

ANNUAL CYCLE OF PERMAFROST MIGRATION IN SCHIRMACHER OASIS

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Abstract

The soil in Schirmacher Oasis is poorly formed and is mostly a remnant of glacial moraines. In this soil, a pit — about a metre deep — was dug and it touched the bedrock. Five thermistors were placed in it, at 20 cm intervals. From March '96 to January '98, thermal data were recorded on a daily basis, barring highly windy days. In these two annual polar cycles, 358 sets of data have been collected. The dates of the onset of summer thawing and the migration of permafrost levels have been worked out; which could be useful in planning for buildings and foundations. The thawing dates for deeper levels appear to be consistent, irrespective of surface warming dates.

Introduction

Muller (1947) has defined permafrost as "a thickness of soil or other superficial deposit, or even of bedrock, at a variable depth, in which a temperature below freezing has existed continually for a long time." The properties of permafrost vary considerably, depending on local climatic, morphological and hydrogeological conditions. The temperature in the upper layers of permafrost crosses the freezing point, due to the influence of seasonal variations. The depth and the dates of these migrations are important for planning any foundation work. Schirmacher Oasis is a rocky hill range of about 35 sq. km area, surrounded by glaciers and polar ice sheet. The glaciers have retreated, leaving behind a thin and sporadic cover of soil on an undulating terrain. The site of the present study is about 50 m north of Indian Antarctic Station, Maitri (70°45'39" S latitude and 11°44'4" E longitude) in Schirmacher Oasis. It has a cover of morainial soil of about 1 m thickness over the bedrock. The prevalent winds from SE are quite persistent and do not allow the formation of any snow cover over the exposed study area.

Equipment and Methodology

In March 1996, a small pit was dug in the permafrost, till the bedrock was encountered at a depth of about a metre. Five calibrated thermistors (PT-100) were installed in the pit, at regular intervals of 20 cm from the surface. The range of the thermistors was -40°C to $+20^{\circ}\text{C}$ and the accuracy was $\pm 0.1^{\circ}\text{C}$. The pit was filled up with the scooped out material to replace the original medium. A sixth thermistor was calibrated to record the ground surface temperature. Since the diurnal variations do not affect the sensors at a depth of one metre (Chaturvedi and Asthana, 1996), observations were taken once-a-day in the afternoon, on a daily basis, except on days the Antarctic blizzards precluded a visit to the site.

Observations

During the 15th and 16th Indian Antarctic Expeditions, observations covering a total span of 691 days, from 11th March 1996 to 30th January 1998, have been used in the present study. The study period spreads across two polar winters. The constraints of Antarctic weather permitted 358 days' observations during this time. On each observation day, thermal data from 6 thermistors were recorded; However, late in August 1997, the bottom-most thermistor (at 100 cm depth) developed some mechanical fault and the data from this thermistor could not be recorded thereafter. The day-to-day observations have been presented in **Table-1**. The temperatures of two polar cycles have been compared for their amplitudes in **Table-2** and the dates of thawing have been presented in **Table-3**.

Discussion and Conclusions

1. From **Table-2** and **Fig.1**, the comparison of minimum and maximum temperatures of the two polar cycles shows that the amplitude of variation was much more in year 1996-97 than 1997-98, both for colder as well as warmer limits. However, as the depth increases, the differences in the two cycles taper out and at 100 cm depth, both the cycles show a uniform- 16°C .
2. The annual average temperature also goes down with depth, but the mean values for the depths of 40, 60 and 80 cm are almost a uniform -7.3°C . The 100 cm depth is slightly colder with a mean value of -7.5°C , while the 20 cm depth is warmer with a mean of -6.7°C .
3. It is seen that the annual average temperature for the ground surface is -5.7°C . Rasal and Mahor of IMD, in this publication, have announced an annual mean temperature of -8.4°C for Maitri station.

Table 1 : Thermal Data for Soil Sensors

Date	Seq-day	Surf	S-1	S-2	S-3	S-4	S-5
11-Mar-96	1	-7.3	-4.4	-3.8	-2.9	-2.2	-2.1
12-Mar-96	2	-5.5	-5.8	-4.2	-3.2	-2.5	-2.6
14-Mar-96	4	-5.2	-4.9	-4.5	-3.9	-3.2	-3.1
15-Mar-96	5	-5.7	-6.3	-5.2	-4.2	-3.5	-3.3
16-Mar-96	6	-8.6	-7.1	-5.9	-4.7	-3.7	-3.6
17-Mar-96	7	-14.1	-9.7	-6.2	-4.9	-3.9	-3.8
18-Mar-96	8	-5.9	-9.2	-6.7	-5.4	-4.4	-4.3
19-Mar-96	9	-9.7	-9.7	-6.7	-5.7	-4.7	-4.3
20-Mar-96	10	-8.7	-10.2	-6.9	-5.9	-4.9	-4.5
21-Mar-96	11	-4.9	-8.1	-6.9	-6.2	-5.2	-5.1
22-Mar-96	12	-8.1	-8.2	-6.7	-6.2	-5.2	-5.1
23-Mar-96	13	-3.1	-6.8	-6.2	-5.9	-5.2	-5.1
25-Mar-96	15	-6.3	-6.6	-5.7	-5.7	-5.4	-5.3
26-Mar-96	16	-7.3	-7.8	-6.2	-5.7	-5.4	-5.3
28-Mar-96	18	-7.1	-7.8	-6.2	-5.9	-5.7	-5.6
29-Mar-96	19	-9.7	-10.2	-6.9	-6.2	-5.7	-5.6
30-Mar-96	20	-5.2	-9.5	-7.2	-6.4	-5.7	-5.6
02-Apr-96	23	-7.1	-7.5	-6.4	-8.6	-5.9	-5.8
03-Apr-96	24	-10.8	-10.2	-7.2	-6.4	-5.9	-5.8
04-Apr-96	25	-4.9	-8.3	-7.7	-7.1	-6.2	-6.1
05-Apr-96	26	-4.4	-7.3	-7.2	-6.9	-6.4	-6.3
07-Apr-96	28	-2.0	-5.8	-6.2	-6.4	-5.9	-6.1
08-Apr-96	29	-8.4	-8.3	-6.4	-6.2	-5.9	-5.8
09-Apr-96	30	-11.8	-11.7	-7.7	-6.9	-6.2	-6.1
10-Apr-96	31	-1.74	-13.8	-9.4	-7.6	-6.7	-6.3
12-Apr-96	33	-8.9	-11.4	-9.6	-8.6	-7.6	-7.3
13-Apr-96	34	-9.2	-9.7	-9.1	-8.6	-7.6	-7.3
14-Apr-96	35	-9.4	-10.7	-9.1	-8.6	-7.6	-7.6
16-Apr-96	37	-5.5	-8.3	-8.6	-8.4	-7.6	-7.6
17-Apr-96	38	-8.1	-8.3	-8.1	-8.1	-7.6	-7.7
20-Apr-96	41	-10.0	-9.2	-7.9	-7.6	-7.4	-7.3
21-Apr-96	42	-4.4	-9.7	-8.9	-8.1	-7.4	-7.3
22-Apr-96	43	-7.6	-8.0	-8.1	-8.1	-7.6	-7.3
23-Apr-96	44	-10.5	-10.2	-8.6	-8.1	-7.6	-7.6
24-Apr-96	45	-11.6	-11.2	-9.1	-8.4	-7.6	-7.6
25-Apr-96	46	-14.0	-12.4	-9.8	-8.9	-7.9	-7.6
26-Apr-96	47	-8.9	-15.8	-10.8	-9.4	-8.4	-7.8

Contd.

Table 1: Contd.

Date	Seq-day	Surf	S-1	S-2	S-3	S-4	S-5
27-Apr-96	48	-20.6	-16.8	-12.3	-10.3	-8.9	-8.3
28-Apr-96	49	-21.1	-16.8	-13.0	-11.1	-9.6	-9.1
29-Apr-96	50	-20.6	-18.5	-14.0	-12.1	-10.1	-9.3
30-Apr-96	51	-20.9	-18.2	-14.2	-12.6	-10.6	-9.8
06-May-96	57	-19.0	-13.6	-12.1	-11.8	-10.8	-10.3
07-May-96	58	-17.1	-16.8	-13.3	-12.1	-10.8	-10.3
09-May-96	60	-20.3	-16.3	-14.2	-13.3	-11.6	-11.3
11-May-96	62	-21.6	-18.2	-14.2	-12.8	-11.8	-11.3
17-May-96	68	-12.6	-13.8	-13.8	-13.8	-12.8	-12.5
18-May-96	69	-18.2	-13.6	-13.3	-13.1	-12.6	-12.5
19-May-96	70	-22.7	-15.3	-13.8	-13.3	-12.6	-12.5
20-May-96	71	-23.5	-16.5	-14.5	-13.6	-12.6	-12.5
21-May-96	72	-18.7	-16.5	-15.0	-14.0	-13.1	-12.5
22-May-96	73	-19.5	-16.3	-15.0	-14.0	-13.1	-12.8
23-May-96	74	-24.0	-17.2	-15.2	-14.3	-13.3	-12.5
24-May-96	75	-22.7	-18.0	-15.7	-14.8	-13.6	-13.0
29-May-96	80	-16.0	-13.1	-13.8	-14.0	-13.6	-12.8
30-May-96	81	-15.3	-15.5	-14.0	-13.6	-12.8	-12.8
03-Jun-96	85	-18.2	-15.1	-14.0	-13.6	-13.1	-13.0
09-Jun-96	91	-10.5	-13.6	-14.0	-13.6	-13.3	-13.0
17-Jun-96	99	-13.4	-13.4	-12.3	-11.8	-11.6	-11.8
18-Jun-96	100	-16.6	-16.8	-13.0	-12.3	-11.8	-11.8
21-Jun-96	103	-23.0	-21.4	-16.9	-15.0	-13.3	-13.0
22-Jun-96	104	-21.9	-20.6	-17.4	-17.7	-14.0	-13.5
23-Jun-96	105	-23.2	-20.2	-17.6	-16.0	-14.5	-13.8
24-Jun-96	106	-29.3	-23.1	-18.4	-16.5	-15.0	-14.3
04-Jul-96	116	-10.2	-12.1	-12.0	-12.3	-12.3	-12.5
07-Jul-96	119	-8.9	-10.9	-11.3	-11.8	-11.8	-12.0
08-Jul-96	120	-11.3	-11.4	-11.3	-11.8	-11.6	-12.0
13-Jul-96	125	-12.9	-14.1	-13.8	-13.6	-12.8	-12.8
16-Jul-96	128	-18.2	-18.2	-15.9	-14.5	-13.3	-13.3
26-Jul-96	138	-10.5	-12.3	-12.0	-12.1	-11.8	-12.0
28-Jul-96	140	-10.2	-13.1	-12.0	-12.3	-11.8	-12.0
30-Jul-96	142	-9.2	-11.4	-11.6	-11.8	-11.8	-12.0
01-Aug-96	144	-10.5	-13.1	-12.0	-12.3	-11.8	-11.8
02-Aug-96	145	-13.7	-13.8	-13.0	-12.6	-12.1	-12.0
03-Aug-96	146	-12.1	-15.5	-13.8	-13.1	-12.3	-12.0

Contd.

Table 1: Contd.

Date	Seq-day	Surf	S-1	S-2	S-3	S-4	S-5
06-Aug-96	149	-12.9	-12.4	-12.3	-12.3	-12.1	-12.3
08-Aug-96	151	-12.9	-14.1	-13.8	-13.3	-12.6	-12.3
10-Aug-96	153	-11.6	-13.6	-13.8	-13.6	-12.8	-12.8
12-Aug-96	155	-19.8	-17.2	-14.5	-13.6	-12.8	-12.5
13-Aug-96	156	-22.2	-19.7	-15.7	-14.3	-13.3	-12.8
14-Aug-96	157	-18.5	-19.2	-16.4	-15.3	-13.8	-13.5
15-Aug-96	158	-20.1	-19.2	-16.9	-15.5	-14.0	-13.8
16-Aug-96	159	-25.9	-21.1	-17.4	-16.0	-14.5	-14.0
17-Aug-96	160	-14.5	-21.6	-18.6	-16.5	-14.8	-14.3
18-Aug-96	161	-15.5	-18.5	-17.7	-16.5	-15.0	-14.8
19-Aug-96	162	-16.3	-17.2	-16.7	-16.3	-15.0	-14.8
20-Aug-96	163	-29.1	-18.2	-17.4	-16.3	-15.0	-14.8
21-Aug-96	164	-23.0	-23.1	-18.6	-16.8	-15.3	-14.8
22-Aug-96	165	-25.6	-23.8	-19.1	-17.5	-15.8	-15.3
23-Aug-96	166	-19.5	-24.0	-20.1	-18.2	-16.3	-15.5
24-Aug-96	167	-4.4	-14.8	-18.1	-18.0	-16.5	-16.0
25-Aug-96	168	-2.5	-10.4	-14.7	-16.0	-15.8	-15.5
26-Aug-96	169	-6.5	-10.0	-12.8	-14.3	-14.5	-14.8
31-Aug-96	174	-3.3	-8.3	-10.1	-11.3	-11.8	-12.5
01-Sep-96	175	-5.5	-9.2	-10.1	-11.1	-11.8	-12.3
02-Sep-96	176	-5.5	-9.5	-10.3	-11.1	-11.6	-12.0
03-Sep-96	177	-6.5	-9.2	-10.6	-11.1	-11.6	-11.8
04-Sep-96	178	-7.6	-9.7	-10.6	-11.1	-11.3	-11.8
05-Sep-96	179	-8.4	-9.2	-11.1	-11.3	-11.3	-12.0
10-Sep-96	184	-8.4	-13.4	-13.3	-13.1	-12.6	-12.3
11-Sep-96	185	-7.6	-13.8	-12.8	-12.8	-12.3	-12.3
15-Sep-96	189	-4.9	-9.7	-10.8	-11.3	-11.6	-12.0
16-Sep-96	190	-8.6	-10.4	-10.8	-11.3	-11.3	-11.8
20-Sep-96	194	-3.3	-9.0	-10.1	-11.1	-11.1	-11.5
22-Sep-96	196	-7.3	-9.2	-10.1	-10.3	-10.8	-11.0
24-Sep-96	198	-13.4	-13.6	-11.6	-11.1	-10.8	-11.0
25-Sep-96	199	-10.8	-13.4	-12.0	-11.8	-11.3	-11.3
26-Sep-96	200	-12.1	-14.8	-12.8	-12.1	-11.6	-11.5
27-Sep-96	201	-7.6	-12.6	-12.5	-12.3	-11.8	-11.8
30-Sep-96	204	-7.6	-9.0	-10.3	-11.3	-11.1	-11.5
01-Oct-96	205	-3.4	-8.3	-10.1	-10.8	-11.1	-11.3
05-Oct-96	209	-3.3	-8.7	-9.8	-10.6	-10.3	-10.8

Contd.

Table 1: Contd.

Date	Seq-day	Surf	S-1	S-2	S-3	S-4	S-5
08-Oct-96	212	-9.7	-9.0	-9.8	-10.1	-10.1	-10.5
09-Oct-96	213	-6.3	-10.0	-10.1	-10.3	-10.3	-10.5
10-Oct-96	214	-6.0	-10.0	-10.1	-10.3	-10.3	-10.5
11-Oct-96	215	-5.2	-8.5	-9.8	-10.3	-10.1	-10.5
12-Oct-96	216	-8.1	-9.2	-9.6	-10.1	-10.1	-10.3
13-Oct-96	217	-7.9	-10.0	-10.1	-10.1	-9.9	-10.3
14-Oct-96	218	-12.2	-9.2	-9.8	-10.1	-10.3	-10.3
16-Oct-96	220	-6.8	-8.5	-10.1	-10.1	-10.1	-10.3
17-Oct-96	221	-6.8	-9.2	-9.6	-10.1	-10.1	-10.3
18-Oct-96	222	-2.0	-7.5	-9.4	-10.1	-10.1	-10.3
19-Oct-96	223	-4.9	-6.3	-9.4	-9.9	-9.9	-10.3
20-Oct-96	224	-10.3	-5.6	-8.9	-9.4	-9.9	-10.1
21-Oct-96	225	-8.1	-9.0	-9.1	-9.4	-9.6	-10.1
22-Oct-96	226	-9.7	-9.2	-9.4	-9.6	-9.6	-10.1
23-Oct-96	227	-6.7	-8.0	-9.6	-9.9	-9.9	-10.1
24-Oct-96	228	-12.2	-6.6	-9.1	-9.6	-9.9	-10.1
27-Oct-96	231	-0.2	-7.0	-9.1	-9.9	-9.9	-10.1
28-Oct-96	232	0.6	-4.9	-9.6	-9.1	-9.6	-9.8
29-Oct-96	233	0.9	-2.7	-7.4	-8.6	-9.1	-9.6
30-Oct-96	234	4.9	-3.4	-6.4	-7.9	-8.6	-9.3
31-Oct-96	235	1.2	-2.2	-6.2	-7.4	-8.1	-9.1
01-Nov-96	236	0.9	-2.2	-5.9	-6.9	-7.9	-8.6
02-Nov-96	237	2.2	-1.5	-5.5	-6.9	-7.6	-8.3
03-Nov-96	238	-1.0	-2.4	-5.5	-6.7	-7.4	-8.1
04-Nov-96	239	-4.7	-3.9	-5.7	-6.4	-7.1	-7.8
05-Nov-96	240	-4.4	-4.9	-6.2	-6.7	-7.1	-7.8
06-Nov-96	241	-4.1	-4.1	-6.4	-6.7	-7.1	-7.6
07-Nov-96	242	-0.4	-3.7	-5.9	-6.7	-7.1	-7.8
08-Nov-96	243	-5.2	-3.9	-5.7	-6.4	-6.9	-7.6
09-Nov-96	244	-2.5	-5.4	-6.2	-6.7	-6.9	-7.6
10-Nov-96	245	-1.0	-3.9	-5.9	-6.7	-7.1	-7.6
12-Nov-96	247	-0.2	-4.4	-5.7	-6.4	-6.9	-7.3
13-Nov-96	248	6.5	-3.7	-5.7	-6.4	-6.7	-7.3
14-Nov-96	249	-1.2	-1.0	-4.5	-5.9	-6.7	-7.3
15-Nov-96	250	0.6	-2.4	-4.5	-5.4	-6.4	-7.1
16-Nov-96	251	3.3	1.0	-4.2	-5.4	-6.2	-6.6
17-Nov-96	252	2.5	0.2	-3.5	-4.9	-5.7	-6.6

Contd..

Table 1: Contd.

Date	Seq-day	Surf	S-1	S-2	S-3	S-4	S-5
18-Nov-96	253	2.8	0.0	-2.8	-4.2	-5.4	-6.3
19-Nov-96	254	3.3	-1.5	-3.3	-4.4	-5.2	-6.1
20-Nov-96	255	2.5	0.7	-3.5	-4.2	-4.9	-5.8
21-Nov-96	256	-0.7	-2.2	-3.3	-4.2	-4.9	-5.8
22-Nov-96	257	2.8	0.0	-3.5	-4.4	-4.9	-5.8
23-Nov-96	258	3.6	0.5	-3.0	-4.2	-4.9	-5.8
24-Nov-96	259	4.4	1.7	-2.8	-4.4	-4.7	-5.6
25-Nov-96	260	1.7	1.0	-2.3	-3.5	-4.4	-5.6
26-Nov-96	261	4.1	1.7	-2.5	-3.7	-4.2	-5.3
27-Nov-96	262	4.6	2.7	-2.0	-3.5	-4.2	-5.1
28-Nov-96	263	4.9	2.7	-2.0	-3.2	-4.2	-5.1
29-Nov-96	264	1.7	3.1	-1.6	-3.0	-4.0	-4.8
30-Nov-96	265	3.0	2.9	-1.1	-2.5	-3.5	-4.6
01-Dec-96	266	7.3	3.4	-1.0	-2.2	-3.2	-4.1
02-Dec-96	267	3.3	3.1	-1.0	-2.2	-3.5	-4.1
03-Dec-96	268	2.8	2.7	-1.0	-2.2	-3.2	-4.1
04-Dec-96	269	0.4	1.2	-1.0	-2.2	-2.7	-4.1
05-Dec-96	270	2.5	1.0	-1.3	-2.2	-3.0	-3.8
06-Dec-96	271	4.1	3.4	-1.0	-2.5	-3.2	-3.8
07-Dec-96	272	3.3	5.3	0.1	-1.7	-3.0	-3.8
08-Dec-96	273	7.0	9.5	1.9	-1.7	-2.5	-3.6
09-Dec-96	274	8.1	6.5	0.8	-1.7	-2.7	-3.6
10-Dec-96	275	5.7	7.5	2.4	-1.5	-2.2	-3.4
11-Dec-96	276	4.6	2.7	0.6	-1.0	-2.2	-2.9
12-Dec-96	277	9.7	4.8	0.2	-1.2	-2.2	-2.9
13-Dec-96	278	2.0	5.6	0.4	-1.0	-2.0	-3.1
14-Dec-96	279	4.1	4.8	0.6	0.0	-1.2	-2.9
15-Dec-96	280	2.0	3.4	0.2	-1.0	-1.5	-2.9
16-Dec-96	281	4.1	0.2	0.8	-0.5	-1.7	-2.9
17-Dec-96	282	7.3	3.6	-0.3	-1.0	-1.7	-2.9
18-Dec-96	283	5.1	4.1	-0.1	-1.0	-1.7	-2.6
19-Dec-96	284	2.5	2.2	0.2	-0.3	-1.2	-2.4
20-Dec-96	285	13.1	6.5	0.2	-1.0	-1.7	-2.6
21-Dec-96	286	7.8	7.3	0.9	-0.5	-0.1	-2.4
22-Dec-96	287	8.9	7.5	0.9	0.0	-1.5	-1.9
23-Dec-96	288	10.5	7.5	1.6	-0.3	-1.2	-2.1
24-Dec-96	289	9.1	7.0	1.9	0.5	-1.0	-2.1

Contd.

Table 1: Contd.

Date	Seq-day	Surf	S-1	S-2	S-3	S-4	S-5
25-Dec-96	290	6.5	4.8	1.9	0.2	-1.0	-2.1
26-Dec-96	291	10.2	7.3	1.9	0.5	0.7	-1.9
27-Dec-96	292	9.9	7.5	2.4	0.5	-0.7	-1.6
28-Dec-96	293	8.3	6.3	2.6	0.7	-0.7	-1.6
29-Dec-96	294	7.5	4.6	2.6	0.7	0.2	-1.4
30-Dec-96	295	5.4	0.2	0.4	0.0	-0.7	-1.4
31-Dec-96	296	6.2	2.2	0.2	-0.3	-0.7	-1.6
01-Jan-97	297	12.6	7.5	1.4	-0.3	-0.7	-1.4
02-Jan-97	298	7.5	8.0	3.8	-0.3	-0.5	-0.9
03-Jan-97	299	8.6	8.0	2.4	0.7	-0.2	-1.4
04-Jan-97	300	8.9	8.2	3.6	1.2	-0.2	-1.4
05-Jan-97	301	8.1	8.5	3.1	1.2	0.0	-1.1
06-Jan-97	302	8.1	9.7	3.3	2.0	0.5	-1.0
07-Jan-97	303	4.4	6.5	3.3	2.0	0.2	-1.0
08-Jan-97	304	8.9	7.5	3.6	1.5	0.2	-1.0
10-Jan-97	306	9.4	7.3	2.6	1.7	0.5	-0.1
12-Jan-97	308	8.1	7.0	3.6	1.5	0.5	-0.4
13-Jan-97	309	7.8	4.4	2.1	1.2	0.2	-0.6
14-Jan-97	310	13.4	9.0	2.1	1.2	0.2	-0.6
15-Jan-97	311	12.1	6.1	3.8	2.7	2.5	2.0
17-Jan-97	313	16.3	6.1	3.1	2.0	0.5	-0.4
18-Jan-97	314	7.5	7.5	4.3	1.7	1.7	0.4
19-Jan-97	315	9.4	6.8	2.6	1.5	0.7	-0.1
20-Jan-97	316	9.4	6.3	2.4	1.7	1.2	-0.4
22-Jan-97	318	16.0	7.8	2.8	1.2	0.5	-0.4
23-Jan-97	319	10.7	6.8	2.8	0.5	0.5	-0.4
24-Jan-97	320	7.3	7.0	3.6	2.5	1.5	-0.4
25-Jan-97	321	5.4	9.0	3.1	2.0	0.7	0.6
26-Jan-97	322	3.3	4.1	2.1	1.7	0.5	-0.1
27-Jan-97	323	7.0	3.9	1.6	0.7	0.2	0.9
28-Jan-97	324	6.5	3.4	1.4	1.2	0.5	0.1
29-Jan-97	325	3.3	3.9	1.1	0.7	0.2	0.6
30-Jan-97	326	3.0	2.9	1.6	1.0	0.5	-0.4
01-Feb-97	328	3.0	3.9	1.1	0.5	0.2	-0.1
02-Feb-97	329	10.2	3.1	2.6	1.3	0.5	-0.1
03-Feb-97	330	4.9	3.6	1.6	1.0	0.7	-0.4
04-Feb-97	331	4.6	2.7	1.4	1.2	0.7	-0.1

Contd.

Table 1: Contd.

Date	Seq-day	Surf	S-1	S-2	S-3	S-4	S-5
05-Feb-97	332	6.8	4.4	1.4	1.0	0.5	-0.1
06-Feb-97	333	7.5	3.1	2.4	0.7	0.2	-0.6
07-Feb-97	334	5.4	5.1	1.9	1.5	1.7	1.9
09-Feb-97	336	8.1	4.1	0	0.7	0.2	-0.4
10-Feb-97	337	9.9	3.6	3.6	0.7	0.5	1.4
14-Feb-97	341	-0.7	2.7	0.2	-0.5	0.0	-0.9
15-Feb-97	342	2.0	2.4	-0.3	-0.3	-0.3	-0.6
16-Feb-97	343	-1.8	0.7	-0.3	-0.3	-0.3	-0.9
18-Feb-97	345	-2.3	1.0	-0.3	-0.5	-0.5	-0.9
22-Feb-97	349	-0.4	1.9	0.2	0.3	0.0	-0.4
25-Feb-97	352	-1.2	-0.5	-0.8	-0.5	0.0	-0.9
01-Mar-97	356	-1.5	-2.7	-1.1	-0.5	-0.7	-1.1
03-Mar-97	358	-1.0	-3.7	-1.3	-1.0	-0.7	-1.4
05-Mar-97	360	-2.5	-3.9	-1.8	-1.2	-1.0	-1.4
07-Mar-97	362	-3.1	-2.4	-2.3	-1.7	-1.5	-1.6
09-Mar-97	364	-1.0	-3.7	-1.3	-1.0	-0.7	-2.1
12-Mar-97	367	-3.9	-2.4	-3.0	-2.5	-2.0	-2.1
14-Mar-97	369	-3.9	-3.9	-3.5	-3.0	-2.7	-2.6
17-Mar-97	372	-7.1	-6.8	-4.2	-3.2	-3.2	-3.1
19-Mar-97	374	-6.5	-7.8	-5.9	-4.7	-3.9	-3.6
21-Mar-97	376	-6.5	-6.3	-5.7	-5.2	-3.2	-4.1
23-Mar-97	378	1.4	-4.1	-3.7	-3.7	-2.5	-3.4
25-Mar-97	380	-5.2	-7.5	-5.7	-4.9	-4.2	-4.6
27-Mar-97	382	-6.8	-7.0	-5.9	-5.2	-4.4	-4.6
29-Mar-97	384	-7.6	-10.0	-7.7	-6.7	-5.7	-5.3
31-Mar-97	386	-7.3	-9.5	-7.9	-7.4	-6.2	-5.3
02-Apr-97	388	-5.2	-8.7	-7.9	-7.1	-6.4	-6.1
04-Apr-97	390	-5.7	-7.0	-7.2	-6.9	-6.2	-6.1
07-Apr-97	393	-5.2	-7.8	-7.2	-6.7	-6.2	-6.1
09-Apr-97	395	-11.8	-10.9	-7.7	-7.1	-6.4	-6.3
13-Apr-97	399	-8.9	-9.0	-7.9	-7.6	-6.9	-6.8
15-Apr-97	401	-12.4	-11.2	-8.4	-7.9	-6.9	-6.8
17-Apr-97	403	-12.6	-11.9	-9.8	-6.7	-7.9	-7.6
21-Apr-97	407	-4.9	-5.8	-6.9	-7.4	-7.1	-7.3
24-Apr-97	410	-5.5	-5.8	-6.7	-6.9	-6.7	-6.8
27-Apr-97	413	-7.9	-7.5	-6.9	-6.9	-6.7	-6.8
30-Apr-97	416	-9.4	-9.2	-7.4	-7.1	-6.7	-6.8

Contd.

Table 1: Contd.

Date	Seq-day	Surf	S-1	S-2	S-3	S-4	S-5
05-May-97	421	-10.0	-9.7	-8.9	-8.6	-7.6	-7.3
07-May-97	423	-14.8	-14.1	-11.1	-9.4	-8.1	-7.8
10-May-97	426	-17.9	-16.8	-12.0	-10.6	-9.1	-8.8
13-May-97	429	-15.5	-14.8	-13.0	-12.1	-10.3	-10.1
17-May-97	433	-8.4	-9.7	-11.1	-11.1	-10.3	-10.3
19-May-97	435	-8.9	-9.0	-9.6	-9.9	-9.6	-9.3
21-May-97	437	-8.6	-9.2	-9.4	-9.6	-9.1	-9.3
23-May-97	439	-11.8	-11.4	-10.1	-9.6	-8.9	-9.1
27-May-97	443	-9.2	-10.0	-10.6	-10.8	-10.1	-9.8
29-May-97	445	-15.5	-14.6	-12.0	-10.3	-9.9	-9.8
31-May-97	447	-15.3	-14.6	-12.8	-12.3	-11.1	-10.5
03-Jun-97	450	-13.7	-13.4	-12.3	-11.8	-11.1	-10.5
06-Jun-97	453	-8.4	-9.7	-11.3	-11.3	-10.8	-10.5
09-Jun-97	456	-14.2	-13.1	-11.1	-8.9	-8.6	-8.3
12-Jun-97	459	-20.6	-18.5	-14.2	-12.6	-11.1	-10.5
16-Jun-97	463	-11.3	-11.2	-11.1	-11.3	-10.8	-11.0
20-Jun-97	467	-7.1	-8.7	-8.4	-9.4	-9.6	-9.8
23-Jun-97	470	-9.4	-10.4	-10.6	-9.6	-9.6	-10.1
26-Jun-97	473	-11.8	-11.9	-10.8	-10.6	-9.9	-9.8
27-Jun-97	474	-14.5	-13.6	-12.3	-8.9	-7.9	-8.1
29-Jun-97	476	-16.9	-16.0	-12.5	-12.1	-10.8	-10.5
01-Jul-97	478	-14.2	-16.0	-12.5	-12.1	-10.8	-10.5
03-Jul-97	480	-15.5	-15.1	-13.3	-12.3	-11.3	-11.0
05-Jul-97	482	-19.0	-17.2	-15.0	-13.8	-12.6	-12.3
07-Jul-97	484	-17.4	-16.8	-14.7	-13.8	-12.8	-12.3
09-Jul-97	486	-22.4	-20.4	-16.2	-14.3	-13.1	-12.3
13-Jul-97	490	-19.3	-18.7	-15.9	-15.3	-14.0	-14.0
15-Jul-97	492	-20.9	-20.4	-16.9	-14.0	-13.6	-13.8
19-Jul-97	496	-18.7	-18.2	-17.9	-17.0	-15.8	-13.8
21-Jul-97	498	-20.6	-19.4	-17.7	-16.5	-15.3	-15.0
25-Jul-97	502	-19.0	-11.2	-18.1	-17.2	-16.3	-15.8
27-Jul-97	504	-13.2	-14.1	-15.7	-15.8	-15.5	-15.3
30-Jul-97	507	-12.9	-13.8	-13.5	-14.5	-13.8	-14.0
01-Aug-97	509	-16.9	-16.8	-14.5	-14.3	-13.8	-14.0
03-Aug-97	511	-18.7	-18.0	-15.0	-14.8	-14.3	-14.0
06-Aug-97	514	-15.0	-15.1	-15.7	-15.8	-15.0	-14.3
08-Aug-97	516	-18.5	-18.2	-15.7	-14.8	-14.5	-14.5

Contd.

Table 1: Contd.

Date	Seq-day	Surf	S-1	S-2	S-3	S-4	S-5
10-Aug-97	518	-10.2	-12.1	-14.5	-15.0	-14.8	-14.8
13-Aug-97	521	-12.9	-14.1	-14.7	-14.3	-13.8	-13.3
16-Aug-97	524	-15.3	-15.8	-14.7	-13.8	-13.3	-12.8
20-Aug-97	528	-9.7	-10.9	-12.5	-13.3	-13.3	-13.5
23-Aug-97	531	-17.1	-15.1	-14.0	-13.6	-13.6	-13.5
25-Aug-97	533	-17.1	-16.5	-15.2	-14.3	-13.6	-13.8
27-Aug-97	535	-16.3	-16.0	-15.7	-15.3	-14.3	
29-Aug-97	537	-17.7	-16.8	-15.7	-15.5	-14.5	
01-Sep-97	540	-20.1	-19.2	-16.9	-15.8	-14.8	
06-Sep-97	545	-13.7	-14.6	-15.2	-15.5	-15.0	
08-Sep-97	547	-17.4	-17.7	-15.5	-14.8	-13.3	
10-Sep-97	549	-16.1	-15.8	-15.7	-15.5	-14.5	
14-Sep-97	553	-18.2	-18.0	-16.4	-16.0	-16.5	
21-Sep-97	560	-15.0	-15.5	-15.2	-15.5	-15.0	
23-Sep-97	562	-16.6	-15.8	-14.7	-14.8	-14.5	
27-Sep-97	566	-12.9	-13.4	-14.7	-15.3	-14.8	
29-Sep-97	568	-12.6	-13.4	-14.2	-14.5	-14.3	
01-Oct-97	570	-11.6	-12.4	-13.3	-14.0	-13.8	
03-Oct-97	572	-10.8	-12.1	-12.5	-13.1	-13.3	
05-Oct-97	574	-14.5	-14.8	-13.3	-13.3	-13.1	
07-Oct-97	576	-11.8	-12.4	-13.5	-13.8	-13.3	
09-Oct-97	578	-14.0	-13.4	-14.0	-14.0	-13.6	
12-Oct-97	581	-10.0	-10.7	-11.8	-12.1	-12.3	
14-Oct-97	583	-9.7	-10.7	-12.3	-12.6	-12.8	
16-Oct-97	585	-13.2	-13.8	-12.8	-12.6	-12.3	
18-Oct-97	587	-12.4	-13.1	-13.0	-12.8	-12.6	
20-Oct-97	589	-14.8	-15.1	-16.2	-15.8	-12.8	
23-Oct-97	592	-10.0	-10.2	-12.0	-12.8	-12.6	
25-Oct-97	594	-12.1	-12.6	-12.0	-12.3	-12.3	
29-Oct-97	598	-11.3	-11.2	-11.1	-11.3	-11.1	
01-Nov-97	601	-8.9	-9.5	-11.1	-11.1	-11.1	
04-Nov-97	604	-4.1	-6.1	-9.1	-10.1	-10.6	
07-Nov-97	607	-5.2	-6.6	-7.9	-8.9	-9.4	
09-Nov-97	609	-7.3	-8.5	-8.1	-8.9	-8.9	
16-Nov-97	616	-3.9	-5.8	-3.3	-5.2	-5.4	
19-Nov-97	619	-2.8	-3.9	-6.2	-7.4	-7.9	
21-Nov-97	621	-1.2	-3.7	-5.9	-6.7	-7.4	

Contd.

Table 1: Contd.

Date	Seq-day	Surf	S-1	S-2	S-3	S-4	S-5
24-Nov-97	624	-2.0	-3.4	-4.2	-5.2	-5.9	
27-Nov-97	627	-3.9	-4.6	-5.2	-5.9	-6.2	
29-Nov-97	629	-2.5	-4.1	-5.0	-5.9	-6.4	
01-Dec-97	631	0.9	-1.7	-4.2	-5.4	-5.9	
03-Dec-97	633	2.5	2.2	-1.6	-3.9	-4.9	
05-Dec-97	635	4.9	1.2	0.4	-1.7	-3.9	
07-Dec-97	637	2.0	0.2	-0.3	-1.7	-2.0	
09-Dec-97	639	2.2	0.5	0.2	-1.2	-2.5	
11-Dec-97	641	2.8	1.0	-0.3	-1.5	-2.7	
14-Dec-97	644	5.4	3.1	0.2	-0.5	-2.2	
16-Dec-97	646	3.6	1.4	0.4	-0.5	-1.5	
19-Dec-97	649	3.8	2.2	0.4	-0.5	-1.5	
22-Dec-97	652	8.1	3.4	1.1	-0.3	-1.5	
24-Dec-97	654	9.4	5.6	2.1	0.0	-1.0	
27-Dec-97	657	5.1	4.4	1.4	0.0	-1.2	
29-Dec-97	659	5.4	4.8	1.4	-0.3	-1.0	
31-Dec-97	661	10.5	5.8	2.1	0.5	-0.7	
04-Jan-98	665	11.0	6.3	4.1	1.5	-0.5	
07-Jan-98	668	7.3	4.1	3.3	1.5	0.2	
12-Jan-98	673	4.4	2.7	1.6	1.0	0.2	
16-Jan-98	677	6.7	3.1	1.9	1.2	0.2	
19-Jan-98	680	6.2	1.9	1.6	1.5	0.5	
21-Jan-98	682	5.9	2.2	1.4	1.0	0.2	
25-Jan-98	686	5.1	1.7	0.6	0.2	0.7	
30-Jan-98	691	2.0	2.7	1.9	0.7	0.0	

Seq-Day = Sequential number of the observation day,

Surf, = temperature in deg C of the permafrost surface,

S-1 = temperature in deg C of permafrost at the depth of 20 cm,

S-2 = temperature in deg C of permafrost at the depth of 40 cm,

S-3 = temperature in deg C of permafrost at the depth of 60 cm,

S-4 = temperature in deg C of permafrost at the depth of 80 cm,

S-5 = temperature in deg C of permafrost at the depth of 100 cm.

The observations of the IMD are taken for air-temperature, at a height of about 150 cm above the ground. Thus, we get an interesting curve. At Maitri, the air at the height of 150 cm is the coldest with a mean temperature of -8.4°C , while the ground surface below is the warmest with an annual mean value of -5.7°C , and in between these two values lie the mean temperatures of upper layers of permafrost.

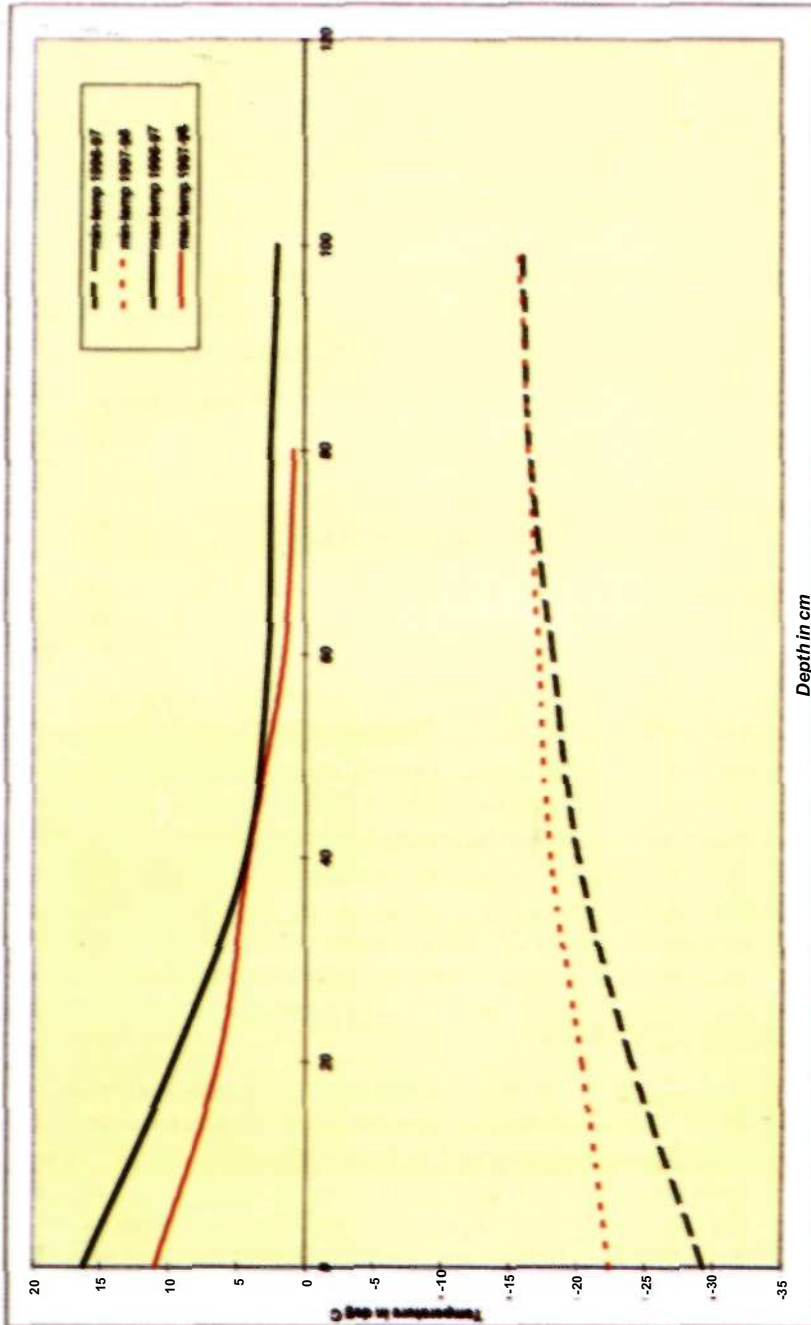


Fig. 1: Comparison of minimum and maximum temperatures in two consecutive polar seasons

Table 2 : Minimum and Maximum Temp, for Two Polar Cycles

Sensor	Depth in cm	Total no. of Observation Days	min temp 1996-97	min temp 1997-98	max temp 1996-97	max temp 1997-98	over all min temp	overall max temp
Surface	0	358	-29.3	-22.4	16.3	11.0	-29.3	16.3
S-1	20	358	-24.0	-20.4	9.7	6.3	-24.0	9.7
S-2	40	358	-20.1	-18.1	4.3	4.1	-20.1	4.3
S-3	60	358	-18.2	-17.2	2.7	1.5	-18.2	2.7
S-4	80	358	-16.5	-16.5	2.5	0.7	-16.5	2.5
S-5	100	302	-16.0	-15.8	2.0		-16.0	2.0

Table 3 : Thawing Dates for Two Polar Cycles

Sensor	Depth in cm	Total number of Observ. Days	Days with Positive Temp.	Percentage of Days with + ve temp (+ ve temp %)	Date of summer thawing 1996-97	Date of summer thawing 1997-98
Surface	0	358	112	31.28	15.11.96	01.12.97
S-1	20	358	103	28.77	16.11.96	03.12.97
S-2	40	358	78	21.79	07.12.96	05.12.97
S-3	60	358	48	13.41	24.12.96	31.12.97
S-4	80	358	37	10.34	29.12.96	07.01.98
S-5	100	302	8	2.65	15.01.97	

- The temperature at all levels remained below the freezing point most of the time. However, it rose (**Table-3**) above the freezing point at all the recorded depth levels, indicating that the entire observation zone of 1 m thickness is within the migratory layer of permafrost. At 20 cm depth, 28.77% of the days show positive temperatures, while, at 80 cm depth, this has been reduced to 10.34%. At 100 cm depth, the percentage of such days is only 2.65%, but this sensor recorded data for only one polar summer. Assuming that the second polar summer shows similar values, the true percentage of above-freezing temperature days would be around 5.3% for this depth.
- From **Table-3**, it is observed that the dates on which summer thawing sets in, varies considerably on and near the surface; but with increasing depth, the dates correspond to each other within a week. Though the surface temperatures turned positive on 15th Nov and 1st Dec in 1996 and 1997 respectively; the thawing dates for 40 cm depth were 7th Dec '96 and 5th Dec '97. Similarly, for 60 cm depth these dates were 24th Dec '96 and 31st Dec '97 and for 80 cm depth these happened to be 29th Dec '96 and 7th Jan '97. Thus, it may be stated that in the upper layers of permafrost, the summer thaw sets in at 40 cm depth around first week

of December, while at 80 cm depth it sets in around the last week of December.

Future Work

The present study was constrained by the limited depth of the permafrost-pit. The available means of digging did not permit us to go deeper than this level, as bedrock was encountered at one metre depth. However, to really pronounce a utilitarian verdict on the behaviour of the permafrost for building, foundation and scientific purposes, it is necessary to have a deeper borehole. Again, if boreholes of shallow depths are provided in different ground media available around Maitri -like soil, bedrock, dried up lake bottom etc.- a more meaningful study can be carried out in future.

Acknowledgements

Digging a narrow pit in frozen ground is always a difficult task. The help received from Shri P.K. Dey of R & D E (Engrs) is gratefully acknowledged. Thanks are due to Shri M.K. Kaul, Director-Antarctica Division-GSI for his guidance during various stages of the study.

References

- Black, R.F. 1954. Permafrost, a Review. *Bulletin of Geological Society of America*, 65. 39-856.
- Chaturvedi, A. and Asthana, R. 1996. A Study of the Thermal Behaviour of Different Ground Media in Response to the Polar Cold Front in Antarctica. *Dept of Ocean Development, Technical Publication No. 10*. 123-142.
- Cooley, William C. and Lohnes, Paul R. 1971. Multivariate Data Analysis. *John Wiley & Sons, New York*. 49-80.
- Davis, John C. 1986. Statistics and Data Analysis in Geology. 2nd ed., *John Wiley & Sons, New York*. 225-234 and 469-478.
- Davies, W.F. 1967. Surface features of Permafrost in Arid areas. *Geology of Arctic*, 2. 981-987.
- Muller, S.W. 1947. Permafrost or permanently frozen ground and related Engineering problems. *United States Geological Survey Special Publication Strategic Engineering Study*, No. 62. 231.
- Rock, N.M.S. 1988, Lecture Notes in Earth Sciences: Numerical Geology. *Springer Verlag, New York*. 218-221 and 253-258.