Baltic Sea Climate Scenarios for Sea Surface Temperature and Ice.

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A mini-ensemble approach is taken to quantify possible changes in Sea Surface Temperature (SST) and sea ice extent of the Baltic Sea in response to atmospheric greenhouse scenarios. Mean quantities, interannual variability and uncertainty are addressed.

The Rossby Centre regional coupled ocean-ice-atmosphere model RCAO (Döscher et al. 2002) in a northern European domain is applied to dynamically downscale global control and scenario simulations from two global models (HadAM3H (“HC”) and ECHAM4/OPYC3 (“MPI”)) and two emission scenarios (A2 and B2, see Nakicenovic et al. 2000). RCAO has been run for today’s climate (1961 - 1990, 'control run') and for future time slices (2071-2100, 'scenario run'). Details on the component models of RCAO can be found in Jones et al. (2004) for the atmosphere (RCA) and in Meier et al. (2003) for the ocean and ice model (RCO).

Some conclusions on robustness and ambiguity of projected climate change are possible only due to the availability of several control and scenario experiments (2+4). This represents major progress compared to earlier regional investigations. The regional simulation length allows for statistical significance in the change of not only mean SST but also of the mean annual cycle of heat flux. Furthermore, frequency distributions and interannual variability of monthly mean SST would not be meaningful with shorter experiments. Another general improvement of regional scenario technique is seen in the consistent model set up. The ocean model interacts directly with the atmosphere model, rather than passively accepting forcing in offline standalone runs, which might be affected by the imprint of a simpler representation of the sea surface. Detailed results can be found in Döscher and Meier (2004) for temperature and heat fluxes and in Meier et al. (2004) for sea ice and impact on the Baltic’s seal habitat.

	mean SST in ^{o}C	SST change scenario-control in ^{o}C	Mean max annual ice volume in 10^{9} m^{3}	Change of mean max annual ice volume (scenario – control) in 10^{9} m^{3}	Change of mean max annual ice volume (scenario – control) in %
Observations	7.2	-	-		
HCCTL	7.7	-	42.4		
MPICTL	7.3	-	46.9		
HCA2	10.7	+ 3.0	7.1	-35.3	-83
MPIA2	11.1	+ 3.8	4.1	-42.1	-90
HCB2	9.6	+ 1.9	10.2	-32.2	-76
MPIB2	10.2	+ 2.9	8.2	-38.7	-83
average change	-	+ 2.9		-37.1	-83

Table 1. 29-year mean SST and sea ice volume. The SST observations are climatological monthly means calculated by Janssen et al. (1999) . Model runs are denoted as combination of the name of the driving GCM (HC, MPI) and the type of run (CTL for control or A2/B2 for the scenario runs).

The Baltic Sea mean SST for the different runs are given in table 1 together with climatological observations. SST mean values of the control simulations show only small positive biases of less than 0.6 ^{0}C. These differences correspond to a generally too warm surface air temperature over Europe in the regional atmosphere model (Räisänen et al., 2003). The ensemble mean surface warming is 2.9 ^{0}C. The uncertainties due to the emission scenario and the global model are indicated by the differences between the individual experiment’s signals. Warming is stronger for the A2 cases (3.4 ^{0}C on average) and smaller for the B2 cases (2.4 ^{0}C on average). Surface warming based on MPI scenarios is stronger than HC-based increases by 0.9 ^{0}C. Differences are consistent with the greenhouse gas scenarios and the associated global mean GCM and regional mean RCM surface air temperature (Räisänen et al., 2003). Sea surface warming is strongest during the period May to September for all cases.

Interannual variability of Baltic Sea SST is increased by up to 0.5 ^{o}C in terms of standard deviation of individual monthly means. The related frequency distribution for SST (i.e. the distribution of colder and warmer than normal years) is smoothed in northern basins during the colder period of the year as not limited by the freezing point temperature.

The Baltic Sea heat budget has been calculated for control and scenario experiments. Both show similar total surface heat fluxes close to zero. Component fluxes show robust and coherent changes under a warmer climate: solar radiation is increased, net longwave radiation (out of the ocean) is increased, sensible heat flux (out of the ocean) is reduced and latent heat flux (out of the ocean) is increased. The amplitude of change is higher in the MPI case, corresponding to the higher SST change.

The Baltic Sea takes up heat from the atmosphere during the warm months and returns heat during wintertime. Both control runs confirm this picture. Under a warmer climate, atmosphere-to-ocean heat fluxes show a different distribution over the seasons. The ensemble mean heat loss is reduced between during winter, heat uptake is increased in April and heat uptake is reduced between May and July. By arriving of the summer, any additional net heat transfer into the ocean is counteracted by a negative feedback mechanism: the warm ocean responds with increased heat release by longwave outward radiation and latent heat. These signals are significant due to the length of experiments. Thus they cannot be explained as caused by interannual variability only. This general picture is a robust feature of all our experiments independent of the scenario (A2 or B2) and the driving global model (MPI or HC). Locally, in the northern part of the Baltic, heat fluxes change by up to 30 Wm^{-2} in the ensemble mean when strong ice cover changes (during spring) occur, and when the latent heat flux changes most (during fall).

The simulated mean annual maximum ice extent and the number of ice days in the control runs matches observations (SMHI & FIMR, 1982) for the period 1961 – 1990 well. Ice extent and volume (Tab. 1) are dramatically reduced in the scenarios. The ensemble mean reduction of ice volume is 83%. Corresponding to the SST changes, reduction is stronger for MPI and A2 scenarios. Large parts of the Bothnian Sea, the Gulf of Finland, the Gulf of Riga and the southwest archipelago of Finland are ice free in all scenarios. Severe ice winters do not occur anymore. However, sea ice is found in the Baltic in every single winter.

Some aspects of the simulated changes are contradictory within the ensemble, i.e. more uncertain than coherent findings. This is true for single months of the seasonal cycle of SST, certain secondary maxima in the seasonal cycle of surface warming and for the horizontal heat flux change pattern in the Baltic Proper. Sea surface salinity changes have not been discussed due to biases in precipitation (originating from the large scale circulation of global models) and the associated river runoff into the Baltic Sea. To overcome this problem, delta change experiments can be carried out (Meier and Kauker 2003), whereby the runoff and precipitation change is added on the recent observed forcing. In addition, the introduction of flux corrections for precipitation might be considered to enable salinity scenarios. Quality considerations with respect to the Baltic Sea climate projections are directly linked with processes of hemispheric and global scales. Thus improved GCMs are a precondition for major improvements of regional climate projections. Besides, clouds, radiation and turbulent heat fluxes are targeted for further improvement in the regional model. Even a model system with further improvements will contain uncertainties. Thus future efforts with large ensembles will be necessary to better quantify future climate uncertainty in the Baltic Sea.

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