Experimental and Theoretical Studies of Ice-Albedo Feedback Processes in the Arctic Basin

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LONG TERM GOALS

The overall goal of our proposed work is to develop a quantitative understanding of the processes that collectively make up the ice-albedo feedback mechanism.

OBJECTIVES

To achieve this goal, we must first determine how shortwave radiation is distributed within the ice-ocean system, then assess the effects of this distribution on the regional heat and mass balance of the ice pack. Specifically we wish to determine:

- How is shortwave radiation partitioned between reflection, surface melting, internal heat storage, and transmission to the ocean, and
- How is this partitioning affected by the physical properties of the ice, snow cover, melt ponds and the distribution of particulates?
- What is the areal distribution of ice, ponds, and leads,
- How does this distribution vary with time, and
- What is the impact on area-averaged heat and mass fluxes?
- What are the crucial variables needed to characterize ice-albedo feedback processes and their effect on the heat and mass balance of the ice pack, and
- How accurately can the ice-albedo feedback processes be treated through simplified models and parameterizations?

APPROACH

These objectives are being addressed through a combination of field observations and theoretical modeling. The field observations were directed towards acquiring a complete time series of ice mass balance and optical properties over an entire annual cycle. Particular attention was paid to the spring and summer when changes in ice conditions and ice optical properties are rapid and the impact of the ice-albedo feedback is the greatest. One of our objectives is to apply information obtained from local process and time evolution studies to the estimation of areally-integrated heat and mass fluxes. For this purpose, numerous surveys were conducted to give us a statistical picture of the spatial variability

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within individual ice types, and provide quantitative information on the fractional area covered by these categories within the SHEBA region.

Process-oriented modeling will supplement and augment the field studies. Field data on ice structure and optical properties will be combined with laboratory data to develop and verify a model that relates structural and optical properties in warm sea ice. Such a model is needed in any advanced treatment of radiative transfer in sea ice and will form the basis for modeling efforts to predict the optical evolution of the ice cover during the summer melt season. We will also carry out a theoretical investigation of how reduced ice growth beneath melt ponds affects their impact on the regional mass balance. Other models will be used to generalize observational results on lateral melting and floe size distribution, and to evaluate possible effects of soot released from the ship on albedos, melting and heat fluxes.

WORK COMPLETED

We participated in the SHEBA field experiment for its full 13 month duration. During this time we made extensive time series measurements of the snow cover; the ice mass balance, temperature, and morphology; and the albedo and transmittance. In addition we performed surface and aerial surveys to investigate the spatial variability of these properties. Activities during the first fall involved selecting the primary floe, surveying the floe, selecting measurement sites and deploying instrumentation. Continuously recording instrument packages were deployed at several time series measurement (TSM) sites where ice temperature profiles, ice growth rates and snow depths were routinely monitored throughout the SHEBA year. Over 120 hot wire thickness gauges were installed at other sites on the floe, including young ice, ponds and ridges. Routine observations carried out during the winter focused on monitoring changes in ice thickness and snow depth. Activity increased in the spring with detailed snow studies, ice properties work, and optical measurements. The spring effort defined the initial conditions at the onset of melt. In the summer, we measured the temporal evolution and spatial variability of such quantities as albedo, light absorption in the ice, transmittance, mass balance and pond coverage. Figure 1 shows a mass balance site that included both bare ice and ponded ice. Melt ponds were extensive during the summer. Surface-based surveys sampling albedo, snow and ice properties, melt pond depth and area, and surface topography were conducted routinely during the spring and summer. Weekly helicopter surveys were flown from May to September, as weather permitted, examining the local and larger-scale variations in ice concentration, melt pond fraction, floe size distribution, floe perimeter, and surface reflectivity. This data will play an important part in obtaining regional estimates of shortwave input to the ocean, lateral melting on floe edges, and melt pond effects.

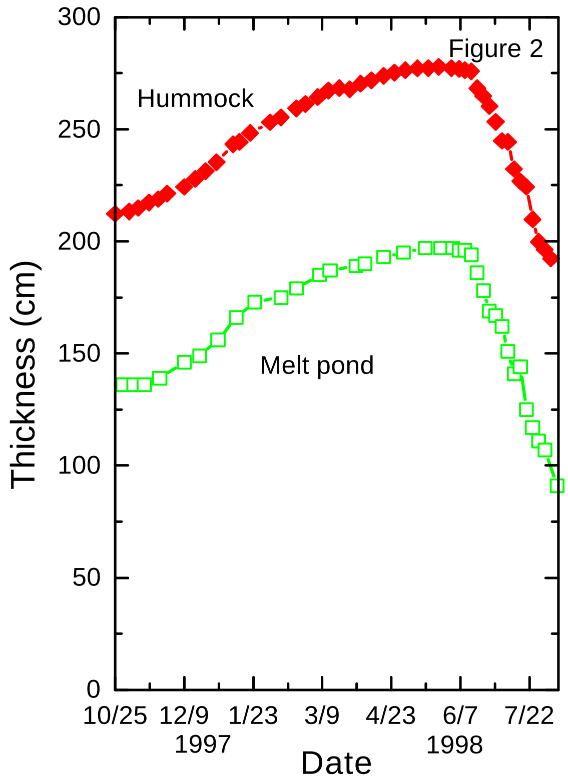
Figure 1. Ice Station SHEBA August 1998. Mass balance measurements were made at each white stake. Note the variegated nature of the ice surface, with a mixture of bare ice and ponds.

RESULTS

We have just completed the year-long SHEBA experiment and data reduction and analysis has begun. Preliminary findings include:

1. The thermal conductivity of the snow cover was half the value previously reported.
2. The ice conditions in Fall 1997 indicated heavy melting during Summer 1997.
3. There was a net thinning of the ice between October 1997 and October 1998.
4. During the melt season spatially averaged albedo decreased from 0.9 to 0.4.
5. The seasonal evolution of albedo was a continuous process punctuated by discrete events.
6. There was very little blue ice present during the summer melt season.

Examples of mass balance measurements are shown in Figure 2. During the growth season the thickness of the hummock increased by 65 cm and the melt pond by 60 cm (Figure 2). Melt started in mid-June and by early August the hummock thinned by 88 cm and the pond by 105 cm. We were surprised to find that there was a net thinning of the ice cover between October 1997 and October 1998. As part of our solar radiation studies, we measured albedo averaged over a 200 m transect line from April through October. In the spring there was a gradual decline in albedo from 0.9 to 0.8 as the snow cover warmed and the snow grain size increased (Figure 3). There was a sharp decrease in late-May associated with the first rain of summer. There was a general reduction in albedo during the summer that was punctuated by a few transitory increases caused by light snowfalls.



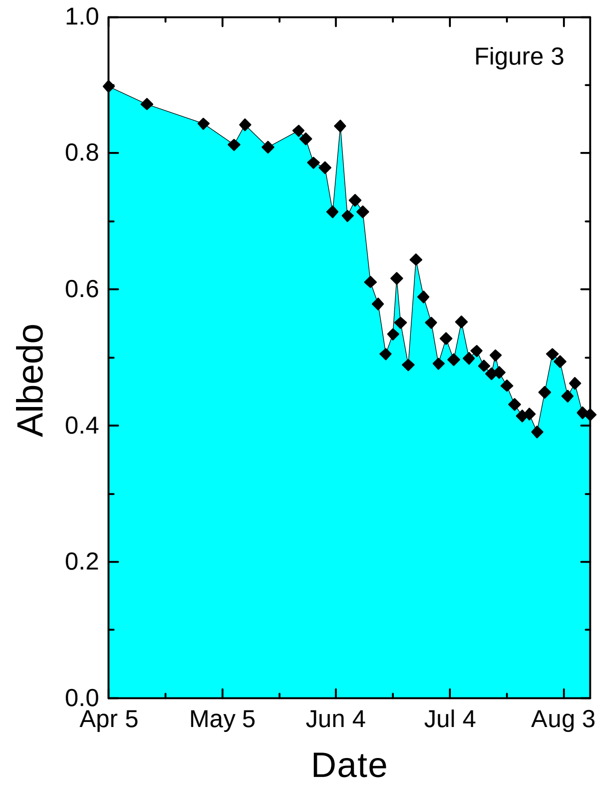


Figure 2. Evolution of ice thickness for a hummock and a melt pond.

Figure 3. Time series of areally-averaged albedo.

IMPACT / APPLICATIONS

Results from this work will help improve sea ice models used for ice forecasting and general circulation models used in climate studies. In particular, more accurate parameterizations of sea ice radiative transfer and mass balance will result from these studies

TRANSITIONS

The instruments developed in year 1 of this work were installed and used this past year at Ice Station SHEBA. Data from that experiment are currently being reduced and analyzed. Preliminary results are being used by atmosphere and ocean researchers and have been incorporated into the SHEBA column dataset.

RELATED PROJECTS

This work is being performed jointly with G.A. Maykut and T.C. Grenfell (ONR Contract N00014-97-1-0765) on this program. We are also collaborating with other SHEBA investigators, such as Eicken's studies of ice thickness and permeability; Paulson and Pegau's work on summer leads; McPhee and Morison's upper ocean studies; and the atmospheric boundary layer group's heat flux effort.