Journal of Atmospheric and Solar-Terrestrial Physics 99 (2013) 117–122

Contents lists available at SciVerse ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Influence of geomagnetic disturbances on atmospheric electric field (Ez) variations at high and middle latitudes

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ARTICLE INFO

Article history:
Received 16 March 2012
Received in revised form
27 July 2012
Accepted 28 July 2012
Available online 23 August 2012

Keywords:
Atmospheric electricity
Global atmospheric electric circuit
Magnetic storm
Magnetospheric substorm

ABSTRACT

The variations of the vertical atmospheric electric field (Ez) represent the state of the global atmospheric electric circuit, which is controlled by the world thunderstorm activity and by magnetosphere–ionosphere disturbances as well. Here we present a synthesis of our main results of the effects of the geomagnetic disturbances on the Ez variations, measured at the Earth's surface at high and middle latitudes, which were previously published by Kleimenova et al. (2008, 2010). We studied the high latitude geomagnetic substorm effects on the Ez variations on the base of the continue Ez registrations at the polar station Hornsund (Spitsbergen). This station can map into the polar cap, auroral oval or near the border between these structures in dependence on the local time and the level of the geomagnetic activity. The high-latitude Ez variations associated with the substorm activity have been established. It was found that the Ez deviations were positive (Ez values increase) in the local morning and negative ones (Ez values decrease) in the local evening. We speculate that the direction of the Ez excursion depends on the station location relative to the positive or negative vortex of the polar ionospheric plasma convection.

The Ez variations at the mid-latitude station Świder (near Warsaw) have been studied during 14 magnetic storms. To avoid the meteorological influences on the Ez measurements we used only the Ez data, obtained under the "fair weather" conditions. For the first time the main phase effect of all mentioned above magnetic storms was established in the mid-latitude atmospheric electricity variations. The strong daytime Ez negative excursions (Ez value decreases) were found in association with the simultaneous night-side magnetospheric substorm developing during the studied magnetic storms. The considered Ez deviations could be results an interplanetary electric field penetration into the magnetosphere. Another plausible reason could be related to the common ionosphere conductivity increasing due to substorm energetic electron precipitation, modifying the high-latitude ionospheric part of the global atmospheric electric circuit.

1. Introduction

The vertical atmospheric electric field (Ez) variations, measured at ground stations, exhibit the state of the global electric circuit. The main source of this circuit is the lightning discharges in the global centers of the tropical thunderstorm activity, located in Central America, Africa, and Asia. The global electric circuit is closed by currents flowing in the ionosphere. At high latitudes, these currents are strongly influenced by the solar wind and interplanetary magnetic field change. The topic of the global atmospheric electric circuit has been recently reviewed by Rycroft and Harrison (2011) and Rycroft et al. (2012), which discussed the background to the subject as well as several mechanisms by which the global circuit can couple to the lower troposphere, and gave a large number of key references to the literature. Different solar wind effects, manifested in geomagnetic phenomena, can provide some influence on the atmospheric electric field behavior (e.g. Sao, 1967; Michnowski, 1998; Rycroft et al., 2000; Tinsley, 2000; Frank-Kamenetsky et al., 2001; Singh et al., 2005). Thus, the atmospheric electricity plays an important role in the highly coupled system representing the Earth's atmosphere and the near-Earth space environment (e.g. Burns et al., 1998; Rycroft et al., 2000, Singh et al., 2005; Rycroft, 2006). The details of physical mechanisms of this coupling are still not clearly understood. The physical base of the solar wind influence on the high-latitude atmospheric electricity has been pointed out by several authors (e.g. Michnowski, 1998; Morozov and Troshichev, 2008). The model calculations (e.g. Park, 1976; Tinsley, 2000) showed that the large scale horizontal ionospheric electric fields can penetrate deep into the atmosphere and change the values of

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1364-6826/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jastp.2012.07.009

vertical atmospheric electric field (Ez), measured at the Earth's surface.

The effects of the solar wind interactions with the magnetosphere and ionosphere, evident especially at the auroral and polar latitudes, can be seen in the atmospheric electric field variations as well. Some of such effects have been experimentally confirmed by the ground-based Ez measurements (e.g.; Olson, 1971; Angelo et al., 1982; Bandilet et al., 1986; Burns et al., 1995; Michnowski, 1998; Kleimenova et al., 1998; Belova et al., 2000; Corney et al., 2003; Nikiforova et al., 2003; Kozyreva et al., 2007; Michnowski et al., 2007).The analysis of the experimental data obtained at different latitudes is very important for study the magnetosphere–ionosphere–atmosphere coupling which is a topic of great research interest during the last decades. The aim of this paper is to underline some important effects of the geomagnetic disturbances influence on the Ez variations, measured at the Earth's surface at high and middle latitudes, based on the data previously published by Kleimenova et al. (2008,2010).

2. Data

The results of Kleimenova et al. (2008,2010) are based on the data of variations in the vertical component of the atmospheric electric field (Ez), observed at the polar Polish station Hornsund at Spitsbergen (HOR, corrected geomagnetic coordinates: $\Phi' = 74.0^\circ$, $\Lambda' = 110.5^\circ$) and at the mid-latitude Polish station Swider (SWI, corrected geomagnetic coordinates: $\Phi' = 47.8^\circ$, $\Lambda' = 96.8^\circ$).

The vertical component of the atmospheric electric field is measured by the field mill of the rotating dipole type developed at Warsaw University of Technology (Berliński et al., 2007). The field mill is mounted on the steel tower at the distance of 3 m above the surface and 70 m away from the main building. The accuracy of the electric field measurements is 2 V/m. The data are sampled by10 s. Under the "fair weather" conditions, the final registered the vertical electric field polarity is positive. The level of the Ez magnitudes for a given day can be different depending on the season and other conditions, and may change from ~50 V/m to ~500 V/m. We call the Ez deviations positive if the Ez magnitude increases and negative ones if the Ez magnitude decreases. The details of the used instruments are described by Kubicki (2001).

Only the data obtained during the so-called "fair weather" conditions have been used in our analysis. This means the absence of local disturbances of the near-Earth electric field caused by a strong wind (at the velocity higher than 6 m/s), low cloudiness, precipitation in the form of snow or rain, snowdrift, fog, etc. These limitations are of the special importance at the polar latitudes, where the motion of snow and ice particles, suspended in an air flow, results in the generation of considerable electric fluctuations, which significantly exceed the effects of the magnetospheric and ionospheric sources (e.g., Guglielmi et al., 1994; Burns et al., 1995; Frank-Kamenetsky et al., 2001). We found that only 15–20% of the continuous registration at Hornsund satisfies these conditions, which hinders a statistical analysis of the Ez data. Unfortunately, due to strong criteria of the "fair weather" conditions, we could not find the simultaneous Ez records at Hornsund and Swider.

3. Observation results and discussion

3.1. *The substorm effects in the Ez variations at polar latitudes (Hornsund station)*

Geomagnetic substorms are the fundamental night-side phenomena in the auroral and polar ionosphere and magnetosphere. Substorms are originated by plasma instabilities in the magnetosphere tail and provide high-latitude ionosphere currents enhancement and energetic particle precipitation. In the paper (Kleimenova et al., 2010), we studied the substorm effects on atmospheric electricity based on the Ez observation at polar station Hornsund (HOR). Under magnetically quiet conditions, in the local night time, this station is usually projected into the polar cap. In the morning and evening hours, the projection of this station can be both within the auroral oval and in the region of its polar boundary, depending on the level of geomagnetic activity. Under magnetically disturbed conditions, the auroral oval moves toward lower latitudes, and Hornsund station appears in the polar cap independently of the local time (e.g., Kleimenova et al., 2010).

We studied the Ez data at the near equinox periods (March, October, and November) in order to eliminate the possible strong seasonal (summer–winter) effects. For the detail analysis, we selected 20 high-latitude geomagnetic substorms in 2004–2006, during which the strong criteria of the "fair weather" conditions for the Ez measurements at Horsund were satisfied at least for 24 h; 12 events were observed in the local morning and 8 events in the evening. We found that all considered substorms caused perturbations in the atmospheric electric field (Ez) and showed the similar feature which was depended on the local time: the Ez disturbances were positive (Ez values increase) during all studied morning substorms and negative (Ez values decrease) during all studied evening substorms.

Two events (03–04.11.2004 and 03–04.09.2006) of morning and evening sustorms are shown in Fig. 1. Fig. 1 demonstrates the Ez variations at HOR and magnetograms from several Scandinavian stations, located approximately along the same meridian, the geomagnetic latitudes of these stations are shown under their codes. The geomagnetic midnight at this meridian is near 21 UT. Some details of these events are discussed in (Kleimenova et al., 2010).

One can see that on November 3, 2004 (Fig. 1a), the intense magnetic substorm developing at the auroral zone (SOD, SOR), was accompanied by the considerable Ez magnitude decreasing (we call that the negative deviation) at HOR at ~20–22 UT. At ~04–08 UT on the following day (November 4, 2004), the polar substorm was observed at polar stations NAL and HOR and it was absent in the auroral zone. The preliminary phase of this substorm was accompanied by the considerable positive Ez deviations (Ez magnitude increases) at Hornsund. The similar positive Ez deviations were observed on September 4, 2006 (Fig. 1b) during the morning substorm. The late evening substorm was observed on this day at ~19–20 UT and it was accompanied by the negative Ez deviations. All considered events demonstrated the same features: the morning substorms were accompanied by the positive Ez deviations and the evening and night-time substorms by the negative ones.

It is well known, that in the polar regions, the interaction of the solar wind and the Earth's magnetic field leads to polar convection driven by horizontal electric fields from dawn-to-dusk across the polar cap. Some authors (e.g., Angelo et al., 1982; Tinsley et al., 1998; Corney et al., 2003) showed that variations in the atmospheric electric field at polar latitudes are strongly affected by electric fields of the ionospheric convection.

We used the global maps of the polar ionospheric convection distribution obtained by the system of the high-latitude SuperDARN radars (http://superdarn.jhuapl.edu) to study this effect during two considered above events. One can see in Fig. 2 that on November 3, 2004 at 19 UT, HOR was located inside of the negative convection cell (Fig. 2a, left panel). However, in the morning on November 4, 2004 (04.40 UT), HOR was located inside of the positive convection cell (Fig. 2a, right panel). The same signature is seen in the second event on September 4, 2006.