Multimodel estimates of the changes in the Baltic Sea ice cover during the present century

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Background

- Sea ice conditions a good indicator of the climate variability
- Consequences for the shipping, breeding of the Baltic ringed seal etc.
- Ice severity classification on the basis of annual maximum ice extent (MIB)
- The aim of this study:
  - Future changes in MIB and maximum fast ice thickness
  - Scatter across a multitude of climate models
  - Uncertainty induced by future GHG emissions

<table>
<thead>
<tr>
<th>Severity</th>
<th>MIB (km²)</th>
</tr>
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<tbody>
<tr>
<td>mild</td>
<td>&lt; 115 000</td>
</tr>
<tr>
<td>average</td>
<td>115 000 – 230 000</td>
</tr>
<tr>
<td>severe</td>
<td>230 000 – 345 000</td>
</tr>
</tbody>
</table>
Data

- Observed annual maximum ice extent (MIB) 1951-2011
- Temperature observations: E-OBS gridded dataset 1951-2011, spatial resolution 0.25 degrees (Haylock et al., 2008)
- Air temperature data from global climate model simulations
  - 28 CMIP5 models
  - 2011-2099
  - scenarios RCP4.5, RCP8.5
Methods and results: Annual maximum ice extent (MIB)

- A regression model was fitted to the observed Nov-Mar mean temperatures and MIB data for the years 1951-2011:
  \[ MIB = (90.2 \pm 4.2) \times e^{-(0.253 \pm 0.015) \times T} \]
- \( R^2 = 82.8\% \)
• Temperature for the regression equation for seven future decades: 2021-2030, 2031-2040, 2041-2050, 2051-2060, 2061-2070, 2071-2080, 2081-2090

• Delta-change method: model-based temperature increases for the decade in question were added to the observed values in the years 1961-2010
  – The temperature changes for each decade was calculated as a 30 yr mean, centred on that decade

• Artificial frequency distributions of MIB for the future decades

• 28 models and multi-model mean
• Inter-model scatter and inter-annual variability of MIB in 2041-2050
• Median values of almost all of the models belong to the class of mild ice winters
- 1. CESM1-BGC (USA)
- 28. CMCC-CMS (Italy)

- 1. CCSM4 (USA)
- 28. CMCC-CM (Italy)
Methods and results: maximum fast ice thickness $h$

- **FDD-model** (Stefan, 1890; Zubov, 1945; Leppäranta, 1993):
  \[ h = \sqrt{a^2 \times S + d^2 - d} \]
- $S$: annual cumulative sum of daily mean air temperatures below 0°C (freezing degree-day sum)
- Baseline period 1971-2000: observed 30 yr mean temperatures for computing $S$
- S for the future decades: delta-change method
- 28 models, multi-model mean
- **Weaknesses:**
  - No snow layer on top of the ice $\rightarrow$ ice thicknesses systematically overestimated
  - Only valid for the coastal fast ice
- Resulting $h$ can be considered as the upper limit for the ice growth
• Multi-model mean values for the annual maximum coastal sea-ice thickness (cm) in typical past and future winters

• RCP4.5: The ice thickness in the Bay of Bothnia may still exceed 60 cm in 2081-2090

• RCP8.5: Most of the Baltic sea ice-free in 2081-2090
Percentual decrease from 1971-2000

<table>
<thead>
<tr>
<th></th>
<th>RCP4.5 (%)</th>
<th>RCP8.5 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2041-2050</td>
<td>2081-2090</td>
<td>2041-2050</td>
</tr>
<tr>
<td>Kemi</td>
<td>25</td>
<td>37</td>
</tr>
<tr>
<td>Loviisa</td>
<td>40</td>
<td>57</td>
</tr>
<tr>
<td>Vilsandi</td>
<td>88</td>
<td>97</td>
</tr>
</tbody>
</table>
Conclusions

• According to both RCP scenarios, the MIB and the ice thickness were found to decrease markedly
• The Baltic Sea is unlikely to become totally ice free in the typical winters of the coming decades
• Large uncertainties:
  – Statistical calculation methods
  – A large number of different climate models and two RCP scenarios
• The spread among the changes derived from different climate models quite large → when regional Baltic Sea circulation models are used, it is important to use a large number of different climate models for boundary conditions
References:


• Haylock et al., 2008: A European daily high-resolution gridded dataset of surface temperature and precipitation. J. Geophys. Res. Atmos. 113, D20119

