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Short communication

Topsoil and snow: a continuum system

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ABSTRACT

Snow cover plays a fundamental role in terrestrial ecosystems, because it influences the Earth's climate, water quantity and quality, global biogeochemical cycles and soil properties. In particular, snow helps to create and maintain a specific pedo-environment through its influence on pedogenesis and topsoil characteristics, such as the thermal and water regimes and soil biogeochemistry. Importantly, seasonally snow covered regions are particularly susceptible to climate change, which could alter the timing and the quality of snow cover, with consequences on ecosystems and pedo-environments.

1. Introduction

Seasonal snow cover and soil frost affect about 60% of the terrestrial earth surface, ranging from high latitude tundra and forest biomes to mid-latitude forests and grasslands biomes, and includes many mountain regions (Zhang et al., 2004; Brooks et al., 2011). Seasonal snow cover is an important part of Earth's climate system, and in fact helps regulate the temperature of the Earth's surface because of its high albedo. The insulating properties of snow influence the underlying soil temperature regime and the extent to which soil is directly exposed to freezing and thawing episodes (Edwards et al., 2007). In forest and tundra greater snow depth insulates soils from cold air temperatures and allows higher levels of microbial nitrogen immobilization under snow, as well as decreases soil N_2O efflux (Li et al., 2016), while shallower snowpacks are associated with higher hydrologic nitrogen export (Brooks et al., 2011). Both CO_2 and CH_4 flux studies during winter demonstrate active carbon (C) cycling under seasonal snowpacks in different ecosystems (Brooks et al., 2011). Snow also accumulates significant amounts of particulates and solutes due to atmospheric deposition, which can be rapidly released during spring melt in the form of an ionic pulse (Filippa et al., 2010). Therefore, the seasonal snowpack has the potential to exert a significant impact not only on terrestrial but also on aquatic ecosystems (Edwards et al., 2007; Williams et al., 2009). Brooks and Williams (1999) reported that more than half of the annual inorganic nitrogen (N) deposition can be stored in the snowpack and released during snowmelt episodes. Nitrogen is flushed through the snowpack at the beginning of snowmelt and, in combination with that released from soil mineralization, results in a pulse of inorganic N under the snowpack (Edwards et al., 2007). The soil may function either as a source or sink of nutrients depending on the species involved and the extent to which snowmelt infiltrates (Brooks and Williams, 1999).

The seasonally snow covered regions are particularly susceptible to climate change, because small changes in temperature or precipitation may result in large changes in the amount and timing of snow cover (Brooks et al., 2011). Climate change may affect the seasonal snow cover in several ways: higher temperatures result in a higher percentage of the precipitation falling as rain instead of snow, causing snow covers to be thinner and to melt earlier, a phenomenon already visible in many mountain ranges (e.g. Laternser and Schneebeli, 2003; Viglietti et al., 2014). Snow density is likely to increase in a warmer climate, as higher temperatures may cause wetter snow and increase the frequency of wet-snow avalanches which exert considerably erosive forces on soils (e.g. Rasmus et al., 2004; Ceaglio et al., 2012). Interestingly, a warmer climate will not necessarily result in warmer soils: a thinner and denser snow cover will reduce the insulation of the soil (Rixen et al., 2008a). Consequently, alpine ecosystems might face the counterintuitive situation that soils could become colder in winter in a warmer climate (Groffman et al., 2001). Give that soil and snow are obviously connected, they could be considered a continuous system, therefore an interdisciplinary approach is required, with competences from snow and soil scientists (Guymon, 1978).

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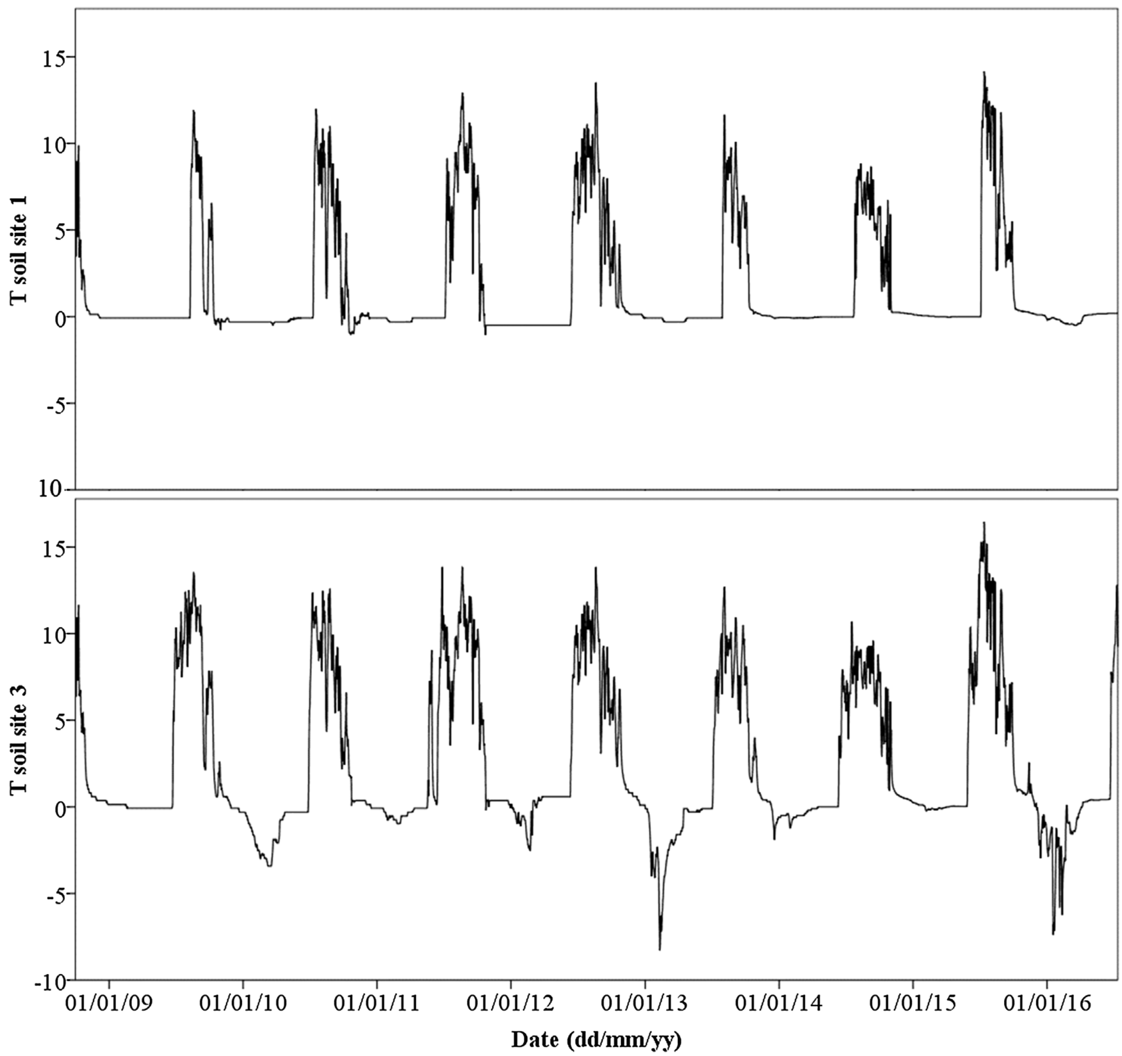

Fig. 1. Mean daily topsoil temperature (10 cm depth, °C) at site 1 (snowbed site, 2840 m a.s.l.) and site 3 (windblown snow site, 2770 m a.s.l.) registered from Fall 2008 to Summer 2016 at the LTER site Istituto Mosso (Piemonte Region, NW-Italian Alps).

2. Snow cover and subnivean soil properties

2.1. Soil temperature and microbial activity

Snow is an excellent thermal insulator and consistent seasonal snow cover effectively decouples soil temperature from the air temperature (Edwards and Cresser, 1992) (Fig. 1). Soils typically experience freezing conditions during early winter, sometimes before a deep snow cover accumulates to protect the soils from low air temperatures, remaining in a partially unfrozen condition (+1–−3 °C) (Jones, 1999): biological activity is surprisingly high at temperatures approaching subzero, which are typical of these subnivean conditions (Federer et al., 1990; Mikan et al., 2002; Panikov et al., 2006). The presence of liquid water has been identified as an essential prerequisite for physiological activity of microbes in any environment, including soils at near or subzero temperatures (Coxson and Parkinson, 1987; Mikan et al., 2002). In addition microbial activity is strongly affected by the supply of labile organic carbon (Boddy et al., 2008; Brooks et al., 2005; Buckeridge and Grogan, 2008) which during winter could be influenced by the effects of snow depth and soil thermal status on litter decomposition rates (Hobbie and Chapin, 1996; Sulkava and Huhta, 2003).

2.2. Snowmelt and soil nutrient cycling

The mountain snowpack represents an important source of nutrients and water for soils, because it can accumulate significant amounts of wet and dry atmospheric deposition which may be held in storage until release during a melt period (Filippa et al., 2010). In high-elevation areas, more than half of the year's N deposition is periodically stored in the snowpack (Hiltbrunner et al., 2005). Filippa et al. (2010) reported that in the NW Italian Alps dissolved inorganic N (ammonium and nitrate) stored in snow was comparable to concentrations found in other sites of the Alps, and corresponding to about 2–6% of the over-winter N mineralization in alpine soils. The melting of the snow cover defines the start and length of the growing season, and water and nutrients released from the snowpack influence soil moisture and nutrient status until later in the summer. Field and laboratory experiments have demonstrated that initial stages of snowmelt often have ionic concentrations many times higher than averages for the whole snowpack, referred to as an ionic pulse (Johannessen and Henriksen, 1978). Therefore, during snowmelt soluble inorganic N compounds and other N sources such as dust particles, are released into the soil in a relatively short time period, favouring the plant species which take up nutrients during snowmelt (Bilbrough and Welker, 2000; Hiltbrunner et al., 2005).