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The Earth's passage of coronal mass ejecta on october 29-31, 2003: ULF geomagnetic field fluctuations at very high latitude

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Abstract. We study ULF geomagnetic field fluctuations detected on October 29-31, 2003, when the Earth's arrival of solar wind CMEs produced major geomagnetic storms; these solar wind structures are characterized by extremely high plasma speed and long-duration intervals with northward interplanetary magnetic field. The analyzed geomagnetic field data are from four high latitude stations (three in Antarctica), located deep in the polar cap. The analysis is extended also to low latitude European stations, in order to discriminate between local and global magnetospheric phenomena.

Key words. Magnetosphere: MHD waves – Magnetosphere: polar cap

1. Introduction

Several studies analyzed the interaction between coronal ejecta, characterized by long periods of out-of-ecliptic interplanetary magnetic field (IMF) orientation, and the Earth's magnetosphere. While southward IMF conditions are associated with major geomagnetic storms (Lepping et al. 1991; Gopalswamy et al. 2005), during northward IMF conditions solar wind (SW) density enhancements can compress the magnetosphere and trigger geomagnetic field fluctuations (Lepidi et al. 1999; Francia et al. 1999).

This study focuses on geomagnetic field fluctuations ($\sim 1-5$ mHz) observed on Oct. $29-31$, 2003, when complex interplanetary structures, with anomalous IMF and SW conditions, hit the Earth. We analyze the geomagnetic field variations at the Antarctic stations Mario Zucchelli Station (MZS, formerly Terra Nova Bay), Scott Base (SBA) and Dumont D'Urville (DRV), at the same geomagnetic latitude but different magnetic local time, and at the Canadian station Cambridge Bay (CBB), at the same magnetic local time and almost opposite corrected geomagnetic latitude as MZS (Table 1). These stations are located in the polar cap, at the footprint of open geomagnetic field lines; around noon they approach the cusp. In order to ascertain the global character of the pulsations simultaneously observed at the high latitude stations, the analysis is extended to a latitudinal chain of European low latitude stations, located at the footprint of closed geomagnetic field lines. The analysis is based on 1-min values of the geomagnetic field horizontal component H. Stations MZS, GIB, AQU and CTS

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Table 1. IGRF2003 corrected geomagnetic latitude and time in UT of the magnetic local noon for the stations.

Station	CGM lat	MLT NN
MZS	80.0 S	20 : 11
SBA	80.0 S	19 : 01
DRV	80.4 S	00 : 55
CBB	77.2 N	19 : 54
FUR	43.4 N	10 : 28
CST	40.8 N	10 : 28
AQU	36.3 N	10 : 24
GIB	30.6 N	10 : 24

are run by INGV; data from SBA, DRV, CBB and FUR are from INTERMAGNET CDroms. Interplanetary data are from ACE spacecraft; standard SW measurements (SWI mode ion data, collected every 64 sec) were recorded only from Oct. 31, 0051 UT; for preceding period, only STI mode ion data, collected every ~ 30 min, were available.

2. Experimental observations and discussion

In Fig. 1 we show interplanetary and geomagnetic field data on Oct. 29-31, 2003. There are several periods with strongly southward IMF (~ 06 − 09 UT and 14-03 UT on Oct. 29-30 and 17-01 UT on Oct. 30-31) which correspond to strong geomagnetic storms, with Dst index reaching ~ −180 nT, −360 nT and −400 nT, respectively. There are also periods with strongly northward IMF: ~ 03 − 10 UT on Oct. 30 and 01-11 UT on Oct. 31. Plasma data show exceptionally high SW speed, mostly exceeding 1000 km/s, and several variations of the density, especially during Oct. 31. The geomagnetic activity is intense, especially during storm main phases. There is a strict similarity in the geomagnetic variations at low latitude and also between Antarctic stations, expecially between MZS and the closest station SBA. Fig. 2 shows, in the upper panels, the dynamic power spectra, computed from differenced data (in order to make more evident higher frequency variations). The dynamic spectra show

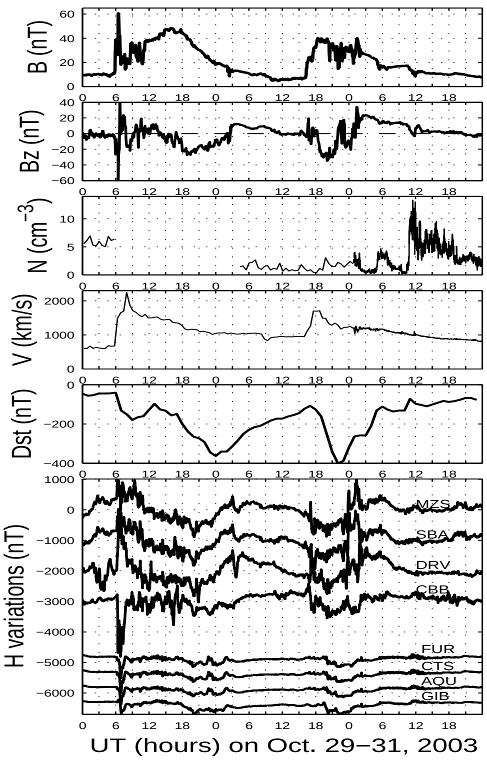

Fig. 1. From top: IMF strength and north-south component; SW density and speed; Dst index; geomagnetic field H component variations at the eight stations.

a strong similarity between the high latitude stations in the time sequence of the broadband major power enhancements corresponding to the onset of geomagnetic storms (i.e. from ~ 06 UT on Oct. 29 and from ~ 17 UT on Oct. 30). We also performed a coherence analysis (not shown here) and found that these fluctuations are not coherent, even between the two closest stations MZS and SBA. At low latitude, only the onset of the first storm, occurring during daytime hours, emerges.

The power spectra show also fluctuations which are observed only at some of the stations, and then can be considered as local phenomena. For example, we note the power peaks at discrete frequencies at 20-21 UT on Oct. 29, only at Antarctic stations, and the broader power enhancement around 18 UT on Oct. 31, only in the northern hemisphere station CBB.

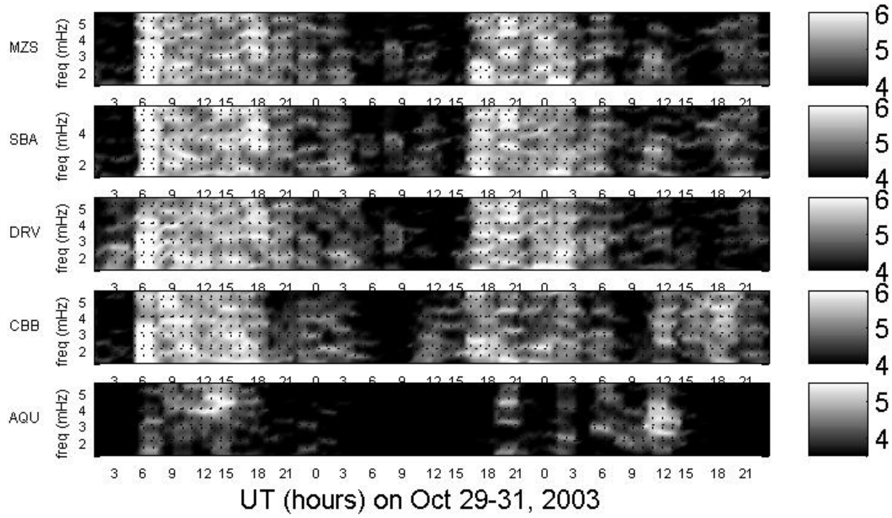

Fig. 2. Dynamic power spectra (log scale) at the four high-latitude stations and at AQU, taken as reference for the low latitude stations (note the different color scale at AQU).

More interestingly, there are also fluctuations which are simultaneously observed over a wide spatial separation, with high coherence between stations, and then are not just local phenomena. In this sense, we selected for a more detailed analysis, including also low latitude observations, four fluctuation events. Two of them, around 23UT on Oct. 29 and 20 UT on Oct 30, occur during southward IMF conditions, in the main phase of strong geomagnetic storms, in correspondence to Dst ~ -350 nT and Dst~ -300 nT, respectively. The other two, around 06 UT and 11 UT on Oct. 31, occur during northward IMF conditions, at the end of the recovery phase of a strong geomagnetic storm, and can be related to SW pressure pulses observed from ACE.

We show only the analysis of the event around 20 UT on Oct. 30 (Fig. 3), occurring in the main phase of a strong storm, when MZS, SBA and CBB are around magnetic local noon, DRV in the morning and the European stations in the evening sector; this event could be related to the small SW pressure pulse observed by ACE at $\sim$ 1930 UT. From the filtered data it can be seen at all stations a signal intensification just before 20 UT, a phase jump around 2020 UT, a strong damping around 2045 UT and a smaller signal intensification just before 21 UT; the peak-to-peak amplitude of these pulsations exceeds 100 nT at the antarctic stations and reaches 30-40 nT at the low latitude stations. The spectral and coherence analysis show that two major power peaks emerge at all stations, around 3.2 and 4.2 mHz. The corresponding fluctuations are highly coherent between high latitude stations and also between high and low latitude.
Also in the other event occurring during a geomagnetic storm (not shown here), observations are quite coherent between all stations. Conversely, in the other two events pulsations at CBB are decoupled from those in Antarctica.

3. Conclusions

We found that during the Earth's passage of the CMEs, characterized by extreme values of the SW speed and by several rotations of the IMF, geomagnetic field fluctuations with different characteristics are observed:

- broadband fluctuations at the onset of strong geomagnetic storms, observed at all stations but not spatially coherent;

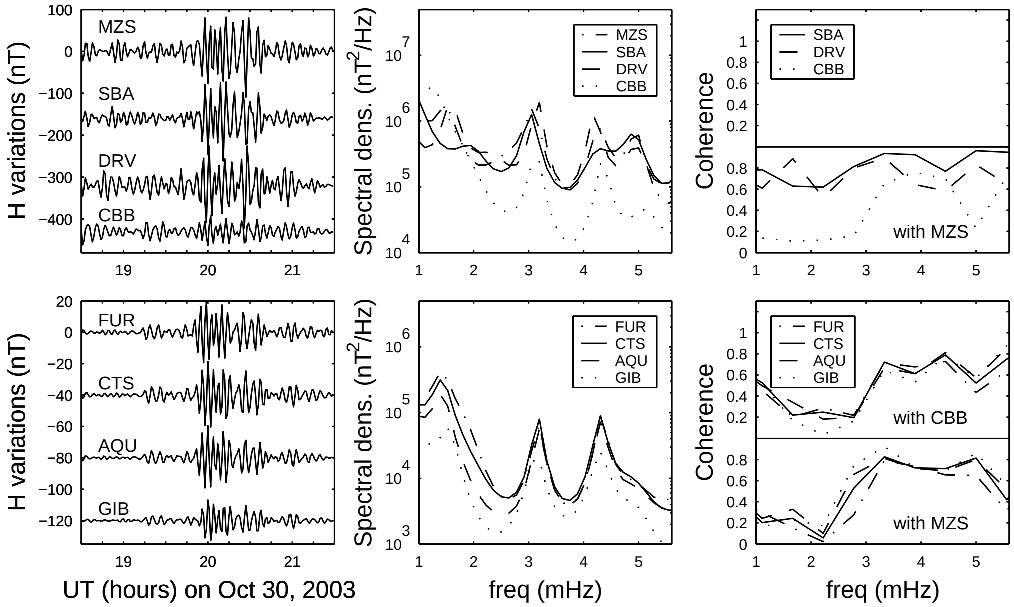

Fig. 3. Analysis of the pulsation event around 20 UT on Oct. 30. From left: filtered (2.5-5 mHz) data, power spectra and coherence (1930-2130 UT). The coherence is between CBB and the other high latitude stations (upper panel); between MZS and the low latitude stations (lower panel, upper curves); between MZS the low latitude stations (lower panel, lower curves).

- fluctuations observed only at some stations, corresponding to local phenomena;
- fluctuations simultaneously observed at all stations which are spatially coherent, even between high and low latitude.

Focusing on the spatially coherent fluctuations, we selected four wave packets: two occurring during southward IMF conditions, in the main phase of strong storms, and two, triggered by SW pressure pulses, during northward IMF conditions, in the recovery phase of storms.

We found that the events occurring during closed geomagnetic conditions do not show common peaks at all the high latitude stations and tend to be coherent only among Antarctic stations, while there is a lack of coherence between high latitude opposite hemispheres. Conversely, during open geomagnetic conditions the pulsation events are characterized by discrete frequencies, the same at all stations, and are generally highly coherent between high and low latitudes and between opposite hemispheres. Such pulsations could be interpreted in terms of global oscillation modes of the whole magnetosphere (Walker et al. 1992; Villante et al. 1997); this result is interesting in that previous studies have shown that, during the Earth's passage of CMEs, global magnetospheric oscillation modes tend to occur during closed magnetospheric conditions (Lepidi et al. 1999).

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