Modelling of superimposed ice formation during the spring snow melt period

Bin Cheng[1], Timo Vihma[2], Roberta Pirazzini[1,3] and Mats A. Granskog[4,5]

[1]Finnish Institute of Marine Research, P. O. Box 33, 00931 Helsinki, Finland
[2]Finnish Meteorological Institute, P.O. Box 503, 00101 Helsinki, Finland
[3]Department of Physical Sciences, P. O. Box 64, 00014 University of Helsinki, Finland
[4]Arctic Centre, University of Lapland, P. O. Box 122, 96101 Rovaniemi, Finland
[5] Present address: Centre for Earth Obs. Science, Univ. Manitoba, Winnipeg, Manitoba, Canada R3T 2N2

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 acoording 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_{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_{FB} (dashed lines in Figure 1) and B_{FB} (dotted lines in Figure 2).

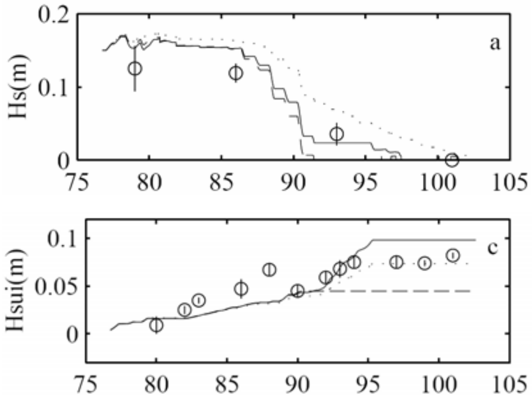

Figure 1. Observed and modelled evolution of (a) snow thickness H_s, and (b) superimposed ice thickness H_{sui}. The observations are marked by circles with the vertical bar indicating the spatial standard deviation. The solid lines indicate model results of A_{REF}, while the dotted and dashed lines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

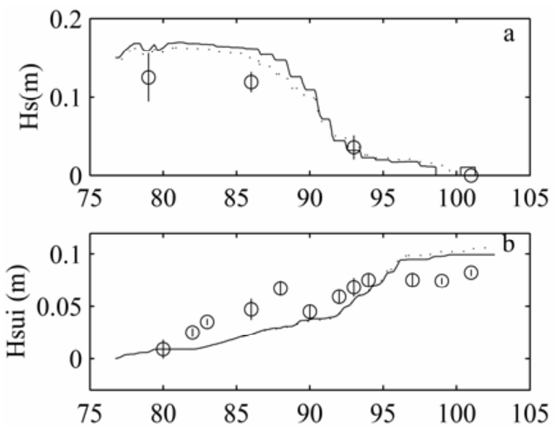

Figure 2. Observed (circles) and modelled evolution of (a) snow thickness and (b) superimposed ice thickness. The solid lines indicate results of B_{REF} while the dotted lines indicate results of B_{FB}.

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

Cheng, B., T. Vihma and J. Launiainen. 2003. Modelling of the superimposed ice formation and sub-surface melting in the Baltic Sea. *Geophysica,* **39**(1-2), 31-50.

Flato, G.M. and R.D. Brown. 1996. Variability and climate sensitivity of landfast Arctic sea ice. *J. Geophys. Res.,* **101**(C11), 25,767-25,777.

Launiainen, J. and B. Cheng. 1998. Modelling of ice thermodynamics in natural water bodies. *Cold Reg. Sci. Technol.,* **27**(3), 153-178.

Perovich, D.K. 1996. The optical properties of sea ice. *CRREL Monogr.* 96-1.