REQUEST FOR A SPECIAL PROJECT 2019–2021

MEMBER STATE: ……Germany……………………………………………………...…

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Project Title:

…In case mitigation fails: Exploring alternative methods to protect Europe against sea level rise , using the NEMO ocean model ..……

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.)	2019	
Would you accept support for 1 year only, if necessary?	YES **X**	NO ☐

Computer resources required for 2019-2021: (To make changes to an existing project please submit an amended version of the original form.)		**2019**	**2020**	**2021**
High Performance Computing Facility	(SBU)	9 million		
Accumulated data storage (total archive volume)[2]	(GB)	160 Tb		

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] 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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Extended abstract

The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

All Special Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used.

Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF as well as the Scientific and Technical Advisory Committees. The evaluation of the requests is based on the following criteria: Relevance to ECMWF's objectives, scientific and technical quality, disciplinary relevance, and justification of the resources requested. Previous Special Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.

Requests asking for 1,000,000 SBUs or more should be more detailed (3-5 pages). Large requests asking for 10,000,000 SBUs or more will receive a detailed review by members of the Scientific Advisory Committee.

Please find the extended abstract enclosed.

When mitigation fails: Exploring alternative methods to protect Europe against sea level rise, using the NEMO ocean model

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Motivation

The IPCC projects a global mean sea level rise (GMSLR) in 2100 between 0.51-0.98 m, while it is virtually certain that GMSLR will keep increasing beyond 2100 (*Intergovernmental Panel on Climate Change*, 2013). Locally however, sea level rise (SLR) may reach levels much higher than the projected GMSLR. In addition, recent studies suggest that ice sheets in Antarctica may be less stable than assumed in *Intergovernmental Panel on Climate Change* (2013), potentially adding a lot more SLR than previously considered (*DeConto and Pollard*, 2016).

DeConto and Pollard (2016) added new physical processes that were previously not taken into account, such as ice loss caused by warming ocean currents, rising atmospheric temperatures and melt water effects. This resulted in a projected GMSLR up to 15 meters in 2500, including potential of a few meters as early as 2100. In addition, historical results show that sea level has been at least 6 meters higher than present day, with only 1-2°C warming compared to present day (*Dutton et al.*, 2015). These GMSLR increases may happen at time scales of decades to centuries, while recovering from such events may take thousands of years. The increased potential for high GMSLR increases poses a large threat for coastal based communities.

The projected GMSLR requires either 1) mitigation, 2) relocation or 3) protection. With large uncertainty on the effects of ongoing mitigation efforts, the community also needs to consider alternatives. Here we start to explore a possible method for protection (option 3) of the coasts of 13 European countries.

We propose to run a series of experiments with the NEMO ocean model to investigate the impact of isolating the North Sea, Baltic Sea and the English

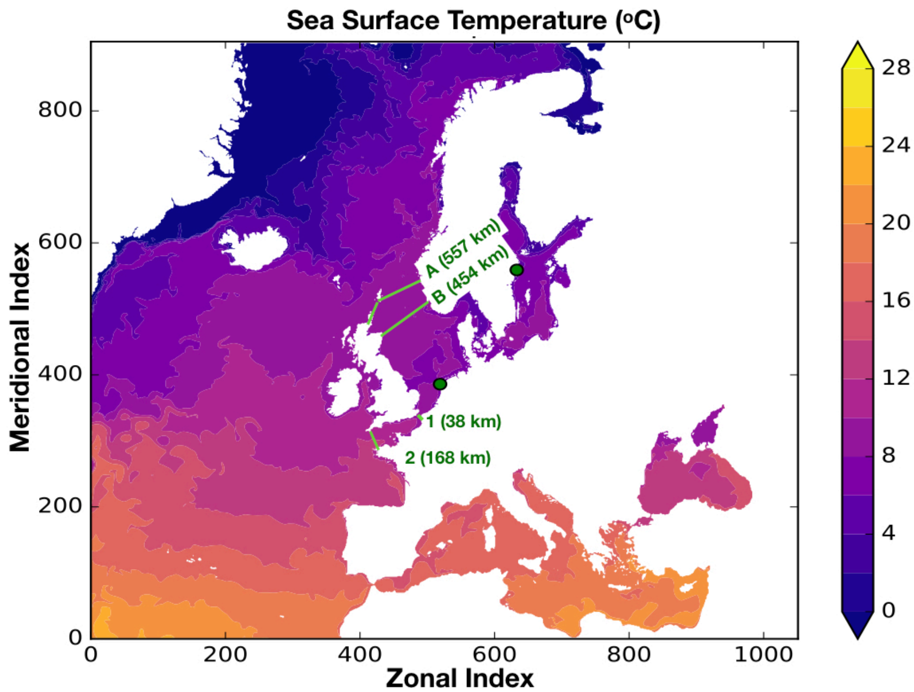

Figure 1: Sea Surface Temperature in our regional NEMO simulation at 1/12° horizontal resolution. Green solid lines show the possible position of solid walls that can isolate the North Sea and Baltic Sea from the Atlantic Ocean, thereby protecting 13 countries from sea level rise. With two suggested option between the UK and Norway (Options A and B) and two option in the English channel (Options 1 and 2). The green dots at Texel and Stockholm, indicate the positions of the SSH and velocity shown in figure 2.

Channel from the open Atlantic Ocean (Fig. 1). Such an enclosement would protect the entire or part of the coast and most of the capital or major cities of 14 countries from sea level rise. These countries are 1-Netherlands (entire coast), 2-Belgium (entire coast), 3-France, 4-UK, 5-Germany (entire coast), 6-Denmark (entire coast), 7-Poland (entire coast), 8-Russia, 9-Lithuania (entire coast), 10-Latvia (entire coast), 11-Estonia (entire coast), 12-Finland (entire coast), 13-Sweden (entire coast) and 14-Norway.

Placing solid walls in the North-East Atlantic Ocean (Fig. 1) protect these countries from the threat of GMSLR, but will also cause huge changes to ocean circulation, biology, shipping and many more features of nature and society. However, protection measures of this magnitude are validated simply by the magnitude of the threat that GMSLR poses.

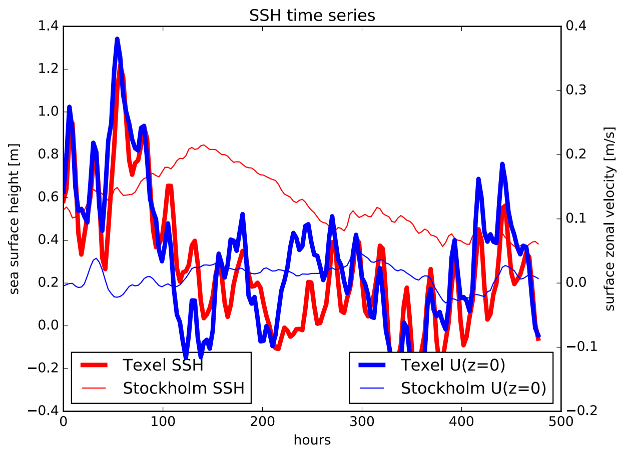

Figure 2: An example of a 3-hourly time series of sea-surface height (SSH, red line) and surface zonal velocity (blue line) near Texel, Netherlands (thick lines) and Stockholm, Sweden (thin lines) in our regional NEMO simulation at 1/12° horizontal resolution.

As a first step, we will study how the construction of these solid walls will change the ocean circulation and predictability of coastal sea levels. In addition we will study if inflowing river water will pose a threat to SLR within the enclosed basin (do we have to pump water out, and how much energy does that cost?) and investigate the resulting freshening rate of the enclosed basin. We will use the results above to provide an estimate of the effect on: shipping, biology, fisheries, Baltic Sea-North Sea exchange, cost of building the enclose, population now not affected by sea level rise, and more.

Constructing the walls will remove large components of tides in especially in the North Sea and English Channel. This will change the tidal behaviour over the entire simulated domain. This is why this investigation is required to take into account the effect of tides and requires a series of ocean-only simulations run at high horizontal resolution with oceanic tides. Our computational domain will cover the North-East North Atlantic, including the Nordic, Mediterranean and the Baltic Sea (Fig .1 and 2). All data will be made available on request and can thus also be used for other studies which focus on the above mentioned areas. We request 9 million SBUs for 1 year to conduct our simulations.

Proposed simulations

We propose to investigate at least three scenario's (Fig .1), which are 1A, 2A and 1B. The difference between 1A and 2A is required to understand the effect of tides in the English channel, while the difference between 1A and 1B is required to understand if a shorter Dam (454 km instead of 557) over shallower water would still provide the protection that is needed.

As a result of including the tides, a high resolution numerical simulation is needed. We propose to run a series of experiments with the NEMO ocean model with a $1/12°$ and $1/36°$ horizontal resolution with 75 vertical levels. The computational domain will only cover the North-East Atlantic, including the Mediterranean, Black, Baltic and Nordic Seas (Fig. 1). Open boundary conditions of velocity and tracers will be taken from a previous global simulation at $1/12°$ and 75 levels. The NEMO ocean model will run with the tidal potential from 11 components, and on the boundaries the tidal forcing will be taken from the TPXO9.1 data set. Some key model parameters are listed in Table 1.

Our NEMO configuration at $1/12°$ has already been set up and tested on the German high-performance computer, HLRN. Winter SST and time series of SSH variability are shown in Figs. 1 and 2. This simulations successfully ran with boundary conditions and tides, ensuring a quick start of this project (Fig .1 and 2). As both the HLRN HPC (in Berlin, Germany) and the ECMWF HPC are Cray XC30 machines, moving the model setup to the ECMWF Cray is easily done. One year of simulation at $1/12°$ horizontal resolution and 75 levels with 5-daily output costs approximately 6600 CPU hours, equivalent to $\approx 10^5$ SBUs. We wish to run ~ 10 years as a model spin-up, which is not enough to spin up the deep ocean, but the upper ocean does equilibrate well in terms of kinetic energy in that time. We will then perform a series of ~ 10 year simulations with different configurations of walls in the open ocean, as well as one control simulation with no wall. As the internal waves associated with tides can only be represented in very-high resolution models, we also wish to perform one simulation at $1/36°$ horizontal resolution, which will be much more expensive. The $1/36°$ simulation will start from the 10-year spin up of the $1/12°$, reducing the need for a long spin up. Our estimate is that such high-resolution simulation will cost $\sim 2 - 3$ million SBUs per simulated year, so we aim for 1 year of simulation. The storage need for 10 years of simulation at $1/12°$ requires ~ 30 Tb, which includes 5-daily 3D temperature and velocities and 3-hourly surface variables. For the $1/36°$ simulation, the storage requirement is ~ 30 Tb for one year.

Further use

The resulting changes to ocean surface conditions due to the construction of solid walls in Fig. 1 can also be imposed as boundary conditions to the OpenIFS model currently run at GEOMAR to investigate possible implications for the atmospheric state. In addition, the North Sea is known to dissipate a lot of the tidal energy. With a solid wall now blocking the entrance to the North Sea, this energy will have to be dissipated elsewhere. In related future work we

Table 1: Details of the proposed NEMO simulations. Numbers for NEMO-ORCA36 are only estimated.

	NEMO-ORCA12	**NEMO-ORCA36**
Horizontal resolution	$1/12°$	$1/36°$
z^* levels	75	75
Time step, Δt	300 s	100 s
Hor. visc., $A_{h,m}$	$-1.25 \cdot 10^{10}\mathrm{m}^4\ \mathrm{s}^{-1}$	$-4 \cdot 10^{8}\mathrm{m}^4\ \mathrm{s}^{-1}$
Hor. diff., $A_{h,t}$	$125\mathrm{m}^2\ \mathrm{s}^{-1}$	$30\mathrm{m}^2\ \mathrm{s}^{-1}$
SBU per year	10^5 SBU	$3 \cdot 10^6$ SBU
Storage per year	3 Tb	30 Tb
Number of years to simulate	40	1

can investigate where this energy will dissipate instead, and the influence this will have on circulation in the Atlantic Ocean. This will help us understand how the enclosed basin influences the Atlantic Meridional Overturning Circulation (AMOC). Furthermore, two recent studies (*Kjellsson and Zanna*, 2017; *Kjellsson et al.*, 2018) on the energetics of ocean currents and the spreading of particles warrant follow-up studies using models that resolve the mesoscale and submesoscales. Using a very-high resolution simulation at $1/36°$ that also includes tides will be ideal for this purpose. Other projects, such as focusing on the Nordic Sea circulation, the fate of Mediterranean Sea water in the Atlantic, or air-sea interactions on the submesoscales can also benefit from the data produced.

Data availability

The model configuration as well as all input and output data from the simulations will be stored at the GEOMAR data cluster in Kiel, Germany and be made available upon request.

References

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