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Preface

Recent advances in the study of active layer thermal regime and seasonal frost dynamics in cold climate environments

This Special Issue entitled "Recent advances in the study of active layer thermal regime and seasonal frost dynamics in cold climate environments" encompasses a wide and diverse range of studies focusing on soil thermal characterization and its implications for terrestrial ecosystems. The Special Issue arise from the necessity of better understanding thermal regime dynamics of active layer and seasonal frost in different areas of the globe. A session was convened at the European Geosciences Union (EGU) General Assembly 2015 focusing on these topics that attracted 32 contributions divided into two oral sessions and a well-attended poster session. The result is this Special Issue, the first work that compiles the recent research studies on active layer and seasonal frost dynamics in one unique number.

Environmental dynamics and landforms in Polar Regions, mountain environments and high plateaus are profoundly affected by the cold climate conditions. Hydrological, ecological, edaphic, and geomorphic processes in ice-free environments from these areas depend on the magnitude and persistence of the cold. The moisture regime and particularly snow cover strongly influences terrestrial ecosystem dynamics in these regions. However, temperatures as well as the depth and duration of snow cover are highly variable depending on the latitude, altitude, topography and/or distance to moisture sources. Based on the combination of cold temperatures and snow cover, the ground will remain seasonally or permanently frozen.

Approximately 25% of Earth's land surface is currently experiencing periglacial conditions (French, 2007), with 22 million km^2 underlined by permafrost and the rest affected by seasonal frost conditions (Gruber, 2012). Most permafrost and seasonal frost environments are distributed in the Northern Hemisphere (Brown et al., 1997); Zhang et al. (2003) quantified this as ~48.1 × 10^6 km^2 or 50.5% of exposed land in the Northern Hemisphere that experiences seasonally frozen ground conditions. The depth of the seasonal frost in periglacial environments without permafrost conditions ranges from a few centimetres to several few meters (French, 2007).

Together with climate, topography is a key factor controlling frozen soil conditions. The geomorphic setting strongly influences the distribution and depth of snow cover, delaying or advancing its melting (Ishikawa et al., 2003; Zhang, 2005; Edwards et al., 2007). Snow melting leads to soil thawing; the rhythm of freezing and thawing, both for seasonal frost and active layer dynamics, has strong implications for cryogenic, geomorphic and ecologic processes, conditioning the extent and type of vegetation cover, surface runoff, sediment production, erosion and mass-wasting processes (Oliva et al., 2011). At the same time, the thermal regime of the ground, together with soil types, lithology, orography and aspect, also controls the physical and chemical processes affecting soil, sediment and bedrock exposed to atmospheric oscillations (Hanson and Hoelzle, 2004).

While mechanical properties of the ground are important to geotechnical engineering, physical characteristics are more useful to periglacial geomorphology, geocryology and hydrology (French, 2007). Landscapes and landforms in periglacial and permafrost environments can be mostly explained through the frozen ground conditions (Ballantyne and Harris, 1994). These landforms result from: (a) the growth of discrete ice bodies within permafrost; (b) the unusual groundwater hydrology that characterizes permafrost terrain; (c) the thermal properties of earth materials when subject to freezing; (d) and from the ability of warm, ice-rich permafrost to creep and deform under its own weight (Washburn, 1979; Harris, 1986). Relict permafrost landforms exist today in non-permafrost environments reveal past climate conditions (French, 2007). However, deep seasonal frost, rather than permafrost, was probably more typical for much of the past, disturbing the ground at different depths (Williams and Smith, 1989). Seasonal frost results in fluctuations of temperature and moisture, which promote the occurrence of freeze–thaw induced processes, such as frost creep, shallow solifluction or patterned ground (Matsuoka, 2001). Despite producing small movement processes, the cumulative amount of these processes can be considerable in some areas and result in the formation of periglacial landforms. Ground temperatures have also an important effect on soil engineering behaviour and must be considered in the design of frozen ground support systems and other constructed facilities in cold regions. A significant number of geotechnical and engineering problems are related to the existence of permafrost or seasonal frost conditions. These can be summarized as being either frost heave, thaw-subsidence or hydrologic in nature (Andersland and Ladanyi, 1994).

Despite the vast areas Earth's surface occupied by cold environments, little work has encompassed the study of processes directly related to soil thermal conditions. The first references to the study on soil thermal regime were published during the first half of the 20th century (e.g., Krylov, 1934; Jenness, 1949). During the second half of the 20th century, researchers have examined the factors controlling soil thermal regime from a wide range of perspectives, with a major focus on snow cover (e.g., Goodrich, 1982). The most significant advances occurred following the International Polar Year (2007–2009), which enhanced permafrost research in Polar Regions, particularly in mountain regions (e.g., Haeberli et al., 2010), the Arctic (e.g., Romanovsky et al., 2010), and to a lesser extent in Antarctica (e.g., Vieira et al., 2010). Many of these studies have focused on the monitoring the thermal state of permafrost (Lewkowicz, 2010) as well as its distribution on Earth (Gruber, 2012).

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The International Permafrost Association has played a key role in the development of these studies through the coordination and implementation of the Global Terrestrial Network for Permafrost (GTN-P), which supports two international monitoring networks that includes Thermal State of Permafrost (TSP) and Circumpolar Active Layer Monitoring (CALM). The first network aims to assess the rate of change of permafrost temperatures and distribution, while the essential objective of the CALM network is to observe the evolution and response to climate change of the active layer and near-surface permafrost in a long-term perspective. Most of the study sites of these networks are located in polar and subpolar environments; a wide range of data derived from these initiatives are accessible online (http://gtnp.arcticportal.org/). During the last few years, there has also been an increase of studies on active layer and seasonal frost dynamics in mountain environments, mainly in the major ranges of the world (e.g., Harris et al., 2003; Magnin et al., 2015; Oliva et al., 2014; Pogliotti et al., 2015). As some of these regions are densely populated, new approaches on permafrost and seasonal frost studies are essential to achieve a better understanding of terrestrial ecosystem dynamics in these areas as well as to help mitigate natural hazards associated with ground thermal conditions (Kääb et al., 2005; Fischer et al., 2012).

Projected climate changes will most likely lead to decreases in the global extent of permafrost, seasonal frost and snow cover, and sea ice (IPCC, 2014). This will affect both local and global hydrology, nature and distribution of plants and animals, local and regional terrain instability, urban infrastructures and socio-economic implications (IPCC, 2014). Consequently, more studies on these topics are necessary to anticipate the environmental consequences of this future warming climate.

This Special Issue includes fourteen works focusing on several of these topics in Polar Regions and mountain environments. The first nine papers focus on Antarctica, mostly on active layer thermal conditions in remote areas and its influence on geomorphic and geoecologic processes; the following focuses on the Arctic and the role of grazing activities in CO_2 and soil temperatures; finally, the last three contributions discuss about seasonal frost and active layer dynamics with regards to topography and their implications for geomorphic processes in mid-latitude high mountain environments.

Ramos et al. (2016–this issue) studied the local variability of the active layer dynamics in Deception Island (South Shetland Islands, Antarctica) at the Crater Lake CALM site between 2006 and 2014. The authors observed that on average the permafrost temperatures ranged from −0.3 to −0.9 °C; the active layer was located at ~40 cm depth with a decreasing depth of about 1.5 cm/year as a result of an increased duration of snow cover during the study period. This study remarked the key role of snow cover in controlling active layer dynamics in areas where permafrost is close to their boundary climate conditions. Correia et al. (2016–this issue) carried out a combined geophysical and geomorphic approach to identify the elevation limits of permafrost distribution in Byers Peninsula (Livingston Island, South Shetland Islands, Antarctica). Electrical resistivity tomography surveying across Holocene marine terraces revealed the existence of sporadic permafrost patches at only 4–5 m asl. Consequently, this study provides new multidisciplinary evidence for redefining the limits of the lower limits of sporadic to discontinuous in the Maritime Antarctica. De Pablo et al. (2016–this issue) investigated the variability of snow cover between 2009 and 2014 near an Antarctic lake also in Byers Peninsula. They observed that the mean annual snow thickness during the study period was around 45 cm, with an increase of the snow cover duration over the last three years, from 267 to 338 days, which contributed to the reduction of active layer thickness and aggradation of permafrost. They concluded that the increasing snow cover duration is decreasing the thaw period and reducing the thickness of the active layer. As in the study by Ramos et al. (2016–this issue), these findings suggest the crucial importance of snow cover for explaining the interannual variability of active layer development in permafrost environments. Oliva et al. (2016–this issue) conducted a study focusing on its dynamics in three lake catchments from Byers Peninsula with distinct topographic characteristics and under different snow cover regimes with the purpose of better understanding the role of topography on active layer dynamics. The authors concluded that the relief played a key role explaining snow accumulation: the thickness and duration of snow determined ground thermal insulation and the variability of soils temperature in the different three studied sites. This work shows evidence of how the geomorphological setting controls snow accumulation and the variability of active layer thermal regimes. Ferreira et al. (2016–this issue) examined ground temperatures and the permafrost distribution in Hurd Peninsula (Livingston Island, Antarctica) using the Temperature at the Top Of the Permafrost (TTOP) model during the freezing seasons of 2007 and 2009. The authors confirmed the existence of continuous permafrost in bedrock above 140–150 m in this archipelago, with an active layer exceeding 5 m depth. As in study of Oliva et al. (2016–this issue), the existence of permafrost and active layer dynamics in Hurd Peninsula is also constrained by topography, in this case, the altitude. Almeida et al. (2016–this issue) investigated active layer dynamics in King George Island (South Shetland Islands, Antarctica) from March 2011 to November 2015. Soil temperatures near glaciated areas in this island showed a high variability in summer, which favour freezing-thawing cycles and the effectiveness of periglacial processes. The authors detected that soil temperature buffering was low due to the reduced soil moisture content, thick snow cover and absence of vegetation cover in this proglacial environment. The authors highlighted the fact that small changes in the thermal state of the active layer in recently deglaciated areas may have significant geomorphological consequences in these areas. Schaefer et al. (2016 this issue-b) studied the consequences of penguin distribution on permafrost and active layer thermal regime in Hope Bay (Antarctic Peninsula) from 2009 to 2011. The authors observed the strong impacts of guano deposition and their activity in active layer depth and soil thermal regime, stating their role as biological agent inducing permafrost degradation at these sites. This study emphasizes the wide range of factors affecting the soil thermal regime in the Maritime Antarctica; not only climate must be taken into account when interpreting changes in active layer dynamics, but also other factors such as biological activity must be also considered. Hrbáček et al. (2016–this issue) investigated active layer dynamics in two different lithological areas in Ulu Peninsula (James Ross Island, eastern Antarctic Peninsula) between January 2012 and December 2014. Significant differences were observed between the two sites: in areas composed of muddy to intermediate diamictites, tuffaceous siltstones to fine-grained sandstones, the active layer was thicker than the areas made of calcareous bedrock. The authors stated that the lithological properties of the ground have strong implications on active layer dynamics and thus in permafrost thermal state. Schaefer et al. (2016–this issue) monitored the active layer thermal regime in two sites in the Ellsworth Mountains (Continental Antarctica) during two years, between January 2012 and December 2013. The authors observed a significantly different soil thermal regime pattern than in the Maritime Antarctica. Despite the fact that the temperatures never reached positive values, soil temperatures within the thin active layer showed frequent oscillations in response to solar radiation changes. The authors defined the soil thermal regime in Ellsworth Mountains as typical from a polar desert with dry-frozen permafrost. Consequently, they concluded that the periglacial landforms existing in the area must have formed during past warmer climates.

In the Northern Hemisphere, Koster et al. (2016–this issue) studied the influence of reindeer grazing in soil temperatures, water content, and CO_2 emissions in a subarctic boreal coniferous forest along the borderline between Finland and Russia. The results showed that soil