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Observations of surface dynamics with thermokarst initiation, Yukechi site, Central Yakutia

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ABSTRACT: The authors have been monitoring surface dynamics at the Yukechi site near Yakutsk since 1992. This paper mainly presents data on flat areas of inter-alas meadows that were not previously subject to active thermokarst formation. The measurements show that the melting of upper ground ice and the surface subsidence at these sites averages 7–8 cm on an annual basis on flat areas, and 14–15 cm at the boundaries of these areas. The melting of ground ice is mainly connected with general climate changes in the 1990s that resulted in an increased flooding of young thermokarst depressions.

1 INTRODUCTION

At present a significant amount of attention is paid to the study of global change effects on permafrost. Many authors observe a considerable increase of ground temperature (Romanovsky & Osterkamp 1995, Zhang et al. 1997, Gilichinsky et al. 1998, Pavlov 1998). The Circumpolar Active Layer Monitoring (CALM) project (Brown et al. 2000) is also providing comparable data on long-term observations for thaw depths in different permafrost areas (USA, Canada, Russia, Switzerland, Antarctica etc.).

A complex of permafrost-landscape investigations are carried out at the Yukechi monitoring site located 50 km southeast of Yakutsk on the right bank of the Lena River (61°35′N, 130°40′E). Special attention is given to the monitoring of changes in soil temperature and water regime, and to the surface dynamics under present climate changes.

The site is a typical Central Yakutian landscape containing thick ice wedges (ice complex) and extensive alases. The surface is inclined gently to the northwest and is located at 200–220 m a.s.l. Silty and sandy loams dominate the upper horizons of the Quaternary deposits, sometimes with interlayers of silty sands. The inter-alas areas are widely occupied by ice complexes. The ice wedges on undisturbed sites occur at a depth of 2–2.5 m. The width of their upper portion varies from 1–1.5 to 2.5–3 m (Fig. 1). Ground blocks between ice wedges are less than 5–6 m in diameter. The volumetric ice content of these deposits reaches up to 50%. The depth of seasonal thaw varies between 1.2 and 2.5 m depending on landscape conditions.

The observations on flat inter-alas areas containing ice-rich deposits are conducted in order to obtain information on permafrost degradation under present climate changes. During the period 1992 to 2001 quan titative data on the surface dynamics related to climate changes have been observed.

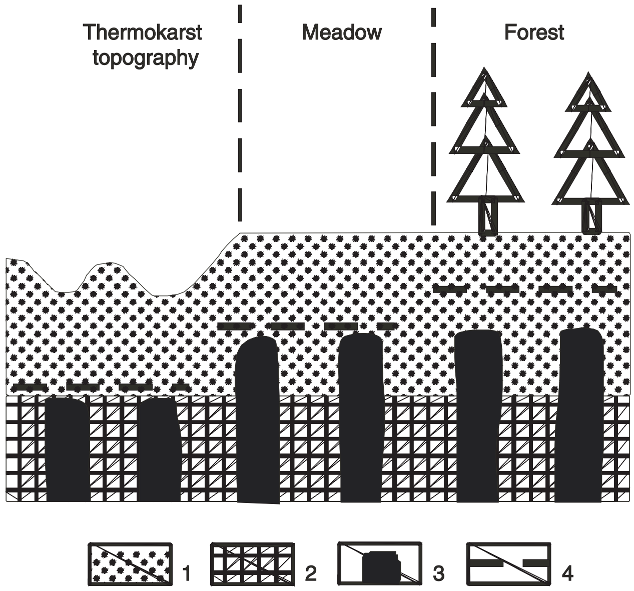

Figure 1. Schematic profile of upper part of ice-complex. 1 – ice-poor ground; 2 – ice-saturated ground; 3 – wedge ice; 4 – top of permafrost.

We published some information on surface subsidence rates at the Yukechi site in Central Yakutia in the proceedings of the 7th International Conference on Permafrost (Fedorov et al. 1998). The main focus of attention was on surface dynamics of young thermokarst depressions. Most of thermokarst terrains at the Yukechi site are more than 50 years old based on the analysis of aerial photographs of 1946 and 1954.

Our earlier publications dealt only with rates of surface subsidence in thermokarst terrains (Fedorov et al. 1998, Fedorov & Fukuda 2001). This paper analyzes the surface dynamics at the points located on relatively stable flat areas of inter-alas meadows. These points were chosen on each site to compare relative subsidence on different landscape units.

2 DATA SOURCES AND METHODS

A total of eleven experimental sites for levelling surveys were established to study the surface dynamics (Fig. 2). Within these sites, there are 125 permanent marker points for determining relative elevations, including three datum points to depths down to 4 m. Of these, levelling has been done at 33 points since 1992 and on the rest of the points – since 1993 or 1994.

Surveys were made every year in August-September; i.e. at the end of thaw season. The measurements were made using the NS4 level with the mean-square error within 3 mm. Results for the 1992–2001 period are presented.

A network of observation points was established to carry out the observations of surface subsidence. This network consists of two types of points. The first one refers to check or control points. Here a borehole of 3–4 m depth is drilled, about half of which penetrates into the permafrost. A wooden rod or a metal pipe is installed in the borehole and freezes through natural soil and moisture conditions. A short portion of the rod (10–20 cm) is above the soil surface. There are five control points in this area: two points with wooden rods and three points with metal pipes. As our experiments show, these points are stable and may be used as long-term control points. These five points are within the levelling line of 1000 m length: two points between sites 2 and 3, and three points between sites 9 and 10. These points are measured at every levelling. The measurement error is insignificant.

The second type of points are established for measurements of surface dynamics. They are marked by wooden pegs set in the soil at 20- to 40-cm depth depending on soil density. In thermokarst depressions they are set at 1 m depth. The results are obtaining by observing the difference between soil surface (indicated by wooden pegs) and a main control point (pipe end in borehole 3, which is between sites 2 and 3) (Fig. 2).

To analyse the data, we used climatic data and thawing indices from the weather station at Yakutsk.

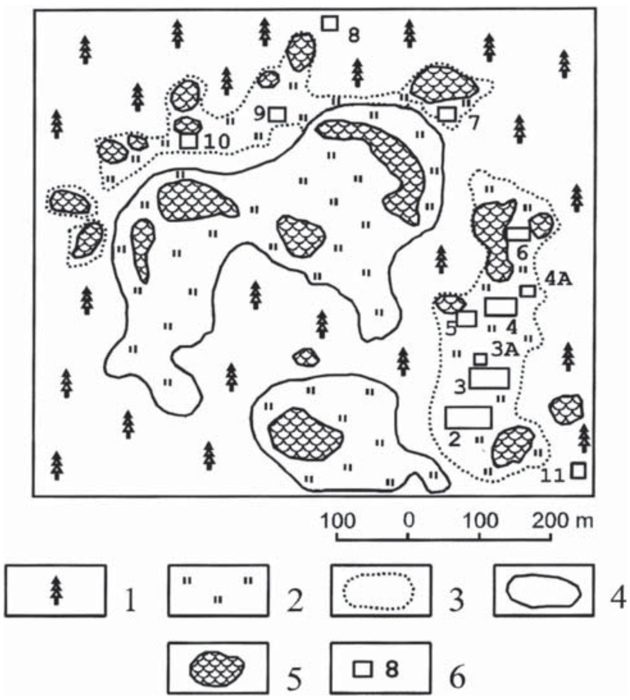

Figure 2. Location map of Yukechi experimental site, Central Yakutia. 1 – Larch forest; 2 – meadow; 3 – meadow contours in inter-alas; 4 – alas contours; 5 – lakes; 6 – sites.

3 RESULTS

3.1 *Surface dynamics*

Aerial photographs of the past years (1946, 1954, 1971, 1987 and 1992) and the results of instrumental observations for thermokarst terrain dynamics in 1992–2001 allow us to conclude that thermokarst development was very active over these years. During the period of 1992–2001 the shape of these landscapes has changed markedly. Significant expansion and deepening of the bottom of thermokarst lakes occurred accompanied by coalescing of separate lakes. The largest rates of subsidence (17–24 cm/year) were observed in depressions with young thermokarst lakes (sites 5 and 10). Many markers, established on dry places were flooded over time.

In the central parts of thaw depressions with young lakes (sites 2 and 3) with depths of 2 to 2.5 m, the rates of subsidence were 5–10 cm/year (Fig. 3).

Before our observations these sites had maintained their original shapes for 50 years. This may be explained by a small drainage area compared to other thermokarst depressions which have become lakes. In this regard, the active thermokarst development may be explained

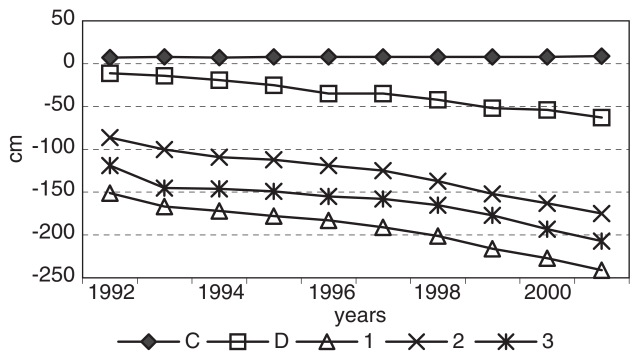

Figure 3. Surface subsidence in thermokarst depression, site 2. C – check point, undisturbed inter-alas area; D – incipient thaw depression; 1–3 – centers of polygons within thaw depression.

by the recent climate changes. Intense melting of ground ice in the last years has virtually changed these depressions into thermokarst lakes.

On some inter-alas areas with polygonal micro-topography, thermokarst has been more active in recent years with average rates of subsidence from 2.6 to 5.4 cm/year.

In 1995 three additional sites were established for observations of the surface dynamics on small thermokarst pits. The observation points were placed on different micro-topographic levels ranging in elevation up to 2 m. The depth to the upper ice-wedge boundary was 2.0–2.4 m depending on the degree of thermokarst development. In the zones of active thermokarst development, especially in deep pits, the layer between the upper contact with ground ice and the active layer boundary was virtually absent, and thaw depth reached the upper boundary of the ice wedge. On flat sites the thickness of this zone was 5 to 20 cm. Only this thin zone prevents the underlying ground ice from melting. Since this layer is quite sensitive to the influence of present climate changes, the probability of surface subsidence related to thaw of the upper ice wedges is very high. From 1995 to 2001 the rates of subsidence on these sites averaged 2 to 5 cm/year. It should be noted that at some points subsidence was not observed.

However, the most interesting data, in our opinion, were obtained on relatively stable flat areas of inter-alas meadows that were not previously subject to thermokarst.

Observation points (markers) were set at all 11 sites on stable flat areas of inter-alas areas. These points showed few changes relative to our datum points in the first years of observations. A few years later these points began to show a definite tendency to subsidence. Since the general tendencies for changes in elevation at 11 sites are relatively similar, we show the changes on site 2 as an example (Fig. 4).

Analysis of the subsidence diagrams shows that each point develops in its own individual way. On stable flat inter-alas areas (markers A and B) the stable

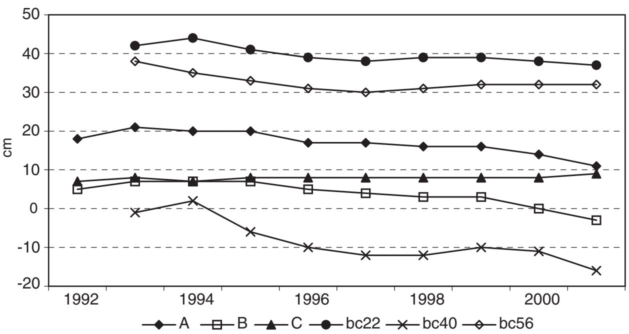

Figure 4. Surface subsidence of flat inter-alas areas, site 2. A, B, C – markers on flat inter-alas areas; bc22, bc40, bc56 – markers near small thermokarst depression.

conditions existed before 1995, and then a little subsidence occurred in 1996–1997. The 1998–1999 period can be characterised as being rather stable. However, in 2000–2001 subsidence became highly pronounced. Subsidence at the edges of small thermokarst depressions (markers bc22, bc40 and bc56) occurred in 1995–1996. The years 1997–1999 were stable again, followed by the years 2000–2001 with subsidence even on stable flat areas. It cannot however be reported that all points on inter-alas areas show a tendency to subside. For instance, after little fluctuations in the first two years of observation, the surface at some points (marker C) on the same site remained stable through 2001.

In general, short-term changes of surface subsidence are found on thermokarst-sensitive sites. Periods with relatively stable conditions changed into periods with noticeable directional subsidence. Between 1993 and 2001 the surface subsidence on flat areas was 7–8 cm, and up to 14–15 cm on the edges. Climate warming in the 1990s caused intense flooding of young thermokarst depressions. This was an additional factor for enhancement of the thermokarst process on our experimental site and on the areas undisturbed by thermokarst.

Thermokarst has been of special interest to geocryologists. For example, Shur (1988) provided data on the rate of thermokarst development after disturbance of soil organic layer in northern Siberia. Burn (1998) calculated potential subsidence for increasing active layer thickness in Northwest North America. Allard et al. (1996) provide an example of thermokarst development (soil subsidence of 1 m in 1993–1994) in northern Quebec, Canada.

Direct observations for subsidence on undisturbed sites are not commonly observed. Therefore, there is little possibility to compare results of similar research from other regions. However, the data of Pavlov (1998) taken in northern West Siberia show the tendency for an increase of the active layer thickness that may cause thermokarst development.

3.2 *Temperature measurements*

The period considered (1992–2001) in Central Yakutia shows significant deviations based on data from the Yakutsk weather station.

Mean annual air temperature. According to records from Yakutsk weather station for the period 1931–2000 the mean annual air temperature of the near-ground layer was −10.0°C. During the period of observations at Yukechi (1992–2000) the mean temperature was −8.8°C (13% deviation), the maximum temperature being −7.6°C in 1996. The observation period of surface dynamics at the Yukechi site corresponds to a cycle with a significant rise in air temperature (Fig. 5). This rise is a regional phenomenon that is common to

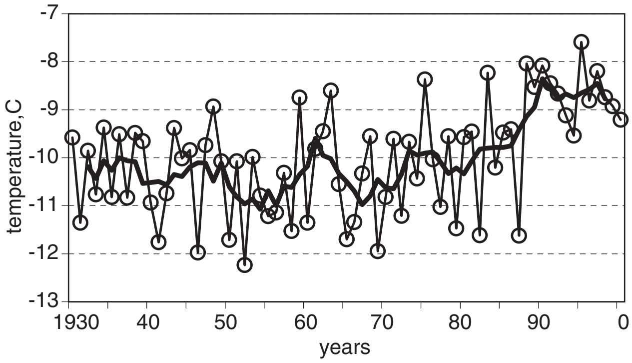

Figure 5. Variability of mean annual air temperature in Yakutsk (thin line – actual data; thick line – 5-year mean).

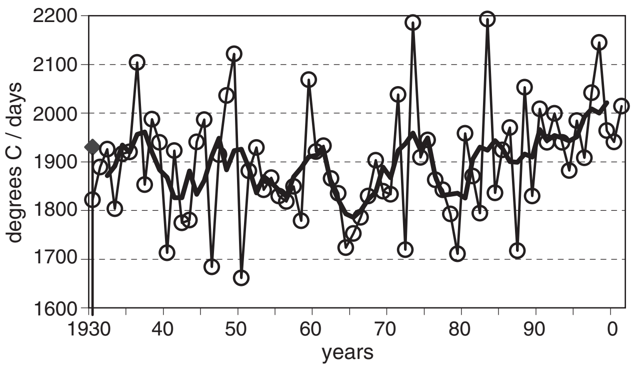

Figure 6. Variability of air thawing index in Yakutsk (thin line – actual data; thick line – 5-year mean).

the most territories of Central Yakutia (Fedorov & Svinoboev 2000, Skachkov 2000).

Air thawing index. The period of 1992–2001 is characterised by a significant increase in summer temperatures. Mean thawing index was 1978°C, while the long-term mean was 1899°C (about 4% deviation) (Fig. 6). Therefore, there was a tendency for the increase of the thawing index in the last 20 years, which could have influenced the pronounced flooding of young thermokarst depressions and the progressive surface subsidence.

Soil temperatures at a depth of 3.2 m. Regular observations of soil temperature in Central Yakutia have been conducted since 1931. For several reasons however, the retrospective diagrams of soil temperature development could not be compiled. These include the relocation of weather stations and related changes in lithologic conditions, as well as strong influences of the anthropogenic factor on the soil temperature regime.

In order to remove the heterogeneity of data series caused by the relocation of weather stations and by anthropogenic effects, the observed temperatures were converted into relative values. Normalised anomalies were calculated for each year as follows:

$$A = (i - i_{av})/\delta$$

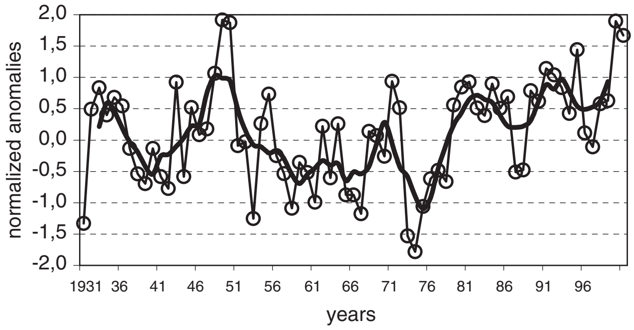

Figure 7. A generalised diagram of variation in soil temperature at a 3.2 m depth, Central Yakutia (thin line – actual data, thick line – 5-year mean).

where i = the value for a given year; i_{av} = the long-term mean of a continuous series; δ = the root-mean-square deviation of a series.

Correlation coefficients for measured temperatures between the stations Yakutsk, Pokrovsk and Churapcha are not very high, but are quite high with the generalised values: 0.80 to 0.87 at a depth of 1.6 m and 0.79 to 0.81 at a depth of 3.2 m.

A generalised diagram of variations in soil temperature at 3.2 m depth was compiled for Central Yakutia (Fig. 7) using recent monitoring data from different sites. In the context of this diagram, the observation period is also characterised by positive values exceeding the long-term mean.

4 CONCLUSION

The melting of upper ground ice on stable areas of inter-alas meadows and the activation of thermokarst processes in young thermokarst depressions were observed over the last 10 years in Central Yakutia. This caused a significant surface subsidence. For example, from 1993 to 2001 the surface subsidence on flat areas was 7 to 8 cm, and 14 to15 cm on the boundary of young thermokarst depressions.

Many climatic parameters were observed to change in these years. A thin layer between the upper ground ice and the base of the active layer on inter-alas meadows does not protect the ice-rich zone, and, therefore, the depth of thaw reaches the upper ice wedge resulting in thawing of the ice-rich zone, and subsequent surface subsidence.

Surface subsidence is not always correlated with the dynamics of individual elements of climate; rather many factors are involved. Thus, high summer temperatures in 1998 did not affect subsidence. The continuity of stable conditions (without subsidence) of that year may be explained by the enhanced biota productivity. The index of larch tree-ring growth increment was 1.43, that is 43% higher than the long-term norm (according to the data from the Neleger station near Yakutsk).

Tendency for directional subsidence on previously undisturbed areas indicates the influence of climatic stresses on landscapes containing ice-rich deposits. The activation of the process on present thermokarst depressions and directional subsidence on drained, flat inter-alas meadows are examples of stress formation in the landscapes of Central Yakutia.

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