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MAGNETOSPHERE-IONOSPHERE RESPONSE TO MAGNETOSPHERE COMPRESSION BY THE SOLAR WIND

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Abstract. Analysis of the global magnetosphere-ionosphere response to solar wind dynamic pressure variations under the negative IMF Bz has been performed. It is shown that an increase in the dynamic pressure leads to a double response of the ionospheric currents and aurora, i.e. simultaneously (within the accuracy of 1 min) and ~ 5-7 min afterward. Thereby, the eastward and westward convective electrojets are enhanced in the evening and morning sectors, respectively, followed by intensification of the westward current in the near midnight and evening sectors. The intensification of the electrojets is followed by extension of the diffuse precipitation zone and its high latitude boundary movement to the pole and to the east in the midnight-to-morning sector. In our case, no poleward or westward extension of aurora before midnight is observed. The disturbance triggered by a dynamic pressure increase may be considered as a convection disturbance associated with reconstruction of the DP2 current system.

Introduction

Interaction of the solar wind (SW) with the magnetosphere leads to a series of magnetosphere-ionosphere disturbances, of which convection and substorm disturbances are the principal ones. It is considered [Sergeev et al., 1996] that the convection disturbances are associated with the processes of magnetospheric convection enhancement and direct transfer of the SW energy to the magnetosphere. The substorm is a result of a sudden release of the accumulated magnetic energy in the magnetotail under the southward IMF Bz-component, having duration of ≥ 0,5-1.0 h.

The substorm onset can be initiated by inner magnetospheric processes (spontaneous substorms) or owing to sharp variations in SW and IMF conditions (triggered substorms) [Dmitrieva and Sergeev, 1983]. One of the major external triggers of substorms is interaction of a discontinuity in the SW structure with the magnetosphere leading to compression of the latter [Kokubun et al., 1977].

According to Kokubun et al. [1977], the probability of a disturbance triggered by SW dynamic pressure impulse (Pd) is higher if the magnetosphere is 'prepared' for substorm onset through development of the growth phase under the negative IMF Bz. Thus, Kokubun et al. [1977] argue that a sharp magnetosphere compression is not a direct source of the substorm onset. At the same time, according to Akasofu and Chao [1980], substorm onset during sharp magnetosphere compression is a direct result of the intensified coupling between the SW and magnetosphere. In this case the substorm is a result of the direct transfer of the SW energy to the magnetosphere without its previous accumulation.

In the present study the characteristics of magnetosphere-ionosphere disturbance triggered by Pd variations are considered based on global ground geomagnetic and auroral observations as well as on satellite measurements of the magnetic field and plasma parameters. The event registered on January 6, 1998 is analyzed.

Experimental Data

The ionospheric response was studied using 1-20 s resolution data of the global magnetic station chain, which includes ~70 stations, within the following projects: CPMN, MACCS, IMAGE, Canopus, Greenland Coast. Data of several low-latitude and equatorial stations, which were not included in any of the above projects, as well as auroral luminosity observations from the POLAR satellite, were also treated.

The magnetosphere response was monitored by data of geostationary satellites GOES 8, LANL 90 and LANL 94, located at 1600 UT in 11 MLT, 13 MLT and 23 MLT sectors, respectively.

The conditions in the SW were detected by the WIND satellite with coordinates $X_{GSM} = 222.3\ R_E$, $Y_{GSM} = 20.0\ R_E$, $Z_{GSM} = 3.7\ R_E$ at 1700 UT. Comparison of SI onset with the moment of the Pd increase, as registered by the WIND satellite, has shown that it is ~ 48 min delayed from the Pd impulse; so that a correction on this delay was introduced when using the WIND data (Fig. 1).

Ionospheric and Magnetospheric Response to the Solar Wind Dynamic Pressure Variations

Ionospheric response. The disturbance related to a sudden increase of Pd followed by the magnetosphere compression is analyzed. The compression of the magnetosphere by the SW at ~ 1416 UT occurred under small southward IMF Bz (Bz ~ -1,5 nT) (Fig. 1) and did not cause any noticeable bay-like disturbance in the magnetic

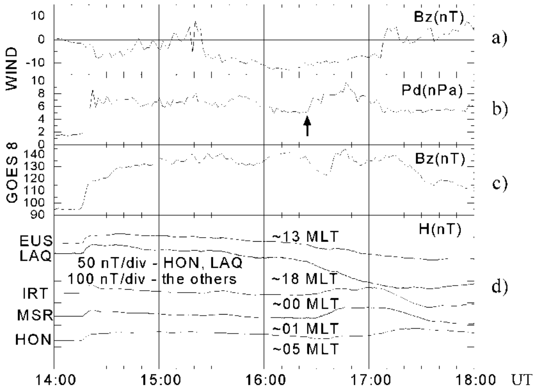

Fig. 1 IMF Bz (a) and sw dynamic pressure (b) as observed by the WIND; Bz-component of the magnetic field as observed by the GOES 8 (c) and geomagnetic field H-component at low-latitude stations in other MLT sectors (d) on January 6, 1998 at 1400-1800 UT.

field (the values of AE-index lower than 50-100 nT are not shown). The subsequent compression at ~ 1625 UT, i.e. ~1 h after IMF Bz turning southward, led to an intensive disturbance (AE $\geq$ 400-1000 nT).

The sharp increase of Pd at ~ 1625 UT marked by the arrow in Fig. 1 caused a simultaneous enhancement of the eastward (MUO, PEL) and westward (DIK, CPS) electrojets in the evening, midnight and morning sectors, respectively. This can be seen in Fig. 2, where the beginning of the Pd increase is marked by the dashed line. A new sharp intensification of the westward electrojet occurred ~ 5 minutes later, at 1630 UT, in the early morning sector (KTN, TIX and CPS) with $\Delta H \approx 800$ nT and then, at ~ 1648 UT, close to the midnight meridian (CCS, DIK) with a similar magnitude of ΔH. Simultaneously, there was an enhancement of the eastward electrojet in the evening hours, as seen from Fig. 2. Note, that the currents at PEL station during the whole disturbance had the eastward direction ($+\Delta H$), being weakened from 1630 UT to ~ 1720 UT, i.e. during the intensification of the westward current, which was of a large intensity and probably compensated the eastward currents.

The intensification of the electrojets was accompanied by the growth of the background luminosity with emergence of separate bright spots and extension of the luminosity high-latitude boundary to the pole from Φ' ~70° to 78° and to the east in the night and morning sectors (Fig. 3). In this case neither extension of theauroras to the pole and to the west in the evening-to-midnight sector nor formation of auroral surge and westward traveling surge (WTS) were observed.

Magnetospheric response. From Fig. 4 it follows that the sharp compression of the magnetosphere at 1416 UT resulted in simultaneous growth of the particle flux intensity in all energy ranges in the dayside magnetosphere (Fig. 4б) as well as in the energy range of 225-315 keV and at higher energies (not shown) in the night sector. At 1625 UT, simultaneously with the Pd increase onset (the dashed vertical line), a dispersionless particle injection in the night magnetosphere (LANL 94 – Fig. 4a) occurred. After 1640 UT on the dayside (LANL 90, Fig. 4b) the electrons drifting through the morningside with a velocity proportional to the particle energy were registered.

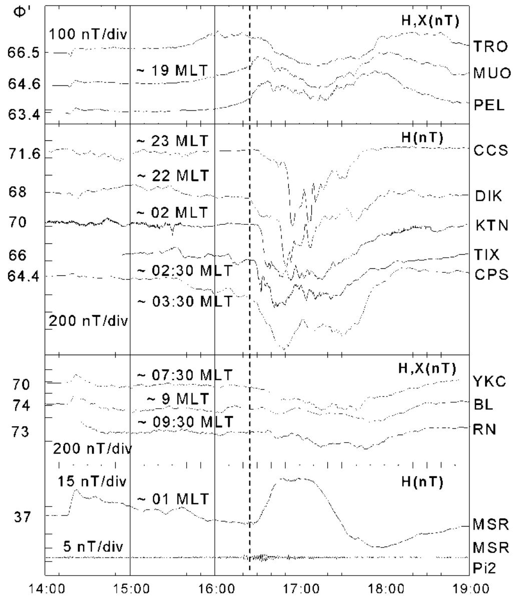

Fig. 2 Magnetic field variations at high-latitudes in midnight, morning and evening sectors, accompanied by Pi2 geomagnetic pulsations and low-latitude magnetic bay in MSR on January 6, 1998 at 1400-1900 UT.

Summary and Discussion

The disturbance caused by an increase in Pd was found to have the following features:

(a) Simultaneously with the increase in Pd (within accuracy of ~ 1 min) excitation of Pi2 pulsations, sharp intensification of the convective electrojets for ~ 5-10 min, onset of a low-latitude positive bay and growth of auroral luminosity are observed.

(b) About 5-7 minutes after the increase in Pd a sharp enhancement of the westward electrojet everywhere but predominantly in the early morning hours takes place, the eastward electrojet in the evening hours being also intensified. In the pre-midnight sector the westward electrojet intensification is comparable to that of the westward electrojet in the morning sector ~20 minutes after the disturbance onset.

(c) The enhancement of the auroral electrojets is accompanied by the growth of the background luminosity with appearance of separate bright spots and extension of the high latitude boundary of the luminosity region to the pole and to the east in the night and morning sectors.

(d) In the magnetosphere, simultaneously with the increase in Pd, an injection of energetic electrons is observed both in the nightside and dayside magnetosphere.

The features (b) and (c) of the disturbance considered are consistent with the results of Shue and Kamide [1998] and Kamide et al. [1998], who have shown that the disturbance stimulated by an increase in Pd is characterized by an intense growth of the westward electrojet and extended diffuse zone.

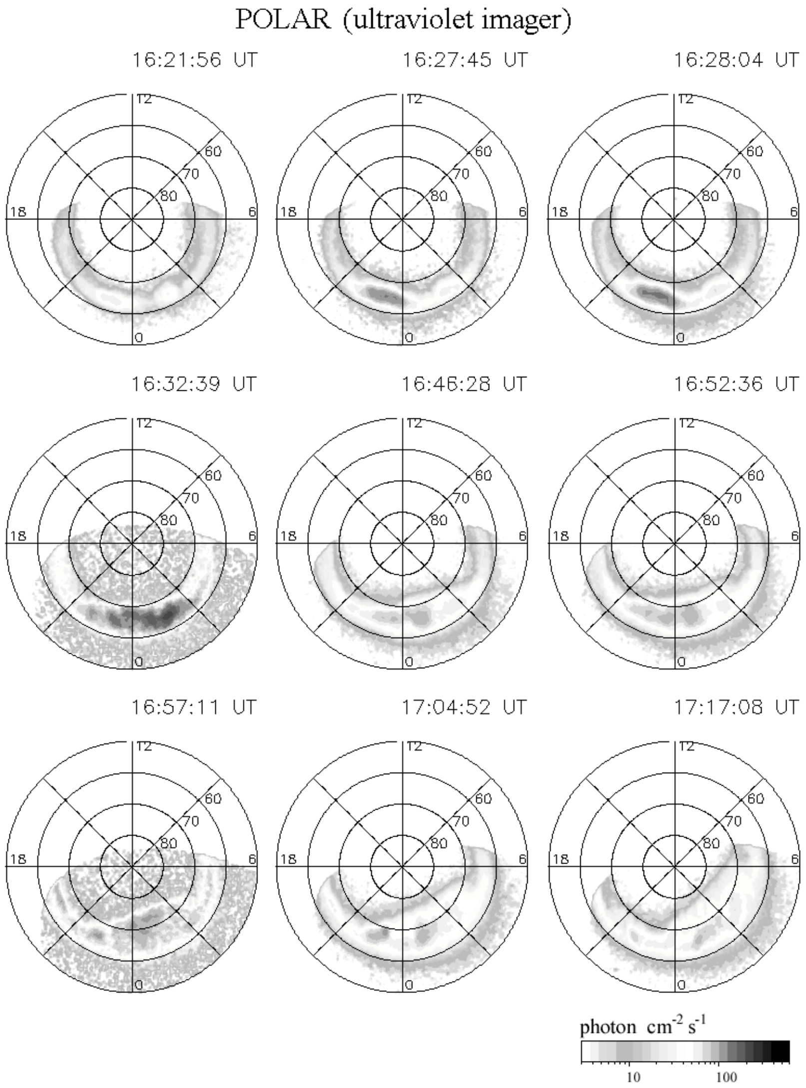

Fig. 3 Dynamics of aurorae from the POLAR satellite on January 6, 1998 at 1621-1717 UT.

Auroral dynamics in the event considered is in agreement with the behavior of auroras suggested by Ponomarev [1985]. According to the Ponomarev [1985] model, the disturbance evolution is connected with variations of the electric field of the magnetospheric convection and “freshening” of the plasma precipitation owing to development of the plasma pressure gradients in the magnetosphere. From this point of view, the disturbances observed in our case can be classified as convective ones.

According to Kokubun et al. [1977], after the magnetosphere compression both typical substorms and convective disturbances can be observed.

Such indications of the substorm expansion phase as excitation of Pi2 pulsations, enhancement of the westward electrojet in the near midnight sector, with currents flowing in the evening sector, low-latitude positive bays, impulsive injection of energetic particles at geostationary orbit were registered in our event. At the same time, formation of the auroral surge in discrete aurora and WTS in the evening-to-midnight sector, typical for the development of the substorm current wedge (SCW), was not observed.

It is possible that the above indications are not immediately connected with the formation of the SCW. As shown in [Solovyev et al., 2000], the excitation of Pi2 reflects the initial brightening of an auroral arc, and not the formation of the auroral surge or WTS. According to Friedrich and Rostoker [1998], the enhancement of the westward current in the evening-to-midnight sector can be connected with the reconstruction of the DP2 convective ionospheric currents without formation of the SCW. A similar conclusion follows from the Ponomarev [1985] model.

The source of the low-latitude positive bays in the event considered could be eastward currents on the magnetopause during the magnetosphere compression [Nishida, 1980] and (or) eastward currents at low latitudes, typical for the DP2 disturbances [Gizler et al., 1976]. As follows from Fig. 4, the impulsive particle injection in the inner magnetosphere simultaneously with the sharp growth of Pd is registered also in the dayside magnetosphere, i.e. most likely it is associated with the enhancement of the electric field across the magnetosphere.

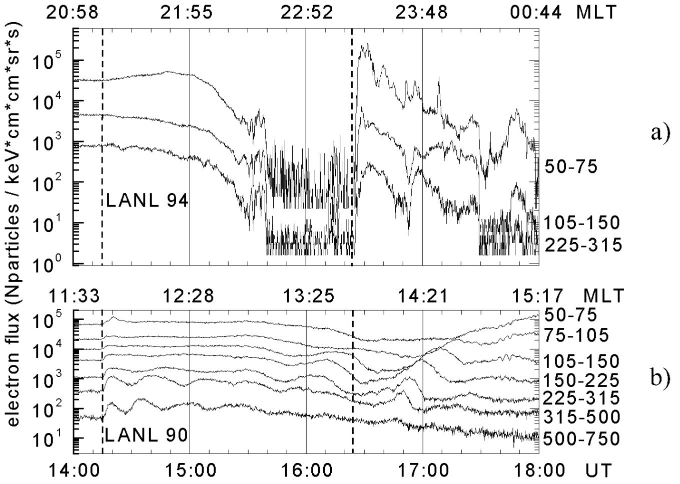

Fig. 4 Variations of the energetic electron flux in different energy ranges at geostationary orbit in the 1100-0100 MLT sector from Lanl 94 (a) and Lanl 90 (b) satellites on January 6, 1998 at 1400-1800 UT.

It is possible that in the works of Kokubun et al. [1977] and Akasofu and Chao [1980] the convective disturbances were also registered. In the work of Kokubun et al. [1977] a typical substorm was considered to be an event with the westward electrojet intensification in the near midnight sector and the low-latitude positive bay development. As was mentioned above, these indications are not sufficient to identify substorm. In the work of Akasofu and Chao [1980] the geomagnetic disturbances was estimated by the value of AE-index. It is not enough for substorm identification either, since according to Sergeev et al. [1996] during the convective disturbances the AE-index can be as large as ~1000 nT.

Thus, we suggest that despite some indications of substorm expansion phase, the magnetosphere-ionosphere disturbance stimulated by an increase in Pd can be classified as a convective disturbance related to the reconstruction of the DP2 ionospheric currents in accordance with the Ponomarev [1985] and Friedrich and Rostoker [1998] models.

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References

Akasofu S.-I., Chao J.K. Interplanetary shock waves and magnetospheric substorms // Planet. Space Sci. V. 28. P. 381-385. 1980.

Dmitrieva N.P., Sergeev V.A. Spontaneous and compelled beginning of a burst phase of the magnetospheric substorm and its preliminary phase duration // Geomagnetism and Aeronomy. V. 23, № 3. P. 470-474. 1983 (in Russian).

Friedrich E. and Rostoker G. Reconfiguration of the directly driven currents during a substorm expansive phase: implications for the substorm current wedge // ICS-4, Japan P. 83. 1998.

Gizler V.A., Kuznetsov B.M., Sergeev V.A. and Troshichev O.A. The sources of the polar cusp and low latitude bay-like disturbances during substorms // Planet. Space Sci. V. 24. P. 1133. 1976.

Kamide Y., Shue J.-H., Li X., Lu G., Brittnacher M.J., Parks G.K. and Reeves G.D. Internally and externally triggered substorms: a case study of the January 10, 1997 events // ICS-4, Japan, P. 305. 1998.

Kokubun S., McPherron R., Russell C. Triggering of substorms by solar wind discontinuities // J. Geophys. Res. V. 82. P. 74. 1977.

Nishida A. Geomagnetic diagnosis of the magnetosphere // Moscow: Mir, 1980. 302p. (in Russian)

Ponomarev E.A. Mekhanizmy magnitosfernykh subbur // M.: Nauка. 1985. 158s. (in Russian)

Sergeev V., Pellinen R.J. and Pulkkinen T.I. Steady magnetospheric convection: A review of recent results // Space Sci. Rev. V. 75. P. 551. 1996.

Shue J.-H. and Y. Kamide. Effects of solar wind density on the westward electrojet // ICS-4, Japan, P. 677. 1998.

Solovyev S.I., Baishev D.G., Barkova E.S., Molochushkin N.E, Yumoto K. Pi2 magnetic pulsations as response on spatio-temporal oscillations of auroral arc current system // Geophys. Res. Lett. V. 27, P. 1839-1842. 2000.