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THERMAL VARIATIONS WITHIN A GLACIER FROM THE SURFACE TO THE BED-ROCK

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Introduction

In 1996, two boreholes were drilled by the GSI-team in polar continental ice. The first of these boreholes was sunk about 3 km south of Maitri station and its location was 70° 46' 51.9" south latitude and 11° 43' 05.3" east longitude. This work was carried out between March and May, 96. The total depth of this borehole was 76.23 m and the bedrock was encountered at the bottom. This borehole was subsequently utilised for studying the thermal variations within this part of the glacier.

Equipment and Methodology

Fourteen thermistors (PT-100) were calibrated and installed at depths of 1, 2,3,4, 5, 10, 15, 20,25,35,45, 55,65 and 76 metres depths, respectively. Then the borehole was filled up with water **(Fig.l)** to replace the original medium, i.e. ice. A few days were given to the borehole-column to cool down to the level of the surrounding depths. After that, the readings of the thermistors were recorded with a multimeter. Additionally, one reading was taken for the surface temperature also.

Observations

It was found that two thermistors, (at the depths of 20 m and 35 m, respectively), failed to function properly, so the data collected is for twelve thermistors only. Since the location is about 3-4 km away from Maitri station, the observations were taken on a weekly basis. All these observations are presented in **Table-1.** The annual thermal profile for the surface of the glacier is drawn in **Fig.2.** The thermistors, depending on the annual observations, have been classified into three broad groups: upper, middle and lower. These show similar trends of thermal variations. The annual profiles of these three groups

Fig. 1 : The borehole being filled up with water, after installing 14 thermistors

are displayed in **Figs 3,4&5** respectively. The overall annual average profile of the entire column is shown in **Fig.6.** From 14th May 96 to 6th February 97, a period of 269 days is covered by observations. During this period, 55 sets of observations have been recorded.

Discussion and Conclusions

1. The annual profile of the surface temperature at the borehole site **(Fig.2)** was recorded to vary between -31°C to +5°C. Since the observations were only taken on a weekly basis, the limits are not true, but it does give a general trend on the surface of the glacier.
2. From **Fig.3,** it is seen that the temperatures from 1 m depth to 5 m depth, fluctuate wildly with the surface fluctuations. These depths display variations between -1 °C to -18°C. However, with increasing depth, the fluctuations subside and so the 5 m depth is more steady.
3. From **Fig.4,** it is observed that the middle level depths, ie 10 m to 25 m, are mildly affected by the surface fluctuations. These display almost steady temperatures varying between -8°C to -11 °C. Thus, the maximum depth of cold front penetration is confined to a depth of 25 m and beyond that depth, the levels are not affected by seasonal surface changes in temperatures.

Table 1: Thermal Data for Glacier, Surface to Bedrock

Date	Day-unit	Surface	1m	2m	3m	4m	5m	10m	15m	25m	45m	55m	65m	76m
14.5.96	1	-24.1					-9.0	-8.6	-8.6	-9.4	-9.0	-8.3	-8.3	-7.7
19.5.96	6	-23.5					-9.7	-8.8	-9.0	-9.4	-9.3	-8.3	-8.3	-7.7
20.5.96	7	-24.3					-9.7	-8.8	-9.0	-9.7	-9.3	-8.3	-8.3	-7.7
04.6.96	22	-20.9					-10.6	-9.0	-9.3	-9.7	-9.6	-8.6	-8.8	-7.9
06.6.96	24	-17.9	-14.4	-12.6	-11.0	-10.5	-10.6	-8.8	-9.0	-9.7	-9.6	-8.6	-8.7	-7.9
09.6.96	27	-14.2	-15.1	-13.1	-11.5	-10.8	-10.9	-9.0	-9.3	-9.9	-9.6	-8.6	-8.7	-7.8
17.6.96	35	-13.4	-13.6	-13.1	-12.4	-11.3	-11.1	-9.0	-9.0	-9.7	-9.4	-8.4	-8.4	-7.8
24.6.96	42	-30.1	-15.6	-13.4	-12.4	-11.6	-11.3	-9.3	-9.3	-9.9	-9.3	-8.6	-8.3	-7.7
08.7.96	56	-15.8	-14.1	-13.7	-13.0	-12.2	-11.8	-9.3	-9.0	-9.7	-9.5	-8.3	-8.5	-7.7
15.7.96	63	-24.0	-14.9	-13.8	-12.9	-12.2	-11.8	-9.0	-9.0	-9.9	-9.3	-8.3	-8.5	-7.7
30.7.96	78	-11.6	-13.9	-13.7	-12.9	-12.4	-12.2	-9.3	-9.0	-9.9	-9.5	-8.6	-8.3	-7.7
01.8.96	80	-14.0	-13.6	-13.4	-12.9	-12.4	-12.2	-9.3	-9.0	-9.9	-9.5	-8.3	-8.5	-7.7
02.8.96	81	-16.1	-13.9	-13.4	-12.9	-12.4	-12.0	-9.3	-9.0	-9.9	-9.5	-8.3	-8.5	-7.7
09.8.96	88	-15.0	-14.6	-13.4	-12.9	-12.7	-12.2	-9.5	-9.0	-9.9	-9.5	-8.6	-8.3	-7.7
11.8.96	90	-18.2	-14.6	-13.7	-12.9	-12.2	-12.2	-9.5	-9.3	-9.9	-9.5	-8.3	-8.5	-7.7
16.8.96	95	-22.2	-15.9	-13.9	-12.9	-12.4	-12.2	-9.5	-9.0	-9.7	-9.3	-8.3	-8.3	-7.7
19.8.96	98	-19.3	-16.6	-14.5	-12.7	-12.4	-12.2	-9.3	-8.8	-9.7	-9.3	-8.3	-8.5	-7.7
23.8.96	102	-14.0	-17.4	-15.0	-13.5	-12.7	-12.4	-9.5	-9.0	-9.9	-9.3	-8.3	-8.5	-7.7
26.8.96	105	-19.2	-17.1	-15.6	-13.8	-13.0	-12.4	-9.5	-9.0	-9.7	-9.3	-8.3	-8.5	-7.7
28.8.96	107	-7.1	-15.9	-15.3	-13.8	-13.0	-12.4	-9.5	-9.0	-9.7	-9.3	-8.3	-8.5	-7.7
31.8.96	110	-7.3	-14.6	-15.0	-14.1	-13.0	-12.7	-9.5	-9.0	-9.9	-9.5	-8.3	-8.5	-7.7

Contd.

Table 1—Contd.

Date	Day-unit	Surface	1m	2m	3m	4m	5m	10m	15m	25m	45m	55m	65m	76m
02.9.96	112	-8.4	-13.6	-14.5	-13.8	-13.0	-12.7	-9.5	-9.0	-9.7	-9.3	-8.3	-8.5	-7.7
04.9.96	114	-11.0	-13.6	-14.2	-13.8	-13.2	-12.7	-9.5	-9.0	-9.7	-9.3	-8.3	-8.5	-7.7
11.9.96	121	-11.8	-14.4	-13.7	-13.5	-13.2	-12.7	-9.5	-9.0	-9.9	-9.3	-8.3	-8.5	-7.7
14.9.96	124	-9.4	-14.4	-13.9	-15.2	-13.2	-12.7	-9.7	-9.0	-9.9	-9.3	-8.3	-8.5	-7.7
23.9.96	133	-12.9	-13.4	-13.7	-13.5	-13.2	-12.9	-9.9	-9.3	-10.1	-9.7	-8.6	-8.3	-7.9
27.9.96	137	-10.0	-13.4	-13.4	-13.2	-13.0	-12.7	-9.7	-9.0	-9.9	-9.3	-8.3	-8.5	-7.7
01.10.96	141	-6.3	-13.4	-13.4	-13.2	-13.0	-12.7	-9.7	-9.0	-9.7	-9.5	-8.3	-8.5	-8.2
06.10.96	146	-6.5	-12.9	-12.9	-12.9	-13.0	-12.4	-9.7	-9.0	-9.9	-9.5	-8.3	-8.5	-7.7
07.10.96	147	-11.6	-12.6	-12.9	-12.9	-13.0	-12.4	-9.9	-9.0	-9.9	-9.5	-8.6	-8.5	-7.9
09.10.96	149	-9.8	-12.6	-12.9	-12.9	-13.0	-12.4	-9.7	-9.0	-9.7	-9.5	-8.3	-8.5	-7.7
12.10.96	152	-12.9	-12.6	-12.6	-12.9	-13.0	-12.4	-9.7	-9.0	-9.9	-9.5	-8.3	-8.5	-7.7
19.10.96	159	-8.1	-12.4	-12.3	-12.7	-12.7	-12.4	-9.9	-9.3	-9.9	-9.5	-8.3	-8.3	-7.9
23.10.96	163	-10.8	-12.4	-12.6	-12.7	-12.7	-12.2	-9.9	-9.0	-9.9	-9.5	-8.6	-8.5	-7.7
29.10.96	169	-5.2	-11.6	-12.3	-12.4	-12.4	-12.2	-9.9	-9.0	-9.9	-9.5	-8.6	-8.5	-7.7
4.11.96	175	-4.9	-10.1	-11.4	-12.4	-12.4	-12.2	-9.9	-9.0	-9.9	-9.3	-8.3	-8.5	-7.9
12.11.96	183	-3.1	-9.6	-10.7	-11.8	-12.2	-11.8	-9.9	-8.8	-9.7	-9.3	-8.3	-8.5	-7.7
17.11.96	188	-1.2	-7.8	-9.9	-11.3	-11.9	-11.8	-9.9	-9.0	-9.7	-9.3	-8.1	-8.5	-7.7
20.11.96	191	-3.9	-7.3	-9.3	-11.0	-11.9	-11.3	-9.9	-8.8	-9.7	-9.3	-8.3	-8.5	-7.5
24.11.96	195	-1.2	-6.8	-11.2	-10.7	-11.9	-11.3	-9.9	-9.0	-9.9	-9.3	-8.3	-8.5	-7.7
29.11.96	200	-5.2	-5.8	-8.2	-10.1	-11.1	-13.1	-10.2	-9.0	-10.1	-9.3	-8.3	-8.5	-7.7
02.12.96	203	-4.7	-4.6	-7.4	-9.3	-10.5	-10.2	-9.9	-9.0	-9.2	-9.3	-8.3	-8.5	-7.7

Contd.

Table 1—Contd.

Date	Day-unit	Surface	1m	2m	3m	4m	5m	10m	15m	25m	45m	55m	65m	76m
09.12.96	210	5.7	-3.3	-5.8	-8.4	-10.3	-10.2	-9.7	-9.0	-9.2	-9.3	-8.3	-8.5	-7.7
13.12.96	214	3.0	-3.3	-6.1	-8.4	-10.5	-8.6	-9.7	-9.0	-8.9	-9.3	-8.2	-8.5	-7.2
18.12.96	219	-2.3	-3.3	-5.5	-7.6	-9.4	-9.5	-9.7	-9.0	-9.7	-9.0	-8.1	-8.1	-7.0
25.12.96	226	3.3	-3.1	-4.6	-6.8	-6.4	-9.0	-9.7	-9.0	-9.7	-9.2	-8.3	-8.5	-7.2
30.12.96	231	1.2	-2.1	-3.1	-7.0	-8.0	-8.2	-8.3	-9.0	-9.7	-9.0	-8.3	-8.1	-6.8
06.01.97	238	2.5	-2.6	-4.7	-7.0	-8.8	-8.3	-9.9	-9.3	-9.7	-9.3	-8.3	-8.5	-7.7
10.01.97	242	0.1	-1.1	-3.9	-6.5	-8.3	-6.8	-9.7	-9.0	-9.2	-9.3	-8.3	-7.9	-77
15.01.97	247	0.1	-1.8	-3.4	-6.2	-8.3	-7.9	-8.8	-9.0	-9.4	-9.0	-8.3	-8.5	-7.7
18.01.97	250	2.0	-1.8	-3.1	-5.3	-8.0	-7.7	-9.7	-8.8	-9.7	-9.3	-8.1	-8.5	-7.5
23.01.97	255	3.0	-1.6	-3.4	-5.6	-8.0	-7.2	-9.7	-9.0	-9.7	-9.3	-8.1	-8.5	-7.7
28.01.97	260	-2.8	-1.3	-3.1	-3.6	-7.8	-7.4	-9.5	-9.3	-9.7	-9.5	**-8.3**	-8.3	-7.9
04.02.97	267	1.2	-1.3	-2.5	-4.2	-6.7	-7.0	-9.7	-8.8	-8.5	-9.3	-7.7	-8.5	-7.5
06.02.97	269	2.8	-0.8	-2.3	-4.0	-6.1	-6.8	-9.5	-9.0	-9.4	-9.3	-7.9	-7.4	-7.1

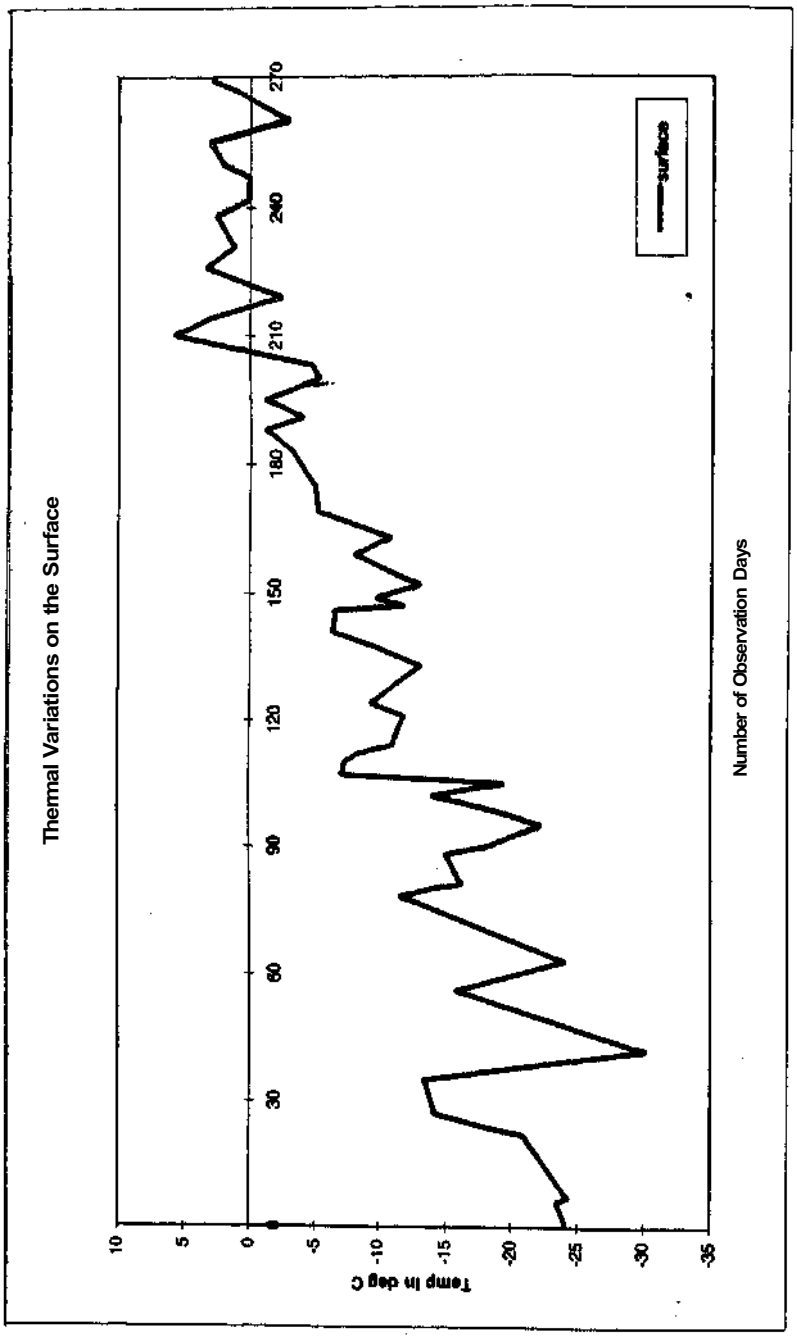

Fig. 2 : The annual thermal profile on the surface of the glacier

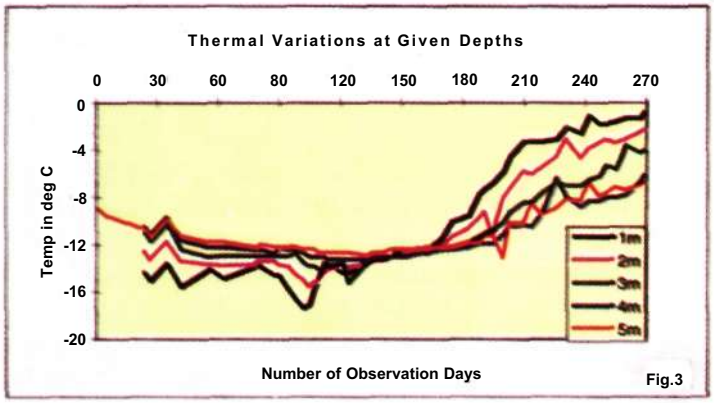

Fig.3

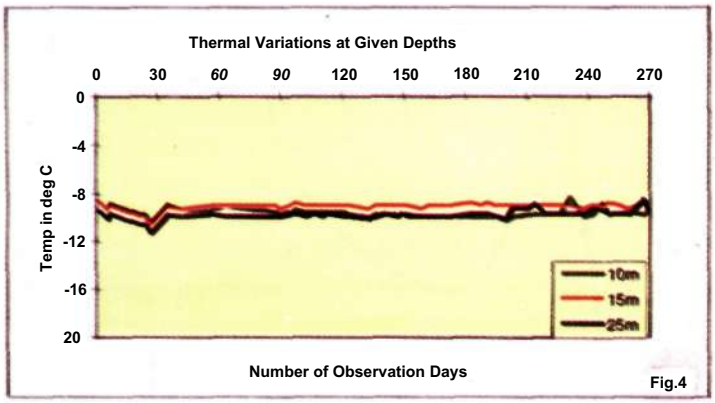

Fig.4

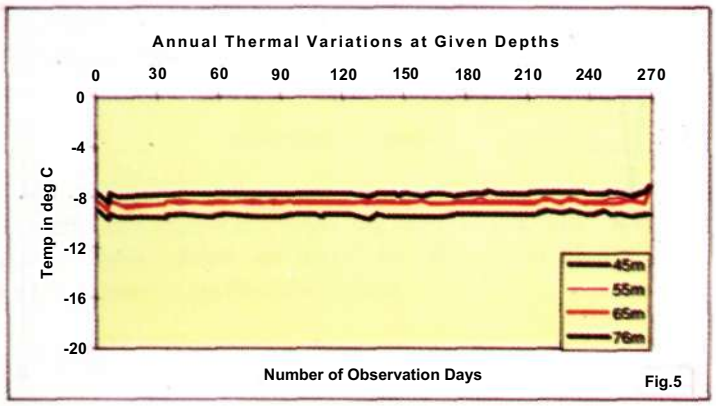

Fig.5

Fig.3-5 **: *The annual profiles of shallow depth, middle depth and deeper thermistors.***

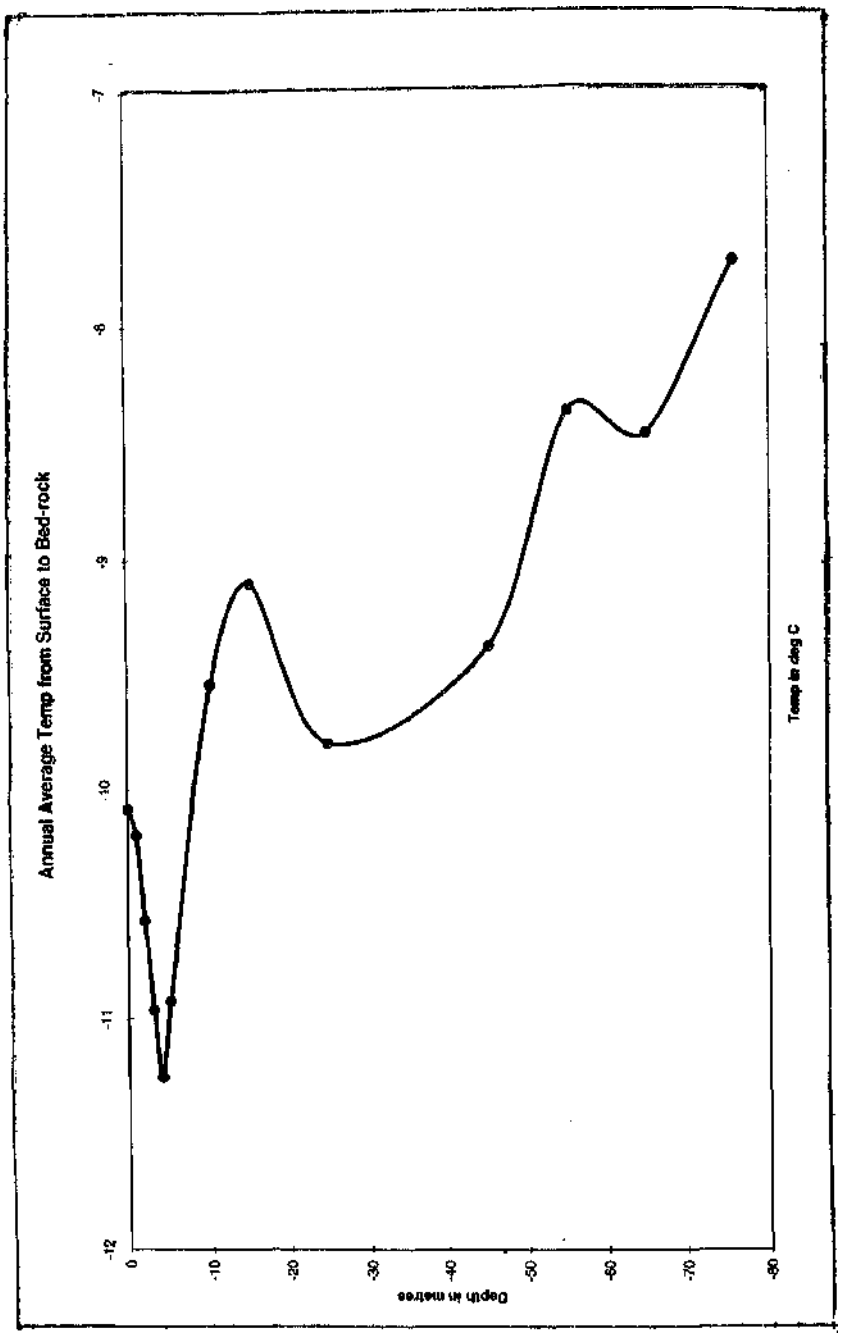

Fig.6: The overall average annual profile of the entire column.

4. It is clear from Fig.5 that the deeper levels, ie 45 m to 76 m, are not affected at all by the surface temperature. These depths displayed steady values throughout the year. A significant observation is that these depths were warmer, compared to the middle level depths; so a temperature inversion has taken place.
5. The overall average thermal variations (Fig.6) in the borehole from surface to bedrock, were confined to a small thermal band of -7.5°C to -11.5°C. Within this zone, the coldest average temperature was -11.3° C and it was recorded at 4 m depth, while the warmest temperature was -7.7°C and it was displayed at the bottom, at 76 m depth. The zone of temperature-inversion was observed between 25 m to 30 m depth. After this zone, the temperature gradually kept on rising, till the bedrock. The bottom of the glacier was the warmest, a clear manifestation of the geothermal effect, even below the column of 76 m of ice.
6. It is well-known that the temperature at the 10 m depth very closely represents the average annual temperature on the surface, for that site (Thomas 1976; Mortin & Peel 1978). In this case, the 10 m temperature was -9.5°C, which would be the annual average temperature for this place. The recordings of the surface temperature, though not very reliable due to many gaps, give an annual average of -10.1°C for this site; which closely match the 10 m temperature.
7. It is interesting to compare this temperature with the annual average temperature at Maitri station also, for the same year. Rasal and Manor of IMD, in this publication, have calculated -8.4°C as the annual mean temperature for Maitri in 1996. Since the site of the borehole is 200 m higher in altitude than Maitri, its being colder by 1.1 °C of annual average temperature is quite likely. Thus, the indirect observations for the depth of 10 m are confirmed by this additional analogy.

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