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.

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

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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)

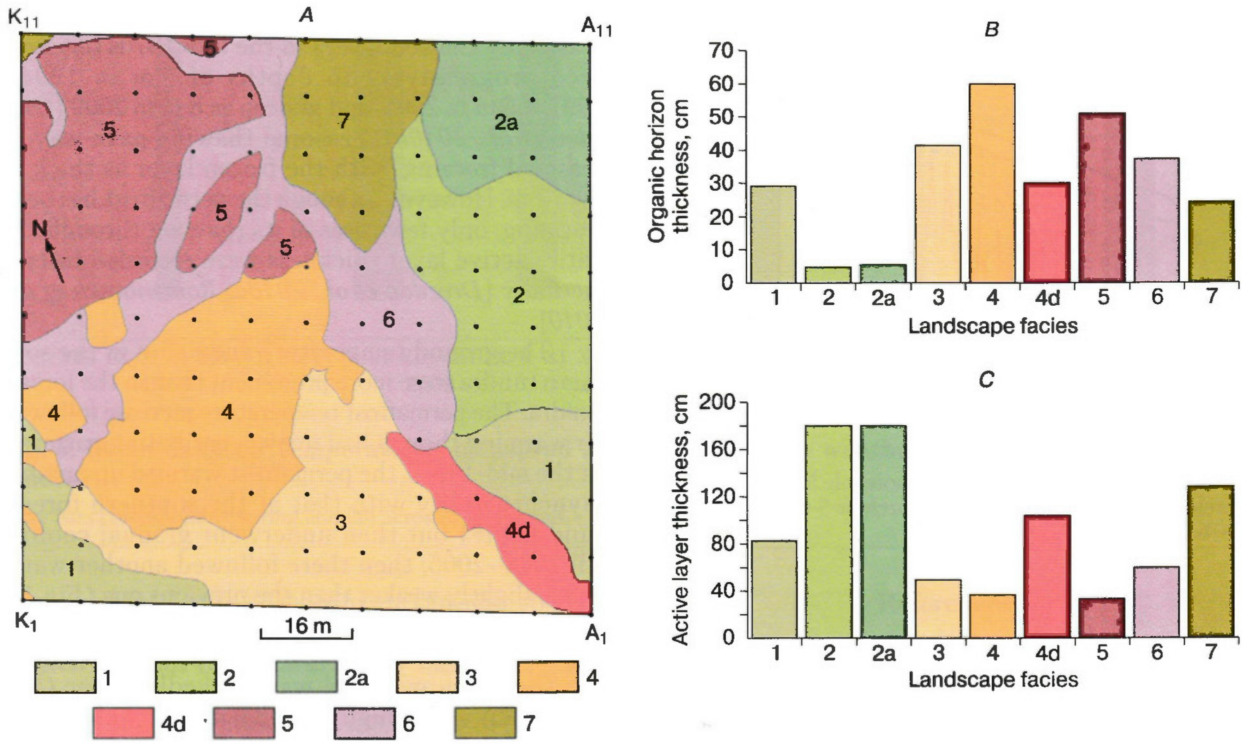

Fig. 1. CALM site in southern forest-tundra (UKPG-5).

A – landscape map; *B* – thickness of organic soil horizon; *C* – active layer thickness (seasonally thawed or seasonally frozen). Landscape facies: 1 – hilly open shrub-moss areas; 2 – sparse larch-lichen forests; 2a – same, with sag-and-swell microtopography; 3 – flat-hill cloudberry-sphagnum peatbogs; 4 – polygonal ledum-sphagnum-lichen peatbogs; 4d – same, but disturbed areas with old ruts; 5 – polygonal dwarf-birch (yernik)-ledum-lichen peatbogs; 6 – hummocky grass-shrub-moss ravines; 7 – ravines with shrub-grass-moss birch thickets (yernik) (to 1.0–1.5 m high). A_1, A_{11}, K_1, K_{11} are indices of points at CALM sites.

and fluviolacustrine plains. The plain is composed of loam-sand deposits, often overlain with peat. Permafrost, mostly with high ice contents, is continuous or discontinuous and occupies over 80 % of the surface area. The landscapes are largely affected by frost cracks and thermokarst and are swampy.

The dominant landscape facies at the site is watershed peatbog which and larch-lichen open forest both shrubby ravines along a creek valley (Fig. 1, *A*). The above-surface phytomass[1] measured as air-dry weight per area is 1–3 kg/m^2 in the peatbog and exceeds 5 kg/m^2 in the larch open forest [*Ukraintseva et al., 2010*]. The active layer thickness (seasonally thawed layer) is inversely proportional to the total thickness of organic soil horizons (Fig. 1, *B, C*). Underneath the larch open forest, the permafrost table is as deep as 4–8 m, and the ground is seasonally frozen.

The CALM site of southern tundra (UKPG-15) is located within coastal plain III composed mainly of loam. The permafrost is ice-rich (total water contents 60 % in loam and 21–28 % in sand) and continuous from the surface. The site has a uniform facies structure dominated by grass-shrub-moss-lichen tundra with a thin organic soil layer; limited dwarf willow and birch thickets and sporadic grass-sphagnum bogs are restricted to ravines. In the bottoms of large erosional landforms, there are low perennial frost heaves. The phytomass is 1.7–2.3 kg/m^2, or 0.8–1.2 kg/m^2 without litter. The active layer thickness is from 80–90 to 100–115 cm [*Ukraintseva et al., 2010*].

PERMAFROST MONITORING RESULTS

The permafrost temperature over the 1974–2008 period showed a positive trend all over the study area [*Drozdov et al., 2010a*]. Borehole temperature logging at the southern forest-tundra site, along with geophysical data, indicate permafrost table deepening on the background of steady ground temperature increase associated with global warming through the recent decades (Fig. 2) [*Shur and Jorgenson, 2007; Pavlov, 2008; Melnikov et al., 2009; Romanovsky et al., 2010*]. For instance, the permafrost table underneath

[1] Phytomass is measured in air-dry weight units per surface area unit (square meter, hectare, etc.).

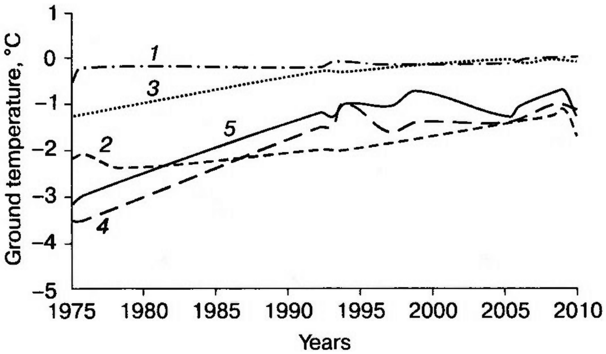

Fig. 2. Time-dependent ground temperature variations at depth of zero annual amplitude (southern forest-tundra).

1 – borehole 5-01, larch forest; *2* – borehole 5-02, peatbog; *3* – borehole 5-05, ravine shrub; *4* – borehole 5-06, slope tundra; *5* – borehole 5-09, bog edge, peat.

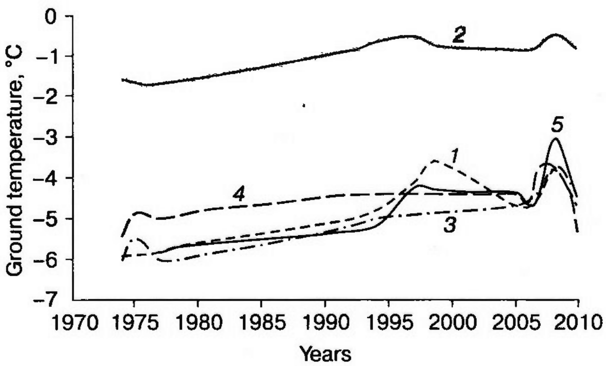

Fig. 3. Time-dependent ground temperature variations at depth of zero annual amplitude (southern tundra).

1 – borehole 15-03, tundra with peat; *2* – borehole 15-06, slope alder wood; *3* – borehole 15-08, moss-lichen tundra; *4* – borehole 15-20, moss-lichen tundra; *5* – borehole 15-21, disturbed moss-lichen tundra.

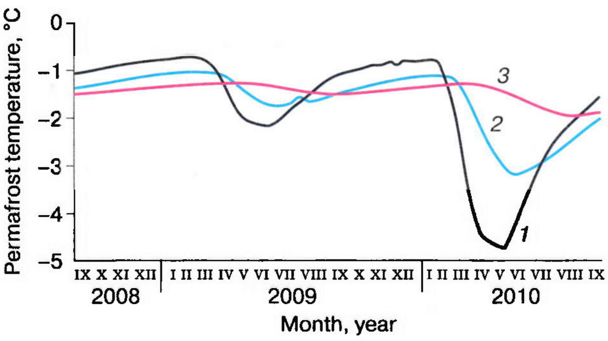

Fig. 4. Permafrost temperature in watershed peatbog (southern forest-tundra).

Depths: *1* – 3 m; *2* – 5 m; *3* – 10 m.

the sparse larch forest was at the surface (1.5–2.0 m seasonally thawed layer) in the late 1970s but lowered progressively to depths of 3 m in 1994–1997, 4.5 m in 2005, and as deep as 8 m in 2009 [*Drozdov et al., 2010b*]. Seasonal thawing gave way to seasonal freezing, with the frozen layer as thick as over 2 m. However, although the permafrost has been warming, only few cases of its thawing through the entire active layer thickness were recorded instrumentally [*Drozdov et al., 2010a; Romanovsky et al., 2010*].

The ground temperature anomalies in the southern tundra were more prominent than in the forest-tundra. The permafrost temperature increase followed air warming though had uneven oscillating patterns. In the mid-1990s, the permafrost warmed up notably (synchronously with that at the southern forest-tundra site) but then underwent gradual cooling till 2004–2005; then there followed another warm wave, slightly weaker than the previous one (Fig. 3). The permafrost temperature was originally higher (–1.7 °C in 1974) than in the surrounding area, but the warming trend was markedly lower (less than 1 °C) under high (1.5–3.0 m) alder shrubs on southern slopes protected from cold, due to the shrub buffer [*Drozdov et al., 2010a, b; Ukraintseva et al., 2010*].

The general climate trends within the Urengoy oil-gas field began to change in the fall of 2009. Abrupt cooling in fall time followed by an anomalously cold and low-snow winter (2009/10) led to an up 0.5 °C decrease in permafrost temperature at the active layer base in most landscape facies (Figs. 2, 3). The temperature drop was still greater in the upper section: e.g., 3 and 1.5 °C cooling at subsurface depths 3 and 5 m, respectively, in a watershed peatbog within the southern forest-tundra (Fig. 4). Note that no permafrost cooling was observed in the 3 to 8 m thick near-surface ground under open forest and shrubs because of the damping effects of phase transitions (Fig. 2).

A NEW INDICATOR OF THE PERMAFROST THERMAL STATE

A new parameter of large diagnostic importance for the state of permafrost and thawing rate has been revealed in data inventory from weather stations in the vicinity of the test sites within the subzones of southern forest-tundra (Novyi Urengoy) and southern tundra (Yamburg). This is the duration of time in spring and fall when diurnal air temperatures fluctuate between positive and negative, which we called briefly an "across 0 °C" season. This season may be as long as 1.5 months or more in the Urengoy field, while the monthly and ten-day means may remain positive or negative, the passage across 0 °C being reduced to

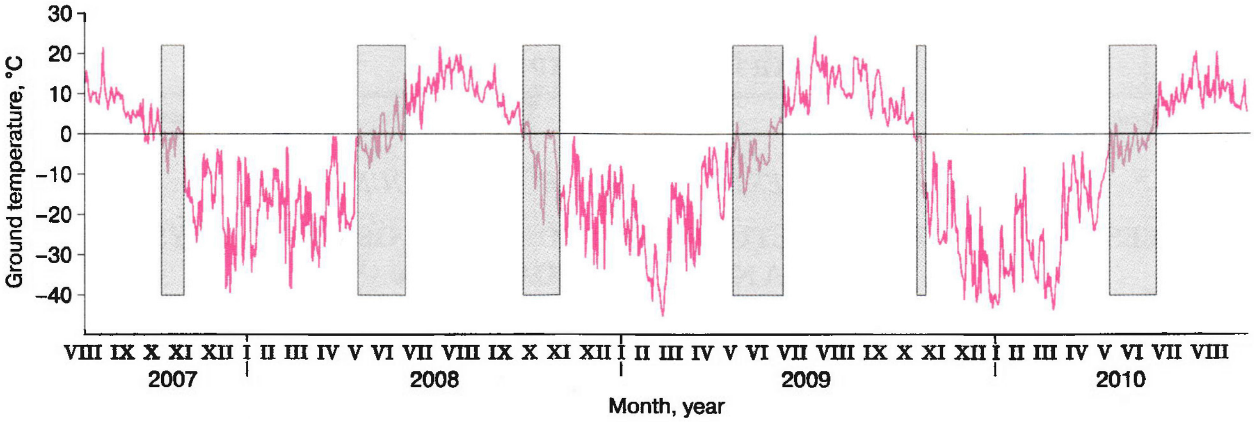

Fig. 5. Mean daily air temperatures measured at Novyi Urengoy weather station (southern forest-tundra).

Gray bars correspond to spring and fall across 0 °C seasons.

single points (ends of months or ten-day spans). Meanwhile, the duration of the across 0 °C time calculated from air temperature daily means may be a meaningful indicator of the thermal state of permafrost. For instance, prominent shortening of this time in the fall of 2009 (Fig. 5) was accompanied by notable permafrost cooling in the following year of 2010 (Figs. 2–4).

CONCLUSIONS

The rate and depth of permafrost thawing in forest-tundra are largely controlled by diverse vegetation with considerable amounts of above-surface phytomass. As a result, there arises a pattern of alternating zones of deep and shallow permafrost table, the active layer being additionally buffered by organic soil horizons.

The soil and vegetation control of the permafrost temperature and active layer thickness at the southern tundra site is much smaller than in the southern forest-tundra.

The duration of the season when mean daily air temperatures fluctuate between positive and negative may be of significant diagnostic value as an indicator of the thermal permafrost state. The latter inference requires further support with more observations.

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References

Bozhilina E.A., Ukraintseva N.G., 2010. Specialized field surveys for nature mapping. Geodeziya i Kartografiya, No. 6, 36–41.

Drozdov D.S., Ukraintseva N.G., Tsarev A.M., et al., 2010a. Changes of permafrost temperature field and geosystem state on Urengoy oi-gas-field territory during the last 35 years (1974–2008). Kriosfera Zemli, XIV (1), 22–31.

Drozdov D.S., Ukraintseva N.G., Tsarev A.M., 2010b. Active layer and permafrost table lowering in the Tundra/Forest-tundra transition zone at Urengoi oil-gas field (West Siberia), in: Thermal State of Frozen Ground in a Changing Climate during the IPY: Abstracts, III European Conference on Permafrost (EUCOP III), Svalbard, Norway, p. 102.

Melnikov V.P., Drozdov D.S., Pavlov A.V., et al., 2009. Climate change and response of northern ecosystems, in: Global Change and Adaptation Mechanisms. Proc. Workshop, Moscow, pp. 36–37.

Moskalenko N.G., 1999. Anthropogenic Dynamics of Vegetation in Plainland Permafrost Areas of Russia [in Russian]. Nauka, Novosibirsk, 280 pp.

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

Romanovsky V.E., Drozdov D.S., Oberman N.G., et al., 2010. Thermal state of permafrost in Russia. Permafrost and Periglacial Processes, 21 (2), 136–155. (Special Issue: The International Polar Year http://onlinelibrary.wiley.com/doi/10.1002/ppp.683/abstract).

Shur Y.L., Jorgenson M.T., 2007. Patterns of permafrost formation and degradation in relation to climate and ecosystems. Permafrost and Periglacial Processes, 18, 7–19.

Ukraintseva N.G., Drozdov D.S., Popov K.A., et al., 2010. Active layer response to biomass and soil-vegetative cover changes at CALM-site in the Tundra/Forest-tundra transition zone (West Siberia, Urengoi oil-gas field), in: Thermal State of Frozen Ground in a Changing Climate during the IPY: Abstracts, III European Conference on Permafrost (EUCOP III), Svalbard, Norway, p. 107.

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