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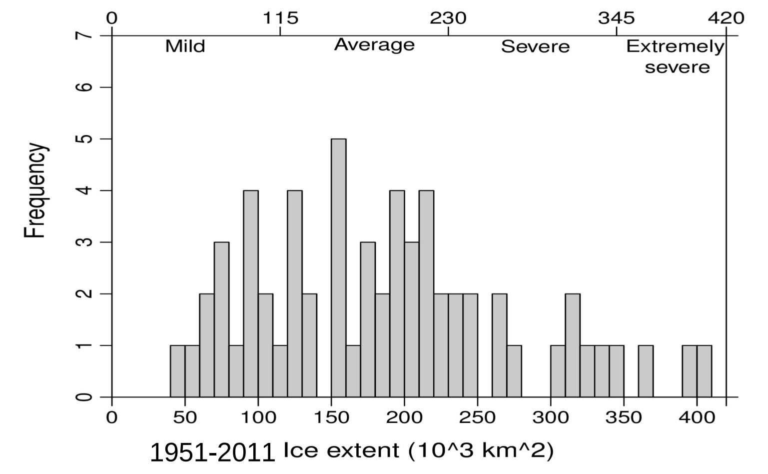
Multimodel estimates of the changes in the Baltic Sea ice cover during the present century

Anna Luomaranta, FMI

Background

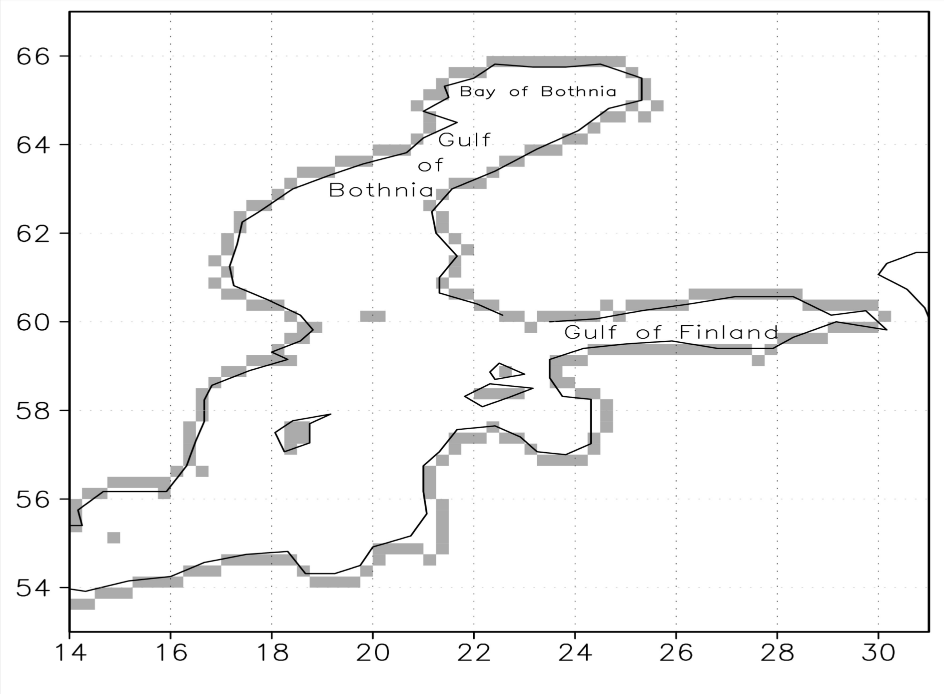
- Sea ice conditions a good indicator of the climate variability
- Consequences for the shipping, breeding of the Baltic ringed seal etc.
- Ice severity classification on the basis of annual maximum ice extent (MIB)
- The aim of this study:
  - Future changes in MIB and maximum fast ice thickness
  -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

Severity	MIB (km^2)
mild	< 115 000
average	115 000 – 230 000
severe	230 000 – 345 000



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

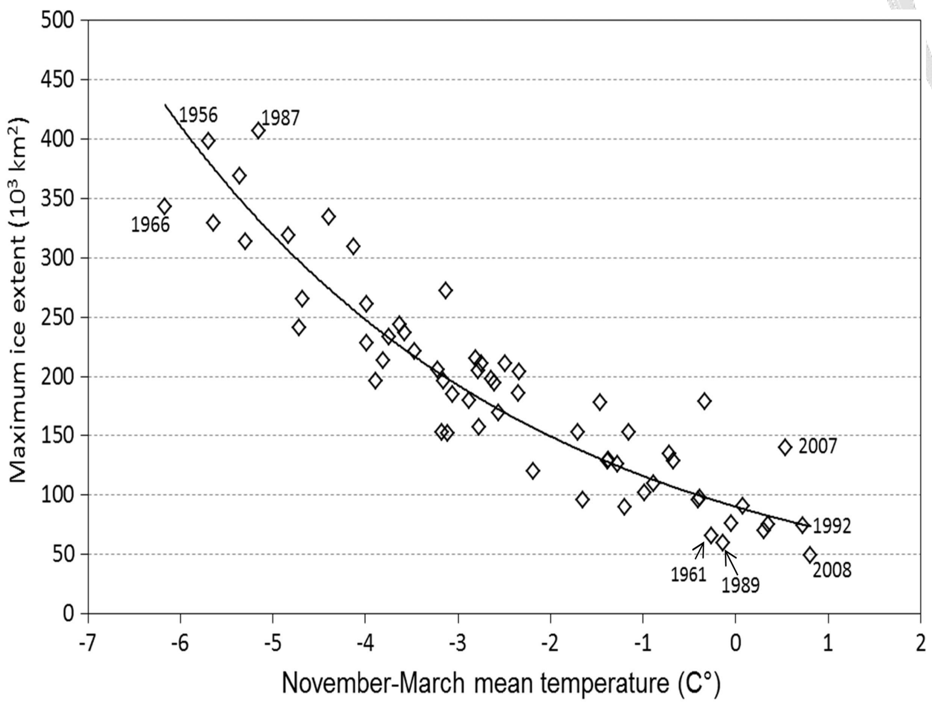


Methods and results: Annual maximum ice extent (MIB)

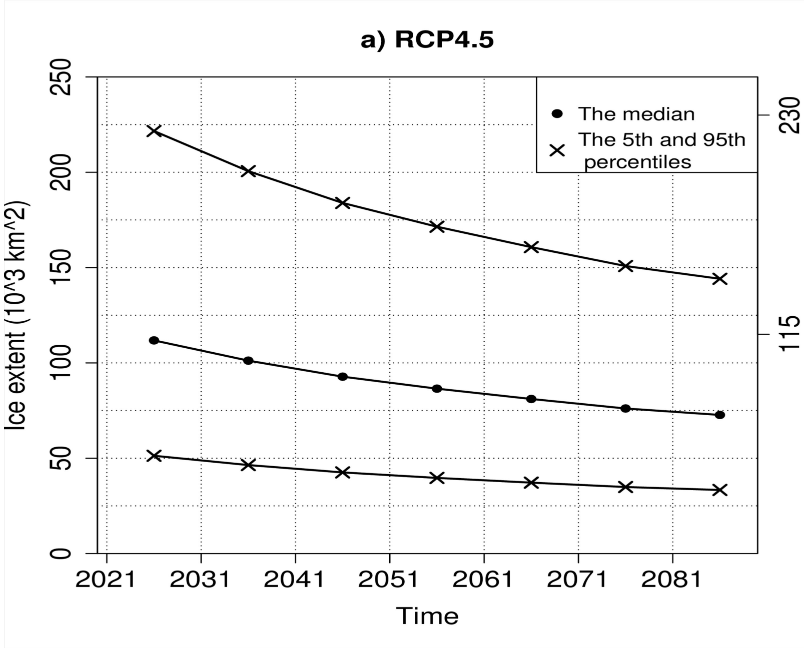
- A regression model was fitted to the observed Nov-Mar mean temperatures and MIB data for the years 1951-2011:

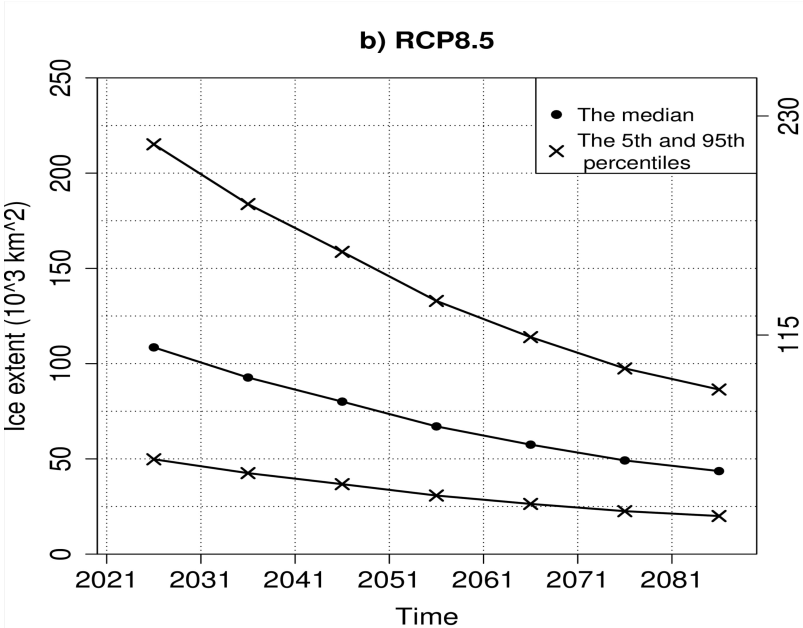
$$MIB = (90.2 \pm 4.2) \times e^{-(0.253 \pm 0.015) \times T}$$

- R^2=82.8 %

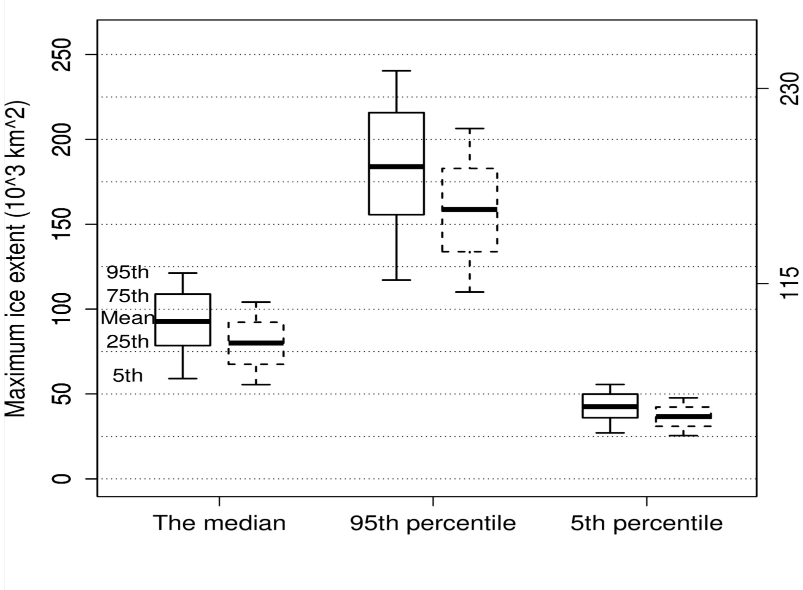


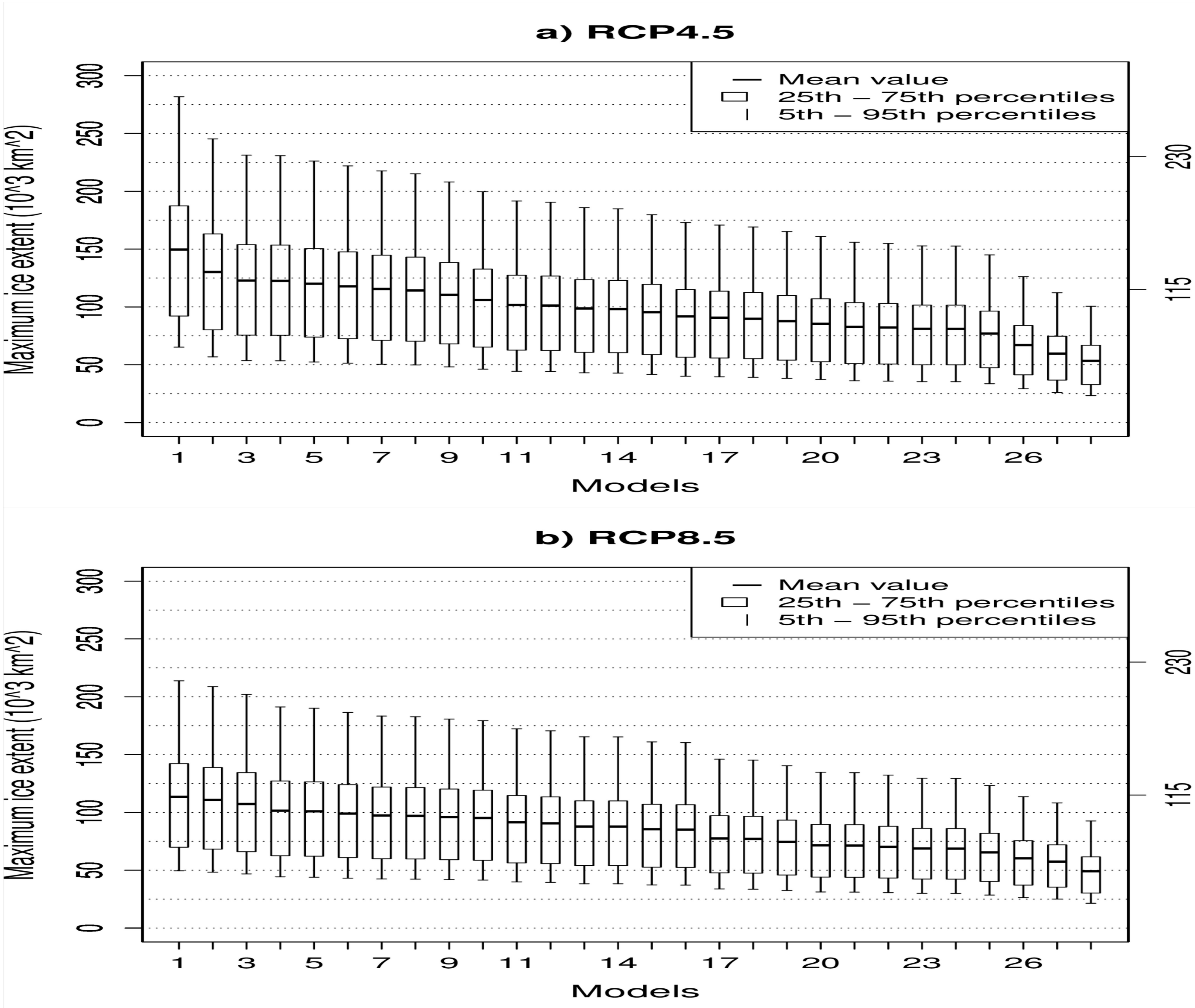
- Temperature for the regression equation for seven future decades: 2021-2030, 2031-2040, 2041-2050, 2051-2060, 2061-2070, 2071-2080, 2081-2090
- Delta-change method: model-based temperature increases for the decade in question were added to the observed values in the years 1961-2010
  - The temperature 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)

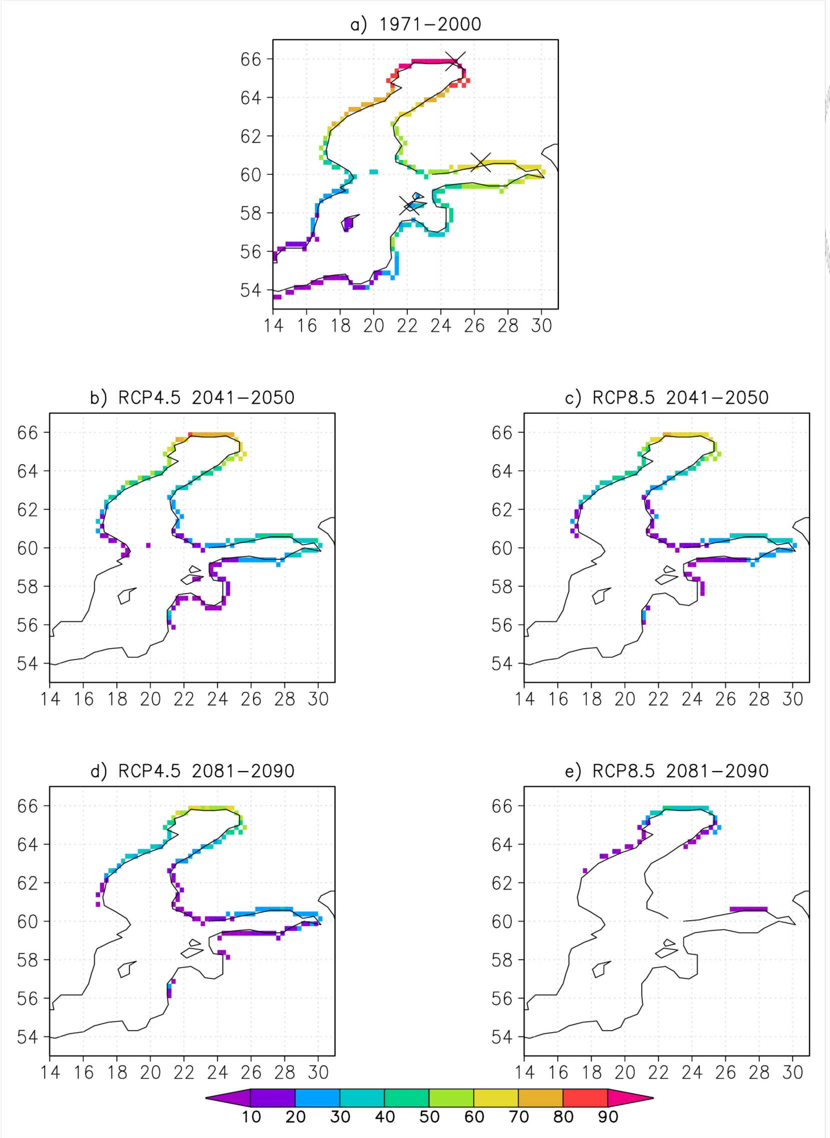
Methods and results: maximum fast ice thickness h

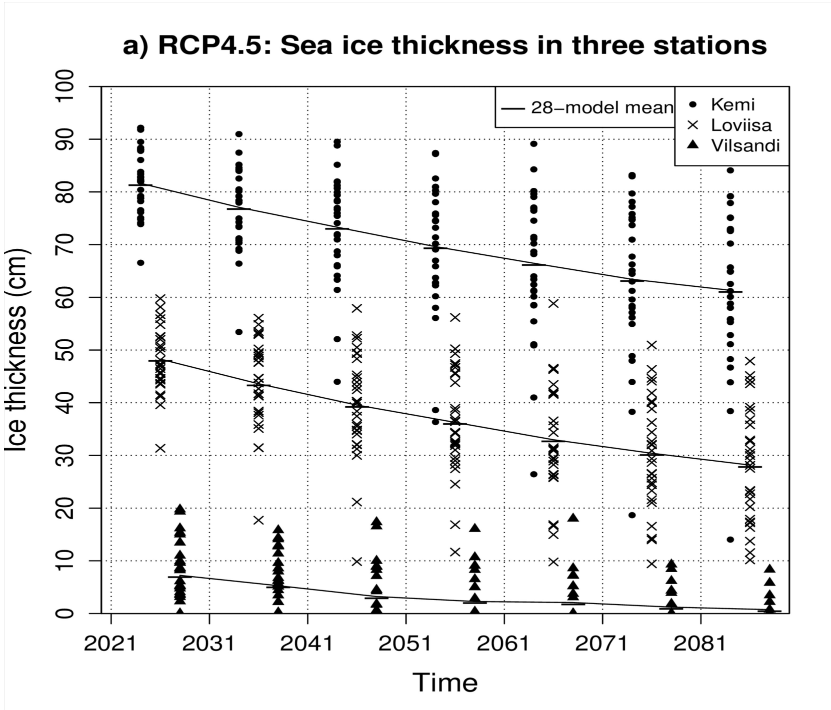
- FDD-model (Stefan, 1890; Zubov, 1945; Leppäranta, 1993):

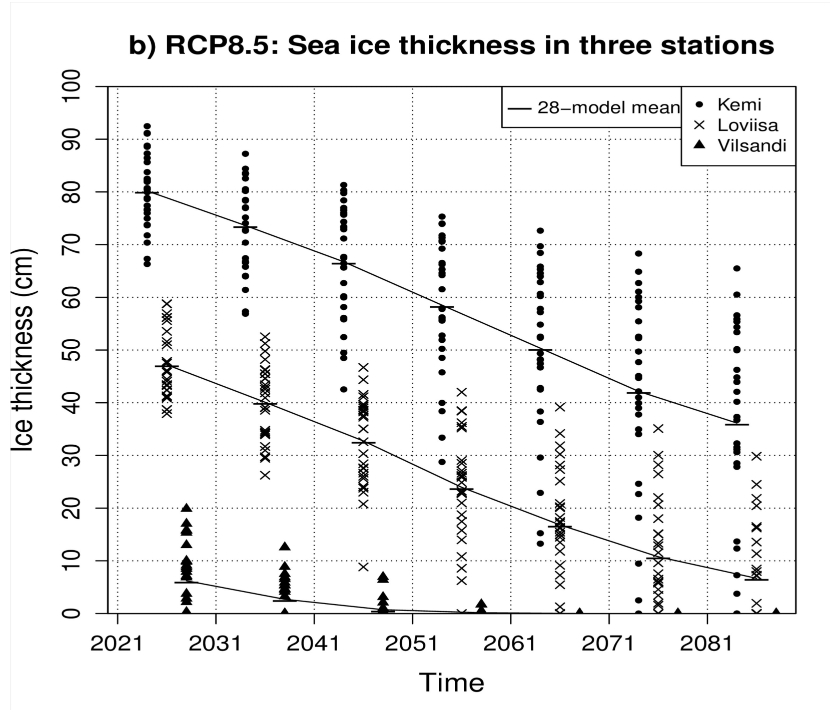
$$h = \sqrt{a^2 \times S + d^2} - d$$

- 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 → 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

	RCP4.5 (%)		RCP8.5 (%)	
	2041-2050	2081-2090	2041-2050	2081-2090
Kemi	25	37	32	63
Loviisa	40	57	50	89
Vilsandi	88	97	97	100

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

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