POLAR GEOMAGNETIC EFFECTS OF MAGNETIC STORM OF 24 NOV 2001 UNDER STRONG POSITIVE Bz IMF

N.G. Kleimenova¹, N.R. Zelinsky¹, L.I. Gromova², L.A. Dremukhina², A.E. Levitin², S.V. Gromov²

¹Schmidt Institute of the Earth Physics RAS, Moscow, 123995, Russia, e-mail: kleimen@ifz.ru;
²Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, RAS, Moscow, Troitsk, Russia

Abstract. The huge positive Bz IMF values (up to ~+60 nT) were observed during the main phase of the strong magnetic storm on 24 Nov 2011 (Dst~220 nT) under the very high solar wind speed (~ 900 km/s) and several sharp bursts of the solar wind dynamic pressure (at ~7.30, 09.30, 12.00 and 14.00 UT). About 30 min after SC, the Bz IMF value reached ~40 nT and the strong substorm with the highest amplitudes at the morning sector occurred. Later on, at ~07 UT, the Bz IMF turned to the very high positive values reaching more than +60 nT. The most unusual phenomenon during this storm was the bay-like magnetic disturbance at 08-11 UT with the amplitude of ~1500 nT which was observed near local magnetic noon only at the polar latitudes (> 70º) at the Scandinavian IMAGE magnetometer profile. At that time, AE-index was < 300 nT. This event occurred after very strong burst of the solar wind dynamic pressure (up to ~60 nPa). We suppose that the polar magnetic bay was caused by the enhanced high-latitude NBZ system of the field aligned currents (FAC). The IZMEM model distribution of the high-latitude FAC confirmed this suggestion and demonstrated strong FAC at the polar magnetic bay location. The irregular bursts of 2-7 mHz geomagnetic pulsations (ULF waves) represented the fine wave structure of this daytime magnetic bay. However, the ULF bursts were not coincided with the similar frequency range bursts of the fluctuations in the solar wind density and IMF. We suppose the polar ULF pulsations represented the fluctuations of the intensity of the corresponding field aligned currents associated with processes of nonlinear interactions of solar wind irregularities at the magnetopause.

Introduction

The last time, there are very many papers denoted to discussions of non-typical geomagnetic effects of extreme events of the space weather such as very strong magnetic storms, e.g. [Du et al., 2008; Dandouras et al., 2009; Baker et al., 2013; Dmitriev et al., 2014; and etc].

One of the strong magnetic storms was the event on 24 November 2001 with Dst ~220 nT. There were unusually strong variations in the solar wind and in Interplanetary Magnetic Field (IMF). After the SC near 06 UT, during the storm main phase beginning, the IMF Bz suddenly turned from very strong negative vales (- 42 nT at 07 UT) to very strong positive values (~+20 nT), which quickly increased up to +64 nT at ~10 UT. The solar wind speed was as high as ~850 km/s, and some peaks of the solar wind dynamic pressure sometimes reached ~50-70 nPa. The positive IMF Bz occurrence at 08-11 UT leads to slow the typical storm main phase Dst (SymH) decreasing. The UT time variations of the Dst (SymH) as well as some IMF and solar wind parameters are shown in the upper part of Fig. 1. The aim of this paper is to study the untypical geomagnetic effects of the strong positive IMF Bz lasting about 4 hours in the storm main phase.

Observation data analysis and Discussion

1. We studied high-latitude geomagnetic disturbances by applying the new method proposed by Levitin et al. [2014] for determining geomagnetic activity based on calculation of the hourly amplitudes of magnetic field variations at ground-based observatories. Observations, performed in 2009, when extremely low solar and geomagnetic activity was registered, were used as a reference level. According to this method, the observation data are counted off from the reference level 2009.
We assume that the ground-based magnetic measurements performed on the quietest days in this year register only the main geomagnetic field and the deviations from this level represent the amplitude of a variable magnetic field.

This assumption forms the basis for the characterization of geomagnetic activity based on the energy of a variable magnetic field.

To quantitatively describe local magnetic activity, we selected the geomagnetic field $H$ component registered at observatories since this component most intensely responds to a change in a variable geomagnetic field generated by the magnetospheric and magnetospheric-ionospheric current systems.

We used the following calculation method for the ground-based data of the Northern Hemisphere:

For each month of 2009, we select the day when geomagnetic activity was the lowest and the $H$ component amplitude variations (the difference between the maximal and minimal amplitudes) were the smallest. A correction for the geomagnetic field secular variations is found from the difference between the quietest days in January for two adjacent years since the geomagnetic field at the observatories in the Northern hemisphere is most quiet precisely in January in our opinion.

The hourly average amplitudes of the $H$ component on a geomagnetically quiet day corrected for the secular variations are then subtracted from the hourly average amplitudes for the same month in all previous and subsequent years.

The middle part of Fig. 1 demonstrates the calculated the hourly magnetograms from several high latitude ground stations located at different longitudes by the described above method. The MLT hours have been indicated on the horizontal axis for each given stations, thus, we may compare the simultaneous geomagnetic disturbances at different local magnetic time. It is seen that after SC under negative IMF $B_z$ there was a strong substorm at the night side of the Earth (obs. BRW, CMO, MEA). It is typical for magnetic storms.

With the positive IMF $B_z$ turning (at ~07 UT), the night substorm activity dropped, and AL index, shown in the bottom part of Fig. 1, became very small (~-300 nT).

Fig.1. IMF and solar wind parameters during this storm and geomagnetic data from some high latitude stations. The solid lines are the hourly values and the thin lines – the minutes ones.
However, an unusual strong negative magnetic bay occurred in the dayside sector of the Earth at polar geomagnetic latitudes (obs. HRN, $\Phi\sim74^\circ$, $\sim11$-14 MLT), where the dayside polar cusp could be located. This bay disappeared with negative values of IMF $B_z$ occurred.

2. We applied the IZMIRAN model of the field aligned currents and convection distribution in the North hemisphere based on the correlation of the X and Y geomagnetic field at high-latitude ground stations with the solar wind density and velocity and the IMF $B_z$ and $B_y$ components [Feldstein and Levitin, 1986; Dremukhina et al., 1998]. The calculated maps are presented in Fig. 2 for 3 selected intervals marked by the vertical dotted lines in Fig. 1: before SC (leftward), under high negative IMF $B_z$ (in the middle) and under huge positive IMF $B_z$ (rightward). The middle plots shows typically strong enhancement of FAC intensity and convection under high negative IMF $B_z$ values.

Under the very strong positive IMF $B_z$, the auroral latitude FAC intensity significantly dropped as it is seen in the rightward maps of Fig. 2. However, in the dayside polar cusp area (near HRN station), the upward and downward FACs were intense. The station HRN was located in the area of negative convection sell. These FAC could be attributed to the special NBZ current system under positive IMF $B_z$ [Iijima et al., 1984; Zanetti et al., 1990]. Some authors, e.g. [Wilhjelm et al., 1976] showed that in the northern dayside polar cusp under negative IMF $B_y$, the westward electrojet is dominated as it is seen in Fig. 1 at HRN station at 08-11 UT (11-14 MLT).

3. The magnetograms from the selected stations of the IMAGE magnetometer chain are presented in Fig. 3 for the discussed time interval (04-14 UT). One can see that a strong negative magnetic bay with the amplitude about 1500 nT was observed at 08-11 UT only at polar geomagnetic latitudes higher 71° (obs. NAL-HOP), at lower latitudes there were no magnetic disturbances. We call this magnetic bay “dayside polar magnetic substorm” by parity of reasoning with the magnetic substorm. However, there were no a Pi2 geomagnetic pulsation burst which is typical for classical substorm onset.

It is known that a source of a night substorm is the energy accumulated in the magnetosphere tail under previous negative IMF $B_z$, and the substorm onset (breakup) if a result of dipolization and current disruption exiting Pi2 pulsation generation. However, at the dayside of the magnetosphere, there is no such energy
reservoir. So, it is logical to assume that a source of the daytime polar substorm could be associated with the solar wind and IMF interaction with the Earth magnetosphere at the sunlit magnetopause.

Fig. 3. The magnetograms (X-component) from selected IMAGE magnetometer chain.

4. The ULF (2–7 mHz) geomagnetic pulsation accompanied the dayside polar magnetic substorm (08-11 UT) have been studied by applying of fuzzy logic methods of the Discrete Mathematical Analysis –DMA [e.g., Agayan et al., 2005; Zlotnicki et al., 2005; Gvishiani et al., 2008].

The first step of observation processing included data filtration within the 2–7 mHz range using a band-pass Butterworth filter with a zero-phase shift [Kanasevich, 1985], the amplitude-response curve of which is maximally smooth in the frequency bandwidth. In this work for investigation of geomagnetic pulsations, we used a DMA “survey fragment energy” rectifying functional (Agayan et al., 2005). The applying of this rectification allows us to identify sections of the initial time series that are anomalous in a certain vicinity of a given point, i.e., the “energy” rectification carries information about the signal amplitude relative to the neighboring points of the time series and does not correspond to the absolute signal amplitude.

The obtained results of these calculations are demonstrated in Fig. 6 for fluctuations of the IMF components and solar wind dynamic pressure as well as for geomagnetic pulsations from some stations at polar, auroral and equatorial latitudes (auroral obs CMO and equatorial obs. PPT are located at the night side). It is seen that the strongest high-latitude ULF wave were observed during SC (near 06 UT) and strong negative IMF Bz (near 07 UT). During the discussed above dayside polar magnetic substorm, there were irregular pulsations at polar latitudes not correlated with fluctuations in the interplanetary medium. Despite the fact that the time interval of the polar irregular geomagnetic pulsations and interplanetary fluctuations was the same, it was unlikely a direct wave penetration from the solar wind to the ground.

At this time, there were observed three strong ULF bursts at dayside equator (obs. AAE) in association with similar bursts in the solar wind dynamic pressure fluctuations as it was found previously by Pathan et al. [1999].

We suppose that the polar irregular geomagnetic pulsations accompanied the dayside polar magnetic substorm are associated with processes of the solar wind – magnetosphere interaction which leads to
fluctuating NBZ field aligned current generation or nonlinear wave penetration (or generation) in the turbulent boundary layer over polar cusps. Some of such phenomena have been discussed by Savin et al. [2002].

Fig. 6. The results of applying the calculations of DMA “survey fragment energy” rectifying functional to the analysis of interplanetary fluctuations and ground-based geomagnetic pulsations at different latitudes.
Conclusion

The key non-typical phenomena of the magnetic storm main phase of Nov 24, 2001 was a negative magnetic bay-like disturbance in the day side polar cusp area as a result of the huge positive Bz IMF values reaching more than +60 nT occurrence. We call this disturbance dayside polar magnetic substorm.

The substorm was accompanied by irregular pulsations at polar latitudes not correlated with fluctuations in the interplanetary medium. Despite the fact that the time interval of the polar irregular geomagnetic pulsations and interplanetary fluctuations was the same, it was unlikely a direct wave penetration from the solar wind to the ground. We suppose that the polar geomagnetic pulsations accompanied the dayside polar magnetic substorm are associated with processes of the solar wind – magnetosphere interaction which leads to fluctuating NBZ field aligned current generation or nonlinear wave penetration (or generation) in the turbulent boundary layer over polar cusps.

Acknowledgment. This study was supported by RFBR grant № 13-05-00233 and partly by the Program № 7 of the Earth Science Department RAS.

References


Akasofu, S.I. (1975), The roles of the north-south component of the interplanetary magnetic field on large-scale auroral dynamics observed by the DMSP satellite, Planet. Space Sci., 23 (10), 1349–1354.


