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Stratospheric polar vortex as a possible reason for temporal variations of solar activity and galactic cosmic ray effects on the lower atmosphere circulation

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Abstract

Possible reasons for the temporal instability of long-term effects of solar activity (SA) and galactic cosmic ray (GCR) variations on the lower atmosphere circulation were studied. It was shown that the detected earlier ~60-year oscillations of the amplitude and sign of SA/GCR effects on the troposphere pressure at high and middle latitudes (Veretenenko and Ogurtsov, Adv.Space Res., 2012) are closely related to the state of a cyclonic vortex forming in the polar stratosphere. The intensity of the vortex was found to reveal a roughly 60-year periodicity affecting the evolution of the large-scale atmospheric circulation and the character of SA/GCR effects. An intensification of both Arctic anticyclones and mid-latitudinal cyclones associated with an increase of GCR fluxes at minima of the 11-year solar cycles is observed in the epochs of a strong polar vortex. In the epochs of a weak polar vortex SA/GCR effects on the development of baric systems at middle and high latitudes were found to change the sign. The results obtained provide evidence that the mechanism of solar activity and cosmic ray influences on the lower atmosphere circulation involves changes in the evolution of the stratospheric polar vortex.

Keywords: Solar activity; Galactic cosmic rays; The lower atmosphere circulation; Climate variability

1. Introduction

An apparent instability of relationships between the Earth's climate and solar variability is a very important problem in solar-terrestrial physics. Indeed, links between the lower atmosphere characteristics and solar activity phenomena may appear, disappear and even change the sign depending on the time period (e.g., Herman and Goldberg, 1978, and references therein). This instability may result in rather weak correlations over the entire interval of observations and give rise to doubt the reality of solar-atmospheric links (e.g., Pittock, 1978). The most recent manifestation of such instability has been established in decadal scale correlation between low cloudiness and galactic cosmic ray intensity (Sloan and Wolfendale, 2008). So, to study temporal variations of solar-atmospheric connections is of great importance to understand the physical mechanism of solar activity influence on the state of the lower atmosphere, weather and climate.

In the previous work (Veretenenko and Ogurtsov, 2012) we studied the spatial and temporal variability of solar activity (SA) and galactic cosmic ray (GCR) effects on troposphere pressure. It was shown that these effects strongly depend on the latitudinal belt and the region under study. The spatial distribution of the correlation coefficients between troposphere pressure and SA/GCR variations is determined by climatic positions of the main atmospheric fronts. The character of the regional pressure changes correlated with SA/GCR characteristics was found to depend on the peculiarities of baric systems forming in the studied regions. It was revealed that the temporal structure of SA/GCR effects on the troposphere circulation at middle and high latitudes is characterized by a roughly 60-year

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periodicity, with several reversals of the correlation sign taking place during the last 130 years. These sign reversals were found to coincide with the changes in the epochs of the large-scale tropospheric circulation according to Vangengeim–Girs classification (Vangengeim, 1952; Girs, 1974). So, in this work we continue studying possible reasons for the temporal variability of SA/GCR effects on lower atmosphere dynamics and considering processes which may influence the evolution of the large-scale circulation and, correspondingly, the character of SA/GCR effects on troposphere pressure.

2. Stratospheric vortex as an important factor of the large-scale circulation and climate variability

The polar vortex is a large-scale cyclonic circulation forming in a cold air mass in the polar region and covering the middle and upper troposphere and the stratosphere. Its formation is due to air inflow to the Arctic region from middle latitudes and its cooling over icy surface under the conditions of negative radiation balance. Cooling and descent of air result in the increase of pressure near the Earth's surface and contribute to the formation of near-surface high-pressure areas (anticyclones) (e.g., Girs, 1974). Due to high density of cold air, the heights of isobaric levels in a cold air mass get lower, so, simultaneously with the increase of near-surface pressure, a low-pressure area arises at the 500 hPa level and above. The vortex is strongest in the hemisphere's winter due to the increase of temperature gradients between low and high latitudes. In summer the vortex weakens and even can disappear. In the Northern hemisphere the polar vortex is usually elongated in shape and centered over Canada, but the second center may arise over Eastern Siberia. The Arctic vortex is less strong and persistent than the Antarctic one, as the distribution of ocean and land surfaces at middle and high latitudes of the Northern hemisphere is favorable for the formation of planetary-scale Rossby waves propagating upward and contributing to the breakdown of the vortex.

Fig. 1 presents the distributions of mean monthly temperature and magnitude of the horizontal temperature gradient in the stratosphere for January 2005 when the vortex was extremely strong and cold. The presented characteristics were calculated using NCEP/NCAR reanalysis data (Kalnay et al., 1996). As the vortex deepens, a circular motion of air intensifies isolating the polar air inside the vortex from the warmer air of middle latitudes. It results in a decrease of heat exchange between polar and middle latitudes and contributes to the temperature drop inside the vortex, as well as to the increase of temperature gradients at its edges. In Fig. 1 we can see the typical location of the vortex as a low temperature area, with the increase of temperature gradients being observed at the vortex edges.

Many recent studies showed that the stratospheric polar vortex is implicated in a variety of atmospheric processes including the formation of ozone holes in the Antarctic,

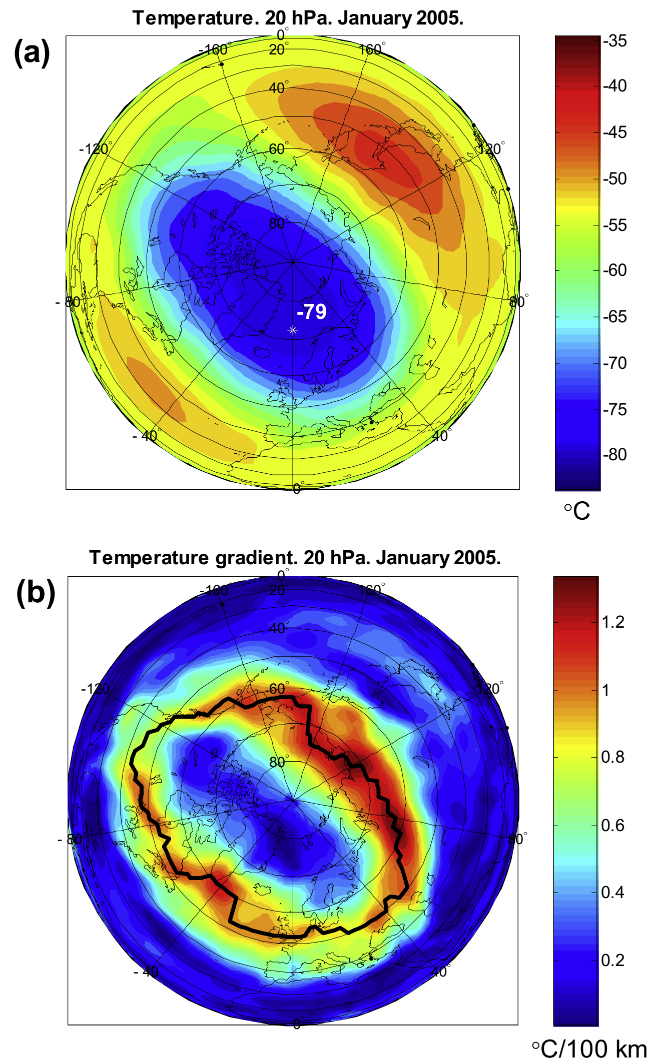

Fig. 1. (a) Distribution of mean monthly temperature in the stratosphere of the Northern hemisphere at the level 20 hPa in January 2005. The asterisk shows the temperature minimum in the vortex center. (b) Distribution of mean monthly magnitude of the horizontal temperature gradient at the level 20 hPa in January 2005. The black curve connects the points of the maximal value of the temperature gradient magnitude at a given longitude.

the North-Atlantic Oscillation (NAO) and the Arctic Oscillation (AO), interannual and secular climate variability (e.g., Solomon, 1990; Tompson and Wallace, 1998; Baldwin and Dunkerton, 2001; Walter and Graf, 2005; Frolov et al., 2009; Gudkovich et al., 2009, etc.). In particular, the temperature drop below −80 °C inside the vortex produces favorable conditions for the formation of polar stratospheric clouds (PSC). In turn, chemical reactions occurring on PSC particles result in the formation of chlorine which catalyzes the photochemical ozone destruction (Solomon, 1990). A number of studies show the links between the state of the polar vortex and the North Atlantic Oscillation and the Arctic Oscillation which are, respectively, the dominant modes of sea-level pressure variability in the North Atlantic and over the Northern hemisphere. According to Baldwin and Dunkerton (2001), more