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ON CLIMATIC CHANGES IN THE KHIBINY MOUNTAINS (KOLA PENINSULA, RUSSIA)

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Abstract
The results of climatic change study in the Khibiny mountains using the data of glaciological, landscape and instrumental meteorological observations are presented. There is a significant positive temperature trend if time series analysis is limited by the period only from 1962 to 2005. At the same time a statistical significance between air temperatures for periods of 1937-1967 and 1976-2005 is not detected. It is shown that air temperature variations in regions have oscillation character and the inference about irreversibility of the modern warming is not possible.

Introduction
Analysis of weather observations at surface stations around the globe have indicated that surface temperature has risen by ~0.6°C over the last century (IPCC, 2001). At the same time regional and global pictures of the climatic change frequently do not coincide. In this paper the analysis of climatic changes in the Khibiny mountains is presented. The data of glaciological, landscape and instrumental meteorological observations were indicators of the climate change.

Result of observations
1. Dynamics of snow patches and glaciers
The first glacier in the Khibiny mountains was discovered in 1958. There are four glaciers which have an area between 15000 to 30000 m^2.
The glacier nr.3 (according to the Catalogue of glaciers of the USSR) is located in Kukisvumchorr massif. It occupies a hollow of circle in the upper reaches of the Tuliok river. The glacier length was about 350 m according to measurements of September, 1 1958, it was 40–90 m wide; the ice thickness reached 6.5 m.
The length of the glacier nr. 3 was reduced to 270 m between 1958 and 2004 (August, 28 2006). The modern glacier area is 35% of its total area in 1958.
The length of glacier nr. 4 was reduced by 45 m between 1959 to 2004. At present (September, 2006) the glacier nr.4. does not represent a single whole and is divided into 3 separate parts. This is an evidence that thawing of glaciers continues.
The snow patches prevail in the Khibiny mountains. The snow patch on Kukisvumchorr mountain is the second largest. It was first described in 1933 as a permanent snow patch. The snow thickness was about 7 m at the end of July.
This snow patche on Kukisvumchorr mountain did not thaw in warm summer months of 1972, when the regional absolute air temperature maxima were exceeded (July temperature reached 24-25°C even on top of Khibiny mountains). However, its area was reduced rapidly. The snow patches on Kukisvumchorr mountain thawed completely in 2002.

2. Dynamics of landscape zones
The districts of tundra vegetation in the Khibiny Mountains are replaced with forest-tundra, and forest-tundra is replaced with forest. This is an evidence of warmer present-day summer temperatures in comparison with previous centuries.
This valley around lake Malyi Vudyjavr was occupied with tundra vegetation according to the result of studies of vegetative and soil covers in the 1930s. At that time, according to the description, the valley looked like a wide plain minus trees, which was overgrown with ling, dwarf birch and reindeer moss. At present the valley is overgrown with downy birches. There are not any signs of tundra.
The comparison of the old and new landscape maps indicates that the upper tree-line limits rise, which accelerated notably in the second half of the 20th century. The present-day upper limits of the pine forest is approximately 100 m higher, than it used be 100 years ago [1].

3. Instrumental meteorological measurements
Meteorological observations were carried out on Yukspor mountain between 1936 and 1982. Since 1962 till present meteorological observations have been implemented on Lovchorr mountain.
The significant trend in the mean annual air temperature on Lovchorr mountain can be seen in Fig. 1.

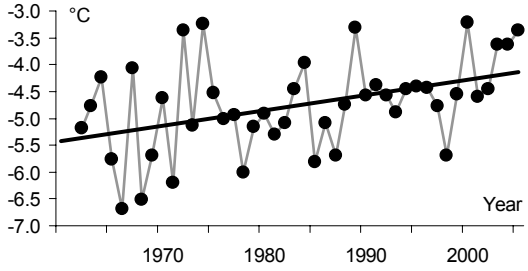

Fig. 1 Mean annual temperatures and linear trend on Lovchorr Mountain

This trend looks more visually, if it is described as an anomaly from the 1962-1990 average (this period was recommended by the World Meteorological Organization for the calculation of the modern climate parameters).

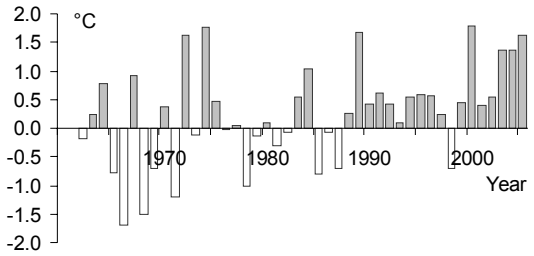

Fig. 2 Anomalies of mean annual air temperature on Lovchorr mountain in °C (from the 1962-1990 average)

As it can be seen from Fig. 2, there are significant positive anomalies of mean annual temperature since 1989 to the present except of 1998.

The increase of mean annual temperature on Lovchorr mountain is 0.28°C/ decade in the period of 1962-2005. It is noted that in other parts of the Kola Peninsula the increases of mean annual temperature are between 0.22 and 0.45°C/decade [2].

All the seasons have the positive temperature trend (table 1), but the contribution of the linear trend to the total dispersion is little in spring, in summer and in autumn (3-5%). This suggests that the trend can be a result of measurements insufficiency. It is necessary to carry out further studies.

Table 1. Temperature changes on Lovchorr mountain

Months	Trend °C /decade	R2
Winter	0.32	0.12
Spring	0.18	0.03
Summer	0.26	0.05
Autumn	0.24	0.03
Year	0.28	0.18

To do this, all the time-series of observations were divided into periods of 1962-1991 and of 1992-2005. Under such division the period of 1991-2005 is warmer. The analysis shows (table 2) that only winter and annual temperatures have statistical significance. The trends in other seasons have not any statistical significance.

Table 2. Statistical significance of the temperature changes on Lovchorr mountain

Months	1962-1990	1991-2005	ΔT °C	α=*0.05*
Winter	-10.6	-9.8	0.8	+
Spring	0.2	0.6	0.5	
Summer	6.4	6.7	0.2	
Autumn	0.1	0.6	0.5	
Year	-5.0	-4.3	0.6	+

The annual precipitation in the Khibiny mountains decreased. The decrease of total precipitation was due to the winter (solid) precipitation decrease (fig.3). At that time the summer precipitation changed weakly.

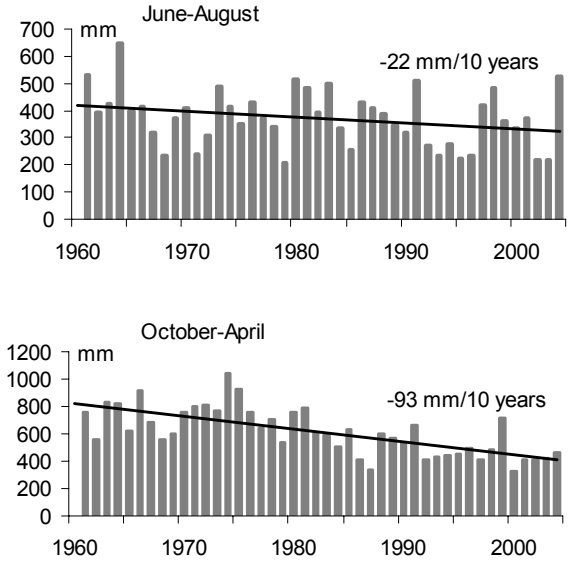

Fig. 3 Total summer and winter precipitation and linear trends on Lovchorr Mountain.

It is significant that the sign of annual precipitation trend over the greater part of the Kola Peninsula is small, but it is positive [2].

Analysis of results

The results of glaciological, landscape and instrumental meteorological observations indicate the existing change of climate in the region. However, we can not assume the present-day climate warming has irreversible character.

As shown above the glaciological environment in the Khibiny mountains is reducing. However the thawing of glaciers is caused not by warming of the second half of the 20th century! The Khibiny glaciers are the relic of the last mountain glaciation. They are situated below the modern climatic snowline by more than 500 metres. Under such conditions the thawing of glaciers is a natural process. This is a result of global increase of temperature in the interglacial period. The warming of the second half of the 20th century and the solid precipitation decrease only accelerated this process. It is significant that the sign change of the temperature trend can not induce a cessation of this situation. While the glaciers are situated below the climatic snowline, the reduction of their area in the Khibiny will continue.

The rise of upper tree-line limits indicates that the air temperature in the 20th century is warmer in comparison with the 19th. However the remains of trees can be found above the modern upper tree-line

limits. This is an evidence that the temperature in the past was higher. Consequently the present-day high temperatures in the Khibiny are not any exclusion.
Besides, during the last millennium the temperature trend has changed the sign repeatedly. For example, the range of vertical movement of the tree line in the Khibiny Mountains during the last thousand years has been 240-260m, which corresponds to the mean of summer temperature amplitude change of 2°C [3].
It is known, that the short-term climate fluctuations has practically no impact on the location of the upper tree-line limits. Only the century and especially the centuries-old fluctuations cause the destruction or the forming forest at the border with the tundra phytocenosis [4]. In this connection, the modern rise of the upper tree-line limits in the Khibiny and the replacement of tundra districts with forest-tundra are the result of the global and slow increase of the temperature, which started at the end of «the Little Ice Period». It is unlikely, that the discovered phenomenon is caused by the short-time climate fluctuations as the sign of these fluctuations changed repeatedly even during some decades.
In fact, as shown above, the air temperature has been increasing since the 1960s. However, the instrumental meteorological measurements indicate a different sign temperature variation in the 20th century. The period of warming of 1920-1940s was followed with a period of air cooling between 1950s and 1970s. The modern warming began with the later half of 1980s (for example, see fig. 4).

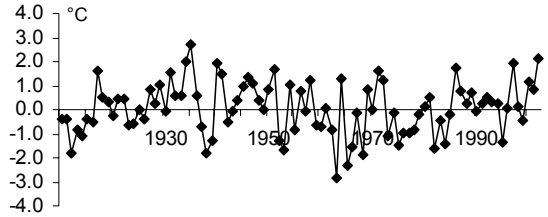

Fig. 4 Annual air temperature in Kandalaksha

Meteorological observations on Lovchorr mountain have been carried out since 1962. We have continued the time-series to 1937 year using the technique of reduction to a long time series, the measurements data on Yukspor mountain and the regression equation for the period of synchronous records on Lovchorr mountain and Yuksporr mountain (the standard deviation is 0.1°C). The temperature anomalies of the new time series are shown in figure 5.
As indicated by fig. 5, the modern air temperature on Lovchorr mountain does not exceed the ones in the period of warming of 1920-1940. We can conclude that there is a significant positive temperature trend if analyses of time series are limited by the period of only 1962-2005. At the same time a statistical significance between air temperatures in periods of 1937-1967 and 1976-2005 is not available. The 1930s were approximately as warm as the 1990s.

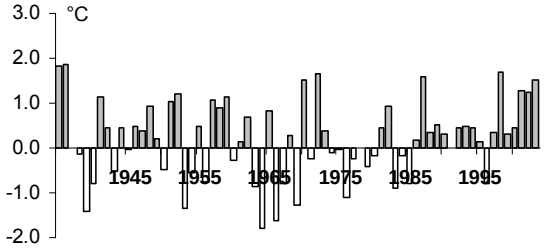

Fig. 5 Total annual air temperature anomalies on Lovchorr mountain in °C (from the 1961-1990 average) after the reduction of the time series to 1937 was carried out.

We can not talk about the future climate change as the physical mechanisms of the modern warming are not known. The causes of modern warming are the discussion item. The study results indicate to the compound character of the modern Arctic climate changes. They can not be described only by the man-made influence. This question demands further research and longer time series of meteorological measurements.
The temperature fluctuations in the Kola Peninsula are similar to the ones in other Arctic regions (Alaska, Greenland, North of Canada and Siberia) (fig.6). We can assume that the temperature time-series have the oscillation with a period of 60-80 years. Theoretically, in this case, the rapid warming can be caused by the superposition of the positive phase of this fluctuation and the global temperature increase which has started since the end of the "Little Ice Period".

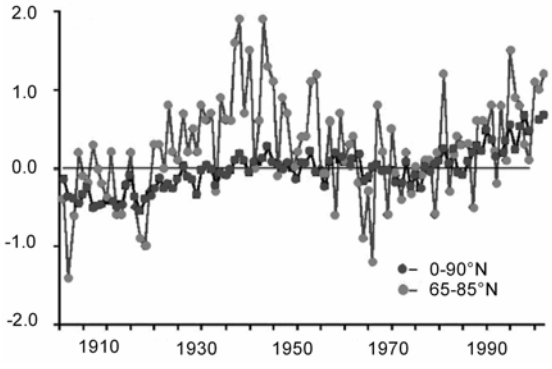

Fig. 6 Anomalies of annual mean temperature in different latitudes zones in the 20th century

However, we do not exclude that the natural warming process can be intensified by the increase of greenhouse gases in the atmosphere. It is quite possible that the greenhouse gas concentration increase produced the changes of the planetary waves

structure (the Arctic and North-Atlantic Oscillations) and it intensified the natural warming process.

Summary

The data of instrumental meteorological measurements, glaciological and landscape studies are indicative of the evident changes of climatic conditions in the Khibiny Mountains (Kola Peninsula) during the second half of the past century.
However, we have not any incontestable reasons for the conclusion that this process has irreversible character. During the last thousand years the sign of air temperature trend has changed repeatedly.
The significant trends of air temperature were found between 1962 and 2005. However the present-day temperatures in the Khibiny mountains do not exceed those in the warming period of 1920 -1940.

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