Variations of the Mid-Latitude Atmospheric Electric Field (Ez) Associated with Geomagnetic Disturbances and Forbush Decreases of Cosmic Rays

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Abstract

Observations of the atmospheric vertical electric field component (Ez) at the mid-latitude Polish station Świder have been analyzed during 14 strong and moderate magnetic storms. Only data recorded under the so-called “fair weather” periods have been used for this analysis. The daily Ez variations under quiet geomagnetic conditions were established. The seasonal Ez level variations have demonstrated the winter maximum and summer minimum. The effect of the main phase of magnetic storm was discovered in the daytime mid-latitude Ez variations during any local magnetic activity. Short-time strong negative Ez excursion relative to the magnetically quiet daily level has been observed in the daytime simultaneously with magnetosphere substorm onset at the night sector. The long-duration depletion of the Ez amplitudes was found in association with Forbush decreases of galactic cosmic rays.

The results obtained can be interpreted as a significant influence of the changes in the solar wind-magnetosphere-ionosphere system on the global electric circuit state.

1. Introduction

Variability of the atmospheric vertical electric field component (Ez) near the Earth surface has been investigated in many studies. It has been commonly accepted that the integrated worldwide thunderstorm activity is considered as a main source of the atmospheric electricity variations. However, different solar wind effects manifested in
geomagnetic phenomena can provide some influence on $E_z$ behavior due to ionosphere electric field disturbances which may significantly control the global electric circuit state (e.g., Sao 1967, Olson 1971, Apsen et al. 1988, Michnowski 1998, Tinsley 2000, Rycroft et al. 2000). Strong manifestations of the solar wind interactions with the magnetosphere and ionosphere processes, evident especially at the auroral and polar zones, were observed in high latitude $E_z$ variations (e.g., Olson 1971, Nikiforova et al. 2003, Kleimenova et al. 1995, Michnowski 1998). The physical base of the solar wind influence on the high-latitude atmospheric electricity has been pointed out by Michnowski (1998).

Recently, the effects of magnetic storms in $E_z$ ground-based measurements were found also at middle latitudes (Kleimenova et al. 2008, Kubicki 2008). In the present paper we continue the investigations of these newly discovered effects. In addition, we extend our study on a possible influence of the cosmic rays Forbush decreases associated with magnetic storms. Effects of transmission of the ionospheric and interplanetary electric fields to the lower atmosphere are to be distinguished.

There is still a serious difficulty in separating various local meteorological effects, existing in $E_z$ variations even under the “fair weather” conditions, from the changes caused by solar wind, magnetosphere and ionosphere disturbances. Here we try to explain some of these problems by including in our analysis a study of the seasonal variability of $E_z$ daily distributions observed under the geomagnetically quiet periods.

2. Observations

This study is based on regular registrations of the vertical component of atmospheric electric field ($E_z$) at mid-latitude Polish geophysical observatory at Świder (geographical coordinates are $\phi = 52^\circ 07'\mathrm{N}$, $\lambda = 21^\circ 15'\mathrm{E}$, and the geomagnetic ones are $\Phi = 47.8^\circ$, $\Lambda = 96.8^\circ$). Magnetic local noon is at ~10 UT. The instruments and their location are described by Kubicki (2001). We used the 1-hour data as well as the 1-min sampling data averaged at 5 min intervals, rejecting the short period fluctuations.

Only the data obtained during the so-called “fair weather” periods lasting through all 24 hours during the given day have been used for our analysis. The “fair weather” conditions request the absence of rain, drizzle, snow, hail, fog, lower cloudiness, local and distant thunderstorms, wind velocity exceeding 6 m/s, negative $E_z$ values. Such demands in long-lasting intervals are usually seldom satisfied, so we could find not more than ~40-60 “fair weather” days in the year (i.e., ~12-15% of the total observations).

3. $E_z$ diurnal variations

Historically, the diurnal global variations of the atmosphere electric field were studied during the cruises of the research vessel Carnegie in the early decades of the 20-th century. An average ground-level electric field diurnal curve (known as “Carnegie curve”) with a minimum near 03-05 UT and a main maximum near 18-21 UT was obtained due to longitudinal distribution of the global centers of the thunderstorm
activity. The “Carnegie curve” is still generally accepted as a reference standard global synchronous signature of the “fair-weather” atmospheric electric field behavior. This curve was obtained in the sea regions. At middle-latitude land stations, the diurnal $E_z$ variations are strongly affected by local convective turbulent currents, which are attenuated in the night and significantly enhanced with sunrise that leads to $E_z$ values increasing in that time (e.g., Apsen et al. 1988).

To find out the possible effects of the solar wind–magnetosphere disturbances on the atmospheric electricity it is very important to establish the mid-latitude $E_z$ diurnal variations under quiet geomagnetic conditions. For this analysis we used the 1-hour averaged $E_z$ registrations at Świder observatory and selected about 30 days of the “fair weather” under Kp $\sim$ 0-2 in the years 1996-2005. The daily $E_z$ variations in all selected days are shown in Fig. 1.

Despite a very strong dispersion of $E_z$ amplitudes, a common tendency is seen. There were two enhancements that roughly matched the “Carnegie curve”: before local noon (at ~06-10 UT, which corresponds to 08-12 MLT) and in the local evening (at ~14-18 UT, which corresponds to 16-20 MLT). These maxima correspond to the American and African thunderstorm activity centers.

In many cases, a comparison of the $E_z$ measurements in two consecutive magnetically quiet days has not demonstrated any significant $E_z$ amplitude differences (Fig. 2). It is possible to expect that the observed $E_z$ values scattering is at least a result of the seasonal changes in the global electric circuit state, partly due to seasonal variations of the worldwide thunderstorm activity. In fact, Fig. 2 demonstrates that the $E_z$ amplitude level in summer (the bottom panel) was significantly smaller (particularly the evening maximum) than that in spring (the middle panel) and in autumn (the upper panel).

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![Fig. 1. The $E_z$ diurnal variations at Świder under magnetically quiet periods (Kp ≤ 2); solid line – averaged quiet day data.](image-url)
Fig. 2. Examples of the $E_z$ diurnal variations in two consecutive magnetically quiet days.

Fig. 3. The averaged diurnal $E_z$ variations in winter and summer.

The statistical study of more than 30 year data (without the separation of the magnetically quiet and disturbed periods) (Kubicki et al. 2007) supported this assump-
tion. The daily variations of the averaged $E_z$ values at Świder in the summer and winter seasons are shown in Fig. 3. The winter $E_z$ values are much higher than the summer ones.

Similar seasonal $E_z$ variations were reported by Adlerman and Williams (1996) with the local summer (May–September) minimum, observed at 9 mid-latitude stations at the northern hemisphere. Earlier, the same result was reported by Paramonov (1950) and Israel (1973).

In our analysis we compared the observed $E_z$ amplitudes in each studied event with the $E_z$ records in the previous magnetically quiet days because the application of the year-averaged fair-weather data is not correct. This is demonstrated in Fig. 4, where the 5-min sampled $E_z$ variations in three consecutive magnetically quiet days are presented in comparison with the year averaged $E_z$ variations (solid curve).

### 4. Effect of the magnetic storm main phase on the $E_z$ variations

We analyzed 14 magnetic storms in 2000-2004 observed under “fair weather” periods. We use the Dst-index, the 1-min sampled solar wind and interplanetary magnetic field (IMF) parameters data collected from the OMNI base (ftp://msdfftp.gsfc.nasa.gov/spacecraft_data/omni/high_res_omni/monthly_1min/) as well as the calculated interplanetary electric field variations. Two-day data of the May 23-24, 2000, and March 30-31, 2001, magnetic storms are presented in Fig. 5 and compared with the $E_z$ observations at Świder. The previous day was the “fair weather” magnetically quiet day.

![Fig. 4. The examples of the $E_z$ diurnal variations in three magnetically quiet days by comparison with year averaged data (solid line in Fig. 1).](image)

As a rule, a magnetic storm main phase development is accompanied by nightside magnetosphere substorms and energetic electron precipitations in the high latitude ionosphere. The magnetograms from two auroral stations: College (CMO, $\Phi = 64.7^\circ$, $\Lambda = 263^\circ$) and Sodankyla (SOD, $\Phi = 63.8^\circ$, $\Lambda = 108^\circ$) and the mid-latitude station Belsk (BEL, $\Phi = 47.3^\circ$, $\Lambda = 96^\circ$) are shown in the lower part of Fig. 5. CMO is located at the opposite side of the Earth than Świder, thus the magnetic local noon at Świder
Fig. 5. Two examples of magnetic storms; from the top down: Dst-index, the interplanetary magnetic field (IMF) Bz component, solar wind dynamic pressure (P), interplanetary electric field (Em), the $E_z$ observations (solid line), the difference between the observed and quiet $E_z$ values, and the magnetograms at BEL, CMO, and SOD.

(~10 UT) approximately corresponded to the magnetic local midnight at CMO (~11 UT). The strong magnetic substorms were observed during the main phase of considered magnetic storms; the simultaneous negative daytime $E_z$ deviations relative to the magnetically quiet $E_z$ level were observed at Świder (at ~08 UT on 24.05.2000, and at 12-16 UT on 31.03.2001).

The auroral observatory SOD is located in the same longitudinal sector as Świder, and in that time there were no significant magnetic disturbances either there or at mid-latitude observatory Belsk (BEL), located not far from Świder. A similar day-
time $E_z$ decrease associated with night-side substorms was typical for all analyzed magnetic storms.

5. **$E_z$ changes associated with Forbush decreases of cosmic rays**

It is well known that one of the important effects of the solar coronal mass ejection (CME) caused magnetic storms (e.g., Cane 2000) is a Forbush decrease of the galactic cosmic rays. The Forbush decrease starts with an interplanetary shock arrival and storm sudden commencement (SSC) onset.

We have analyzed several cases of Forbush decrease observed in the course of magnetic storm. Two such examples (August 16-19, 2001, and September 10-12, 2005) are shown in Fig. 6. The AE-index represents the global night side substorm activity. One can see the strong $E_z$ depletion in the days of Forbush effect development. Besides, the evening $E_z$ maximum, typical for quiet daily variations, was sometimes completely ceased, as it is seen on 17.08.2001 and 11.09.2005.

Earlier, the decrease of the atmospheric electric field at times of Forbush decrease events was reported, e.g., by Apsen et al. (1988) and Märcz (1997), but without a comparison with the geomagnetic conditions.

Fig. 6. Two examples of the Forbush decrease influence on the $E_z$ changes; from the top down: Dst-index, auroral AE index, the data of neutral monitor in Oulu, and the $E_z$ observations (solid line) in reference to the averaged magnetically quiet $E_z$ variations in the correspondent season (thin line).
6. Discussion

Typically, the magnetic storm main phase is accompanied by magnetosphere substorms and corresponding strong impulsive auroral AE index magnification, associated with particle precipitation at auroral latitudes, which strongly enhances the ionosphere conductivity. The cosmic ray Forbush decreases are observed also in the main phase of magnetic storms under strong ring current enhancement due to the injection of particles from the magnetosphere tail, which later precipitate into the high-latitude ionosphere. As a result, the total resistance of the ionosphere part of the global electric circuit may decrease.

According to previous authors (e.g., Olson 1971, Apsen et al. 1988, Nikiforova et al. 2003, 2005), magnetosphere substorms and visible auroras at high latitudes are accompanied by negative night-side $E_z$ anomalies. But in the presented study similar $E_z$ changes were for the first time revealed at mid-latitude station Świd in the daytime. The considered effect of the storm main phase in atmospheric electricity could be a result of large-scale changes in the ionosphere part of the global electric circuit and the energetic particle precipitation into the lower ionosphere. There is one more agent that could affect the mid-latitude $E_z$ variations. That is the penetration of the interplanetary electric field ($E_m$) to the low-latitude ionosphere, as discussed by Huang et al. (2005). However, there is no linear dependence between the observed $E_z$ effects and $E_m$ intensity (Fig. 5).

The seasonal variations of $E_z$ level in the northern hemisphere demonstrate the summer minimum. It is important to mention that according to Adlerman and Williams (1996), the minimum in the $E_z$ seasonal variations at the southern hemisphere stations (e.g., Buenos Aires and Johannesburg) was observed also in local summer (from October to April). It means, there is the opposite phase between the hemispheres. This fact strongly points to the dominance of a local influence over a global one. According to Lutz (1939) and Israel (1973), the seasonal variations of the atmospheric conductivity demonstrate the summer maximum, i.e., opposite to $E_z$ seasonal change. The $E_z$ seasonal variations appear to be the result of several seasonal factors, including the variations of the boundary layer aerosol concentration. The air conductivity increase leads to the atmospheric electric field ($E_z$) decrease.

7. Summary

1. For the first time there was found the effect of the main phase of a magnetic storm in the daytime $E_z$ changes at mid-latitude as short time negative $E_z$ anomalies associated with night-side magnetospheric substorm development under any local magnetic activity.

2. During the days of cosmic ray Forbush decrease development, the mid-latitude $E_z$ depletion was found in comparison with magnetically quiet-time $E_z$ data.

3. The season dependence of the $E_z$ diurnal variations at mid-latitudes were established, demonstrating the local summer minimum and local winter maximum.


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