Sea-ice studies

Ice thickness variability of the McMurdo Sound landfast ice runway

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Every year an ice runway is prepared on the landfast ice of McMurdo Sound (figure 1). It is built specifically for aircraft (C-141, C-130, and C-5B) equipped with wheels, which accommodate larger quantities of personnel and material in a shorter period of time than is possible using ski-equipped aircraft at Williams Field. The ice runway program begins in July with ice coring to determine the sea ice thickness in and around the proposed runway site, and by the second week in September, the runway has been completed and is in operation. During its lifetime, the ice thickness is measured weekly at sampling sites established at roughly 100-meter intervals along each side of the runway.

At each sampling site a measuring rod of known length, with a horizontal bar at its bottom, is embedded in the ice for the lifetime of the runway. The ice thickness is determined by drawing the rod up out of the ice until the bar abuts the ice bottom, measuring the amount of rod above the ice, and subtracting that value from the total length of the rod. The ice runway data are a valuable source of information on the growth of the landfast ice in McMurdo Sound from midwinter to early spring. However, the data appear to be ignored or underutilized by the science community. This paper examines the ice-thickness data acquired during 1989, 1990, and 1991.

The mean ice thickness along the runway and its standard deviation was calculated for each set of measurements made on a given day for each year. A plot of mean ice thickness versus time (figure 2) shows the ice thickness increasing during the life of the runway each year. The 1989 data are unusual compared to the other data sets, as they suggest fluctuations in the ice thickness. This is most likely a measuring error and not an actual ice phenomenon. During the course of the sampling programs, the ice thickness increased by 0.57± 0.08 meters in 1989; 0.6±0.03 meters (main runway) and 0.26± 0.02 meters (crosswind runway) in 1990; and 0.56±0.1 meters in 1991. The maximum mean ice thickness was generally attained in early December, with values of 2.28±0.13 meters (1989), 2.34±0.05 meters (1990), 2.27±0.12 meters (cross wind runway), and 2.22±0.1 meters (1991). Thus, the amount of ice grown during the operation of the runways was approximately 25 percent of the maximum ice thickness (except for the crosswind runway, which operated for a shorter period of time at the end of the season).

The data for maximum mean ice thickness for each sampling site were examined. T-tests performed on the measurements made on each side of the runway revealed no significant difference at a 95 percent confidence level, indicating fairly uniform ice thicknesses along the runway. T-tests with a 95 percent confidence level compared the mean maximum ice thicknesses for each year. The 1989 crosswind, and 1991 samples were not significantly different from each other, but all three of these data sets were significantly different from the 1990 main runway data. It should be noted that the 95 percent confidence level holds for the individual comparisons (two data sets) and not the entire range of comparisons (six combinations of two data sets). The 1990 maximum mean ice-thickness values were consistently higher than the values from the other runways.

An interannual comparison of the mean ice thickness on the same Julian date was made. Ice-thickness differences on the same date in different years (26 pairs) have a mean of 0.079± 0.05 meters (range 0.0122 meters to 0.1762 meters). Paired t-tests (95 percent confidence level) were performed on the coincident data subsets of 1989-1990 and 1989-1991 (seven samples), as well as on the 1989 and 1990 crosswind runways (four samples). The analysis indicates that on a given date the 1989 ice thickness differed significantly from the 1990 and 1991 data but not from the crosswind data set. Only the 1990 main-runway data differ significantly from the crosswind data, but the relatively few data points and coincident data sets make it difficult to draw any substantial conclusions. However, it is clear that on any given date, the ice thickness varies from year to year. This may be related to such factors as the time the landfast ice cover was first established and subsequent variations in the growth rate.

The mean ice-thickness data illustrate the thickening of the landfast ice during the lifetime of the ice runway. The standard deviation values over the entire runway illustrate considerable variation from year to year as well as within years (figure 3). The standard deviations in 1989 are much larger than those in 1990, and the standard deviations in the crosswind data are larger than those of the adjacent main runway in 1990. Also note the large standard deviation of the ice thickness on 1 November 1990 (JD

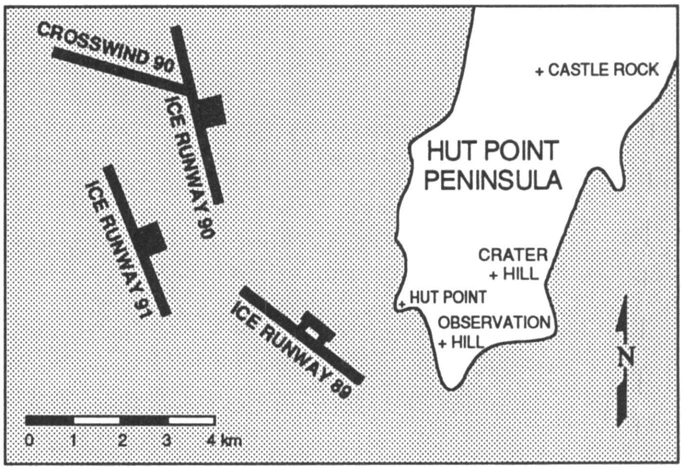

Figure 1. Map of the south end of Hut Point Peninsula, Ross Island, showing the positions of the McMurdo Sound sea-ice runways in austral spring of 1989, 1990, and 1991.

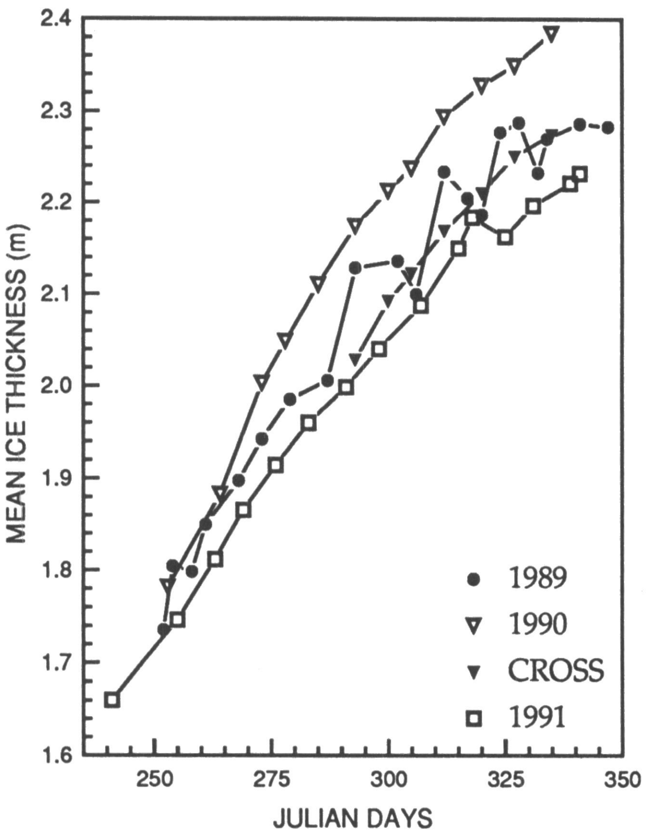

Figure 2. Mean ice thickness vs. time for all data sets.

305) as compared with the other values in the data set. It is unclear whether this is the result of an error in measurement or real variation in the ice thickness.

The ice-thickness measurements show considerable spatial and temporal variability, which may be due to measurement errors or to physical phenomena, such as the accumulation of platelet ice while the landfast ice is developing. The ice-runway operation occurs when the ice cover is thickening by the accumulation and consolidation of platelet ice crystals, which relieve the supercooling adiabatic decompression related to low-density water flowing from under the Ross Ice Shelf (Foldvik and Kvinge 1974; Jeffries et al. in press). Spatial and temporal variations in the supercooled water currents cause variations in the number of unconsolidated platelet crystals and the thickness of the consolidated platelet ice layers (Lewis and Perkin 1985; Crocker and Wadhams 1989; Jeffries et al. in press). The year-to-year and within-year ice-runway-thickness variations may reflect the variability of supercooled-water flow and platelet-ice occurrence, or they may reflect the measurement method. Because the platelet crystals get caught between the true bottom of the ice and the horizontal bar on the end of the rod, the loose lattice of platelet crystals that forms directly beneath the consolidated sea-ice cover may cause a false reading.

The McMurdo Sound ice-runway-thickness data provide valuable information on the development of the McMurdo landfast ice. The existing data could be more fully analyzed and future measurements made part of a more rigorous environmental monitoring program, the end result of which would be a database of ice-thickness variations over time.

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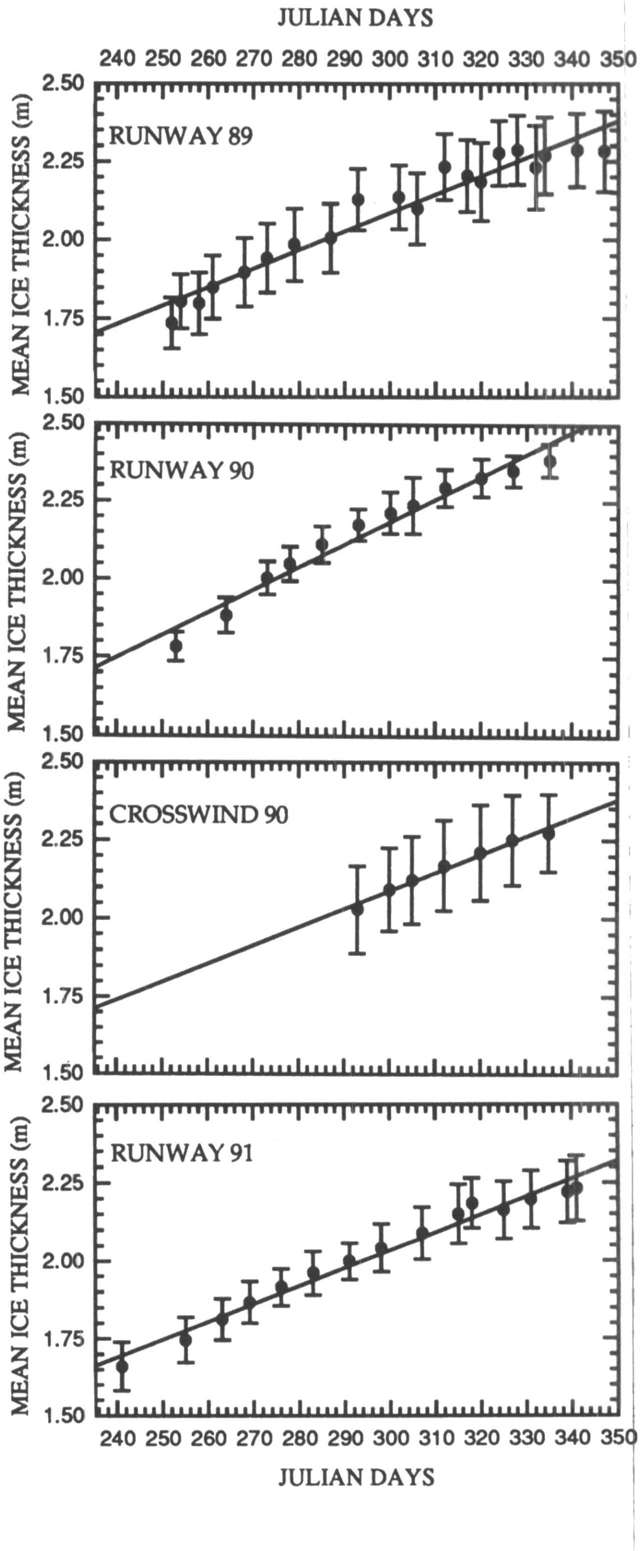

Figure 3. Mean ice thickness (solid dots) and standard deviations (whiskers) plotted with a first-order regression line (solid line) for: (a) 1989; (b) 1990; (c) crosswind; and (d) 1991 data sets.

References

Crocker, G. B. and P. Wadhams. 1989. Modelling antarctic landfast ice growth. *Journal of Glaciology,* 35(119):3-8.

Foldvik, A. and T. Kvinge. 1974. Conditional instability of seawater at the freezing point. *Deep Sea Research,* 21:169-174.

Jeffries, M. O., W. F. Weeks, R. A. Shaw, and K. Morris. In press. Structural characteristics of congelation and platelet ice and their role in the development of antarctic landfast sea ice. *Journal of Glaciology.*

Lewis, E. L. and R. G. Perkin. 1985. The winter oceanography of McMurdo Sound, Antarctica. In S. S. Jacobs (Ed.), *Oceanology of the Antarctic Continental Shelf.* (Antarctic Research Series.) Washington, D.C.: American Geophysical Union, 43.

Small-scale variability of physical properties and structural characteristics of a single ice floe

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Most studies of the physical properties and structural-stratigraphic characteristics of sea ice have concentrated on large-scale regional variations evident in multiple floes. In order to understand the large-scale variability it is also important to understand the small-scale variability within single floes. Apart from studies by Tucker et al. (1984) and Eicken et al. (1991) there have been few such investigations. Our study focuses on small-scale variations of snow depth, ice thickness, structure-stratigraphy, temperature, and salinity of an ice floe located 1 kilometer south of the Drygalski Ice Tongue (75° 32'.191' S 164° 22.631' E) in the western Ross Sea.

On 1 January 1992 snow depth and ice-thickness measurements were made at 1-meter intervals along lines A, B, and C, and at 2-meter intervals along line D (figure 1). Salinity, temperature, and structure-stratigraphy analyses were completed for ice cores DRY 1-7 (with the exception that no structure-stratigraphy core was obtained at site DRY 7).

The mean snow depth over the entire site is 0.16± 0.034 meters (see table), with a range of 0.095 to 0.27 meters. Although snow depth varies very little over the entire site, there is a significant difference between transects, e.g., A and B (table). The mean ice thickness over the entire site is 1.218± 0.066 meters (table) with a range of 1.02 to 1.335 meters. This is only slightly lower than the 1.40± 0.45-meters mean ice-thickness value calculated from data obtained in February and March on first-year ice in the Weddell Sea, as presented by Gow et al. (1987). As with the snow-depth variability, although statistically the ice thickness varies by only 0.066 meters over the entire site, there are significant differences between individual transects, e.g., A and B, A and D (table). In the Weddell Sea, Lange and Eicken (1991a) report thinner mean snow depths ranging from 0.08 to 0.59 meters and a wider range of ice thickness, 0.52 to 2.65 meters. Their standard deviations were significantly greater than ours, with the mean snow-depth standard-deviation values ranging from 0.12 to 0.84 meters. The greater ice-thickness standard deviations reported by Lange and Eicken (1991a) probably reflect the greater number of floes and deformed sites they sampled compared to our study of a single, apparently undeformed floe.

Overall, the data show a general relationship of deep snow overlying thinner ice. This is common in floes dominated by congelation growth and is due to the insulating effects of the snow reducing the heat floe from the water to the atmosphere through ice and snow. In the case of the Drygalski floe, the snow-ice thickness relationship is probably a coincidence, since none of the cores contain congelation ice.

Each core contained granular frazil ice in amounts varying between 95 and 100 percent of the core length. Platelet ice was found only at the base of core DRY 2. The large amount of frazil ice is not unusual and reflects ice growth as small crystals in the turbulent, supercooled water conditions that are common in the antarctic ice pack (Gow et al. 1987; Jeffries and Weeks in press (a); Lange and Eicken 1991b).

Each ice core has a roughly S-shaped temperature profile, with the warmest temperatures at the ice surface and the coldest temperature at the base (figure 2). Ice temperatures are all close to the melting point, with an overall mean temperature of -1.09 °C and a range of -1.4 °C to -0.6 °C. For all cores, the least ice temperature variability occurs at depths of 0.3 to 0.4 meters, where the temperature is -1.0 °C (figure 2). The S-shaped temperature profile probably results from surface heating during the summer as the air temperature rises and raises the temperature of the near-surface ice.

The mean ice salinity of the seven cores is 3.60 parts per thousand, with a range of 0.8 to 5.25 parts per thousand. The salinity profiles have a reverse S-shaped pattern, with the lowest salinities at the surface and the highest salinities at the base of the ice. Similar profiles have been observed in McMurdo Sound (Jeffries and Weeks in press (b)) and the northwestern Weddell Sea (Eicken et al. 1991). Two zones of maximum salinity in each core group occur at 0.4 to 0.6 meters (salinity range, 3.74 to 3.9 parts per thousand) and in the bottom 0.2 meters (salinities exceeding 5.0 parts per thousand). Standard-deviation values are

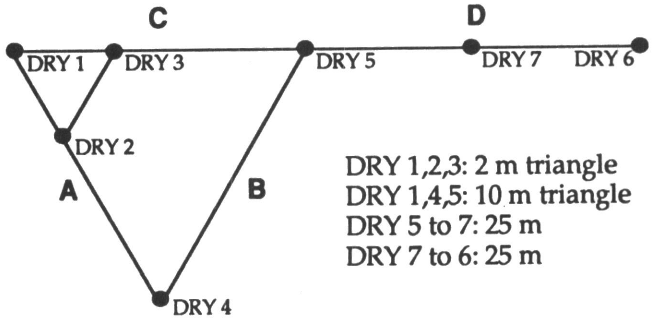

Figure 1. Diagram of the 1992 Drygalski ice-floe sampling scheme with ice-core (DRY 1 to 7) positions. The 10-meter triangle connecting sites DRY 1, 4, and 5 consists of lines A, B, and C, and line D is the 50-meter distance between DRY 5 and 6.