supplies information on specific locations, which requires interpolations techniques for all locations without observations. For those reasons, the aim is to turn from statistical extrapolation of observations to the outcomes of long-record climate- and weather models. A huge step forward is already taken by the analysis of the wind- and stress fields from the ECMWF seasonal forecasts SEAS5, which cumulate to over 8,000 years of meteorological data. KNMI has used all these stress fields to drive the surge model DCSM5 (with a resolution of 8km) in order to compare the results from SEAS5 with the observational records.

Figure 1 gives the Gumbel plots[2] of the skew surge[3] at Vlissingen (a) and Delfzijl (b). The blue line, which is based on DCSM5 fed by the 6-hourly stress from SEAS5, shows a good agreement with observations for Vlissingen (black), although it tends to underestimate the most extreme events. This might be caused by the statistical uncertainty in the observational record (indicated by the shaded area) or by the time window that is used (the results for the 1979-2018 period are considerably lower), but it also may be caused by the resolution of the SEAS5 fields. These fields have a spatial resolution of about 35km, and a temporal resolution of 6 hours. Especially the relatively low temporal resolution of SEAS5 may be of influence on the calculated surges. This effect is even more pronounced for Delfzijl (right panel) which shows a severe underestimation of the extreme (skew) surges. This is caused both by the local wind near Delfzijl (situated in the Wadden Sea) that is not well represented in SEAS5 due to the influence of land, as well as due to shortcomings in DCSM5 which is known to underestimate the extreme surges in Delfzijl.

2 Methodology

In order to use the 8000+ years of SEAS5 stresses for the calculation of extreme surges and sea levels along the Dutch coast, the effect of the spatial and temporal resolution of SEAS5 on the outcomes, as well as the effect of the limited resolution of DCSM5 has to be explored.

Ideally, we would prefer to downscale the whole SEAS5 dataset with the regional weather model Harmonie[4], and use the hourly stress fields from Harmonie on a 2.5x2.5km resolution to drive the operational surge model, called DCSM6. DCSM6 is the successor of the DCSM5 model, with higher resolution (1.6km versus 8km) and a better representation of the astronomical tides.

Unfortunately, this preferred configuration is not possible for several reasons. Firstly, Harmonie is computationally far too expensive to downscale the whole SEAS5 dataset. Secondly, also the surge model DCSM6 is too expensive to be used for the whole SEAS5 dataset. Thirdly, the 3D fields needed to drive Harmonie of SEAS5 are not archived on a 6-hourly basis, which prevents the downscaling with Harmonie from SEAS5 forecasts.

The first and second limitations can be circumvented by downscaling only a selected number of extreme surge events with Harmonie and calculating the corresponding surge with DCSM6. The already calculated surges with DCSM5 can be used to select the cases of interest. The third limitation (i.e., no 3D boundary conditions in SEAS5) can be circumvented by using 16 ensemble members of the KNMI EC-Earth climate model over the 1950-2100 period, cumulating to 2400 years.

[2] On a Gumbel plot, the extreme-value Gumbel distribution is shown as a straight line.

[3] The skew surge is the difference between the maximum water level and the corresponding maximum high tide, i.e. the shift in time of the maximum water level with respect to the maximum high tide is disregarded.

[4] Harmonie is the operational NWP model of KNMI, and runs on a 2.5x2.5km resolution with a hourly output.

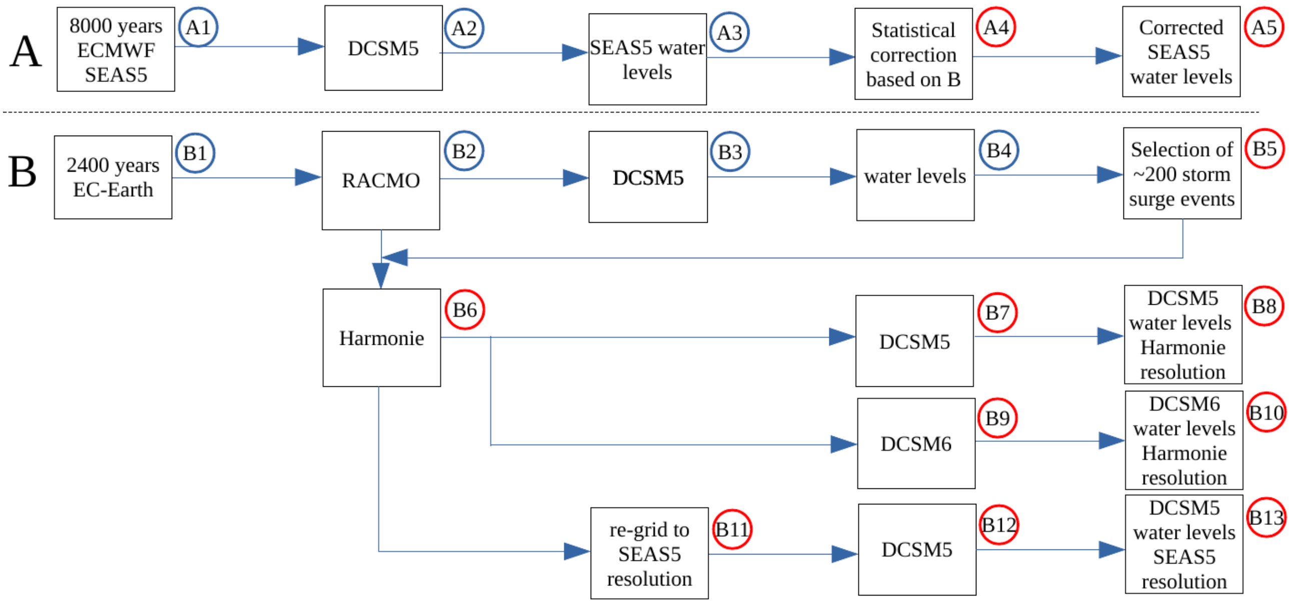

Figure 2: Stream flow how the SEAS5/DCSM5 surges can be corrected for insufficient temporal and spatial resolution. The blue circles indicate steps that are already executed, the red circles are steps that are part of this special project.

The alternative configuration that is suggested is explained below and schematically shown in Figure 2. This figure shows the stream flow of the meteorological and hydrological calculations that are (possibly) necessary in order to derive a good transformation of the low-resolution SEAS5 results. The blue circles indicate steps that are already executed, the red circles are steps that are part of this special project. We clarify the stream flow below:

- We distinguish two parts: one part, called A, uses the SEAS5 data (A1) to calculate the surge with DCSM5 (A2) and that is corrected statistically (A4) in order to come to unbiased results for the SEAS5/DCSM5 combination.
- In order to derive the statistical correction (A4), we cannot use the SEAS5 data itself (due to the lack of the necessary 3D boundary conditions in the archive). That’s why part B starts with the EC-Earth model, for which we have the boundary conditions for 2400 years in total. Although the dataset of EC-Earth is a factor 2 à 3 smaller in length than SEAS5, we assume that the statistical scaling that will derived based on the most extreme storms in EC-Earth is also applicable to the most extreme events in SEAS5.[5]
- The second step of part B consists of downscaling of the whole 2400-year EC-Earth dataset with the regional climate model RACMO (B2). This step is already executed as part of the KNMI’14 climate scenarios.
- Next, all 2400 years of RACMO are used to drive the DCSM5 surge model (B3), which means that a 2400-year dataset of sea levels is available (B4). Also this step is already executed.
- In this project, we will select a large number of extreme storm surges (B5) for a number of coastal stations along the Dutch coast. The exact number is not yet known, and may depend on how different the types of storms are: it is imaginable that large-scale depressions require a different statistical postprocessing than small-scale depressions. Also different tracks, wind directions, and tracking speeds will be considered.
- The depressions causing the extreme surges will be downscaled – via RACMO – with Harmonie to a resolution of 2.5km (B6).
- The Harmonie fields will be used to drive both the DCMS5 (B7) and the DCSM6 (B9) surge models.
- In order to avoid influence of different parametrizations of the 10m wind, we will use the surface stress in all surge calculations.

[5] So we assume that the lower resolution of EC-Earth does not lead to another type of storms. Direct effects of resolution, as well as differences in parametrization between SEAS5 versus EC-Earth are not important here, as the downscaling with RACMO and Harmonie guarantees the uniformity in resolution and parametrization.

- Additionally, we will reduce the resolution of the Harmonie fields by sub-sampling to the temporal and spatial resolution of SEAS5 (B11), and we calculate the surge again with DCSM5 (B12) with those low-resolution stress fields.
- From the differences between the maximum surges of DCSM5 (B8) and DCSM6 (B10), a (location-dependent) correction can be derived that indicates what the influence is of using DCSM6 instead of DCSM5.
- From the differences between the maximum DCSM5 surges from the re-gridded Harmonie fields (B13) and the original Harmonie fields (B10), a (location-dependent) correction can be derived that indicates what the influence is of the resolution of SEAS5.
- It is likely that the hydrological correction (of the surge model) and the meteorological correction (of the resolution) are independent and can be combined to get an overall correction.

We make the following comments that are of importance:

- Special attention will be paid to the size of the domain that is used for downscaling, to be sure that the whole depression is well captured within the Harmonie domain.
- We aim on 200 events, but ask extra SBU's and data storage for another 200 events to be downscaled in the 2nd year of the project. This will be necessary if we conclude that 200 events are not enough for deriving accurate transformations; or either we extend the research to events that are relevant for the Lake IJssel.
- The events will be downscaled from 10 days before till 5 days after the moment of maximum surge, i.e. 15 days per event. Running Harmonie for a single event on a domain 800x800 grid points costs about 100kSBU. The output that is stored is about 25GB per event.

3 Scientific questions and applications

The research questions are:

- What meteorological situation causes the most severe sea surges along the Dutch coast?
  - Are these depressions extraordinary in size, in pressure depth, in tracking speed, or something else?
  - Are the characteristics of these depressions similar along the whole Dutch coast?
  - How important are non-linear effects, e.g. resonance in the North Sea basin?
- How sensitive are the modelled extreme surges along the Dutch coast to the resolution of the driving model?
- Does this sensitivity depend on the location along the Dutch coast?
- How well does the climatology of extremes of the observational correspond with the modelled – and corrected – climatology?

4 Application

- Derivation of correction coefficients that translate the extreme SEAS5/DCSM5 surge heights into values that reproduce the observed surge heights and can be used to estimate extreme return values.

5 Collaboration

There will be close collaboration both with Rijkswaterstaat (Directorate-General for Public Works and Water Management) and Deltares.

6 Computation requirements

As mentioned above, downscaling a singe depression during 15 days with Harmonie costs about 100kSBU. We aim at downscaling 200 events in the first year, cumulating to 20MSBU. Storing 25GB per event cumulates to 5TB of storage. A similar amount is requested for the 2nd year.