SCIENTIFIC JOURNAL
EARTH'S CRYOSPHERE

Kriosfera Zemli, 2011, vol. XV, No. 4, pp. 29–32 **http://www.izdatgeo.ru**

PERMAFROST MONITORING AND PREDICTION

ASSESMENT OF PERMAFROST STABILITY UNDER CONTEMPORARY CLIMATIC CHANGES

G.V. Malkova, A.V. Pavlov, Yu.B. Skachkov*

Institute of Earth's Cryosphere, Siberian Branch of the Russian Academy of Sciences, 86, Malygina str., Tyumen, 625000, Russia; galina_malk@mail.ru
** Melnikov Institute of Permafrost, Siberian Branch of the Russian Academy of Sciences, 36, Merzlotnaya str., Yakutsk, 677010, Russia; skachkov@mpi.ysn.ru*

The contemporary climate trends within the permafrost extent in Russia have been evaluated and mapped on the basis of synthesized meteorological data during the period from 1965 to 2010. The reasons of lagging of permafrost temperature trends from the trends of mean annual air temperature have been examined. The small-scaled maps of permafrost thermal stability under the contemporary climate warming have been worked out.

The global warming tendency has been evident for the past 100–110 years. The climate patterns since 1995 have become notably more variable, with frequent anomalies. On this background, mean annual air temperatures show increasing trends in Arctic regions and their immediate surroundings while the warming rates in some Subarctic areas are slowing down or even locally experience a reversal (Turukhansk, Aldan, Olekminsk) [*Melnikov et al., 2007; Pavlov, 2008a; Pavlov and Malkova, 2010*].

The frequency of modern climate anomalies is commonly estimated by comparing meteorological data over the past decade with the norm, using three air warming grades (Δt_{air}): weak ($\Delta t_{air} < 0.7$ °C), temperate (0.7 °C $\le \Delta t_{air} \le$ 1.0 °C), and strong ($\Delta t_{air} >$ >1 °C) [*Pavlov and Malkova, 2005*].

Inasmuch as mean annual air temperatures for the past decade (2000–2010) have been anomalously strong in many areas, there are only two warming grades (temperate and strong) used in the map of Fig. 1. The climate norm (imaging by dint of isolines, Fig. 1) varies within the permafrost extent from –2 to –16 °C. Warming is strong over most of the territory (temperature rise more than 1 °C) while temperate climate warming are restricted to local areas in the European north, in West and Central Siberia, and in the Russian Far East (Primorie).

In order to highlight regional features of warming patterns, one has to calculate mean annual air temperature trends for different time limits. The basic map of these trends was presented earlier for 1965–2000 [*Pavlov and Ananieva, 2004; Pavlov and Malkova, 2005*]. Having continued the observations till 2010, we picked the modern trends and compared them with those for the period from 1965 to 2000. The 1965–2000 mean annual air temperature trends (Fig. 2) divided into seven grades (see the color code in Fig. 2) make up prominent N–S (western Arctic and Subarctic areas) and W–E (eastern sector) zones. The warming rates are the highest (to 0.08 °C/yr) in southern Siberia and the lowest (less than 0.03 °C/yr) in the European North and in West and Central Siberia.

Unlike these, the air temperature trends for 1965–2010 (isolines at 0.01 °C/yr in Fig. 2) have markedly different patterns, namely (1) the orientations of contour lines have changed in a way that no W–E or N–S features show up any longer; (2) the variations of trend values are generally much lower; (3) the minimum trends (0.03...0.04 °C/yr) are concentrated in the Lena-Olenek interfluve, in the middle reaches of the Yenisei, and in the northern Yamal Peninsula; (4) the maximum trends (0.06 °C/yr or more) are recorded in southern Siberia, central Yakutia, and in the Chukchi Peninsula.

Taking into account the great climate variability through the past decade, each following year may be expected to bring about more correction to the mean linear air temperature trends and thus change the mapped patterns.

Permafrost monitoring at the steady-state-stations since the late 1960s shows an increasing trend of frozen ground temperatures to follow the climate warming [*Skachkov et al., 2005, 2007; Malkova, 2010*]. The contemporary mean annual ground temperature trends are highly variable over the permafrost extent but the warming rates are most often within two thirds of the air values. The air temperature trends range from 0.02 to 0.07 °C/yr while the range for frozen ground is from 0.004 to 0.050 °C/yr. Air warming causes the strongest effect on the permafrost temperature patterns in the case of stable long-term unidirectional trends in both air temperature and snow

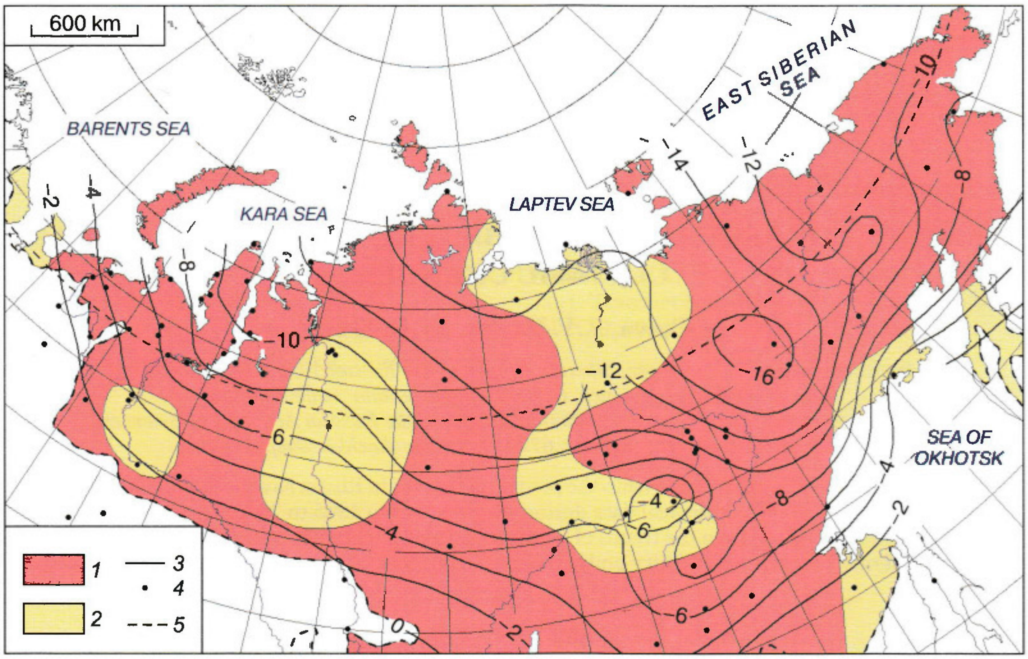

Fig. 1. Variations of mean annual air temperature in northern Russia over the past decade.

1, 2 – temperature rise relative to climate norm: *1* – strong ($\Delta t_{air} > 1$ °C), *2* – temperate (0.7 °C $\leq \Delta t_{air} \leq$ 1.0 °C); *3* – mean annual air temperature isolines (climate norm); *4* – weather stations; *5* – southern limits of cryolithozone.

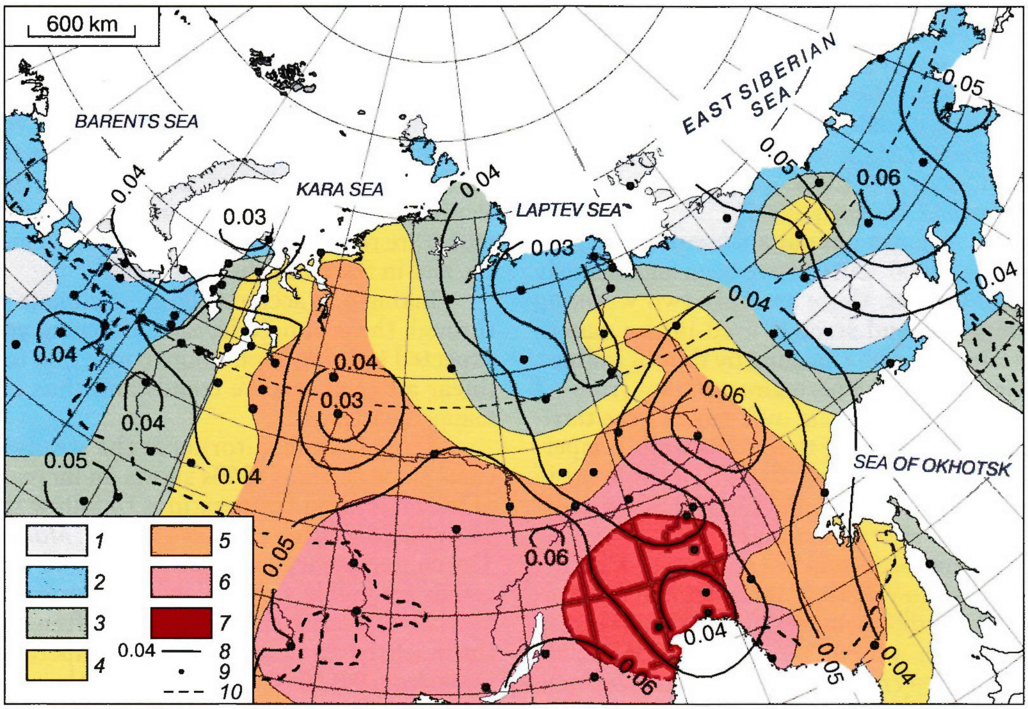

Fig. 2. Mean annual air temperature trends in northern Russia.

1–7 – trend (warming rate), in °C/yr, for 1965–2000: *1* – less than 0.02; *2* – 0.02–0.03; *3* – 0.03–0.04; *4* – 0.04–0.05; *5* – 0.05 – 0.06; *6* – 0.06–0.07; *7* – more than 0.07; *8* – trend (warming rate), in °C/yr, for 1965–2010; *9* – reference weather stations; *10* – southern limits of cryolithozone.

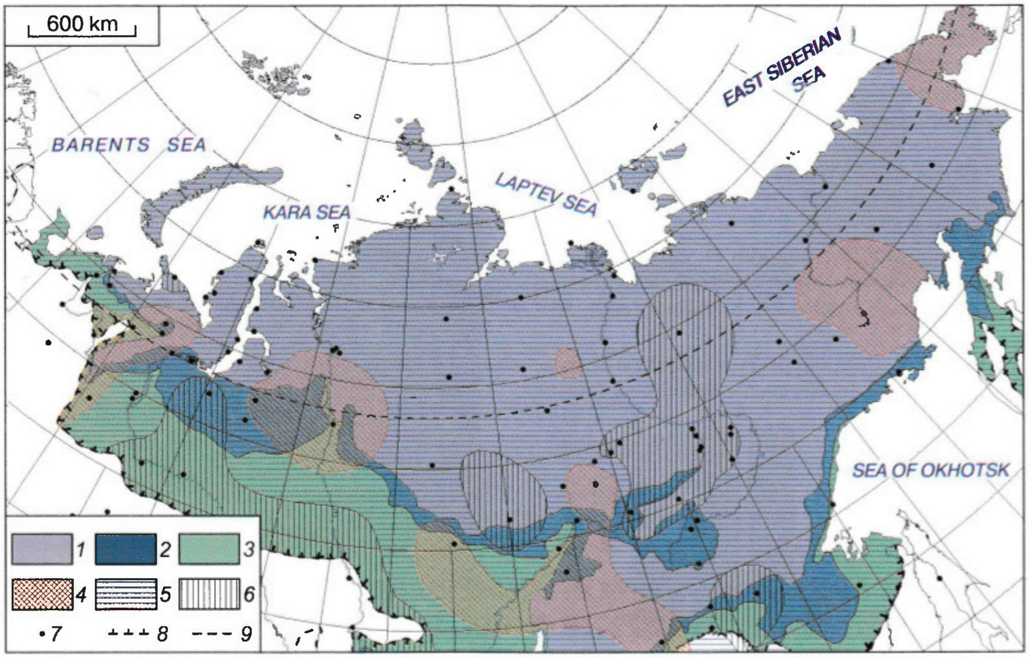

Fig. 3. Map of thermal stability of frozen ground in cryolithozone of Russia.

1–3 – extent of permafrost: *1* – continuous, *2* – discontinuous, *3* – sporadic and patched; *4–6* – thermal stability: *4* – low ($K_\alpha > 0.75$), *5* – medium ($0.50 < K_\alpha \le 0.75$), *6* – high ($K_\alpha \le 0.50$); *7* – weather stations and observation sites; *8* – southern limits of cryolithozone; *9* – Arctic circle.

thickness [*Pavlov, 2008b; Pavlov and Malkova, 2010; Pavlov et al., 2010*].

It is convenient to estimate the stability of frozen ground and its sensitivity to climate change using the dimensionless coefficient $K_\alpha = \alpha_{tg} / \alpha_{ta}$, which is the ratio of mean annual temperature trends of ground (α_{tg}) to that of air (α_{ta}) [*Pavlov and Malkova, 2009*].

The coefficient $K_\alpha \le 0.50$ corresponds to a high stability of frozen ground (long-term temperature changes below 50 %: the ground temperature trends are more than twice slower than the air temperature ones); the range $0.50 < K_\alpha \le 0.75$ corresponds to medium stability (the ground temperature trends are slower than the air temperature ones for a factor of 1.5 or 2); at $K_\alpha > 0.75$ the permafrost stability is low.

These grades were used to map the thermal stability of upper permafrost (Fig. 3). The greatest part of the permafrost zone pertains into the range $0.50 < K_\alpha \le 0.75$ corresponding to medium warming stability, while the areas of high and low stability are local.

In spite of rapid recent warming, permafrost in southern Yakutia remains highly stable, as a result of variability in snow thickness and a strong control from winter freezing patterns and peculiarity of snow accumulation [*Skachkov, 2008*]. Note that frozen ground temperatures in the south of West Siberia and in the Russian Far East do not show increasing trends synchronous with the air warming. The reason may be that the permafrost is high-temperature (close to 0 °C) and much heat coming from the Sun is spent on phase change in the ground [*Pavlov and Malkova, 2009*]. However, if stable warming continues, frozen ground can thaw all over those areas. Especially vulnerable is permafrost in the Komi Republic, in the middle reaches of the Yenisei, and in the Baikal region where it is discontinuous or sporadic and shows rapid warming rates.

Thus, monitoring and small-scale GIS mapping of permafrost are efficient tools to study the geocryological consequences of climate warming. The reported studies allowed compiling a set of small-scale maps, with thermal stability division, and estimating the responses of permafrost to the contemporary climate change.

References

Malkova G.V., 2010. Mean-annual ground temperature monitoring on the steady-state-station Bolvansky. Kriosfera Zemli, XIV (3), 3–14.

Melnikov V.P., Pavlov A.V., Malkova G.V., 2007. Consequences of contemporary global change in permafrost. Geografiya i Prirodnye Resursy, No. 3, 19–27.

Pavlov A.V., 2008a. Permafrost Monitoring [in Russian]. Geo, Novosibirsk, 229 pp.

Pavlov A.V., 2008b. Contemporary ground temperature trends in northern Russia. Kriosfera Zemli, XII (3), 22–27.

Pavlov A.V., Ananieva G.V., 2004. Assessment of the contemporary air temperature change over permafrost territory of Russia. Kriosfera Zemli, VIII (2), 3–9.

Pavlov A.V., Malkova G.V., 2005. Contemporary changes of climate in northern Russia. Album of small-scale maps [in Russian]. Geo, Novosibirsk, 54 pp.

Pavlov A.V., Malkova G.V., 2009. Smal-scale mapping of trends of contemporary ground temperature changes in the Russian North. Kriosfera Zemli, XIII (4), 32–39.

Pavlov A.V., Malkova G.V., 2010. Permafrost dynamics in the changing climate through the 20th–21st centuries. Izv. RAN. Ser. Geogr., No. 5, 44–51.

Pavlov A.V., Perlshtein G.Z., Tipenko G.S., 2010. Actual aspects of modeling and prediction of the permafrost thermal state under climate change conditions. Kriosfera Zemli, XIV (1), 3–12.

Skachkov Yu.B., 2008. Contemporary variability of snow cover parameters in Yakutia, in: Cryogenic Resources of Arctic and Highland Terrains. State and Prospects of Engineering Permafrost Studies. Proc. Intern. Conf., Express, Tyumen, pp. 271–274.

Skachkov Yu.B., Skryabin P.N., Varlamov S.P., 2007. Results of 25-year long summer permafrost monitoring at the Chabyda site (Central Yakutia), in: Cryogenic Resources of Arctic Regions. Proc. Intern. Conf. TyumNGU, Salekhard, Book 1, pp. 167–170.

Skachkov Yu.B., Skryabin S.P., Varlamov S.P., 2005. Effects of contemporary climate change on permafrost in Central Yakutia, in: Proc. 3rd Russian Cryological Conference [in Russian]. Moscow University Press, Moscow, Book 2, pp. 146–152.

Received
3 February 2011

Kriosfera Zemli, 2011, vol. XV, No. 4, pp. 32–35 **http://www.izdatgeo.ru**

LANDSCAPE INDICATION OF LOCAL PERMAFROST VARIABILITY (URENGOY TERRITORY, WEST SIBERIA)

N.G. Ukraintseva, D.S. Drozdov, K.A. Popov, A.G. Gravis, G.V. Matyshak*

Institute of Earth's Cryosphere, Siberian Branch of the Russian Academy of Sciences, PO box 1230, Tyumen, 625000, Russia; ukraintseva@mail.ru
**Lomonosov Moscow State University, Department of Soil Science, 1-12, Leninskie Gory, Moscow, 119992, Russia*

The highly variable properties of frozen ground make engineering-geological mapping in the permafrost zone impossible without cryological monitoring. Integrate monitoring of natural and technogenic landscapes has been run at test sites in southern forest-tundra and southern tundra (area of Urengoy oil-gas-condensate field) by remote sensing along with surface route and instrumental (automated) surveys and GIS mapping. As a result, a set of map models have been obtained that demonstrate obvious relationship between the landscape features and the thicknesses of peat and active layer. The studies have revealed a new indicator of the permafrost thermal state.

INTRODUCTION

Several test sites were set up in northern West Siberia in 1974–1976 to monitor space-time variations in properties of frozen ground. Two sites were on the left bank of the Pur River, within the Urengoy oil-gas-condensate field, one in southern forest-tundra (UKPG-5) and the other in southern tundra (UKPG-15) [*Drozdov et al., 2010a*]. In 2008, the observations at the two sites became complemented with thaw depth monitoring on a 100 × 100 m grid, with a spacing of 10 m, as part of the CALM International Project (Circumpolar Active Layer Monitoring). Exhaustive landscape studies at the CALM sites have yielded a set of map models that demonstrate obvious relationship between the local landscape features and the thicknesses of peat and active layer.

METHODS

The test sites within the Urengoy oil-gas-condensate field were created as early as in 1975–1976. Permafrost temperature monitoring was performed as yearly measurements in 10–12 m deep boreholes; since 2008, the monitoring has been continuous due to permanent loggers that provide year-round records. Local undisturbed and disturbed ecosystems associated with different landscapes within the CALM sites have been classified (at the level of landscape facies), investigated in terms of above-surface phytomass, and mapped to scale 1:5000 (Fig. 1, *A*). Maps of this kind, based on the landscape-indication approach, can be used as a basis for estimating local variations in the active layer thickness and for map modeling [*Moskalenko, 1999; Bozhilina and Ukraintseva, 2010*].

LANDSCAPE SYSTEMS: STRUCTURE AND CRYOTIC PROPERTIES

The CALM site in southern forest-tundra (UKPG -5) is located within fluviolacustrine plain IV in the Nadym-Pur subprovince of coastal (marine)