Impact of modern climate changes on soil condition and stability of structures in the permafrost zone of Russia

Artem B. Sherstiukov All-Russian Research Institute of Hydrometeorological Information – World Data Centre, 6 Koroleva street, Obninsk, 249020, Russian Federation; artem@meteo.ru

Participation in conference is kindly supported by travel grant of the World Climate Research Program (WCRP in coordination with other sponsors) and by the Asia-Pacific Network for Global Change Research (APN).

Introduction

The current global warming was most strongly showed in moderate and high latitudes of the northern hemisphere and has captured the permafrost zone in Eurasia and North America.

The northern regions of Russia have rich natural resources (oil, gas). In recent years in these areas are increasingly built engineering structures for oil and gas production and their transportation.

Climate change influences on soil condition in the permafrost zone and can have negative effects on buildings and infrastructure, including pipelines, bridges, roads. Structures in this zone are built on frozen soils, the strength properties of which depend on their thermal condition.

Changes in the state of soil is a problem for permafrost areas and demands serious studying.

Two problems had been solved by the author : 1) creation of soil temperature data set; 2) research of spatial features of changes in the state of soil in permafrost zone in connection with climate changes.

1. Creation of soil temperature data set

The daily data set of soil temperatures at depths up to 320 cm at the meteorological stations of the Russian Federation has been prepared. Period of observations at stations is different, the earliest year of data set is 1963, the current version of data set ends in 2008 (available online: http://meteo.ru/english/climate/soil.php).

The data set contains information on soil temperature under original surface at depths of 2, 5, 10, 15, 20, 40, 60, 80, 120, 160, 240, 320 cm from 431 stations of international exchange (Figure 1).

The data set presented was subject to quality control by using four methods of statistical control. Statistical control was necessary since initial observations contained errors associated with different reasons.

In the course of the quality control, none of the original data were corrected. The result of the quality control is quality flags of each value. This was done on purpose, so that each user could perform additional quality control and make his/her own decision as to reliability of one or another value.

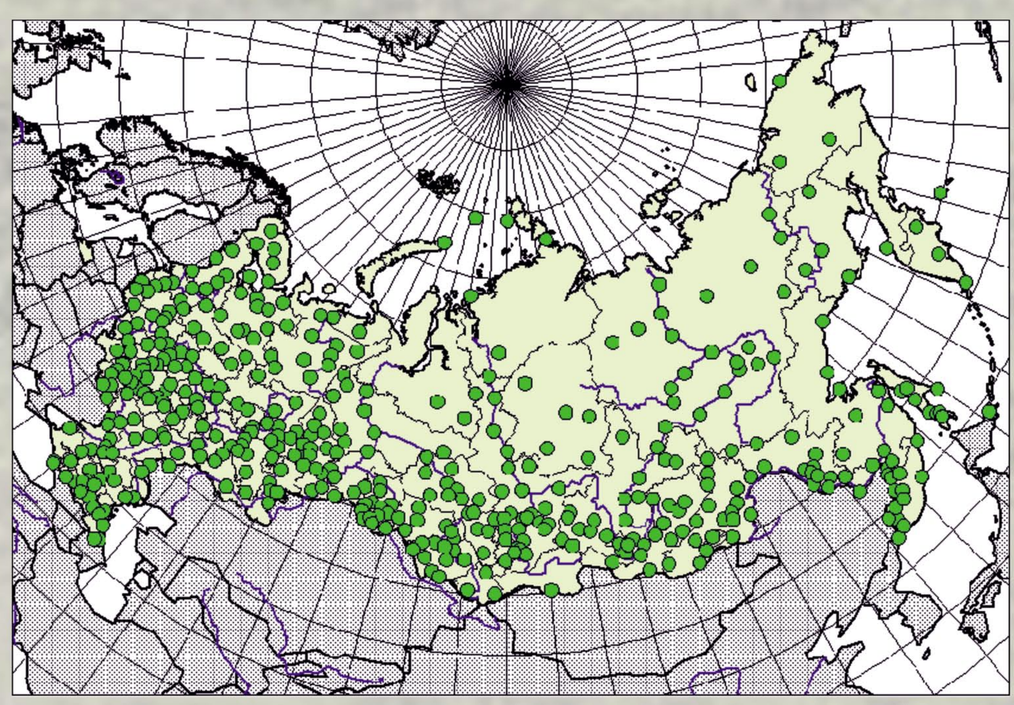

Figure 1. Network of Russian soil stations. Daily temperature WMO stations (431).

2. Research of spatial features of changes in the state of soil in permafrost zone in connection with climate changes

The main results:

Based on prepared data set, changes of soils' condition for the last four decades were researched:

A) The change of mean annual soil temperature at depths was considered and soil warming in the vast area for the period 1965 - 2006 was shown, herein the greatest trends (0,2 - 0,4^{o}C /10 years) of the mean annual temperature increase at a depth of 320 cm (Figure 2) were found in the southern part of Siberia.

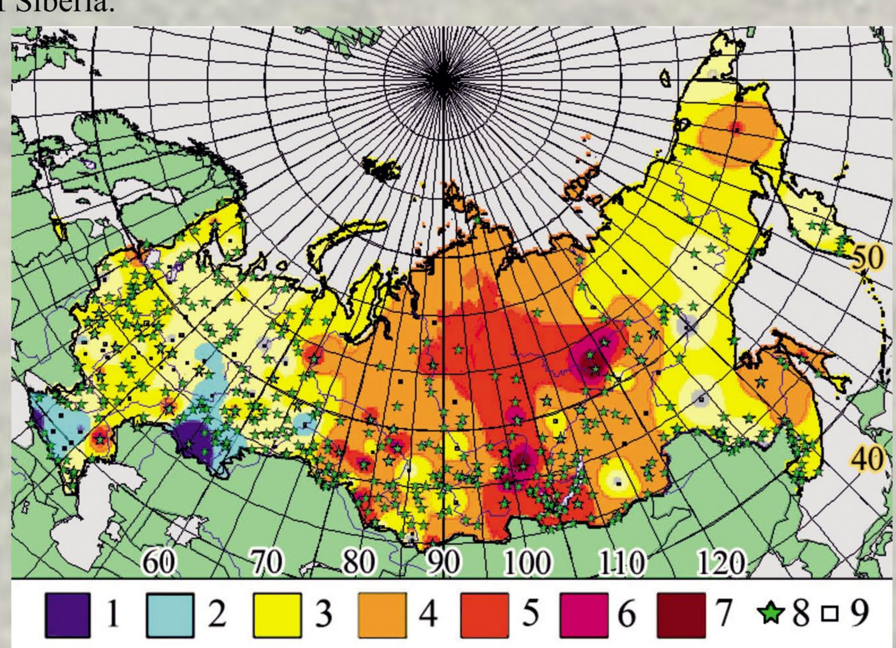

Figure 2. Linear trends of the mean annual soil temperature at the 320 cm depth for 1965 – 2006: 1 – -0,3<k<-0,1; 2 – -0,1<k<0; 3 – 0<k<0,1; 4 – 0,1<k<0,2; 5 – 0,2<k<0,3; 6 – 0,3<k<0,4; 7 – 0,4<k<0,6; 8 – stations with trends significant at 95% level; 9 – stations with insignificant trends

In the south of this territory permafrost is thought to be least stable and more sensitive to climate warming. Warming creates conditions for thawing of permafrost upper layers and for negative impacts on infrastructure and economic activities. Permafrost degradation is a serious environmental challenge for Siberia.

In the permafrost regions the depth of seasonal thawing is of great interest and importance.

The depths of seasonal freezing and thawing are very important in laying foundations of all buildings and structures. The depth of seasonal thawing is of special importance in the permafrost zone, where soil has specific properties depending on climate.

The depth of summer thawing defines the depth of laying foundations of buildings and structures and as well as some of their design features.

It is known that seasonal thawing is only in the warm season.

The analysis of soils' temperature trends at depths of 80, 160 and 320 cm during the warm season was carried out. It showed that the greatest warming of soils during the warm season was observed in Siberia and amounted (0,4 - 0,6 ^{o}C /10 years). Soil temperature trends are 0,5 - 0,6^{o}C/10 at stations in a southern part of Siberia and in the middle Siberia at depths of 80 and 160 cm, and great trends are (0,5 - 0,6^{o}C/10 years) at stations in south part of Eastern Siberia, near Angara, Pribaikalia and Transbaikalia at a depth of 320 cm (Figure 3).

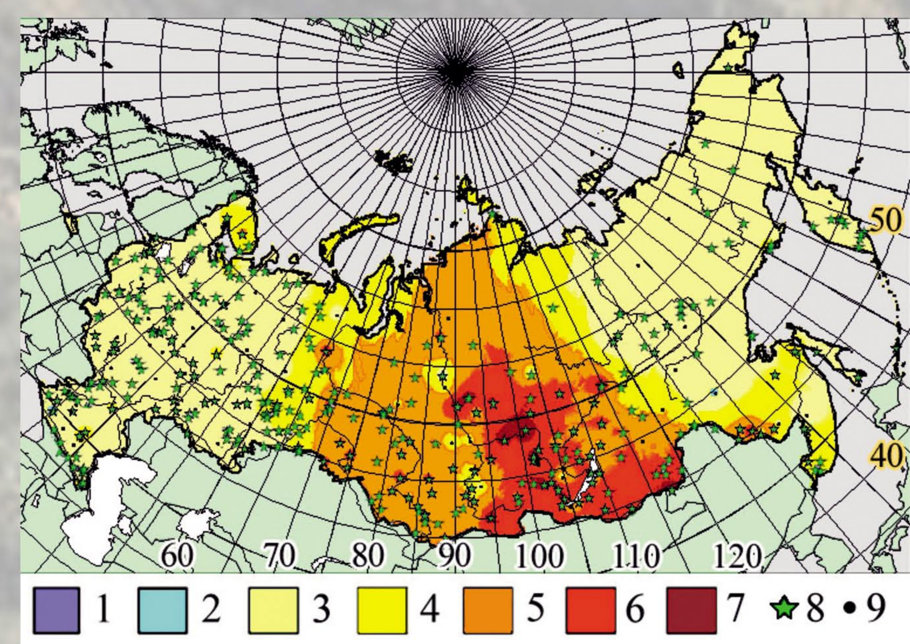

Figure 3. Linear trends of soil temperature (°C/10 y) in 1965 -2005 at the 320 cm depth. Warm season: 1 – -0,2<k<-0,1; 2 – -0,1<k<0; 3 – 0<k<0,1; 4 – 0,1<k<0,3; 5 – 0,3<k<0,4; 6 – 0,4<k<0,5; 7 – 0,5<k<0,6; 8 - stations with trends significant at 95% level; 9– stations with insignificant trends

Thus, favorable conditions for increase of seasonal thawing depth in a permafrost zone has been shown.

B) Change of seasonal thawing depth was considered.

The depth of seasonal thawing was defined as follows. Based on soil temperature daily data mean temperatures were calculated for each day of a year for the periods of 1977-1981 and 2001-2005 at the depths of 80, 160, 240 and 320 cm. Such data averaged over the region's stations and over the two five-year periods allowed a smooth annual cycle of temperature to be obtained to be able to clearly detect maximums.

On the graphs (Figures 4 - 6) dots designate temperatures at individual depths and curves shows the logarithmic approximation of changes in soil temperature at depths down to 320 cm as well as extrapolation to greater depths.

The point, where the smoothed curves cross the depth axis, shows the depth at which annual maximums and minimums are 0^{0}C. The point, where the max curve crossed the depth axis, shows the seasonal thaw depth. Comparison of max curves for two periods allows changes in the seasonal thaw depth to be estimated.

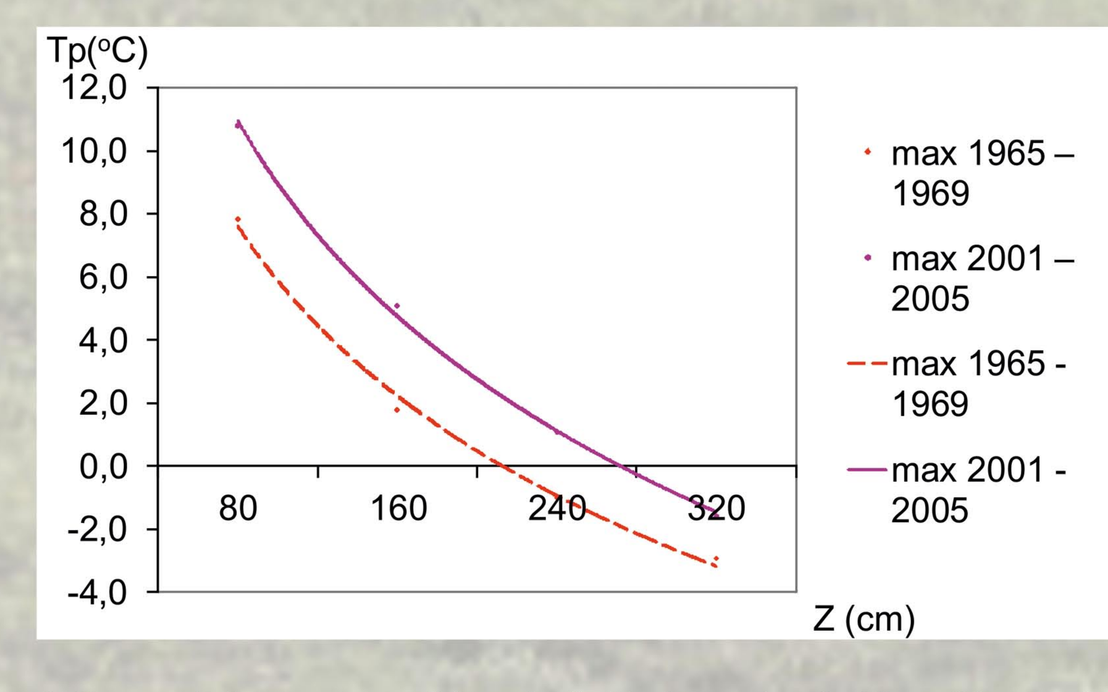

Figure 4. Changes in the seasonal soil thaw depth. Maximums (max) of the soil temperature annual cycle at various depths (Z) calculated on the basis of the mean daily soil temperature data for the periods of 1965 – 1969 and 2001 – 2005. Zhiganzk.

Changes of the seasonal thawing depth in population places in Siberia, vulnerable in terms of increase of the depth of seasonal thawing, were submitted.

In Zhigansk (Figure 4) the depth of seasonal thawing in 1965 - 1969 was about 210 cm, by 2001 – 2005 it increased for about 60 cm, at present - about 270 cm and it reaches the base of the foundations of the buildings and structures that were built earlier. This leads to an increase of cases of basement subsidence.

In Verkhoyansk (Figure 5) the seasonal thawing depth has increased for about 40 cm. Such an increase also leads to a significant decrease of stability of buildings and infrastructure constructed in the past.

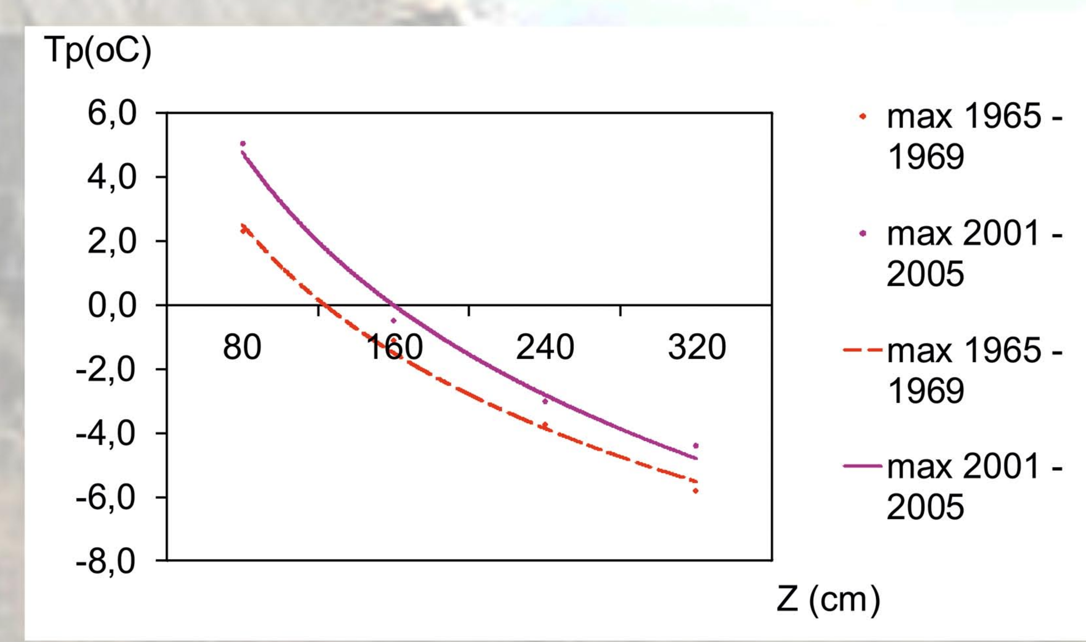

Figure 5. Changes in the seasonal soil thaw depth. Maximums (max) of the soil temperature annual cycle at various depths (Z) calculated on the basis of the mean daily soil temperature data for the periods of 1965 – 1969 and 2001 – 2005. Verkhoyansk

In Norilsk (Figure 6), the seasonal thawing depth was increased approximately by 80 cm for the period 2001 – 2005 in comparison with the period 1977 - 1981. The increase in the number of buildings in Norilsk, received various kinds of damage because of uneven basement subsidence for the period under review, is mentioned in various researches.

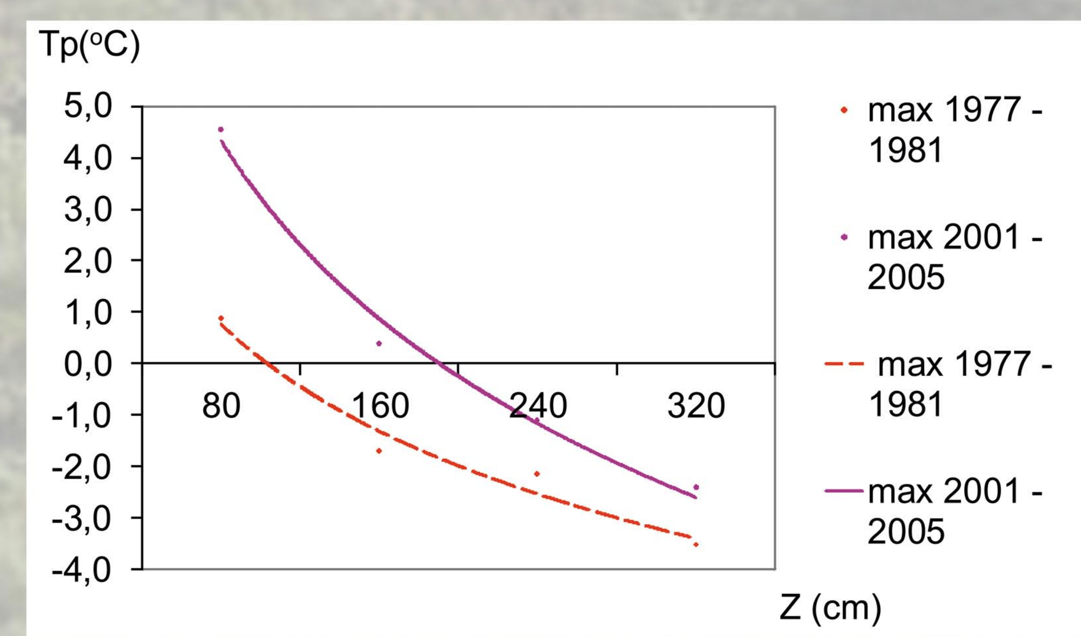

Figure 6. Changes in the seasonal soil thaw depth. Maximums (max) of the soil temperature annual cycle at various depths (Z) calculated on the basis of the mean daily soil temperature data for the periods of 1965 – 1969 and 2001 – 2005. Norilsk.

General tendency of depth increase of seasonal thawing in Siberia is the result of climate change. The increase of seasonal thawing depth of permafrost soils in the basement of buildings creates a deformations of the basements and buildings and their further destruction. In some population places from 10 to 80% of the buildings are in a dangerous condition.

Most of engineering structures in the permafrost zone are built on support systems and foundations based on permafrost ground below the seasonal thaw depth. Because of increase of the seasonal thawing depth there are deformations and failures of the pipelines running through the permafrost zone.

Accidents may be accompanied by release of oil products to the environment, which may have environmental and economic impacts.

One of the negative impacts of the permafrost degradation is the increasing malfunction of foundations of engineering structures designed without taking into account the probability of global climate warming.

The conclusion

The soil temperature data set was created. It has allowed to make the spatial analysis of influence of climate changes on the state of Russia soils in the permafrost zone.

Maps with estimation of trends of soil temperature on depth of 320 sm were constructed and estimations of change of seasonal thawing depth in the permafrost zone which are the major characteristic of stability of foundations of buildings and structures were received.

It is shown that for last decades climate changes have led to increasing of seasonal thawing depth in vast territory in the permafrost zone that create a serious problem for stability of buildings and structures on this territory.

The photo of D. S. Drozdov was used for preparation of background.