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Detection of mountain permafrost by combining conventional geophysical methods and thermal monitoring in the Retezat Mountains, Romania

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ABSTRACT

A combined approach consisting in thermal monitoring and geophysical investigations by means of ground penetrating radar and electrical resistivity tomography was used to examine permafrost distribution within four rock glaciers in the Retezat Mountains. The small-scale variability of permafrost presence or absence above 2000 m in Southern Carpathians is determined by local surface cover characteristics. Therefore, the permafrost existence is limited to those sites where very large boulders occur, the income of solar radiation is reduced and the cooling effect of the coarse blocks is extremely efficient. Based on the thermal data, permafrost appears likely at those sites, where a strong cooling occurs in the early winter due to ground air flow (convection, advection). During the winter, below the thick snow cover an additional cooling mechanism is likely the result of low thermal conductivity of coarse blocks at sites where internal ventilation is inhibited. At these sites the mean annual ground surface temperature (MAGST) is negative, the temperatures at the bottom of the snow cover (BTS) at the end of the winter are lower than −3 °C and the ground freezing index (GFI) values are higher than 600 °C days. By contrast, BTS, MAGST and GFI values show a warmer pattern in the upper part of the ventilated zones, where inverse thermal behavior at the ground surface occur especially during cold seasons.

1. Introduction

The spatial distribution of mountain permafrost at middle and low latitudes is strongly controlled by local topo-climatic factors and surface characteristics (Harris et al., 2009). Among the local factors, incoming solar radiation and the presence or absence of coarse blocks along with the snow cover are the main factors controlling the ground thermal regime and thus the characteristics of the permafrost (Otto et al., 2012; Rödder and Kneisel, 2012). In mountain regions, these factors show extreme spatial variability because of the influence of rugged topography. Therefore, permafrost at the lower limits of its occurrence is restricted only to those sites in which the energy fluxes at the ground surface are thermally favorable (Haeberli and Gruber, 2009).

Because large differences in the energy balance at the ground surface may exist within short distances, the spatial distribution of permafrost is often complicated (Hoelzle et al., 2001). Because of the heterogeneous surface and subsurface conditions and the restricted drilling possibilities, alternative methods have been established over the last few decades to provide subsurface information regarding permanently frozen ground (Kneisel and Hauck, 2008).

Because several physical parameters record remarkable changes when the water within the substrate reaches the freezing point, geophysical techniques are suitable methods for permafrost detection, mapping, characterization and monitoring (Hauck, 2001). The applied geophysical methods in mountain permafrost consisted of mainly electrical resistivity tomography (ERT), refraction seismic tomography and ground penetrating radar (GPR). To avoid ambiguities in the interpretation of the results, at least two methods should be combined (Kneisel and Hauck, 2003). In addition, the spatial distribution of mountain permafrost is assessed by generally using a combination of conventional geophysical methods and measurements of the bottom temperature of snow cover and the ground surface temperature (GST) (Vonder Mühll et al., 2002).

In Romania, scientific evidence concerning the permafrost is sparse (Onaca, 2013). According to previous studies, sporadic permafrost could occur in the Southern Carpathians at sites particularly favorable for permafrost conservation (Onaca et al., 2013; Popescu et al., in press). These isolated patches of permanently frozen materials are expected to occur above 2000 m on the north-facing slopes of the highest mountain ranges in the Southern Carpathians (e.g., Făgăraş, Parâng and Retezat Mountains). In the Southern Carpathians, the permafrost is associated with permafrost creep landforms (e.g., rock glaciers), and its

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occurrence is restricted only to those openwork structures characterized by a high porosity (Urdea, 2000).

Despite several recent findings, the spatial distribution of permafrost in the Southern Carpathians is still poorly known. The earliest pioneer study on permafrost distribution was performed by Urdea (1992). That study was the first to conduct BTS measurements in the central part of the Retezat Mountains. His assumption regarding the occurrence of sporadic permafrost in several rock glaciers in the Retezat Mountains was confirmed by recent geophysical investigations, BTS measurements and GST monitoring (Urdea et al., 2008; Vespremeanu-Stroe et al., 2012; Onaca et al., 2013).

In this context, our paper aims to examine the local permafrost distribution at several sites in the Retezat Mountains and to characterize the thermal conditions within unconsolidated coarse sediments. A better understanding of the role of the parameters governing the ground surface thermal regime is also required for future models of the spatial distribution of permafrost in the Romanian Carpathians. To achieve these goals, conventional geophysical investigations using electrical resistivity tomography and ground penetrating radar and thermal monitoring using miniature thermistors have been recently performed in the Retezat Mountains.

2. Study area

Field investigations were performed in the central part of the Retezat Mountains (45°20′N, 22°23′E) (Fig. 1) in which a high density of rock glaciers is present (Urdea, 2000). This mountain range is located in the western part of the Southern Carpathians and is one of the highest mountain units in Romania. Several peeks exceed 2400 m (e.g., Peleaga, 2509 m; Păpuşa, 2502 m; Retezat, 2482 m, etc.), whereas the tree line lies at 1700–1800 m. This region is included in the Autohton tectonic domain, and the predominant lithology consists of granodiorites. Numerous active periglacial landforms occur between the highest peaks and the tree line (rock glaciers, solifluction, block streams, patterned ground, etc.) (Urdea, 2000). The alpine landscape is dominated by clear evidence of Pleistocene glaciations (glacial cirques, “U” shaped valleys, moraines, etc.).

According to climatic records in the Southern Carpathians, the calculated 0 °C mean annual temperature is at 2050 m, whereas at 2500 m, the extrapolated mean annual temperature is approximately −2.5 °C (Voiculescu, 2000). The mean annual precipitation on the highest peaks varies between 900 and 1000 mm, but between October and May, the precipitation falls primarily as snow. At Bâlea Lac meteorological station

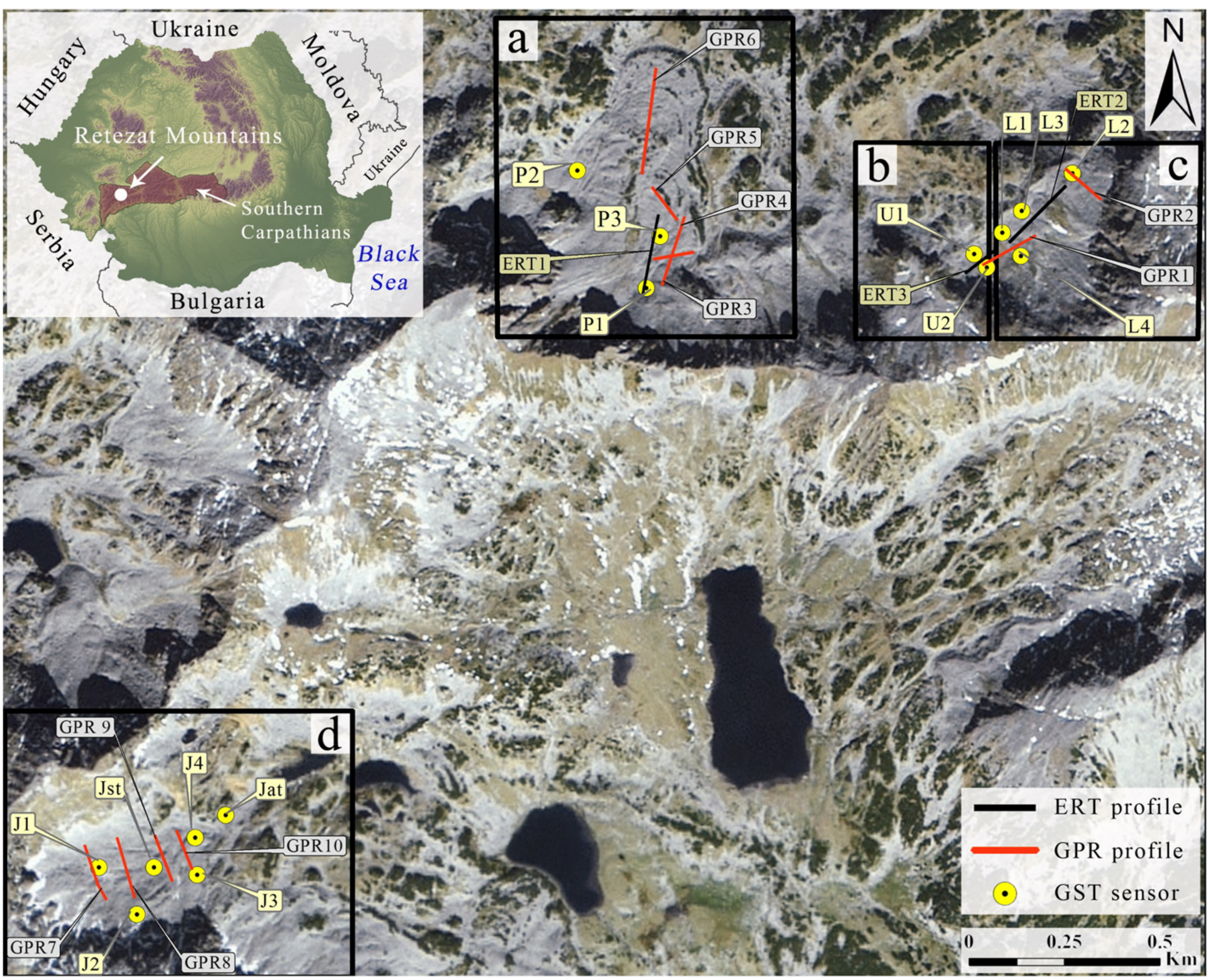

Fig. 1. Location of the central part of Retezat Mountains with the position of the GST sensors and the location of ERT and GPR profiles on the orthophotomap. Sites: (a) Pietrele; (b) Upper Pietricelele; (c) Pietricelele; (d), Judele.