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IMF-associated cloudiness above near-pole station Vostok: Impact on wind regime in winter Antarctica

O. Troshichev *, V. Vovk, L. Egorova

Arctic and Antarctic Research Institute, St. Petersburg 199397, Russian Federation

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ABSTRACT

Changes in the cloudiness above the Antarctic station Vostok during the winter season were examined in relation to strong disturbances in the interplanetary magnetic field (IMF). A reliable relationship between cloud formation and IMF has been found: cloudiness increased under the influence of a strong southward IMF and decreased under the northward IMF. The surface temperature at Vostok station, which is derivative of the constant radiation cooling of air situated at the ice sheet and adiabatic warming of the air masses, incoming into the central Antarctica from the middle and upper troposphere, is enhanced or reduced. Quite opposite regularity in the temperature changes is typical of altitudes higher than the suggested cloud layer position (5–8 km). The processes occurring on the Antarctic ridge leads to anomalous winds at the ice dome and decay of the circumpolar vortex at the periphery of the Antarctic continent. As a result, the surface easterlies at the coast stations are replaced by southerlies, and the cold air masses flow from Antarctica out over the Southern Ocean.

1. Introduction

Existing models of atmospheric variability and change do not take into consideration the changes of solar activity. Indeed, the total energy, contributed by the solar wind and the solar and galactic cosmic rays in the Earth's atmosphere, is extremely insignificant in comparison with the total solar irradiance. But, as distinct from the total solar irradiance, the energy of solar wind and cosmic rays can increase in hundred-fold in periods of high solar activity. The attempts to find the cause–effect relation between the solar activity variations and weather and climate changeability have a long history (Wilcox, 1975; Herman and Goldberg, 1978). The galactic cosmic rays altered by solar wind are traditionally regarded as the most plausible agent of solar activity influence on the Earth's atmosphere. However, the hypothesis about determining the influence of the galactic cosmic rays on the total cloudiness (Svensmark and Friis-Christensen, 1997) or low-cloud properties (Marsh and Svensmark, 2003) was not supported by the subsequent, more detail researches (Farrar, 2000; Palle and Butler, 2002; Kristjansson et al., 2002; Laut, 2003). However, data on the solar wind variations influence on the atmospheric temperature appeared in recent years.

Sometimes strong warmings (up to 20 °C) happen within a few hours in central Antarctica during the winter seasons. These exclusive events were studied (Troshichev et al., 2003; Troshichev and Janzhura, 2004) on the basis of three sets of meteorological data: (1) daily meteorological observations (temperature, pressure and winds) on the ground level at Vostok station ($h = 3.45$ km) for 1978–1992, (2) hourly temperature values derived from the 10-min observations provided by the automatic stations (AWS) at Dome C, South Pole and Vostok for 2000–2001, and (3) daily aerological measurements of temperature, pressure and winds above Vostok station ($h = 3.5$–20 km) for 1978–1992. It was found that the

* Corresponding author. Tel.: +7 812 3522688.
E-mail address: olegtro@aari.nw.ru (O. Troshichev).

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warming at the ground level at the Antarctic Ridge (at stations Vostok and Dome C) happens after large increase of the negative (southward) B_Z interplanetary magnetic field (IMF) component. The B_{ZS} component is the most geoeffective parameter; the second important one is the solar wind speed V. Increase of the negative B_Z indicates the growth of the interplanetary electric field E_{SW} coupling with the Earth's magnetosphere. It is meaningful that the response of temperature to the E_{SW} influence is quite contrary in the lower and upper troposphere. The average warming at the ground level ($h = 3.45$–3.5 km) responds, within 1–2 days, to the large leap in E_{SW}, with cooling being observed at altitudes more than 10 km at the same time. It has been suggested (Troshichev and Janzhura, 2004) that the interplanetary electric field initiates, through the changes in the global electric circuit, the formation of the cloud layer at altitude of 5–10 km. Warming in Central Antarctica would violate the wind system over the whole of Antarctica. In this paper we shall examine the influence of IMF B_Z variations on cloudiness above Vostok stations in winter seasons and the relationships between IMF B_Z and wind speed and directions at the Antarctic coast stations.

2. Geoeffective solar wind parameters and their relation to variations of cosmic rays

Solar wind plasma is quasi-neutral, consisting mainly of solar protons and electrons emerging from the Sun. The solar wind includes the solar magnetic field, which is called, out of the solar corona, as the interplanetary magnetic field (IMF). The following solar wind parameters are measured on board a spacecraft in the Earth's environment: density of solar wind plasma (n), speed (velocity) of solar wind plasma ($\boldsymbol{V}_{sw}$), three components of IMF-radial ($\boldsymbol{B}_x$), azimuthal ($\boldsymbol{B}_y$) and vertical ($\boldsymbol{B}_Z$). Based on these actually measured quantities, the solar wind parameters producing the strongest impact on the magnetosphere are calculated: the interplanetary electric field $\boldsymbol{E}_{sw} = -\boldsymbol{V}_{sw} \times \boldsymbol{B}_z$ (in the solar-magnetosphere coordinate system) and the solar wind dynamic pressure $Psw = m\, n(\boldsymbol{V}_{sw})^2$, where m is the proton mass. Velocity V_{sw} can change few fold, whereas the IMF B_y and B_z components can increase by ten-fold and change in sign. The IMF B_Z component is regarded as the most geoeffective solar wind parameter: magnetic disturbances (storms) are generated under conditions of the southward ($B_Z<0$) IMF component, and magnetic quiescence is typical of the northward IMF ($B_Z>0$). Correspondingly, the IMF B_z component determines the efficiency of the interplanetary electric field: the increase of the southward IMF component determines the growth of the geoeffective electric field of the dawn–dusk polarity, whereas increase of the northward IMF component is consistent with the growth of the dusk–dawn electric field. The hourly and daily solar wind parameters data are published at many world sites (see for example, http://spidr.ngdc.noaa/gov/spidr/index.html).

The largest changes in the solar wind density Psw and IMF IMF B_z occur in front of the interplanetary shocks, denoted by the high-speed and large-density solar plasma fluxes, emerging from the most intense solar flares. Since the powerful interplanetary shocks sweep the galactic cosmic rays on their way, they are usually followed by reduction in flux of the galactic cosmic rays (Forbush decrease event). As a result, Forbush decreases start simultaneously with the interplanetary shocks, and their possible effects on the atmospheric processes can be closely consistent in time. As an example of such consistency, we show the average changes of the cloudiness above Vostok derived by the epoch superposition method for the same events with choice of different agents and key dates.

The cloudiness at Vostok station was determined by two methods. The first, very rough method, is an estimation of cloudiness power in balls from the visual man-made observations. In conditions of polar night, this method testifies only on availability or absence of cloudiness, not more. The second method is measurement of the radiation balance (BR) value in MJ/m^2 produced by a balancer. It has been known that during the winter season, under conditions of dark polar night, the radiation balance at Vostok is always negative. The larger negative BR values correspond to more intense radiation cooling, the less negative BR values indicate the cooling reduction as a consequence of the cloud layer formation above Vostok station.

The list of Forbush decreases for 1974–1992 was taken from the widely known paper by Todd and Kniveton (2001). According to Todd and Kniveton (2001), these FD events were coincident, as evidenced by the satellite observations, with a decrease in cloudiness above the Antarctic ice dome, when the day of the FD beginning was taken as a key date in the epoch superposition method. Indeed, when we examined the cloudiness above Vostok station with the same choice of the key date and for the same years (data from Vostok for 1993–1994 are not available), we found the evident cloudiness minimum on the key date (Fig. 1a). The same regularity was observed when FD events with intensity $A>5\%$ were examined for the winter seasons (Fig. 1b), the sample size being reduced up to $n = 24$. As this takes place, the cloudiness above Vostok occurs to be maximal just after the FD beginning. In many cases it is difficult to determine the FD beginning unambiguously. As a result, the FD beginning dates are sometimes identified with as large a scatter as 5 days in various studies. In this study we alternatively look on cloudiness at the FD maximum as well. The Forbush event maximum is easily and uniquely identified in each case by minimum in the galactic cosmic ray flux. In our analysis we used data of the neutron monitor at Thule station (Solar Geophys. Data Rep., 1975–1995). As Fig. 1c demonstrates, the cloudiness above Vostok starts to increase 3 days ahead of the FD maximum and reaches the largest intensity just in a day of FD maximum. Based on this result we could suggest that Forbush decreases lead to increase in cloudiness, not to atmospheric transparency, as was concluded by Todd and Kniveton (2001). Table 1 presents the dates of FD beginnings (Todd and Kniveton, 2001) and the dates of the appropriate FD maximums. The last column in Table 1 presents the dates of the minimums