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Wojciech Dobiński*
Sosnowiec

DISTRIBUTION OF MOUNTAIN PERMAFROST IN THE HIGH TATRAS BASED ON FREEZING AND THAWING INDICES

Abstract

Analysis was carried out in order to state whether in the High Tatras exist potential climatic conditions to preserve permafrost. Using freezing and thawing method it has been found that the High Tatras are in zone of potential occurrence of continuous, discontinuous and sporadic permafrost. The results are presented in the paper.

INTRODUCTION

Tatras represent mountains which include periglacial zone. Although the investigation of this zone has been carried out for several decades (e.g. Czudek, 1986; Jahn, 1958, 1970; Klimaszewski, 1988; Kotarba *et al.*, 1988) the problem of occurrence of conditions favourable for permafrost development was neglected. Only recently, this problem was taken up by the Department of Geomorphology, University of Silesia. Several tens electro-resistance soundings and hundreds of BTS measurements have been done to investigate this problem (Dobiński, 1996; Dobiński *et al.*, 1996).

This paper presents results of climatic analysis which shows that in the High Tatras potential climatic conditions exist to preserve permafrost.

PHYSICAL SETTING

Tatra Mountains are located in southern Poland (Fig. 1), and originated in the Alpine orogenesis. The highest summits exceed 2.600 m a.s.l. The features of alpine landscape are derived from the Pleistocene, when local glaciers developed several times.

The total area of these mountains is about 750 km^2, and the High Tatras, being the highest part of the range occupy about one third of this

* Department of Geomorphology, Faculty of Earth Sciences, University of Silesia, ul. Będzińska 60, 41–200 Sosnowiec; dobin @ ultra.cto.us.edu.pl

Fig. 1. Location of research area in Poland

Rys. 1. Lokalizacja obszaru badań w Polsce

area. The main crest of the High Tatras is 26,5 km long. It runs almost with a parallel of latitude and its average height is 2279 m a.s.l. (KLIMASZEWSKI, 1988; LUKNIŠ, 1975).

Because of large absolute altitude of the Tatra massive, two climatic zones, namely moderately cold and cold are distinguished. In the moderately cold zone, 0°C temperature occurs on the northern slopes at the altitude of 1850 m; on the southern slopes, it occurs on the altitude of 2050 m. Average annual air temperature on the highest summits inTatras is −4°C. The sums of temperatures higher and lower than 0°C reach values of 1000°. At this altitude, there are 135 days with frost per year. The amount of precipitation in the Tatra Mts. classifies the climate of this area to a wet type and part of this precipitation makes a snow cover of a thickness from 115 to 230 cm (HESS, 1965, 1974).

THAWING AND FREEZING INDICES METHOD

This method enables to estimate in a large scale, but also more generally, climatic conditions which favour the development and preservation of permafrost. It has been long ago widely used in climatology as indices of sums of plus and minus temperatures. The *thawing and freezing indices method* was first used by HARRIS (1981a, b, c) to estimate conditions of permafrost occurrence. The results of such analysis for the High Tatras show rather potential possiblities of permafrost occurrence in this area than actual climatic limit conditions of permafrost occurrence. Because of the Alpine nature of these mountains, these conditions show considerable changeability, which, in turn, influences changeable character of mezo- and micro-climatic conditions of this area.

The conception of thawing and freezing indices is based on a freezing index which is a sum of minus avearge daily air temperatures in a year, and a thawing index is a sum of plus average daily air temperatures in a year (HARRIS, 1981a, b).

Basing on data from the meteorological stations situated in different parts of the world where permafrost is present, a special diagram was worked out (HARRIS, 1981a). This diagram shows the meteorological stations with thawing and freezing indices calculated for each of them, however, it includes only these regions where average snow thickness is less than 50 cm; the diagram provide also the information about the type of permafrost at each site (continuous, discontinuous, sporadic).

Penetration of the cold from the atmosphere to the soil is possible only when snow cover is not thicker than 50 cm because the cold may easily penetrate down and air temperature may strongly influence the soil surface causing freezing or thawing.

On the diagram, the places with different types of permafrost are separated by limit lines. The limit of continuous permafrost considerably depends on the degree of climate continentalisation of the area and it cuts an isotherm –5°C for the values of thawing and freezing indices of about –3200 and 1300. Such run of this limit results in differences of the limit isotherm for a continuous permafrost from –5°C (JAHN, 1970) to –8°C (HAEBERLI, 1985). The external limit of the discontinuous permafrost is close to an average annual air isotherm 0°C (on its colder side). Below, there is a limit of sporadic permafrost zone, which has been determined mainly on the ice in ice caves.

On the basis of Harris diagram the following conclusions may be taken from the data and relationships between the run of the limit for individual types of permafrost and sums of plus and minus average daily temperatures:

– Increasing sums of plus and minus temperatures indicate more continental climate and decreasing sums indicate more oceanic climate. This is associated with the amount of precipitation;

– In the continental climate, the course of the limits between different types of permafrost is clear, the zones are wider and only considerable change of temperature sums may cause changes in this zone. Quite opposite situation may be observed in the wet climate. Even small differences in sums of annual temperatures may influence changes in the location of the site in particular zones.

RESULTS OF THE CLIMATIC DATA ANALYSIS FROM THE HIGH TATRAS

Climatic data which were used to the analysis of thawing and freezing indices were collected from the meteorological stations situated in the High

Tatras (Łomnicki Szczyt – summit, Kasprowy Wierch – summit, Skale Pleso – lake, Pięć Stawów Polskich Valley, Gąsienicowa Valley and Morskie Oko – lake). Data from the Polish side of the High Tatras concern the period 1985–1989 whereas data from the Slovakian side concern the period 1985–1994. The tables I and II show thawing indices (TI) and freezing indices (FI) calculated for each year and each site.

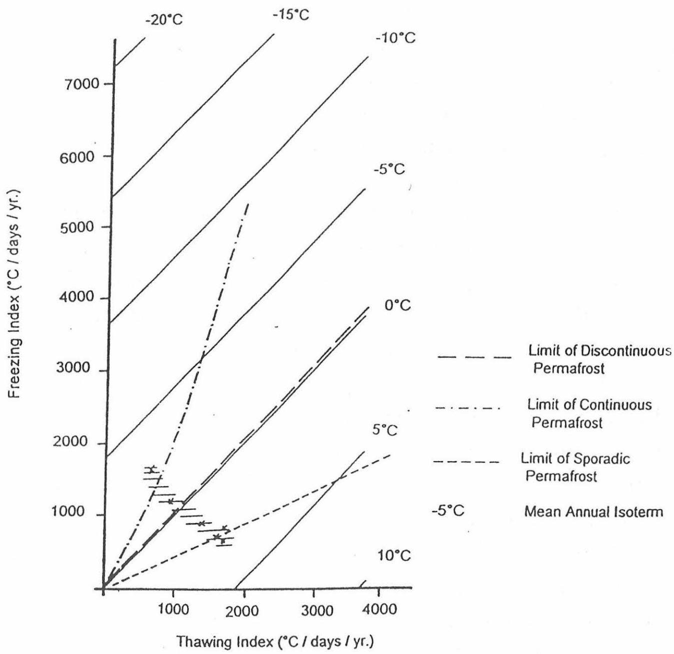

Fig. 2. Freezing and thawing index in High Tatras on HARRIS (1981) diagram (see text)

Rys. 2. Indeks tajania i zamrozu w Tatrach Wysokich przedstawiony na diagramie HARRISA (1981)

5-year and 10-year average values of indices are shown on the HARRIS diagram (Fig. 2)

The occurrence of the permafrost is highly associated with heat balance in the surface layer of the soil because permafrost represents certain thermal state of the soil where temperature is below 0°C. Each body on the Earth the temperature of which is above 0°K emits the energy in the form of radiation. This radiation depends on the temperature and on the nature of the body surface. As compared to the Sun, both the Earth surface and atmosphere are relatively cold and their radiation belongs to the infra-red band. The average temperature of the Earth surface is about 285°K and hence most of this radiation belongs to the wave length from 4 to 50 mm. This radiation is called Earth radiation, or heat radiation as it is a form of thermal energy.

Table I

Freezing (FI) and thawing (TI) indices, and depth of freezing and thawing in the Polish High Tatras

Five Lake Valley, 1670 m a.s.l.

years	1985	1986	1987	1988	1989	sum	5–year average	depth of freezing/ /thawing in cm
FI	−625.5	−1008.6	−118.0	−999.9	−625.5	−4466.5	893.3	89.7
TI	1460.3	1471.1	1310.0	1334.8	1370.3	6946.5	1389.3	111.8
t*(°C)	0.3	1.2	0.4	0.9	2.2		1.0	

Kasprowy Wierch (summit), 1991 m a.s.l.

years	1985	1986	1987	1988	1989	sum	5–year average	depth of freezing/ /thawing in cm
FI	−1308.4	−1115.2	−1416.1	−1285.3	−836.4	−5961.4	1192.28	103.6
TI	985.2	1062.7	894.2	997.0	845.3	4884.4	976.88	93.8
t*(°C)	−1.6	−0.4	−1.4	−0.8	0.3		−0.8	

Gąsiennicowa Valley, 1520 m a.s.l.

years	1985	1986	1987	1988	1989	sum	5–year average	depth of freezing/ /thawing in cm
FI	−944.3	−555.4	−963.8	−789.3	−459.1	−3710.1	742.02	81.7
TI	1554.9	1578.4	1540.9	1614.3	1657.7	7946.2	1589.24	119.6
t*(°C)	1.7	2.7	1.6	2.3	3.3		2.3	

Morskie Oko (lake), 1408 m a.s.l.

years	1985	1986	1987	1988	1989	sum	5–year average	depth of freezing/ /thawing in cm
FI	−980.6	−800.5	−1018.4	−790.2	−578.9	−4168.6	833.72	86.6
TI	1583.5	1860.7	1634.3	1635.9	1788.9	8503.3	1700.66	123.7
t*(°C)	1.6	2.9	1.7	2.3	0.3		1.8	

* mean annual air temperature

Table II

Freezing (FI) and thawing (TI) indices, and depth of freezing and thawing in the High Tatra Mts. in Slovakia

Skalne Pleso, 1751 m a.s.l.

years	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	5–year average	depth of freezing/ /thawing in cm
FI	–1053.	–864.0	–973.3	–884.1	–489.1	–523.6	–821.0	–688.0	–775.3	–667.4	773.95	83.46
TI	1400.6	1661.5	1366.2	1475.6	1573.1	1463.3	1383.6	1686.3	1546.0	1680.7	1523.9	117.1

Łomnica, 2632 m a.s.l.

years	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	5–year average	depth of freezing/ /thawing in cm
FI	–19811	–1781.5	–2082.8	–2695.3	–2156.4	–1588.4	–1915.8	–1743.9	–1731.9	–1606.4	1928.35	131.74
TI	433.7	560.7	470.6	505.7	455.8	441.0	453.0	612.8	459.1	667.4	504.98	6742

The surface of the Earth can not be assumed as an ideally black body, therefore, it is assumed that, as far as the infro-red radiation is concerned, the Earth surface behaves as a grey body (LOCKWOOD, 1984).

To determine the value of the emission in the soil, and then, to determine the depth of freezing and thawing, the following formula, based on Stefan-Bolzmann low, has been applied:

$$Df = a \sqrt{FI}$$
$$Dt = b \sqrt{TI}$$

where a and b are parameters calculated empirically, basing on temperature observation in the soil, and FI and TI are indices of freezing and thawing. For a non-consolidated rubble material, a and b parameters are assumed to equal 3 each (SONE, 1992; URDEA, 1993). Tables I and II show calculated depth of thawing and freezing in different heights of the Polish and Slovakian High Tatras. Basing on these results, a diagram of thawing and freezing depths in individual height intervals was drawn (Fig. 3). This diagram shows that the depths of soil thawing and freezing in the Tatras balance at the altitude of 1930 m a.s.l.

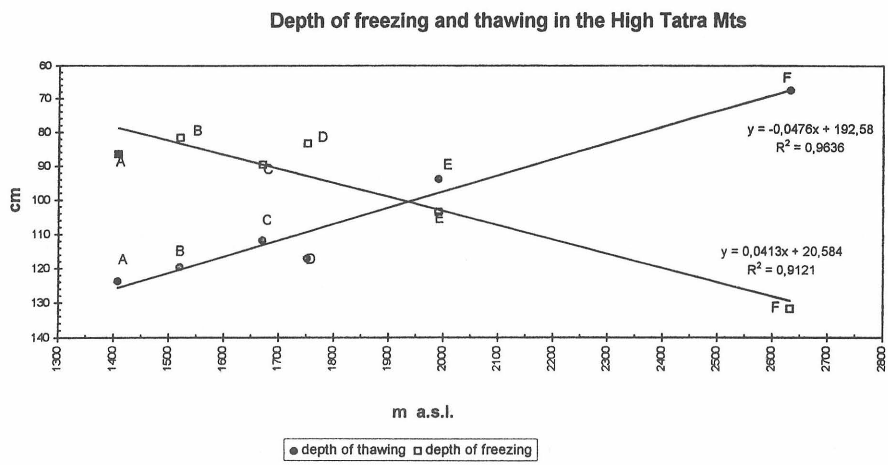

Fig. 3. Theoretical thickness of the ground thawing and freezing in the Tatra Mountains, as calculated from the thawing and freezing indices for the area where the snow cover is less than 50 cm thick

A – Morskie Oko; B – Gąsienicowa Valley; C – Pięć Stawów Polskich Valley; D – Skalnate Pleso; E – Kasprowy Wierch; F – Łomnicki Szczyt

Rys. 3. Teoretyczna głębokość tajania i przemarzania gruntu w Tatrach Wysokich obliczona na podstawie wskaźników tajania i zamrozu dla miejsc z pokrywą śnieżną nie przekraczającą 50 cm

A – Morskie Oko; B – Hala Gąsienicowa; C – Dolina Pięciu Stawów Polskich; D – Skalne Pleso; E – Kasprowy Wierch; F – Łomnica

CONCLUSIONS

The results of the climatic analysis show that the area of High Tatras represent wet climate, where sums of thawing and freezing indices are not considerable, but change considerably according to the altitude. The indices presented in the diagram (Fig. 2) show that the area studied is situated in all three zones of potential permafrost occurrence (continuous, discontinuous and sporadic permafrost). On the other hand, because of a close location of permafrost limits and significant microclimatic and orographic differentiation in the High Tatras, a large extrazonality in these zones is anticipated.

Despite of the fact that the condition of this method (i.e. thickness of the snow cover up to 50 cm) is not always fulfilled in the area studied, the author decided to use it because the snow thickness in the High Tatras is much differentiated due to diversity of the landscape. Steep rock slopes and winds cause that in some places the thickness of snow cover is smaller that 50 cm or even it does not occur at all during winter.

The results of climatic analysis show that the equilibrium line for the occurrence of active permafrost is at the altitude 1930 m a.s.l. and it covers the area about 100 km^2 (Fig. 4).

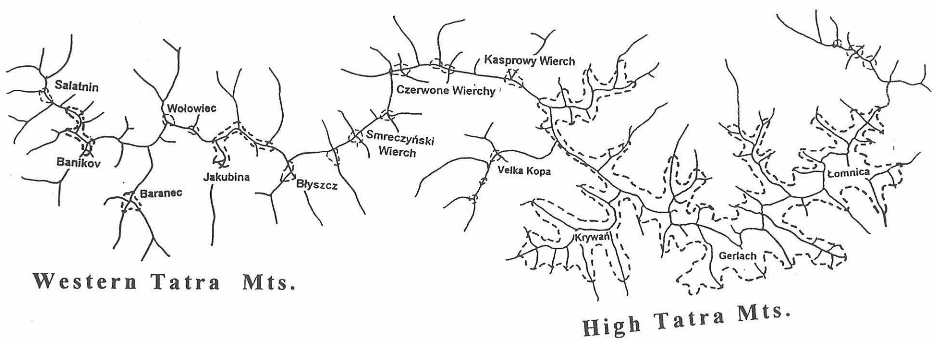

Fig. 4. Area of the potential permafrost occurrence in the Tatras, based on theoretical thickness of ground thawing and freezing

Rys. 4. Obszar potencjalnego występowania zmarzliny w Tatrach określony w oparciu o teoretyczną głębokość tajania i zamarzania gruntu przedstawioną na rysunku 3

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