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ANTARCTIC LANDFAST SEA ICE: THE ROLE OF PLATELET ICE

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ABSTRACT

Platelet ice is the name given to ice crystals that nucleate in the ocean and either grow in the water column, or become attached to and grow at the base of the sea ice cover. Linked to the proximity of ice shelves, platelet ice is known to be associated with supercooled water. Here we re-examine historical surveys of platelet ice in McMurdo Sound, Antarctica. From these data, a map of its relative abundance is constructed, resulting in a remarkably consistent pattern from year to year. On the other hand, our estimate of interannual variability in the absolute amount of platelet ice between 1980 and 2002 yields inconclusive results, requiring further work to assess and understand this variability. We estimate that 10% of the total thickness of the landfast sea ice of McMurdo Sound is a result of heat loss to the ocean. Few growth models allow for this contribution.

KEY WORDS: sea ice; platelet ice; ice shelves; McMurdo Sound; Antarctica

INTRODUCTION

A significant portion of the first-year, landfast sea ice of Antarctica is composed of platelet ice, an ice type that distinguishes it from the sea ice of most other regions. The term platelet ice may refer to unconsolidated crystals either at depth (Dayton et al., 1969; Dieckmann et al., 1986; Penrose et al., 1994) or held by buoyancy at the ice-water interface (Crocker and Wadhams, 1989). Using the backscattered signal strength from an acoustic Doppler current profiler (ADCP) as a proxy for ice crystals in the water column (see Figure 1), Leonard et al. (2006) have linked the appearance of platelet ice in the water column to its incorporation in the sea ice cover. As shown in Figure 1, this incorporated platelet ice is characterized by scattered crystal orientations which are easily distinguished from the well aligned crystals that are typical of columnar ice. Observations to date (Smith et al., 2001; Smith, 2001; Leonard et al., 2006) support the conjecture that incorporated platelet ice grows when the water just below the ice-water interface is supercooled by a few milliKelvin. Limited winter observations suggest variability in the time that platelet ice first appears in the sea ice of McMurdo Sound; e.g. July in 1986 (Crocker and Wadhams, 1989) and May in 2003 (Leonard et al., 2006). Thus, by late spring in McMurdo Sound platelet ice forms a layer of randomly oriented crystals beneath the columnar sea ice (Paige, 1966; Jeffries et al., 1993; Smith et al., 2001; Jones and Hill, 2001; Leonard et al., 2006).

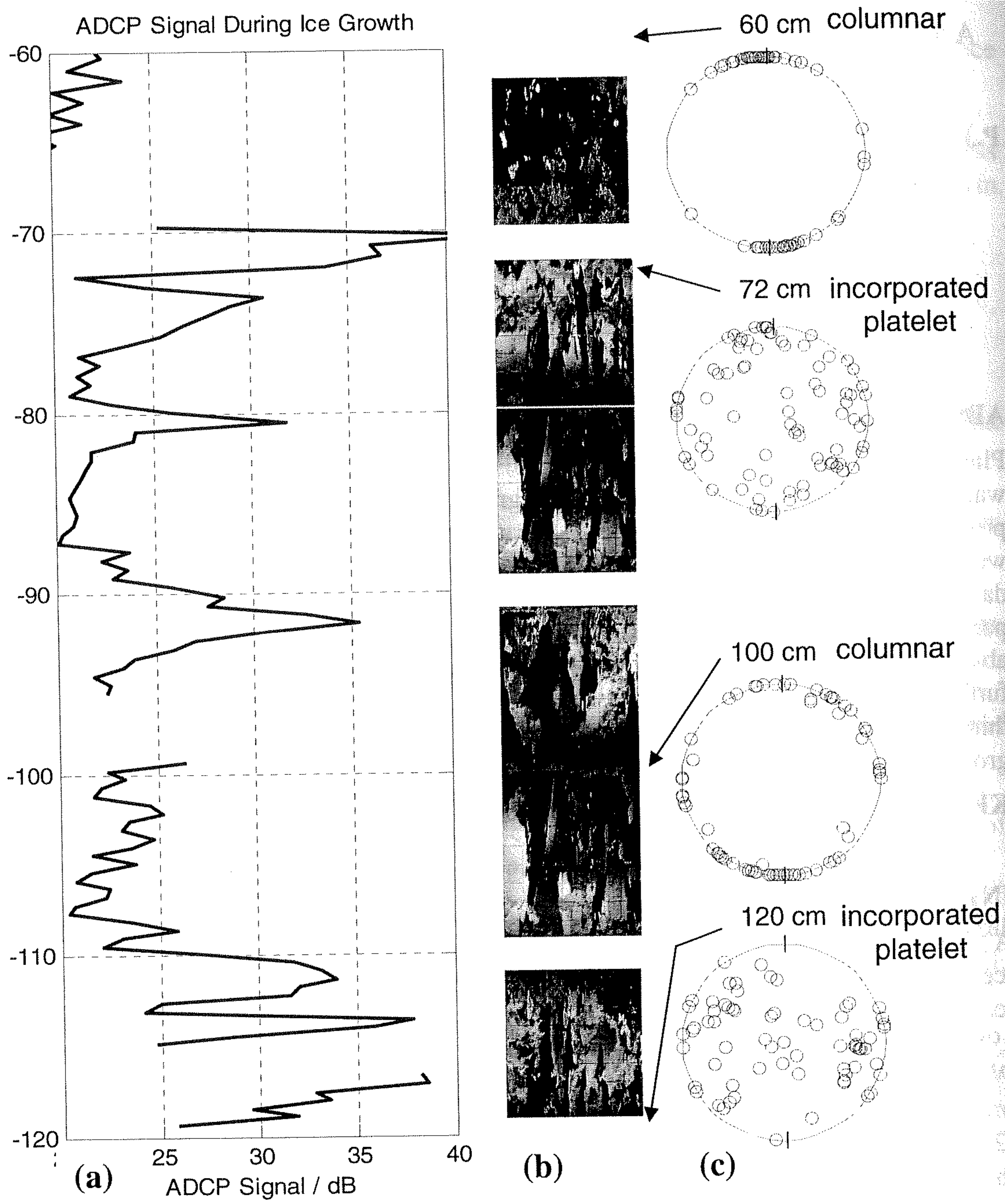

Figure 1: **(a)** ADCP signal strength, as a proxy for ice crystals in the water column **(b)** Vertical thin sections showing crystal structure, scaled to the ADCP plot. Grid is 10 mm. **(c)** Crystal c-axis orientations. Grouping around the edge of the circle is typical of columnar ice, while scattered orientations are characteristic of platelet ice.

While it is well known that the presence of platelet ice is related to the heat content of the upper ocean, details are elusive because of the complicating effects of tidal flow (e.g. Barry, 1988; Barry and Dayton, 1988; Lewis and Perkin, 1985; Gow et al., 1998) and seasonal change (Tressler and Ommundsen, 1962; Barry, 1988; Hunt et al., 2003; Leonard et al., 2006). Some of the McMurdo Sound water mass originates from beneath the Ross Ice Shelf. This water contains signals that reflect the heat and freshwater fluxes at the lower boundary between the ice shelf and the ocean (Robin, 1979; Jacobs et al., 1979; Williams et al., 1998; Holland et al., 2003). In two dimensions this flow has been modelled as a turbulent, frazil-laden plume rising up the inclined base of an ice shelf in a stably stratified environment (e.g. Hellmer and Jacobs, 1992; Jenkins and Bombosch, 1995; Smedsrud and Jenkins, 2004). The ascending plume supercools because of the reduction in freezing point temperature with reduced pressure (Foldvik and Kvinge, 1974). Studies to date conclude that thermohaline convection must play a dominant role in ventilating the Ross Ice Shelf cavity, but that the details of this effect in McMurdo Sound are influenced by topography and tides (MacAyeal, 1984). Platelet ice is not unique to McMurdo Sound; it is also found associated with ice shelves in other regions of Antarctica (see Leonard et al. (2006) for more detail).

The long-term aim of this project is to quantify the contribution that heat loss to the ocean makes to the thickness and properties of the seasonal landfast sea ice around Antarctica, using McMurdo Sound as a natural laboratory. In this paper we compile historical data to map the distribution of platelet ice in the Sound and we outline mechanisms believed to control this distribution. Using recently published data from a single site, we speculate on the average contribution of heat loss to the ocean on the seasonal sea ice thickness. We append our unpublished data in an attempt to generate a measure of the interannual variability of platelet ice formation. Further work is required to overcome uncertainties in these data.

AREAL DISTRIBUTION OF PLATELET ICE

A sketch map showing the relative abundance of platelet ice in McMurdo Sound is given in Figure 2. Data sources, average platelet ice thickness, percentage of total ice thickness occupied by incorporated platelet ice and platelet ice type are given in Table 1. In this paper we define "incorporated platelet ice" as platelet ice that has frozen into the growing sea ice cover, while "loose platelet ice" is an accumulation of unconsolidated ice crystals floating beneath the ice–water interface. Relative abundances shown in Figure 2 were determined by dividing each sources' data set into 5 bins of platelet layer thickness which were equal in magnitude for each year, but different between years as shown in Figure 3. These were then graded from minimum to maximum.

Table 1: Average values of data used to construct Figure 2.

date	platelet thickness (m)	percentage of ice cover (%)	platelet ice type	source
Oct-Nov 1980	0.26	13	incorporated	Gow et al. (1998)
Oct-Nov 1982	0.80	42	incorporated	Jones and Hill (2001)
Jan 1990	0.77	38	incorporated	Jeffries et al. (1993)
Aug & Oct 1986	1.00	NA	loose	Crocker (1988)

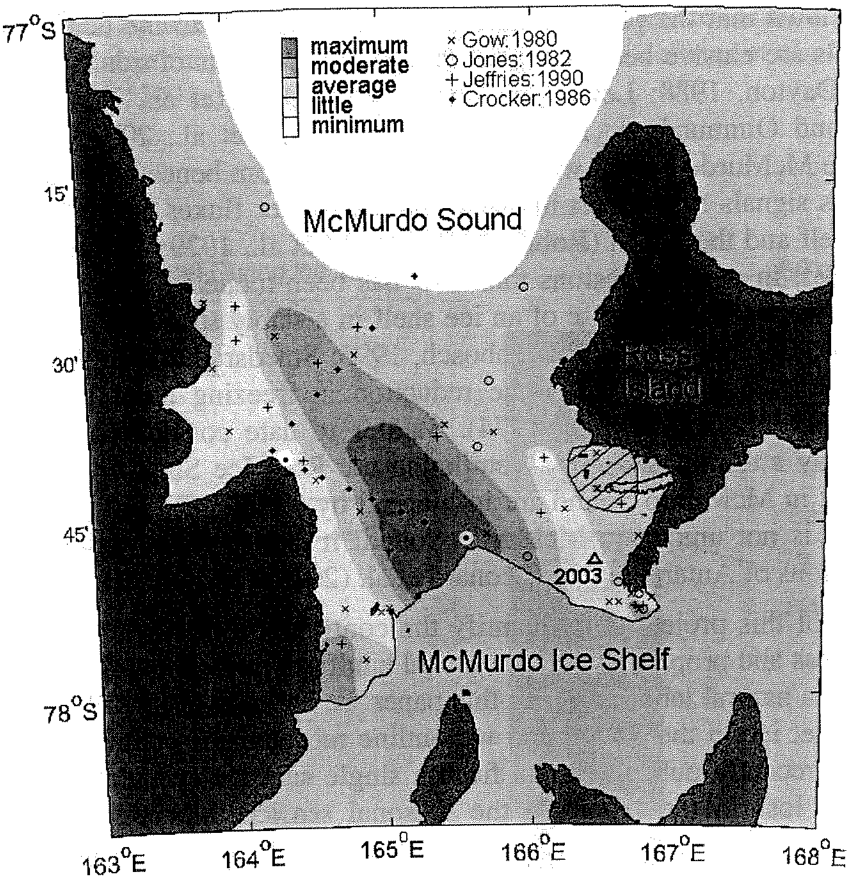

Figure 2: Map of relative abundance of platelet ice over McMurdo Sound, based on data for which average values are given in Table 1. Triangle marks the site of winter 2003 measurements. Figure 4 shows a time series of data from 1980 to 2002 from the hatched area south of Ross Island.

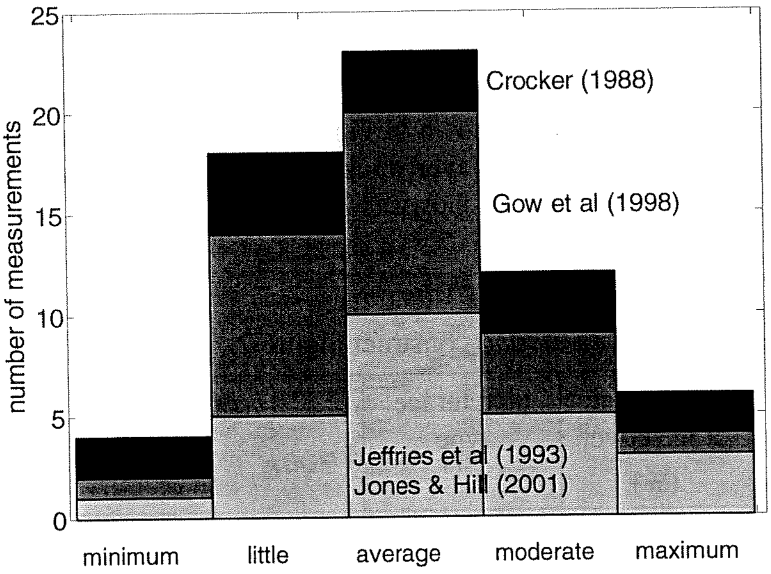

Figure 3: Cumulative histogram of historical measurements, showing data of Jeffries and Jones in 0.30 m bins (light grey), Gow in 0.12 m bins (medium grey), and Crocker in 0.42 m bins (in black).

The relative abundance of platelet ice emerges as a remarkably consistent pattern, independent of year, month of measurement, and whether the platelet ice measured was incorporated in the sea ice cover or whether it was loose at the ice-water interface. Further, the distribution is very similar to the platelet ice abundance index distribution of Barry (1988), compiled for November 1984 from the amount of loose platelet ice in hyrdocast holes, on mooring lines, and from diver observations.

As has been suggested by others (e.g. Barry, 1988), this pattern is consistent with oceanographic and biological measurements. In the eastern Sound, there is a southerly flow of relatively warm, saline water from the Ross Sea into the Sound (Tressler and Ommundsen, 1962). Some of this water continues south under the Ross Ice Shelf, where it mixes with sub-ice shelf water before moving northwards to exit the Sound on its western side (Lewis and Perkin, 1985; Barry and Dayton, 1988). This northward-flowing water, having been diluted by melt water from the base of the ice shelf, is less saline. The paucity of platelet ice in the eastern southerly flow, and its predominance in the relatively fresh, cold, western water is therefore as expected. While this circulation pattern is well established, what is less clear is the extent to which the circulation is driven by thermohaline processes. The slope of the underside of the McMurdo Ice Shelf (McCrae, 1984) would be consistent with a buoyant flux emerging on the western side of the Sound.

Examination of the variation of the average platelet ice thickness in Table 1 shows that there appears to be a factor of three change in the total amount of platelet ice in just 2 years. Thus, in McMurdo Sound the absolute thickness of platelet ice appears to vary annually, but the spatial distribution is consistent from year to year.

INTERANNUAL VARIATION OF PLATELET ICE

We now consider possible trends in the variation of incorporated platelet ice from year to year. A time series of the structure of the first year sea ice, in the hatched area of Figure 2 for 1980 to 2002, is shown in Figure 4. The data are mainly from our field work and are mainly taken in October, unless otherwise stated. There are no obvious trends over this time period (Figure 4).

There are two major uncertainties in these data. First, the hatched area covers approximately 65 km^2 and therefore spatial and temporal variability may be intermingled. Second, techniques used to assess platelet ice amount vary with time and researcher.

CONTRIBUTION FROM THE OCEAN

Figure 4 is a measure of the incorporated platelet ice in each year. Our hypothesis is that this forms with two heat sinks: conduction through the sea ice cover to the atmosphere, and heat transfer to the supercooled ocean. Throughout winter 2003 at the site marked on Figure 2, Purdie et al. (in press) measured the temperature gradient close to the sea ice-water interface. They then calculated the conductive heat flux through the sea ice cover. Since the ice growth rate was also obtained, the residual growth due to heat lost to the ocean can be deduced from the data (Purdie et al., in press). The data cannot distinguish between a sensible heat flux from the ice to a cooler water body and a latent heat flux due to the advection of crystals formed in the water column. Purdie et al. (in press) found that by late September, 0.25 m of the total incorporated platelet ice thickness of 0.70 m was due to oceanic heat flux. That is, approximately 1/3 of the incorporated platelet ice is due to heat flux to the ocean, with the remaining heat being conducted through the sea ice to the atmosphere. Previous estimates range between 1/3 and 1/2 (Crocker and Wadhams, 1989; Trodahl et al., 2000; Smith et al., 2001; Smith, 2001).

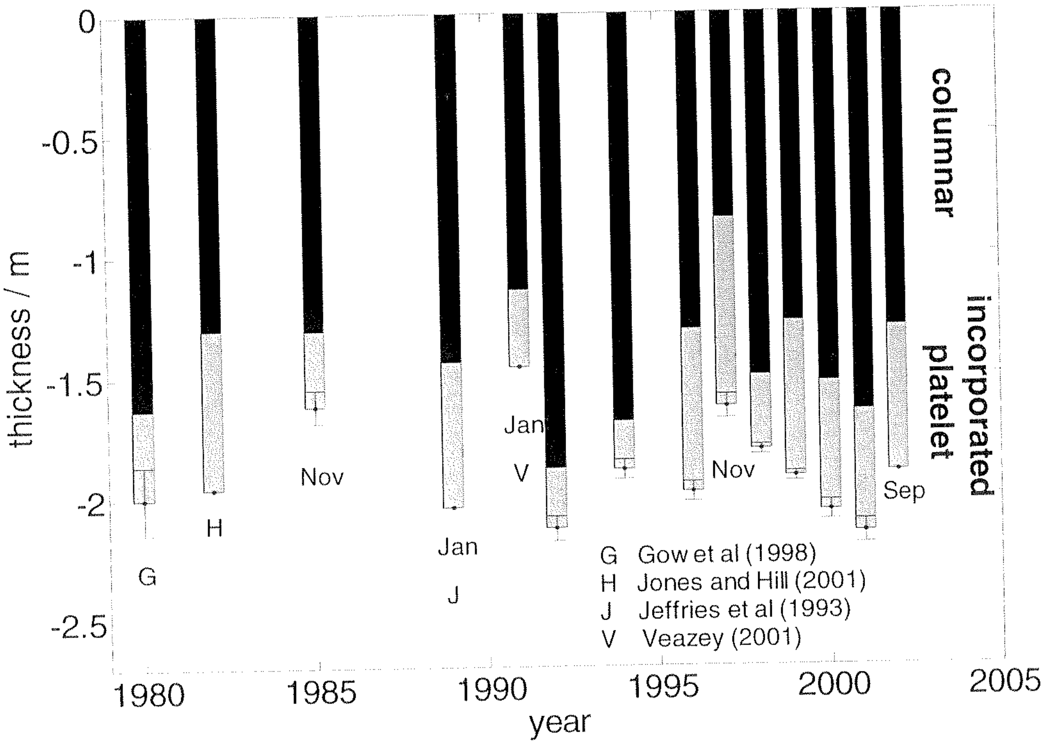

Figure 4: Time series of the structure of the first year sea ice in the hatched area marked on Figure 2 from 1980 to 2002. Data mainly from our field work and mainly taken in October (unless otherwise stated).

DISCUSSION AND CONCLUSIONS

From the above discussion we may conclude that the absolute thickness of platelet ice in McMurdo Sound appears to vary from one year to the next, while its spatial distribution remains constant and can be largely explained by the circulation in the Sound.

Given that we have a measure of the incorporated platelet ice thickness, we may now make an estimate of the contribution of the ocean to sea ice thickness near an ice shelf. Purdie et al. (in press) have shown that 30 % of incorporated platelet ice layer is due to heat flux to the ocean. Further, about 40 % of total seasonal ice cover thickness is incorporated platelet ice. Therefore, close to an ice shelf, approximately 10 % of total ice thickness is due to a combination of latent and sensible heat flux to the ocean. Although this will make a small contribution to sea ice thickness globally, its influence on the landfast ice thickness around Antarctica may be significant. Very few sea ice growth models account for platelet ice growth.

Our examination of historical data raises a number of questions. There appears to be a factor of 3 change in the total amount of platelet ice in just 2 years. However we are unable to tell if this is a real effect or a measurement problem. If it is real, then further work is required to establish why there should be more platelet ice in some years than others.

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REFERENCES

Barry, J.P. (1988) Hydrographic patterns in McMurdo Sound, Antarctica and their relationship to local benthic communities. *Polar Biol.*, 8:377-391.

Barry, J.P. and Dayton, P.K. (1988) Current patterns in McMurdo Sound, Antarctica and their relationship to local biotic communities. *Polar Biol.*, 8:367-376.

Crocker, G.B. (1988) Physical processes in Antarctic landfast sea ice. PhD thesis, University of Cambridge, UK.

Crocker G.B., and Wadhams, P. (1989) Modelling Antarctic fast-ice growth. *J. Glaciol.*, 35:3-8.

Dayton, P.K., Robilliard, G.A. and DeVries, A.L. (1969) Anchor ice formation in McMurdo Sound Antarctica and its biological effects. *Science*, 163:273-274.

Dieckmann, G., Rohardt, G., Hellmer, H. and Kipfstuhl, J. (1986) The occurrence of ice platelets at 250 m depth near the Filchner Ice Shelf and its significance for sea ice biology. *Deep-Sea Res.*, 33:141-148.

Foldvik, A. and Kvinge, T. (1974) Conditional instability of sea water at the freezing point. *Deep-Sea Res.*, 21, 169-174.

Gow, A.J., Ackley, S.F., Govoni, J.W. and Weeks, W.F. (1998) Physical and structural properties of land-fast sea ice in McMurdo Sound, Antarctica. In *Antarctic Sea Ice: Physical Processes, Interactions and Variability*, Antarctic Research Series, 74:355-374.

Hellmer, H.H. and Jacobs, S.S. (1992) Ocean interactions with the base of the Amery Ice Shelf, Antarctica. *J. Geophys. Res.* 97:20,305-20,320.

Holland, D. M., Jacobs, S. S. and Jenkins A. (2003) Modeling the ocean circulation beneath the Ross Ice Shelf, *Antarctic Science,* 15:3-12.

Hunt, B.M., Hoefling, K. and Cheng, C-H. C. (2003) Annual warming episodes in seawater temperatures in McMurdo Sound in relationship to endogenous ice in notothenioid fish. *Antarctic Science*, 15(3):333-338.

Jacobs, S.S., Gordon, A.L. and Ardai, L.D. (1979) Circulation and melting beneath the Ross Ice Shelf. *Science*, 203:439-443.

Jeffries, M.O., Weeks, W.F., Shaw, R. and Morris, K. (1993) Structural characteristics of congelation and platelet ice and their role in the development of Antarctic land-fast sea ice. *J. Glaciol.*, 39:223-238.

Jenkins, A. and Bombosch, A. (1995) Modelling the effects of frazil ice crystals on the dynamics and thermodynamics of Ice Shelf Water plumes. *J. Geophys. Res.,* 100:6967-6981.

Jones, S.J. and Hill, B. (2001) Structure of sea ice in McMurdo Sound, Antarctica. *Annals of Glaciology*, 33:5-12.

Leonard, G. H., Purdie, C. R., Langhorne, P. J., Haskell, T. G., Williams, M. J. M. and Frew, R. D. (2006), Observations of platelet ice growth and oceanographic conditions during the winter of 2003 in McMurdo Sound, Antarctica. *J. Geophys. Res.*, 111: C04012, doi:10.1029/2005JC002952.

Lewis, E.L. and Perkin, R.G. (1985) The winter oceanography of McMurdo Sound, Antarctica. In *Oceanology of the Antarctic Continental Shelf*, Antarctic Research Series, 43:145-165.

MacAyeal, D.R. (1984) Thermohaline circulation below the Ross Ice Shelf: A consequence of tidally induced vertical mixing and basal melting. *J. Geophys. Res.,* 89:597-606.

McCrae, I.R. (1984) A summary of glaciological measurements made between 1960 and 1984 on the McMurdo Ice Shelf Antarctica. University of Auckland, *School of Engineering, Report* No 360.

Paige, R.A. (1966) Crystallographic studies of sea ice in McMurdo Sound, Antarctica. *U.S. Naval Civil Engineering Laboratory, Technical Report* R-494.

Penrose, J.D., Conde, M. and Pauly, T. J. (1994) Acoustic detection of ice crystals in Antarctic waters. *J. Geophys. Res.*, 99:12753-12880.

Purdie, C., Langhorne, P., Leonard, G. and Haskell, T. (in press) Growth of first year land-fast Antarctic sea ice determined from winter temperature measurements. *Annals of Glaciology*, 44: in press.

Robin, G. de Q. (1979) Formation, flow and disintegration of ice shelves. *J. Glaciol.*, 24:259-271.

Smedsrud, L.H. and Jenkins, A. (2004). Frazil ice formation in an ice shelf plume. *J. Geophys. Res.,* 109:C03025, doi10.1029/2003JC001851.

Smith, I.J. (2001) Platelet ice in McMurdo Sound, Antarctica. PhD thesis, University of Otago, Dunedin, New Zealand.

Smith, I.J., Langhorne, P.J., Haskell, T.G., Trodahl, H.J., Frew, R. and Vennell, R. (2001) Platelet ice and the land-fast sea ice of McMurdo Sound, Antarctica. *Annals of Glaciology*, 33:21-27.

Tressler, W.L., and Ommundsen, A.M. (1962) Seasonal oceanographic studies in McMurdo Sound, Antarctica. *Technical Report 125*, USN Hydrographic Office.

Trodahl, H. J., McGuinness, M., Langhorne, P.J., Collins, K., Pantoja, A.E., Smith, I.J. and Haskell, T.G. (2000) Heat transport in McMurdo Sound first year fast ice. *J. Geophys. Res*, 105(C5):11,347-11,358.

Williams, M.J.M., Jenkins, A. and Determann, J. (1998) Physical controls on ocean circulation beneath ice shelves revealed by numerical models. *Ocean, Ice and Atmosphere: Interactions at the Antarctic Continental Margin, Ant. Res. Ser.,* 75:285-299.

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Preface

It is a great pleasure for us to welcome you to the 18th IAHR International Symposium on Ice that is held from 28 August to 1 September 2006 at the Conference Hall of Hokkaido University in Sapporo, Japan. This is the second time for Sapporo to host the conference since the 9th IAHR International Symposium on Ice in 1988. During the time period between the two conferences, Sapporo has amazingly grown as a core city of the North.

The IAHR Symposium on Ice has developed as one of the prominent international forums on ice since the first symposium was held in 1970 in Iceland. This premier symposium has provided ice experts with valuable opportunities to exchange expertise and experience on ice engineering and cold regions science. At the 18th Symposium, more than 70 papers have been accepted through rigid review for presentation and publication.

We gratefully acknowledge the support of our sponsors including the Foundation of Hokkaido River Disaster Prevention Research Center, Hokkaido Road Management Engineering Center, Hokkaido Office of the Service Center of Port Engineering (SCOPE), Cold Region Port and Harbor Engineering Research Center, and the North Japan Port Consultants Co., Ltd., as well as the assistance of other organizations to realize this symposium.

As conference chair, I would like to express heartfelt appreciation to efforts and cooperation of all of you including the keynote speakers, authors and participants to make the symposium successful. I also deeply thank support of the IAHR Ice Committee members, Scientific Committee members, paper reviewers, and of Local Organizing Committee members.

Finally, I hope that what you may have learned from this symposium will contribute to further development of ice studies toward the future.

August 2006

Hiroshi Saeki, Dr. Eng.,
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