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Active layer and permafrost monitoring in Livingston Island, Antarctic. First results from 2000 and 2001

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ABSTRACT: In the year 2000 two shallow boreholes were drilled in the vicinity of the Spanish Antarctic Station Juan Carlos I in Livingston Island (South Shetlands, Antarctic - 62º39'S, 60º21'W). One borehole was located in Cerro Incinerador at 35m ASL and was drilled to 240 cm depth in quartzite bedrock (Myers Bluff Formation). The other was located in Reina Sofia Peak at 275 m ASL and was drilled in a matrix-supported diamicton to a depth of 110 cm. PVC tubes were inserted in the drillings and thermistor chains based on miniature data loggers were installed inside them. Temperature data were collected at 4-hour intervals. The first year of data from the boreholes evidence their different settings, in respect to both altitude and ground thermal properties. The results from the borehole at Cerro Incinerador suggest that the active layer is very thick and the borehole does not reach the (possible) permafrost table. At Reina Sofia Peak, the lower section of the drilling is below the permafrost table. In this paper, the ground temperature data from the two boreholes from 2000 to 2001 will be presented.

1 INTRODUCTION

In the Polar and Subpolar zones there are large areas of terrain subject to high energy transfers in the ground surface that give rise to permafrost (Bockheim, 1995). Permafrost is a very significant element of thermal inertia in the modulation of climate change. Therefore, the study of its evolution and especially of the associated active layer is particularly important in the framework of prognostic research on climate change (Nelson, 1993, Lachenbruch, 1996).

This paper presents the results of the temperature monitoring of the active layer in a polar area during the freezing periods of 2000 and 2001. For this purpose, two boreholes were drilled during the Spanish Antarctic Campaign of 2000.

The study area is in Livingston Island (South Shetlands), some 50 km west from the coast of the Antarctic Peninsula. Ninety per cent of the island is glacierized and the rest shows a seasonal snow cover and coincides with the periglacial domain. Most of the ice-free area supports permafrost. Field observations suggest a tentative boundary between continuous and discontinuous permafrost at ca. 100 m ASL. The climate is cold oceanic with long and cold winters, marked by subfreezing air temperatures, and short and cool summers. During the summer, there are often positive air temperatures, and rainfall occurs near sea-level. The Circumantarctic low-pressure system gives origin to high cloudiness and very wet conditions.

The mean annual air temperature at sea-level is about –3ºC and the thermal range is moderate. During the summer the temperature rise induces significant snow melt and freeze-thaw cycles (diurnal and seasonal). Precipitation ranges from 470 to 700 mm with a summer average of 100 mm. Relative humidity is very high with average values from 80 to 90% (Simonov, 1977, Rakusa-Susczewski, 1993).The detailed research sector, which includes glacierized and ice-free terrain is located in the northwest part of Hurd Peninsula in the vicinity of the Spanish Antarctic Station "Juan Carlos I" (62º40'S, 60º23'W). Air and ground temperature monitoring was made with single-channel miniature data loggers connected to NTC-100 thermistors, allowing an average precision of 0.25ºC and 1800 records (Ramos, 1995).

In the winters of 2000 and 2001 ground temperatures were recorded in boreholes at Cerro Incinerador (35 m ASL) and Reina Sofia Peak (275 m ASL) (Table 1 and Fig. 1). The former is located on quartzite bedrock to a depth of 2.4 m. The latter was drilled on a quartzite boulder that lies on a matrix supported diamict. The borehole traverses the 0.4 m thick boulder and penetrates the diamict to a depth of 1.1 m. Both boreholes were drilled with a portable water refrigerated diamond drill of 122 mm

Table 1. Characteristic ground and air temperature data.

Sensor	Location	Altitude	Type of measurement	Year	Sensor position	Periods with data
Borehole-1	C. Incinerador	35 m ASL	Ground - Quartzite	2000	Depth: 0.5 and 2.3 m	25/02 - 16/12/2000
Borehole-1	C. Incinerador	35 m ASL	Ground - Quartzite	2001	Depth: 0.25, 0.5, 1.0 and 2.3 m	10/01 - 04/11/2001
Borehole-2	R. Sofia Peak	275 m ASL	Ground - Diamict	2000	Depth: 0.1 , 0.5 and 1 m	9/03 - 9/11/2000
Borehole-2	R. Sofia Peak	275 m ASL	Ground - Diamict	2001	Depth: 0.25 m	10/01 - 04/11/2001
STA-1	SAS	15 m ASL	Air	2000	Height: 2 m	25/02 - 4/12/2000
STA-2	R. Sofia Peak	275 m ASL	Air	2000	Height: 2 m	25/02 - 4/12/2000
STA-3	Skidoo's hut	165 m ASL	Air	2000	Height: 2 m	25/02 - 4/12/2000

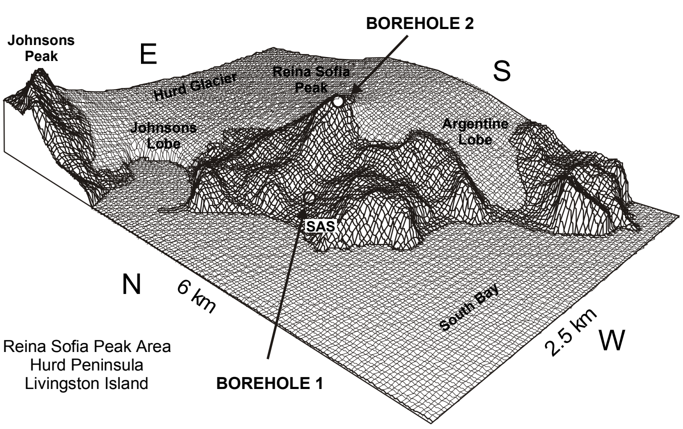

Figure 1. Study area and location of the borehole sites.

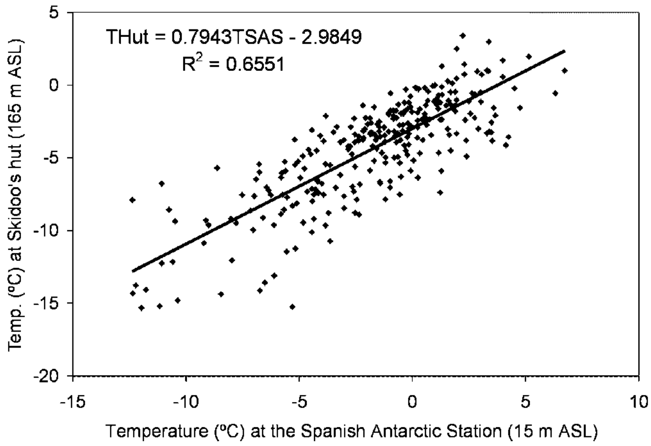

Figure 2. Regression analysis of the air temperatures at 15 m and at 165 m ASL during the winter of 2000.

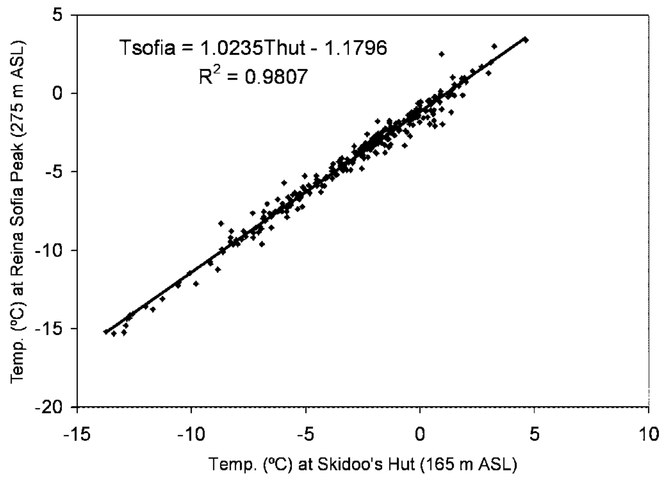

Figure 3. Regression analysis of the air temperatures at 165 m and at 275 m ASL during the winter of 2000.

diameter (Hilti). The sensors were installed inside 90 mm PVC tubes.

In order to evaluate altitude lapse rates for the air temperatures, in the winter of 2000 air temperatures were measured at three sites (Spanish Antarctic Station – 15 m ASL, Skidoo's hut – 165 m ASL, Reina Sofia Peak – 275 m ASL) (Table 1).

2 ALTITUDINAL VARIATION OF AIR TEMPERATURES

Based on air temperature measurements taken at 4-hour intervals during the winter of 2000 at the three monitoring sites (Fig. 1 and Table 1), two linear-regression models were calculated (Figs. 2 and 3). The best-fit straight lines for the two sites at higher altitude (165 and 275 m ASL) show much smaller residuals than the one for the lower sites (15 and 165 m ASL). The air temperatures at low altitude areas are clearly influenced by the thermal inertia of the sea-water. This is especially significant in the freezing and melting periods, which are not solely dependent on air temperature, but also on the thermodynamic conditions of the sea-water.

The energy fluxes at the water surface are used in gradual solid-liquid phase-changes, inducing slower variations of air temperature. A similar energy flux at higher altitude is used to modify the ground temperature and, as a result, the temperature of the air layer that contacts with it. Therefore, during freezing and melting of the pack-ice, this difference in thermodynamic processes gives origin to a large scattering of the regression plot in comparison to what happens in the higher areas (Figs. 2 and 3). The calculated values for the lapse rates correspond to 0.99ºC/100m and are similar from 15 to165 m and from 165 to 275 m ASL.

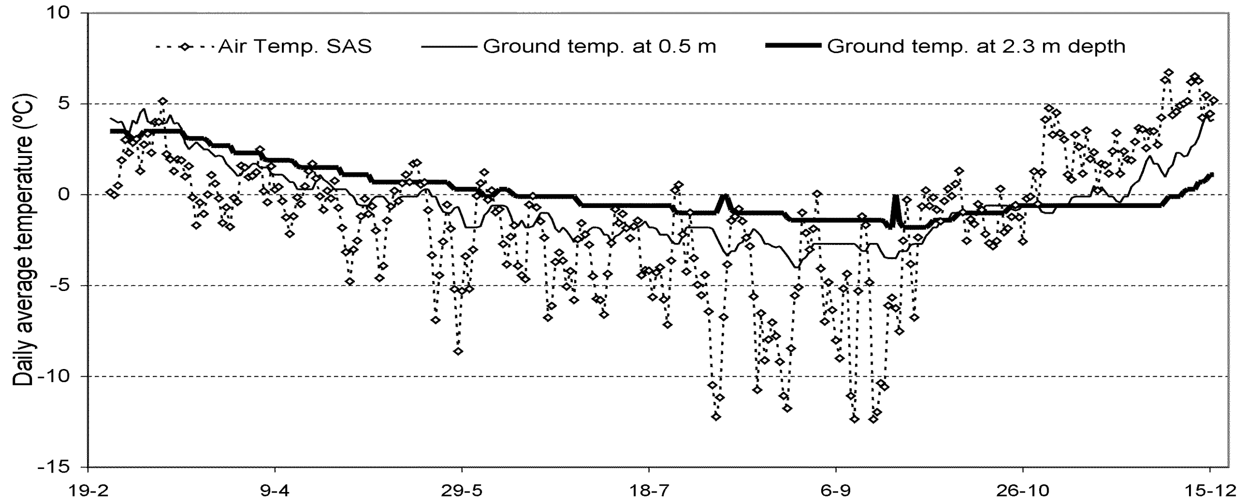

Figure 4. Ground and air temperatures at Borehole-1 (Cerro Incinerador, 35 m ASL) during 2000.

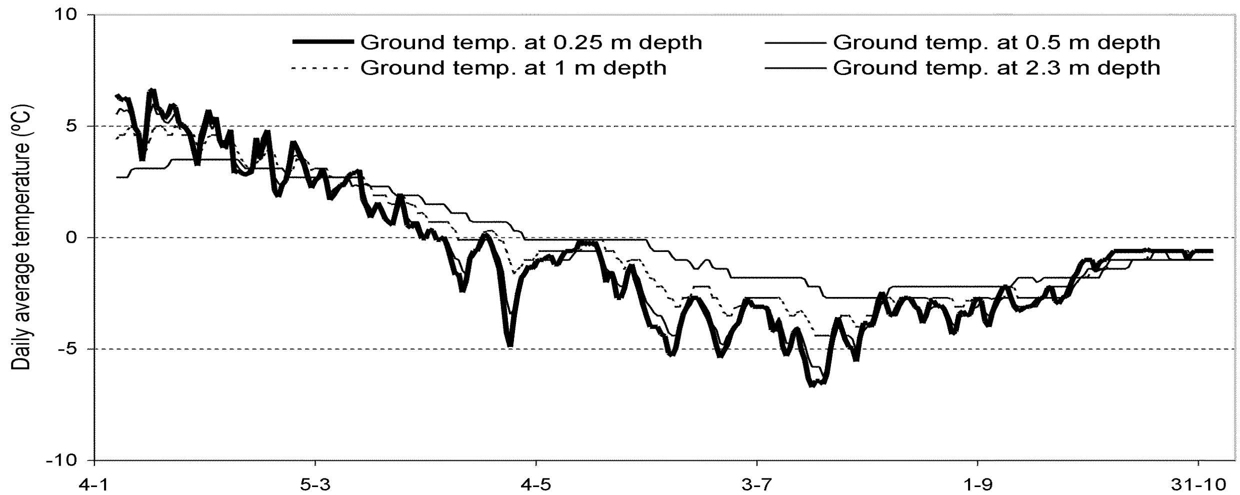

Figure 5. Ground and air temperatures at Borehole-1 (Cerro Incinerador, 35 m ASL) during 2001.

3 TEMPERATURE PROFILES IN THE BOREHOLES

In Borehole-1, located at Cerro Incinerador, the temperature profile (Figs. 4 and 5) is characterised by the absence of phase change processes, due to the quartzite bedrock setting. The evolution of the daily average ground temperatures shows a reduction of amplitude and a delay with depth.

The superficial levels (0.25, 0.5 and 1.0 m) show similar behaviour to the air temperature, with a similar period. It is significant to note that during the winter (from June to September) an harmonic wave thermal signal with a period of 15 days (Fig. 6) has been detected during the two years. The application of a sinusoidal best-fit to this temperature signal at different depths was used to calculate the thermal diffusivity of the bedrock (Ayra, 1992). A thermal diffusivity of 1.23 10^{-6} $m.s^{-2}$ was obtained. The sensor at 2.3 m depth loses these short-term temperature signals and reflects only the seasonal variation. Therefore, it shows a small temperature range (1.1ºC in 2000 and 0.8ºC in 2001) in comparison to what occurred at 0.5 m depth (2ºC in 2000 and 2.4ºC in 2001).

Freeze-thaw cycles were observed at all monitored depths, indicating that the borehole does not reach the permafrost table. Figures 7 and 8 show the evolution of the temperatures at Borehole-2 (Reina Sofia Peak). The most superficial sensor (0.1 m depth) shows a conductive process without phase change (positive temperatures) in the beginning of the monitoring period (9/03 to 15/03/2000). It shows similar variations to the air temperatures, but with a buffering and delay. By mid-March the temperature drops below 0ºC and phase-change begins and goes on for 15 days. By that time, freezing also takes place at 0.5 m depth. Nevertheless, at 1.0 m freezing is delayed since thermal equilibrium takes longer to be attained and a long lasting freezing curtain is visible until early November 2000. Then, the temperature drops suddenly to –2.2ºC and the ground stays frozen, even when superficial levels show a warming trend.

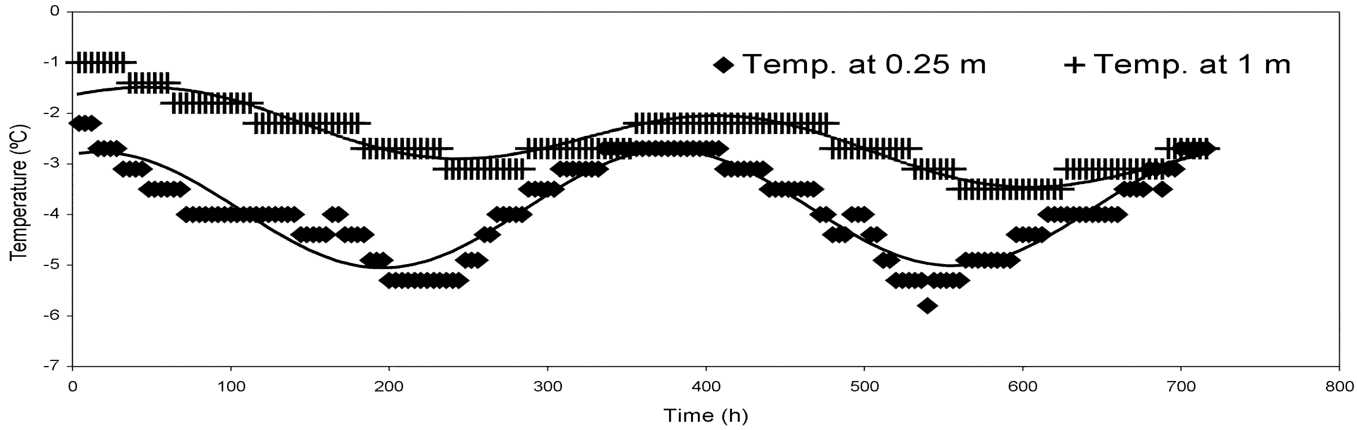

Figure 6. Thermal harmonic wave signal (theoretical-line and experimental-points) measured from 1 June to 15 July 2001 in Borehole-1 used to calculate the thermal diffusivity of the bedrock of Cerro Incinerador.

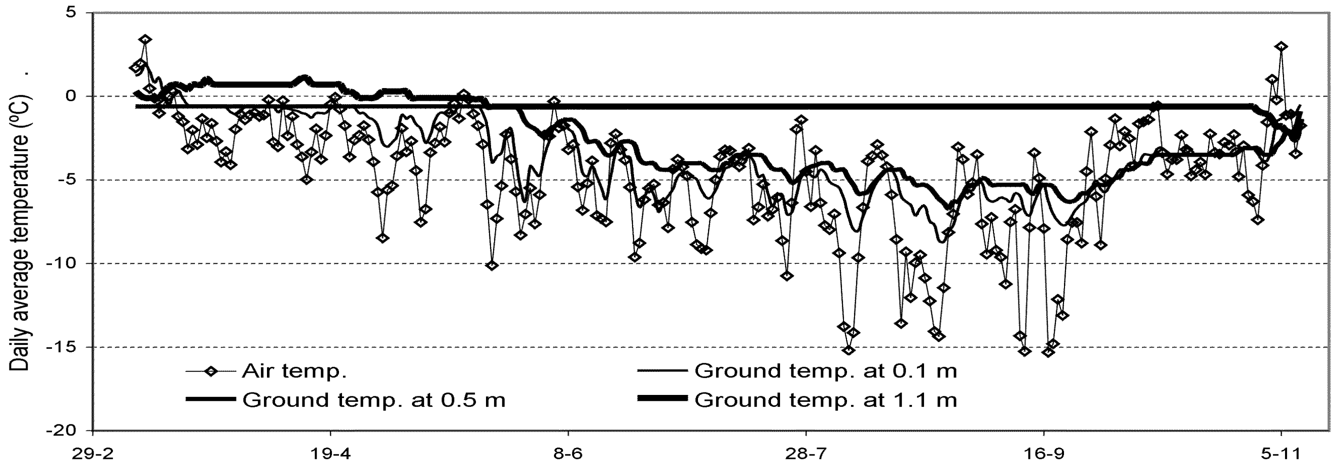

Figure 7. Ground and air temperatures at Borehole-2 (Reina Sofia Peak, 275 m ASL) during 2000.

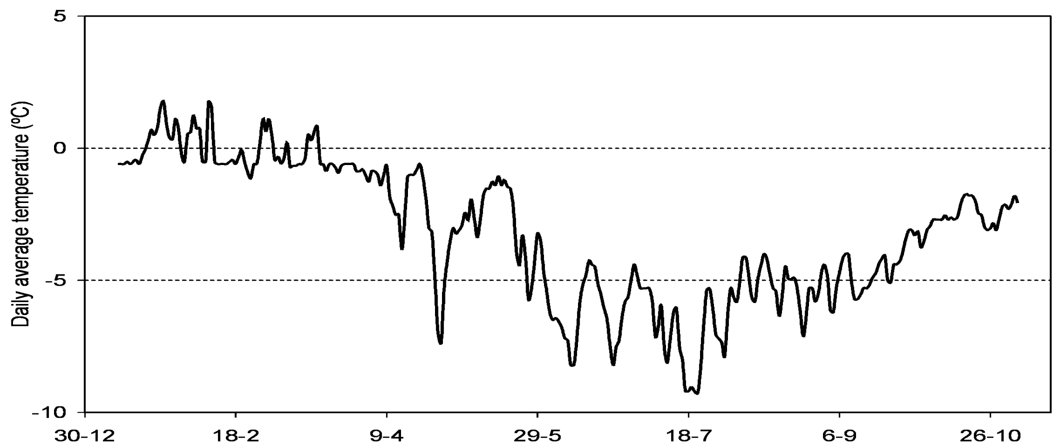

Figure 8. Ground temperatures at 0.25 m depth at Borehole-2 (Reina Sofia Peak, 275 m ASL) during 2001.

These data and several excavations down to the frost table conducted in previous years in the same spot, suggest that the permafrost table is located between 0.5 and 1.0 m depth. At 0.5 m depth freezing progressed slowly during 10 weeks, with an evident freezing curtain effect. After that, the temperature dropped quickly, evidencing simple heat transfer conditions without phase-change in high-diffusivity frozen ground. This situation favours the appearance of a regime strongly controlled by air temperature, but with delay and loss of signal. The 15-day period is also present in this bore-hole during winter, a fact that suggests some kind of regional control, not yet identified. A thermal diffusivity of the frozen ground of $0.55\ 10^{-6}\ m.s^{-2}$ was calculated. The value is lower than at Borehole-1, because of the porosity and thermodynamic properties of the diamict. Borehole-2 shows a larger temperature range at all depths when compared to Borehole-1, since air temperature range is also larger in the former (Tables 2 and 3).

Table 2. Statistical measures of the temperatures at different depths at Borehole-1 from April to October of 2000 and 2001.

Temperature sensor (ºC)	April-October 2000		
	Mean	Maximum	Minimum
Air	-2.9	0.9	-7.8
Ground (0.5 m depth)	-1.4	-0.7	-2.4
Ground (2.3 m depth)	-0.3	0.4	-0.7
	April-October 2001		
Ground (0.25 m depth)	-2.5	-1.2	-4.2
Ground (0.5 m depth)	-2.5	-1.4	-3.7
Ground (1 m depth)	-1.8	-1.1	-2.7
Ground (2.3 m depth)	-1.1	-0.7	-1.6

Table 3. Statistical measures of the temperatures at different depths at Borehole-2 from April to October of 2000 and 2001.

Temperature sensor (ºC)	April-October 2000		
	Mean	Maximum	Minimum
Air	-5.3	0.1	-15.3
Ground (0.1 m depth)	-4.1	-0.6	-8.7
Ground (0.5 m depth)	-3.2	-0.6	-6.7
Ground (1 m depth)	-0.4	1.1	-0.9
	April-October 2001		
Ground (0.25 m depth)	-4.4	-0.6	-9.3

4 CONCLUSIONS

The record of the shallow-ground temperature regimes presented here allow a first insight into the thermal structure of the active layer in two sites with distinct geographic characteristics (altitude, type of ground material, and topographic position). The thermal diffusivity of the ground in frozen conditions was calculated for both sites, and is in agreement with the significant differences in the depth of the active layer. A cyclicity of 15 days in the ground temperatures was observed in both sites during the winters of 2000 and 2001. The preliminary results presented here are part of a longer-term research project, which will be enlarged to year-round continuous monitoring of the ground temperatures, in order to include the freezing and thawing seasons. This will allow the modelling of the influence of climate change on the energy fluxes in the ground and particularly in the active layer.

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