Attribution of the 1995 and 2006 storm surge events in the southern Baltic Sea

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1. Attribution of storm surges in the Baltic Sea

In November 1995 and 2006, the German Baltic Sea coast experienced severe storm surge conditions. Exceptional water level heights of about 1.8 m above mean sea level were measured at German tide gauges. Extreme event attribution poses unique challenges trying to distinguish the role of anthropogenic influence, as e.g. greenhouse gas emissions or land-use changes, from natural variability (Allen 2003, Christidis et al. 2013, Stott et al. 2016).

This study wants to estimate how the contribution of anthropogenic drivers has altered the probability of single extreme events such as the 1995 and 2006 storm surge events. This work is part of the European **EUCLEIA project** (EUropean CLimate and weather Events: Interpretation and Attribution, www.eucleia.eu). The aim is to calculate the probabilities of exceeding observed extreme values, used as thresholds, in the human-induced historical climate and natural climate without human influence.

Research Question

Have individual storm surge events, such as e.g. of November 1995 and 2006 in the Baltic Sea**, changed due to human influence on climate** or is the knowledge still too vague to obtain robust information of attribution**?**

2. A new HadGEM3A-TRIM-based System

- We use the regional ocean model TRIM-NP (Kapitza, 2008)
- Simulation of water level: Two 7-member ensemble simulations over the Baltic Sea in 12.8 km spatial resolution for 1971-2010: historical vs. natural
- Atmospheric Forcing: Two atmosphere-only multi-decadal ensembles of Hadley Centre Global Environmental Model version 3-A (HadGEM3-A) model data (Christidis et al. 2013)
- Atmospheric forcings represent historical climate and natural climate without human influence
- As gridded reference: Model reconstruction using dynamically downscaled NCEP-R1 Reanalysis (CoastDat, Geyer 2014)

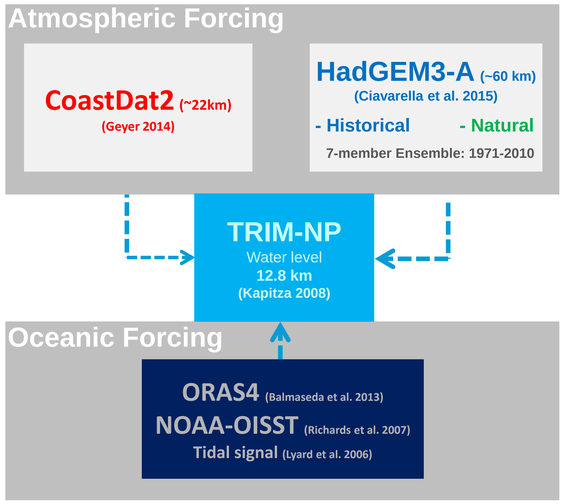


Fig. 2:Model-chain of TRIM-NP presenting the atmospheric (HadGEM3-A, CoastDat2) and oceanic forcing (ORAS4, NOAA-OISST) data used in this study.

Domain & Drivers of storm surges

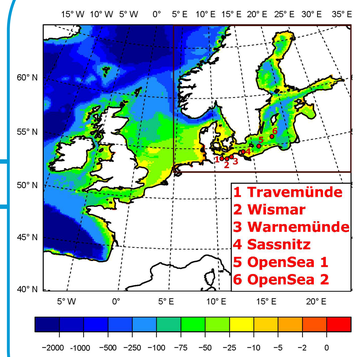


Fig. 1: Model domain and Bathymetry [m] of the ocean model TRIM. Red points illustrate considered grid boxes co-located to coastal cities of Travemünde, Wismar, Warnemünde and Sassnitz and open sea.

+ Onshore Winds, Cyclones

+ Prefilling of water

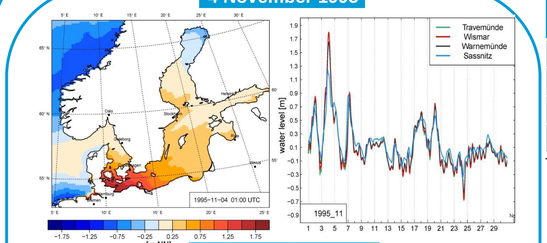
+ Seiches (standing waves)

+ (Tides)

+ Sea level change

3. Storm surges in the southern Baltic Sea

4 November 1995



1st November 2006

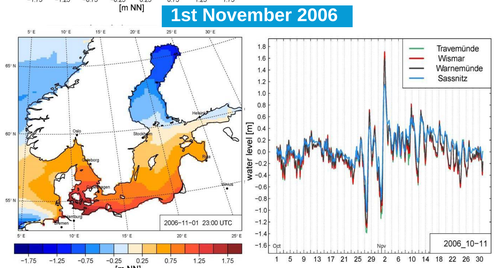


Fig. 3: Spatial patterns of water level [m] on 4 November 1995 and 1st November 2006 over the Baltic Sea based on reconstructed model data (CoasDat-TRIM). In addition, intra- and interdaily variations for selected grid boxes of locations co-located with coastal cities.

Intensity classes of storm surges	m above mean sea level
storm surge	1,00 – 1,25
moderate storm surge	1,25 – 1,50
severe storm surge	1,50 – 2,00
very severe storm surge	> 2,00

Table. 1: Federal Maritime and Hydrographic Agency, 2016.

Evaluation of HadGEM-TRIM ensembles

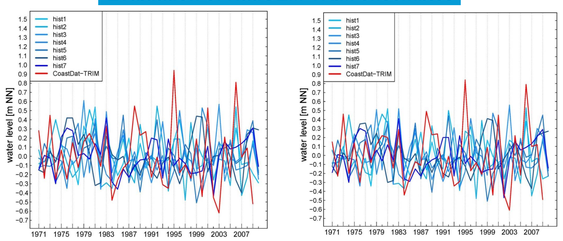


Fig. 4:November anomalies of maximum water level [m] for 1971-2010 based on reconstructed model data (Coastdat-TRIM, red) as reference data and historical HadGEM3-A-TRIM (hist) ensemble members (1-7, blue). Selected grid boxes represent locations co-located with German cities of Wismar (left) and Travemünde (right).

- HadGEM-TRIM ensemble members underestimate temporal variability compared to CoastDat-TRIM

4. Attribution & Conclusion

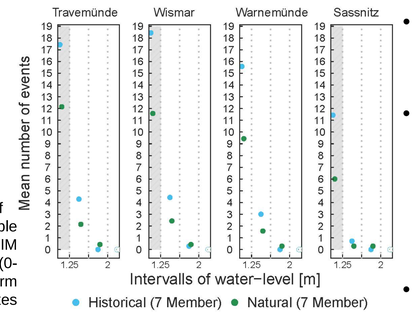


Fig. 5: Mean number of threshold exceedances of maximum November water level (1971-2010) of the 7 historical HadGEM-TRIM (historical) ensemble members (blue) and 7 natural HadGEM-TRIM ensemble simulations (green) for 3 intervals (0-1.25m,1.25-1.5m, 1.5m-2m) based on the storm surge classification (Table 1). Selected grid boxes represent locations co-located with coastal cities.

- Underestimation of extreme water level → no single event attribution possible with this setup
- However, findings (Fig. 5) indicate: Probability of weak storm surges (1 m-1.25 m) is higher in the climate with anthropogenic forcings than in the natural climate without human influence
- Similar result for moderate storm surges (interval of 1.25 m-1.5 m)

- Both TRIM ensembles driven with HadGEM3-A do not represent extreme water levels
- However: Likelihood of storm surges (weak, moderate) higher in the historical ensemble with anthropopenic forcings than in the natural without human influence
- Changes are only atmospheric-driven, no historical vs. natural forcings within the ocean

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