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Snow Accumulation and Ablation Pattern on Ice Shelf near Dakshin Gangotri, Antarctica, and Development of fast Ice off Dakshin Gangotri

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Abstract

There is a lot of variation in the accumulation and ablation pattern of snow of the shelf ice around Dakshin Gangotri station, mainly defined by the wind direction and wind force. Studies carried out in this aspect around Dakshin Gangotri for the summer of 1985-86 and 1986-87, and the intervening winter period, reveal that the net accumulation of snow/firn is of the order of 18.51 gm/cm^2 cf water equivalent in a calendar year. The average density of snow/firn works out to be 0.37 gm/cm^3.

Maximum development of fast ice was observed in the month of January, 1987 and its average density was recorded as 0.50 gm/cm^3. The maximum ram hardness was of the order of 37 kg.

Introduction

The ice shelf surrounding the Dakshin Gangotri station is a conspicuous morphological feature of this part of Princess Astrid Coast of Queen Maud Land. It is reported to be generally floating, though grounded at a few localities. With open, sea in the north and Schirmacher hill range and polar ice sheet in the south, this ice shelf is about 100 km. in width. Snow accumulation and ablation studies were carried out on this coastal ice shelf during two summer seasons and one winter season, beginning with the Fifth Indian Expedition in December, 1985.

The Indian station is located about 15 km towards south from the Lazarev coast. A cyclonic weather regime prevails in the area with the result that snow accumulation is mainly contributed by drift snow. When the winds are stronger than 30 knots/hour, ice surface gets ablated. For such accumulation and ablation studies, a plot of ice shelf, measuring 100 m X 100 m was selected about 1.25 km east of station. It was totally free of any obstruction and devoid of any human activity. For this purpose, aluminium stakes of 3 metres length, fitted with rubber shoes to avoid sinking of stakes, were fixed at 50 metres interval, in a rectangular pattern (Fig. 1). Total of nine stakes were fixed. These stakes

Stake No.	26.12. to 7.2	7.2.86 to 18.2.86	18.[illegible] to 27.3.8	27.3.8 to 12.4.8	12.4.8 to 27.4.8	27.4.8 to 37.5.8	[illegible]	7 6R to 13.6.8	13.6.8 to 26.6.S	26.6.8 to 16.7.8	16.7.8 to 2.8.8)	2.8.81 to 22.8.S	[illegible]	I 9.S(to [illegible]
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[illegible]	[illegible]	29.9. to 15.10	15.10 to 31.10	31.10.8 to 18.11.8	18.11 to 29.11	29.11. to 15.12	15.12 to 27.12	27.12 to 15.1.	15.1. to 30.1.	30.1. to [illegible]	26.12. to 15.2.	26.1 [illegible]
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were observed at fortnightly interval, as far as possible, during December, 1985 to February, 1987.

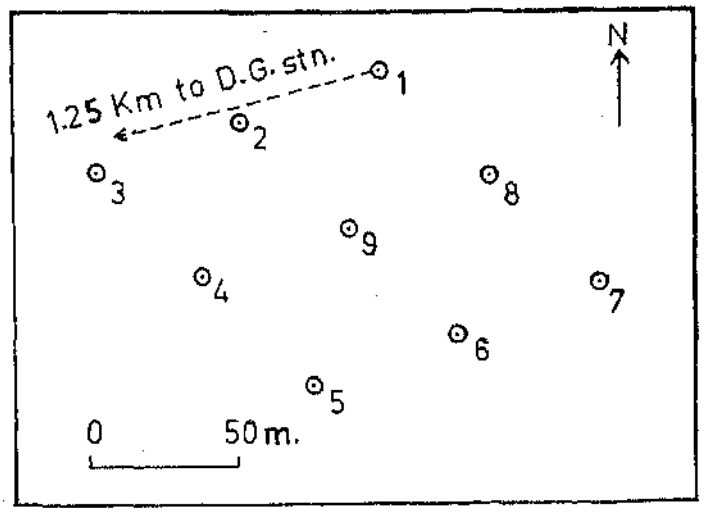

Fig. 1. *Location of stakes near Dakshin Gangotri station*

Accumulation and Ablation on Shelf

The periodic snow accumulation/ablation monitored at each stake is shown in Table I. The average accumulation on the shelf between 26.12.85 and 15.2.87 was of the order of 13.58 cm of water equivalent. For a calendar year i.e. 26.12.85 to 27.12.86, net accumulation recorded was 18.51 cm (W.E.). The obvious difference in accumulation is attributed to net ablation in months of January and February, 1987.

The maximum net accumulation of 18.68 cm (W.E.) was noted at stake no. 1 and on the lower side, net ablation of the order of 9.2 cm (W.E) was recorded at stake no. 9.

Cumulative average accumulation at the stake network has been plotted in Fig. 2. Accumulation rate was uneven throughout the year. March, May and August were the months when higher rate of accumulation was recorded. In the months of January and February conspicuous ablation of the ice shelf surface was noticed. Little ablation was observed in the months of June and July. Ablation in winter months is mainly because of drifting of snow due to wind. In the summer months, the level of snow shrinks because of snow subsidence, evaporation and erosion by winds.

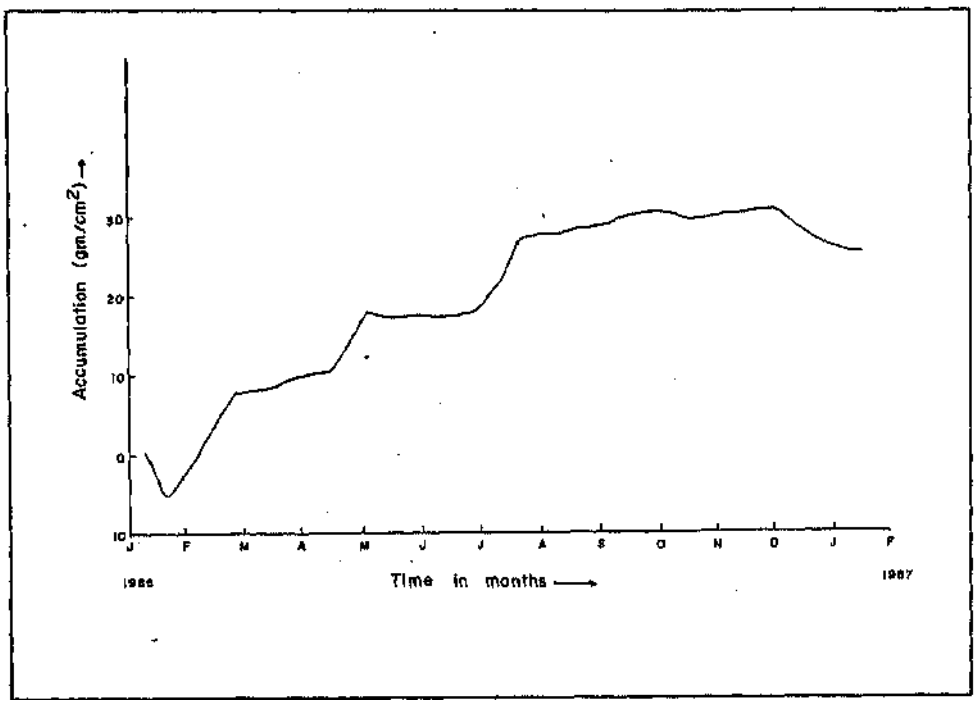

Fig. 2. Average cumulative accumulation

Accumulation and ablation patterns at the stakes have been drawn showing accumulation and ablation contours (Figs. 3-26). These patterns correspond well with tha prevalent wind direction. Usually the ablation troughs are along the wind direction. In Fig. 27, the accumulation/ablation pattern for the duration December, 1985 to February, 1987 is shown.

Effect of Obstruction

Once snow laden winds hit an obstruction, their carrying capacity decreases and the snow accumulates in the process, trying to bury the obstruction. For observation of snow accumulation around obstructions, wooden stakes were fixed around the station. The location of the four stakes is shown in Fig. 28. The net cumulative accumulation at the four stakes is plotted in Fig. 29. Minimum accumulation was recorded at stake A. It was located in front of the hangar garage, the latter being aligned perpendicular to the wind direction ,with a convex roof. The garage hangar was covered upto roof top from windward side but on the leeward side there was little accumulation for a horizontal distance of about 20 metres, Maximum accumulation was recorded at stake B; at stakes C and D accumulation comparable to overall accumulation on the shelf was recorded.

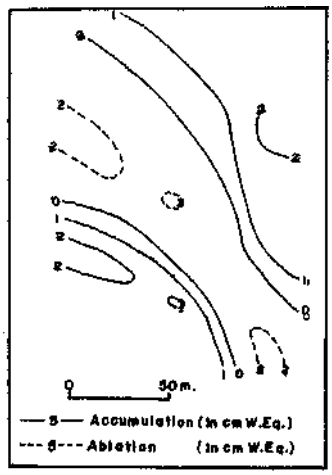

Fig.3. Ablation Accumulation Pattern of shelf ice near D.G. station -between 26.12.85 to 7.2.86.

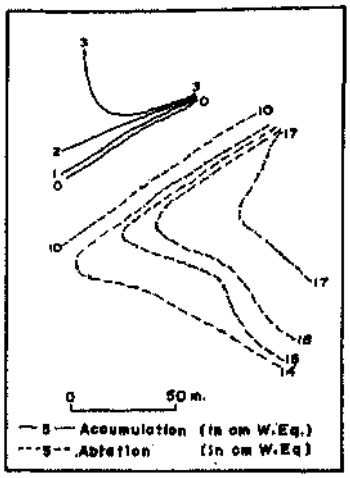

Fig. 4. Ablation/Accumulation Pattern of shelf ice near D.G. station between 7.2.86 to 18.2.86.

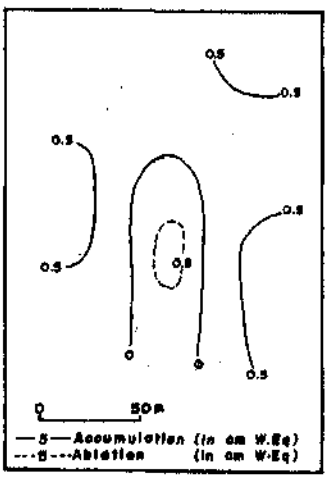

Fig. 5. Ablation/Accumulation Pattern of shelf ice near D.G. station between 18.2.86 to 27.3.86.

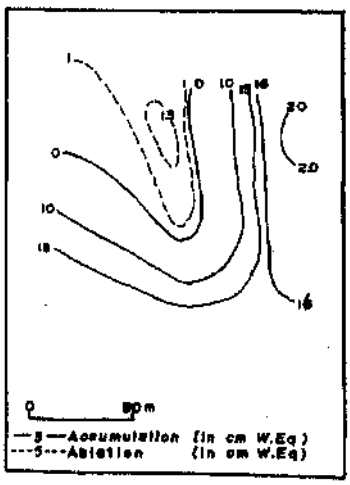

Fig. 6. Ablation/Accumulation Pattern of shelf ice near D.G. station between 27.3.86 to 12.4.86.

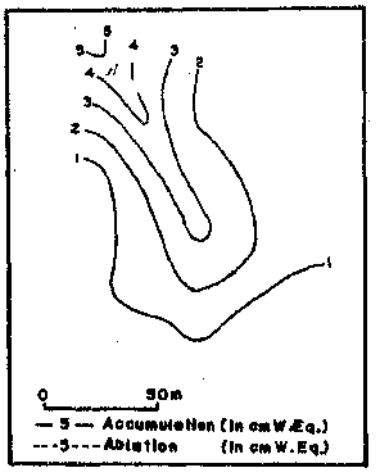

Fig. 7. Ablation/Accumulation Pattern of shelf ice near D.G. station between 12.4,86 to 27.4.86.

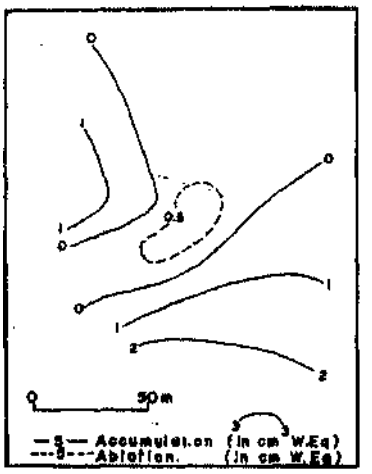

Fig. 8. Ablationi/Accumulation Pattern of shelf ice near D.G. station between 27.4.86 to 17.5.86.

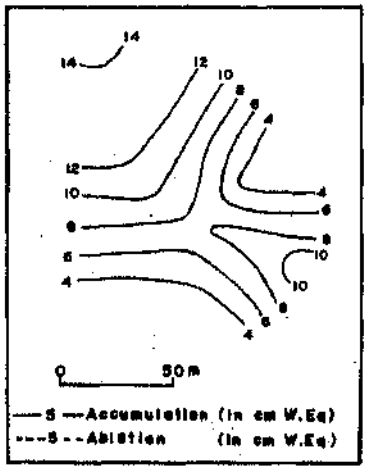

Fig. 9. Ablation/Accumulation Pattern of shelf ice near D.G. station between 17.5.86 to 2.6.86.

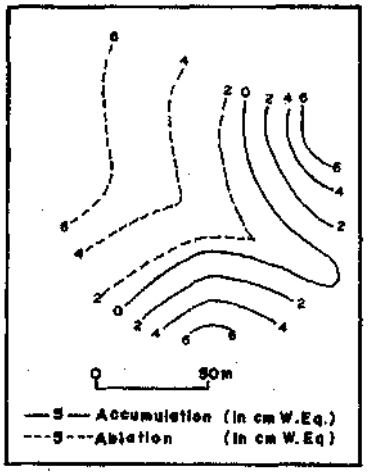

Fig. 10, Ablation/Accumulation Pattern of shelf ice neat D.G. station between 2.6.86 to 13.6.86.

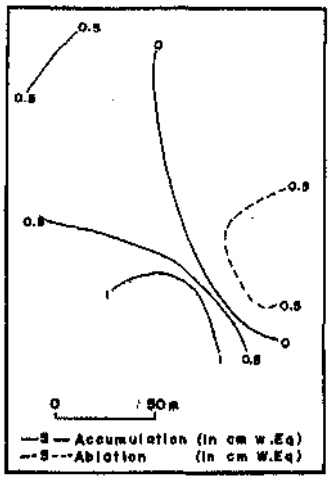

Fig. 11. Ablation/Accumulation Pattern of shelf ice near D.G. station between 13.6.86 to 26.6.86.

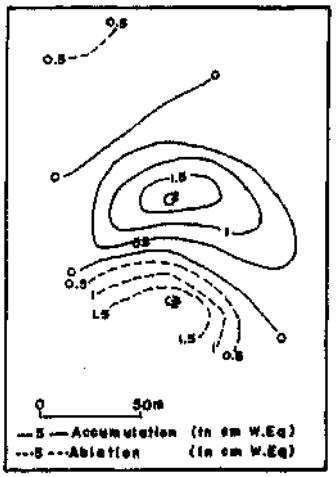

Fig. 12. AblationlAccumulation Pattern of shelf ice near D.G. station between 26.6.86 to 16.7.86.

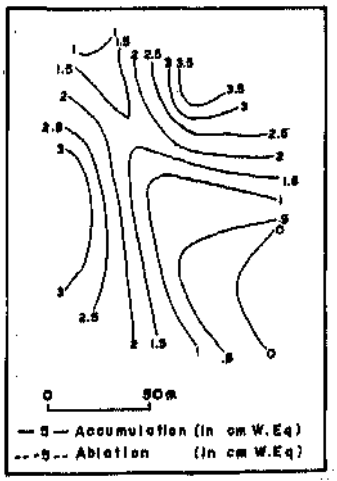

Fig 13. Ablation/Accumulation Pattern of shelf ice near D.G. station between 16.7.86 to 2.8.86.

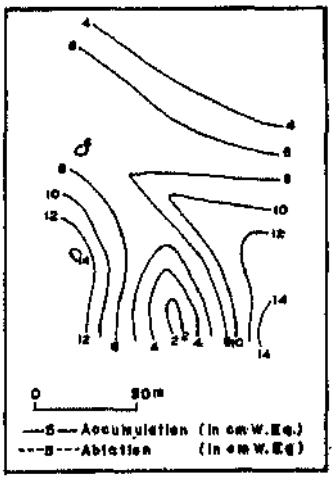

Fig. 14. Ablation/Accumulation Pattern of shelf ice near D.G. station between 2.8.86 to 22.8.86.

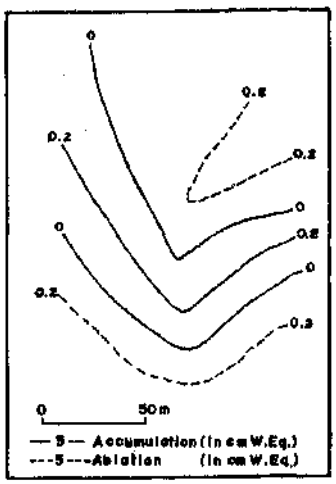

Fig. 15. Ablation/Accumulation Pattern of shelf ice near D.G. station between 22.8.86 to 1.9.86.

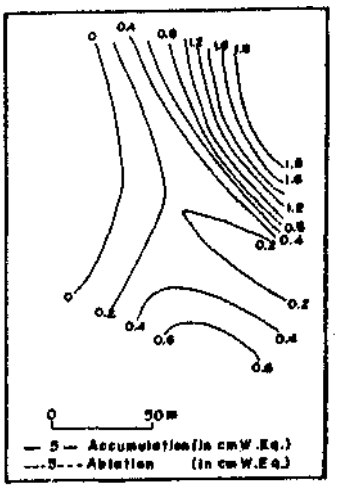

Fig 16. Ablation/Accumulation Pattern of shelf ice near D.G. station between 1.9.86 to 15.9.86.

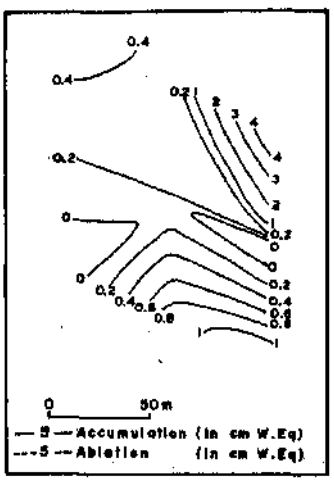

Fig. 17. Ablation/Accumulation Pattern of shelf ice near D.G. station between 15.9.86 to 29.9.86.

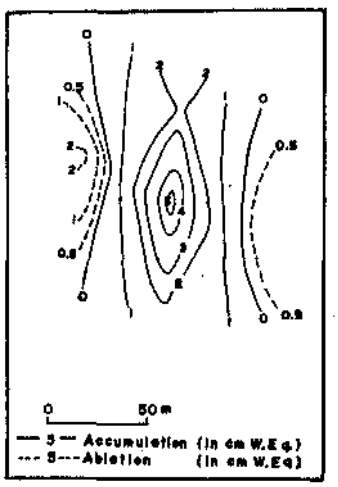

Fig. 18. Ablation/Accumulation Pattern of shelf ice near D.G. station between 29.9.86 to 15.10.86.

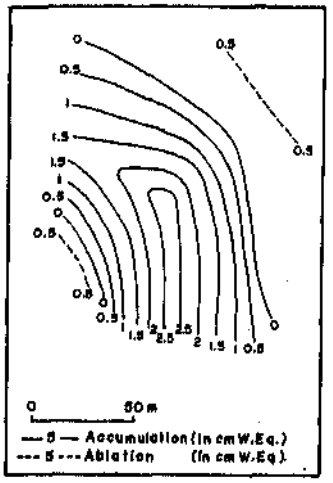

Fig. 19. Ablation/Accumulation Pattern of shelf ice near D.G. station between 15.10.86 to 31.10.86.

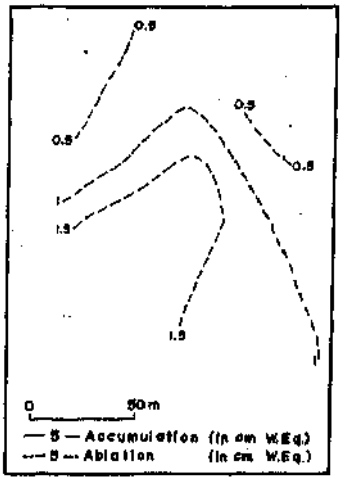

Fig.20. Ablation/Accumulation Pattern of shelf ice near D.G. station between 31.10.86 to 18.11.86.

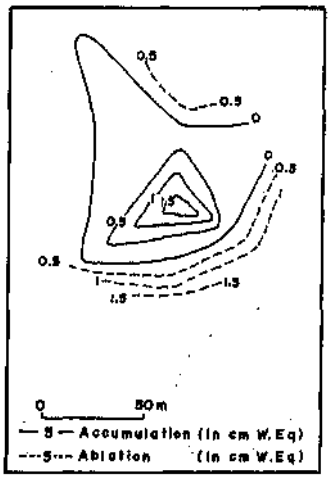

Fig 21. Ablation/Accumulation Pattern of shelf ice near D.G. station between 18.11.86 to 29.11.86.

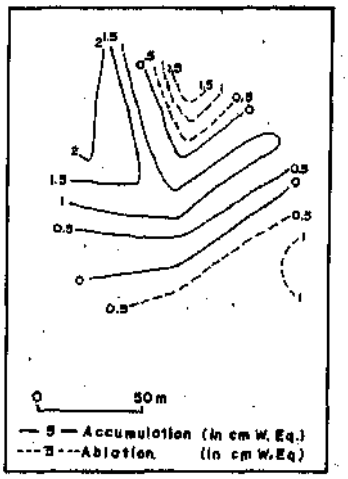

Fig. 22. Ablation/Accumulation Pattern of shelf ice near DG. station between 29.11.86 to 15.12.86.

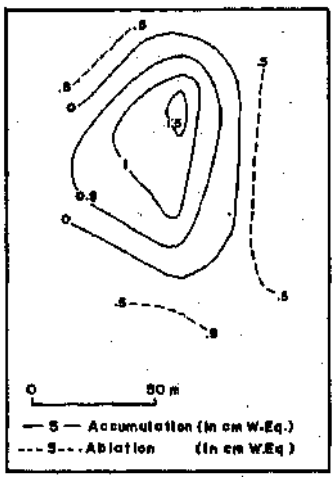

Fig.23. Ablation/Accumulation Pattern of shelf ice near D.G. station between 15.12.86 to 27.12.86.

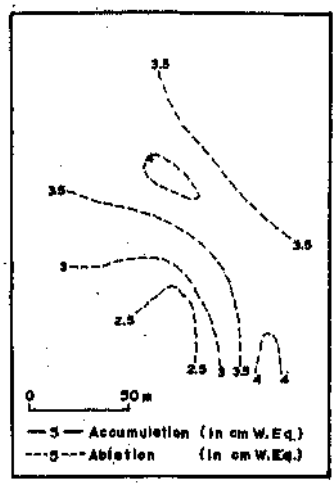

Fig.24. Ablation/Accumulation Pattern of shelf ice near D.G. station between 27.12.86 to 15.1.87.

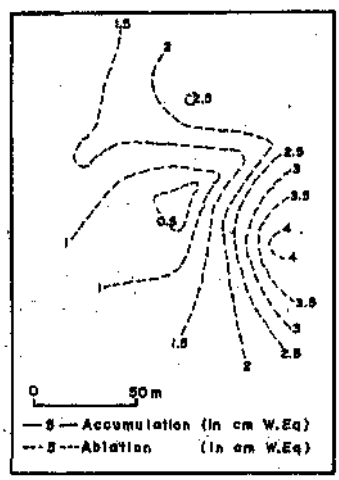

Fig 25. Ablation,/Accumulation Pattern of shelf ice near D.G. station between 15.1.87 to 30.1.87.

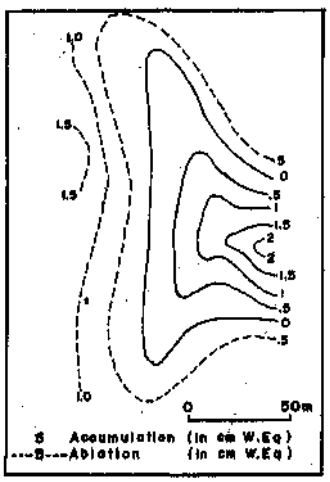

Fig. 26. Ablation/Accumulation Pattern of shelf ice near D.G. station between 30.1.87 to 15.2.87.

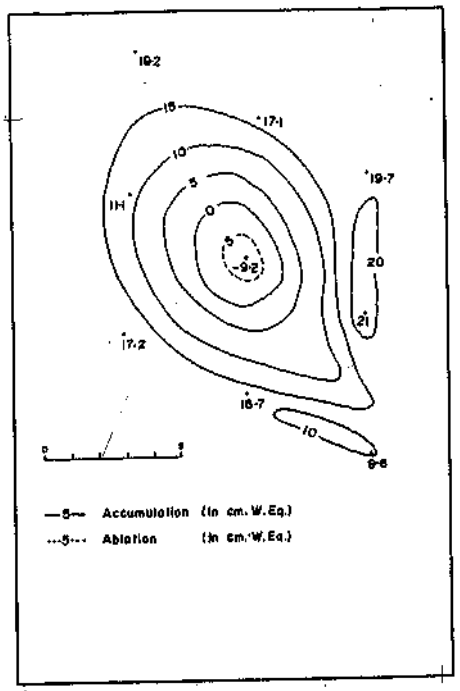

Fig. 27. Ablation/Accumulation pattern of shelf ice near D.G. station, between 26.12.85 to 15.2.87

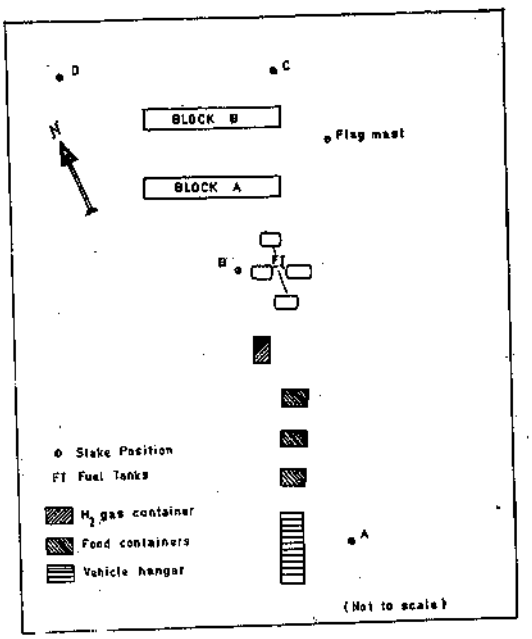

Fig. 28. Schematic diagram showing location of stakes A, B, C, D around Dakshin Gangotri station complex, Antarctica

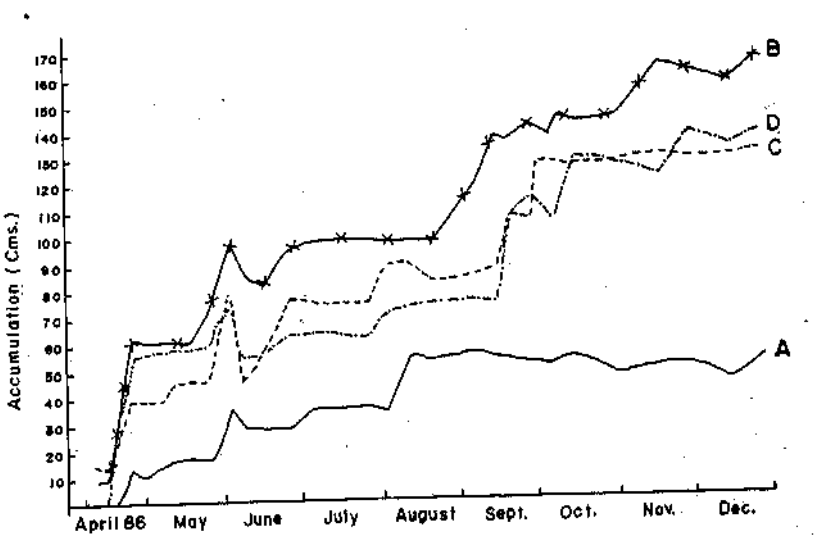

Fig. 29. Cumulative accumulation at four stakes near D.G. station

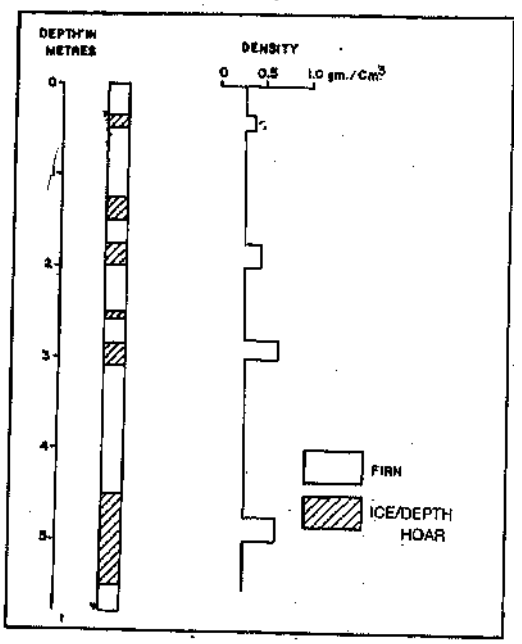

Fig. 30. Stratigraphic and density profile of shelf ice near Dakshin Gangotri station

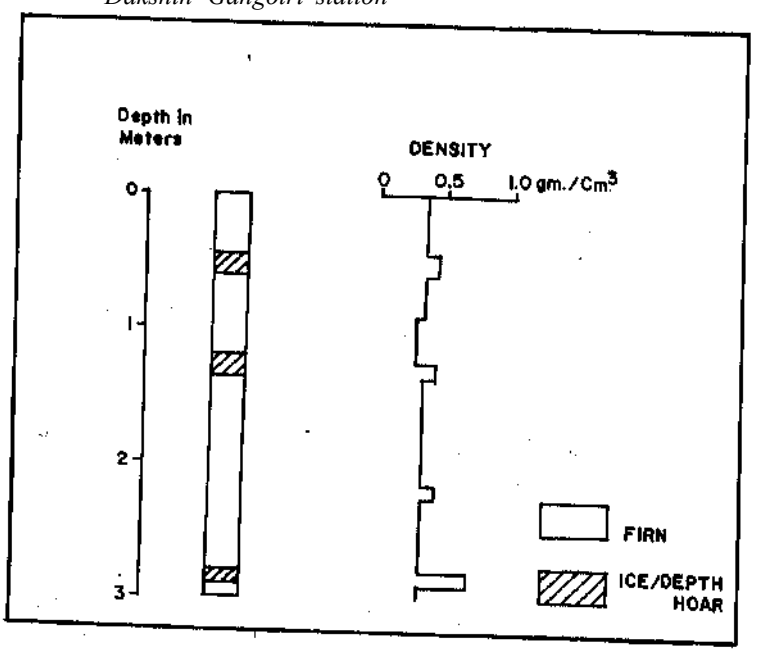

Fig. 31, Stratigraphic and density profile of the upper layers of an ice berg

Density Profiling of Shelf Ice

Density measurements were carried out by digging pits upto the annual accumulation surface and weighing known volumes of snow/ice with accurate spring balance. For consistency of results same steel cylinder of known volume was used. Stratigraphy and density variation in a sample pit are given in Fig. 30. Density varied with depth hoar which was encountered at several depths in the profile. Density ranged from 0.3 gm/cm^3 to 0.70 gm/cm^3. For comparative study, stratigraphic and density profile of ice from an iceberg was also recorded and is shown in Fig. 31. In upper layers, the ice from icebergs had slightly higher density values. Monthly average density of ice from shelf, near Dakshin Gangotri is given in Table II.

Table II. Density variation in shelf ice

Month	Av. Density (gm/cm^3)
April, 1986	.0.40
May, 1986	0.36
June, 1986	0.36
July, 1986	0.39
August, 1986	0.33
September, 1986	0.35
October, 1986	0,34
November, 1986	0.45
Average	0.37

Studies on Fast Ice

Two of the authors (RKS and SM) who wintered over at Dakshin Gangotri station, carried out regular studies on the development of fast ice off Dakshin Gangotri ice shelf. This area of fast ice was visited every month from May, 1986 to January, 1987. It was recorded that the first indications of the fast ice development were noticed in May, 1986 prior to which a firm base had developed for its accumulation and sustenance in the form of sea ice during March and April, 1986. During May, 1986 the shelf and fast ice had got well connected by a gradual slope emerging from shelf to fast ice with an imperceptible transition. The hinge line developed as such between the two types of ice did not show development of any tensional and compressional cracks till upto end of austral winter.

Thickness: Regular monitoring of the thickness parameter of fast ice was done, which is given in Table III.

Table III. Thickness changes in fast ice

Date	Thickness of snow (m)	Thickness of sea ice (m)	Total thickness (m)
15.5.86	0.05	0.56	0.61
22.7.86	0.51	1.30	1.81
25.8.86	1.03	1.43	2.46
23.9.86	0.89	1.79	2.68
16.10.86	0.85	2.32	3.17
26.11.86	0.73	2.39	3.12
17.12.86	0.72	2.41	3.13
22.1.87	0.55	2.52	3.07

It was observed that the growth rate is faster in the initial months. Maximum development of fast ice was observed in the month of January, 1987, but total thickness of fast ice attained a maximum of 3.17 metres in the month of October, 1986. The dominant factors controlling the accumulation appear to be the wind, being faster in the month of October.

Density: Regular observations in the change of density every month were also made. The variation in the density of fast ice is attributed to compaction and freezing by wind, tidal pressure and capillary action due to sea water. The average density of the fast ice is tabulated in Table IV and graphically shown in Fig. 32.

A comparison of Tables III and IV reveals that fast ice has a higher density of 0.50 gm/cm^3 than the shelf ice with a density of 0.37 gm/cm^3 during the

Table IV. Density variation in fast ice

Month	Average density (gm/cm^3)
May, 1986	0.65
June, 1986	0.47
July, 1986	0.44
August, 1986	0.40
September, 1986	0.58
October, 1986	0.44
November, 1986	0.48
December, 1986	0.55
Average	0.50

same period. The fast ice by virtue of its getting subjected to tidal pressure and more meltfreeze changes than the shelf ice, may be showing this density-high.

Hardness: Observations on the ram hardness of fast ice, were also made. The ram hardness values steeply increased till July, 1986 and showed a gradual diminution till October, 1986. Coincidentally highest hardness value of 37 kg appeared along with the minimum temperature of - 34°C observed during this period. This interesting relationship between temperature and hardness is presented in Fig. 33.

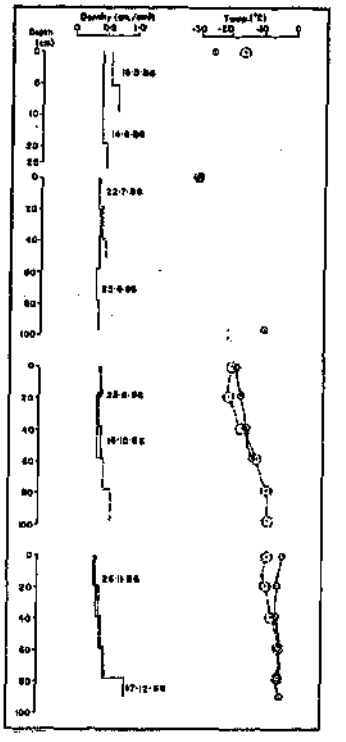

Fig. 32. Density and temperature profiles recorded in the fast ice off Dakshin Gangotri

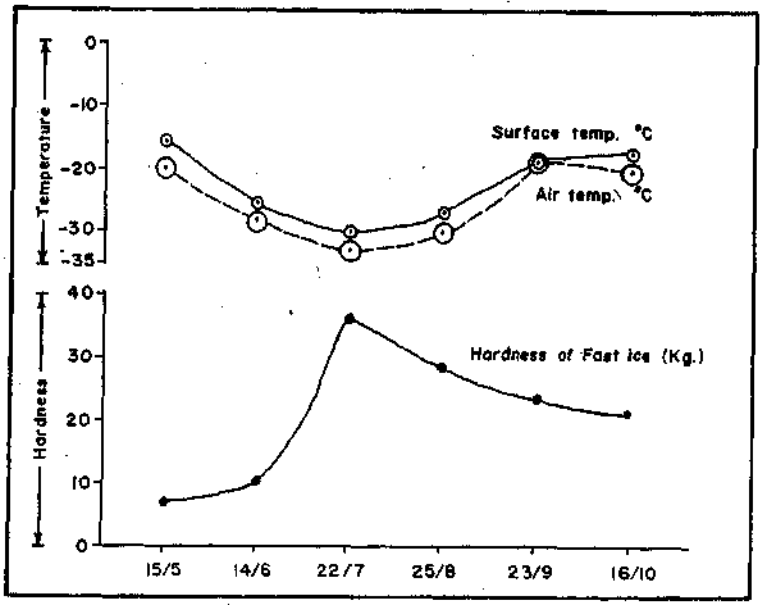

Fig. 33. Variation in rammsonde hardness of fast ice from 15.5,86 to 16.10.86

Conclusions

In comparison with snow accumulation in other shelf areas of Antarctica, snow accumulation near Dakshin Gangotri is slightly higher. The annual accumulation recorded at Wilkes station, for example, is between 7.9 and 15.9 gm/cm^2 (Cameron, 1964). The accumulation/ablation patterns drawn for the shelf are comparable to the patterns obtained by Kaul *et al.* (1985). The data on fast ice being collected for the first time from Dakshin Gangotri, reveals some interesting features about the development and characteristics of fast ice, which can be correlated with the changing Antarctic seasons.

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References

CAMERON, R.L. (1964): Glaciological studies at Wilkes station, Budd Coast, Antarctica. Antarctic Research Series. *Am. Geoph. Union,* Vol. 2, pp 1-36.

KAUL, M.K., CHAKRABORTY, S.K. AND RAINA, V.K. (1985): Ablation on the Antarctic shelf ice. *Sci. Rep. of Second Indian Expedition to Antarctica. Tech. Publ. No. 2, D.O.D., New Delhi.*