Storm surge climate in the western Baltic Sea 1948-2012

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Germany coastline ~ 3.700 km; 50% Baltic Sea coast (BSH)

Western part
- relatively shallow (around 20m)
- low lying coast
- fragmented coastline

At risk for storm surges, rising mean sea levels and erosion

Green: Land with elevation below height of the 1872 storm surge
Source: www.kuestenschutzbedarf.de
Motivation of this study

→ Can we describe the storm surge climate of the western Baltic Sea from numerical modelling?
→ Can we analyze long-term changes in a consistent and homogeneous way?
→ Can we enhance the understanding of potential contributions from processes such as prefilling and seiches?
→ Can we provide a first step towards a climatology of such processes including their long-term changes?

(PhD Thesis, Hendrik Weidemann, To be submitted by the end of February 2014)
Approach

- Ocean model TRIM-NP (Kapitza 2008)
- 4 nests from 12.8 km to 1.6 km
- Tides from FES2004 (grid 1)

- Atmospheric Forcing:
  - Dynamically downscaled NECP Reanalysis 1948-2012 (Geyer 2013)
  - Hourly near-surface marine wind fields and sea level pressure
  - Approx. 18x18km grid bilinearly interpolated to model grids

- Barotropic simulation
  (no temperature and salinity effects)
- No sea-ice model included
Can we describe the storm surge climate of the western Baltic Sea from numerical modelling?
Validation

**Wind**

<table>
<thead>
<tr>
<th>Observation</th>
<th>CCLM vs CCLM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kiel (1974-2007)</td>
<td><img src="image1" alt="Graph" /></td>
</tr>
<tr>
<td>Warnemuende (1954-2010)</td>
<td><img src="image2" alt="Graph" /></td>
</tr>
<tr>
<td>Arkona (1973-2010)</td>
<td><img src="image3" alt="Graph" /></td>
</tr>
</tbody>
</table>

**Waterlevel**

<table>
<thead>
<tr>
<th>Observation</th>
<th>Hindcast vs Hindcast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flensburg (1955-2010)</td>
<td><img src="image4" alt="Graph" /></td>
</tr>
<tr>
<td>Warnemuende (1954-2010)</td>
<td><img src="image5" alt="Graph" /></td>
</tr>
<tr>
<td>Sassnitz (1955-2010)</td>
<td><img src="image6" alt="Graph" /></td>
</tr>
</tbody>
</table>
Validation

Feb. 1979 water level Flensburg / wind Kap Arkona
Validation

→ Barotropic simulation
No sea-ice model included

→ Does it matter?

→ Comparison with baroclinic simulation including sea-ice

→ Example here: Kiel
  → Baroclinic simulation reveals systematic bias not present in the 2D simulation
  → Problem might be associated with model and/or tide gauges
  → When bias removed skill of simulations comparable

→ Barotropic simulation adequate for the purpose of this study
Storm surge climate 1948-2012

- Seasonal 99-Percentiles from hourly values
- Generally extremes are highest in winter and lowest in summer
- Intermediate values in the intermediate seasons
- Values generally smaller in open sea; increasing towards the coast
- More comprehensive analysis in Hendrik’s PhD
→ Can we analyze long-term changes in a consistent and homogeneous way?
Long-term changes

Example here Flensburg

Upper panel: Metric
- Number
- Duration and
- Intensity of events exceeding the long-term 99 Percentile

Lower panel: Different Metric
- BSH operational definition (light, average, severe storm surge)

Pronounced inter-annual and decadal variability in all metrics
Upward trends over the analysis period not significant
Long-term changes

Change in annual 99 Percentiles in cm/65 years derived from linear trend

Decadal variability illustrated by 15-year means of annual 99 Percentiles
→ Can we enhance the understanding of potential contributions from processes such as prefilling and seiches?
Prefilling
- Mean sea level in Landsort exceeds long-term average by 15 cm or more for at least 15 days

Seiches
- Detected by means of a moving harmonic analysis
- Using prescribed frequencies from Wuebber and Kraus (1979) (31.0, 26.4, 22.4 and 19.8 hrs)
- Analysis window 96 hrs shifted by 1 hr to account for the pulse-like character of the seiches
- Time series of amplitude, phase and contribution to observed water level for each constituent
Prefilling

Example here: Wismar

Separation of storm surge cases according to prefilling
→ Approx. half of the storm surge occurred when prefilling was observed
→ Approx. half when prefilling conditions were absent

Wind speeds
→ On average smaller when storm surge occurred and prefilling was observed
→ For cases without prefilling distribution shifted towards higher values

When prefilling occurs, lower wind speeds are needed to exceed storm surge thresholds
→ Example here: Wismar

→ Separation of storm surge cases according to contribution from seiches
  → Approx. 60% of storm surges with contributions from seiches <10 cm
  → About 37% with contributions >+10 cm
  → ~3% with contributions <-10 cm

→ Preferred phase-shift between peak of surge and peak of seiche
  → For Wismar and T=31 hrs ~90 degrees
  → On average only small contributions
  → However, considerable amount of cases with substantial contributions
→ Can we provide a first step towards a climatology of such processes (seiches and prefilling) including their long-term changes?
Example: Prefilling

→ Example here: Landsort

→ Number, duration and intensity of prefilling conditions

→ On average conditions lasted for 43 days

→ Longest event: 123 days (12/91-04/92)

→ Pronounced inter-annual and decadal variability with strongest events occurring in the early 1990s

→ No significant trends
→ Storm surge climate of the western Baltic Sea can reasonably be derived from numerical modelling.

→ Results suggest pronounced inter-annual and decadal variability of the storm surge climate but no substantial long-term trend.

→ Prefilling and seiches contributed substantially to some of the observed peak water levels at the German coast.

→ When prefilling occurs, generally lower wind speeds were needed to sustain comparable peak water levels.

→ In roughly 1/3 of the storm surge cases (in Wismar) contribution from seiches to peak water levels exceeded 10 cm.