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THERMAL DYNAMICS OF THE PERMAFROST ACTIVE LAYER IN EBBA VALLEY (CENTRAL SPITSBERGEN) IN THE YEARS 2009-2012

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ABSTRACT

During the period between summer 2009 and summer 2012 measurements of ground temperature in active layer of permafrost were conducted. Studies were realised in Ebba valley (central Spitsbergen). For this part of Svalbard archipelago dry polar climate type is distinctive. Variations in the ground temperatures had a typical course in the summer months but some significant anomalies were observed during winter periods. Ground thermal conditions are strongly influenced by air temperature changes but vegetation cover and sediment moisture are also relevant. Studies show that active layer properties are spatially differentiated and selection of representative measuring positions is a complex issue.

KEYWORDS: Active Layer, Ground Temperature, Permafrost, Svalbard

INTRODUCTION

Permafrost occurs in basis of 20% of the terrestrial area on the Earth (French 2007; Repelewska-Pękalowa, Pękala 2007). It is also one of the most sensitive components of the arctic system (French, Dobiński 1998; Miętus, Filipiak 2004). Due to forecasted and locally observed global warming effect permafrost becomes a significant scientific problem. It is defined as a ground or rock which has at least for two subsequent years temperature below 0°C (Jahn 1970; French 2007). Most frequently various forms of ground ice are present in the sediment. While in rocks and in some deposits permafrost can be ice-free. Furthermore the water contained in the sediment despite exceeding the freezing point may occasionally remain in a liquid state (French 2007). Seasonally thawing upper part of permafrost is described as active layer.

The aim of this studies was to determine the ground temperature changes of active layer in the Ebba valley with reference to generally observed trends in the cryosphere. Moreover to describe the differences in temperature variations between different parts of the valley. Measurements started in the summer 2009 and were continued until the end of summer 2012. Currently it is one of the longest series of ground temperature measurements in this part of central Spitsbergen.

Research on permafrost thermal dynamics and active layer changes are conducted on a wide scale in Arctic regions. The most important organisation coordinating the permafrost studies is International Permafrost Association (IPA). Thanks to its activity actions designed to propagate data and knowledge about periglacial environments are undertaken. Establishing Global Terrestrial Network on Permafrost (GTN-P) and Circumpolar Active Layer Monitoring Network (CALM) should be mentioned, providing standards of permafrost observations. Synthesis on thermal state of permafrost in the Polar Northern Hemisphere was presented by Romanovsky *et al.* (2010) and Christiansen *et al.* (2010). More detailed works on the permafrost properties on Svalbard were realised by Humlum *et al.* (2003), Isaksen *et al.* (2000), Isaksen *et al.* (2007).

Study Area

Ebba Valley (figure 1) is located in Svalbard's largest island – Spitsbergen and is perpendicular to the eastern coast of Petunia Bay (the northern tip of Bille Fjord).

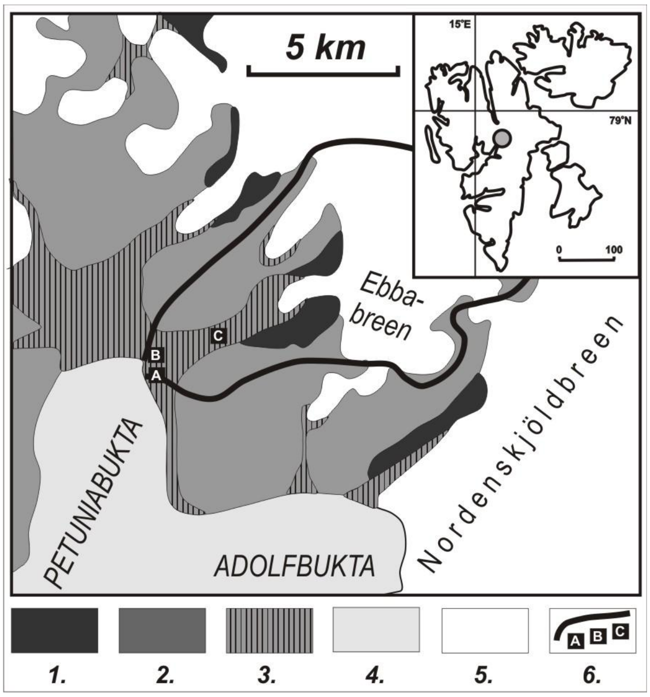

Figure 1: Location of the Study Site: 1. Metamorphic Bedrock, 2. Sedimentary Rocks, 3. Quaternary Sediments, 4. Fjord, 5. Glaciers, 6. Ebba Valley Catchment Border and Measurement Points Location

It is very diverse region. The analysed area is characterised by relatively large differences in sediment and forms (Rachlewicz *et al.* 2013). Typical for the mouth section of the Ebba Valley are raised marine terraces mainly consisting of sands and gravels. Material often contains fragments of mollusc shells. The bedrock and also locally slopes of the valley are covered with glacial sediments. Landforms of glacial origin are dominating. The modern ground surface is mainly modelled by fluvioglacial processes. On the slopes of the mountain massifs mass movements induced by periglacial processes are often observed (Kłysz *et al.* 1989).

The mean annual temperature of the Petunia Bay region is about -6.5°C (Rachlewicz, Szczuciński 2008). Warmest months are July and August (average temperature about 5- 6°C). The period with temperatures above 0°C begins in mid-May or early June and usually lasts until early September. In relation to the other meteorological stations located on Spitsbergen relatively high air temperature during summer is observed (Rachlewicz 2003; Rachlewicz, Styszyńska 2007; Przybylak *et al.* 2014). Values of the annual precipitation are relatively low (less than 200 mm per year). Precipitation very rarely is exceeding 10 mm per day. Snow cover is usually not thick due to strong local winds (Rachlewicz 2003; Przybylak *et al.* 2006; Rachlewicz, Szczuciński 2008). For the Ebba Valley the presence of southern and north-east winds is characteristic (Przybylak *et al.* 2006). However, maximum wind speed gusts were observed from the east, north and north-west (Rachlewicz 2003).

The study area is located in the Arctic tundra zone, mostly with the moss and lichen vegetation. Vascular plant species like *Dryas octopetala*, *Salix polaris*, *Saxifraga oppositifolia*, *Saxifraga cernua* and *Cassiope tetragona* are also observed (Buchwal *et al.* 2013a). Ebba valley is considered as representative for the Bille Fjord region in terms of relief, land coverage, topoclimate, etc. (Rachlewicz *et al.* 2013).

Previous studies on ground temperature changes and periglacial processes in Ebba valley were conducted by Kostrzewski *et al.* (1989), Gibas *et al.* (2005) and Rachlewicz, Szczuciński (2008). They recorded maximum active layer thickness, depending on the character of sedimentary covers, reaching 2.5 m, and registration of positive temperatures of the ground were limited only to the period of observations, between half of June and end of September (Rachlewicz, Szczucinski 2008), showing dynamic early summer heat propagation down the active layer and the zero curtain effect formation during the fall.

METHODS

Measurements were conducted on three measuring points. First (A) was located on one of raised marine terraces (about 5 m above sea level) with dense vegetation cover. Second (B) on relatively more humid tundra surface on lower terrace (2-3 m above sea level) in the river mouth section. Points A and B were located at the distance of about 200 m from the coast (figure 1). Third point (C) represented middle part of the valley, about 2 km from the coast and *ca.* 25 m a.s.l., with very low vegetation cover. “Log Tag TRIX-8” sensors were used for temperature measurements. This devices can operate in the range of temperatures -40°C do 85°C with an accuracy better than ±0.5°C and ±0.8°C. Measurements were recorded constantly at specified intervals (in this case 1 hour) throughout the whole year with a resolution of 0.1°C. Unfortunately, this equipment has proved to be very sensitive to moisture.

Sensors were located at depths: 5, 10, 25, 50 and 75 cm below the ground surface at measuring points A and C. Due to the high water content of the soil at measuring point B measurements were possible only at depths 5 and 10 cm.

Basic meteorological monitoring was conducted for the whole period near the point A (however, beyond the summer seasons only the air temperature was measured). As a part of broader research, analyses of sediment properties changes with depth (standard particle size distribution laboratory analysis of the deposits at points A, B and C) and vegetation cover spatial characteristics were additionally made.

RESULTS

The most complete data set was collected for the measuring point A (figure 2). Data represents three full winter and two full summer seasons (figure 2, figure 3, figure 4).

Extreme values observed at point A were between +10.8°C and -29.7°C. For point B they amounted +11.4°C and -20.2°C. The values at point C ranged from +13.5°C to -27.7°C.

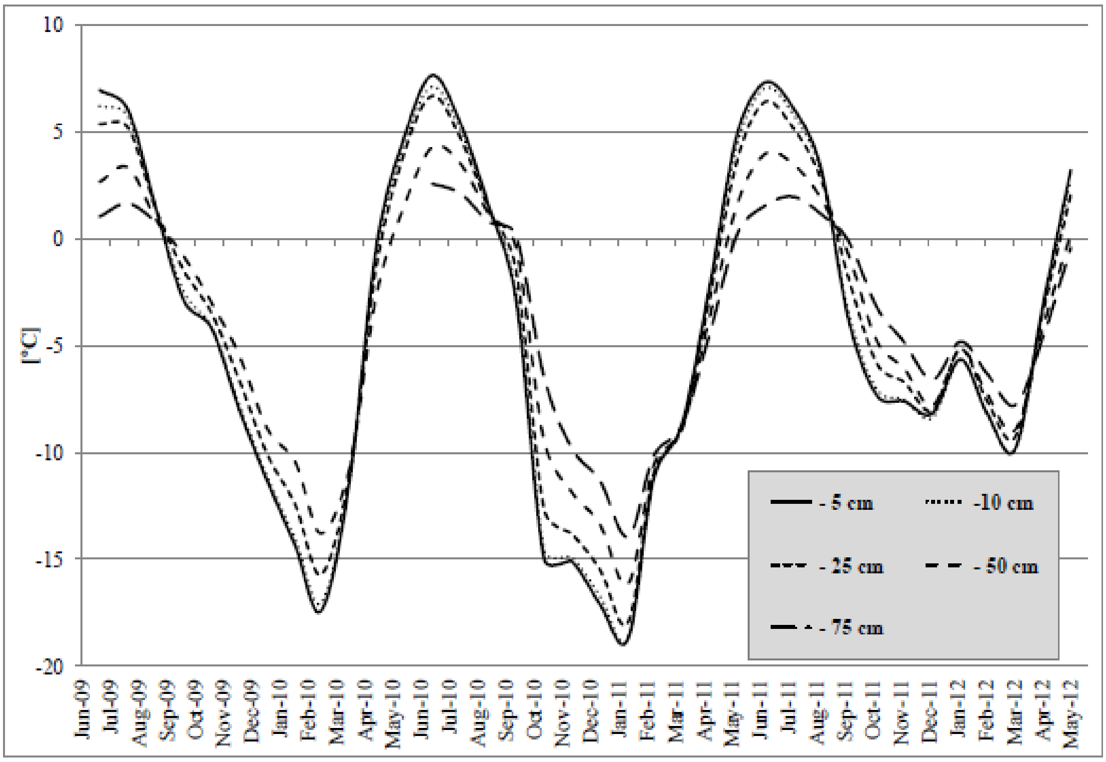

Figure 2: Monthly Average Ground Temperature 2009-2012, Point A, Ebba Valley, Svalbard

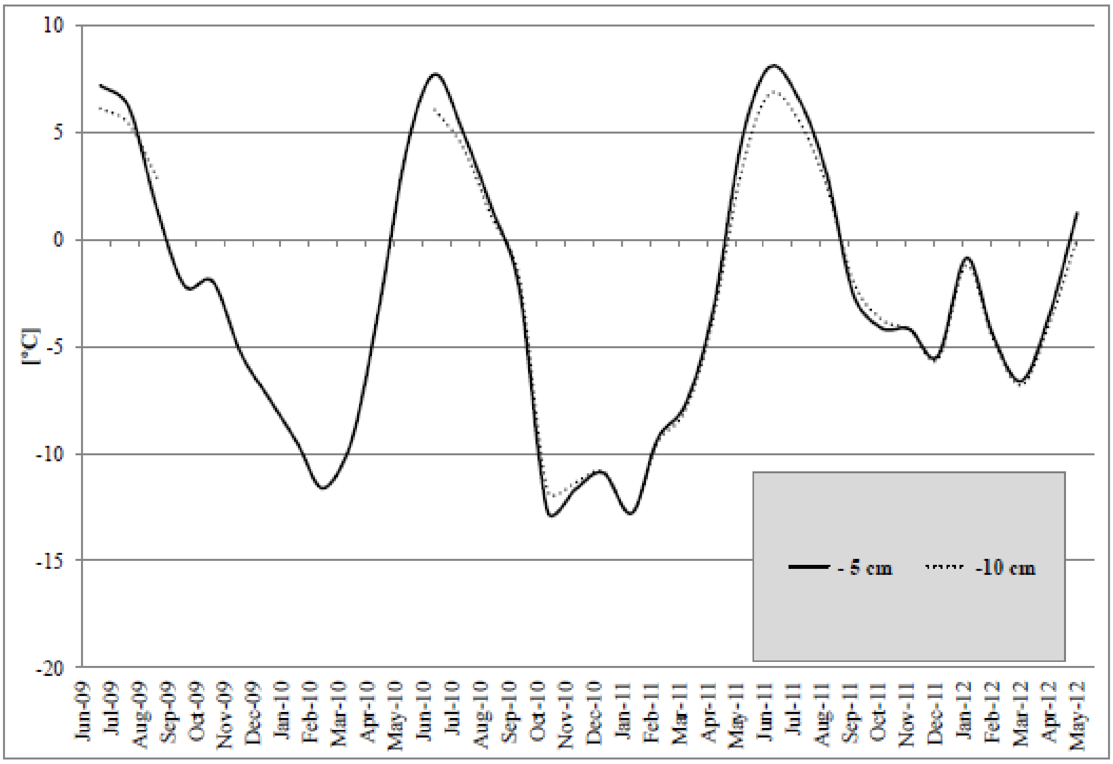

Figure 3: Monthly Average Ground Temperature 2009-2012, Point B, Ebba Valley, Svalbard

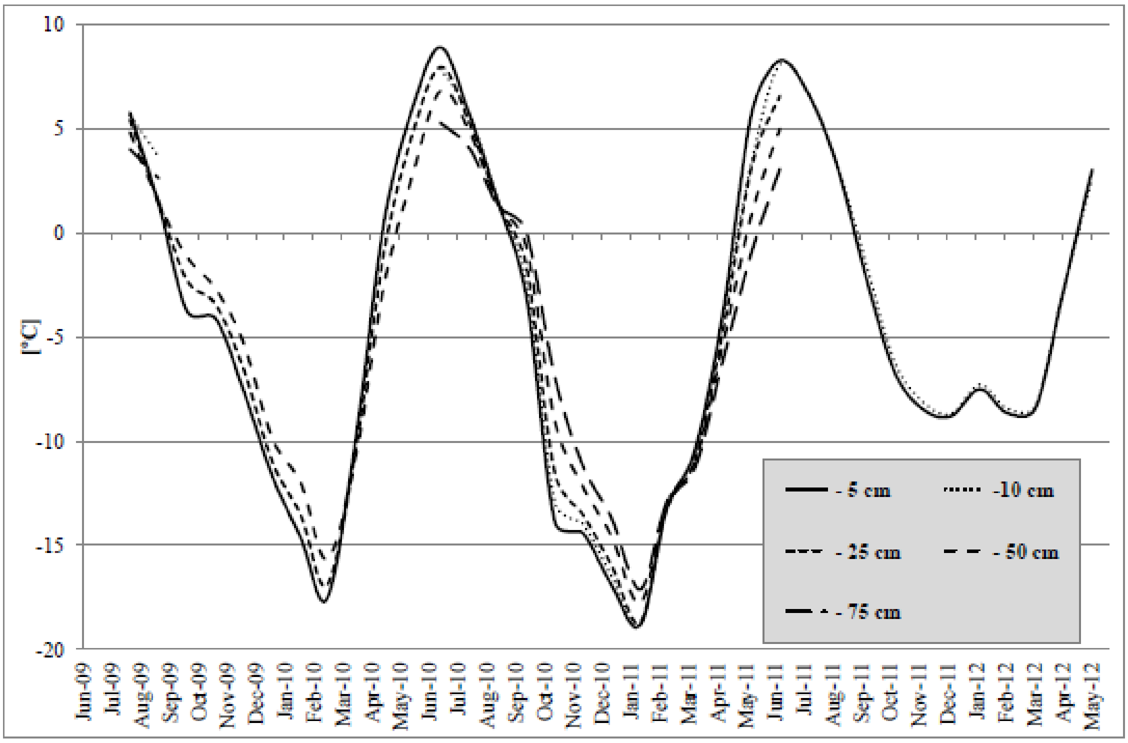

Figure 4: Monthly Average Ground Temperature 2009-2012, Point C, Ebba Valley, Svalbard

In the summer seasons ground temperature had typical thermal gradient. The highest temperatures were recorded closer to the ground surface. Furthermore greater and more frequent temperature variations occur also in the upper part of the ground profile. However, thermal gradient after total freeze-up (in cold season) keeps reversed: temperature rises with depth.

Closer analysis of the dataset shows that heat pulse reaches the lower lying layers of the soil with a well-defined delay. The delay varies from 1 hour to 2 days. Moreover ground temperature is responding more quickly to increase of the air temperature than to the cooling. Mentioned response of the lowermost layers of permafrost active layer may be up to 50% slower to the cooling than to the heating.

Authors observed very clear occurrence of the zero curtain effect during freezing and thawing of the soil. It is closely connected with the water content of the sediment.

The sediments in the analysed locations are composed of poorly to moderately sorted sands and gravels. Lithology of the sediments at points A and B shows increase of grain size with depth. At the less humid point A it is the transition from medium sand, through coarse sand, to fine gravel. At point B very fine sand, fine and medium sand, to coarse sand percentage increase occurs with depth. Changes of the sediment at point C does not show any significant trend. Here are primarily very coarse sand, coarse and medium sand. Deposits genesis is connected mostly with marine and fluvial activity in Ebba valley area.

Vegetation cover in the costal part of the valley depends mostly on the terrain type and in lower and more humid parts of the area greater diversity of plant species is observed. Tundra is composed here of *Dryas octopetala*, *Equisetum arvense*, *Salix polaris*, *Carex rupestris*, *Cassiope tetragona* and *Saxifraga oppositifolia*. This species cover up to 70% of the terrain. Middle part of the Ebba valley has a very low vegetation cover. Only some species occur sporadically, covering up to 10% of the ground surface.

DISCUSSIONS

Analysis of the ground temperature changes in the years 2009 and 2012 (figure 2) shows that courses of the temperature during the summers are relatively stable. However, the situation differs in winter seasons. First winter 2009/2010 was generally typical for this climatic zone, starting with temperature drop below 0°C at 16.09.2009. Second one 2010/2011 has started earlier with higher decrease in average ground temperatures. Third winter 2011/2012 was definitely warmer than the previous ones. Winter thaws are not unusual for Svalbard climate but recently are more noticeable. It is also valuable information from the climatological point of view and important in terms of vegetation development (Buchwal *et al.* 2013b).

Calculations concerning the period from 11.08.2009 to 27.08.2009 have shown a strong correlation (0.9-0.8) between air and ground temperatures for the 0.1 m subsurface layers of the ground. The strongest dependence was at points A and B. This is related to the fact that more humid sediments are characterized by higher thermal conductivity. Thus in spatial diversity of ground temperature the most important factors were: the presence of vegetation cover, preventing soil drying, and sediment moisture (poor correlation with soil grain size composition and other factors were found). However, topography and sediment properties have also an indirect impact.

Comparison of the thermal conditions on the three measuring points was done by combining average data for the warmest (August 2010) and coldest (February 2011) months (table 1). In the summer the highest ground temperatures were recorded at point C and the lowest at point B. Lack of vegetation cover and lower moisture content at the point C result in more effective ground surface heating and faster heat supply to the lower parts of the active layer. On the other hand at point B water contained in the sediment longer heats up. While during the winter season ground cools down much more slower.

Some impact may also come from topoclimatic conditions, air temperature and humidity distribution within the valley, depending on the distance from the coast and slopes exposition as shown by Bednorz, Kolendowicz (2010).

Table 1: Mean Ground Temperature in August 2010 and February 2011, Ebba Valley

Depth	A [ºC]	B [ºC]	C [ºC]
5 cm	5.4 / *-18.7*	5.0 / *-12.8*	5.7 / *-18.8*
10 cm	5.1 / *-18.7*	4.3 / *-12.8*	5.7 / *-18.8*
25 cm	4.7 / *-18.0*	-	5.3 / *-18.7*
50 cm	3.5 / *-16.2*	-	4.9 / *-17.8*
75 cm	2.1 / *-14.0*	-	4.1 / *-17.1*

CONCLUSIONS

Changes of the ground temperature within permafrost active layer in Ebba valley show important anomalies in cold seasons. Because majority of research works are realized during the short summer seasons greater attention should be given to crucial winter period.

Most important role in ground temperature profile development play temporal air temperature distribution, however, variations are generated because of differences in ground water content and plant habitats level of development, strongly connected with geomorphic stability.

Thanks to this studies it was demonstrated that monthly average ground temperatures can vary up to 6°C even in very close locations in one valley. Selection of adequate and representative measuring point should be always based on good recognition of the particular geoecosystem.

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