Solar radiation processes in the east antarctic sea-ice zone

STEPHEN G. WARREN, *Department of Atmospheric Sciences, University of Washington, Seattle, Washington 98195*
COLLIN S. ROESLER, *Department of Marine Science, University of Connecticut, Groton, Connecticut 06340*
RICHARD E. BRANDT, *Department of Atmospheric Sciences, University of Washington, Seattle, Washington 98195*

Seasonal sea ice covers a large part of the Southern Hemisphere and plays an important role in the climate of the southern oceans. The input of solar energy to the ocean is limited by reflection from the snow/ice system and absorption within the ice. The goals of this study are to investigate

- the reflection of solar radiation by the variety of snow and sea-ice types in the Antarctic and
- the concentrations, distributions, and absorption properties of organic material in the snow and sea ice to evaluate its role in the absorption of solar radiation, trapping of heat, and the summertime decay of the ice.

The experiment is a follow-on to work begun on the first topic in 1988 (Allison, Brandt, and Warren 1993). The project was expanded in 1996 to cover other types of ice not sampled in the 1988 experiment, as well as to make measurements with a greater spectral range and to initiate a study of absorptive constituents (Roesler and Iturriaga 1994).

Fieldwork was carried out in collaboration with the Australian Antarctic Division on voyage 2 of the *Aurora Australis*, by all three authors, during the springtime period 26 September to 25 November 1996 during which all types of new and young ice could be sampled, as well as first-year ice. Similar studies of melting snow and ice are planned for November and December 1999 in the marginal ice zone.

In addition, studies of green icebergs consisting of frozen seawater were possible on this voyage, extending the studies begun in the 1988 experiment (Warren et al. 1993).

Optical measurements and ice sampling from the ship's basket

A spectral radiometer, covering the wavelength range 320 to 1,060 nanometers (nm) with 11 filters, and a pyranometer were used to measure the incident and reflected irradiance for the determination of cloud transmission and ice albedo. They were mounted on the end of a 3-meter (m) carbon-fiber tube supported on the inboard end by an aluminum frame. The frame could be mounted either in a basket to be hung from the ship's crane or in a helicopter with a sliding window. This apparatus was designed to position the radiometers as far as possible horizontally from the basket, so that the ice being sampled would be minimally shadowed by the basket. The frame allowed positioning, leveling, and inverting of the radiometers. A second radiometer, covering the wavelength range 410 to 683 nm with seven filters, each of 10-nm bandwidth, was used to measure incident and transmitted irradiance through the ice. This instrument was deployed through the ice on an articulating arm, which positioned the instrument on the underside of the ice 0.5 m from the hole.

Most measurements were made within 2 hours of solar noon to maximize the solar altitude. The basket was hung off the sunny side of the ship to avoid shadowing of the ice by the ship. The surface types sampled were water, grease ice, pancakes, nilas, snow-covered nilas, and snow-covered first-year ice (FYI). Spectral albedos are shown in figure 1. Visible transmission varied from more than 90 percent for grease ice to 40 percent for pancakes. Samples of all ice types were collected for analysis of organic constituents.

Measurements on first-year floes and fast ice

Vertical profiles of snow density and grain size were measured at several ice-floe stations and at the fast ice at Davis Station (68°S 79°E). These are the principal variables affecting transmission and reflection of sunlight by snow. Spectral albedos were obtained for FYI with a variety of snow thicknesses. Particularly valuable was a site on 1.5-m-thick fast ice because it included a scene of naturally snow-free and nearly snow-free sea ice (near the coast, where strong winds

volume 32

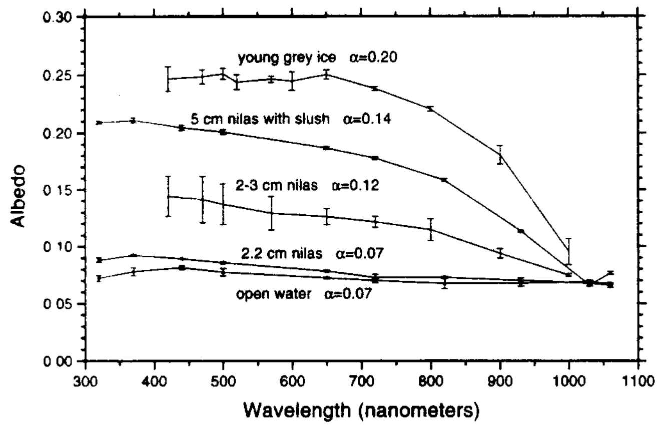

Figure 1. Spectral albedo of new and young ice types. The two samples with restricted spectral range were measured in 1988; the other three in 1996. Allwave albedos (α) are also given.

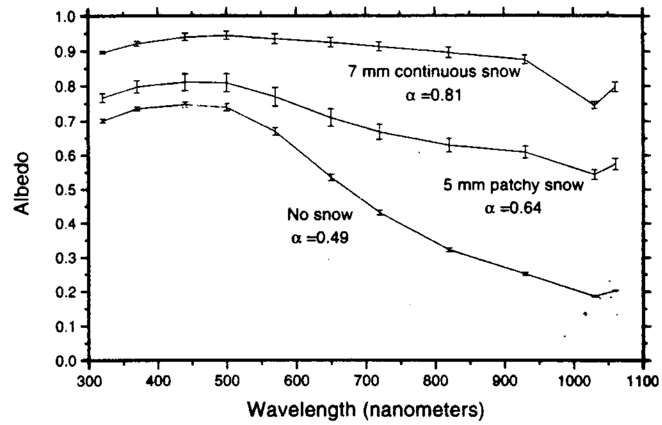

Figure 2. Spectral albedo of 1.8-meter-thick sea ice near Davis Station (68°S 79°E), covered with 0, 5, or 7 millimeters of snow.

often blow the snow away). The large enhancement of albedo due to very thin snow layers of 5 and 7 millimeters is illustrated in figure 2.

Hundred-meter transects were established on the floes ranging from uniform thin gray ice (0.25 m) to highly ridged annual ice (>6 m). Spectral transmission at visible wavelengths, snow thickness, and ice thickness were measured at 10-m spacings along the 100-m transects. Where time permitted, ultraviolet transmission in four wavebands was also measured. Snow samples and ice cores were collected from the 0-m, 50-m, and 100-m stations. Temperatures were measured at the snow/ice and air/snow interfaces. Ice temperatures were measured at 5-centimeter intervals along the ice cores immediately after retrieval.

Visible transmission decreased from 20 percent for ice thickness of 0.25 m to less than 1 percent for 1 m; however, the variations in attenuation per meter of ice were strongly dependent upon the relative concentrations of frazil, granular, and columnar ice in the ice column. Spectral variations associated with algae and entrapped organic material were observed in the transmission spectra; they will be quantified by optical analyses of the ice samples.

Icebergs

In our earlier work, we discussed the origin and composition of green icebergs calved from the Amery Ice Shelf and sampled near Mawson Station (Warren et al. 1993). To evaluate the generality of those conclusions, two green icebergs (probably calved from the West Ice Shelf) were sampled near Davis Station. Albedos are shown in figure 3 for a large iceberg containing sections of bubbly blue ice, clear blue ice, clear green ice, and cloudy yellow-green ice. The spectral peak moves from 450 to 575 nm in the progression from blue to yellow-green ice. Oxygen isotope analyses show that the bubbly blue ice is glacial ice; the other three types are marine ice consisting of desalinated frozen seawater. The organic constituents responsible for the variations in color will be analyzed. The blue marine ice is likely to contain far less dissolved organic matter than the green or yellow-green ice or than the green iceberg we sampled in 1988.

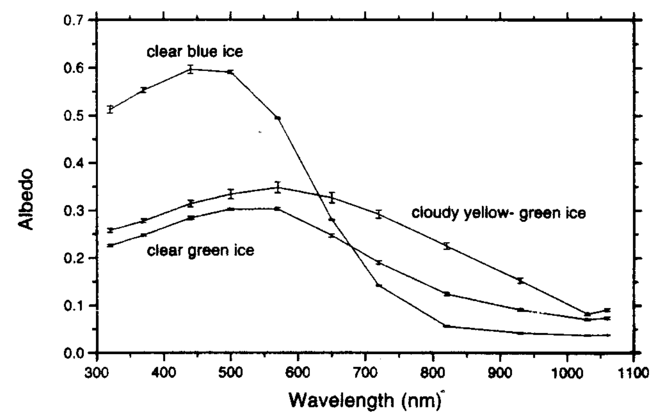

Figure 3. Spectral albedo of three parts of a composite iceberg, all consisting of "marine ice" (formed by freezing of seawater, probably to the base of an ice shelf).

Ice-sample analyses

Ice cores and snow samples were returned to the freezer container on the ship for processing. Ice cores were sectioned into 5-cm-long samples. The samples from cores, thin ice, and icebergs are now undergoing analysis at the University of Connecticut for salinity, algal pigment concentration, particle identification and size distribution, particulate and dissolved spectral absorption coefficients, and, as necessary, thin sections.

Downward solar spectral irradiance

In an attempt to determine cloud radiative forcing in the antarctic sea-ice zone, we measured the spectral and total irradiance transmitted through clouds, as well as the irradiance from clear skies. Taking surface albedo into account, cloud optical thickness will be inferred.

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