Project: **1019**

Project title: **SeaStorm**

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Inundation due to storm floods bears a high damage potential for coastal environments, especially for low-lying areas such as the German Bight. A deeper understanding of the variability of strength and occurrence of extreme storm floods is therefore of uttermost importance for coastal planning and risk assessment. Observations of storm surges from tide gauges in the German Bight show a marked variability on multiple timescales. While the mechanisms for shorter term variability at specific locations have been studied quite extensively, the variability on decadal and longer scales and their associated climatic drivers has – due to the shortness of the observational record – received little attention. Studies analyzing mean sea level records, however, have suggested remote Atlantic drivers to be responsible for variability on (multi)decadal time-scales (e.g. Sturges & Douglas, 2011; Calafat et al., 2012; Dangendorf et al., 2014). This raises the question whether a similar link exists between (multi)decadal climate variability in the North Atlantic and variations in the statistics of extreme sea level. As observational records are not sufficiently long to derive a statistical relation between the above mentioned, long-term simulations with a coupled climate model are required to study this relation. However, currently available long-term climate simulations do not include tides and have an insufficient resolution to realistically represent storm surges in the North Sea. Regional coupled climate models, driven by fields simulated by global climate models, though can provide a better representation of small-scale processes, topographic influences and land-sea contrasts, and are thus better suited for the simulation of extreme events.

Here, the regionally coupled atmosphere-ocean model REMO-MPIOM (Mikolajewicz et al., 2005, Elizalde, 2011, Sein et al., 2015) is employed to dynamically downscale the climate variations from the Last Millennium simulation from MPI-ESM-P using a coupling time-step of one hour. The overarching goal is to understand the (multi)decadal variability of high sea level extremes in the German Bight and their relationship with large-scale climate variability over the North Atlantic. In order to maximize the resolution in the study focus areas, the poles are shifted to Europe and North America, respectively (see Fig. 1). As we are using a global ocean model, there is no need to prescribe open boundary conditions at lateral margins, which allows the full simulation of signals propagating from the open Atlantic onto the North West European shelf.

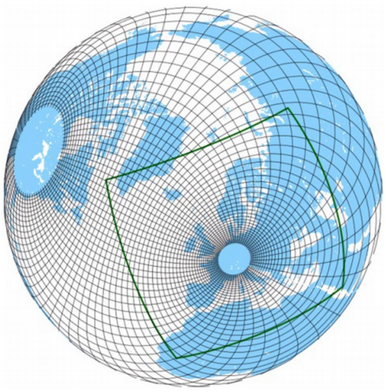

Figure 1: *MPIOM grid configuration (black lines; not all grid lines shown) and REMO coupling domain (green box)*

During the last term, the simulation has been downscaled for the years 1000-1850 providing hourly sea level fields. The remaining 250 years will be achieved by the end of the year.

High water level extremes have been extracted using a peak-over-threshold technique. To study the (multi-)decadal variability of this sample of extremes, a decadal extreme storm-surge index (ESSI), comprising both frequency and intensity of extremely high water levels, has been defined.
The resulting index together with the winter mean sea level (MSL, smoothed with an 11 year average) at an example location at the eastern shore of the German Bight is shown in Fig. 2.

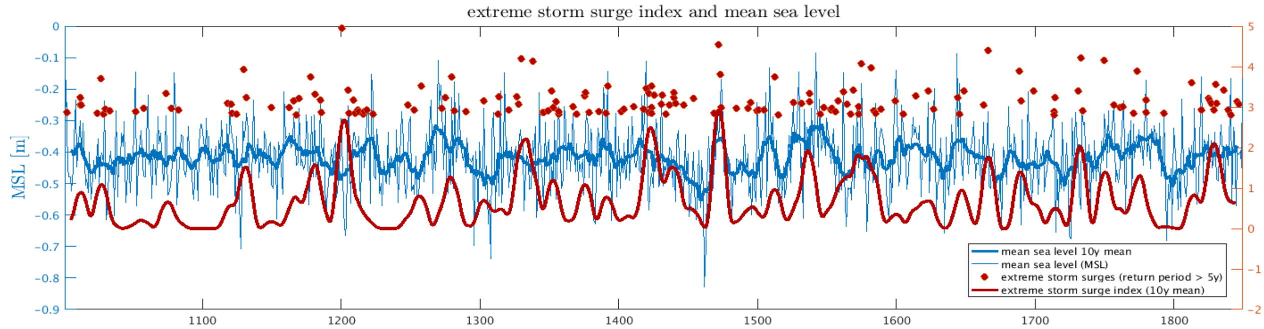

Figure 2: *Winter mean sea level (blue; thick line denotes the 11 year running mean) and extreme storm surge index (red line) with individual filtered extremes (red dots) at Husum*

As can be seen from Fig. 2, ESSI (red curve) exhibits a marked multi-decadal variability. Spectral analysis shows that most of this variability lies in the 20 and 40-50 year bands (see Fig. 3).
Comparison with mean sea level (blue curve, Fig. 2) shows that the multi-decadal variability of extreme storm surges is to a large extent decoupled from mean sea level, with a correlation coefficient of around 0.1 only. This suggests that high sea level extremes are less a result of modulations of the location parameter in the probability density distribution of sea level, but rather stem from variations in the high tail of the distribution.

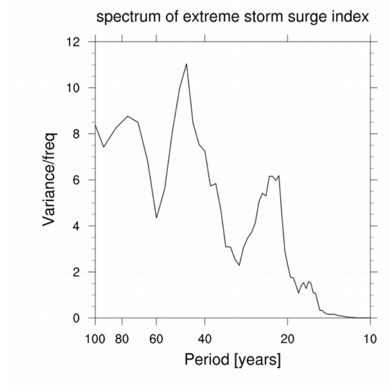

Figure 3: *Spectrum of extreme storm surge index at Husum*

The North Atlantic Oscillation (NAO), which has often been linked to sea level variability in the North Sea (e.g. Wakelin et al., 2003; Dangendorf et al., 2012) shows a low correlation with ESSI (correlation coefficient = 0.1), while it is rather strongly correlated with MSL (correlation coefficient = 0.6; not shown). Wavelet coherency spectra (Fig. 4) indicate a causality between NAO and mean sea level in the German Bight on timescales 10-60 years while no such link seems to exist with the extreme storm surge activity. The sea level pressure (SLP) anomaly pattern associated with periods of extremely high water levels (Fig. 5a) rather exhibits a weak dipole structure of a relative low (high) over Northwestern Russia (the Mediterranean) resulting in an eastward stretched Icelandic Low and thereby affecting the local wind flow through enhanced westerlies over the North Sea. Yet, the anomaly composite is not significant at the 95th percent confidence level.

The North Atlantic gyre pattern associated with extremely high water levels exhibits an anticyclonic anomaly in the southeastern part of the subpolar gyre, and a cyclonic anomaly in the north-eastern end of the subtropical gyre (Fig. 5b). This dipole manifests in a westward contraction of the sub-polar gyre, and a relative weakening of both gyres and hence the North Atlantic current. Yet, only a low coherence with extreme storm surge activity is found at decadal scales (Fig. 4).

For the coming year, a second downscaling simulation is planned in order to get a more robust estimate of the long-term natural variability and its relation to large scale climate variability. Furthermore, following the integrated approach of the project, the model results will be compared with geological and paleontological reconstructions from marsh sediments.

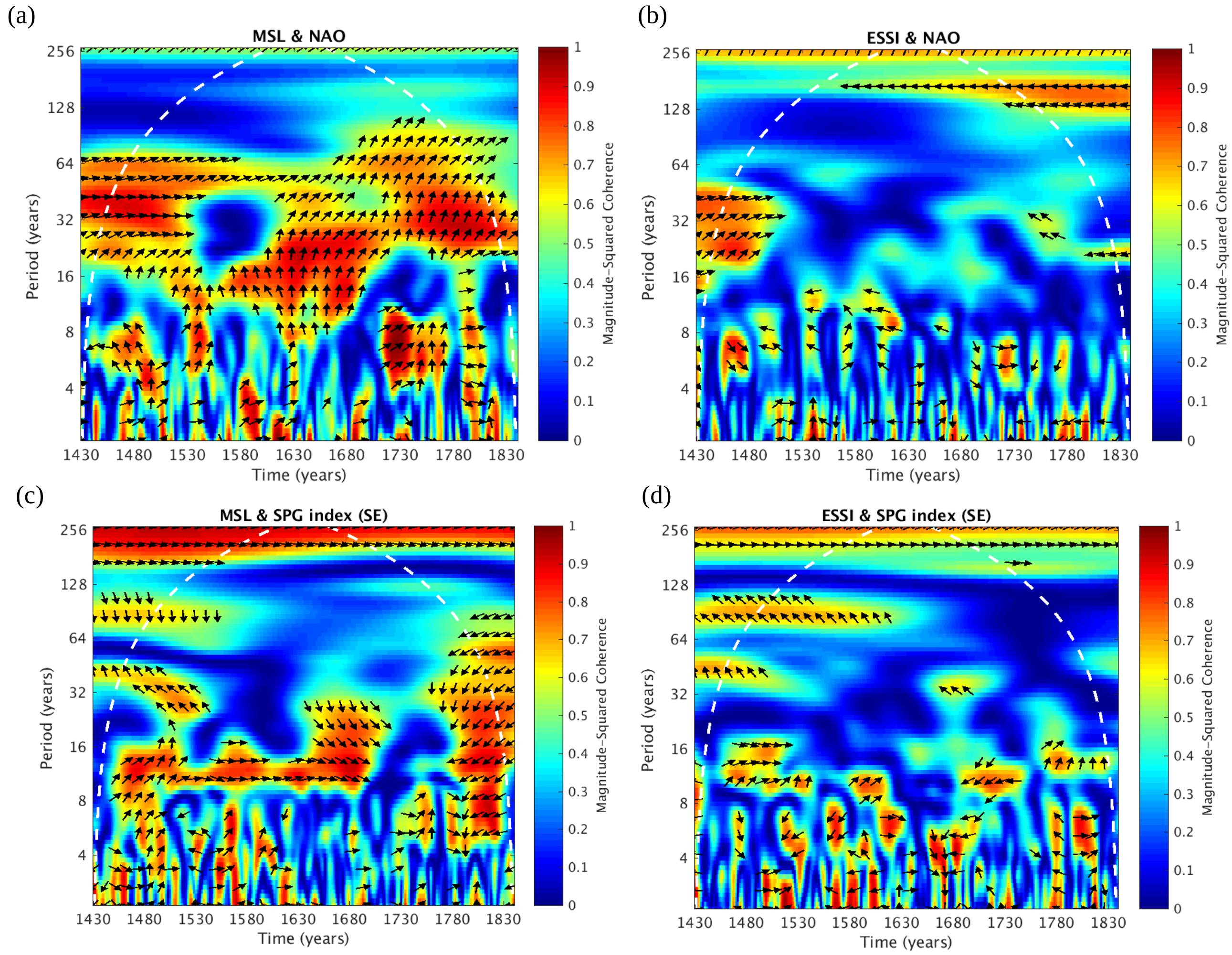

Figure 4: *Wavelet coherency between the (a) NAO and mean sea level, (b) NAO and extreme storm surge index, (c) south-eastern subpolar gyre (SPG) index and mean sea level and (d) south-eastern SPG index and extreme storm surge index at Husum for a 400 year data subset. The SPG index has been computed as the average in the box indicated in Fig. 5. Arrows indicate phase of the relationship: right arrows indicate that the 2 series are in co-phase, left arrows in anti-phase. Up (down) arrows indicate that the second series leads (lags) the first one in quadrature. The white dashed line denotes the cone of influence. Produced using the algorithm described in Grinsted et al. (2004).*

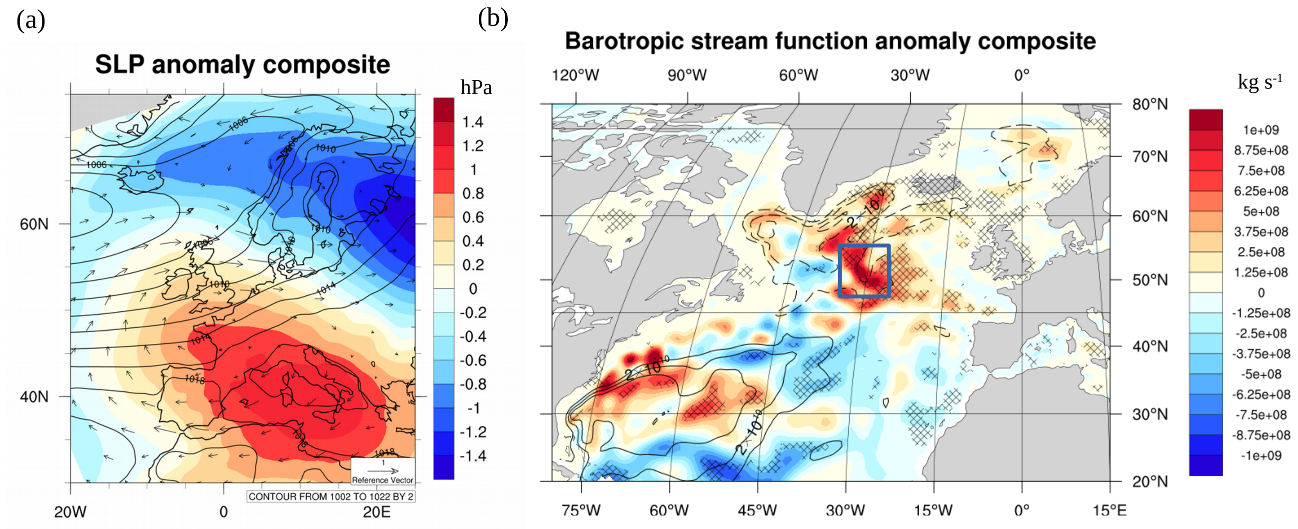

Figure 5: *Composite patterns during periods of high storm surge activity (ESSI > μ +1.5 σ) of (a) winter SLP anomaly with 10 m wind anomaly vectors and (b) winter barotropic stream function anomalies. Contour lines denote the respective climatology 1500-1850, hatched areas denote significance on the 95 percent confidence level.*

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