Extended period of low density solar wind - ground geomagnetic signatures

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Abstract. Earth encountered a very long duration extremely low density event during February 2004. The magnetopause was pushed away from the earth and magnetospheric current systems were modified. Geomagnetic data from ground stations and geostationary satellite are examined. It is seen that the diurnal variation at all the locations is attenuated during this event. The substorm activity is subdued and restricted to very high latitudes. ULF pulsations could not be traced out in the ground magnetic data.

Index Terms. Magnetopause, magnetospheric current, solar wind, substorm.

1. Introduction

Solar wind provides energy to drive various electrodynamic processes within the Earth's magnetosphere. The average solar wind has a speed of 350 km/s, density 8 cm^{-3} and embedded magnetic field of 5 nT. This solar wind stream is continuous and the associated plasma and magnetic field with it vary significantly over time. Density reduction well below 1 cm^{-3} is rare but has been recorded before. During steady state flow of solar wind, particle densities and velocities are known to be inversely correlated. However, on 11 and 12 May 1999 an unusually low density (<0.1 cm^{-3}) and low-velocity (<350 km s^{-1}) was reported by space crafts which lasted for more than one day. The solar corona was unusually quiet around that period and no large CMEs were seen during the entire week preceding the event. Thus this event was not associated with an interplanetary CME. Janardhan et al. (2005) suggested that low density cloud might have originated from a tiny mid-latitude coronal hole. The small area of source and large flux expansion might be responsible for low velocity observed (Neugebaur et al., 1994), the low density can be explained by the outward expansion of the detached low-velocity cloud during its propagation. The decrease in solar wind plasma density leads to decrease in solar wind ram pressure, with subsequent expansion of dayside magnetosphere. The low dynamic pressure led to a huge distension of the Earth's magnetosphere. Extensive studies on this event have been reported using both space–based and ground-based observations. Magnetospheric current system (Le et al., 2000b), magnetic pulsations in space and ground (Le et al., 2000a), geomagnetic disturbances at high latitudes (Papitashvili et al., 2000; Rostoker, 2000; Rajaram et al., 2001) during the event are well documented. Extreme UV telescope onboard SOHO observed Earth inside a solar wind stream flowing from the coronal hole during February 12-17, 2004. As expected, ACE spacecraft registered high solar wind velocity with low density. The density was extremely low (<1 cm^{-3}) during the period 15d09h to 18d02h. This was probably the longest low density event (~65 hours). The geomagnetic signatures of this event are reported here.

2. Data

Solar wind velocity, density and magnetic field measured by ACE during the month of February 2004 are used to infer the interplanetary conditions. GOES10 (134^o W) provided magnetic field at geosynchronized altitudes. Geomagnetic measurements at Maitri (67.23^o S, 58.07^o E; geomagnetic), Mawson (73.41^o S, 109.75^o E) and Tromso (67.21^o N, 116.25^o E) are used to understand the geomagnetic effects of this event at high latitudes while observations at network of geomagnetic observatories in India reflected the signatures in low latitude Sq current system.

3. Results

The first three bottom parts in Fig. 1 show ACE insitu measurements of solar wind density, velocity and temperature during the month of February 2004 respectively. The magnitudes of interplanetary magnetic field and Bz component in GSM coordinates are shown in the upper two parts of the Fig. 1. The hatched portion represents the period when the solar wind density was extremely low. It is clearly evident that the solar wind velocity and density abruptly increased on 12 February with the arrival of velocity stream from coronal hole. It can be seen that the densities first started dropping on 13 February when the velocities are significantly high. On 15 February the densities dropped below 1 cm^{-3} and remained steady till 18 February at very low values. The velocities started decreasing exponentially when the densities became extremely low. On 18 February the densities started increasing and attended normal values subsequently. The duration of this extremely low density event coincides with trailing end of solar wind stream from the coronal hole. The solar wind temperature show slight increase during this interval. Bz component of the IMF was low and oscillating around zero. The magnitude of IMF magnetic field was around 5 nT during the event.

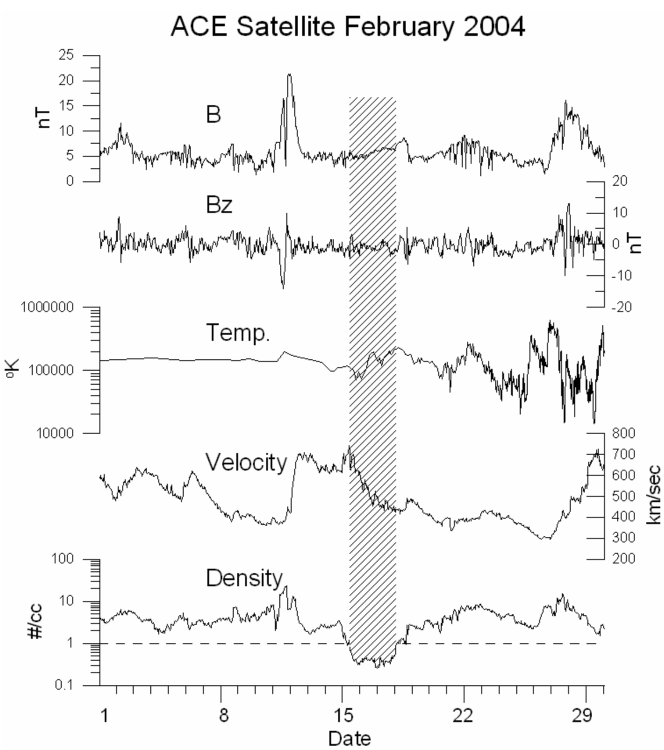

Fig. 1. Starting from the bottom and plotted as a function of date in February 2004 are ACE in situ measurements at 1 AU of proton density, velocity, temperature, Bz component and total IMF magnetic field, respectively. The hatched portion shows the period when the density was extremely low.

The configuration of magnetosphere is governed by a pressure balance equation that relates the kinetic pressure of the solar wind to the magnetic energy density of the magnetic field inside the magnetopause. The dynamic pressure depends heavily on the density which may vary by two to three orders. The relative shape of the magnetopause remains same for all values of solar wind dynamic pressure but the size changes. The magnetopause determines the scale and size of various current systems in the magnetosphere which in turn have integrated effect on the geomagnetic field. Using Olson and Pfizer (1982) dynamic model of the magnetospheric magnetic and electric fields, the standoff distances are determined which are further used to estimate the relative strength of magnetopause current. Traditionally, Dst measure at mid latitudes is considered the best index for representing variations in the strength of the ring current. However, the estimated Dst indices have contributions from the magnetopause currents. The ring current strength is calculated after removing the magnetopause contributions, Tail current can be estimated by using epsilon index ε. The estimated magnetopause, tail and ring current strengths along with standoff distances and observed solar wind density are shown in Fig. 2.

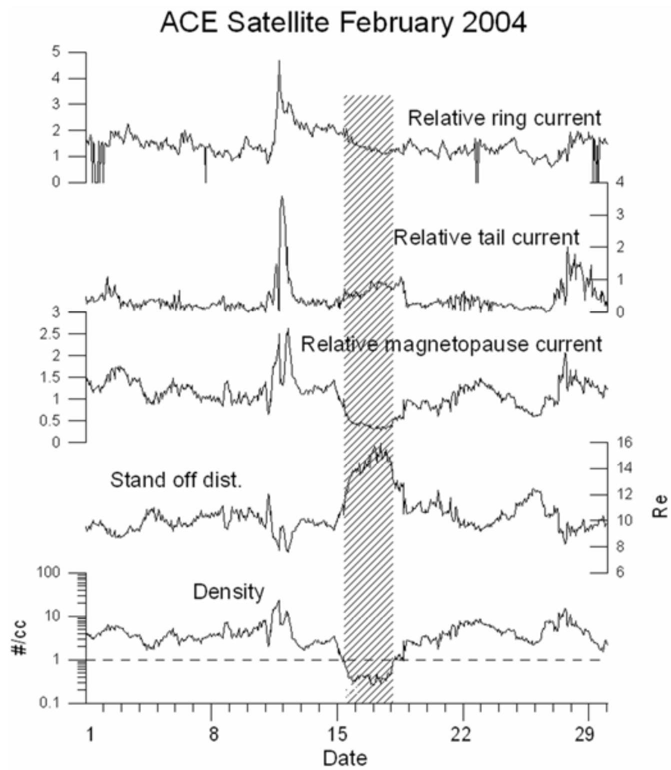

Fig. 2. Magnetopause standoff distances, relative magnetopause, tail and ring current strengths during the month of February 2004. Solar wind densities, as measured by ACE, are also shown in the bottom panel

During the first half of February 2004, the magnetopause is around 10 Re (quiet conditions) except for a brief period on 12 February when the high speed solar wind from the coronal hole encountered the magnetosphere. On 15 February the magnetosphere suddenly started expanding when the low density solar wind cloud arrived. Though the densities start increasing on 18 Feb, the magnetopause remains at greater distance till the following day in response to the decreasing solar wind velocities. Relative magnetopause current, tail current and ring current strengths are significantly high on 12 February resulting in a moderate magnetic storm. During the low density event, the magnetopause current decreased significantly but the tail current remained nearly steady. A slight decrease in ring current was noticed when the solar wind density was gradually decreasing.

As mentioned earlier, during this interval the magnitude of the IMF lay in the range ~ 4 – 6 nT with the north-south Bz component fluctuating but rarely with magnitude of more than 3 nT on either side of zero. One associates such conditions with contracted oval and very little activity either in auroral luminosity or in the geomagnetic field. We now examine the effects of this event on geomagnetic field at high latitude stations Tromso (67.21°N, 116.25°E; geomagnetic), Mawson (73.4°S, 109.75°E) and Maitri

(76.23°S, 58.07°E) along with parallel component (Hp) at Goes-10 (134°W).

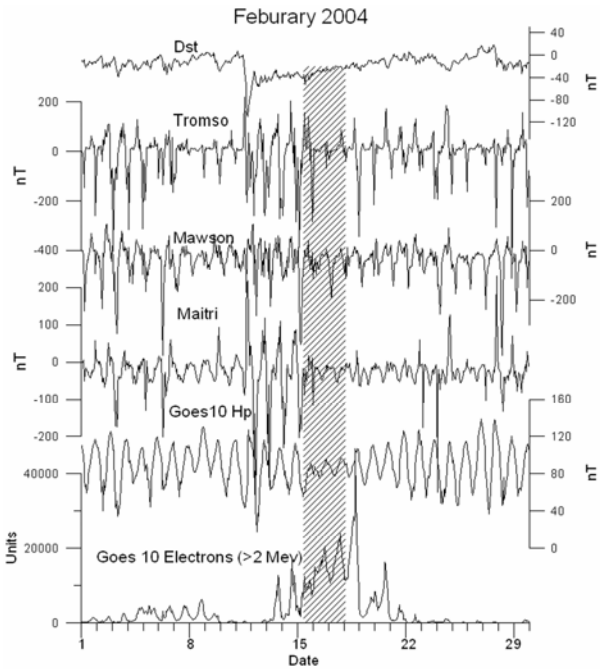

Fig. 3. Average hourly values of horizontal component of geomagnetic field at Tromso, Mawson and Maitri during February 2004. Parallel component (Hp) and electron flux (> 2 Mev) measured at geostationary altitude and low latitude Dst index are also shown.

Fig.3 shows the average hourly values of horizontal component of geomagnetic field during February 2004 at Tromso, Mawson, Maitri along with magnetic field component parallel to Earth's rotation axis (Hp) and electron flux (>2Mev). The diurnal variation in magnetic field and electron flux is clearly evident in the Figure. The diurnal variation in magnetic field is highly attenuated on 16, 17 and 18 February at all the stations and at geostationary orbit. Dst index is negative and increased slightly during the event period. Interestingly the electron flux starts increasing on 13 February and remains at elevated level during the low solar density period. It attains maximum value after the event and then suddenly reduces. Attenuation in diurnal variation in other components of magnetic field at ground and geostationary orbit is also remarkable.

Diurnal variation of horizontal component of geomagnetic field at low and equatorial latitudes represents the structure and intensity of global Sq and electrojet current systems respectively. Daily ranges of magnetic field at various low latitudes are computed from the minute interval recorded data at network of observatories in the Indian latitudes. Daily ranges for 15, 16, 17, 18 and 20 February 2004 at these stations are shown in Fig. 4. Though the low density event started on 15 February the ranges are very high as the strengths of global Sq current electrojet current are local time dependent. The onset of this event is 1430 LT (9 UT). The ranges are attenuated on 18 February too as the density started increasing after the local sunrise. The ranges returned to the normal on 20 February. Both 17 and 20 February are internationally quiet (IQ) days, the small ranges on 17 February suggest that the low solar wind density has effect on global current systems. It appears that the attenuation is more in the global Sq current system when compared to the electrojet current. In low latitude region under quiet conditions predominantly diurnal variations in declination are reported. However on 16-17 February during this event the semi diurnal variations are more prominent (not shown here) indicating that field aligned currents are modified considerably.

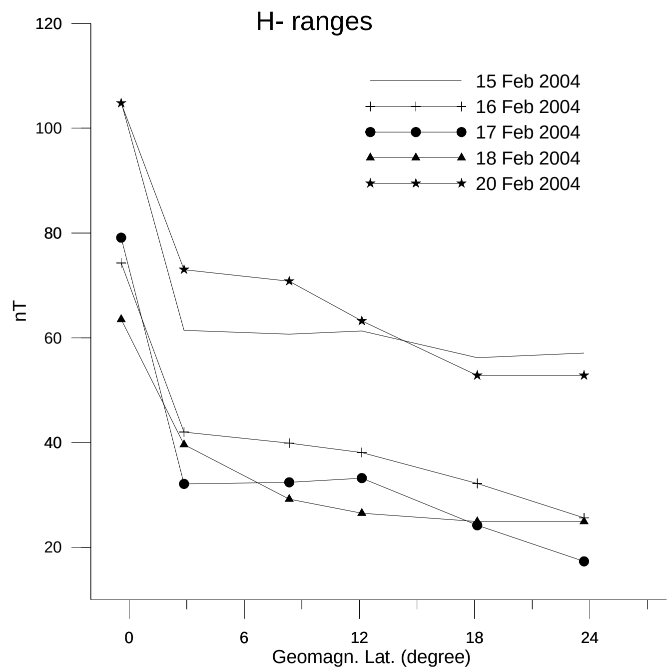

Fig. 4. Diurnal ranges of horizontal magnetic field against the geomagnetic latitudes during some selected days of February 2004.

In Fig. 5 we examine 1 min. sampled variation data of horizontal component at Maitri, Tromso and Mawson during the period 15 – 20 February 2004 to understand the effect of the low solar wind density on substorm and ULF pulsations. As substorm activity is mainly controlled by the Bz component of interplanetary magnetic field, 64 sec. averaged Bz component as measured by ACE is also shown in the top panel of Fig. 5. On 15 February when the extreme low density event started, Bz component is pointing northward. After sometime the magnetic field turned southward and remained oscillating between zero and -5 nT. In response of this southward magnetic field substorm triggered at high latitudes and is seen up to Maitri. On 16 February, the magnetic field is oscillating between +/-2 nT and no substorm activity is recorded at Maitri although a weak substorm can be seen at Mawson and Tromso around 14 UT. On 17 February the magnetic field was mainly southward with a magnitude of about 3 nT. Magnetic disturbances of moderate intensity can be seen at Mawson and Tromso but very weak disturbances are registered at Maitri. After the density event, on 18 February Bz again started oscillating between +/-5 nT. Intense magnetic disturbances are recorded at all the three stations. The intensity of the disturbance is more at Tromso compared to the other two stations. On 19 and 20 February the disturbances are very weak at Maitri while at other two stations moderate effects are evident. It appears that the low density is having no significant effect on the onset of substorm but it affects the intensity and duration of the same. 1Hz magnetic data at Maitri reveals no ULF pulsation in the frequency range of 10-100 mHz.

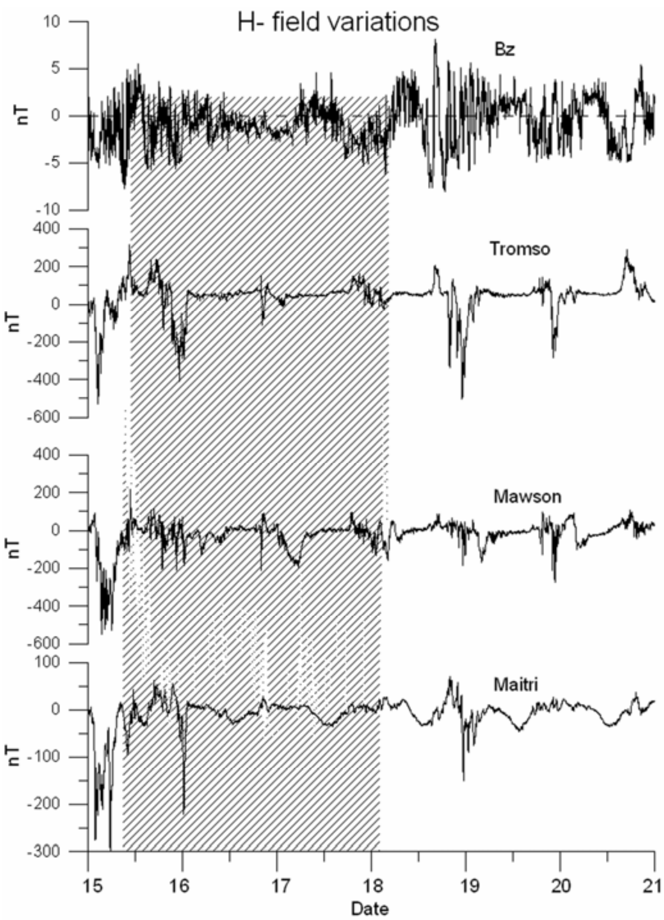

Fig. 5. 1 min. H component data recorded at ground stations Maitri, Mawson and Tromso during the period 15-20 February 2004. 64 sec. sampled data of interplanetary magnetic field Bz component are shown in the top panel.

4. Discussion and conclusion

A low density solar wind stream, having its origin in medium sized coronal hole, encountered Earth's magnetosphere during 15-18 February 2004. The solar wind velocity was decreasing monotonously during this period. The magnetosphere was expanded and the magnetopause was pushed away to a distance of about 14 Re modifying the magnetospheric current systems. The diurnal variation of magnetic field at all the latitudes was attenuated. GOES satellite registered high energy electron flux during this time. Substorm activity is subdued and restricted in very high latitude region only. Such prolonged low density events are rare. The longest event reported in the literature is of May 1999 when the solar wind density and velocity were low for ~ 24 hours when the magnetopause reached to a distance of ~ 17 Re. The behaviour of substorm activity during this event was of great interest because the energy input from the solar wind was significantly low. However some substorm activity was seen both at Mawson and Tromso. Rostoker (2000) also reported substorm during May event. During May event ULF pulsations were recorded both at ground (Papitashvili et al., 2000) and in space (Le et al., 2000a). However pulsations were not seen during this reported event. The global Sq current system was significantly modified during this event.

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