Modelling of superimposed ice formation during the spring snow melt period

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1. Introduction

In the sea ice modelling community, it is customary that ice melt is calculated both at the ice surface and bottom, but in many models ice growth is only considered at the ice bottom. In the melting season, however, formation of superimposed ice can take place via refreezing of surface snowmelt or rain. In March-April, 2004, an ice station was set up on land-fast sea ice in the Gulf of Bothnia, Baltic Sea. During the four-week period, the entire snow layer, originally 0.15 ± 0.05 m thick, was transformed to 7 cm of superimposed ice, except for 2 cm of snow that sublimated. We use observations of the meteorological conditions and radiative fluxes at the ice station for forcing a thermodynamic snow/ice model, while we use observations of the snow and ice evolution for the model initial conditions and validation, the latter being the basic motivation of this work.

2. Model experiments and results

A one-dimensional high-resolution thermodynamic snow/ice model (Launiainen and Cheng, 1998; Cheng and others, 2003) was used in this study. The following processes are taken into account in the model: heat conduction, penetration of solar radiation in the snow and ice, surface and subsurface melting, percolation of melt water to the snow/ice interface, refreezing of the melt water to superimposed ice, flooding of seawater and its refreezing, and bottom growth/melt of ice. In order to reproduce the exponential decay of penetrating solar radiation in snow and ice, high vertical resolution in a Lagrangian grid mode with 10 layers in the snow and 20 layers in the ice is used. Two strategies were applied: (A) forcing the model with parameterized air-ice fluxes, and (B) prescribing the air-ice fluxes according to the observations. Comparing the results of (A) and (B) against observations tells us about the relative importance of errors related to model forcing and modeling of the processes inside snow and ice. In both strategies, we also studied the model sensitivity to the snow/ice surface albedo.

The model results with the surface albedo prescribed according to the observations are referred to as the reference run (A_ref). In the first sensitivity test, A_p, the albedo was parameterized according to Perovich (1996). In the second test, A_FB, the albedo was calculated according to Flato and Brown (1996), hereafter FB. A comparison of the time series of the observed and modelled snow and superimposed ice thickness is shown in Figure 1.

We made a simulation B_ref with the surface temperature, albedo, and radiative fluxes prescribed according to the observations (Figure 2). The evolution of the snow thickness from day 90 onwards is now better reproduced than in A_ref, which suggests that the internal processes in the snow cover are reasonably well modelled. In a sensitivity study B_FB the surface temperature and surface fluxes were prescribed according to the observations, as in B_ref, except that surface albedo is parameterized according to FB. Although the surface temperature is prescribed in B_FB, the parameterized albedo
affects both surface and subsurface melting. The results are, however, almost equal to those of B\textsubscript{REF} with the prescribed albedo (Figure 2) due to the lack of feedback between the surface temperature and albedo. The importance of the feedback is demonstrated by the large difference between the results of A\textsubscript{FB} (dashed lines in Figure 1) and B\textsubscript{FB} (dotted lines in Figure 2).

Figure 1. Observed and modelled evolution of (a) snow thickness $H\textsubscript{s}$, and (b) superimposed ice thickness $H\textsubscript{sui}$. The observations are marked by circles with the vertical bar indicating the spatial standard deviation. The solid lines indicate model results of A\textsubscript{REF}, while the dotted and dashed lines indicate model results of A\textsubscript{F} and A\textsubscript{FB}, respectively.

Figure 2. Observed (circles) and modelled evolution of (a) snow thickness and (b) superimposed ice thickness. The solid lines indicate results of B\textsubscript{REF} while the dotted lines indicate results of B\textsubscript{FB}.

3. Conclusion

A high vertical resolution was a needed for successful simulations. This is critical under conditions of large solar radiation and during rapid temperature changes. The modelled snowmelt and superimposed ice growth were consistent with the observations, but the net accumulation of superimposed ice was slightly overestimated. The modelled snow thickness was sensitive to the atmospheric forcing, and the influence was amplified when the albedo was parameterized as a function of surface temperature. In the sensitivity tests without this feedback, the direct effect of the inaccuracy in the albedo parameterization was minor. In further development of high-resolution thermodynamic snow and ice models, focus is needed on the parameterization of (1) surface albedo, (2) radiative fluxes, and (3) air-ice exchange during the night. In this study, surface temperature errors were not critical for the ice and snow mass balance, but in slightly warmer conditions equally large errors could have been critical if the erroneous simulations had not yielded freezing temperatures at night.

References


