Present post-disturbance dynamics of permafrost in Central Yakutia

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1. INTRODUCTION

Post-disturbance dynamics of permafrost landscapes has been the focus of our research starting from the 1980s. Special-purpose monitoring sites were established to study thermokarst and boreal forest recovery in the disturbed areas. The heavy human impacts on the environment and recent climatic changes provided a good example of how the permafrost properties change following disturbances. Our observations coincided in time with the greatest increase in air temperature in Central Yakutia (Fig. 1 and 2). From 1960 to 1985 were the years of intensive agricultural activities in the region when large areas of the taiga were developed for agricultural use. These activities have had negative effects on permafrost terrain.

Major permafrost disturbances result from impacts that are accompanied by the loss of vegetation. These primarily include clearing and grubbing, wildfires, killing of trees by insects. In Central Yakutia, up to 30% of the area are affected by these types of disturbance. The difficulty in documenting disturbances is that fires often have several generations. A good point, on the other hand, is that the developmental activities and disturbances occurred in phases and this allows us to look simultaneously into several stages of post-disturbance dynamics. This pertains to the processes of both degradation and recovery.

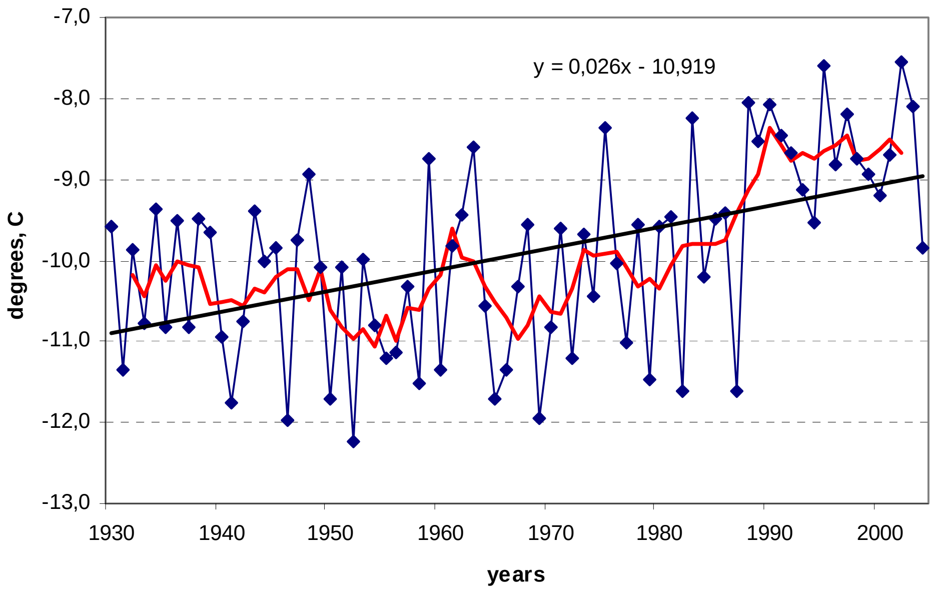

Fig. 1. Variation of mean annual air temperature, Yakutsk.

Symptom of Environmental Change in Siberian Permafrost Region,
Eds. Hatano R and Guggenberger G, p 225-231, Hokkaido University Press, Sapporo, 2006

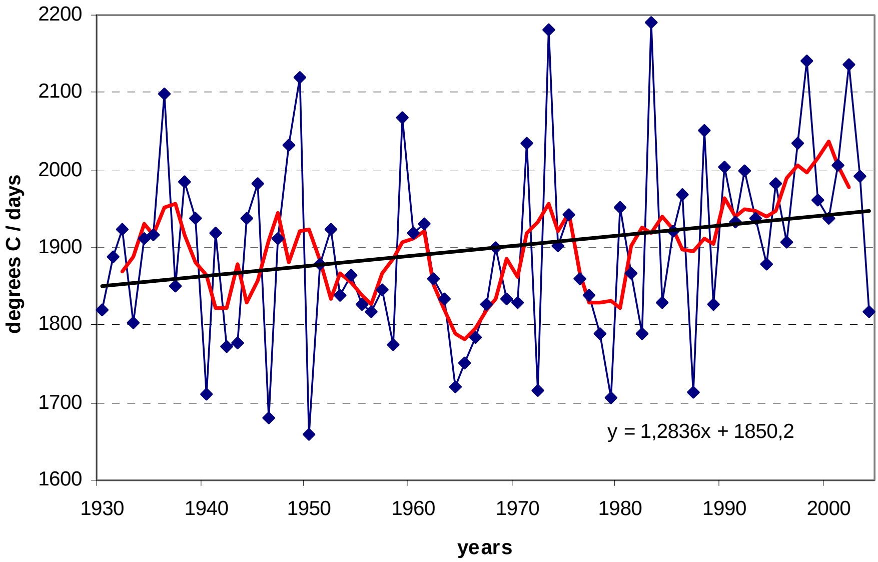

Fig. 2. Variation of the thawing index, Yakutsk.

2. MATERIALS AND METHODS

Materials were obtained from monitoring sites of Permafrost Institute near Yakutsk in Central Yakutia (Fig. 3). Neleger, Spasskaya Pad, Yukechi and Umaibyt sites are within a 100 km radius of Yakutsk. Ground temperature, soil moisture content, surface subsidence and land surface dynamics studies on any stages in these sites.

Ground temperature and active layer thickness were measure by thermistors and permafrost gauge. Soil moisture content was determined from soil samples by drying. Surface dynamics was study by levelling. Ages of forest stages after disturbance were used for permafrost succession construction.

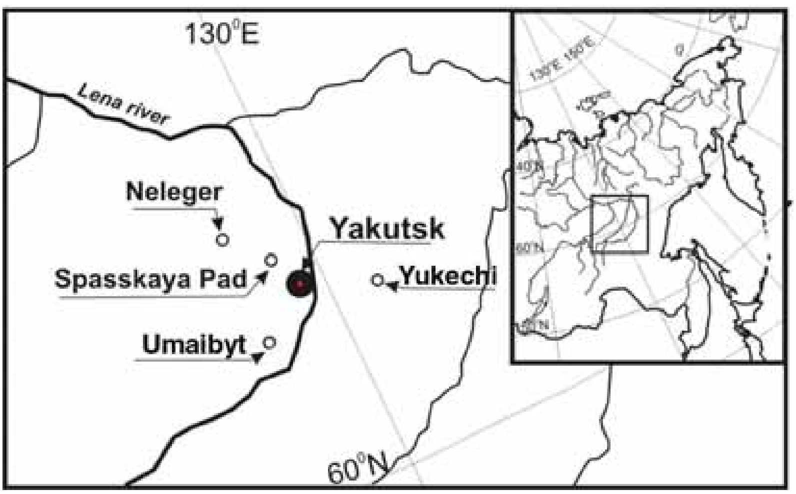

Fig. 3. Location of monitoring sites of Permafrost Institute SB RAS in Central Yakutia.

3. RESULTS AND DISCUSSION

The initial stage of permafrost response to disturbances was studied in detail at the Neleger and Spasskaya Pad sites (Fig. 3). The investigations were started in 1996 with a detailed survey of landscape and permafrost conditions. A permafrost-landscape map at a scale of 1:25,000 was constructed and an inventory of basic environmental characteristics prepared. Also, plots were established to study the temperature and moisture regimes in various permafrost landscapes, including various post-disturbance stages. Investigations at these sites are special in that the effects of disturbance were begun to be studied immediately after the impacts had occurred.

We found that cryogenic processes are most active during the first 5-6 years after disturbance, then the processes stabilize and conditions develop for the recovery of permafrost terrain. If the forest cover is re-established over this period, the disturbed area is no more the locus of ecological risk.

At the Kys-Alas site near Yakutsk which is underlain by ice-rich sediments, intensive thermokarst development with surface subsidence up to 10-15 cm began after the area was clear cut of trees in 1996 (Fig. 4). This was not surprising in view of the recent regional increase in mean annual and summer air temperatures. However, the oversaturation of the active layer in the first few years after tree removal, as well as periodic strong cooling of the ground in early winter due to low snowfall caused the formation of a new protective layer. Such layer results from freezing of suprapermafrost water and oversaturated soils on recent cuts. This is manifested on the topography by 10 to 15 cm rising of the relative surface levels (see Fig. 4). This mechanism of permafrost stabilization is the main condition for recovery and optimization of the permafrost landscapes which are in a critical state.

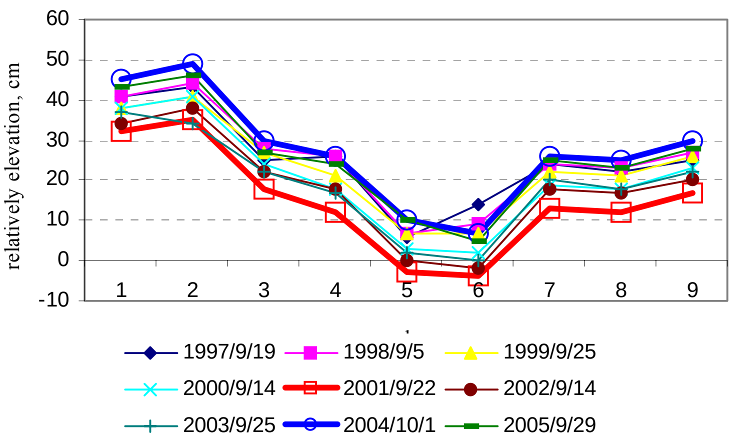

Fig. 4. Changes in relative surface elevation, Kys-Alas site.

However, not all the disturbed areas respond in this manner. Many landscapes are vulnerable and highly sensitive to climatic change. Among them are forest-free inter-alas areas with an ice-rich substrate. These landscapes were kept treeless for long to be used as pastures and farm fields. Ground ice here occurs at shallow depths, on average within 2 to 2.2 m of the surface. The long existence of the landscapes in an artificial state can not but leave a trace. The active layer becomes heavily desiccated requiring more heat for thawing compared to wet soils. As a result, seasonal thaw reaches the tops of ice wedges in critical years, causing ice melting and ground subsidence.

Such landscapes were studied at the Yukechi site which is situated on the right bank of the Lena River, 50 km east of Yakutsk. The area is characterized by extensive development of thermokarst landforms. Recent climate warming has intensified thermokarst activity in the existing thaw depressions. Over the period from 1990 to 2005 thermokarst has evolved from a polygonal mound and ditch form to a lake stage. Correspondingly, the rates of ground subsidence are high (Fig. 5). In central portions of the young water-filled thermokarst depressions 2 to 2.5 m in depth, an average rate of surface subsidence is 5-10 cm/yr.

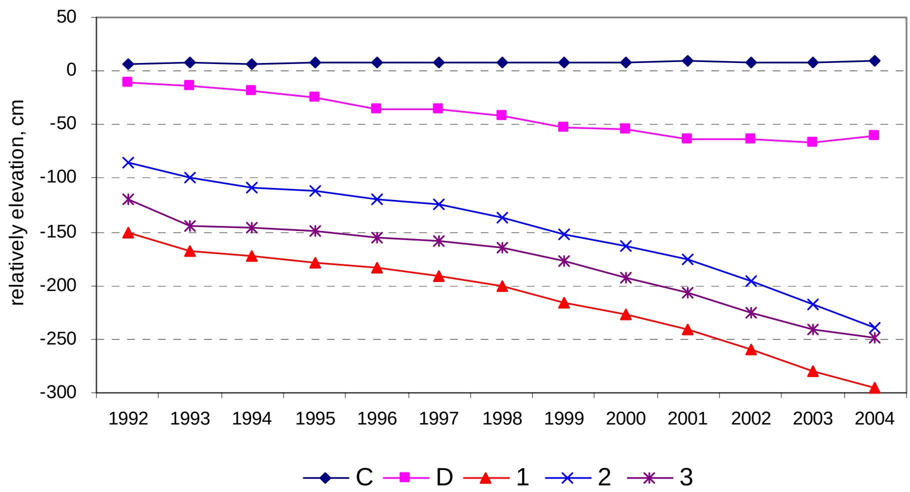

Fig. 5. Surface subsidence in thermokarst depression on site 2, Yukechi.
C: check point, undisturbed inter-alas terrain; D: incipient thaw depression;
1-3: centers of polygons within thaw depression.

Interesting data were obtained from the areas that had not been affected by cryogenic processes before. These are flat treeless inter-alas areas with no visible indications of thermokarst such as thaw troughs over ice wedges. Ground subsidence is now observed on these sites. Our investigations since 1992 show that this process has a distinctive trend. At many observation points, the ground surface has subsided 20-30 cm between 1992 and 2005 (Fig. 6). This subsidence can be attributed primarily to climate warming. Other studies also indicate intensive activity of cryogenic processes in the treeless landscapes of Central Yakutia. P.P. Gavriliev (2002) found that the abandoned farm fields reached the critical state over the last 15 to 20 years with subsidence up to 0.5-1 m. It is thus evident that the treeless landscapes with the desiccated active layer are most sensitive to climatic warming and most threatened upon further disturbances.

The activation of subsidence on the existing thermokarst depressions and directed subsidence of the well-drained, flat interalas meadows are a dramatic indicator of current climatic changes in Central Yakutia.

The response of permafrost to impacts largely depends on the environmental conditions by the time of disturbances related to cyclic climate variations. Therefore, in order to determine the state of the environment, we have developed an assessment of cryoecological stress in landscapes. *Cryoecological stress in landscapes* considered by us as an integral index of changes in climatic, geocryological and biological characteristics is one of the basic criteria for the development of a critical environmental state in the permafrost areas (Fedorov, 1996).

Stress in the landscapes occurs when some critical characteristics coincide. We selected summer air temperature and precipitation, ground temperature, seasonal thaw depth, and tree-ring growth index as the main indicators. During these periods the landscapes become more vulnerable to anthropogenic disturbances due to the rapid development of cryogenic processes.

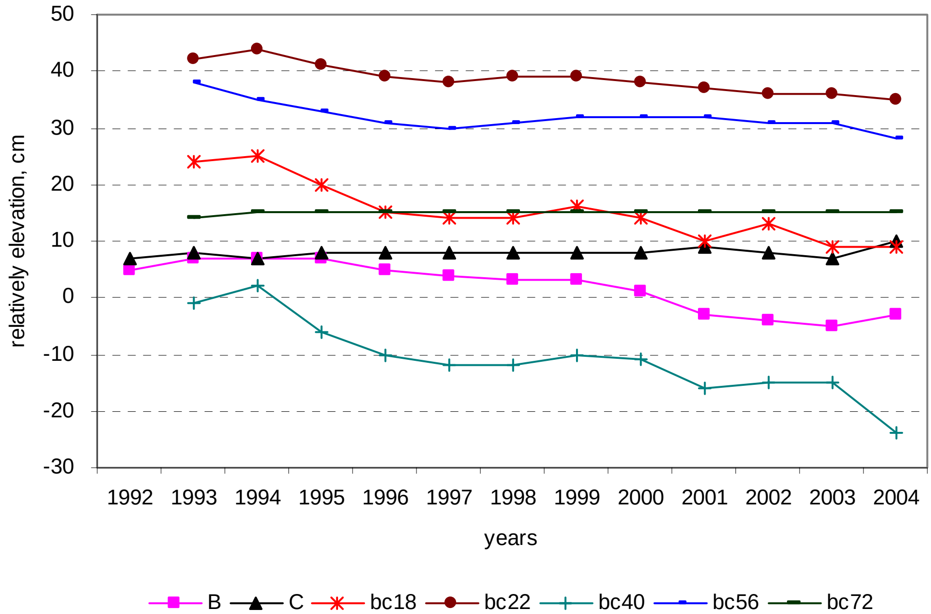

Fig. 6. Surface subsidence of flat inter-alas on site 2. B, C – markers on flat inter-alas; bc18, bc22, bc40, bc56, bc72 – markers near small thermokarst

Our studies indicate that the development of cryoecological stress in the landscapes of Central Yakutia has been cyclic in recent years as it was in the previous years (Fedorov, 1996; Svinoboev, 2005). The cycles are approximately 9 years in length (Fig. 7). The observed periodicity of extreme cryoecological conditions allows more reliable prediction of possible critical cryoecological situations with highly active cryogenic processes.

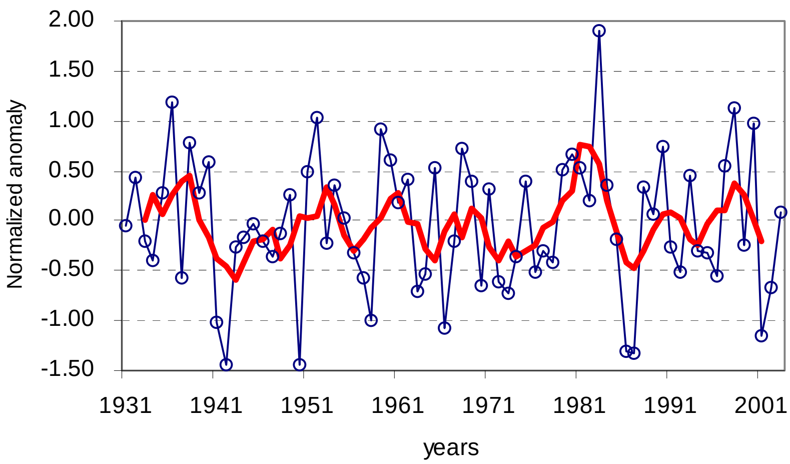

Fig. 7. Dynamics of cryoecological stress in landscapes, Central Yakutia.

Restoration of the permafrost conditions following disturbance is studied using the method of anthropogenic vegetation successions. As the focus of the study is permafrost, we call them permafrost successions. *Permafrost successions* are investigated at the monitoring sites of the Permafrost Institute (Yukechi, Umaibyt, Spasskaya Pad and Neleger) located in Central Yakutia. The sites are within a 100 km radius of Yakutsk. Observations are conducted here to monitor variations in ground temperature and seasonal thaw, as well as changes in the landscape conditions in the natural and disturbed areas.

Based on the study of landscape dynamics after fires and tree removal, we constructed permafrost succession models for Central Yakutia (Fig. 8). In successional stages, an increase in biomass is the main force which acts as an insulating layer for permafrost. We determined the restoration patterns of permafrost conditions, such as ground temperature and active layer thickness, in relation to the age of successional stages. The permafrost conditions recover completely 120-130 years after disturbance.

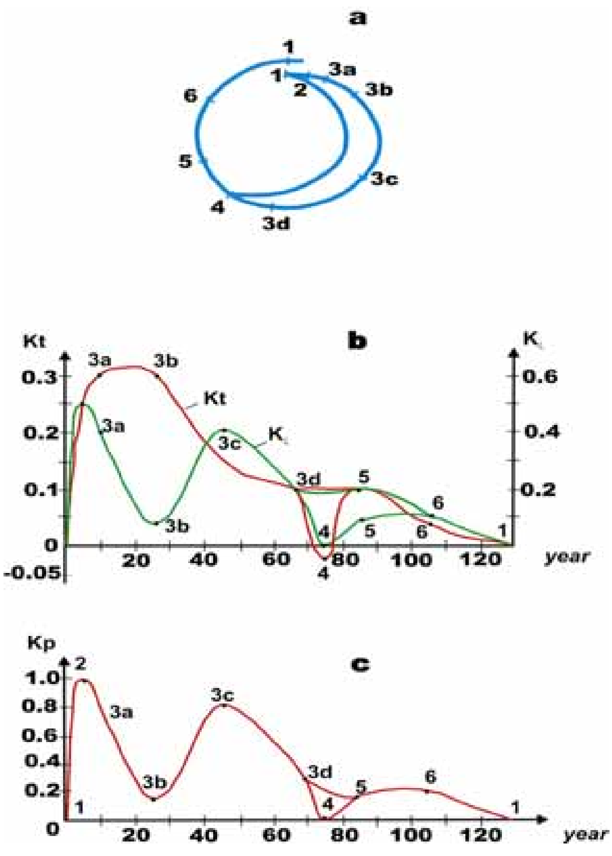

Fig. 8. A succession scheme of landscape evolution at Umaibyt site (a), variability of ground temperature (Kt), seasonal thaw depth (Kξ) – (b) and protective thickness (Kp) – (c).

The majority of the recovering areas which are presently dominant in the landscapes of Central Yakutia are returning to their original state. At Umaibyt, for example, the ground temperature has cooled up to 0.5°C over the period 1980-2005, while an expected increase in ground temperature has been observed in the open sites of weather stations. Thus, many permafrost landscapes at the various post-disturbance stages show a negative trend in ground temperature during the period of climatic warming.

The study of successions makes it possible to reliably predict permafrost dynamics and to assess spatial differences in the response of permafrost landscapes to global climatic change.

4. CONCLUSION

The present-day permafrost dynamics in response to anthropogenic disturbances varies. Much is dependent on site-specific conditions. There are both degrading and aggrading forms. The permafrost landscapes possess protective functions which bring to restoration of the original state after disturbance.

The permafrost landscapes are resistant to climate warming as well. As is known, during the Pleistocene and Holocene warming periods about 75-80% of ice-rich terrain in Central Yakutia remained unchanged. Only about 20-25% of the area was subject to thermokarst resulting in alas terrain (Bosikov, 1978). It suggests that there are some forces that tend to stabilize the landscapes. The factors and mechanisms controlling *ice-rich terrain stability* are as yet little understood and require further research.

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