Microwave backscatter measurements from first-year pack ice in the eastern Weddell Sea

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We collected measurements of C band [5.3 gigahertz (GHz)] microwave backscatter from first-year sea ice in the eastern Weddell Sea during July and August 1994. Measurements were made aboard the R/V *Nathaniel B. Palmer* during the Antarctic Zone Flux Experiment (ANZFLUX) cruise through the eastern Weddell Gyre

(McPhee, *Antarctic Journal*, in this issue). Data were collected at 21 locations at incidence angles ranging from 30° to 60°. In addition, during the second drift camp of the cruise, where the ship was moored to a single ice floe over Maud Rise, we made a series of measurements over a 5-day period, which included two distinct warming events associated with strong low-pressure systems. What makes our backscatter time series unique is that it can be compared with a detailed thermal history of the ice/snow/air system, as obtained from a thermistor string embedded in the ice and snow at the radar site, as well as with observed physical properties of the ice and snow. Our objective is to understand how the physical properties of the ice pack determine measured backscatter coefficients and, in particular, to study in detail how backscatter changes in response to the dynamic variations in atmospheric and oceanic influences, particularly during the powerful winter storms and large vertical heat fluxes we encountered. Although much work in this direction has been done in the Arctic, relatively few studies have been done in the Antarctic, for example, Drinkwater, Early, and Long (1994) and Hosseinmostafa et al. (1995).

We used a frequency-modulated continuous-wave (FMCW) radar having center frequency at 5.3 GHz and a 500-megahertz (MHz) bandwidth. The signal was transmitted by a parabolic dish antenna at vertical polarization and was received by standard gain horn antennas, oriented to receive either vertical or horizontal polarization, resulting in measurements of vertical-vertical (VV) or vertical-horizontal (VH) backscatter coefficients. The dish and horns were mounted on a metal plate bolted to the outside railing of the bridge on the port side of the ship, about 17 meters above the ice; the temperature-sensitive electronics were located inside the ship. The data were recorded on a portable computer located near the radar. An internal delay line and a luneberg lens were used to calibrate the radar system. Hosseinmostafa et al. (1995) used a similar system.

Let us now focus on the thermal and backscatter time series we obtained while at the Maud Rise drift camp (McPhee, *Antarctic Journal*, in this issue). Thermistor strings were inserted into the snow and ice, and temperatures were recorded at 5-centimeter (cm) vertical intervals, every 15 minutes. Figure 1 shows the temperature profile over the 5-day period. We see two significant warming events, which began in the early morning hours of days 216 and 219. Figure 2 shows the backscatter coefficients measured over the 5 days for VV polarization, at all incidence angles, whereas figure 3 shows the same for VH polarization. We remark that the VV backscatter is likely determined primarily by surface scattering, whereas the VH, or cross-polarization backscatter, results primarily from volume, or multiple, scattering from snow grains and air pockets.

Detailed snow and ice measurements were collected, including snow- and ice-thickness profiles, snow density, salinity, and observations for the presence of slush and flooding. The snow thickness on the floe varied from 8 to 28 cm, having an average depth around 12 cm, and snow salinities generally were in excess of 23 parts per thousand (ppt), except on day 219, when a new layer of wind-deposited snow was 5 ppt. These high

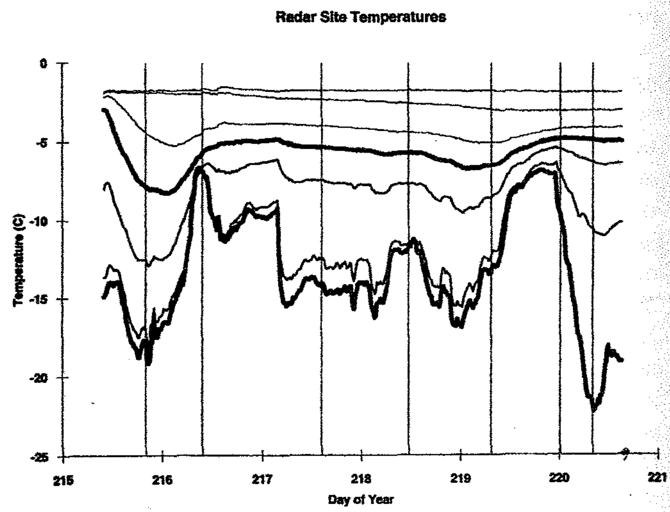

Figure 1. Temperatures of the ice and snow during the Maud Rise drift camp. Thermistor data at 10-cm vertical intervals are displayed. The curves corresponding to the temperature of the ice surface and air are bold lines. The vertical lines coincide with the times of the radar measurements.

salinities were typical of the region and indicative of the frequent slush layers we observed at the snow/ice interface, caused by flooding of the snowpack with sea water (Ackley et al., *Antarctic Journal*, in this issue). For example, on day 215, we found damp snow near the snow/ice interface, which was likely frozen by the early morning of day 216. By noon on day 217, after a day of air temperatures warmer than −10°C, we observed a thick layer of slushy snow, consisting of 30 to 50 percent liquid brine. Early on day 219, after a period of colder air temperatures, this slush layer had refrozen. Based on the ice-surface temperature profile, it is likely that liquid water was again at the base of the snow pack during, or immediately after, the second warm spell (day 220). It is interesting to note that our observations of slushy conditions followed periods when the temperature of the entire sea-ice layer was above $T_c \approx -5$°C, corresponding to about 5 percent brine volume, where the brine inclusions percolate (Cox and Weeks 1975) and the sea ice becomes porous, allowing transport of sea water and brine to the surface.

Preliminary analysis of the results shows a rather complex relationship between backscatter and temperature profile,

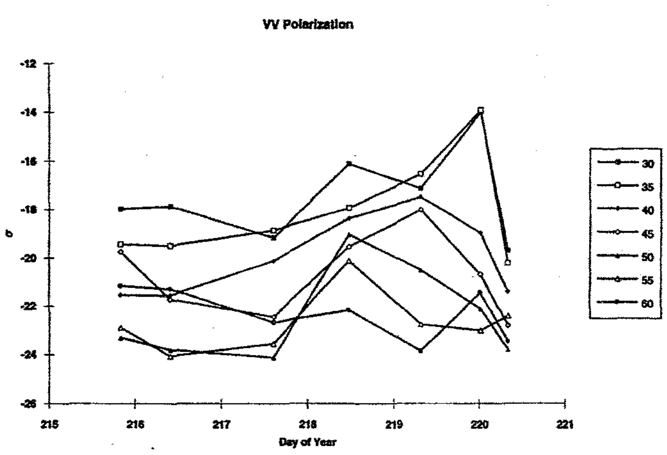

Figure 2. Backscatter coefficients σ for VV polarization, at C band (5.3 GHz) during the Maud Rise drift camp. Incidence angles range from 30° to 60°.

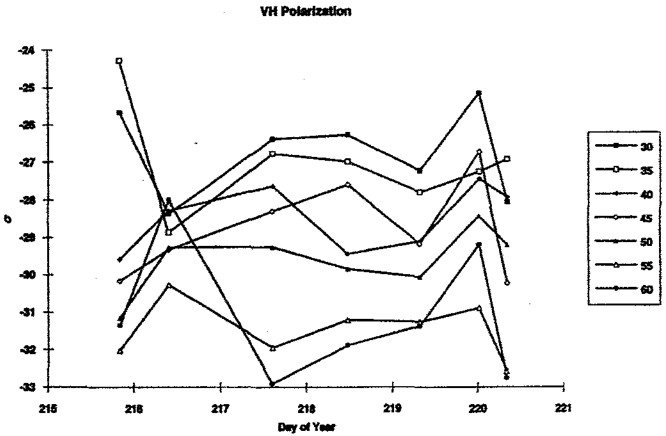

Figure 3. Backscatter coefficients σ for VH polarization, at C band (5.3 GHz) during the Maud Rise drift camp. Incidence angles range from 30° to 60°.

although some features, such as the importance of slush, are initially apparent. For example, the slow freezing of the slush layer encountered on day 217 results in an increase in the VV backscatter (surface dominated) over all angles, as the smoothing effect of the slush diminishes, which is consistent with the findings of Hosseinmostafa et al. (1995). This should be contrasted with the precipitous drop-off of all backscatter coefficients on day 220, which may be due to the presence of slush remaining at the snow/ice interface, with freezing of the snow layer above. Finally, we also note that VH backscatter at high angles 50°–60°, correlates well with air temperature. These relationships will be examined in more detail in subsequent work, which will include analytical and numerical modeling of the backscatter and heat-flux profiles.

Thanks to Prasad Gogineni and Reza Hosseinmostafa of the University of Kansas for use of the radar equipment. We wish to thank Steve Ackley, Gary Kuehn, Naomi Darling, and the other participants, Antarctic Support Associates personnel, and Captain Joe Borkowski and crew on the ANZFLUX cruise for all their assistance and good cheer. V.I. Lytle was supported by the Antarctic CRC, University of Tasmania, ONR grant N0001495MP30019 and by National Science Foundation grant OPP 93-15934. K.M. Golden was supported by ONR grant N000149310141 and by National Science Foundation grant DMS 93-07324.

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