Ice-Albedo Feedback Process in the Arctic Ocean

Donald K. Perovich
John Weatherly
Mark Hopkins
Jacqueline A. Richter-Menge
U. S. Army Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover NH 03755
Voice: 603-646-4255   FAX: 603-646-4644   perovich@hanover-crrel.army.mil

Award Number: N0001401MP20022

LONG-TERM GOALS

The overall goal of this proposal is to quantitatively understand the ice-albedo feedback and incorporate this understanding into large-scale models.

OBJECTIVES

To achieve the project 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. Specific objectives of this study are:

- To quantify the contribution of ice and snow processes to the surface energy balance and the ice albedo feedback (IAF) through synthesis of the SHEBA Phase 2 ice, atmosphere, and ocean data.
- To determine how shortwave radiation is partitioned between reflection, surface melting, internal heat storage, and transmission to the ocean; and how this partitioning is affected by the physical properties of the ice, snow cover, and melt ponds.
- To define the areal distribution of ice, ponds, and leads?
- To integrate floe-scale process models of IAF into a granular model of the ice cover and perform simulations of the SHEBA summer to develop aggregate-scale parameterizations for use in the GCM's ice model.
- To validate improvements in the GCM's ice model simulation of ice conditions within the SHEBA Phase 2 domain and in the larger Arctic Ocean basin.
- To ascertain the impact of the newly parameterized processes on the simulation of IAF in GCMs.

APPROACH

The goal and objectives of this program are being addressed through a combination of both data analysis and modeling. We are conducting a detailed analysis and assimilation of field observations we made during the SHEBA year. Results from this work are providing the basis for development and

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE **Ice-Albedo Feedback Process in the Arctic Ocean**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U. S. Army Cold Regions Research and Engineering Laboratory,,72 Lyme Road,,Hanover,,NH, 03755**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The overall goal of this proposal is to quantitatively understand the ice-albedo feedback and incorporate this understanding into large-scale models.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

testing of parameterizations and process models that will be incorporated in a discrete element model, a single grid cell GCM ice model, and the NCAR global GCM. While much of our effort is concentrated on the complex and poorly understood summer melt season, there are crucial questions related to the longer-term evolution of pressure ridge keels and connections between ice dynamics and thermodynamics. These questions require us to examine the heat and mass balance of the ice cover over the entire annual cycle.

It is critical to scale up the local and regional observations made during the SHEBA field experiment to the larger scales used in basin wide sea ice models and GCMs. For this reason, a central component of our approach is to investigate ice-albedo feedback processes on three scales: the local scale, the aggregate scale, and the large scale. At the local scale, we are examining data from the SHEBA floe and its neighbors, then are using those data to develop process models and parameterizations that treat the temporal evolution of albedo, the formation and development of melt ponds, seasonal mass changes on the top, bottom and sides of floes, and the storage and transmission of shortwave energy by the ice. At the aggregate scale, we are analyzing aerial photographs and satellite imagery to obtain time-dependent statistics on the state (e.g., concentration, pond coverage, floe size distribution) of the ice cover in a 50 km by 50 km region, centered on the ship. These statistics are being combined with results from the local studies to calculate areally-averaged quantities such as albedo, heat input to the ocean, lateral melt losses, surface melt water storage, and internal heat storage within the ice pack. These data will provide both initial conditions and a comparison for simulations using a discrete element model and a single grid cell GCM. Parameterizations will be developed and tested at the aggregate scale and then incorporated into large-scale sea ice and global climate models. Sensitivity tests using these large-scale models will be carried out to assess the impact of these parameterizations.

WORK COMPLETED

During FY01 we completed the analysis of the SHEBA mass balance, ice temperature, albedo, and aerial photography results. We developed a basin-scale granular sea ice model that uses standard geostrophic wind forcing data and have run simulations at 13, 10, and 7 km resolutions. Model simulations of the SHEBA year were performed with the NCAR CCSM/Bitz and Lipscomb thermodynamic ice model using SHEBA ice, snow, meteorological and ocean data. Several journal publications were prepared and submitted and we helped organize a SHEBA workshop.

RESULTS

The analysis of the SHEBA snow and ice observations has produced interesting insights regarding the mass balance of the ice, the time-averaged ocean heat flux, and the distribution of the incident solar radiation. Ice thickness, and snow depth, as well as ice surface conditions and ice topography, all impact the growth and melt of the ice in a complex and interrelated manner. Paradoxically, we may be able to make some progress in generalizing the results by examining the data in less detail. Figure 1a is a histogram of total surface melt at mass balance gauges, highlighting results from ponded and unponded ice. There is a strong peak in the surface melt histogram with 30% of the cases falling in the 50 – 60 cm bin. Extending the range from 40 to 80 cm includes nearly 80% of all the mass balance gauges. Most of the gauges with more than 80 cm of melt were ponded ice. Unponded ice had a mean surface melt of 56 cm and a standard deviation of 17 cm. Surface melt was greater for the ponded ice sites, where the mean was 78 cm and the standard deviation was 21 cm. This difference in surface melt was significant at the 99% confidence level.

The distribution of bottom melt also exhibits a peak (Figure 1b), with 27% of the gauges having 40–50 cm of bottom melt and 70% in the 30- to 70-cm range. Approximately 13% of the gauges had more than 1 m of bottom ablation, all of which were in deformed ice. The difference in bottom melting between deformed and undeformed ice was statistically significant at the 99% confidence level. The deformed ice locations had a mean bottom melt of 76 cm and a standard deviation of 51 cm, compared to a mean of 48 cm and a standard deviation of 17 cm for the undeformed locations. This simple analysis confirms that for the SHEBA year, ponded ice had more surface melt than unponded ice and that deformed ice had more bottom melt than undeformed ice. It also indicates that a substantial fraction of the locations had similar amounts of surface melting and that many also had similar amounts of bottom melting.

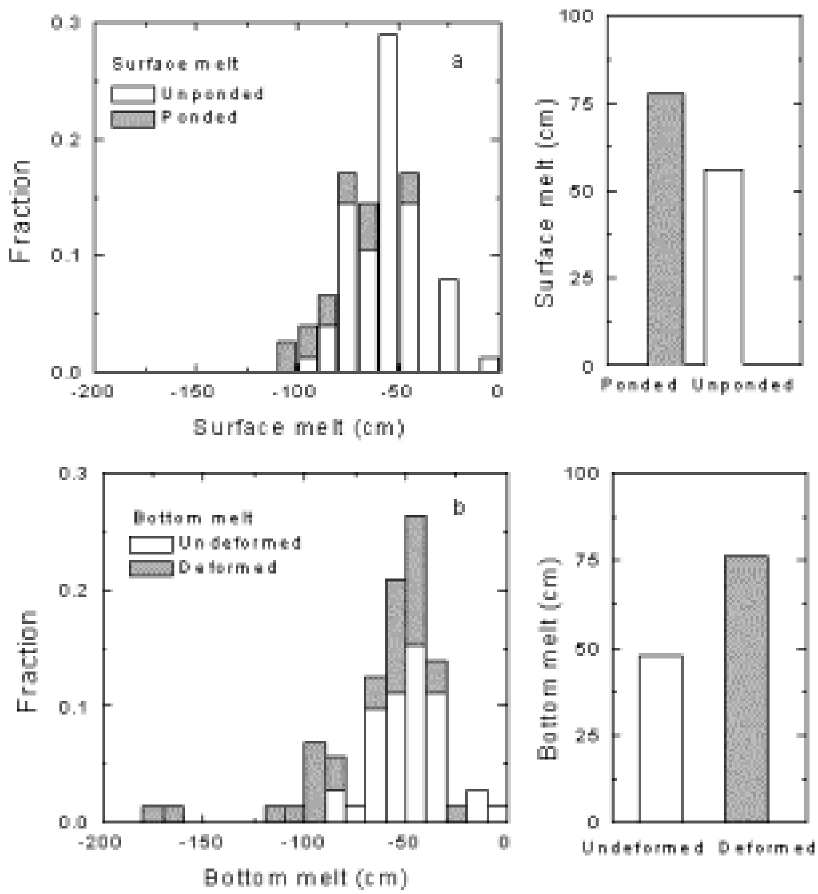

Figure 1. Histograms of the total amount of a) surface melt and b) bottom melt, along with comparisons of the average surface melt for ponded and unponded ice and the average bottom melt for deformed and undeformed ice. [graph: 30% of all sites had surface melt of 50 to 60 cm; average surface melt was 75 cm for ponded sites and 50 cm for unponded; bottom melt mode was 50 to 60 cm; deformed ice average 75 cm of bottom melt and undeformed 50 cm]

Over 2000 aerial photographs from 12 survey flights were analyzed to determine the relative areas of ice, ponds, and leads. These results were combined with surface-based measurements of albedo and modeled values of light transmittance to estimate the aggregate scale distribution of incident solar irradiance. Results for June 15 and August 7 are compared in Figure 2. Between June 15 and August 7 there was a four-fold increase in pond fraction and a five-fold increase in the open water fraction. These changes resulted in a significant shift in the solar energy partitioning. As portion of the incident solar energy reflected decreased from 70% to 50%, there was an attendant increase in the energy input to the ice-ocean system. There was a large increase in the portion transmitted to ocean from 5% to 25% and a more modest increase of a few percent in the energy absorbed in the ice. Much of the solar energy input to the ocean is transmitted through leads, but a significant fraction portion was transmitted through ponds.

Discrete element modeling focused on constructing a basin scale granular sea ice model that consists of tens of thousands of discrete polygonal floes. Deformation of the model ice pack is driven by geostrophic winds and Coriolis forces. Relative motion between pairs of neighboring floes strains the frozen joints that connect them. When the stress at either end of a joint exceeds the tensile or compressive strength failure begins. Once a joint has fractured that pair of floes can be pushed together to form a pressure ridge or pulled apart to form a lead. Pressure ridging between floes is modeled using a parameterization developed from simulations of the ridging process. The interior of each floe is a continuum with its own thickness distribution that is affected by ridging and thermal growth and melt. When pairs of neighboring floes are pushed together the polygons defining the shape of each floe intersect. The intersection area is interpreted as thin ice destroyed by ridging. Redistribution is defined by a parameterization determined from simulations of the ridging process. Thermal growth and melt are modeled using a program developed by Flato based on the work of Ebert that includes multiple vertical levels allowing energy storage. We are using SHEBA observations to modify the treatment of thermodynamics in the model. The ice thickness distribution of discrete floes responds to temperature fields and radiative fluxes. A simulation of the fracturing of the ice is shown in Figure 3.

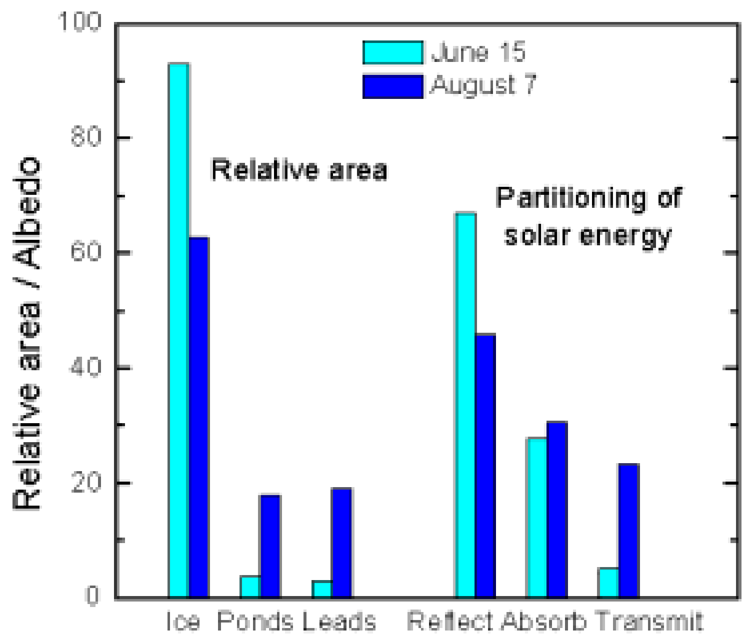

Figure 2. Estimates of the partitioning of solar energy on June 15 and August 7. [graph: histogram shows four-fold increase of pond fraction and 5-fold increase in lead fraction from June 15 to August 7 and increase of solar energy input to the ice-ocean system from 30% to 50%]

The NCAR climate model ice thermodynamics was used, along with SHEBA meteorological data, to simulate SHEBA mass balance observations. Comparisons between model results and observations were made for ponded ice, undeformed ice, and deformed ice. The model's average surface melt in summer over all thickness gauges agrees with the observations to within about 5 cm.

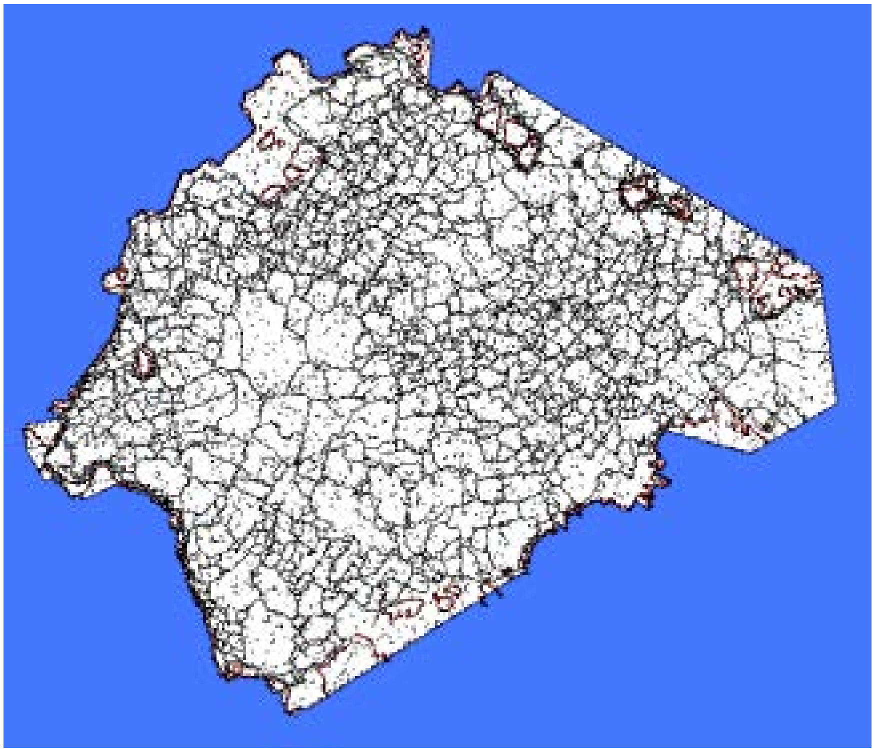

Figure 3. The fracture patterns produced in a simulation of the Arctic ice pack by the wind and Coriolis force. Fram Strait is on the right. [picture: simulation of ice cover showing fracturing]

IMPACT/APPLICATION

Results from this work are being used to improve the sea ice component of ice forecasting models and of general circulation models. Observations are being used to improve parameterizations of the ice-albedo feedback. The granular model allows detailed prediction of the distribution and size of leads and pressure ridges, and the explicit location of the ice edge and marginal ice zone. A new cloud-water parameter is being incorporated into the new version of the NCAR CCSM released to the community. This has already improved the results of a simulation of climate change from the pre-industrial period to the present-day.

TRANSITIONS

Results from our field measurements have been reduced and archived. Over 200 CD-ROM’s have been distributed and are being used by atmosphere and ocean researchers, and have been incorporated into the SHEBA column dataset. Over the past year, findings have been disseminated to the general community in 8 conference presentations, 3 published journal articles and 11 journal articles in press.

RELATED PROJECTS

This work on this program is being performed jointly with G.A. Maykut T.C. Grenfell, and B. Light. We are also collaborating with other SHEBA investigators, such as Paulson and Pegau's work on summer leads; McPhee and Morison's upper ocean studies; Curry's aircraft and modeling studies; the Moritz and Bitz modeling efforts; and the atmospheric boundary layer group's heat flux effort.

PUBLICATIONS

Curry, J.A., J.L. Schramm, D.K. Perovich, and J.O. Pinto, Applications of SHEBA/FIRE data to evaluation of snow/ice albedo parameterizations, *J. Geophys. Res*., 106, 15,345-15,355, 2001.

Eicken, H., H.R. Krouse, D. Kadko and D.K. Perovich, Tracer studies of pathways and rates of meltwater transport through arctic summer sea ice, submitted to *J. Geophys. Res*.

Eicken, H., W.B. Tucker III, and D.K. Perovich, Indirect measurements of the mass balance of summer Arctic sea ice with an electromagnetic induction device, accepted *Ann. Glaciol*.

Hopkins, M.A., 2001, The effect of tensile strength in the Arctic ice pack, in "Scaling Laws in Ice Mechanics and Ice Dynamics", eds. J.P. Dempsey and H.H. Shen, Kluwer, Dordrecht, 2001.

Perovich, D.K. and B. Elder, Temporal evolution and spatial variability of the temperature of Arctic sea ice, accepted *Ann. Glaciol*.

Perovich, D.K., J.A. Richter-Menge, and W.B. Tucker III, Seasonal changes in sea ice morphology, accepted *Ann. Glaciol*.

Perovich, D.K., T.C. Grenfell, B. Light, and P.V. Hobbs, The seasonal evolution of Arctic sea ice albedo, submitted to *J. Geophys. Res*.

Perovich, D.K., W.B. Tucker III, and K.A. Ligett, Aerial observations of the evolution of ice surface conditions during summer, accepted *J. Geophys. Res*.

Perovich, D.K., T.C. Grenfell, J.A. Richter-Menge, B. Light, W.B. Tucker III, H. Eicken, Thin and thinner: ice mass balance measurements during SHEBA, , under review *J. Geophys. Res*.

Richter-Menge, J.A., D.K. Perovich, and S. Pegau, The Impact of Summer Ice Dynamics on the Surface Heat Budget of the Arctic Ocean, accepted *Ann. Glaciol*.

Richter-Menge, J.A., S.L. McNutt, J.E. Overland, R. Kwok, Relating Arctic Pack Ice Stress and Deformation under Winter Condition, accepted *J. Geophys. Res*.

Sturm, M. D.K. Perovich, and J. Holmgren, Snow-ice Interface Temperature Measurements from SHEBA: Implications for winter heat flux, accepted *Ann. Glaciol*.

Sturm, M., J. Holmgren, and D. Perovich, The winter snow cover on the sea ice of the Arctic Ocean at SHEBA: Temporal evolution and spatial variability, accepted *J. Geophys. Res*.

Sturm, M., J. Holmgren, and D. Perovich, Thermal conductivity and heat transfer through the snow on the ice of the Beaufort Sea, submitted to *J. Geophys. Res*.

Weatherly, J. W., Thermodynamic ice model simulations of SHEBA: initialization and albedo sensitivities. *Sixth Conference on Polar Meteorology and Oceanography*, American Meteorol. Soc., Boston, 209-212, 2001.