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Low Cloud Anomalies at Middle Latitudes and Their Relationship to Variations of Galactic Cosmic Rays for the Different States of the Polar Vortex

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Abstract—Long-term correlations between low cloud anomalies at middle latitudes of the Northern and Southern hemispheres and fluxes of galactic cosmic rays (GCRs) are studied. It is shown that the relationship between the state of clouds and GCR fluxes on a decadal time scale is due to GCR influence on the intensity of cyclonic processes, which dependence on the state of the stratospheric polar vortex. A possible reason for the reversal of the sign of the correlation between low cloud anomalies and GCR fluxes in the early 2000s is a sharp weakening of the polar vortices in both hemispheres that altered the role of GCRs in the development of extratropical cyclogenesis.

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INTRODUCTION

The mechanism of solar–climate relationships, which includes changes of the state of clouds under the action of galactic cosmic rays (GCRs) [1], is now being widely discussed. A possibility of this mechanism was supported by a high positive correlation between low cloud anomalies (LCAs) and the fluxes of GCRs in 1983–1994 [2]. The violation of this correlation in the early 2000s caused doubts in GCR influence on the state of clouds and their role in the mechanism of solar–atmosphere relationships [3]. It was shown in [4, 5] that the correlation links between LCAs and GCRs at middle latitudes of the Northern Hemisphere are due to GCR influence on the development of baric systems which form cloud fields, the character of this influence presumably depending on the state of the stratospheric polar vortex. The aim of this work was to study the role of the polar vortices of the Northern and Southern hemispheres as a possible cause of the variability of the correlation links between low clouds and the intensity of GCRs.

EXPERIMENTAL DATA AND THEIR ANALYSIS

Clouds are known to form due to cooling and condensation of water vapor when air moves upward [6]. At extratropical latitudes most large-scale ascending air motions are associated with low pressure areas (cyclones and troughs), which results in a close relationship between cloud and pressure fields. These baric objects are characterized by the formation of large systems of stratiform frontal clouds Ns–As–Cs (nimbostratus, altostratus, and cirrostratus). Cloudiness in a cyclone is also created by ascending movements that arise due to the convergence of air flows toward its center near the Earth's surface.

Let us consider the changes of low clouds and pressure at middle latitudes of the Northern and Southern hemispheres, where intensive cyclone activity takes place. In this work we used the ISCCP-D2 satellite data for the period 1983–2009 [7]. According to the ISCCP classification, a cloud is considered as low if pressure at the cloud top $CP > 680$ hPa. Low level clouds include stratus (St), nimbostratus (Ns), stratocumulus (Sc), and convective cumulus (Cu) clouds. Low cloud anomalies are calculated as the difference between the monthly average amount of low level clouds and the climatic average for a given month over the period of observation.

The temporal variation of monthly average values of LCAs is presented in Figs. 1a and 1c for middle latitudes 30°–60° N (S). It is seen that in both hemispheres the changes of LCAs are characterized by negative linear trends. The deviations of LCAs from the linear trends reveal a rather high similarity. The coefficient of the correlation between the low cloud anomalies of the Northern and Southern hemispheres is 0.82 before the removal of trends, and 0.62 after the trend removal. Let us compare LCA variations with variations of pressure characterized by geopotential (gp) heights of the isobaric level 700 hPa (GPH700)

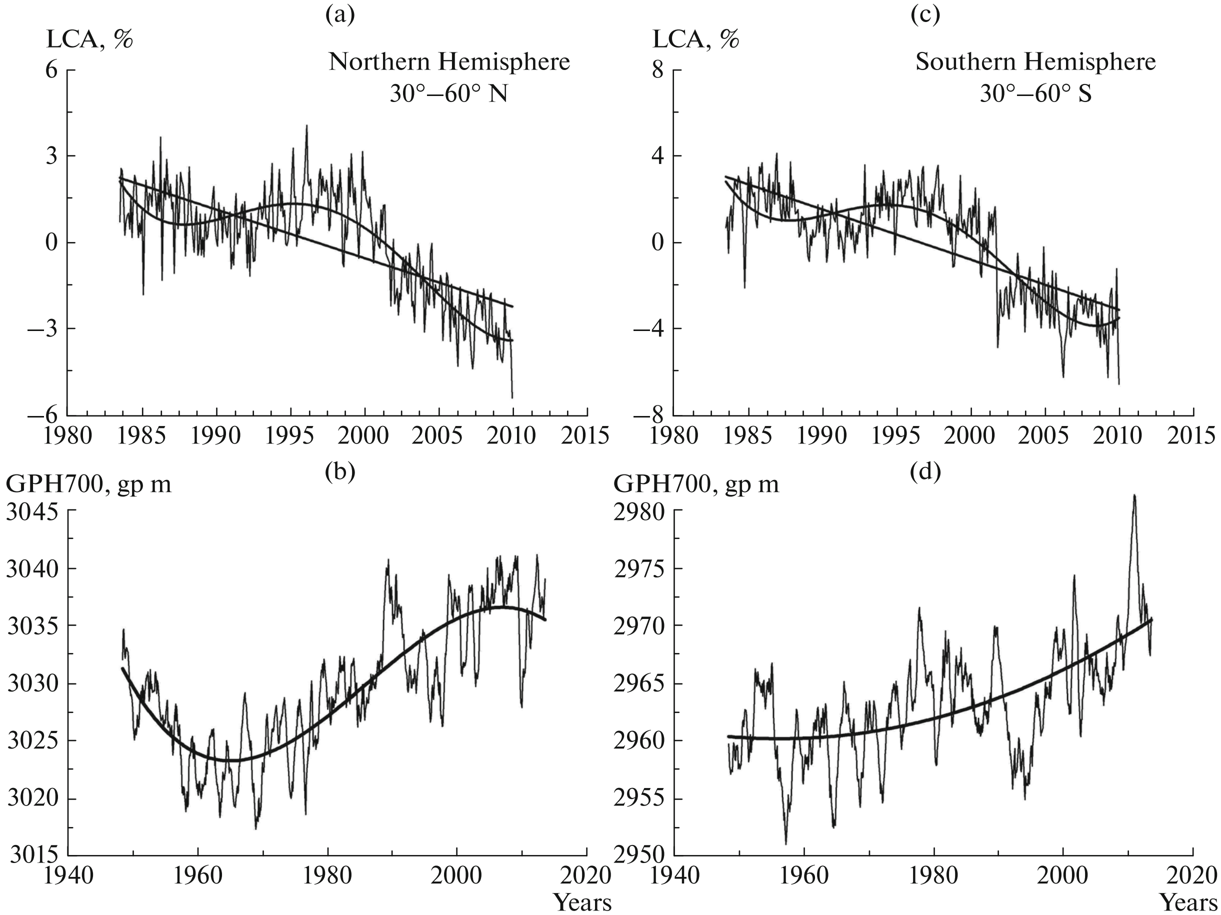

Fig. 1. (a, c) Temporal variation of monthly average low cloud anomalies (LCAs) at middle latitudes 30°–60° of the Northern and Southern hemispheres according to the ISCCP-D2 data (1983–2009) [7]. (b, d) Temporal variation of tropospheric pressure (GPH700) at middle latitudes 30°–60° of the Northern and Southern hemispheres in 1948–2013 (12-month running averages) according to the reanalysis data NCEP/NCAR [8]. Thick lines show linear trends and the polynomial smoothing of anomalies of low clouds and pressure.

according to the data of reanalysis NCEP/NCAR [8]. Figures 1b and 1d show the temporal variation of GPH700 values, area-averaged over the latitude belts 30°–60° N (S) for the period of 1948–2013. It is seen that the long-term changes of pressure differ significantly in these belts; i.e., cyclonic processes in the Northern and Southern hemispheres are independent to a great extent. Nevertheless, during the period of the ISCCP observations in 1983–2009, when low cloud amount was decreasing at middle latitudes, pressure at these latitudes was increasing, which indicates a weakening of cyclonic processes and an intensification of anticyclonic ones. Since a cloud field at middle latitudes is formed by large-scale ascending air motions associated with baric systems (cyclones and troughs), the decrease of LCAs in the latitude belts 30°–60° N (S) is consistent with the character of pressure changes.

Let us consider the relationships of low cloud and pressure anomalies with variations of GCR intensity. It was assumed in [9] that the GCR effects on the development of dynamic processes in the troposphere depend on the epoch of large-scale atmospheric circulation which, in turn, is determined by the state of the stratospheric polar vortex (cyclonic circulation forming in the high-latitude atmosphere above the level 500 hPa). Let us compare the GCR effects on low cloud and pressure anomalies at middle latitudes of the Northern and Southern hemispheres and variations in the intensity of polar vortices, which is characterized by zonal velocity of the western wind (U) in the high-latitude stratosphere.

Figures 2a and 2c present the variations (deviations from the linear trend) of the zonal wind velocity ΔU at the level 50 hPa (~20 km), averaged over the latitude belt 60°–80° N (S) on the base of the data [8]. The variations of the wind velocity were calculated for the cold half of the year in the given hemisphere when the vortex is most intensive. The temporal variations of the correlation coefficients of mean yearly values of low cloud and pressure anomalies with GCR fluxes for sliding 11-year intervals are presented in Figs. 2b, 2d. To characterize the GCR intensity, we used charged

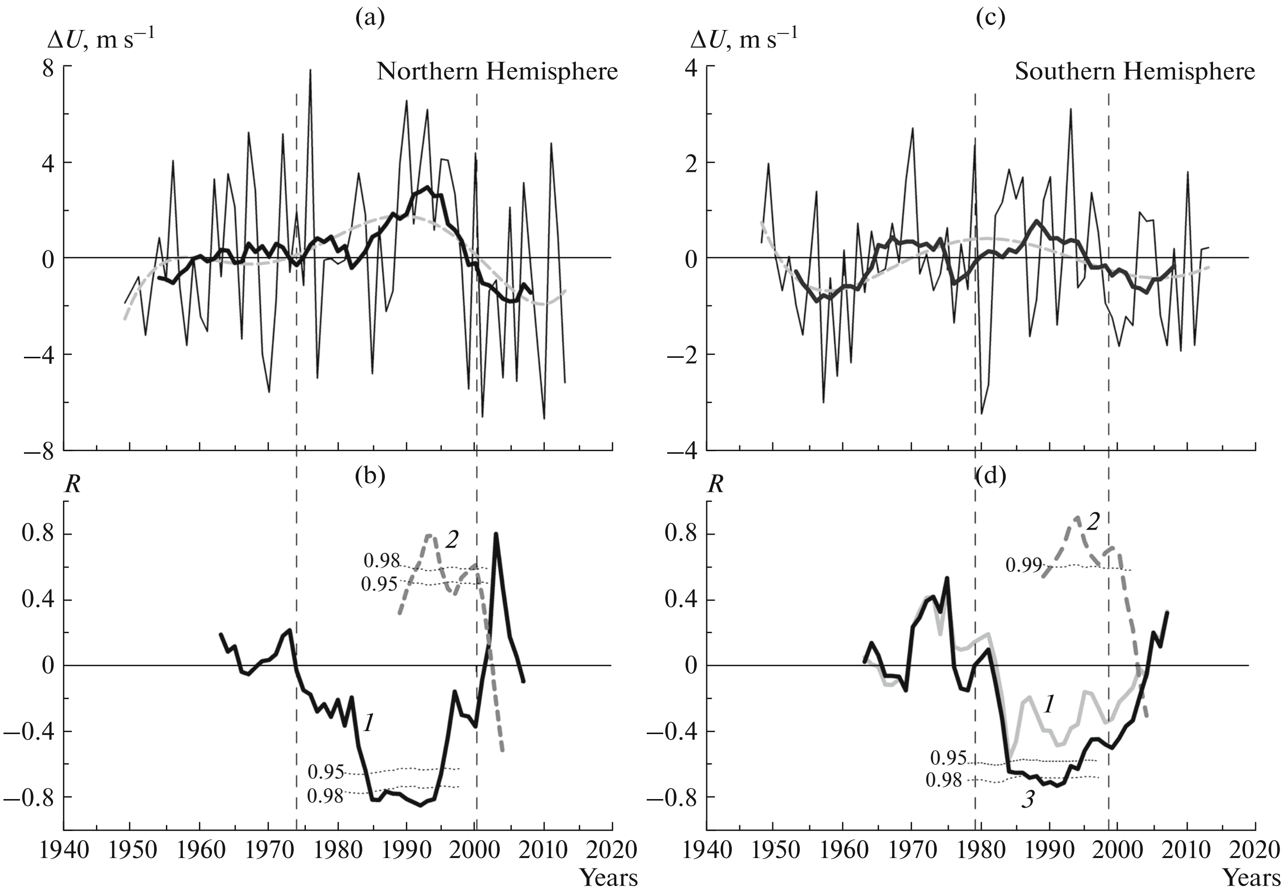

Fig. 2. (a, c) Variations of the zonal western wind velocity (ΔU) at the level 50 hPa in the high-latitude stratosphere 60°–80° of the Northern and Southern hemispheres during the cold half of the year (October–March in the Northern Hemisphere; April–September in the Southern one). Thick black lines show 11-year running averages; gray dashed lines show the polynomial smoothing of the velocity variations. (b, d) Correlation coefficients for sliding 11-year intervals in the Northern and Southern hemispheres: (*1*) between pressure anomalies (GPH700) in the latitude belt 30°–60° and GCR fluxes; (*2*) between low cloud anomalies (LCAs) in the latitude belt 30°–60° and GCR fluxes; (*3*) between pressure anomalies (GPH700) and GCR fluxes for the areas of cyclogenesis in the latitude belt 30°–60° in the Southern Hemisphere. The dotted lines show the significance levels for the correlation coefficients according to the Monte-Carlo tests. Vertical dashed lines indicate the period of the enhanced polar vortex.

particle fluxes F_{CR} at the maximum of the transition curve at Dolgoprudny station (geomagnetic cutoff rigidity R_c = 2.35 GV) [10]. The correlation coefficients were calculated after removing the linear trends from the values under study, and their statistical significance was estimated using the Monte Carlo method as it was described in [5]. Since the major contribution to the correlation between pressure and GCR fluxes in the Southern Hemisphere is given by the areas of cyclogenesis in the South Atlantic and the Indian and Pacific Oceans [9], the GPH700 anomalies for the Southern Hemisphere were calculated over these three regions.

Figures 2a and 2b show that a positive LCA–GCR correlation at middle latitudes of the Northern Hemisphere took place during the period of a negative correlation between pressure and GCR fluxes; i.e., the growth of GCR fluxes contributed to the intensification (deepening) of extratropical cyclones and therefore to the increase of cloudiness. The most significant correlation coefficients $R(\text{GPH700}, F_{CR}) \sim -0.8$ (significance level $P = 0.98$) and $R(\text{LCA}, F_{CR}) \sim 0.6–0.8$ ($P = 0.95–0.98$) were observed from the mid-1980s to the end of the 1990s, when a considerable intensification of the Arctic polar vortex took place ($\Delta U \sim 2–6$ m s^{-1}). The character of the correlations changed in the early 2000s, when the vortex weakened sharply ($\Delta U \leq -2$ m s^{-1}). A similar situation was observed in the Southern Hemisphere, the only difference being that the intensity of the Antarctic vortex, which is more stable than the Arctic one, did not change so strongly.

CONCLUSIONS

The character of long-term correlations between the state of clouds and GCR variations is the same at middle latitudes of the Northern and Southern hemispheres and depends on GCR effects on the intensity of extratropical cyclogenesis, which are determined by the state of the polar vortex. Intensification of cyclonic processes and cloudiness increase with GCR flux growth is observed only under the strong polar vortex. The violation of this correlation between the state of clouds and the GCR fluxes in the early 2000s was likely due to a sharp weakening of the polar vortices in both hemispheres that resulted in the change of the role of GCRs in the development of extratropical cyclogenesis.

According to [11, 12], the state of the vortex plays an important role in the troposphere-stratosphere coupling, via the propagation of planetary waves. When the vortex is strong, planetary waves propagating upward are reflected back to the troposphere, which probably creates favorable conditions for the transfer of disturbances produced by variations of GCRs from the stratosphere to the troposphere. If the vortex is weak, these waves propagate freely upward; in this case only the troposphere can influence the stratosphere. The results obtained provide evidence that the state of the stratospheric polar vortex can considerably influence the development of the dynamic response of the lower atmosphere to solar activity phenomena and GCR variations. The vortex evolution may also be a reason for temporal variability of solar-climatic links.

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