Physical Model of Solar Activity Influence on Climate Characteristics of Troposphere

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Accepted: 12 August 2009

Abstract. A new model of solar activity influence on the parameters of the terrestrial climate system is discussed. The main points of the model of solar activity effect on the terrestrial climate system are presented. The key conception of this model is the influence of heliogeophysical disturbances on the terrestrial climate system parameters controlling the energy flux going from the Earth to the space in polar regions. The model is based on the physical mechanism of the influence of heliogeophysical factors on climate characteristics and atmospheric circulation in high-latitude troposphere through atmospheric electricity. According to this model, the growth of solar activity results in the decrease of radiative cooling in high-latitude regions, increase of temperature of lower and middle troposphere, reorganization of the thermobaric field, decrease of the mean meridional gradient of temperature between polar and equatorial regions, which determine the meridional transportation of heat. The decrease of heat flow-out from low-latitude regions results in temperature increase in lower and middle latitude regions, and increase of heat content of the ocean and climate system. Some observational data are presented that confirm the proposed model.

Keywords: Climate, troposphere, solar activity influence

Introduction

Interest in the problem of solar activity influence on weather and climate has increased again in recent years. This is due to the fact that, firstly, some studies [1, 2] based on experimental data analysis using special technique for detecting diverse climate variations and a number of climate indices show that with a high degree of probability the observed global warming is not related to anthropogenic influence on climate. Secondly, physical mechanisms and models have been developed which relate the heliogeophysical characteristics to thermobaric and climatic parameters of the troposphere. Note that some recent papers pay special attention to research into solar activity (SA) manifestations in atmospheric processes in Polar Regions of the northern and southern hemispheres [3].

The cloudiness is one of the major factors influencing the passage of electromagnetic energy flux, propagating from the Sun, through the climatic system. It influences both the short wave energy flux coming to the surface of the Earth, and the long wave flux leaving the planet. Thus, influences on processes of cloudiness formation can essentially change the radiative balance of an atmosphere and influence not only the properties of the atmosphere, but also the state of the climatic system as a whole. Considering the fact that processes of cloudiness formation essentially depend on the presence of charged condensation kernels, below we present:

1. the mechanism of the effect of heliogeophysical factors on the high-altitude areas of the troposphere;
2. the main points of the physical model of solar activity effects on the earth's troposphere;
3. observational data demonstrating clearly the effect of solar cosmic rays and magnetospheric disturbances on the tropospheric thermobaric field parameters, and atmospheric motions.

The electro-optical mechanism of the effect of heliogeophysical factors on the troposphere's climatic characteristics

The essence of the mechanism lies in increased solar activity (solar cosmic ray flows, solar wind and interplanetary field disturbances) resulting in increased ionosphere-Earth electric potential difference. The increased potential difference is accompanied by increased vertical electric field, leading to charged condensation nuclei re-distributing altitudinally in the troposphere (negatively charged aerosols ascending to higher altitudes). Meanwhile, areas where the concentration of these nuclei has previously been low, with water vapour content high enough, will witness vapour condensation and clouds formation. Cloud formation is accompanied by changed radiation balance. According to paper [4], this mechanism will exert greatest influence on the troposphere's radiation balance and thermobaric field in high-latitude regions when the incoming radiative flow from the Sun is absent (high-latitude regions in winter). In this case, any cloudiness will result in warming due to decreased radiative cooling in high-latitude regions.

A schematic representation of the way the electro-optical mechanism operates is displayed in Fig. 1 (where: Q_0 – the charge prior to the invasion of charged particles, Q_1 – the charge introduced by the flux of charged particles; the distribution of the condensation nuclei is shown as dots; e0 and e1 - the outgoing radiative flux before and after the formation of cloudiness. T_{t0}, T_{b0} and T_{t1}, T_{b1} - temperature before and after the formation of cloudiness in the top and bottom parts of troposphere, respectively).

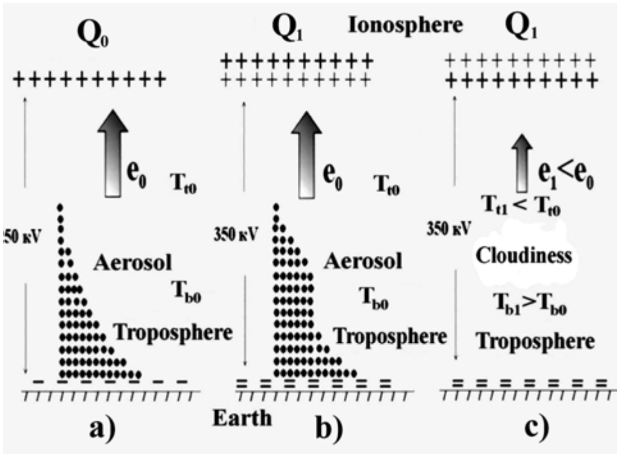

Fig.1. The scheme of electrooptic mechanism of the geliogeophysical disturbance effect on the troposphere climate characteristics: a) in the absence of heliogeophysical disturbances; b) after geomagnetic disturbances, or invasion of SCR.

With heliogeophysical disturbances absent, the ionosphere-Earth potential is determined by the tropical thunderstorms and the intensity of galactic cosmic rays (Fig. 1a).

During periods of heliogeophysical disturbances, a considerable contribution into the ionosphere-Earth potential in high latitudes is made by disturbed magnetospheric convection, charged particle flows precipitating from the magnetosphere, and solar cosmic rays (SCR) (Fig. 1b, 1c).

Altitudinal re-distribution of condensation nuclei under increased electric field (potential) of the atmosphere can result in water vapour condensing in areas where the concentration of these nuclei has been small, while water vapour content is sufficient. This is accompanied by calorification of latent heat (water vapour phase transition) and clouds formation. Cloudiness leads to changed radiation balance, reduced radiative cooling and altered thermobaric field in the troposphere (Fig. 1b).

The manifestations of heliogeophysical effects in the troposphere will depend on the time of day, season and atmospheric situation in a given region, viz.:

a. altitudinal profile of water vapour content and temperature;
b. original altitudinal distribution of condensation nuclei at the moment of the disturbance.

Main points of the physical model

In conformity with the physical mechanism of SA influence on weather-climate characteristics of high-latitude troposphere proposed by the authors, the physical model and a new concept of the SA influence on climate characteristics have been developed [5,6].

According to this concept, the atmospheric electricity is the connecting link between solar activity and climate characteristics of the troposphere. This is due to the fact that on the one hand, the atmospheric electricity parameters are affected by solar activity; on the other hand, they can sufficiently influence the radiation balance in certain regions of high-latitude atmosphere. It should be noted that the energy essential for such influence might be rather low and is of no significance.

It should be emphasized that the initial reaction in the frame of the model is the water vapor phase change and the latent heat release that result in only slightly increased temperature in cloud-forming areas. The subsequent change of the radiation balance is the most important and principal feature of the proposed model. The diagram of the model is shown in Fig. 2.

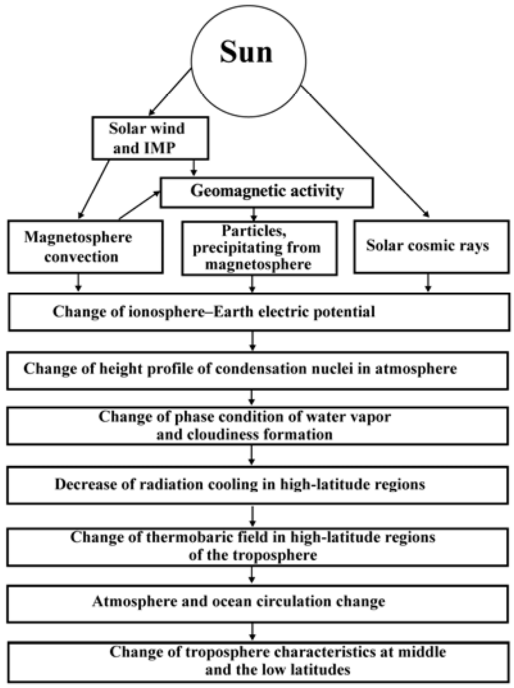

Fig. 2. Diagram of the model of Solar Activity influence on the troposphere.

Based on this model we should expect the following peculiarities of the atmospheric response to solar activity influence:

1. The maximum response should be expected in high-latitude regions, because just here the significant increase of the Earth-ionosphere electric potential is observed during heliogeophysical disturbances.
2. The response depends significantly on the height in the atmosphere, both for individual events and for the long-term trend.
3. One should expect oppositely changing temperatures in the lower and upper troposphere.

4. The response is most explicit in local winter when the incoming short wave flux is low or absent.
5. As expected the response depends on the time of the day (maximum manifestation is at night), and manifests as an increase of the minimum air temperatures.

Space-time analysis of the response of tropospheric thermobaric characteristics to individual heliogeophysical disturbances

The events with anomalously intense fluxes of solar cosmic rays (SCR) during the period of 1975–2005 are analyzed. It should be noted that, as a rule, powerful geomagnetic storms and substorms are observed 1–2 days after SCR invasions. Both intense SCR fluxes and magnetic storms are accompanied by electric field increases in the troposphere. The responses to these events differ only in the localization of the maximum manifestation regions. The region of maximum manifestation for SCR is the geomagnetic pole region, while for geomagnetic storms it is the auroral oval region.

For each of the events, based on the NCEP/NCAR reanalysis data, the daily maps of average temperature anomalies in the tropospheric layer (925-450 hPa) for 31 days (15 days before and 15 days after the event) are constructed for the northern hemisphere. On the basis of the constructed maps, analysis is carried out of the pressure and temperature field variations at the standard levels of high-latitude troposphere during the periods of anomalous heliogeophysical disturbances (HGD). As found, HGD are followed by a changed typical zonal transportation, which manifests itself in the beginning of «stationarity» of certain moving structures. Figure 3 shows an example of maps series for 11 days (from day-5 to day+5), in which the arrows indicate the stationary structure. The 0-day in Fig.3 is the maximum of SCR intensity and the beginning of a powerful geomagnetic storm. Further analysis showed that just the stationary regions are the regions of maximum response of the troposphere to HGD.

For this heliogeophysical disturbance we presents on figure 4 the HGD-induced heat content variation in the 50-90° N latitude zone. The NCEP/NCAR reanalysis data was used for calculation the heat content. As seen in Fig. 4b the heat content changes at latitudes higher than 50° due to an individual HGD can be up to several percent of the amplitude of the annual course.

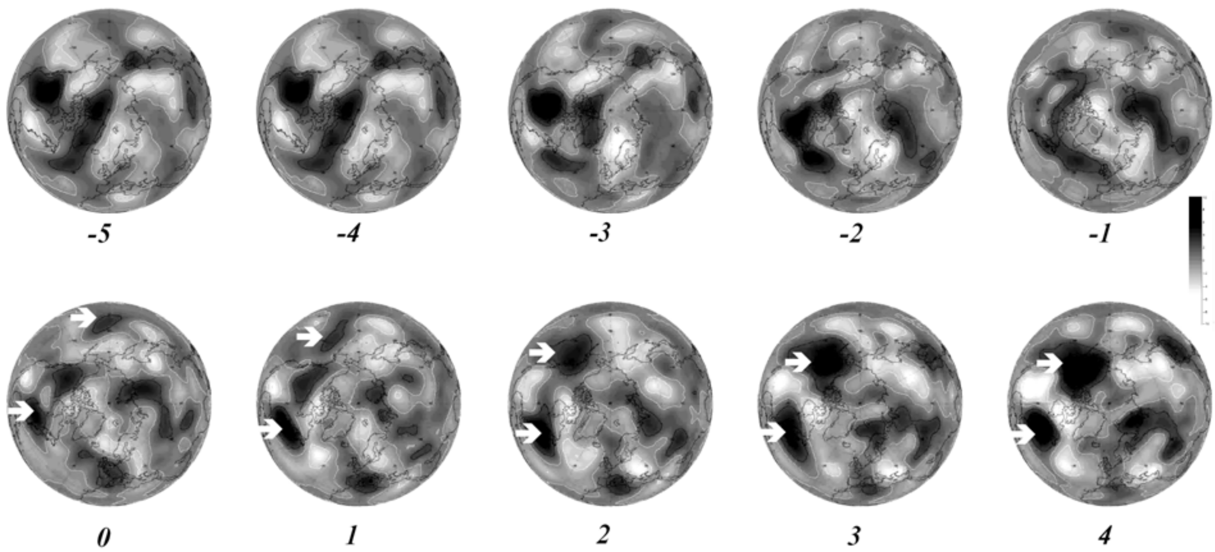

Fig. 3. Series of daily maps of the tropospheric average temperature anomalies in the 925-450 hPa layer for the northern hemisphere during the period from January 26 to February 4, 1982. The zero day (0 day) corresponds to the beginning of the heliogeophysical disturbance.

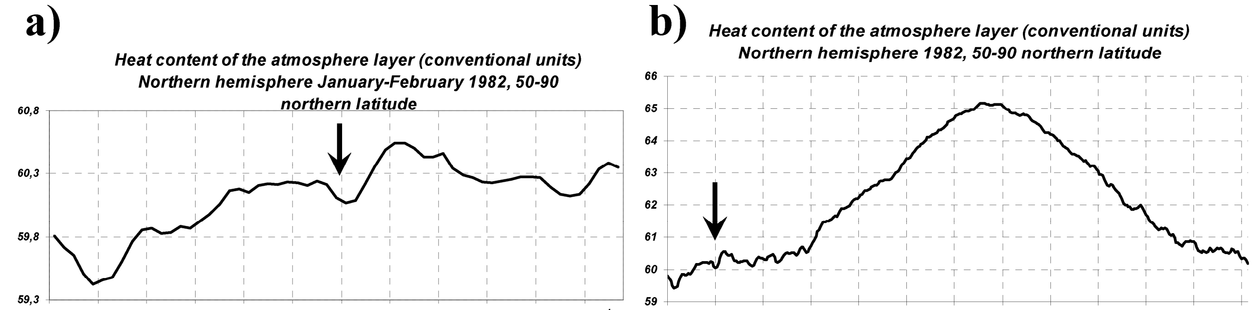

Fig. 4. Variation of the average daily values of the tropospheric layer heat content: a) in the zone 55-65°N, 205-215°E during the period from Jan 1 to Feb 28, 1982; b) in the region of 50-90°N, 0-360°E during the period of Jan 1 to Dec 31, 1982.

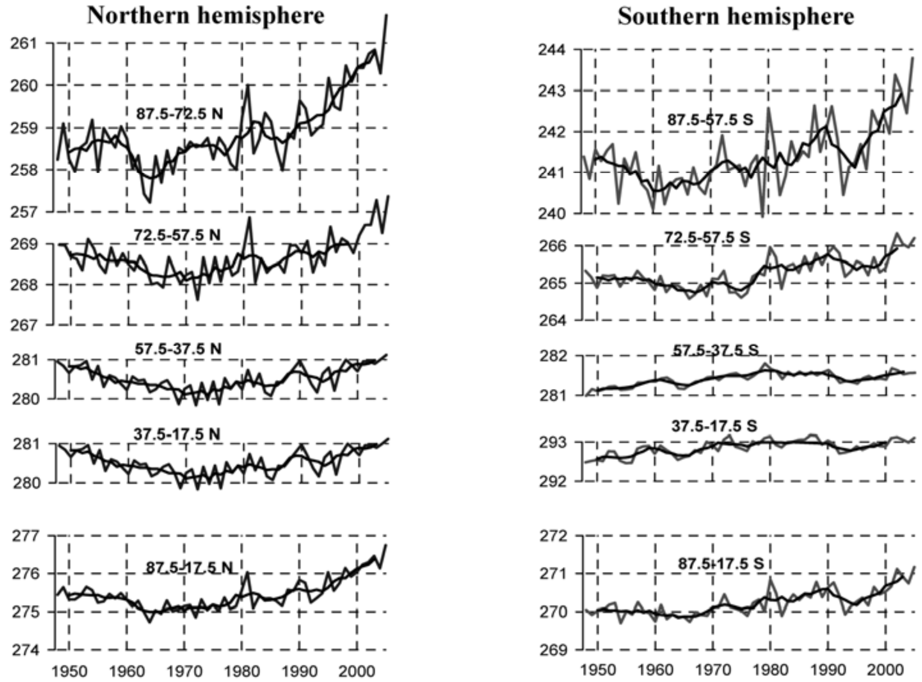

Fig. 5. Variation of the average surface air temperature in different latitude zones of northern and southern hemispheres for the period of 1950-2005.

Long-term variations of the surface air temperature

In accordance with the model of SA influence on the meteorological characteristics of the troposphere, one should expect certain regularities, in particular, the dependence of the amplitude of the long-term surface air temperature (SAT) on latitude. From the data shown in Fig. 5 it is obvious that the warming in the second half of the 20th century began earlier, in the early 1960s, at high latitudes, and in mid-1970s at low latitudes (the SAT data are from NCEP/NCAR reanalysis). The positive SAT anomaly is maximum in Polar Regions of both northern and southern hemispheres, and supposedly has not yet reached its maximum. If we suppose that a significant part of the observed global warming is caused by solar activity, and the levels of solar and, hence, geomagnetic activity at least have not increased over the last decades, the continued SAT increase is most likely due to the ocean thermal inertia.

It should be noted that the SAT variations in high-latitude (polar) regions qualitatively correspond to the global SAT variations. Given that the SAT variation amplitude in high-latitude regions significantly exceeds the low-latitude variations one can conclude that the climatic processes just in Polar Regions are responsible for the observed global warming (global SAT variations). Corresponding variations of the meridional temperature gradient and the atmospheric circulation determine the SAT spatial distribution.

The analysis of SAT variations during different seasons is of special interest in relation to this hypothesis. As is shown from the data in Fig. 6 the increase of the average annual SAT for high-latitude regions are mainly caused by the SAT increases during the cold period. For the warm period the SAT increases at the latitudes higher than 40° are observed practically neither in the northern nor southern hemispheres during the period in question. Thus, the observed seasonal dependence of the warming corresponds entirely to that expected in the frame of the mechanism under consideration.

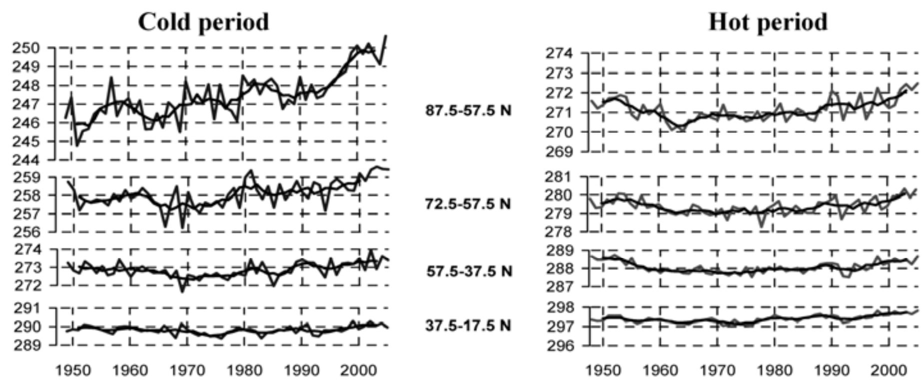

Fig. 6. Variation of the surface air temperature in different latitude zones of the northern hemisphere for cold (December January February) and warm (June July August) periods.

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

Interannual temperature variations and trends for Arctic and Antarctic polar regions of the (87.5–72.5) shown in Fig. 7 are characterized by both similarities and considerable differences. It is obvious that on the one hand, high correlation is observed in interannual variations of troposphere temperature starting with the surface layer (1000 hPa) up to 500 hPa, while at heights of 1000 hPa and 850 hPa the average annual temperatures as well as the variations are completely identical since 1948 till 1980 in the northern hemisphere.

From 1980 to 2005 a significant temperature increase is observed in the surface layer, in contrast to the greater heights, with persistent high correlation in the interannual variations. An exception is the region above the continental ice dome in the southern hemisphere, where the positive trend in the warming is traced over the whole troposphere and stratosphere. In the lower and middle troposphere at heights up to 300 hPa in the northern hemisphere, positive trends are observed. At the same time it should be emphasized that the trend decreases with height in the northern hemisphere and increases in the southern hemisphere. In the upper troposphere and lower stratosphere of the northern hemisphere, negative trends are observed starting from the 400 hPa height. Thus, for the period under consideration in the northern hemisphere, warming is observed in the low and middle troposphere for heights from the surface layer up to the 400 hPa, while cooling is observed in the upper troposphere and in the lower stratosphere.

In the continental zone of the southern hemisphere (ice dome), with data shown in Fig. 7, the positive trend in the warming is traced over the whole troposphere and stratosphere. This is due to the fact that the height of the Antarctic surface is about 3 km above sea level. It is important that, at latitudes 50°–70° (this region is not shown in Fig. 7), just as in the northern hemisphere, a change of the trend sign with height is observed [5]: the temperature increases from the surface layer (1000 hPa) up to 300 hPa and decreases above this level. This important feature, in the view of determining the causes of the observed global warming as well as of the proposed physical mechanism of solar activity influence on weather and climate, was found not only due to NCEP/NCAR reanalysis data in this research but also on the basis of the radio sounding data archive [7]. In paper [8] for the northern polar region (60–90°) the level of 400 hPa is distinguished by the warming being observed below this level and cooling above it during the period of 1959–2000. Above the southern polar region (54–90°) the warming was also found in the 850–300 hPa layer for the period since 1959 till 2003 in paper [9] as well as the temperature decrease at the 50–250 hPa heights. These regularities entirely correspond to those expected in the frame of the proposed model.

Main results:

a. A model of solar activity influence on the parameters of the terrestrial climate system is discussed. The key concept of this model is the influence of heliogeophysical disturbances on the terrestrial climate system parameters controlling the energy flux going from the Earth to the space in Polar Regions.

b. The complex analysis of the response of the troposphere thermobaric characteristics to the separate heliogeophysical disturbances has been carried out. As found these disturbances are accompanied by regular variations of the thermobaric field and atmospheric motions.

c. The features and regularities of the long-term

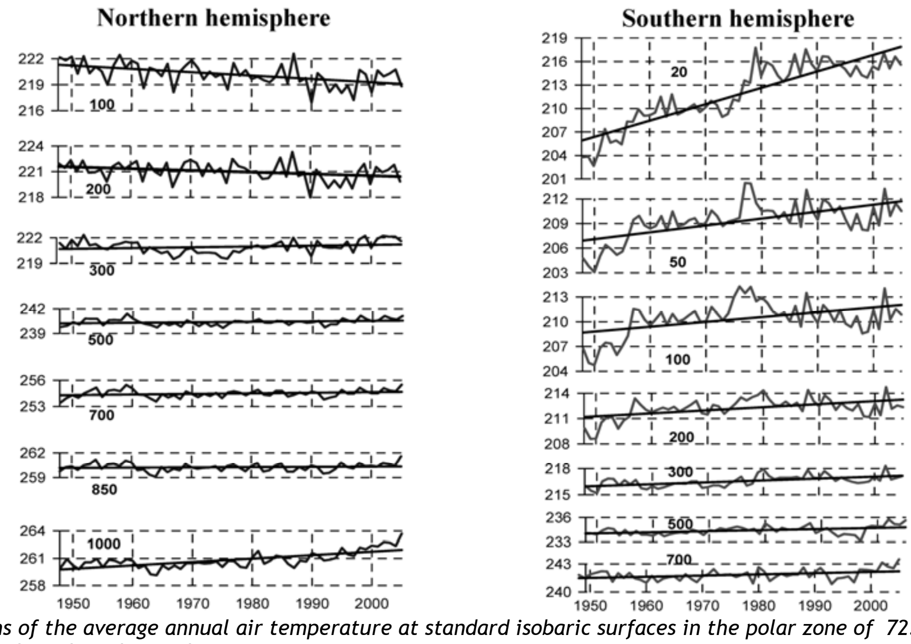

Fig. 7. Variations of the average annual air temperature at standard isobaric surfaces in the polar zone of 72.5-87.5° in the northern and southern hemispheres.

variations of troposphere temperature were determined.

d. It was found that the heat content changes at latitudes higher than 50° due to the separate HGD can be up to several percent of the amplitude of the annual course.

e. The amplitude of long-term SAT variations increases with latitude.

f. A significant difference was revealed between the long-term temperature trends in the troposphere and the surface layer in the northern and southern hemispheres.

g. The revealed regularities are fully explained in the frame of the model and the mechanism of solar activity influence on climate characteristics of the troposphere proposed by the authors.

Acknowledgements

The authors acknowledge the Russian Foundation for Basic Research (Grant No. 06-05-81011-Bel_a), Programme of Basic Research of Presidium of RAS, No 16, and Programme ESD RAS No. 7.11.2 for financial support.

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