Active layer thermal monitoring at two ice-free areas of King George Island, Maritime Antarctica

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Abstract

The present work focuses on soil temperature and moisture data for one year (2008/ 2009) for two sites at King George Island, Maritime Antarctica. The sites were installed in February 2008 and consist of precision thermistors with probes at different depths down to the permafrost table, and one soil moisture probe placed at the bottommost layer at each site, recording data at hourly intervals. The active layer thermal regime in Fildes and Potter Peninsula is dynamic, with extreme variation at the surface during summer resulting in frequent daily freeze and thaw cycles. The soil thermal regime is essentially periglacial with poor thermal conductivity, which in some way reduces thermal degradation of the permafrost. The coarse nature of the active layer, especially at Potter Peninsula, results in large pores occupied by air and water, enhancing nonconductive heat transfer processes. Thermal diffusivity is extremely variable throughout the summer.

Key Words

Soil thermal regime, permafrost, climate change, Maritime Antarctica

Introduction

The active layer and permafrost are key components of the terrestrial cryosphere and are highly sensitive to climate changes. The thermal regime and depth of the active layer, as well as the nature and continuity of the permafrost, are very useful for long-term studies regarding the impacts of global warming on ecosystem functioning. Soil temperature regime at high latitudes is an important indicator of the nature of the permafrost, which strongly influences geomorphologic, hydrologic, and other related phenomena, manifested in the active layer. The depth of frost penetration depends mainly on the intensity and duration of the cold snow cover, precipitation and cloud cover (Guglielmin *et al.* 2008).

Periglacial regions are highly sensitive systems for climate change studies due to their transitional situation. In this respect Maritime Antarctica has been increasingly recognized as a key region for monitoring climate change. The largest and most rapid changes are expected to occur in the periglacial environment and evidences of permafrost degradation are already being observed. Despite the recent interest, few investigations of thermal conditions of the active layer and permafrost have been made based on year round measurements (Leszkiewicz & Caputa 2004, Cannone *et al.* 2006).

During the austral summer of 2008/2009, twelve active layer monitoring sites were installed, distributed in ice-free areas of King George and Livingstone Islands, and at the northernmost portion of the Antarctic Peninsula (Hope Bay). The objective of the present paper is to present and discuss soil temperature and moisture data from the summer of 2008 to the summer of 2009 for two sites installed at King George Island.

Methods

The study sites are located at Potter and Fildes Peninsulas, King George Island, Maritime Antarctica. The region experiments a cold moist maritime climate characterized by mean annual air temperatures of -2°C (Olech 1994) and mean air temperatures above 0°C for up to four months, during the summer period. Precipitation ranges between 350 and 500 mm per year, with rainfall occurring in the summer period, (Øvstedal & Smith 2001).

The active layer monitoring sites were installed in February 2008, and consist of precision thermistors arranged as a vertical array with probes at different depths down to the permafrost table. Soil moisture probes were placed at the bottommost layer at each site. All probes were connected to a Campbell Scientific CR 10 data logger recording data at hourly intervals.

Soil characteristics of the monitored sites and the exact depth of the probes are presented in Tables 1 and 2. Meteorological data for Potter and Fildes were obtained from the Teniente Jubany and Eduardo Frei stations, respectively. Daily estimations of soils apparent thermal diffusivity (ATD) were made, according to McGaw *et al.* (1978), using the following equation: $\alpha' = [\Delta Z2/2\Delta t]x[(Tij+1- Tij-1)/(Tji-1- 2Tji+ Tji+1)]$ Where α'= apparent thermal diffusivity (m²/s), Δt=time increments (s), ΔZ=space increments (m), T= temperature, j= temporal position and i=depth position. Other authors (Nelson *et al.* 1985; Outcalt and Hinkel 1989) have used this estimative in their works.

Table 1. General characteristics of the monitored sites.

Site	Altitude	Soil Class	Vegetation	Depth of the active layer	Thermistors depth (cm)*
Potter	70 m	Umbric Leptic Cryosol	Lichens (*Usnea sp.* and *Himantormia sp.*)	95 cm	8(P1), 36(P2), 56(P3), 90(P4)
Fildes	65 m	Turbic Eutric Cryosol	Mosses and Lichens (*Usnea sp.* and *Himantormia sp.*)	90 cm	10.5(F1), 32.5(F2), 67.5(F3), 83.5(F4)

* the moisture probes were installed at the bottommost part of the trench.

Table 2. Granulometric fractions of the studied profiles.

Depth	cs	Fs	sil	clay	Class
			g/kg		
Potter - Umbric-Leptic Cryosol					
0 – 10	67	9	10	14	Loamy-Sand
10 – 20	68	11	12	9	Loamy-Sand
20 – 40	67	9	14	10	Loamy-Sand
40 – 60	52	19	21	8	Loamy-Sand
60 – 80	47	24	21	8	Loamy-Sand
Fildes - Turbic Eutric Cryosol					
0 – 20	28	18	34	20	Loamy
20 – 50	29	17	36	18	Loamy
50 – 100	14	30	47	9	Loamy

cs – coarse sand; fs – fine sand, sil – silt

Results

The highest soil temperature at Fildes Peninsula was 4.44 °C, registered for the top soil layer in January 08th 2009, while the highest mean daily air temperature was 3.7 °C, on January14th. During the summer period, soil temperature at the upper layers presented high positive correlation with air temperature, (0.80 to 0.93). Soil water content, ranged from 60% in the summer to 30% in winter. Mean annual temperatures of -0.33°C, -0.42°C, -0.67°C and -0.54°C were found for the increasing depths. The temperatures for the bottommost layer indicate that the permafrost occurs deeper than 83.5 cm. At this depth, maximum temperature was 0.38 °C, minimum -3.10 °C, with mean annual value of -0.60 °C. This temperature oscillation close to 0^oC suggests that the permafrost table is situated close to this depth.

Thermal diffusivity was estimated for two intermediate depths for each day. Since it was calculated from the observed temperatures, and includes the thermal impact of nonconductive heat transfer, it is more properly referred to as the apparent thermal diffusivity (ATD), considered always as an average value. In some cases, the ATD may be negative, indicating that nonconductive effects oppose and overwhelm the conductive tendency (Outcalt and Hinkel, 1989). ATD varied widely during the studied period (Figure 1). Seasonal fluctuation is common due to contributions of conductive and nonconductive soil heat transfer mechanisms. Addition of soil water, for example, increases the conductivity, but also increases soil heat capacity (Hinkel *et al.* 2001). Mean ATD for the studied period were $6.78x10^{-08}$ m^2/s and $-6.26x10^{-08}$ m^2/s at 32.5 and 67.5 cm respectively. These values are consistent with those reported by Hinkel *et al.* (2001) for thawed, saturated mixed silty soils (2–$3x10^{-7}$ m^2/s). The difference between the ATDs tends to be greater in early summer, with drastic fluctuations of soil temperature and moist content. Cooler autumn temperatures result in a near-isothermal soil condition with little heat transfer and almost no variation of ATD. Mean ATD during winter (21/06 to 23/09) was positive, except for the deepest horizon (-8.46 $x10^{-09}$ m^2/s); which shows a notable temperature buffering capacity. ATD showed considerable temporal variation and no clear correlation between inflections and periods of significant precipitation.

The highest soil temperature at Potter Peninsula was 6.0°C and occurred in January 15th 2009, while the highest mean daily air temperature was 5.0°C, also in January. During the summer period, soil temperature depended on air temperature in surface showing low correlation in subsurface. Correlation within layers was strong only between surface horizons (0.62 to 0.97), indicating a considerable resistance in temperature changes at permafrost level. The influence of air temperature on the profile thermal regime is greatly reduced from 56 cm depth downwards, where the highest temperature did not exceed 1.0°C. The coarse nature of the profile seems to have a considerable influence over its thermal conductivity, contributing for the permafrost preservation, as shown by the low correlation between air temperature and soil temperature at 90 cm depth. The water content showed a fairly variable behaviour ranging from values around 5.5 % in the winter to 34.4 % in the summer. Mean annual temperatures of -0.60°C, -0.53°C, -0.86°C and -0.84°C were obtained for the increasing depths, suggesting that the permafrost table lies below 90 cm.

As observed in Fildes, ATD varied widely during the studied period (Figure 2), but at Potter it was more affected by variations of the water content. Mean ATD for the studied period was -5.39x10^{-08} m^2/s and 7.59x10^{-09} m^2/s for the 36.0 cm and 56.0 cm layers. Differences were greater in summer, with drastic fluctuations of soil temperature and moisture content. Colder conditions resulted in low variability of ATD. Winter mean ATD (21/06 to 23/09) was positive 8.37x10^{-08} m^2/s, 3.52 x10^{-08} m^2/s, respectively for the 36.0 cm and 56.0 cm layers. The coarse nature of the profile results in high macroporosity. Nonconductive heat transfer processes occur, causing variation of the thermal diffusivity.

Fildes presented higher ATD in surface, revealing an opposite trend in depth when compared to Potter. The finer texture and consequent greater water retention capacity at Fildes appears to work in both directions in relation to ATD. The energy flux is higher thought out the profile but, at the same time, higher water content means greater soil heat capacity. As a consequence, soil temperature rises evenly buffering sudden changes, and contributing to permafrost preservation. At Potter, the coarser nature of the profile reduces the water retention capacity leaving empty pores thought out the soil. Soil air works well as an isolator, preventing temperature changes. However when summer rain or a rapid thaw of snow occur the energy transfer in the profile is rapid.

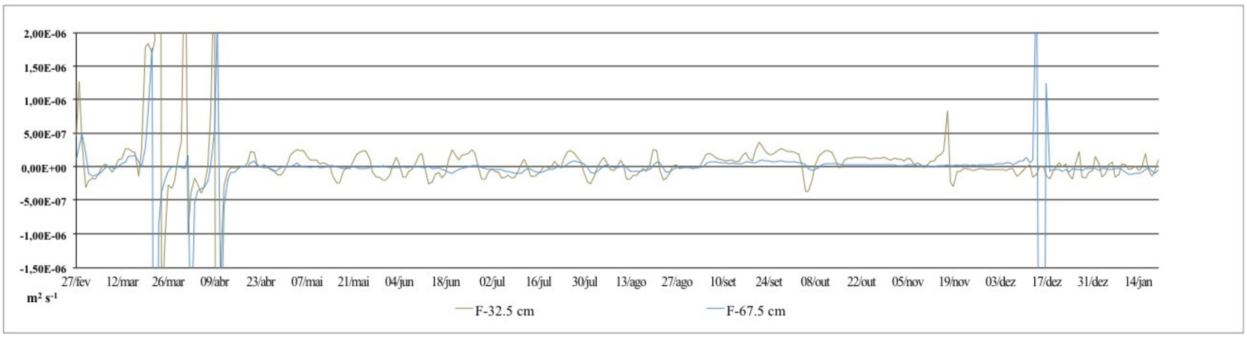

Figure 1. ATD variation during the monitored period for two depths at Fildes Peninsula.

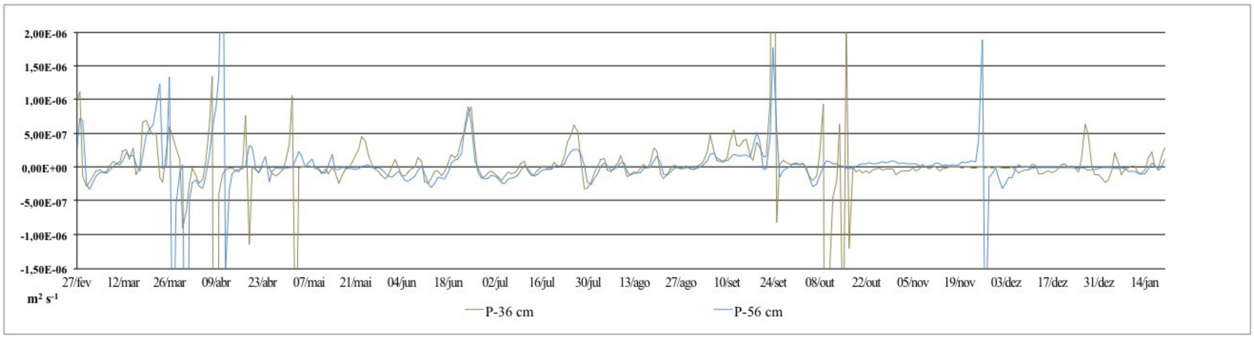

Figure 2. ATD variation during the monitored period for two depths at Potter Peninsula.

Conclusion

The active layer thermal regime in Fildes and Potter Peninsula is dynamic, with extreme variation in surface during summer resulting in frequent daily freeze and thaw cycles. This has implications to soil genesis, favouring cryoturbation and cryoclastic weathering. This annual dataset of 2008-09 indicates that the permafrost table lies below 90 cm for both sites, which is close to the limit established for classifying these soils as Cryosols or Gelisols, according to the WRB and Soil Taxonomy systems, respectively. The profiles thermal regime is essentially periglacial with poor thermal conductivity, which in some way reduces the thermal degradation of the permafrost. The coarse nature of the Potter site results in high macroporosity, favouring nonconductive heat transfer processes.

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