Pergamon

Phys. Chem. Earth, Vol. 22, No. 7–8, pp. 697–700, 1997

Printed in Great Britain
0079-1946/97 $17.00 + 0.00

PII: S0079-1946(97)00198-5

The Strong IMF Fluctuations and their Auroral Zone Geomagnetic Response

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Received 13 September 1996; accepted 15 April 1997

Abstract. The purpose of this paper is to investigate relationship between parameters of disturbed solar wind inside the interplanetary shock wave and the high - latitude geomagnetic activity. Data on correlated variations of the IMF, cosmic rays and geomagnetic field at stations of Alaskan region during the extraordinary strong IMF disturbance on October 20, 1989 have been analysed. It is shown that the amplitude of the magnetosonic type fluctuations exceeded significantly the amplitude of the Alfvenic type of fluctuations, and did not show notable correlation with geomagnetic disturbances. At the same time good correlation with the B_z IMF is observed which showed pronounced latitude dependence.

1. Introduction

Interaction of the solar wind with the magnetosphere is determined by different processes in the outer magnetosphere, such as the local and global reconnection, plasma injections into the low - latitude boundary layer, the magnetosphere reaction on the solar wind "pressure pulses", and others. Each of these processes leads to generation of different types of ionospheric disturbances. It should be noted that the solar wind fluctuations may play as important roles in these processes as the mean values of the solar wind parameters do (e.g., Farrugia et al., 1993). We focus on this process in this paper, and especially examine the fluctuations with time scales of 20 min - 3 hr (0.1 - 1 mHz fluctuations) using the October 20, 1989 event.

The turbulent fluctuations in this time scale can be considered as modified MHD waves (Alfvenic, fast and slow magnetosonic) or simply as static structures. During the large disturbances the non-linear processes lead to a strong interaction between Alfvenic and magnetosonic waves. In the present case the amplitude of the IMF fluctuations δB is comparable to the regular field magnitude Bo ($\delta B \leq$ Bo), and the problem about the structure of disturbance calls for a special discussion. An additional analysis of the cosmic ray fluctuations correlated with those of the IMF is done (taking into account the IMP-8 magnetometer data gaps).

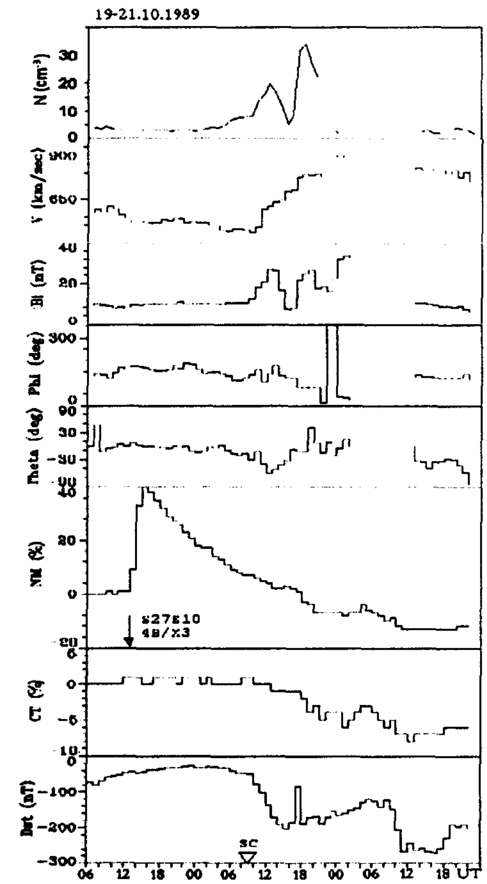

Fig.1. Interplanetary parameters (IMP-8), cosmic ray intensity: neutron monitor (NM) and muon cubical telescope (CT) in Apatity and Dst index variations during the large solar-terrestrial disturbance on October 19-21, 1989. NM and CT are cosmic ray detectors sensitive to the mean energies of primary protons ~3 and ~30 GeV respectively. Percents at the NM and CT scales give an amplitude of cosmic ray variations in respect to a quiet galactic cosmic ray background. Moments of a great solar flare at 12.32 UT, October 19 and SC at 9.15 UT, October 20 are indicated. Note the impulselike positive increase in the Dst-index at the moment of second shock arrival at ~17 UT October 20, 1989.

The characteristic time scale of individual fluctuations is 30 - 50 min, which is of order of time necessary for the energy input to the night sector. The time necessary for the direct energy input at dayside is from a few to 10 - 15 min and is markedly less than the duration of each IMF fluctuation. In other words, response of the dayside geomagnetic activity to the solar wind fluctuations is fast enough to compare the fluctuation pattern between in the solar wind and at the ground. Hence we consider the dayside geomagnetic variations only. The analysis was performed with the following data: 15-sec values of the IMP-8 vector magnetometer data, 10-sec data of the neutron monitor in Apatity, 1-min data of the North American magnetometer chain at the Alaskan meridian.

2. Data analysis and results

Heliospheric disturbance of the 19-21 October, 1989. The large-scale interplanetary disturbance of the October 19-21 was one of the most powerful disturbances in the 22nd solar cycle. The solar wind speed exceeded 900 km/s and the Dst - index in the minimum was 270 nT. Disturbances of such a scale usually enclose the whole heliosphere.

Fig. 1 shows from top to bottom: hourly data of solar wind density and speed, IMF vector components, cosmic ray (CR) intensity on data of the neutron monitor (NM) and cubical muon telescope (CT) in Apatity, Dst-index. NM and CT are ground based instruments measuring the different secondary CR components and sensitive to mean energies of primary cosmic rays of ~3 and ~30 GeV respectively.

The sources of these very complicated events were coronal mass ejections (CME) erupted from the Sun in a series of flares in the active region 5747 (Cane et al., 1995, Bavassano et al., 1995). Namely, as supposed in Cane et al., (1995), the SC at 09.15 UT, October 20 was caused by the interplanetary shock wave, driven by the CME erupted from the Sun on October 18. This first CME caused an increase of solar wind density, speed and IMF |**B**|, whereas only moderate effects in Dst and cosmic ray intensity. But the main disturbance in the event was related with the powerful flare 4B/X13, S27E10, which began at 12.32 UT, October 19 . The flare generated solar cosmic rays (SCR) caused the increase effect of 38% on the NM in Apatity. CT did not register any increase because of its low sensitivity to SCR with a soft energetic spectrum. The CME driven shock arrived at the Earth at ~17.00 UT (~08.00 MLT for the Alaskan magnetometer chain), October 20 as it was observed by the IMP-8 spacecraft (Cane et al., 1995). Though an SC was not reported (may be due to a high level of magnetic activity) the Dst-index showed a short impulselike increase just during the hour (18 UT) of the second shock arrival. Right after the shock the very high amplitude fluctuations of the IMF began (bottom two panels of Fig. 2, where 15-sec data of |**B**| IMF are shown). Note that these IMF fluctuations cannot be discovered from hourly data (Fig. 1). Simultaneously with arrival of these IMF fluctuations the Forbush effect (first step) began as cosmic ray detectors (NM and CT, Fig. 1) showed. The geomagnetic effect of these fluctuations will be discussed below.

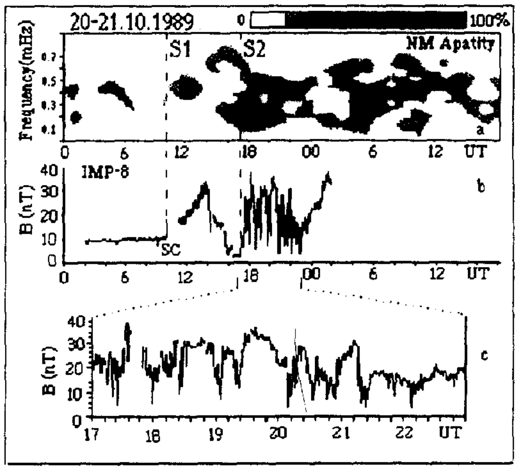

Fig.2. Cosmic ray fluctuation power spectra dynamics on the data of neutron monitor in Apatity (top) and the vector |**B**| IMF magnitude variations (middle) during the period of disturbances on October 20 - 21, 1989. The observed "island" structures means that the CR fluctuation duration varies between 0.6 mHz (30 minutes) and 0.1 mHz (3 hours) in an irregular way. The bottom panel shows anomalous IMF fluctuations (17 - 23 UT) in expanded scale. Dashed lines S1 and S2 denotes the time of arrival of the first and second shocks correspondingly.

The IMF disturbances. Fig.2 shows the fluctuation characteristics of cosmic rays and the IMF. Symbols S1 and S2 with dashed lines denote the time of arrival of two shock waves. The top panel shows the dynamic spectrum of the cosmic ray fluctuations in the 0.1-0.8 mHz range. Note that a harmonic oscillation should produce a straight horizontal band, and the observed "island" structure means that the fluctuation duration varies between 0.6 mHz (30 minutes) and 0.1 mHz (3 hour) in an irregular way. The 10-s sampling rate of primary CR data ensure the spectral resolution of sufficient accuracy in computing the spectrum.

The middle panel shows the behaviour of the IMF |**B**| on the 15-sec data a measured at the spacecraft IMP-8. The large IMF fluctuations were accompanied by intense fluctuations of cosmic rays (a correlation coefficient of the IMF |B| variations and CR fluctuations is ~0.6) during the period of 17-23 UT, October 20. The peak of cosmic ray intensity in the morning hours of October 21 cannot be compared with the IMF due to gap in data. The bottom panel shows in expanded scale the intense IMF |**B**| fluctuations in the period 17-23 UT, October 20. The fluctuations are the quasioscillations with the period of 30-50 min and the amplitude of ~10 nT overlapped on the background of relatively quiet field of ~20 nT.

Structure of the IMF fluctuations. Assuming the solar wind speed 900 km/sec the large IMF fluctuations in the period 17-23 UT, October 20 correspond to the dimension of inhomogenuities in the Sun-Earth direction $L_x \sim 10^6$ km. This corresponds to the gyroradius of CR particles with the energy of $\sim 10^9$ eV ($\rho \sim Lx$) responsible for cosmic ray variations registered by the neutron monitor. The correlation between the IMF and cosmic rays denotes that the spatial scale of disturbances in other directions (Y and Z) is no less than L_x. The limited period of observations does not allow us to carry out the detailed statistical analysis of the fluctuations. So we restrict ourselves by a qualitative consideration. If the fluctuations are small ($\delta B << Bo$) the turbulent pulsations are controlled by a regular field Bo by processes of generation and propagation of disturbances. In this case the difference between the longitudinal $\delta B_{\parallel}$ and lateral $\delta B_{\perp}$ fluctuations may arise. Perhaps it is not so in the case $\delta B \sim Bo$. The disturbance under discussion is hence the "large" one.

Geomagnetic Disturbances. To investigate the direct energy input in the magnetosphere the relationship between the extraordinary large IMF fluctuations in the period of 17-23 UT, October 20 and dayside geomagnetic field variations has been considered. Data of the Alaskan meridional magnetometer chain were used. Statistical analysis has been performed between different components of the IMF and ground based magnetic variations at different stations. The results of this analysis for different stations as function of latitude are shown in Fig. 3. As the Figure shows the peak correlation is found at lower latitude than the ordinary disturbance.

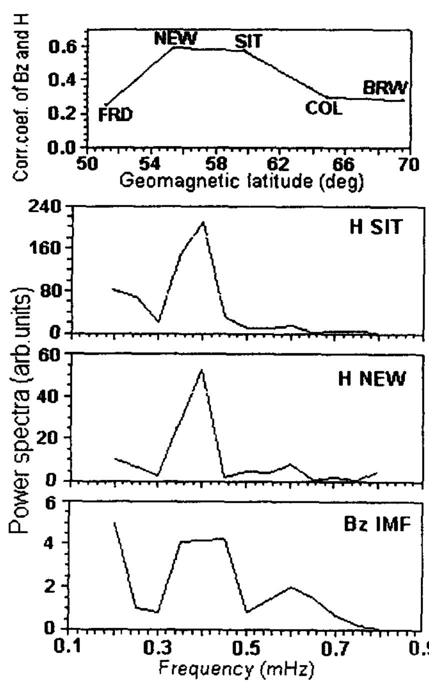

Fig. 3. Top panel: The latitudinal section of correlation coefficient between the IMF Bz and the geomagnetic field H-component calculated for the disturbed period 17-23 UT, October 20 (08-14 MLT for the meridional chain of stations: Frederiksburg, Newport, Sitka, College, and Barrow).

Bottom three panels: Fluctuation power spectra of the IMF Bz, and the geomagnetic H - component at stations Newport and Sitka for the disturbed period 17-23 UT, October 20.

An important parameter of physical processes responsible for the direct driven disturbances is a delay period of ionospheric disturbances in respect to these in the solar wind. Cross - correlation analyses on the filtered data (0.3-0.5 mHz, i.e., 30 - 50 minutes resolution) between the IMF B_z an the H component of the geomagnetic field (Sitka and Newport) indicates that the response time is shorter than 30 minutes. This agrees with the past works for the dayside geomagnetic disturbances.

3. Summary and discussion

The performed analysis of the direct observations of the IMF and ground based variations of cosmic rays and the geomagnetic field allowed to consider both the large and small scale structures of the large heliospheric disturbance of the October 29-21, 1989 and its relationship with geomagnetic variations. Study of correlated fluctuations of the IMF and CR in the frequency range of $10^{-4} < f < 10^{-3}$ mHz gives additional information about the solar wind turbulence. This information is necessary to reconstruct a possible 3-dimentional character of the IMF inhomogenuities. The direct observations of the IMF gives information about only 1-dimensional structure of disturbances in the Sun - Earth direction. If perturbations of interplanetary plasma are small they can be expressed as a superposition of known types of MHD - waves and static structures. For the considered event the non-linear processes limit applicability of the linear approximation (Parker, 1979).

In the considered event the most correlations between the IMF B_z component geomagnetic variations have been observed in the latitude range $\lambda = 55\text{-}65^{\circ}$ at dayside. At other latitudes the disturbances are weakly controlled by the IMF B_z component and perhaps are related with fluctuations of other parameters of the solar wind and (or) by sporadic disturbances of the outer magnetosphere.

References

1.Farrugia, C.I., L.F.Burlaga, V.A.Osherovich, L.G.Richardson, M.P.Freeman, R.P.Lepping, and A.J.Lazarus, A study of an expanding interplanetary magnetic cloud and its interaction with the Earth magnetosphere: the interplanetary aspect, *J. Geophys. Res.*, 98, 7621, 1993.

2.Cane, H.V., I.G.Richardson, Cosmic ray decreases and solar wind disturbances during late October 1989, *J. Geophys. Res.*, 100, 1755, 1995.

3.Bavassano,B., N.Iucci, R.P.Lepping, C. Signorini, E.J.Smith, G.Villoresi, Galactic cosmic ray modulation and interplanetary medium perturbations due to a long-living active region during October 1989, *J. Geophys. Res.* 90, 4277, 1994.

4.Parker E.N. *Cosmical magnetic fields,* Calendon Press, Oxford, 1979.