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Solar wind influence on atmospheric processes in winter Antarctica

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ABSTRACT

Galactic cosmic rays (GCRs) altered by solar wind are traditionally regarded as the most plausible agent of solar activity influence on the Earth's atmosphere. However, it is well known that severe reductions in the GCRs flux, known as Forbush decreases (FDs), are caused by solar wind of high speed and density, which sweeps away the GCRs on its way. Since the FD beginnings are registered at the Earth's orbit simultaneously with dramatic disturbances in the solar wind, the atmospheric effects, assigned to FDs, can be, in reality, the results of the solar wind influence on the atmospheric processes. This paper presents a summary of the experimental results demonstrating the strong influence of the interplanetary electric field on atmospheric processes in central Antarctica, where the large-scale system of vertical circulation is formed during winter seasons. The influence is realized through acceleration of the air masses, descending into the lower atmosphere from the troposphere, and the formation of cloudiness above the Antarctic Ridge, where the descending air masses enter the surface layer. The acceleration is followed by a sharp increase of the atmospheric pressure near-pole region, which gives rise to the katabatic wind strengthening above the entire Antarctica. The cloudiness formation results in the sudden warmings in the surface atmosphere, since the cloud layer efficiently backscatters the long wavelength radiation from the ice sheet, but does not affect the adiabatic warming process of the descending tropospheric air masses. When the drainage flow strengthening the circumpolar vortex around the periphery of the Antarctic continent decays, the surface easterlies typical of the coast stations during the winter season are replaced by southerlies and the cold Antarctic air masses flow out to the Southern ocean.

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1. Introduction

The galactic cosmic rays (GCRs) altered by solar wind were usually regarded as the most plausible agent of the solar activity influence on the Earth's atmosphere. The experimental data were presented showing the influence of the varying GCR flux on the Earth's weather and climate (Tinsley et al., 1989), on high cloud coverage (Pudovkin and Veretenenko, 1995), on temperature in the polar troposphere (Pudovkin et al., 1996, 1997), on the global total cloud cover (Svensmark and Friis-Christensen, 1997; Todd and Kniveton, 2001), and on low cloud coverage (Marsh and Svensmark, 2003). These results suggest that just cloudiness variation affected by cosmic rays lead to changes in the atmospheric and meteorological characteristics.

However, the hypothesis about the determining influence of the GCRs on the cloudiness was not always supported by the subsequent, more detail research. It was indicated that the correlation with GCR disappears when the cloud coverage is decomposed into fractions by cloud type or height, by region (reduce for ocean basis), or by latitude (patterns in the tropical zone are better associated with concurrent El Nino) (Farrar, 2000). A comprehensive study of low cloud coverage for the last 120 years (Palle and Butler, 2002) revealed that the global

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cloudiness has increased during the past century regardless of variations of GCR. The solar irradiance turned out to be correlated better and more consistently with low cloud cover than with cosmic ray flux (Kristjansson et al., 2002). In conclusion, the mechanism linking the cosmic ray ionization and cloud properties cannot be excluded, but its high efficiency is not obvious (Harrison and Carslaw, 2003).

At the same time it is well known that severe reductions in the GCRs flux, known as Forbush decrease (FD), are caused by the high-speed solar wind, which reflects the GCRs on its way. This disturbed solar wind, emerging by the most intense solar flares, is characterized by the largest changes in geoeffective parameters, such as the solar wind pressure P_{SW} and the southward component of the interplanetary magnetic field (IMF B_Z). It was noted that the FD beginnings are recorded at the Earth's orbit simultaneously with dramatic disturbances in the solar wind, and therefore, the atmospheric effects, assigned to FDs, can be, in reality, caused by the solar wind influence on the atmospheric processes (Troshichev et al., 2002). Indeed, subsequent studies (Troshichev et al., 2003, 2004, 2005, 2008; Troshichev and Janzhura, 2004) revealed the steady statistical relationship between the sudden changes of the atmospheric parameters in central Antarctica and the IMF variations. In this paper, we present a brief overview of the main results of these studies.

2. Solar wind and channels of its influence on the atmospheric processes

The solar wind plasma consists mainly of solar protons and electrons. Being emerged from the Sun it carries away the solar magnetic fields which are termed as interplanetary magnetic fields outside of the solar corona. The following solar wind parameters are measured on board spacecrafts: density of solar wind plasma (n), speed (velocity) of solar wind plasma (V_{SW}), and three components of the interplanetary magnetic field: radial (B_X), azimuthal (B_Y), and vertical (B_Z). Based on these actually measured quantities, the solar wind parameters producing the strongest impact on the magnetosphere are calculated: the azimuthal component of the interplanetary electric field $E_{SW} = V_{SW} x B_Z$ and the solar wind dynamic pressure $P_{SW} = mn(V_{SW})^2$, where m is the proton mass. The velocity V_{SW} may vary with a factor of 2–3 at maximum, whereas the IMF B_Y and B_Z components might change the sign and increase by some factors of 10.

The IMF B_Z component is regarded as the most geoeffective solar wind parameter: geomagnetic disturbances (storms) are generated under conditions of southward ($B_Z<0$) IMF, whereas the magnetic quiescence is typical of northward IMF ($B_Z>0$). Correspondingly, the IMF B_Z component determines the efficiency of the interplanetary electric field: an increase of the southward component, B_{ZS}, gives rise to a growth of the geoeffective electric field E_{SW} of dawn–dusk orientation, whereas an increase of the northward component, B_{ZN}, is consistent with a decay of the dawn–dusk E_{SW} field.

While coupling with the geomagnetic field, the solar wind containing the interplanetary magnetic field generates electric currents in the low-latitude boundary layer (LLBL) of the magnetosphere (Troshichev, 1982). These currents, flowing across the boundary layer from the outer edge to the inner edge at the dawn LLBL and from the inner edge to the outer edge at the dusk LLBL, provide the magnetosphere "capacitor" and supply the field-aligned currents connecting the boundary magnetosphere with the polar ionosphere (Fig. 1). The field-aligned currents, flowing into the polar ionosphere at the dawn side and flowing out of the ionosphere at the dusk side, produce a dawn–dusk voltage across the polar cap (Gizler et al., 1979). Although some details of this process continue to be unresolved, the linkage between the interplanetary electric field and the polar cap voltage is principally resolved and well defined.

Fig. 1, adapted from Troshichev (1982), shows only the field-aligned current system affected by coupling of the negative IMF B_Z component with the magnetosphere. There are other field-aligned currents connecting magnetosphere and ionosphere, which are affected by the azimuthal B_Y IMF components, by the quasi-viscous interaction between the solar wind and magnetosphere, and by solar wind dynamic pressure pulses. However, their influence on the cross-polar cap potential is not of primarily importance, since they only slightly change the general cross-polar cap potential pattern (they rather distort the distribution of ionospheric electric fields generated by the IMF B_Z component, see (Troshichev,

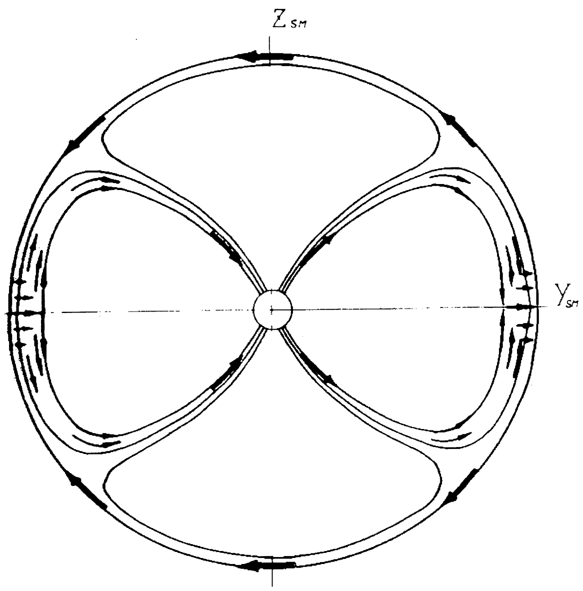

Fig. 1. A conceptual sketch of the generation of electric currents in the low-latitude boundary layer, by the solar wind coupling with the magnetosphere (adopted from Troshichev, 1982). It shows the magnetosphere dawn–dusk cross-section viewed from the Sun. The arrows denote the electric currents generated in LLBL, the field-aligned currents, and the currents forming the magnetospheric tail. The field-aligned currents, flowing in the southern and northern polar caps at the dawn side and flowing out at the dusk side, provide the polar cap electric voltage.

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