3A.3 THERMODYNAMIC ICE MODEL SIMULATIONS OF SHEBA: INITIALIZATION AND ALBEDO SENSITIVITIES

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1. INTRODUCTION

The goal of the Surface Heat and Energy Balance of the Arctic (SHEBA) program is to understand the energy balance in the Arctic Ocean and to use this knowledge to improve climate models. The SHEBA observational field program was conducted between October 1997 and October 1998 in the Beaufort Sea from the Canadian icebreaker *Des Groseilliers*, as well coordinating ice camps, aircraft and satellites. SHEBA collected an extensive observational data set on the atmosphere, sea ice, and the upper ocean. The final phase of SHEBA uses the field data to test and improve Arctic processes that are represented in climate models.

One step in improving ice-albedo feedback in climate models is presented here. SHEBA data are used to test and validate a thermodynamic ice model that is presently used in a global climate model. The SHEBA ice thickness and temperature data are used for the initial conditions and model validation. The surface meteorological, radiation, snow depth, and ocean flux data are used as model forcing.

Some ice modeling studies of the SHEBA ice conditions use an ice-thickness distribution model, and require thickness distribution data such as that from submarine-based sonar. The model simulations presented here are performed for several thickness-gauge observation sites, which provide validation for the model at intervals of several days through the entire year, and thus can illustrate specific model-data comparisons. The main questions addressed in this paper are:

- How much ice growth and surface melt is produced by the model as compared to observations?
- How do the vertical resolution and initial conditions affect the year-long ice simulation?

2. MODEL DESCRIPTION

The model used here is the mass- and energy-conserving thermodynamic ice model of Bitz and Lipscomb (1999). It uses an implicit solution of the heat equation in sea ice, and accounts for the effect of internal brine-pocket melting on surface ablation. It can have any number of vertical layers for temperature within the ice, and 4 layers are used in the control runs here. It uses a temperature- and salinity dependent heat capacity and thermal conductivity for sea ice, and fixes a time-independent vertically-varying salinity profile. The surface temperature and surface fluxes are computed by iteratively solving the surface energy balance equation. The stability-dependent surface fluxes are computed using the bulk formulations used in the NCAR Climate System Model Flux Coupler (Bryan et al., 1996).

The thermodynamic ice model is presently being implemented, in conjunction with ice dynamics and an ice-thickness distribution model, into both the NCAR Community Climate System Model (CCSM) and the Parallel Climate Model (Weatherly and Bitz, 2001).

The snow and ice albedos used in the control runs here are:

Dry snow, $\alpha = 0.77$
Melting snow $\alpha = 0.65$
Melting sea ice $\alpha = 0.65$

The melting ice surface of $\alpha = 0.65$ is approximately what was measured along the SHEBA albedo line for this "white ice" in summer (D. Perovich, pers. comm.).

3. DATA

The hourly meteorological variables used to force the model, 10-m air temperature, wind speed, humidity, downward solar and longwave radiation, were taken from the meteorological flux tower data (Andreas et al., 1999). Gaps in this data were filled in using the main SHEBA tower observations by J. Curry, University of Colorado, who made this data available.

The ocean heat flux under the ice was computed from the turbulence ocean mast cluster data (McPhee et al., 2001). Hourly averages of the 15-minute data were used, and periods of missing data were filled by linear interpolation. The data from the highest-level cluster were used, although this cluster was raised from 4 m to 2 m depth in June 1998. This paper's ocean heat flux calculation should be considered preliminary at best.

The ice thickness (surface and bottom levels), snow depth, and temperature profiles are taken from thickness gauge and thermistor string data on the

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SHEBA Snow and Ice Studies CD-ROM (Perovich et al, 2000). The ice and snow data measured at intervals of several days were interpolated linearly to hours for forcing the ice model (with snow cover) and validating the model (thickness).

4. EXPERIMENTAL DESIGN

For the model simulation of each site (each thickness gauge used), the model was initialized with the ice thickness and snow depth from first thickness gauge measurement, typically Oct. 30, 1997. The temperature profile is initialized from the thermistor-string data that are generally near the thickness gauges used. For cases with no thermistor data, the thermistor data from another site with similar ice thickness was used.

The model was run using a one-hour time step, matching the interval of the meteorological observations. The model runs extend to Oct. 1, 1998, although not all thickness gauges cover the entire period. The model is forced with the meteorological variables listed above, and the ocean heat flux. In addition, the hourly snow depth is prescribed from the measured thickness gauge data. This avoids any discrepancies between the measured precipitation rates and snow depths. One significant adjustment was made to the snow data in this study: the snow depths present during the melt season (when the surface level is decreasing) were typically 1-5 cm. This layer consisted not of snow, but of melting, drained, granular sea ice. This summer snow depth was set to zero in the model forcing data, so the model would not be affected by a falsely insulating snow layer.

For these one-dimensional model runs, there is no variation in ice fraction, and no heat flux through leads into an ocean mixed layer.

5. RESULTS

The thermodynamic ice model results for four thickness gauge sites are shown in Fig. 1. The sites' designated 'names', Pittsburgh, Quebec 1, The Ridge, and Mainline, are taken from the Snow and Ice CD-ROM, and the gauge numbers used are shown. Three of these sites (Pittsburgh, Quebec 1, and Mainline) are characterized by thin-to-moderately thick multiyear (MY) ice, and The Ridge is a thick multiyear pressure ridge. None of these four gauges had a surface melt pond in summer, although melt ponds were often at nearby sites.

The model's growth of ice indicated by the decreasing depth of the ice bottom is consistent with observations into about May 1998, but then lacks the observed summer bottom melting in summer in most cases. This is likely a bias of a lower ocean heat flux, resulting from both data limitations and this experiment's lack of an open water lead fraction, which can substantially add heat under the ice. The large variations under The Ridge are likely due to movement of ice blocks and not growth or melt.

The surface ablation is summer in the control case (upper dash-dot line) is simulated to be similar to the observed (solid) in these cases, except for Pittsburgh. For most of these cases, the surface albedo of α = 0.65 (and the other surface energy components) produces a good fit to the observed surface melting.

When included in the global climate model, the ice model thermodynamics represents the ice distribution in a two-dimensional grid. In such a case, the melting ice albedo is reduced to α = 0.52 to account for the effects of melt ponds over part of the surface. The effect of using the melting ice albedo α = 0.52 is also shown in Fig. 1 (dashed lines). This results in about 35 cm of additional surface ablation, although is closer to that of the Pittsburgh site.

Two additional thickness gauge sites' model results are shown in Fig. 2 in which surface melt ponds were present: Seattle and Mainline ponds, which had ponds 32 cm and 40 cm deep, respectively. For these model runs, α = 0.52 in summer. This thermodynamic ice model has no explicit physics to treat the heat or mass storage or energy exchanges of melt ponds. However, the amount of ice surface ablation simulated by the model is only about 10-15 cm less than that measured at the bottom of the pond (ignoring the actual surface water level of the pond). Other pond sites (not shown) produce similar results.

The temperature profile from Pittsburgh for the control case is shown in Fig. 3, along with the thermistor data, for four times of the year. The initial temperature profile is shown in Fig. 3a, when a temperature gradient is present only in the upper 100 cm. The biggest model-data difference is in mid-May when the surface is warming, and the model's mid-level remains colder, which would contribute to the late-spring bottom growth in Fig. 1.

Several sensitivity experiments have been performed with this model to determine how robust the model results are. One test changed the initial vertical temperature profile from the thermistor data (as in Fig 3a for Pittsburgh) to a linear profile fit between the initial surface temperature and the freezing temperature at the bottom. This linear fit is thus colder in the internal layers than the initial profile in all the thickness-gauge sites tested. The results of these model runs (not shown) are a slight increase in ice growth of between 1 and 3 cm within

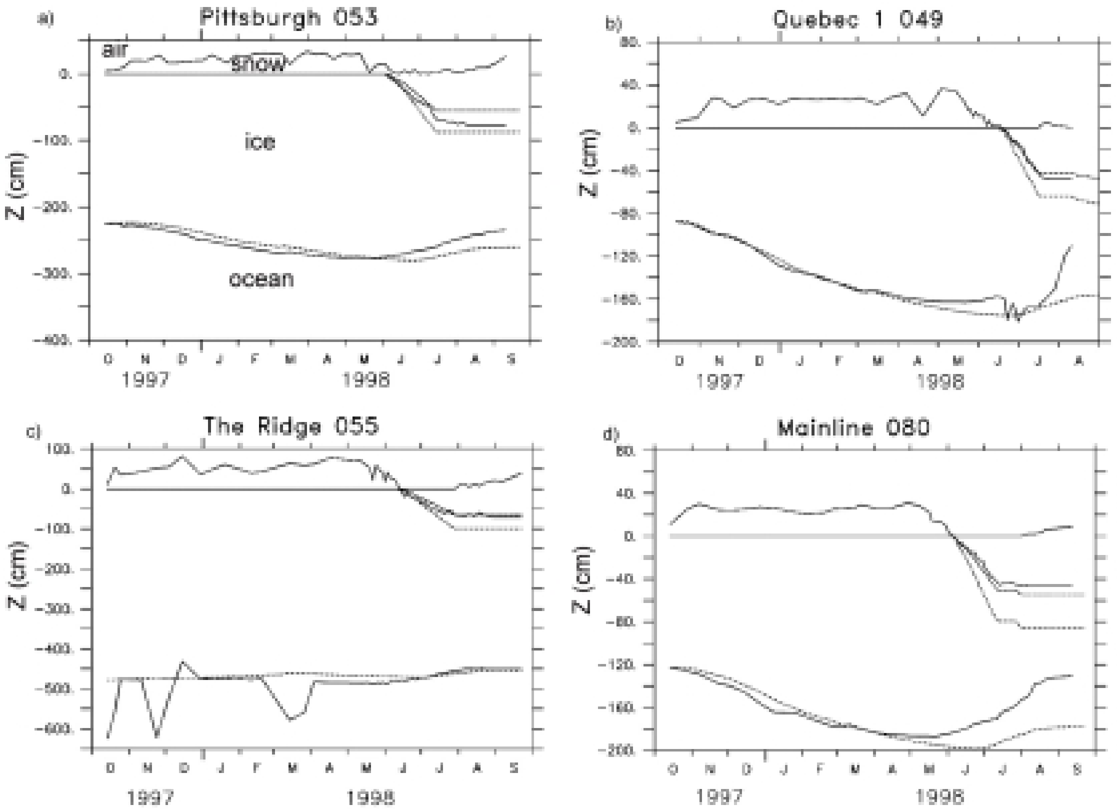

Fig. 1. Snow depth, ice surface, and ice bottom levels for SHEBA observations (solid lines), for ice model control runs (upper dot-dash line), and for melt-pond albedo cases (lower dashed line) for four thickness-gauge cases without melt ponds present.

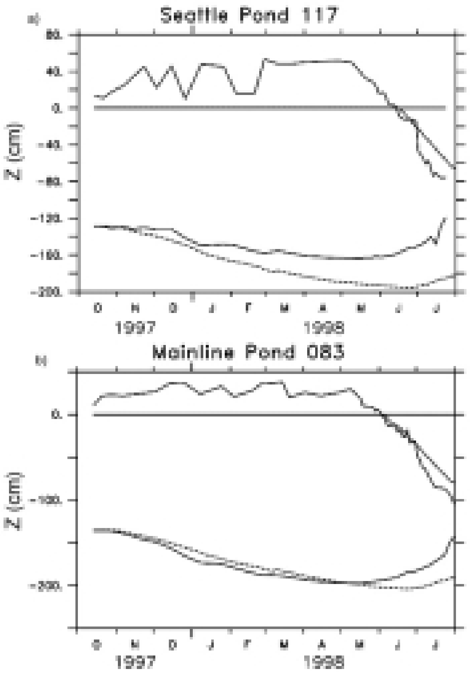

Fig. 2. Snow, surface, and bottom levels as in Fig. 1, for two cases with melt ponds present and using melting ice albedo of $\alpha = 0.52$.

a few days of the initial date. The exception is The Ridge, where temperature perturbation in the 478-cm thickness results in increased ice growth of about 20 cm between Oct. 1997 and June 1998. The impact of the initial temperature is equal to the change in thermal energy for the total thickness of ice, and thus is most important for the thickest ice.

Another experiment involved increasing the number of temperature layers in the model from 4 to 10. The initial temperature profile for the 10 layers was determined from the thermistor data. The 10-layer model resulted in extremely small (< 1 cm) differences in ice thickness, growth and melt rates. The implicit solution of the heat equation and the prescribed upper and lower temperature boundary conditions limit these differences.

6. CONCLUSIONS

The thermodynamic model compares well to observations of ice growth in winter and surface ablation in summer. The underestimate of bottom melt in summer is likely a result of the ocean heat flux computed from the preliminary turbulence data, and the lack of a more complete mixed-layer and lead-fraction model. The surface ablation computed for the ponded sites is slightly less than observed, though no pond physics are presently included in the NCAR climate model.

With this set of baseline model tests and the comprehensive SHEBA database, this research will continue to develop parameterizations to improve ice-albedo feedback in climate models.

7. ACKNOWLEDGEMENTS

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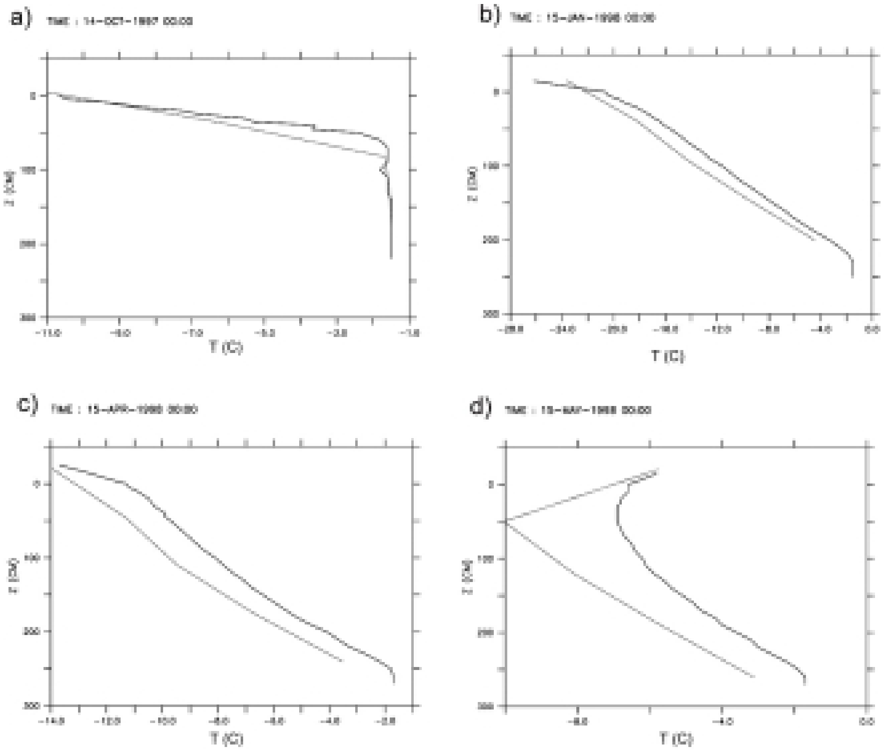

Fig 3. Vertical temperature profiles at the Pittsburgh site from the thermistor data (solid) and the model (dashed) for four days of the year, a) Oct. 14, 1997 (initial data), b) Jan. 15, 1998, c) Apr. 15, 1998, and d) May 15, 1998.