Sea-ice measurements during ANZFLUX

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Our objective was to understand the sea-ice growth, melt, and deformation processes in this presumed high-ocean heat flux environment (McPhee, *Antarctic Journal*, in this issue–a). To achieve this objective, we made estimates of the large-scale ice concentration and ice characteristics along the R/V *Nathaniel B. Palmer* cruise track during July and August 1994 (figure 1 in McPhee, *Antarctic Journal*, in this issue–a) by making visual ice observations and establishing short-term ice sampling stations contemporaneously with the conductivity-temperature-depth casts (Huber, Schlosser, and Martinson, *Antarctic Journal*, in this issue). The visual observations and radar backscatter measurements (Lytle and Golden, *Antarctic Journal*, in this issue) will also provide ground truth for satellite estimates of the ice concentration and ice characteristics. Process studies were conducted to measure the ice–ocean interaction in the presence of large, ocean heat fluxes. Ice-growth and melt-rate measurements, using ice-thickness gauges, were made during the two 5-day drift stations in conjunction with time-series vertical temperature profiles of the air–snow–ice–ocean at these sites (Lytle and Golden, *Antarctic Journal*, in this issue).

Figure 1 shows the derived ice-thickness distribution obtained from statistical compilation of the hourly ice observations near the first drift station. The area sampled

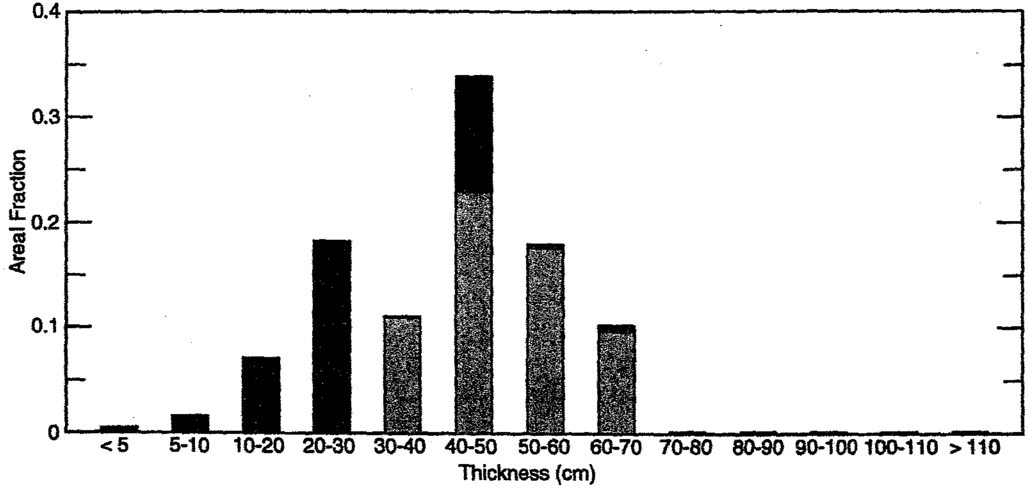

Figure 1. Ice-thickness distribution (fractional area) derived from underway visual observations hourly for the region south of 66°S latitude and between 3°W and 10°W longitude (*see* figure 1 of McPhee, *Antarctic Journal*, in this issue–a, for the detailed track taken).

corresponds to that traversed during the deployment of the buoy array (*see* figure 1 of McPhee, *Antarctic Journal*, in this issue–a). The mean of the ice-thickness measurement, which was obtained at the drift camp by ice drilling 100-meter (m) profile lines, was between 40 and 50 centimeters (cm), corresponding to the most frequently observed ice thickness in the region as shown in figure 1. This thickness peak is about 20 to 30 cm less than that observed farther north, suggesting the ice in the southern warm regime (McPhee, *Antarctic Journal*, in this issue–b; Stanton, *Antarctic Journal*, in this issue; Padman, Robertson, and Levine, *Antarctic Journal*, in this issue) is thinner than the ice in the northern cold regime.

Five ice-thickness gauges, each consisting of a resistance wire with a steel bar tied to the bottom and a wooden handle tied to the top, were installed at the first drift camp. The ice-thickness change at the bottom could then be measured by pulling up the steel bar against the bottom of the ice, and measuring the height change of the top handle against a stake frozen into the ice initially and marked with a reference line at the time of the installation. Figure 2 shows the results, growth rate (positive) or melt rate (negative) in centimeters of ice per day vs. time in days, for the drift station. During this period, the ice averaged (figure 2, bold line) about 1 to 2 cm per day of ice melt, after 1 day of slight ice growth (0.5 cm) at the beginning of the period.

A profile of snow and ice thickness, taken at 1-m intervals over 50 m, from the second drift station at Maud Rise (McPhee, *Antarctic Journal*, in this issue–a) is shown in figure 3. The 30- to 40-cm mean thickness is typical of the profiles for this region. The middle line shows that most of the ice surface is below sea level, because the snow load depresses the ice surface, resulting in widespread surface flooding and the development of a slush layer at the snow-ice interface. The slush layer later refroze during the time of this station (Lytle and Golden, *Antarctic Journal*, in this issue).

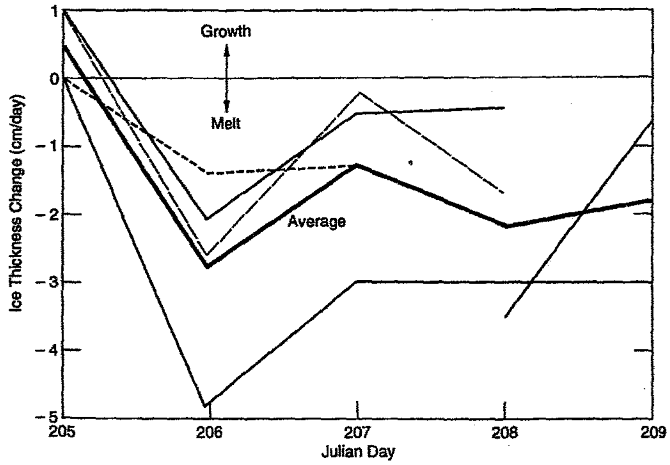

Figure 2. Ice freezing and melting rates obtained from ice-thickness gauges installed at the drift 1 (warm regime) ice camp. Rates are given in centimeters per day of freeze/melt; day of the year is indicated on the horizontal axis. The average of the stations (1–2 cm per day melting) is shown as the bold line.

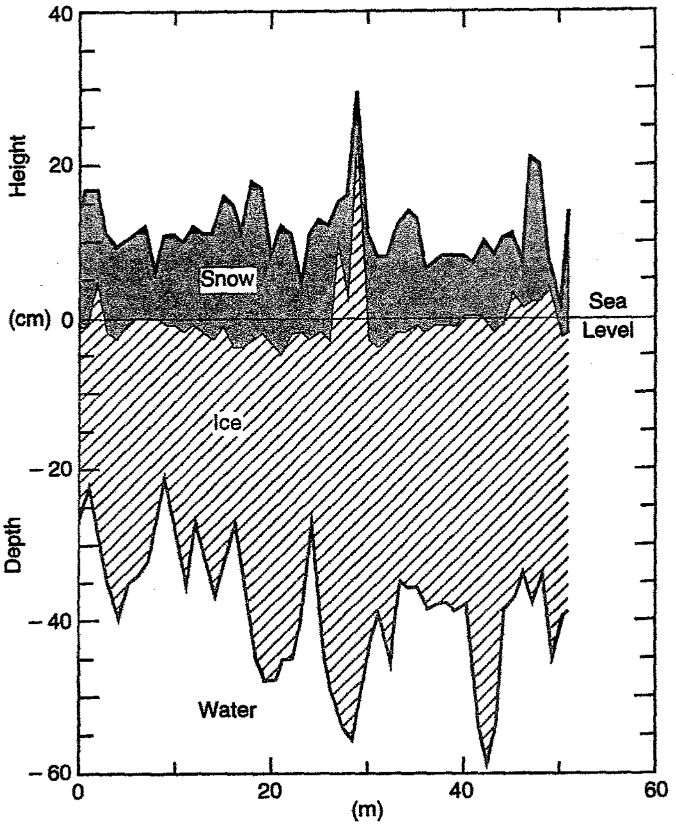

Figure 3. Ice thickness, surface elevation, and snow elevation, referenced to sea level at the 0 line for a 50 m profile taken at drift 2 near Maud Rise (see figure 1 of McPhee, *Antarctic Journal*, in this issue–a, for location). The below-sea-level portions of the ice surface resulted in the flooding of the base of the snow cover.

The measurements of ice melt from figure 2 are commensurate with the estimates of vertical ocean heat flux at the time of these measurements (McPhee, *Antarctic Journal*, in this issue–a,b; Stanton, *Antarctic Journal*, in this issue; Padman et al., *Antarctic Journal*, in this issue). Since ocean heat flux values this high (more than 25 watts per square meter) are the equivalent to an ice melt rate from below on the order of a centimeter per day, this result poses an interesting problem. At this melt rate, ice covers that are only 40 cm thick could not be sustained longer than roughly a month, yet we typically observe ice covers of several months duration in this region. Although the currently estimated open-water percentage is compatible with the modeled level needed to exhaust the ocean heat, the melt-rate measurements show that the ice cover is instead melting in direct response to the ocean heat.

The dilemma of a too-rapid estimated disintegration of the ice cover, that is not actually observed, can however be resolved. Figure 3 shows that the surface flooding, typical of the region, can lay down an additional layer of ice at the top surface if the slush formed is frozen into snow ice. The slush ice at the surface can freeze quickly if cold atmospheric conditions prevail, because it is not insulated from the atmosphere above by the ice-cover thickness. The ocean heat flux also does not slow the freezing of the surface slush because that heat is being dissipated by the bottom ice ablation. Thus, during the winter period, the ice cover may act as a *vertical conveyor belt*: ice is added on the top by slush freezing, and at a similar rate, it is melted from below by the high ocean heat flux.

We wish to thank Captain Joe Borkowski and the deck crew of *Nathaniel B. Palmer* for their assistance in over-the-side deployment and for their support and tolerance of our bridge observations and equipment installation. John Evans and Kevin Wood of Antarctic Support Associates and Jay Ardai of Lamont-Doherty Earth Observatory are acknowledged for their contributions to our efforts and are appreciated for their unrelenting support and assistance. This work was supported by National Science Foundation grant OPP 93-15934 to S.F. Ackley.

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