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Earth's Magnetic Field Fluctuations During CME Events at High Latitude in European Zone

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***Abstract--*The concerning results, are the variations of Geomagnetic Field Components in European Zone during coronal mass ejection (CME) events. The geomagnetic events selected for this study occurred during 2003-2006, a period of solar minimum at Tromso (TRO), Sodankyla (SOD) and Rorvik (ROR) with geomagnetic Latitude and Longitude (69.39^0 N 18.56^0 E), (67.360^0 N . 26.363^0 E) and (64.56^0 N 10.59^0 E). From the present study it is observed that the strength of a geomagnetic storm depends on the interplanetary-magnetospheric coupling parameter VBz. Higher the value of VBz, higher will be the strength of geomagnetic storm. Magnitude of variation at Rorvik is more as compared to Tromso and magnitude of variation is more at Tromso as compared to Sodankyla. Variation in vertical component is less as compared to the north-south and east-west component. Geomagnetic field components shows the variation when either interplanetary magnetic field orients southward or remains southward for few hours.**

***Keywords--* CME, Coronal Holes, Kp and IMF**

I. INTRODUCTION

A geomagnetic storm is a temporary disturbance of the Earth's magnetosphere, associated with coronal mass ejection (CME), coronal holes, or solar flares and is caused by a solar wind shock wave which typically strikes the Earth's magnetic field 24 to 36 hours after the event. This only happens if the shock wave travels in a direction toward Earth. The solar wind pressure on the magnetosphere will increase or decrease depending on the Sun's activity. The solar wind also carries with it the magnetic field of the Sun. This field will have either North or South orientation. If the solar wind has energetic bursts, contracting and expanding the magnetosphere, or if the solar wind takes a southward polarization, geomagnetic storms can be expected. The southward field causes magnetic reconnection of the dayside magnetopause, rapidly injecting magnetic and particle energy into the Earth's magnetosphere.

The dynamic interaction between solar wind and magnetosphere is widely reflected in high to low latitude magnetic field variations. The coupling between the solar wind and the high latitudes results in ionospheric convection and subsequent perturbation in polar cap magnetic activity.

The present study highlights the high-latitude geomagnetic signatures as a consequence of geomagnetic field variations during CME events. For the present investigation, we have selected only extreme, severe, strong, moderate and minor events of 2003-2006 at high latitude European stations. The understanding of the geo-effectiveness of the wide varieties of CME events is imperative in understanding the earth space environment.

CMEs are most numerous near solar maximum (Webb and Howard, 1994)**,** have been demonstrated to cause most major geomagnetic events. Coronal mass ejections from the solar corona are the most spectacular phenomena of solar activity and are huge bubbles of magnetized plasma ejected from the Sun. The enhanced solar wind plasma with their interplanetary counterparts and interplanetary CMEs (ICMEs) propagate through the heliosphere and then interact with geomagnetic fields, implies the possible initiation of a geomagnetic storm, if there exist sufficiently large-magnitude southward components of the interplanetary magnetic field (*Dryer*, 1994). Great geomagnetic storms ($Kp \geq 6$) are generally caused by Earth-directed CMEs that evolve into ICMEs. The Solar flares, geoeffective CMEs and predominantly large magnitude of southward directed IMF are the dominant phenomena during the high solar activity conditions. There is the interaction between coronal ejecta, characterized by long period's southward orientation of IMF, and the Earth's magnetosphere while southward IMF conditions are associated with major geomagnetic storms (Lepping et al., 1991; Gopalswamy et al., 2005).

During the declining phase of the solar cycle, coronal holes and coronal event dominates. For the period of the declining phase of solar activity when the current sheet has a large tilt to the solar equator but there is more order to coronal fields, a more stable fast/slow steam structure arises. In the coronal hole regions on the sun, from which the solar wind flows freely and whose magnetic field lines are open. In these regions the density is lower and the less temperature. Amongst several characteristic features, for example, southward Bz, duration, wind speed and density, Chen et al. (1996, 1997) chose the duration and the magnitude of Bz as important quantities for predicting geo-effectiveness of the event.

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The present study highlights the geomagnetic signatures at high latitude as a consequence of CME events. The present analysis helps in understanding the solar terrestrial relationships.

II. Data Selection And Methodology

We have studied the relationship between the projected speed of coronal mass ejections (CMEs), determined from a sequence of Solar and Heliospheric Observatory/Large Angle and Spectrometric Coronagraph Experiment (SOHO/LASCO) images, and the hourly averaged magnitude of the vertical component Bgsm_z of the magnetic field in an interplanetary ejecta, as measured by the Advanced Composition Explorer (ACE) magnetometer in the Geocentric Solar Magnetospheric Coordinate System (GSM). We had selected three stations Tromso, Sodankyla and Rorvik with Geomagnetic Latitudes 69.39^o N and Long. 18.56^o E, 67.360^o N and 26.363^o E and 64.56^o N and 10.59 ^{o} E respectively of high latitude and data was taken from Tromso and Sodankyla Geophysical Observatory. The declination angles of these stations are TRO (21.22$^{0)}$, ROR (21.15$^{0)}$ and SOD (76.717$^{0)}$. In our analysis we observed 16 CME events according to SOHO/LASCO. Events that have been taken for this study are the extreme, severe, strong, moderate and minor, in which the Kp index is ≥5. For CMEs that originate at the central part of the solar disk we found that the intensity of Bgsm_z is correlated with the projected speed of the CME, V. The relationship is more pronounced for very fast ejecta (V > 1200 km/s), while slower events display larger scatter.

Table 1
Classification of geomagnetic storms according to NOAA space weather scale

S.N.	Geomagnetic Storms	Kp Index	Categories of storms
1.	G5	9	Extreme
2.	G4	8	Severe
3.	G3	7	Strong
4.	G3	6	Moderate
5.	G1	5	Minor

III. Result

We have taken extreme, severe, strong, moderate and minor events occurred during the period 2003-2006 of 23 solar cycle. The geomagnetic storms were categorized depending upon their Kp index and vertical component of IMF. The value of Kp index were 9 and Bgsm_z was <-20 nT for extreme geomagnetic storm.

Case1. : 20 November 2003:

The storm started with the arrival of the shock and the maximum value of vertical component of IMF is -50 nT and it remains south ward for 13 (10-23) hours as in figure 1. A type of flares was M5.8. At stations TRO and ROR the geomagnetic field component X shows increase of 22000 nT and 20500 nT respectively, at Station SOD the X component decreases with value of 2200 nT. Y component shows the increase of 22000 nT at TRO. At ROR and SOD Y component shows decreases with value of 21700 nT and 800 nT respectively. Z component shows increase of value 1000 nT at TRO, where as at ROR and SOD Z component shows the decrease of 900 nT and 1100 nT respectively.

Case2. : 7 Nov 2004:

The Nov. 6th explosion hurled a coronal mass ejection towards the Earth and the Nov. 7th explosion did and types of flares are shown in table 2. As shown in figure2 that on 7th Nov at 13:00 hours the IMF orients southward for one hour and at 22:00 UTC the value of vertical component of IMF is -45 nT for 13:00 UTC as shown in figure 1 and kp index is in table. At station ROR the fluctuation starts as IMF orients southward, at 22:00 UTC of 7th Nov the X component shows the variation of 24000 nT. Y component decreases upto 25000 nT and Z component shows the variation of 1200 ntT. At station TRO the X component increases upto 22000 nT on 8th Nov and X components variation when IMF switches southward direction. Y component also increases upto 22000 nT and Z component shows the variation of 2500 nT. At station SOD there is a decrease of 2500 nT in X component, Y component fluctuates and there is a decrease of 2100 nT in Z component.

Case 3. : 29 May 2003:

According to NOAA this event started 27th May 00:00 UTC. In figure 3 On 28th May at 01:00 UTC the proton flux start increasing to a value 1000 MeV particles cm^{-2}s^{-1}sr^{-1} on 29th May 2003.AT 21:00UTC the proton flux start decreasing. On 28th May there is X type X rays flares. Geomagnetic activity reached severe storm levels for more than 9 hours on May 29th after two solar coronal mass ejections swept past Earth. Another CME struck our planet's magnetic field on 29th May at approximately 1600 UT, which means geomagnetic activity could soon resume. The event takes place on 30th May. The maximum negative excursion of disturbed storm time is 130 nT at 24:00 UTC of 29th May and 131 nT at 03:00 UTC on 30th May and the value of interplanetary magnetic field is -35 nT at 18:00 UTC.

When IMF starts going toward the southward direction the geomagnetic field shows the variation. At Tromso the geomagnetic field components i.e. north-south component shows the increase upto 12000 nT at 15:00 UTC on 29th May, east-west component shows fluctuation between -12000 nT and +12000 nT and vertical component shows the decrease upto 51500 nT, and at Rorvik the geomagnetic field shows the variation as the north-south component shows the decrease upto 12000 nT at 22:00UTC on 29th May and east-west component shows the decrease upto 12000 nT at 15:00 UTC on 29th May 2003 and the vertical component shows firstly decrease upto 4200 nT at 15:00 UTC and then increase upto 5000 nT on 29th May. Similarly at station Sodankya the geomagnetic field components shows the variation as the north-south component shows firstly increase upto 12500nT at 15:00 UTC then a decrease upto 10000 nT on 29th May ,east-west component shows the decrease upto 10000 nT at 15:00 UTC on 29th May and vertical component shows the decrease upto 50000 nT at 15:00 UTC. At station Tromso the magnitude of variation is more as compared to Rorvik as compared to Sodankya.

Case 4. : 13 June 2005:

The types of flare of this event are shown in Table 2 and effect in figure 4 .During this event the geomagnetic field component shows the variation when IMF orients southward and IMF remains southward for 19 hours then geomagnetic field component shows variation. On 12th June IMF is southward with value 19 nT and at ROR the geomagnetic field component X decrease upto 21000 nT, Y component decreases upto 17000 nT and Z component shows the increase of 700 nT. At SOD the X component decreases upto 10500 nT, Y component increases upto 2400 nT and during the same time Z component increases upto 51800 nT .At station TRO the X component increases upto 20000 nT, Y component decreases upto -13000 nT and there is a increase of 600 nT in Z component.

Case 5. : 24 Aug 2005:

The types of flare of this CME event are C 4.7 .The maximum value of vertical component of IMF is -55 nT as shown in figure 5. The geomagnetic field components at Station TRO X increases with the value of 22500 nT at Station ROR and SOD the X component decreases with value of 22000 nT, 730 nT. The Y component at Station TRO and SOD increases with value of 21400 nT and 665 respectively. At Station ROR the Y component decreases with value 17000 nT. Similarly the Z component at Station TRO, ROR and SOD decreases with value of 1333 nT, 1000 nT and 230 nT respectively.

IV. Summary And Discussion

The source region of CMEs was the active regions which appeared in solar disk. The active region will be on the Earth-facing side of the sun for a few days until solar rotation carries it over the sun's western limb. After that, solar and geomagnetic activity should return to low levels. During the declining phase of the solar cycle, the interplanetary medium is dominated by large coronal holes. During the descending phase of the solar cycle, when the holes migrate down to lower latitude the streams emanating from the holes "corotate" at -27 day intervals. When the CME's source region is located near the center of the solar disk, then the CME is directed toward the earth and is normally seen, in coronographs, as an expending faint halo around the sun (*Howard et al.* 1982). Earth-directed CMEs, where the magnetic field has a southward component, are capable of producing large geomagnetic storms (*Russell et al*., 1974; *Gonzalez et al*., 1994; *Cane et al*., 2000; *Pevtsov and Canfield*, 2001). The bright post-eruption arcade at the location of the east-west segment of the filament suggests the possibility that the segment was propelled faster, thus contributing to the predominant north-south orientation of the erupted filament. Intense geomagnetic storms generally occur when solar wind with intense, long duration southward interplanetary magnetic field (IMF) impacts Earth's magnetosphere. During geomagnetic storms, southward IMF reconnects with Earth's geomagnetic field at the dayside magnetopause, resulting in a chain of events leading to the dramatic increase of the ring current westward, which induces a magnetic field opposite to the geomagnetic field and causes global depression in the horizontal component (*H*) of the geomagnetic field. During the main phase of the storm, when vertical component IMF is large and southward oriented, the magnetospheric electric field at high latitude extends to the equatorial ionosphere causing an additional decrease of *H* at the equatorial stations beside the one expected by the ring current alone. Manoharan et al. (2004) studied the influence of CME interaction on propagation of IP shocks, and found that the CME interaction tends to slow the shock. An inter comparison with the AE index indicates that there is a good relationship. During the main phase of storms AE increases. Thus one interpretation of this observation is that AE increases are injecting of plasma particles into the outer radiation belts, preventing the ring current from reaching quiet day values. However, it should be noted that plasma sheet current intensifications or earthward motions of the latter could also cause such effects on the AE index and there is shift in the auroral oval with magnetospheric disturbances.

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When there is magnetic disturbances the AE level also changes from auroral oval to equtoward. The connectivity of coronal holes and the more distant solar wind has been demonstrated by tracing field lines back to the sun (Linker et al., 1999). During solar maximum coronal holes and regions of flux tube divergence are more evenly spread over the Sun's surface than at solar minimum, allowing the Earth to experience a broad range of solar wind velocities, almost independent of its heliographic or heliomagnetic latitude. These CME and coronal hole events have a variety of speeds, but the most effective feature in magnetic storm events that are fast, with speeds exceeding the ambient wind speed by the magnetosonic wave speed, so that a fast plasma and field structure propagates from the sun through interplanetary space. It sweeps up the compresses the slower plasma and field ahead, creating a sheath between the shock and interplanetary manifestation of ejects.

According to latitudinal variation, the variation at Tromso should be greater than Sodankyla and then Rorvik. But we got the variation high at Rorvik as compared to the Tromso as compared to Sodankyla, due to their dip angle.

From the analysis it is observed that

1. The strength of a geomagnetic storm depends on the interplanetary-magnetospheric coupling parameter VBz. The higher the value of VBz, the higher will be the strength of geomagnetic storm.
2. Magnitude of variation at Rorvik is more as compared to Tromso and magnitude of variation is more at Tromso as compared to Sodankyla.
3. Geomagnetic field components shows the variation when either interplanetary magnetic field orients southward or remains southward for few hours.
4. Variation in vertical component is less as compared to the north-south and east-west component.

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FIGURE CAPTION:

In the presented figures along X axis there is time in UTC and along Y axis there is the variation in geomagnetic field components in nT. In all the figures there are nine panels .first three panels there is X component of TRO, ROR and SOD stations in next three panels there are Y component of all the stations and last three panels there are Z component.

Table: Table 1 shows the classification of geomagnetic storms on the basis of NOAA.

Table 2: In this table the Kp and Dst index, vertical component of IMF and duration of the vertical component in southward direction and magnetospheric coupling parameter VBz. Flare type is also shown in last column.

Table 2
Table of duration of southward IMF_Bz, coupling parameter and flare types:

S.N.	Year	Month	Storm Day	Southward IMF (nT)	Kp index	Dst Index In nT	VBZ	Category of storms	Duration Remaining southward (Hrs)	Flare Type
1	2003	11	20	-53	9-	-472	-33065	Extreme	13(10-23)	M5.8
2	2004	11	7	-49	8o	-363	-34300	Severe	13(21-11)	C1.6
3	2003	5	29	-33	7+	-131	-20843	Strong	2(16-18)	M2.8
4	2005	6	13	-18	6-	-100	-5367	Moderate	21(16-14)	C7.4
5	2004	11	11	-9	5	-363	-4207	Minor	1(8-8)	C2.6

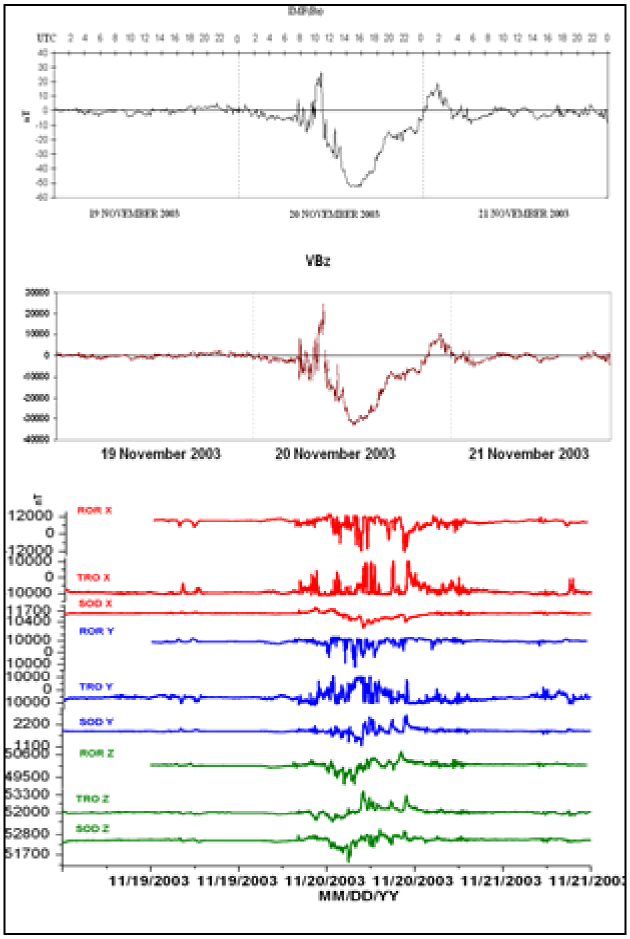

Figure 1

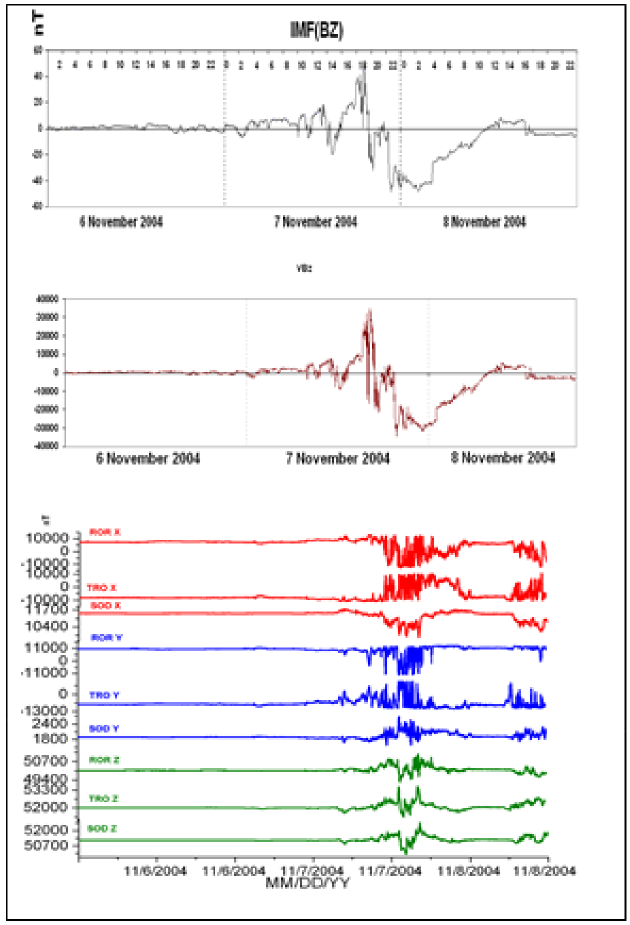

Figure 2

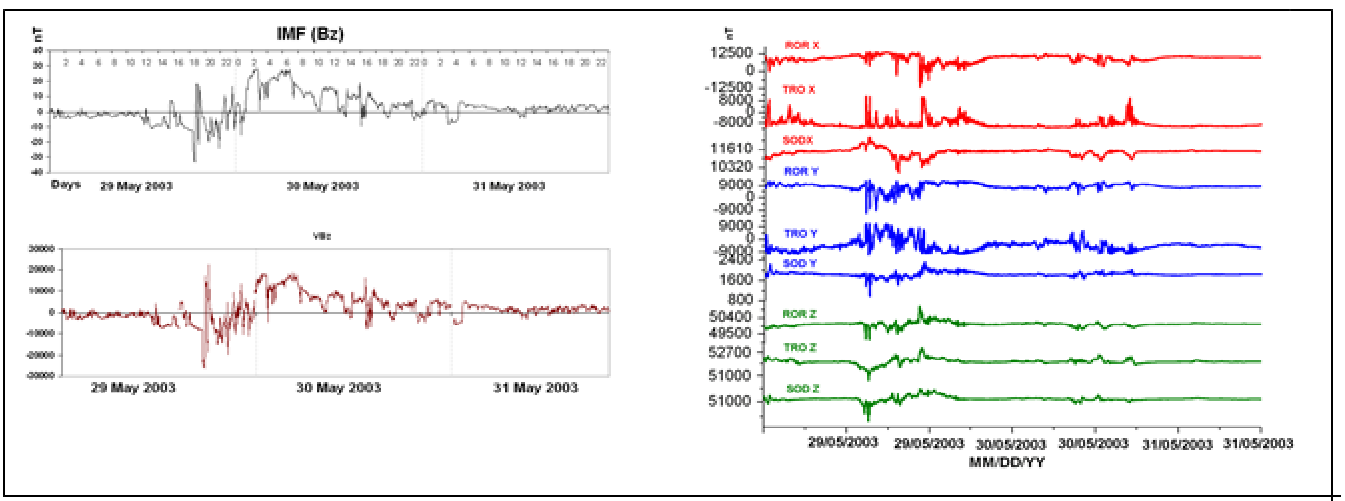

Figure 3

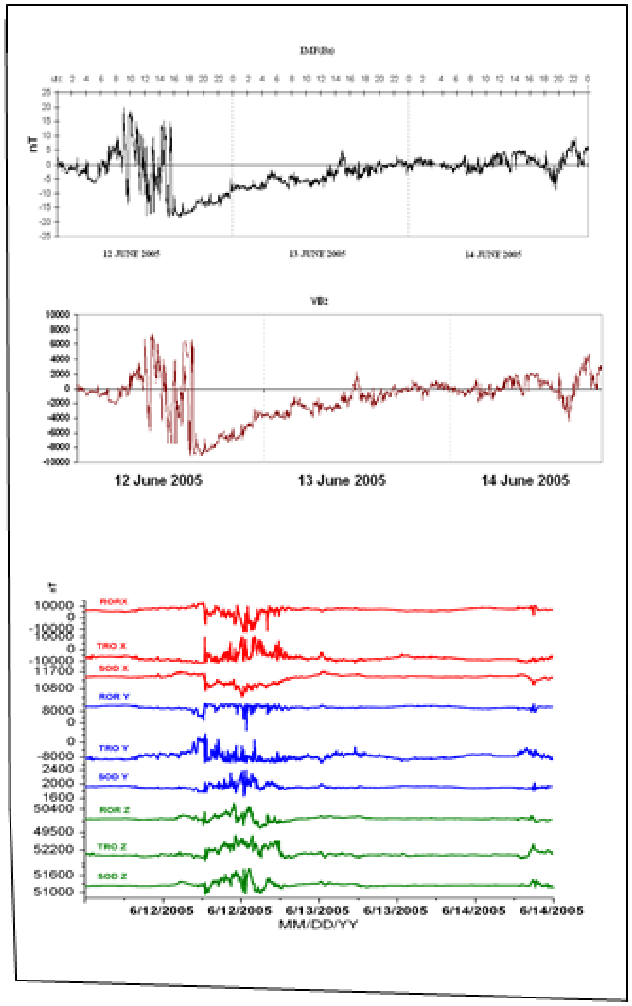

Figure 4

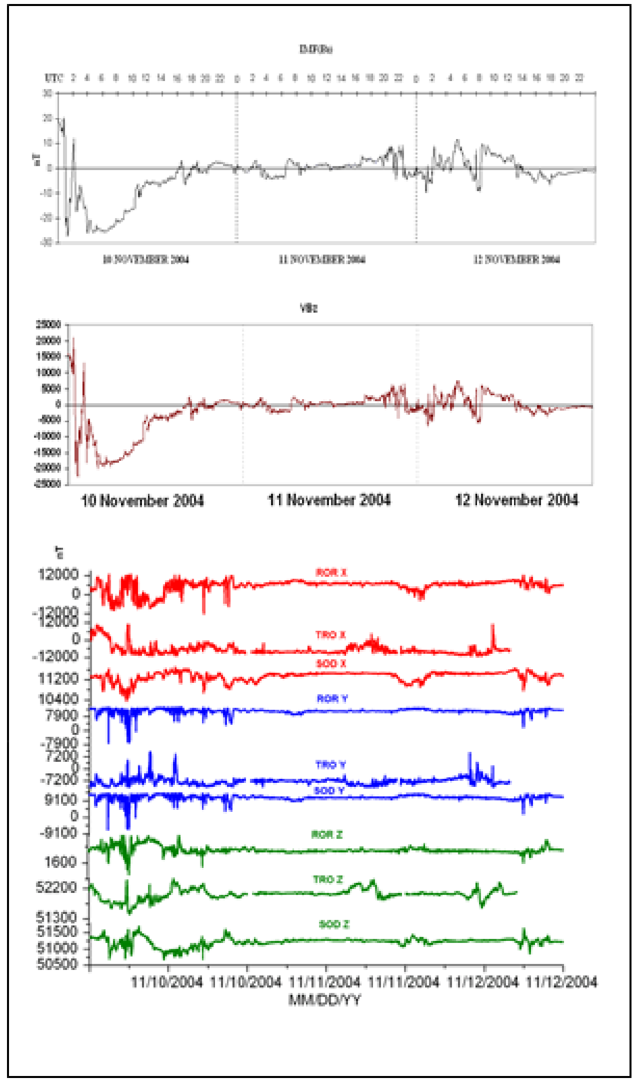

Figure 5