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THE MAGNETOSPHERIC AND IONOSPHERIC DISTURBANCES DURING THE PASSAGE OF THE LARGE-AMPLITUDE ALFVEN WAVE IN THE INTERPLANETARY MEDIUM

A.A. Lubchich, V.S. Smirnov (*Polar Geophysical Institute, Apatity, Russia, lubchich@pgi.kolasc.net.ru*)

1. Introduction

The relationship between disturbances in the solar wind and different regions of the magnetosphere and ionosphere is due to mechanisms of interaction of the solar wind with the magnetosphere. The mechanism of interaction is determined by different processes in the outer magnetosphere, such as the local and global reconnection, plasma injection into the low-latitude boundary layer, the magnetosphere reaction on the solar wind "pressure pulse", and others.

As far as the solar wind is concerned, an empirical approach has been used to find solar wind parameters and their combination which best correlate with magnetospheric and ionospheric perturbances and best characterize the magnetospheric response. Useful parameters and their combinations are the north-south component of the interplanetary magnetic field (*IMF*), B_z, and the dynamic and static pressure of the solar wind plasma [1]. Studies have shown that the southward orientation of the *IMF* favors the coupling with the solar wind, whilst the northward orientation inhibits coupling. It should be noted, however, that in individual cases it can be difficult to distinguish between processes due to changes of *IMF* and solar wind pressure [2].

The relationship between the disturbances in the solar wind and the magnetosphere depends on the time scales of the solar wind perturbation too. It is associated with time characteristics of dynamic processes in the magnetosphere - ionosphere system. Correlation analyses of solar wind parameters with ground magnetic perturbations have revealed two time scales for the response of ionospheric currents (to which ground-based magnetometer are sensitive) to changes in solar wind parameters: the shorter time scale (~10 min) has been attributed to the directly driven response, whilst the longer one (~1 hour) to the storage release component.

This paper is about the relationship between parameters of the disturbed solar wind and the geomagnetic activity during particularly well-behaved interplanetary conditions when the statistical properties of the solar wind fluctuations remain nearly constant for an extended period of time (of order of 10 hours). The observational studies often revealed random and non-reproducible behavior of solar wind parameters as a function of time, thus indicating the properties typical of a turbulent magnetofluid. However, examples were found in the measurement of what resembled pure magnetohydrodynamic waves, notably Alfven waves, stressing the possible persistence and coherence of the fluctuations. The persistence and coherence quasiperiodic oscillation of the north-south (B_z, V_z) components of the interplanetary magnetic field and solar wind velocity with the dominant period of about 40 *min* are observed by the IMP-8 spacecraft in the period of 12-24 UT, December 17, 1990. In this event there is a clear difference between the coherent large-amplitude oscillation and incoherent turbulent fluctuations of small amplitude with a low level of compressive ones. As we will show below, the coherent oscillations are caused by the passage of the large-amplitude linearly polarized Alfven wave.

Our main aim in this paper is to determine relationship between disturbances in the solar wind and different regions of the magnetosphere and ionosphere in this event. Taking into consideration the dependence of the geomagnetic activity on solar wind polarization and time characteristics we believe that, in this case, we have come to a good estimate of the relationship between the statistical properties of the solar wind and geomagnetic disturbances.

2. Data

In the case under study the plasma and magnetic field data obtained by the spacecraft in the solar wind (IMP-8) and magnetosphere (GOES-6, GOES-7), as well as ground-based observations (60 stations in the northern hemisphere) have been used to investigate the coherent fluctuations of the plasma parameters. The data used enabler us to investigate the relations between the solar wind and geomagnetic variations with frequency below $1.7*10^{-2}$ *Hz* or periods above a minute.

The solar wind, the magnetosphere and ionosphere data for the interval 12-24 UT, December 17, 1990, are given in Figure 1. The panels show, from top to bottom, the north-south component of the IMF, the angle between the ecliptic plane and solar wind velocity, the corrected north-south component of the magnetosphere magnetic field, the fluxes of the protons with energy $0.6 < E < 4.2$ *MeV* (at the geosynchronous orbit), the vertical components of the magnetic field observed at Nord, Hopen and Kiruna located in the polar cap, the auroral oval, and far equatorward of the auroral oval respectively. The data on the heliospheric and magnetospheric magnetic fields are presented in the GSE coordinate system. The monthly average day variation and monthly mean level representing the quiet magnetospheric magnetic

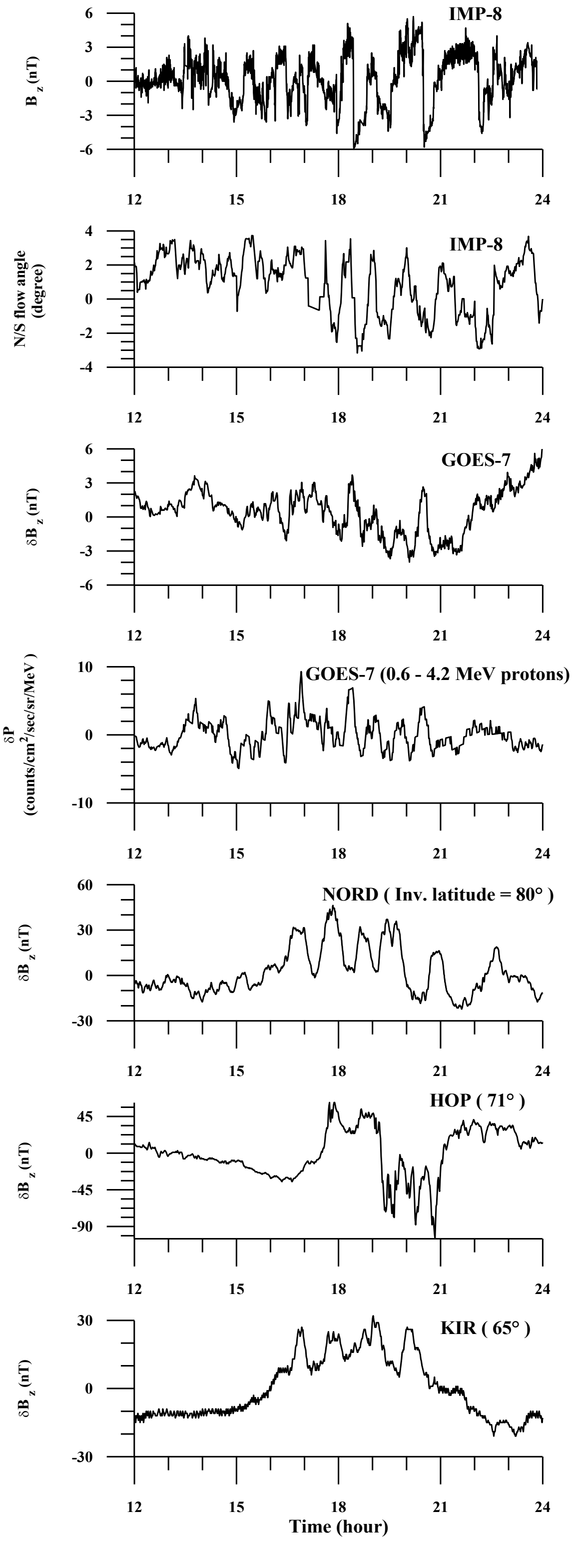

Figure 1. The heliospheric, magnetospheric, and ionospheric disturbances in the period of 12-24 UT, December 17, 1990.

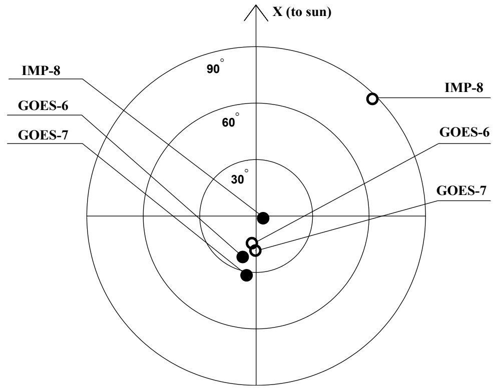

Figure 2. The directions of maximum variation (•) and regular magnetic field (o).

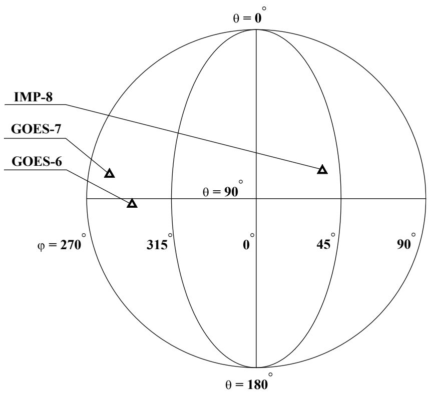

Figure 3. The directions of minimum variation.

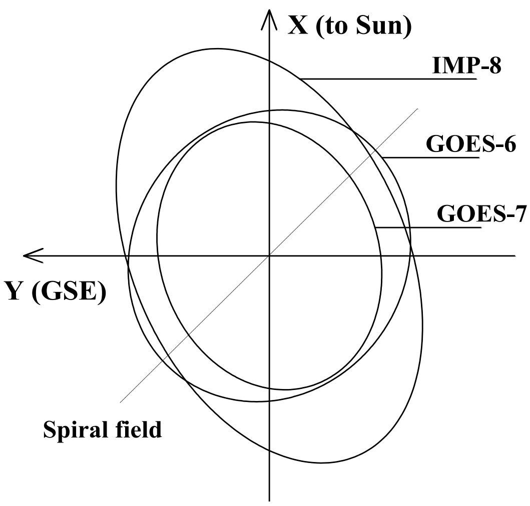

Figure 4. The distribution of the magnetic field fluctuation in the ecliptic plane.

field at the geosynchronous orbit have been removed from the data. From Figure 1 one can see the large-amplitude correlated oscillations of the IMF and the solar wind velocity. At the same time Figure 1 also shows the large-amplitude correlated oscillations of the magnetic field and fluxes of the energetic protons in the magnetosphere. As we will shows below there is a striking similarity between the characteristics of the solar wind and magnetospheric fluctuations. We consider also the relationship between the solar wind and ionosphere disturbed parameter. The visual examination of the ground-based magnetic field data acquired at the polar cap, auroral, and subauroral stations (60 stations of the northern hemisphere located from ~60° to ~80° of geomagnetic latitude) indicated that there are striking differences between the magnetic variation characteristics of different region of the ionosphere.

3. Method of analysis

In a statistical description of fluctuations the detailed behavior of the field variables is of no interest. The statistic characteristics of the fluctuations of vector fields in the solar wind and magnetosphere were obtained by the method of the variance matrix analysis [3]. This analysis enables us to obtain the important statistical properties of the fluctuations: standard deviations, directions of the maximum and minimum variations, correlations between the components of the vector fields, and other characteristics.

The symmetric matrix $T_{ij} = \langle B_i \cdot B_j \rangle - \langle B_i \rangle \cdot \langle B_j \rangle$ formed from components (i, j = 1, 2, 3) of any random vector field will have eigenvalues $\lambda_3 \geq \lambda_2 \geq \lambda_1$ and corresponding eigenvectors $\vec{M}_3$, $\vec{M}_2$ and $\vec{M}_1$ that define the principal axes of a variance ellipsoid. As usual, the brackets, <…>, indicate an averages. Eigenvalues λ_i and eigenvectors $\vec{M}_i$ characterize the intensity and orientation of the fluctuations respectively. $\vec{M}_3$ is the direction of maximum variation, $\vec{M}_1$ is the direction of minimum variation, and $\vec{M}_2$ completes the orthogonal set. If $\lambda_3 = \lambda_2 = \lambda_1$ the ellipsoid is a sphere and the variance of the vector field is isotropic, whereas if $\lambda_3 > \lambda_2 > \lambda_1$ the variance of the vector field is anisotropic.

The eigenvalues λ_i and the directions of the eigenvectors $\vec{M}_i$ calculated according to the data of the solar wind and magnetospheric magnetic field fluctuations are given in Table 1. The coordinate frame mentioned above is used to calculate the colatitude θ_i and the longitude φ_i of the vector $\vec{M}_i$.

An empirical approach has been adopted to find the best correlation between the solar wind and ionospheric disturbances in the case under study. Taking into consideration the complicated distribution of the disturbed ionospheric currents the variations of the different components of the ground-based magnetic field have been investigated in the different regions.

4. Discussion and conclusions

Taking into account the coupling of the different solar wind parameters the structure of the heliospheric disturbance should be considered (static, dynamic, Alfvenic, non-Alfvenic, and others). The high correlation between the *IMF* and solar wind velocity components (the maximum correlation coefficient of > 0.6) indicates that the structure of the event under study is dynamic. The eigenvalues λ_i and the directions of the eigenvectors $\vec{M}_i$ calculated according to the data of the solar wind velocity fluctuations are given in Table 2.

The comparison of Table 1 (IMP-8) and Table 2 shows that the magnetic field and velocity fluctuations of the solar wind are connected by the well-known correlation relation $\delta\vec{v} = \pm \delta\vec{B} / \sqrt{4\pi\rho}$. So this heliospheric disturbance is due to the passage of the large-amplitude (nonlinear) linearly polarized Alfven wave.

The results of the statistical analysis are presented also in Fig. 2 and Fig. 3. Fig. 2 shows the directions of the maximum variations and the regular magnetic fields. According to this Figure, in the magnetosphere, in contrast to the solar wind, the fluctuations are those of magnetosonic type. This is due to the difference of directions of the regular magnetic field in the solar wind and magnetosphere. The directions of minimum variation are presented in Fig. 3. Fig. 4 shows the distribution of the fluctuations in the ecliptic plane. In the solar wind the fluctuations are anisotropic. This is contradistinction to the magnetosphere where fluctuations in this plane are isotropic.

As mentioned above, there are significant differences between the ground-based magnetic variations observed by different magnetometer stations. Taking into account these differences we have calculated the correlation coefficients between the north-south component of the IMF and the ground-based components of the magnetic field observed at Nord, Hopen, and Kiruna located in the polar cap, the auroral oval, and far equatorward of the auroral oval respectively. It is found that the correlation between the IMF and ground-based magnetic field of the Nord magnetometer polar cap station with a lag of 6 *min* is the best (peak correlation coefficient 0.5). It is found also that the correlation between the *IMF* and the ground-based magnetic field of the Kiruna magnetometer station located far equatorward of the auroral oval is the worst (peak correlation coefficient 0.1). The peak correlation coefficient between the *IMF* and the magnetic field of the Hopen magnetometer auroral oval station is 0.2. The dependence of the statistical properties of the ground-based magnetic variations on the region of the observation is consistent with the well-known mechanisms of energy transfer from the solar wind to different regions of the magnetosphere and ionosphere. However, the processes near boundaries of these regions remain still an open question.

Table 1.
Characteristics of the magnetic field fluctuations measured in the period of 12-24 UT, December 17, 1990.

Satellite	λ_1, nT^2	θ_1, degree	φ_1, degree	λ_2, nT^2	θ_2, degree	φ_2, degree	λ_3, nT^2	θ_3, degree	φ_3, degree
IMP-8	0.93	93	294	2.71	88	24	4.52	4	252
GOES-6	0.98	75	35	1.25	108	145	3.96	23	162
GOES-7	0.70	77	282	0.95	62	19	4.70	32	171

Table 2.
Characteristics of the solar wind velocity fluctuations measured by the IMP-8 satellite in the period of 12-24 UT, December 17, 1990.

λ_1, $(km/sec)^2$	θ_1, degree	φ_1, degree	λ_2, $(km/sec)^2$	θ_2, degree	φ_2, degree	λ_3, $(km/sec)^2$	θ_3, degree	φ_3, degree
98	110	323	155	80	49	300	22	294

References

1. Smirnov V.S., V.S. Ismagilov, E.V. Vashenyuk, H. Kananen, K. Mursula and P. Tanskanen, The strong IMF fluctuations and their auroral zone geomagnetic response, Phys. Chem. Earth, vol.22, No.7-8, pp.697-700, 1997.
2. Pudovkin M.I., A.A. Lubchich, S.A. Zaitseva, C.-V. Meister, B.P. Besser, Effective adiabatic index in a wave structure of the solar wind: a case study for 17 December 1990, Physics of plasmas, vol.7, No.11, pp.4683-4689, 2000.
3. Daily W.D., Alfven wave refraction by interplanetary ingomogeneities, JGR, v.78, No.13, pp.2043-2053, 1973.