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Short Communication

A Note on Ground Thermal Regimes and Global Solar Radiation at 4720 m a.s.l., High Andes of Argentina

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ABSTRACT

The near-surface ground thermal regime at 4720 m a.s.l. is described and assessed in terms of its daily and annual fluctuations (frost cycles, freezing and thawing depths, etc.). Correlation between solar radiation and soil temperature in the uppermost parts of the soil is caused by intense radiation (mean annual value of 22.3 MJ m^{-2} d^{-1}). Surface soil temperatures show an enormous amplitude (> 50 °C in a depth of 0.1 m) and frost cycles occur almost throughout the year. The seasonally frozen ground extends to only 1.5 m in depth.

RÉSUMÉ

Le régime thermique du sol se décrit par ses variations journalières et annuelles (cycles de gel, profondeur de gel et de dégel, etc.). On a pu établir une étroite corrélation entre le rayonnement solaire et la température du sol dans ses couches supérieures. Etant donné l'intensité du rayonnement (valeur annuelle moyenne: 22.3 MJ m^{-2} $jour^{-1}$), la température du sol montre de fortes amplitudes (> 50 °C à une profondeur de 0.1 m) et les cycles de gel se produisent quasiment tout au long de l'année. Le gel saisonnier pénètre jusqu'à 1.5 m dans le sol.

KEY WORDS: Solar radiation   Soil temperature   High Andes

INTRODUCTION

Compared with the European Alps, the periglacial belt in the High Andes of Mendoza and San Juan (latitudes 30°–33° south) is large, as a consequence of the extreme semiarid subtropical climate (Barsch and Happoldt, 1985; Corte, 1986). Unfortunately, no precipitation data from the Central Cordillera are available. An extrapolated value of roughly 400 mm/yr can be taken as an approximation (Minetti *et al.*, 1986; Minetti and Sierra, 1989). The low precipitation contrasts with high potential evaporation (Burgos and Vidal, 1951; Prohaska, 1976), caused by high radiation throughout the year. The effect is a negative water balance and a heavy dependence of the population on irrigation systems. Over the last few years melting in the High Andes involving glaciers and permafrost areas has increased enormously. All glaciers (except surging glaciers) between latitudes 30° and 33° south are retreating, while the increasing thickness of the active layer is further evidence of this recent trend (Happoldt and Schrott, 1989). This short note describes some microclimatic and ground thermal measurements made at an elevation of 4270 m a.s.l. (Figures 1, 2).

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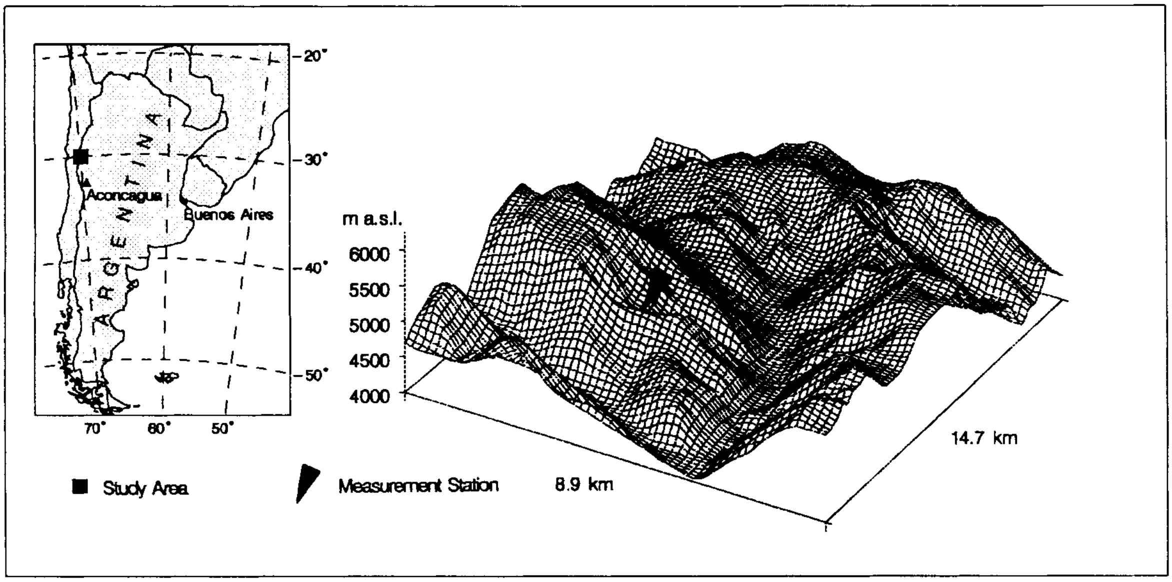

Figure 1 Location of the study area and a 3-D model of the Agua Negra catchment (30° S).

METHODS

Solar radiation, and air and soil temperatures were measured throughout the period December 1989 to March 1991. Measurements were usually taken every 15 min and saved on a 48 kbyte RAM. The low-energy system of an 8-channel datalogger powered by 16 1.5 V monocells made maintenance-free registration during winter possible. The datalogger equipment and calibrated PT-100 sensors had an accuracy of ± 0.1 °C. Thermistors were placed at depths of 0.01 m, 0.1 m, 0.25 m, 0.5 m, 1 m and 2.5

Figure 2 Measurement station at 4720 m a.s.l. (indicated by arrow) situated on an active rock glacier.

m. Solar radiation was measured with a Kipp and Zonen CM-5 pyranometer.

STUDY AREA

The study catchment area (latitude 30°07′-30°16′ S; longitude 69°45′-69°52′ W) includes heights of 4000 m-5740 m a.s.l.. The catchment has a surface area of 57 km^2, and is probably underlain by permafrost. At an altitude of >4000 m stone polygons and stripes at a decimetre scale occur and solifluction is commonly observed. Active rock glaciers are a dominant feature of almost all catchments in the subtropical High Andes. In many cases they cover a larger surface area than glaciers (Schrott, 1991). It is remarkable that at an altitude of 5000 m a.s.l., apart from some snow patches, the

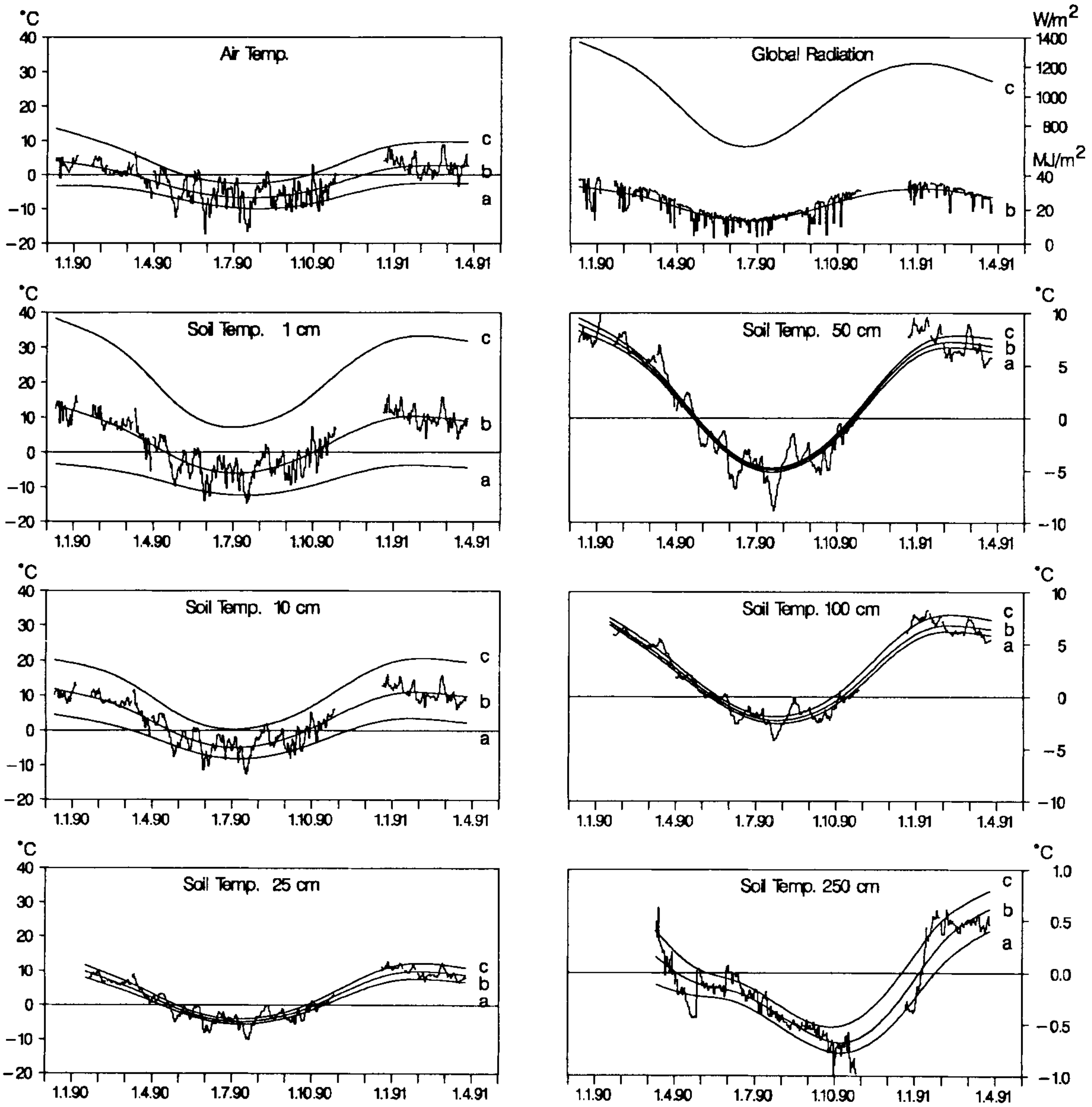

Figure 3 Course of global solar radiation, air and soil temperature plotted with mean daily values and splined minimum (a), mean (b) and maximum (c) values. Registration in 4720 m a.s.l. from 10 December to 26 March 1991.

area is not covered by snow and ice. Therefore, the snowline is inferred to lie above 5000 m a.s.l.. Almost all the data discussed in this paper have been obtained from a measurement station installed on the flat surface (<2°) of a rock glacier at 4720 m a.s.l. in the Agua Negra catchment (see Schrott, 1991).

RESULTS

Figure 3 summarizes measurements of different parameters over a 16 month period. In areas without vegetation and with no significant snow cover the daily and annual temperature variations are heavily influenced by solar radiation. Extremely high peaks up to 1445 W/m^2 or 39.1 MJ m^{-2} d^{-1}, and intense radiation throughout the year (monthly means of 33.2 MJ m^{-2} d^{-1} in January and 13.0 MJ m^{-2} d^{-1} in July) make for a spectacular annual amount of incoming solar radiation of 22.3 MJ m^{-2} d^{-1} (in 1990). A high correlation ($r = 0.82$) exists between the monthly means of solar radiation and the amplitude of the surface temperature (0.01 m).

In agreement with theory, annual temperature waves penetrate deeper than daily waves. The mean daily amplitude of surface temperature (27.7 °C at a depth of 0.01 m) is reduced to 0.8 °C at a depth of 1 m. By contrast, the mean annual amplitude of the surface temperature (20.4 °C) is reduced to 9.6 °C at a depth of 1 m. The mean annual ground temperature (MAGT) in the upper 1 m varies between 0.6 °C and 2.0 °C, whereas at a depth of 2.5 m the MAGT is −0.3 °C; the temperature remains below 0 °C during 9 months of the year.

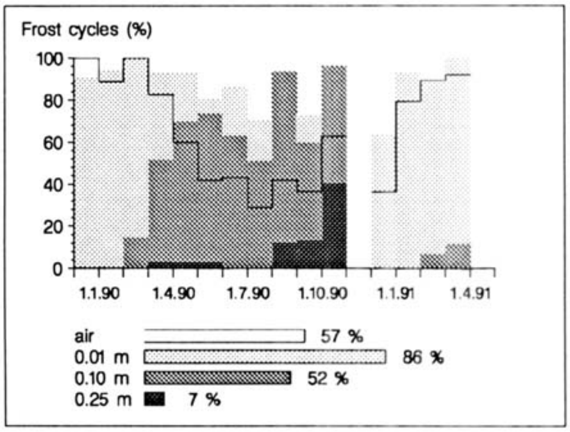

Figure 4 Monthly frequency of frost cycles (%) in air and soil temperature at depths of 0.01 m, 0.1 m and 0.25 m throughout the registration period and their mean annual values (1990).

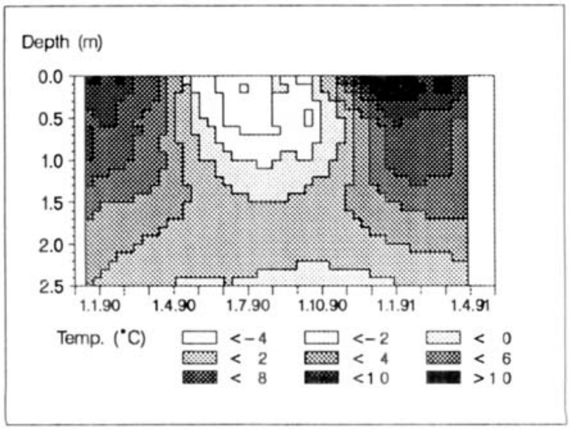

Figure 5 Near-surface ground thermal regime of an active rock glacier at 4720 m a.s.l..

The high daily and annual amplitude of temperature in the upper parts of the soil (<0.25 m) corresponds to the daily and annual cycle of solar radiation. The insignificant snow cover or its total absence produces frost cycles in the soil even in winter. Figure 4 shows the dependence of frost cycles on amplitude values that decrease with increasing depth. Air and soil temperature at a depth of 0.1 m match with respect to mean annual amplitudes and the number of days with and without frost. However, they differ in that their summer and winter peaks are nearly diametrically opposed. This can be explained by the considerable difference between the respective mean annual values (−2.5 °C for air temperature versus 1.6 °C for soil temperature at a depth of 0.1 m).

Figure 5 shows the ground temperature regime in relation to time and space. The average daily means calculated on the basis of 10 day periods are interpolated with a resolution of 0.1 m. The seasonal frost penetrates, with a velocity of about 2 cm/d, to a depth of 1.5 m.

CONCLUSIONS

The thermal regime of the near-surface layer at one locality at 4720 m a.s.l. suggests that: (1) frost penetration does not extend beneath 1.5 m depth, and (2) variations in soil temperature depend on incoming radiation and high-energy exchange throughout the year, even in winter; caused by insignificant snow cover.

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