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Space Weather Effects of Coronal Mass Ejection

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Abstract. This paper describes the space weather effects of a major CME which was accompanied by extremely violent events on the Sun. The signatures of the event in the interplanetary medium (IPM) sensed by Ooty Radio Telescope, the solar observations by LASCO coronagraph onboard SOHO, GOES X-ray measurements, satellite measurements of the interplanetary parameters, GPS based ionospheric measurements, the geomagnetic storm parameter Dst and ground based ionosonde data are used in the study to understand the space weather effects in the different regions of the solar-terrestrial environment. The effects of this event are compared and possible explanations attempted.

Key words. Coronal mass ejection—interplanetary medium—global positioning system—total electron content—interplanetary magnetic field.

1. Introduction

The effect of coronal mass ejections and associated geomagnetic storms on space systems is called space weather. A coronal mass ejection (CME) is a large outburst of coronal magnetic field and typically 10^9 to 10^{10} tons of plasma into interplanetary space at speeds varying from 250 to 1000 km s^{-1} (Gosling 1997). The scale and frequency of these events (several times a day to a few per week) (St. Cyr *et al.* 2000) make CMEs one of the most important contributors to space weather (McAllister *et al.* 1996; Richardson *et al.* 2000). CMEs often drive interplanetary shocks, which upon arrival on the Earth, cause geomagnetic storm. The geomagnetic storms that signal the arrival of CMEs in the near earth space pose hazards to space operations, major effects being release of trapped particles from the magnetosphere to auroral zones causing increased spacecraft charging, interference with satellite communication and surveillance systems, atmospheric heating by charged particles resulting in increased satellite drag, deterioration of magnetic torque attitude control system of satellites, etc.

During solar maximum phase, the number of such CMEs increases and many are capable of accelerating particles up to MeV energies (see special issue of *GRL*, **25(14)**, 1998 for a detailed review). A well observed and thoroughly investigated

CME occurred on July 14, 2000 on the Bastille day and hence called Bastille event (see special issue of *Solar Physics*, **204**, 2001 for detailed analysis of various aspects of this event). The propagation of the associated IP shock in this event down to the location of Voyager-2 at 63 AU has been identified (Burlaga *et al.* 2001). Alongwith the vigorous development of space activities, increasing interest is directed towards space weather in order to mitigate or to avoid damage by space weather calamities to technological systems caused by intense solar events. Recently Jadav *et al.* (2005) have presented the space weather aspects of a large halo CME on April 4, 2000 which appeared to be associated with 2F/C9.7 flare in AR8393. In this paper, the CME which occurred on November 4, 2001 during the violently active phase of the Sun is discussed and its space weather effects studied.

2. Observations and results

Observations of interplanetary medium using the IPS g-maps obtained from the Ooty Radio Telescope, data from SOHO/LASCO coronagraph and EIT at 171 A; magnetic field and plasma data from the ACE/WIND satellites; Dst indices derived from ground-based magnetometer data and ionospheric observations using the GPS receivers are used to understand the complex solar-terrestrial relation during the event of November 4, 2001.

3. CME observations

LASCO and EIT onboard SOHO observed a full halo CME on November 4, 2001. The event was first observed in C2 at 1625 UT as a bright loop over the west limb; by 1650 UT the front had developed into a full halo CME (Fig. 1a and b). The CME was associated with strong X-ray flare observed by EIT at 1620 UT. This flare occurred at S17W20 quadrant in Active Region 9684 between 1603 and 1657 UT with peak emission at 1620 UT. Figure 2 shows the GOES record of X-ray flux emission which peaked at 1620 UT. A large prominence was seen erupting prior to the flare and this prominence material can be seen clearly in the LASCO images. The height-time plot from C2 and C3 observations of the position of the CME material is shown in Fig. 3. The velocity derived from height-time plot is 1868 km s^{-1}.

4. Interplanetary observations

The Ooty Radio Telescope (ORT) observes several radio sources every day and generates the g-maps which represent the excess plasma turbulence in a given direction along the line of sight to the source over the mean value. When CME material crosses the light of sight it will show up as a larger value of g in excess of unity. The ORT observations during this event are given in Fig. 4. ORT observations show significant enhancement in g-value related to the November 4, 2001 event. Radio source 1802 + 110 showed high g-value of 2.363 on November 5, 2001 whereas for sources 1756 + 134 g-values increased substantially to 5.118.

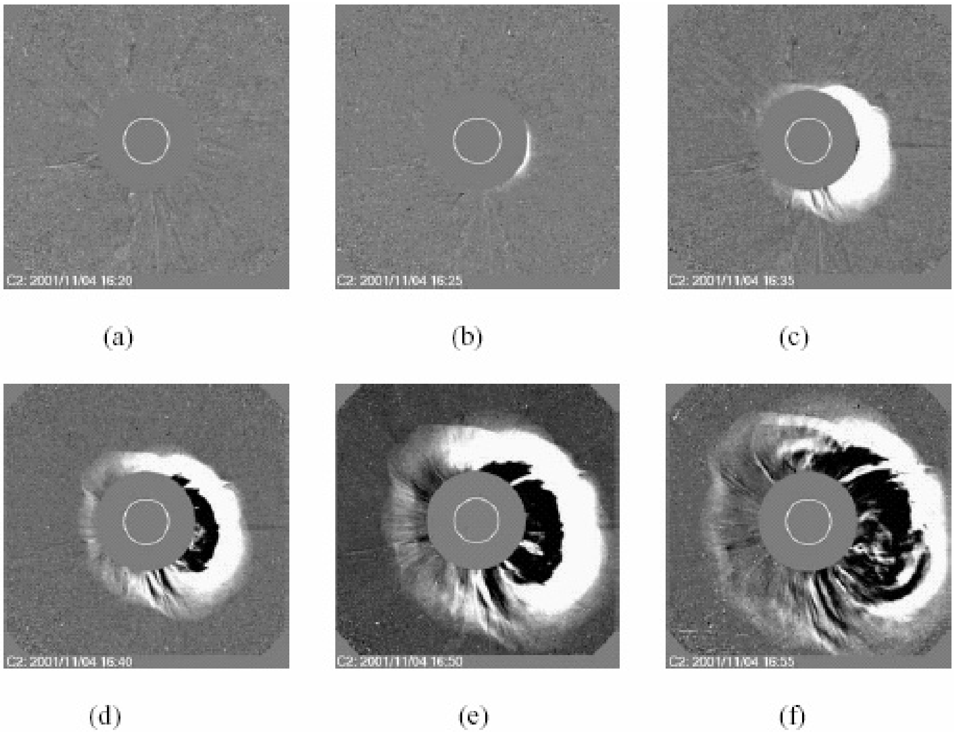

Figure 1(a–f). Image sequence of CME observed by LASCO onboard SOHO on November 4, 2001 (timings: **(a)** 1620 UT, **(b)** 1625 UT, **(c)** 1635 UT, **(d)** 1640 UT, **(e)** 1650 UT, and **(f)** 1655 UT).

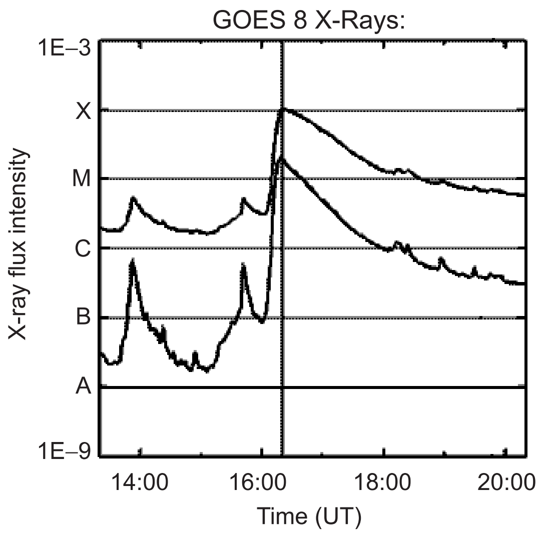

Figure 2. GOES X-ray flux data of November 4, 2001 showing an X-class flare at 1610 UT.

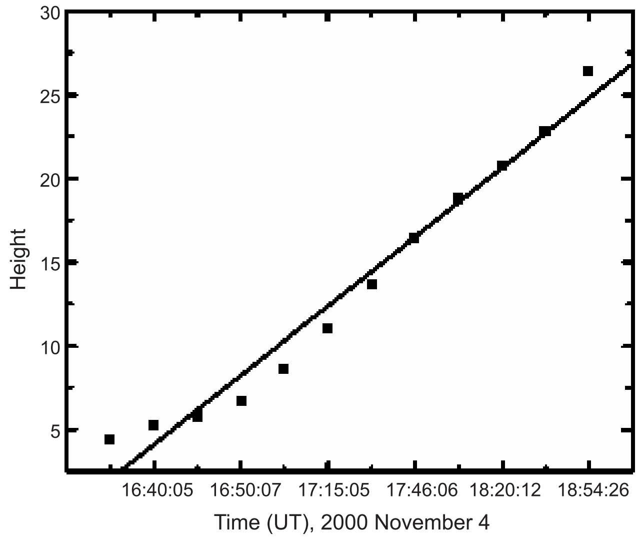

Figure 3. Height *vs.* time plot on November 4, 2001.

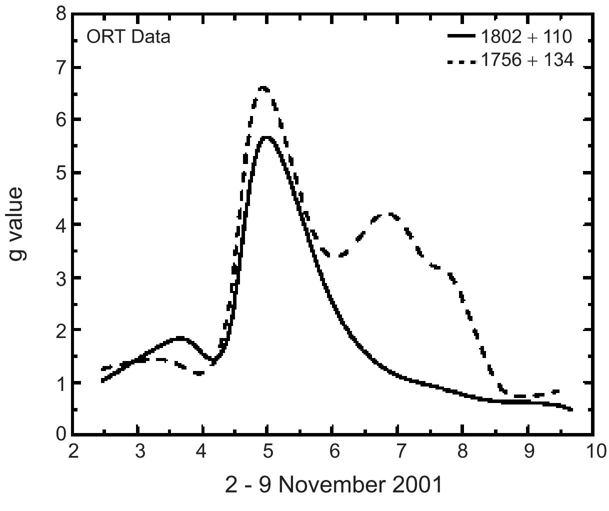

Figure 4. g-value increase observed by Ooty Radio Telescope (ORT) during November 2–9, 2001.

Measurements of interplanetary plasma and magnetic field parameters using ACE satellite during November 4–10, 2001 are shown in Fig. 5. The speed increased to $\sim$700 km s^{-1} on November 6, 2001 at 0200 UT and temperature increased slightly beyond 1.35×10^5 K. Sustained high values of density and speed were coupled with the negative Bz component of interplanetary magnetic field (IMF) which remained negative from 0600 UT on November 6, 2001 for about 5 hours. Such prolonged negative excursions of Bz are conducive for field line reconnection and the coupling of energy from solar wind to the magnetosphere which are described in the next section.

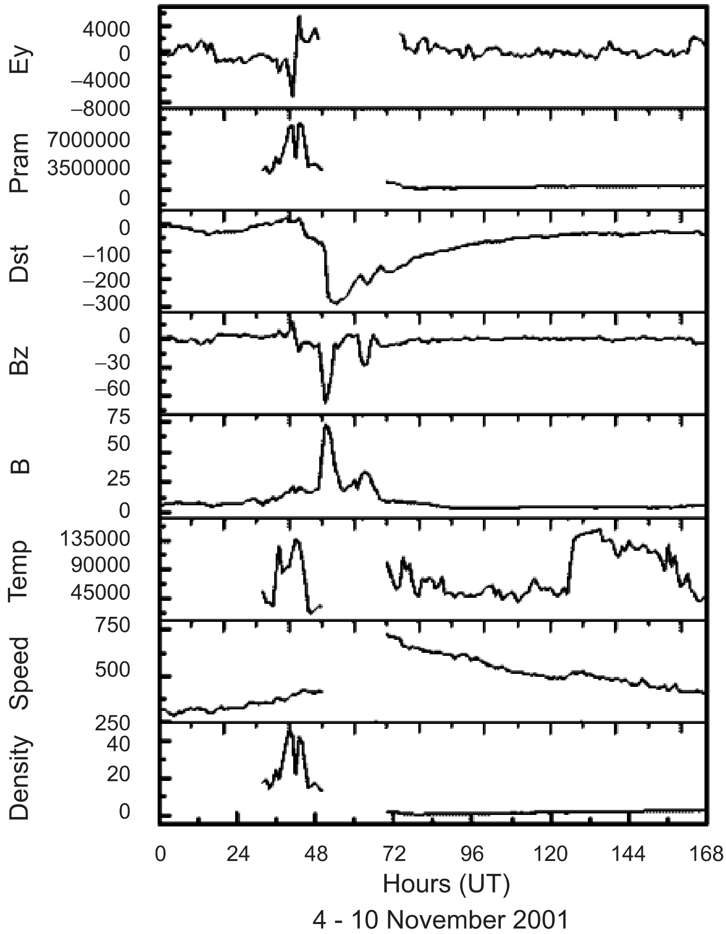

Figure 5. Interplanetary parameters at 1 AU observed by ACE satellite during November 4–10, 2001.

5. Geomagnetic and ionospheric effect

The negative excursions of Bz are well correlated with large negative excursions of the geomagnetic storm parameter Dst, which reached a minimum value of ~ -300 nT at 0600 UT on November 6, 2001 (Fig. 5). The ionospheric effects are manifested in the dual frequency TEC (TEC is the electron content in a unit column extending from the receiver to the transmitter. It is measured in TEC unit which is equal to 10^{16} electron per square meter.) measurements (Fig. 6a and b) using the ground as well as LEO satellite borne GPS receivers and the TOPEX altimeter. The composite of all these observations during 0409 UT and 0456 UT from a number of locations reveals the TEC distribution with magnetic latitude and local time (Fig. 6a). During the mid-day sector (1000–1500 local time, LT) high values of vertical TEC are observed around the magnetic equator while low values are seen around 1900 LT (see the CHAMP satellite pass). This is the typical quiet time situation. The effect of the ionospheric storm is seen in Fig. 6(b), which shows the measurements on November 6, 2001 around the same

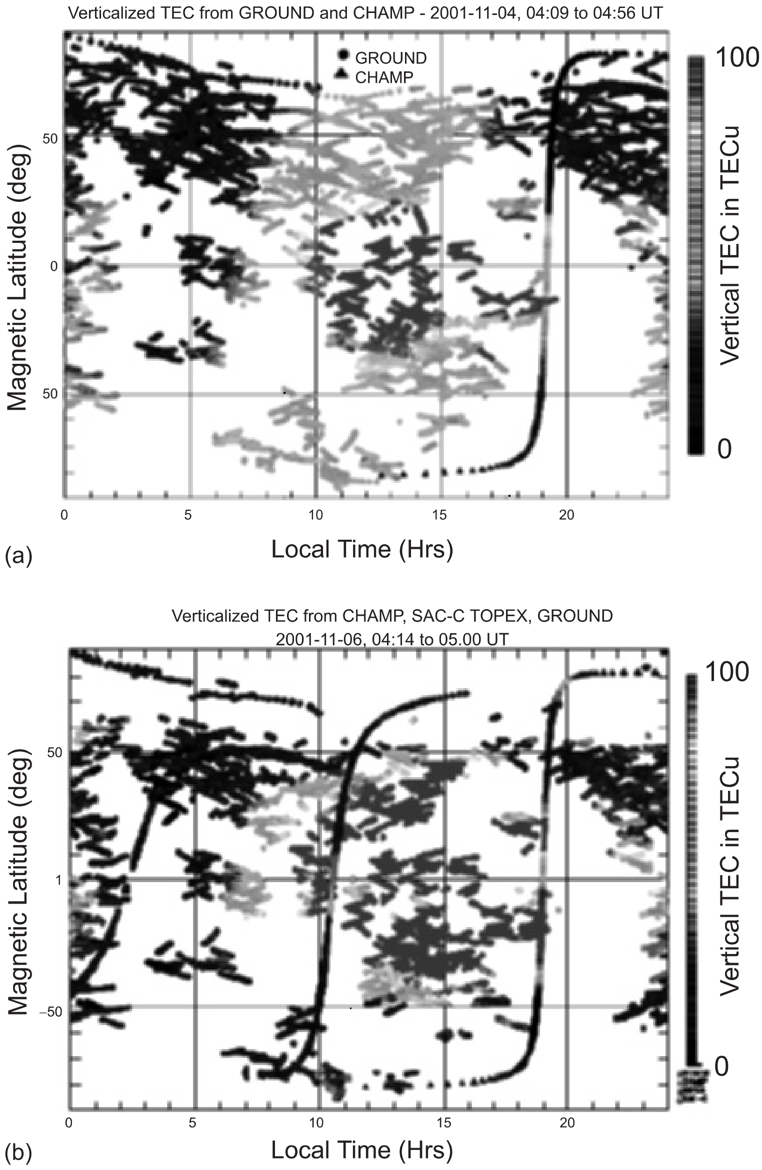

Figure 6(a–b). TEC measurements using the ground and LEO satellite-borne GPS receivers and TOPEX altimeter.

UT period but about 2 hrs after the arrival of the IP shock at 1 AU. The daytime region of high TEC has expanded to higher latitudes of $\sim 30^\circ$ N & S. In general, the TEC has increased indicating a positive ionospheric storm. The ionospheric F-layer heights at low latitudes are affected by the electric fields conveyed from the magnetosphere through the auroral region. Figure 7 shows the variations of h'F (height of the bottom of the F-layer) measured at Ahmedabad. Normally at night-time, the height decreases till the F-region sunrise due to the chemical recombination, but on November 6–7, 2001

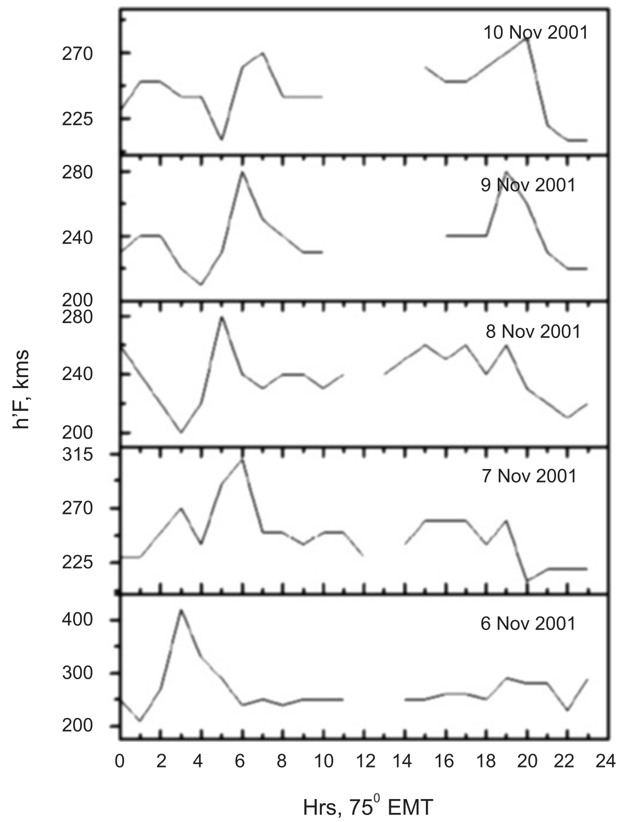

Figure 7. Variation of h'F measured at Ahmedabad during November 6–10, 2001.

(during the main phase of the storm) we find an opposite trend of increasing height between 0 and 3 hrs (75° EMT). This can be attributed to the effect of the electric fields which caused the TEC redistribution shown in Fig. 6.

6. Discussion and conclusion

We have attempted to project the space weather effects associated with major CME event of November 4, 2001. The speed of this halo CME ($\sim 1868\,\mathrm{km\,s^{-1}}$) with some acceleration is considered high, however the resulting geomagnetic storm on November 6, 2001 with Dst ~ -300 nT may seem relatively weak. There can be two reasons for this. One is that the period of high solar wind density (~ 40 particles/cc) was not coincident with high values ($> 750\,\mathrm{km\,s^{-1}}$) of solar wind velocity. Hence, even though Bz was -60 nT, the solar wind magnetosphere coupling was rather weak. The need for positive interaction between solar wind and magnetosphere to produce geostorm was emphasized by Jadav *et al.* (2005). The other may be that, two other halo and partial CMEs were erupted from the Sun with less velocity about fifteen hours earlier. Our concerned CME may have interacted with the above two CMEs in the interplanetary medium resulting into being less powerful in producing geomagnetic storm. The detection of interplanetary disturbance (IPD) resulting from CME on November 5, 2001 by radio telescope (Fig. 4) (a day earlier than satellite) indicates the importance of interplanetary measurements in space weather studies.

The 26–34 nm Solar EUV radiation is responsible for long lived (∼hrs) TEC enhancements. Another important factor contributing to TEC enhancement at low latitudes is the penetration of magnetospheric electric fields to low latitudes. If the storm time electric fields are eastward during daytime it will enhance the E × B drift resulting in lower loss rates and increased TEC. This explains the increase in TEC at low latitudes and its possible association with solar events on November 4, 2001 around 0500 UT.

The interaction between the CME/solar wind and magnetosphere is very complex and varies from event to event. Hence, in order to make space weather prediction one has to study a large number of such events.

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