Long-term changes in the troposphere temperature and heat content in XX century

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Results of the analysis of peculiarities and regularities of long-term changes of the troposphere temperature conditions in northern and southern hemispheres within individual longitudinal zones and at different isobaric surfaces for 1948–2006 are presented. The amplitude of the air surface temperature (AST) variations is maximal in high-latitude regions in the hemispheres, and decreases toward the equator. The warming in the second half of the 20th century began earlier in high latitudes in the early 1960s and in the lower latitudes – in the middle of 70s. The AST positive anomaly is maximal in Polar regions of both hemispheres and apparently has not reached its maximum yet. As for the high-latitude regions, the warming is caused by increasing AST in the cold period. In the warm period at latitudes above 40° in both northern and southern hemispheres, the AST increase can hardly be observed. Moreover, the temperature fall is observed in the warm period in southern hemisphere in the polar region. It has been found that for the last 50 years the lower and middle troposphere (850–400 hPa) temperature has increased in the middle and high latitudes of northern hemisphere, while in the upper troposphere (over 400 hPa) and in the lower stratosphere it has decreased. The results of analysis of space-time variations of the open atmosphere heat content for 1948–2006 are given. The obtained results are discussed.

Introduction

Today a lot of attention is paid to the problem of climate warming. Observational data show the increase of surface temperature all over the world and individually in northern and southern hemispheres. This increase is characterized by a significant space inhomogeneity. In some works[1–4] the variation of the solar activity level is considered to be one of the main reasons for global warming. The comparison of changes in climate and solar activity at a large time scale shows a significant similarity in their behaviors. In particular, there are certain reasons to consider that the periods of warming and cooling were connected with solar activity variations, at least in the former millennium. However, notwithstanding the reliable and statistically proved connection between different indices of heliogeophysical activity and between different weather-climatic characteristics, the question, whether solar activity makes a significant contribution to climate change or not, is still unanswered. The flow of solar radiation incident on the atmosphere top boundary changes no more than by 0.15%. The significant part of changes relates to *X*-ray and UV radiation, which are totally absorbed in ionosphere and stratosphere.

Thus, the changing portion of solar radiation can not be the direct cause of the climate change; however, it can influence the atmospheric parameters, responsible for the radiation balance. According to the model of heliogeophysical disturbance influence on the atmospheric parameters,[5,6] atmospheric electricity is the connecting link between the solar activity and climatic characteristics of troposphere. On the one hand, the parameters of atmospheric electricity are influenced by the solar activity in high latitudes; on the other hand they significantly influence the altitude distribution of charged condensation nuclei in troposphere and, consequently, on the cloud formation and radiation balance of high-latitude areas. The change of radiation balance in high latitudes leads to a change in the meridional temperature gradient and circulations in the atmosphere.

Based on this model, some peculiarities in long-term changes of climate characteristics should be expected under impact of solar radiation.

1. The peak response should be expected in high latitude regions, because in these regions a noticeable increase in the Earth–ionosphere electric potential is observed during heliogeophysical disturbances.

2. The response will significantly depend on the altitude. An opposite temperature change in lower and upper troposphere should be expected.

3. The response is the most prominent in winter, when the flow of electromagnetic radiation from the sun is either low or absent.

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The latitude dependence of long-term changes in the air surface temperature

Based on the data of NCEP/NCAR Reanalysis the fields of daily mean air temperature on the main isobaric surfaces 1000, 850, 700, 500, 300, 200, 100 hPa were received for four latitudes zone of northern and southern hemispheres. On this base, we have analyzed spatiotemporal changes in the troposphere temperature during the period 1948–2006.

According to climatic models, including both natural and anthropogenic factors, the latitude manifestations of the warming differ significantly. In particular, it follows from global climatic models that at the initial stage of the increase of concentration of greenhouse gases in the atmosphere, a significant portion of heat in the Polar region is spent to the ice melting, therefore, the greatest warming occurs in moderate and low latitudes. According to our model, this pattern is opposite, i.e., at first, warming occurs in high latitudes and then it spreads to low latitudes. Besides, the maximal increase of the air temperature should be observed in the cold period, when the incoming shortwave flow of solar radiation in Polar regions is low if any and the appearance of any cloudiness leads to a decrease in the radiation cooling below the level of cloud formation, i.e., to the warming.

Figure 1 demonstrates the examples of air surface temperature variation in different latitude regions of northern and southern hemispheres for winter and summer seasons in 1948–2006.

It is evident that the warming of the second half of the 20th century started earlier at high latitudes, just in the beginning of 60s, while the warming at low latitudes started in the middle of 70s, i.e., the warming wave propagated from high latitudes to low ones. The increase in the air surface temperature in polar latitudes during this period was about ~4–5° (for cold period). The AST change amplitude is maximal in high latitude regions both in northern and southern hemispheres decreasing towards the equator. Note that AST variations in the Polar region qualitatively correspond to changes of the global AST. The warming lag in low latitude regions (especially of the southern hemisphere) can be explained by the influence of the large thermal capacity of the ocean, while the same phenomenon in middle and moderate latitudes of the northern hemisphere is not so prominent.

It is evident that the increase of the average annual AST in high latitude regions is mainly caused by this increase in the cold period. As for the warm period, the AST increase can hardly be observed in the latitudes higher than 40° both in northern and southern hemispheres. Note that during the cooling of the troposphere in the northern hemisphere, observed in 1950–1976, a significant increase in temperature in low and middle latitudes happened in southern hemisphere.

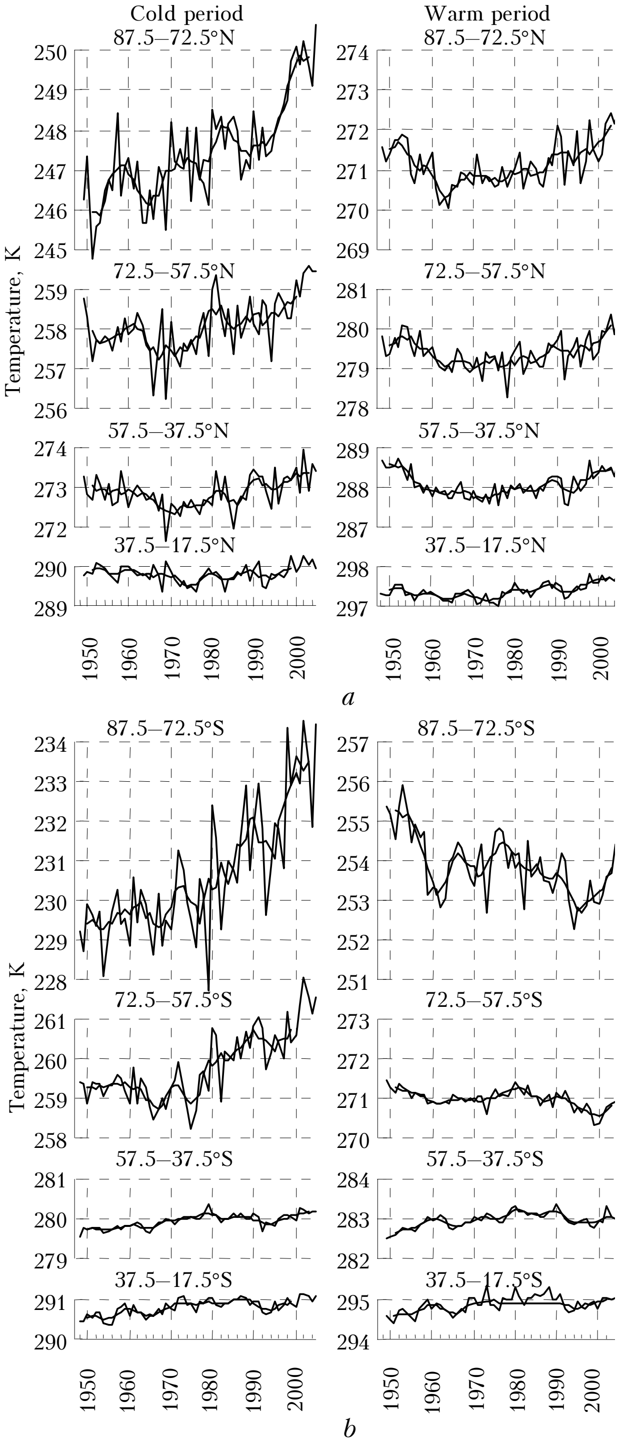

Fig. 1. The latitude dependence of AST variations in cold and warm periods: northern (*a*) and southern (*b*) hemispheres.

Peculiarities of long-term variations in troposphere temperature at standard isobaric surfaces

According to the model concept of the solar activity influence on troposphere thermobaric characteristics,[7] one should expect positive temperature trends up to the altitude, at which the additional cloudiness is formed in high latitude regions under the influence of solar and geomagnetic activity, and negative trends in regions of higher latitudes. In this connection, consider regularities of altitude variations of air temperature trends in northern and southern hemispheres.

Figure 2 shows annual-averaged temperature variations and long-term trends at standard isobaric surfaces in middle latitudes of northern and southern hemispheres.

On the one hand, there is a high degree of inter-annual correlation of temperature variations in troposphere at different altitudes, between the surface layer (1000 hPa) and the level of 500 hPa. On the other, long-term trends significantly vary with altitude. In the northern hemisphere during the cooling period of 1950–1970 the trends are negative at all altitudes of troposphere and decrease with altitude. In the warming period (1976–2006) significant positive temperature trends are observed in polar and middle latitudes at all isobaric surfaces in lower and middle troposphere (1000–400 hPa), but the trends are negative starting with an altitude of 200 hPa in northern and 100 hPa in southern hemispheres. Thus, for that period we can observe the warming in lower and middle troposphere in the altitude range from the surface layer to 400 hPa, as well as the cooling in the upper troposphere and the lower stratosphere. Therefore, the troposphere heat content variations are of particular interest.

The latitude dependence of long-term variations in the atmosphere heat content

Long-term heat content variations in troposphere in the period 1948–2006 significantly differ in northern and southern hemispheres (Fig. 3).

The heat content in troposphere of the northern hemisphere in a given period and at given latitudes is greater than for the southern one. The most significant annual anomalies are caused by the influence of volcanoes and El Nino – La Nina phenomenon. The troposphere heat content almost does not change in the equator region in 1948–1975. In 1976–1979 we observe a spasmodic heat content increase both in northern and southern hemispheres with a following slight increase up to the present moment.

During the past 30 years the maximal air temperature increase was registered in the surface layer in polar latitudes, however, these changes for the whole troposphere layer are minimal. The maximal increase in the atmosphere heat content in a 887–450 hPa layer was observed in low latitudes. In polar regions a significant temperature increase is typical for the lower troposphere, while in upper troposphere the temperature decreases, i.e., there is a process of altitude heat redistribution with no significant change in the mean temperature and heat content of the polar troposphere.

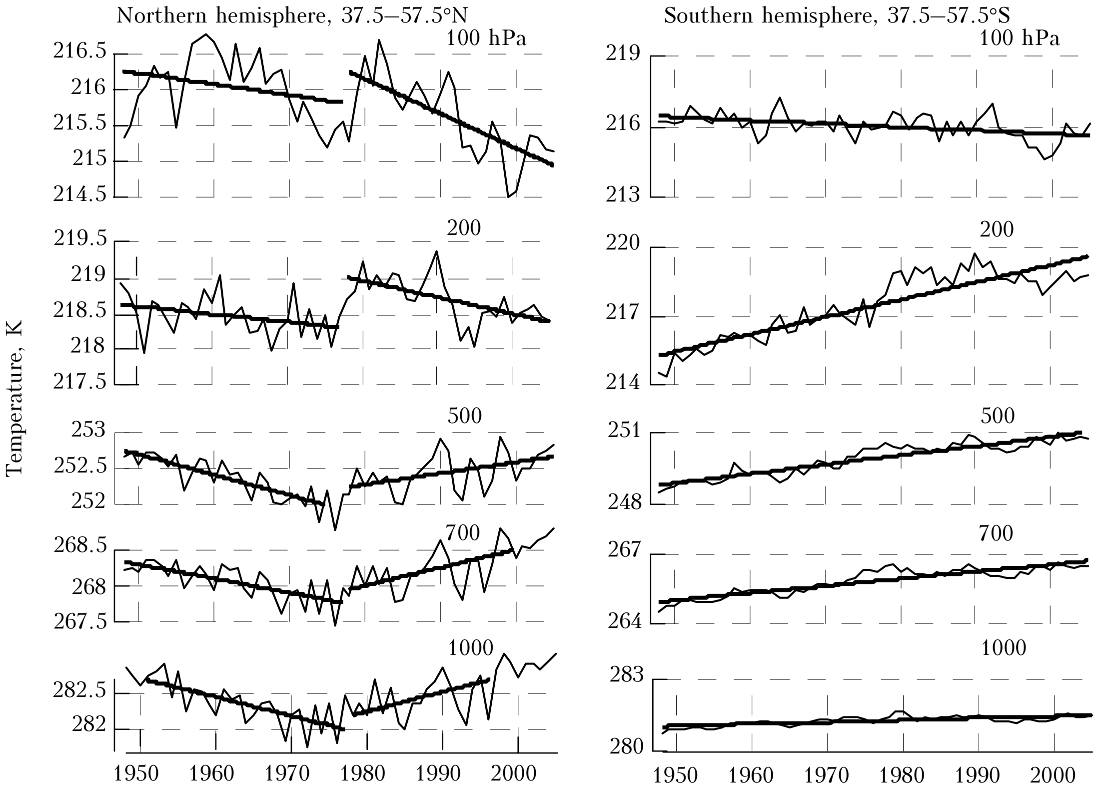

Fig. 2. Long-term air temperature variations at standard isobaric surfaces (thin line) at 37.5–57.5° altitudes of northern and southern hemispheres. Linear trends are denoted by thick lines.

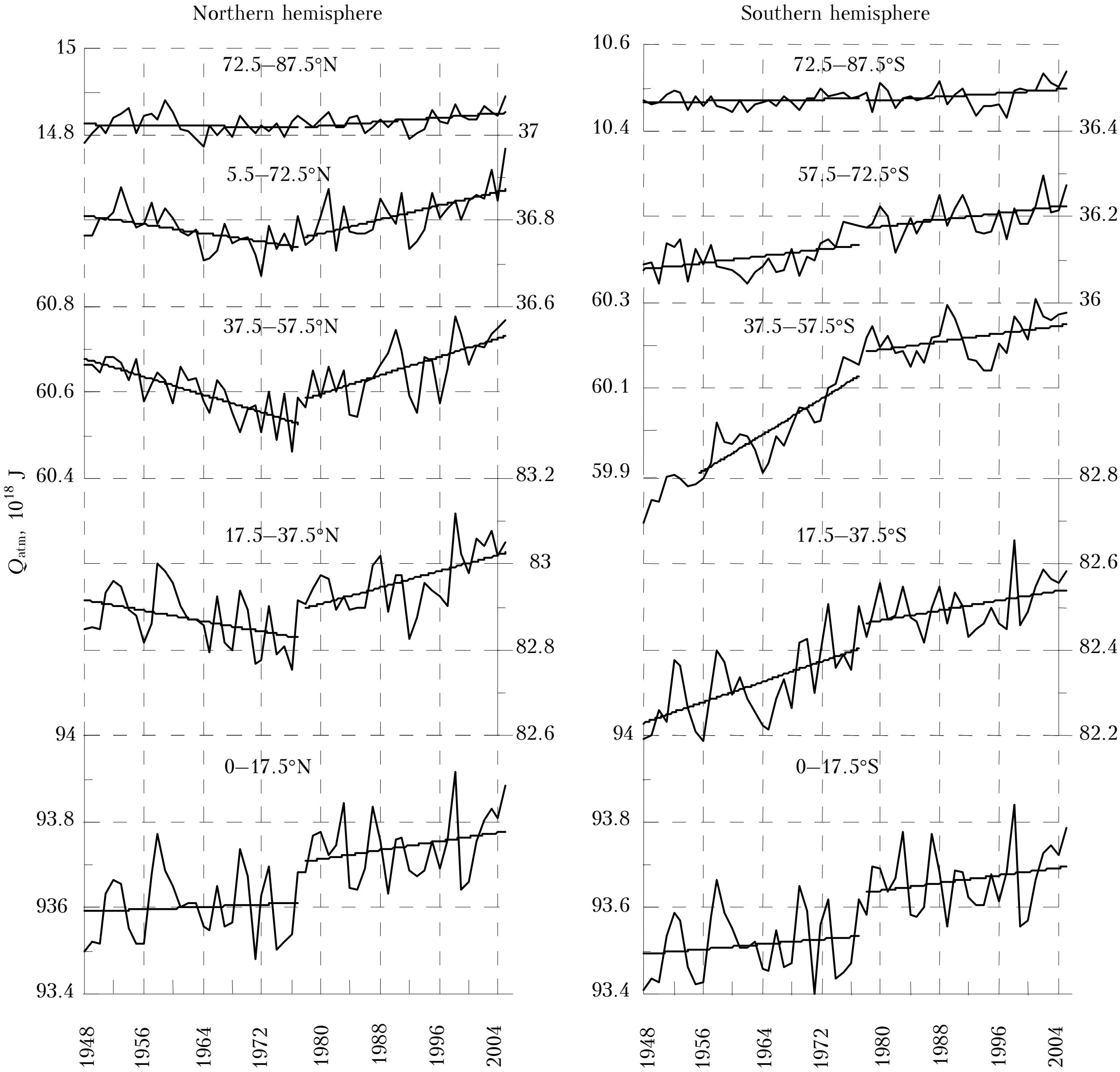

Fig. 3. Variations in the atmospheric heat content in 887–450 hPa layer in 1948–2006 in different latitude regions of northern and southern hemispheres.

In middle and high latitudes of the northern hemisphere in 1948–1976 (the cooling period) a heat content decrease was registered, while the increase in the southern hemisphere, i.e., in that period the heat redistribution proceeded there between hemispheres.

Long-term changes in the global heat content of the atmosphere

The variations of the atmospheric global heat content in 850–300 hPa layer and averaged global AST in 1948–2006 are shown in Fig. 4.

It is evident that variations in the atmosphere heat content correspond qualitatively to the variations of the air surface temperature. Two periods for long-term variations of both characteristics are distinguished: 1948–1976, when the heat content and the surface temperature did not vary, and a period after 1977, when their significant increase was registered. During the first period, the heat content of the northern hemisphere decreased and in the southern hemisphere increased with no changes in heat content of the whole troposphere. Starting from 1977 up to the present moment the continuous increase of the troposphere heat content reaches about $1.4 \cdot 10^{21}$ J which corresponds to the increase of mean troposphere temperature by 0.26 K. In this period, the air surface temperature increased by 0.7 K. Thus, the surface warming exceeds the tropospheric one by 0.44 K.

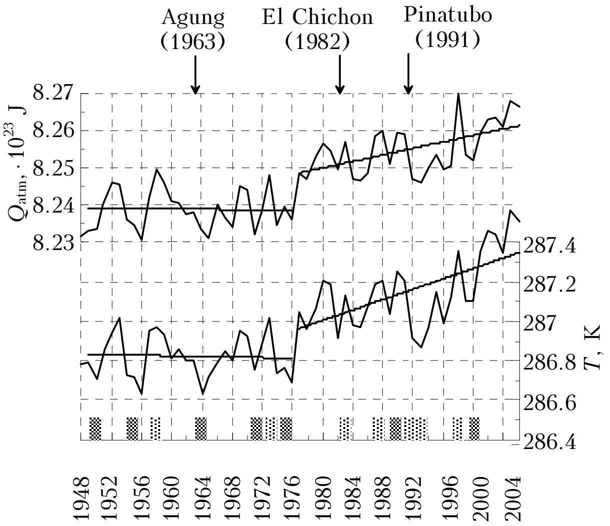

Fig. 4. Long-term variations of atmosphere heat content in 850–300 hPa layer (top curve) and surface temperature (bottom curve) for the whole globe. The eruption time of the greatest volcanoes is indicated with arrows; white rectangles in the bottom indicate the time of action of El Nino, gray rectangles – La Nina. Trend lines refer to 1948–1977 and 1978–2006.

Volcano eruptions El Nino and La Nina had a significant influence on the change of the troposphere heat content. Thus, the heat content suddenly decreased after the eruptions of Agung in 1963, El Chichon in 1982, and Pinatubo in 1991. Maximum values correspond to the El Nino period and minimal to La Nina. However, in the period of 1991–1995, corresponding to the El Nino phenomenon, atmosphere heat content decreased, being under stronger influence of the Pinatubo eruption. The change in the troposphere heat content reached in the considered period its maximum in 1998 under effect of very strong eruption of El Nino.

Conclusion

The amplitude of long-term variations of air surface temperature is maximal in high latitude regions, decreasing to the equator. The maximal AST increase is observed in the winter period. A significant difference in long-term temperature trends in troposphere and surface layer of northern and southern hemispheres was revealed. The temperature of lower and middle troposphere (850–400 hPa) has increased for the last 50 years, while the temperature of upper troposphere and lower stratosphere (higher than 400 hPa) has decreased for the same period. On the whole, troposphere heat content has not changed for the last 30 years. Maximal trends and maximal variability of troposphere heat content were observed in low and middle latitudes.

The received regularities can be fully explained in the framework of the model and the mechanism of solar activity influence on troposphere climatic characteristics proposed by the authors.

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