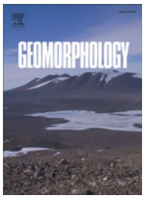
Geomorphology 155-156 (2012) 20–33

Contents lists available at SciVerse ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph



Spatial and temporal variability of ground surface temperature and active layer thickness at the margin of maritime Antarctica, Signy Island

Mauro Guglielmin [a,*], Michael Roger Worland [b], Nicoletta Cannone [a]

[a] *BICOM, Insubria University, Via Dunant, 3, 21100 Varese, Italy*
[b] *British Antarctic Survey, Madingley Road, Cambridge, United Kingdom*

ARTICLE INFO

Article history:
Received 13 January 2011
Received in revised form 24 October 2011
Accepted 7 December 2011
Available online 14 December 2011

Keywords:
Ground surface temperature
Active layer
Vegetation cover

ABSTRACT

A CALM grid with a data logger system to monitor the active layer thermal regime was established on Signy Island (60°43′S, 45°38′W at 80 m a.s.l.) in December 2005. The active layer at each of the 36 nodes of the grid was monitored measuring the ground temperature at least at 4 different depths between 0.02 and 0.4 m at the end of the summer season. In addition, within the grid, we selected four sites closely spaced (in a ray of 25 m) three of which with the same topographical characteristics (north facing aspect) but different vegetation coverage (one bare ground, BG1 and two sites with different vegetation: *Andreaea sp*. and *Sanionia uncinata*) and the fourth (BG2) it is as BG1 a bare ground but with south facing aspect. In particular, 4 thermistors were located at depths of 0.02, 0.3, 0.6, and 0.9 m at BG2 and at the *Andreaea sp* site, 9 thermistors at 0.02, 0.3, 0.6, 1, 1.2, 1.4, 1.6, 2, and 2.5 m at BG1 and at 0.02 and 0.6 m of depth at *Sanionia* site. Generally, with the same aspect, a thick vegetation cover (as in *Sanionia* site) provides a greater insulative effect than a thinner vegetation cover (as in *Andreaea* site) or bare ground (BG1) because vegetation both shades and insulates the ground resulting in a reduction in summer heat flux.

Ground Surface Temperature (GST) was colder and more buffered in spring and summer under the vegetated ground than in BG1, although the coldest GST and lowest Thawing Degree Days (TDD) were recorded at BG2 and related to its southern aspect. Our data confirm that air temperature is the main driver of GST, as already reported both in the Arctic and Antarctic. We also found that the effect of air temperature changes seasonally, being drastically reduced in winter and, to a lesser extent, in fall and spring, when there is generally thin snow cover (<30 cm). During the summer, when snow cover is usually absent, the air temperature is the dominant driver, although incoming radiation also had an effect on the northern exposed bare ground and to a lesser extent on the vegetated and southerly exposed bare ground.

The active layer ranges between 81 and 185 cm on the 4 continuously monitored sites and, considering the sites with the same aspect, it is thicker under bare ground (between 10% up to more than 100%) than under vegetated ground, confirming previous observations in the Arctic and Antarctic. However at our sites, climate forcing has no effect on the active layer thickness, enhancing the role of soil properties including the periods of high moisture content and lateral flow of water.

The lack of a statistically significant regressions between GST and active layer thickness could be due to the limited study period (four years) and/or to the variation with time of changes in soil characteristics such as soil moisture, and the possible occurrence of non-conductive heat transfer processes including the lateral flow of water. Further data are required to understand the role of moisture and possible ground water circulation within the active layer to explain the unexpected strong dichotomy between the GST regime and active layer thickness.

1. Introduction

Antarctica provides environments exclusively influenced by climate change and/or natural processes with negligible anthropogenic effects. Vegetation, the active layer, and the underlying permafrost are the key environmental components of Antarctic terrestrial ecosystems.

Soils that develop in permafrost areas are recognized to be sensitive to climate change and provide both positive and negative feedback associated with vegetation succession and changing soil properties (Walker et al., 2003; Chapin et al., 2005). Vegetation and surface-organic horizons dampen the impact of air temperature on the ground thermal regime, due to their insulating effect (Shur and Jorgenson, 2007), which is particularly important during summer (Kade et al., 2006).

Studies on the interactions between vegetation and the Ground Thermal Regime (GTR) and their potential ecological implications in Antarctica have only recently begun to be developed (Cannone

---

* Corresponding author.
E-mail address: mauro.guglielmin@uninsubria.it (M. Guglielmin).

0169-555X/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.geomorph.2011.12.016

et al., 2006; Guglielmin et al., 2008a). The various insulating effects provided by different vegetation types on the Ground Surface Temperature (GST) were demonstrated for both the summer season and the entire year in both maritime (Cannone et al., 2006; Guglielmin et al., 2008a) and continental Antarctica (Cannone and Guglielmin, 2009).

Annual data for the active layer are available from a few locations in maritime Antarctica (Ramos et al., 2008) and continental Antarctica (i.e. Paetzold et al., 2000; Guglielmin et al., 2003; Guglielmin, 2006; Cannone et al., 2008), but only beneath barren ground.

Changes of the active layer GTR in response to climate change affect the active layer thickness and permafrost temperature, and have consequences for soil weathering processes, (Thorn et al., 2002; Darmody et al., 2004), and the soil carbon budget (Gruber et al., 2004; Zimov et al., 2006). In the Arctic the rapid thaw of the active layer or the top layers of permafrost (perennially frozen ground) may trigger landslides (i.e. Lewkowicz, 2007; Schuur et al., 2007; Lantz et al., 2009). In permafrost areas, slope stability may decrease as permafrost degrades and the active layer becomes thicker (Harris and Lewkowicz, 2000).

Interactions between climate forcing (air temperature, snow cover, incoming radiation), vegetation cover and the type and thickness of the active layer in a climatic change scenario are still poorly investigated, despite the fact that the maritime Antarctic is experiencing a recent period of air warming (e.g. Chapman and Walsh, 2007; Turner et al., 2007) together with glacier shrinkage (e.g. Rott et al., 1996; Vaughan and Doake, 1996) and a contemporaneous vegetation cover change (e.g. Fowbert and Smith, 1994).

Signy Island, South Orkney Islands, provides a rare opportunity in the maritime Antarctic to examine the thermal regime of both barren and vegetated ground and to compare recent records with previous Signy Island data collected on barren ground in 1963 by Chambers (1966a).

This paper aims to contribute to our understanding of the relationship between spatial and temporal variability of GST and active layer thickness in the maritime Antarctic by:

1) Analysis of the GST and GTR at different spatial (intra-site and inter-site variability) and temporal (seasonal versus annual) scales.
2) Assessment of the influence of the presence/absence of vegetation and the vegetation type for dry and wet Antarctic cryptogamic tundra on GST, GTR and active layer thickness.
3) Analysis of the relationships between climate forcing, vegetation and the active layer.

1.1. Study area

Signy Island (60°43′S, 45°38′W) is located in the maritime Antarctic in the South Orkney Islands (Fig. 1), and is characterized by a cold oceanic climate, with mean annual air temperatures of around −3.5 °C, mean monthly air temperatures above 0 °C for at least one (but up to three) months each summer, with an annual precipitation of around 400 mm (primarily in the form of summer rain) and average cloud cover of 6–7 oktas year-round. The island lies south of the much larger and higher Coronation Island, which generates regular Föhn winds, which bring moist misty air over Signy Island. We present the first available snow cover data for this site. The climatic records indicate a progressive warming of air temperatures of 2 °C ± 1 over the past 50 years in the closest long-term station, at Orcadas (Turner et al., 2005).

The bedrock is mainly quartz–mica-schist, although in some parts of the island there are small limestone outcrops. An ice cap covers about half of the island and it is currently shrinking rapidly with a rate of glacier retreat of more than 1 m/year in the last 20 years (Favero Longo et al., 2012).

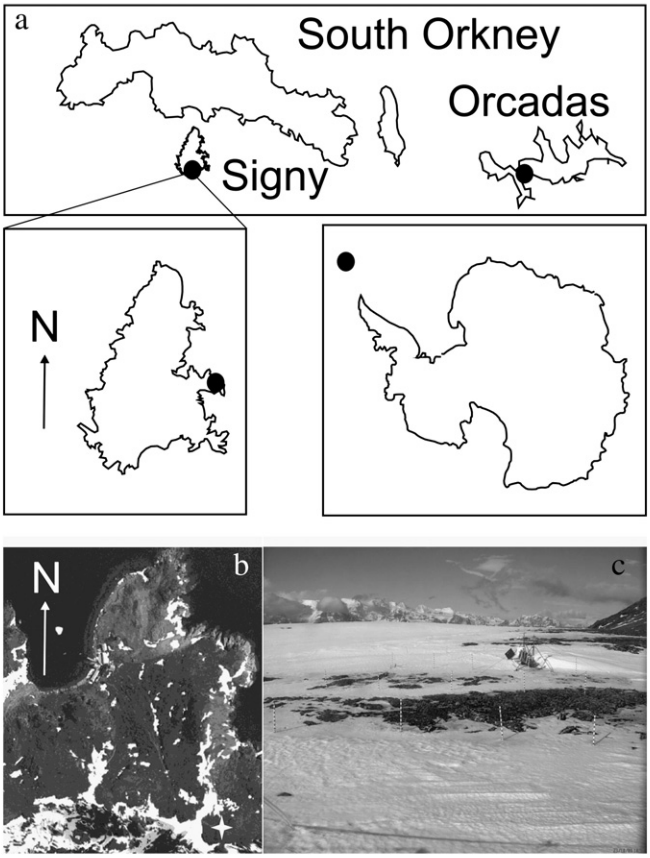


Fig. 1. Study area: a) location of the study area; b) aerial view of the study area and of the CALM grid (white star in the bottom right corner); c) view of the CALM grid, the AWS and the snow calm grid.

Studies carried out from the 1960s and 1970s on Signy Island (Chambers, 1966a,b, 1967, 1970; Holdgate et al., 1967; Collins et al., 1975) reported the occurrence of discontinuous permafrost with an active layer ranging between 40 cm and 2 m. More recently, a permafrost model (PERMDEM, Guglielmin et al., 2008b) based on the digital elevation model and the air lapse temperature shows that permafrost conditions in 2006 (Mean Annual Ground Surface Temperature, MAGST<0 °C) occurred over the entire island from the sea shoreline upward.

Signy soils are mainly Gelisols, with a prevalence of Psammoturbels, Haplorthels, Haploturbels, and Psammorthels. Histoturbels, Historthels, and Fibristels may occur in lowlands and on the western coast.

The geomorphology of the island is characterized mainly by periglacial landforms (Fig. 2), which were described in detail and monitored by Chambers (1966a, 1966b, 1967, 1970). Low-centered sorted circles, sorted stripes and stone-banked lobes are the most widespread landforms. Low-centered sorted circles occur preferentially in flat and depressed areas, at elevations lower than 80 m, and exhibit large variability in size, with diameters ranging between 2 and 5 m. At higher elevations high-centered sorted circles (ranging between 10 and 150 cm) occur, generally on flat summits. Unsorted circles are common, generally of a size similar to the high-centered sorted circles, but these do not show a clear distribution pattern. Frost boils also occur in some depressed and peaty areas, with diameters ranging from 0.2 to 0.7 m. No ice wedge polygons or sand wedge polygons were found, although some poorly defined frost fissure polygons occur on the flat and highest ice-free areas of the island. Soil stripes are mainly sorted with a width ranging from 10 to 210 cm at the same site. Soil stripes are developed in till and on colluvial deposits where the slope is greater than 4°–6°. Transitional features from low-centered circles to sorted stripes are also present.