The Relationship Between the Physical, Optical and Electromagnetic Properties of Arctic Snow and Sea Ice with Special Reference to the Influence of Entrapped Materials

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Award #: N00014-96-1-0003

LONG TERM GOAL

My long term goal is to investigate the effects of particulate and dissolved material on radiation budgets in polar regions by contributing to the understanding their effects on the optical, thermal, electromagnetic and physical properties of snow and sea ice.

SCIENTIFIC OBJECTIVES

The objectives of this project are:

- to investigate the relationships between the physical (temperature, salinity, crystal structure, inclusions) and electromagnetic (optical and microwave) properties of natural sea ice;
- model the first order effects of inclusions on the thermal, optical, and microwave properties;
- model the second order effects of inclusions on the physical properties;
- apply these models to predict melting rates from SAR imagery

APPROACH

A comprehensive field experiment was conducted in mid April to mid May 1994 at the Native Arctic Research Laboratory outside Barrow, Alaska. My contribution to the integrated program was to measure the concentration, composition and absorption coefficients of the particulate and dissolved material entrapped in the sea ice (Perovich et al. and Grenfell et al., submitted). While this work was part of the larger program, the specific goals of this grant were to integrate the particle and optical characteristics to the electromagnetic properties. This work was performed in collaboration with Robert Onstott (ERIM).

Ice cores were collected with stainless steel ice corers manufactured by Jesse Collins (PICO and MSA) from a number of locations at the two major field sites. Temperature profiles were measured immediately upon ice extraction at 5 cm resolution. Cores were sliced into 5 cm sections on site and transported to the laboratory for analysis. Vertical and horizontal thin sections were collected from the core and analyzed under cross polarized light for crystal size distribution and large scale inclusion distribution. The remaining portion of the samples were melted for further analysis. Salinity was determined from conductivity measurements. Particle composition and size distribution was measured with the Galai CIS100 (Roesler and Iturriaga, 1994; Roesler and Hansing, submitted). Chlorophyllic pigments were analyzed fluorometrically. Dissolved absorption spectra were measured spectrophotometrically on the 0.7 μm filtrate; particulate absorption spectra were measured using the quantitative filter technique with correction for pathlength amplification (Roesler, submitted).

All measurements were conducted within a defined area in the Beaufort Sea. After in situ measurements were made in the presence of snow cover, the snow was removed from half of the

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**

4. TITLE AND SUBTITLE **The Relationship Between the Physical, Optical and Electromagnetic Properties of Arctic Snow and Sea Ice with Special Reference to the Influence of Entrapped Materials**	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) **University of Connecticut,Department of Marine Sciences,1084 Shennecossett Rd,Groton,CT,06340-6097**	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

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)**	**5**	

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

area. In situ measurements were repeated. Variability in the surface ice, due to particulate material in the upper 10 cm, was observed once snow was removed. Six sites ranging from optically clear to particle laden ice were selected to investigate the influence of the particulate material one the ice properties.

The goal of this program was to apply a simple static model to predict the influence of absorbing materials on the thermal properties of sea ice (Roesler and Iturriaga, 1994). The increase in temperature within the ice relative to a reference sample, ΔT [°C], was modeled from:

$$\Delta T(z) = \frac{\Delta a(z)\ E(z)\ t}{\rho\ c_{si}} \qquad (1)$$

where Δa is the difference in the absorption coefficient due to the entrapped material over that of pure ice, E is the spectral irradiance incident on the ice surface, t is the time period of solar heating, ρ is the density of sea ice and c_{si} is the specific heat of sea ice. Concurrent with the change in temperature is a predicted change in ice crystal structure, dielectric constant, and wideband (0.5 to 14GHz) scattering enhancement (Roesler and Onstott; Onstott and Roesler[a], submitted).

A second, smaller scale field program was conducted in 1995 (in collaboration with Don Perovich, CRREL, and Scott Pegau, OSU) in early April and early June to complement the 1994 measurements (Perovich et al., 1997). Concurrent with this field effort was an additional project to investigate the relationship between airborne particulate material and the optical, thermal and electromagnetic properties of snow (Onstott and Roesler[b], in prep.). One-kilometer transects were conducted at 25 m resolution perpendicular to the coastline at three sites (Browerville, NARL, AirForce runway) with the assistance of Bruce Elder (CRREL). Snow thickness and snow/ice interface temperature were measured in April. Snow samples were collected for particle and absorption measurements. Snow and slush thickness and water depth were measured were in June. SAR imagery covering the transect area was collected for the period of early April to July. Using the same approach as above, the increase in snow temperature due to the enhanced absorption by the airborne particulate material can be estimated for the springtime melt period. Based upon the particle distributions determined along the transects in April, melting rates will be estimated and compared with the changes in backscattering (σ_o) observed from SAR imagery along the transects.

WORK COMPLETED

All sample analyses from the field programs has been completed. Data analyses and modeling are completed. Final drafts of the remaining papers from this program are being circulated to co-authors.

RESULTS

The particle concentrations varied by almost three orders of magnitude (Fig. 1a) for the six sites. The particles were observed to be concentrated in large inclusions and thus the bulk absorption coefficients had to be scaled to the size of the inclusions (a packaging of the absorption coefficient); inclusion absorption coefficients ranged from less than 0.5 to almost 3 m^{-1} (Fig. 1b). The temperature profiles of the upper ice column for the six sites ranged from approximately -6°C for the cleanest ice to -2°C for the ice with the largest particle concentrations (Fig. 1b).

The heat trapping associated with the absorbing particles, as indicated by an increase in ice temperature, was measured over a two hour period relative to an undisturbed clear ice site. The increased temperatures were also modeled using equation (1) as described above. The estimated temperature profiles differed by less than 20% from the measured values (Fig. 1d). The presence of the entrapped material in the upper ice column has a significant effect on the radiation budget for sea ice. We observed up to 3°C warming in a two hour period due to the presence of particulate material in the ice. While the presence of snow on top of the ice serves to decrease the temperature enhancement (10 cm of snow results in only 0.5°C increase in two hours, Fig. 2a), continued exposure under sunny skies results in up to 3°C increase in temperature in 18 hours under a 10 cm layer of snow (Fig. 2b). Zones of enhanced particle concentrations in the particle-laden ice were coherent with decreases in the modal size distribution of the ice grains relative to clean ice (4 mm and 12 mm, respectively). Based upon the structure of the grains, we suspect that this is a result of thermal modification due to the presence of the particles rather than scavenging of the particles by granular ice during freeze up.

A similar response to enhanced particle concentrations was observed for snow. Airborne particles from populated areas were concentrated downwind on the ice surface and in the snow. Two transects, one downwind of Browerville and one downwind of the unused runway (Fig. 3a), were characterized by an order of magnitude difference in particle concentration and absorption. The distribution of particles generally decreased offshore with local maxima associated with ridges on which airborne particles were trapped. The concentration of particles was significantly correlated with snow/ice interface temperature and appears to be correlated with backscattering estimated from SAR imagery (Figure 3b and c). Direct observations and SAR imagery from June confirms that regions with enhance particle distributions exhibited accelerated melting rates, as predicted.

IMPACT/APPLICATION

This project is focused on the role of marine-derived and airborne particles on the physical, electro-magnetic and thermodynamic properties of snow and sea ice. The variations in these properties that were observed in natural conditions are quite significant and the linkages between the processes are clearly defined. These results indicate that such processes should be included in thermodynamic models of polar regions as the impact of particles results in enhanced melting rates and more ice free days per season. The dramatic increase in the concentration and distribution of "dirty" ice in the Arctic has been documented (S. Martin, A. Gow, T. Tucker pers. comm.).

TRANSITIONS

None that I know of.

RELATED PROJECTS

I am currently collaborating with Dr. Stephen Warren (UWash) on examining the role of marine derived material on the radiation budget of sea ice in the Antarctic (funded by NSF).

REFERENCES

Grenfell, T., G. Cota, A. Gow, K. Jezek, S. Nghiem, R. Onstott, D. Perovich, C. Roesler, C. Swift, and F. Tanis. Evolution of electromagnetic-signatures of sea ice from initial formation through the development of first-year ice. Manuscript to be submitted Nov. 1997.

Onstott, R.G. and C.S. Roesler[a]. Organic material entrapped in arctic sea ice: the influence on the dielectric and microwave properties of arctic sea ice. Manuscript to be submitted Dec. 1997.

Onstott, R.G. and C.S. Roesler[b]. Enhanced melting rates due to airborne particulate material as verified from SAR imagery. Manuscript to be submitted Dec. 1997.

Perovich, D.K., D. Barber, G. Cota, A. Gow, T. Grenfell, A. Hunt, M. Landry, J. Longacre, R. Maffione, C. Mobley, R. Onstott, S. Pegau, C. Roesler, and D. Weinbrenner. Field observations of the electromagnetic properties of first-year sea ice. Manuscript to be submitted Nov. 1997.

Perovich, D.K., C.S. Roesler, and W.S. Pegau. 1997. Variability in Arctic sea ice optical properties. In press, J. Geophys. Res.

Roesler, C.S. Retrieval of particulate absorption coefficients from the quantitative filter technique: a radiative transfer approach to quantifying pathlength amplification. Submitted to Limnol. Oceanogr.

Roesler, C.S., and R.L. Hansing. Analysis of particle concentrations and size distributions in fresh and marine waters. Submitted to Limnol. Oceanogr.

Roesler, C.S. and R. Iturriaga, 1994. Absorption properties of marine-derived particulate and dissolved material in Arctic sea ice. SPIE Ocean Optics XII, 2258: 933-943.

Roesler, C.S. and R.G. Onstott. Organic material entrapped in arctic sea ice: the influence on the optical, thermal and physical properties of arctic sea ice. Manuscript to be submitted Dec. 1997.

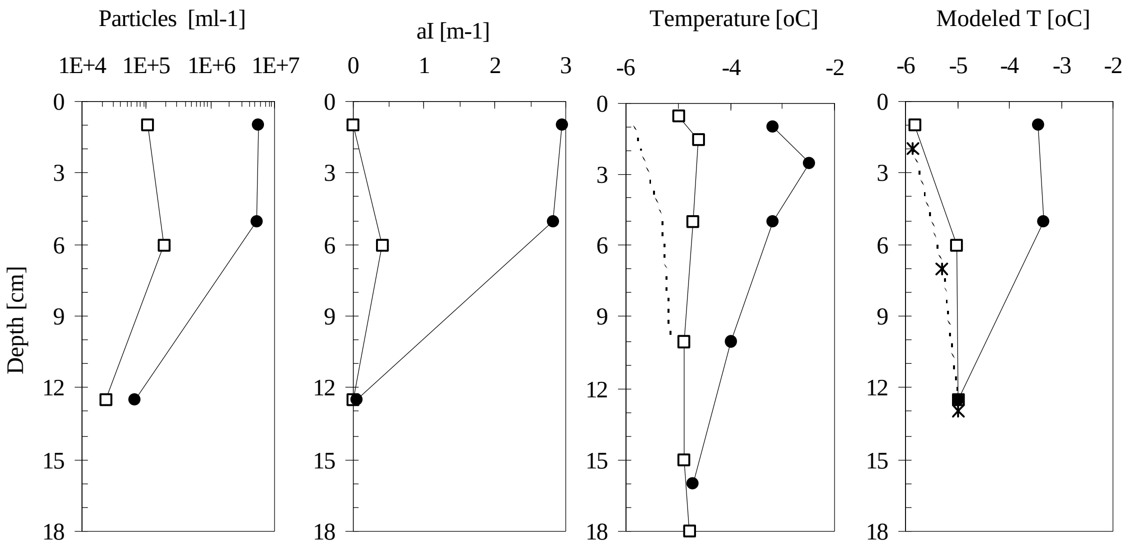

Figure 1. Characteristics of the surface ice sampled in April 1994. Only the data from the cleanest (open symbols) and most particle laden (filled symbols) ice from the six sites are shown for simplicity. *a*. Particle concentrations [ml^{-1}]. *b*. Inclusion absorption coefficients calculated from measured bulk particulate and dissolved absorption coefficients corrected for the packaging effect. Inclusion size distributions measured from thin sections. *c*. Measured temperature profiles. Dashed line indicates the measured temperature prior to snow removal. *d*. Modeled temperature profiles from the initial temperature based upon a two hour exposure to solar radiation in the absence of a snow cover.

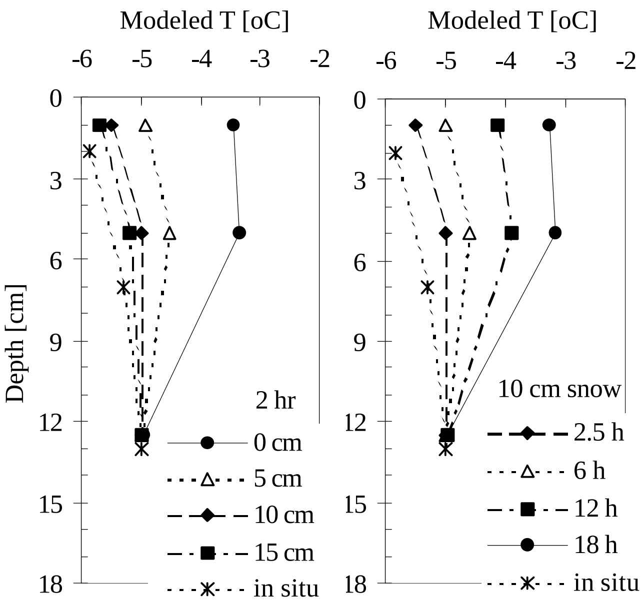

Figure 2. The results of a simulation using the measured values of inclusion absorption coefficients for the particle laden ice in Fig. 1 and equation (1) to estimate the increase in temperature. *a*. Enhanced temperature resulting from exposure to 2 hours of solar radiation in the presence of a variable snow cover. *b*. Enhanced temperature resulting from exposure to a solar radiation for a range of intervals under a 10 cm snow cover. In situ conditions were approximately 20 cm snow cover.

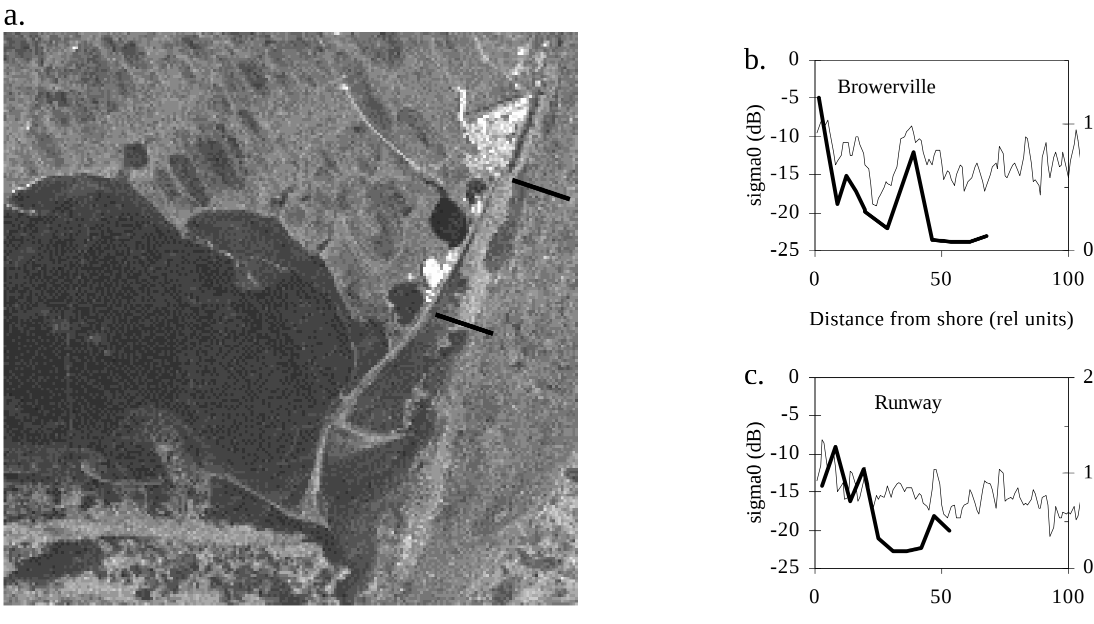

Figure 3. *a*. SAR image of Barrow, Alaska, 14 April 1995. Bars indicate approximate locations of transects of Browerville (top) and Runway (bottom) transects. Backscattering signatures derived from SAR imagery along transects (thin line) and particle concentration (thick line) in the snow along the *b*. Browerville and *c*. Runway transects. Three pixels were averaged for each data point.