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Study of Solar-Terrestrial Interaction Based on Magnetic Field Observations from Bharati Station, Larsemann Hills, Antarctica

Anand K. Singh[1,2], Ajay Dhar[1], A. L. Gudade[1] and B. M. Pathan[1]

[1]Indian Institute of Geomagnetism, Navi Mumbai

[2]National Centre for Antarctic & Ocean Research, Goa

ABSTRACT

Various dynamic processes in the near-Earth space environment, driven by the transient solar activity, severely affect the high latitude regions. Magnetic field data collected at globally distributed observatories have been an important tool for the study of manifestations of solar-terrestrial interaction in different regions of the Earth. A newly commissioned Indian Antarctic station, Bharati located at corrected geomagnetic (CGM) coordinates 74.7° S and 97.2° E is well suited for the study of several polar region specific processes associated with solar-terrestrial interaction. Around 20 days magnetic field variations recorded at Bharati during the austral summer months of XXVI and XXVII Indian Scientific Expeditions to Antarctic (ISEA), form the basis for this study. Initial results of polar geomagnetic substorms and long period geomagnetic pulsation characteristics have been presented in this study.

Keywords: Geomagnetic Disturbance, Pulsations, Solar Wind, Substorm.

1.0 INTRODUCTION

The terrestrial magnetic field is confined in a cavity like shape, called magnetosphere, in the interplanetary space due to the pressure exerted by the continuously impinging solar energetic ions and electrons known as solar wind (Parker, 1959). The magnetosphere quite effectively shields the near-Earth space from direct entry of the solar wind particles. However, in narrow and funnel-shaped regions (around 75° latitudes in both the hemispheres), separating the day and night sides geomagnetic field lines, the solar wind has direct access to about 100 km altitude (Russell, 2000). Moreover, magnetic flux eroded from the day side due to reconnection process, subsequently energizes the magnetotail on the night side and tremendous amount of energy and mass is further released into the inner magnetosphere and ionosphere (Dungey, 1961).

The transfer of particles flux and energy into the inner magnetosphere or ionosphere results in various dynamic geophysical processes, namely geomagnetic storms, substorms and pulsations, etc. which may disturb the near-Earth electromagnetic environment on the global scale (Sastri, 2002 and Singh et al., 2012). From the activity region in the magnetotail, energetic particles find path (i) across the geomagnetic field lines into the inner magnetosphere where they intensify the global scale "ring current" (Williams, 1985) and (ii) along the highly conducting field lines to the high latitude ionosphere resulting in magnificent auroral display and enhancement of the field-aligned and ionospheric currents (Akasofu, 1964).

These intensified currents produce strong magnetic field variations that may be globally observed by magnetometers. The ring current encircles the Earth in the equatorial plane at a distance of about 2-7 RE (where RE is the radius of the Earth = 6378 km). Due to enhanced population of the energetic charged particles and subsequent decay in the ring current region, a systematic magnetic field disturbance is observed at all local times in the equatorial region that is known as geomagnetic storm (Chapman and Ferraro, 1931). Meanwhile during storm times, a series of shorter duration but far more intense magnetic disturbances, known as substorms, are typically observed around 65° latitudes on the night side (McPherron et al., 1973). A geomagnetic substorm is essentially accompanied with visible auroral activity which is direct manifestation of energetic particles precipitation from the magnetotail. Moreover, various types of periodic magnetic field fluctuations having amplitudes about tens of nT and and period range ~ 1-1000 s are observed during the geomagnetic activity (Jacbos et al., 1964). These fluctuations, known as geomagnetic pulsations, are good indicator of the state of the magnetosphere and its interaction with the solar wind (McPherron, 2005).

Magnetic disturbance recorded in different latitude regions are used to compute geomagnetic activity indices. The Dst index, which is an averaged magnetic disturbance observed at a set of globally distributed low latitude stations, monitors geomagnetic storms (Sugiura 1964). The auroral region (60°-70° magnetic latitude) is far more dynamic during substorms than the lower latitudes and different current systems simultaneously exist at different local times. Often an eastward current (electrojet) flows in the dusk hours and westward electrojet prevails in the dawn and midnight local times. The maximum intensities of the eastward and westward electrojets are respectively determined by the AU and AL indices (Davis and Sugiura, 1966). These indices are extremely relevant for the identification of geomagnetic substorms (Singh et al., 2013).

In this study we carry out a detailed analysis of about 20 days geomagnetic disturbance data collected at Bharati station (geographic location 69.4° S, 76.2° E) during the summer season of XXVI (Mar 2006) and XXVII (Feb - March 2007) ISEA. A digital fluxgate magnetometer (DFM) was operated to record variations of three orthogonal components (H in magnetic north-south, D in east-west and Z vertically upward) of the geomagnetic field. The data were originally sampled at 1 s interval with 0.1 nT sensitivity. However, for this study we suitably down-sampled the data by simple averaging, e.g., to 10 s for pulsation study and to 1 min for substorm study. As only about 20 days magnetic data were available from Bharati, the diurnal variations (also known as Sq variations) prevalent on magnetically quiet days have been left for future. This study mainly focuses on magnetic disturbances not exceeding 2-3 hours.

2.0 SUBSTORM ACTIVITY AT BHARATI

Burst of aurora and sharp intensification of the ionospheric current leading to the geomagnetic field depression over a few 100 nT are commonly observed at night side auroral latitudes (60°-70° magnetic) due to the onset of substorm activity (Kisabeth and Rostoker, 1974). The AL index often shows well defined sharp depression followed by a rather smooth recovery. The entire process often lasts for 1-2 hours during an isolated substorm. However, at times especially when solar wind drivers are subsided, the magnetosphere may attain very quiet state and the magnetotail moves further away from the Earth. The previously stored energy in the magnetotail may be released by internal instability and the flux of particles and associated current thereby reach towards higher latitudes (>70°) along the field lines rather than mapping down to the standard auroral region.

The corrected geomagnetic (CGM) location of Bharati is 74.7° S, 97.2° E. Therefore, the station is located poleward of the standard auroral belt and lies close to the polar cusp region in the southern hemisphere. During magnetic night times at Bharati, disturbance in magnetic field components of order of a few 100 nT were quite commonly observed. These magnetic disturbances could be due to the extension of the westward auroral electrojet towards the polar region. However, in this study we report a substorm event which was mainly localized poleward of the typical latitude of occurrence. Case studies and a statistical study of very high latitude substorms based on magnetic data from Bharati have been already reported by Singh et al. (2011) and Singh et al. (2012).

Green aurora was sighted over Bharati on 2 March 2008 during a few hours of darkness over the station. Sharp depression in the H component was simultaneously observed, which should be manifestation of westward flowing ionospheric current. This event has been further examined in detail. Interestingly, magnetic field lines originating from Bharati map in Svalbard, Norway in the northern hemisphere where a dense network of magnetic observatories (IMAGE) is operational. Hornsund station of the IMAGE chain (geographic coordinates 77.0° N, 15.6° E and CGM coordinates 74.3° S, 108.2° E) form a near-conjugate pair with Bharati which provides additional opportunity to examine hemispherical characteristics of the geomagnetic activity. Moreover, data from a magnetic observatory in India-mainland (almost along the same meridian) have been used to examine the low latitude implications of magnetic activities observed over Bharati for the selected event.

We firstly investigate the solar wind and associated interplanetary magnetic field (IMF) conditions as were observed by instruments aboard NASA's ACE satellite. For the event, the satellite was located around 240 RE away from the Earth where the influence of terrestrial magnetic field could be ignored. The satellite being towards the Sun would naturally observe the gust of the solar wind before it encounters the Earth's magnetosphere. Therefore, for comparison of the solar wind properties and the geomagnetic activity, a time constant depending on the speed of solar wind flow needs to be added in the satellite observations.

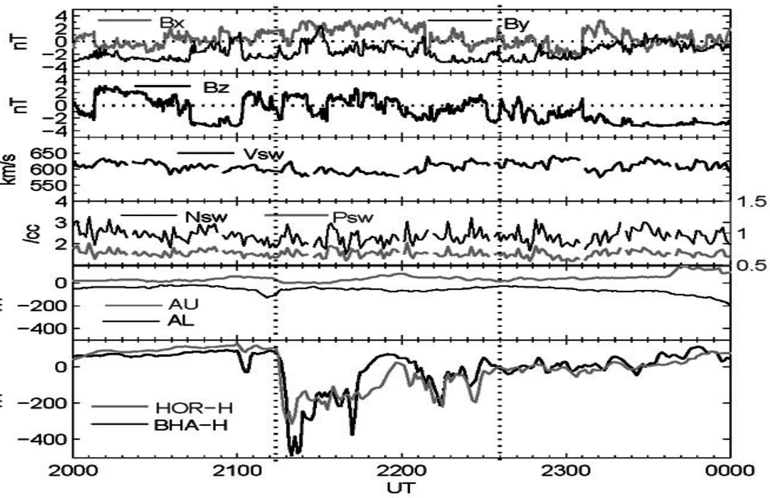

Fig. 1: (Top to bottom) Components of IMF, solar wind speed, density and dynamic pressure variations as observed by ACE satellite, AU and AL indices and H disturbance at high latitude near-conjugate stations on March 02, 2008. Interplanetary observations are delayed by 40 min to compare with the ground data. Event marked between vertical dashed lines clearly shows a quite intense substorm localized to high latitude. (Figure adopted from Singh et al., 2012)

Top four panels of **Fig. 1** depict three orthogonal components of the IMF and solar wind conditions. Satellite data have been delayed by 40 min taking into account the travel time of solar wind at an average speed of 600 km/s. The AU and AL indices characterizing substorms have been shown in fifth panel from the top. No clear substorm activity is evident from these indices. However, H components observed at Bharati (BHA) as well as at Hornsund (HOR) show sharp depression of reaching to about -500 nT which is a typical feature of a substorm. Magnetic local time (MLT) of Bharati is about 2 hours ahead of UT, whereas 3 hours ahead for Hornsund. Therefore, both the stations were near located near midnight during the event.

Data from closely spaced IMAGE chain stations in the northern hemisphere along 100o magnetic meridian have been examined to estimate the center of the auroral electrojet during the substorm. In **Fig. 2(a)** the H (black curves) and Z (grey curves) components disturbances at selected IMAGE chain stations are shown during 2030-2330 UT. Codes of stations and respective latitudes are given on the plot. The standard AE observatory, ABK lying near midnight (where maximum disturbance is expected), does not show appreciable field change during the event. Consequently the AL index does not indicate significant change during the event.

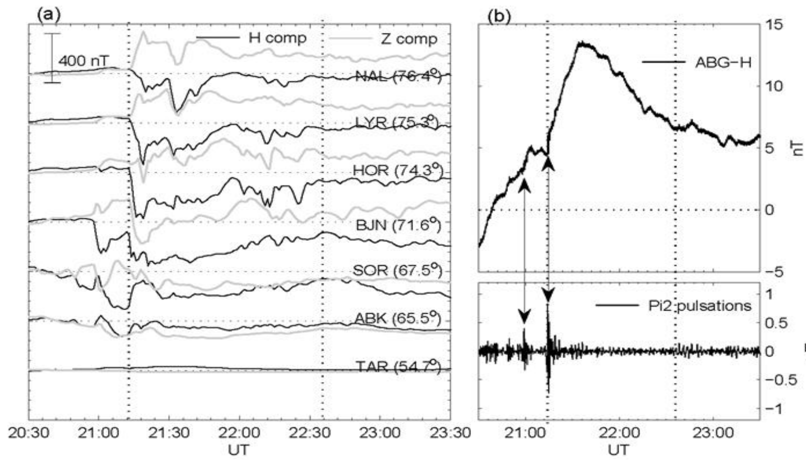

Fig. 2: (a) H and Z component disturbances at closely spaced IMAGE chain stations (~100° magnetic meridian) on the night side of the Earth. Sharp depression in H, first appears at BJN, which maximizes at HOR. Grossly opposite variations in Z component (grey lines) between stations BJN and HOR demarcates the center of westward electrojet for the event. (b) Top panel shows a clear positive bay during the event at low latitude station ABG, which starts with the onset of major Pi2 burst (bandpassed H in frequency range 7–25 mHz) displayed in the bottom panel of the figure. Two vertical arrows correspond to the onset of westward surges observed respectively at 20:58 UT and 21:12 UT at very high latitudes. (Figure adopted from Singh et al., 2012)

Stations, poleward of ABK, witness sharp depression in H field component which gets maximized at HOR as shown in Fig. 2(a). Maximum disturbance in H component is expected near the centre of westward electrojet. It can be precisely estimated using Z disturbance plots along a meridian. Poleward of the centre of electrojet, H component is depressed and Z component is enhanced, whereas equatorward of the centre of electrojet both H and Z components are depressed (Rostoker et al., 1980 and Gupta and Loomer, 1979). For this event, the most prominent depression in the H component was observed at station HOR and the Z variations are grossly opposite between stations BJN and HOR after the onset of substorm as shown in the Fig. 2(a). This observation suggests that the centre of substorm electrojet was lying between BJN and HOR in the northern hemisphere. At BHA, the Z variations were similar to those of HOR.

It should be noted that the first sharp depression in H is observed around 2058 UT at BJN, which however did not reach higher latitudes. Next surge of westward electrojet depresses the H component dramatically at HOR at 2112 UT, which was subsequently observed at stations poleward of HOR.

Positive bay in the H component and Pi2 bursts (period 45-150 s, frequency 7-25 mHz) on the night side low latitude are typical features of a magnetic substorm (Rostoker et al., 1980; Olson, 1999). Further, night side low latitude data from Alibag (ABG; MLT = UT + 5 hours) observatory have been analyzed to examine signatures of substorms occurring at very high latitudes.

As shown in Fig. 2(b) a clear positive bay and Pi2 bursts were observed during the event as depicted in the top and bottom panels, respectively. Two bursts of Pi2's are clearly identified above the background oscillations as marked by a pair of vertical arrows in the figure. First burst of Pi2 corresponds to the westward surge observed around 2058 UT at BJN, whereas second and more pronounced Pi2 burst corresponds to the surge observed at HOR and poleward ~2112 UT. The event of 2 March 2008, discussed above, clearly demonstrates that a substorm activity localized poleward of the standard auroral oval may exhibit the typical low latitude signatures. However, such substorms may remain unnoticed in the standard AE indices which rely only on the auroral latitude data.

3.0 GEOMAGNETIC PULSATION ACTIVITY AT BHARATI

Small amplitude (up to a few tens of nT) periodic magnetic field fluctuations, known as geomagnetic pulsations, are natural response of the Earth's magnetosphere to external or internal disturbances. The period range and waveform of the pulsations depend on the processes that generate them as well as the medium through which these waves propagate. As a consequence, geomagnetic pulsations have been used as a diagnostic tool to understand the state of the magnetosphere for decades (McPherron, 2005).

Pc5 pulsations (period range 150-600 s, frequency 2-7 mHz) lasting for a several cycles are commonly observed at high latitudes (Gupta, 1975). This type of pulsations have drawn special attention of scientific community due to their possible role in the acceleration of magnetospheric plasma to relativistic energies which could be a potential hazard to man-made satellites (Mathie and Mann, 2001). Out of several proposed mechanisms for the excitation of Pc5 waves, the instability generated at the flanks of the magnetopause by the solar wind flow is the most widely accepted mechanism.

The general characteristics of Pc5 waves observed at Bharati have been examined further. For the sake of representation, we depicted observations on 14 March 2007 in **Fig. 3**. Top three panels in the figure

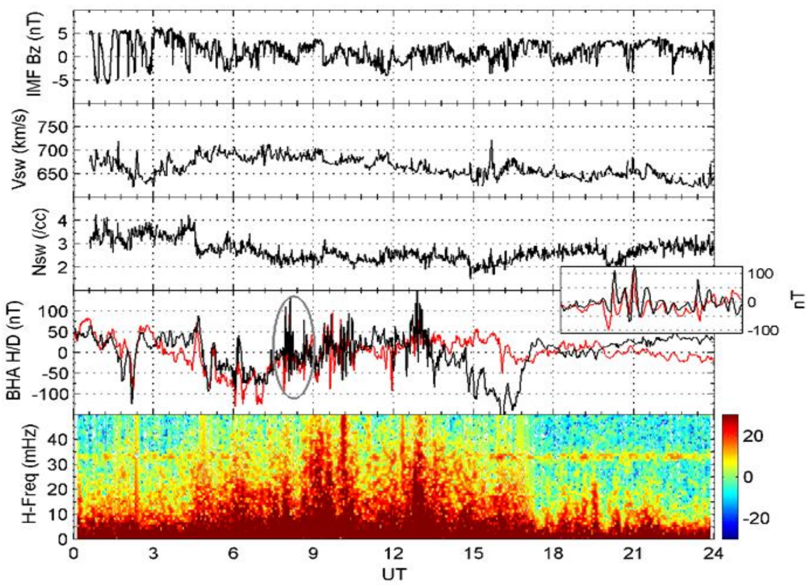

Fig. 3. A typical example of continuous pulsations recorded on 14 March 2007 at Bharati. Top three panels show IMF Bz, solar wind speed and density (delayed by 35 min) as observed by instruments aboard ACE satellite. Fourth panel from the top shows the H and D components observed at Bharati. Magnified data (0730-0900 UT) have been shown in the inset on the right. Dynamic spectra of H component in the bottom panel show the frequency content of the time series.

show IMF and solar wind conditions delayed by 35 min to take into account the propagation time from the location of the spacecraft to the magnetopause. Flow speed of the solar wind was quite high (>650 km/s) in comparison to typical speed (~400 km/s). High speed solar wind flow on the day is very likely to generate instability at the magnetopause which could drive geomagnetic pulsations. The H and D components observed at Bharati have been shown in the fourth panel from the top in Fig. 3. During noon hours, we see oscillations in the magnetic field components, which appear more clearly in the magnified data in the encircled time interval 0730-0900 UT as shown in the inset. Oscillations were also present in the Z component time series, however not shown here. The most dominant frequency of wave lies in the Pc5 band. However, higher frequency components were also present simultaneously as can be seen form dynamic spectra depicted in the bottom panel of Fig. 3.

We further statistically examine the local time characteristics of Pc5 pulsations observed at Bharati. Fourier amplitudes of the H, D and Z components for hourly binned data of 10 second resolution were computed and color-coded on logarithmic scale against MLT hour for available 17 days as shown in **Figure 4.** It should be noted that for Bharati station MLT is ahead of UT by 2 hours. For all the components, pulsation activity clearly maximizes during local noon hours, thereby suggesting the fact that the source of the Pc5 was on the dayside. When the Fourier amplitudes for the Pc5 waves were plotted against hourly solar wind speed, an increase in amplitude was observed with increasing speed. It suggests that flow speed of solar wind played a vital role in the generation of Pc5 pulsations at Bharati.

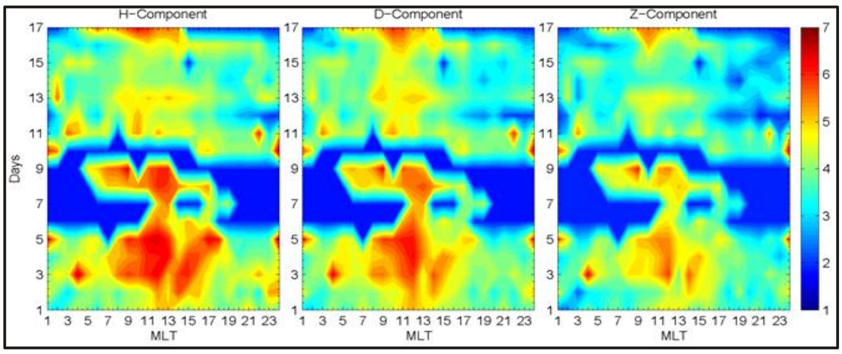

Fig. 4: MLT characteristics of Pc5 wave amplitudes in H, D and Z components at Bharati. Pc5 wave activity clearly maximizes during local noon hours

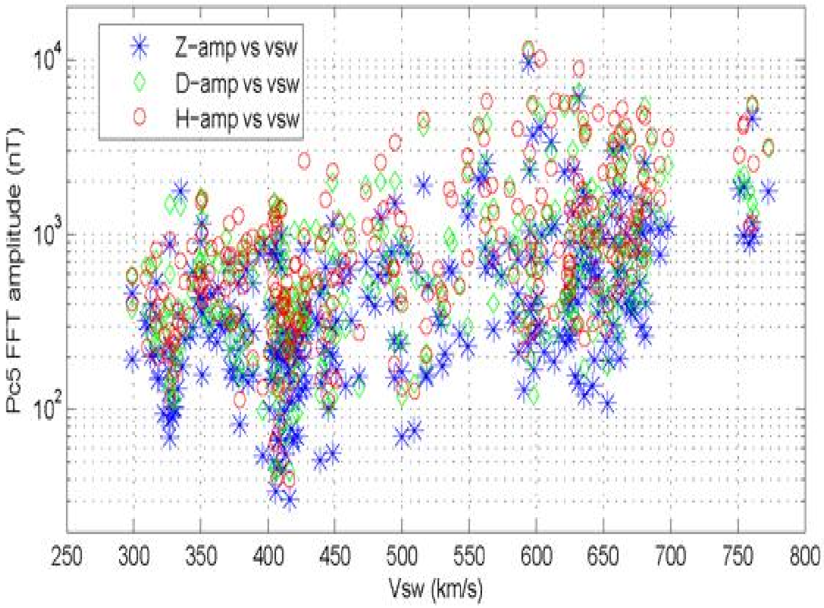

Fig. 5: Dependence of Pc5 wave amplitude at Bharati on the solar wind speed. Despite large scatter in data, an increasing trend in the amplitude of Pc5 pulsations with increase in the solar wind speed is observed for the H, D and Z components

4.0 CONCLUDING REMARKS

The location of Bharati is extremely relevant for the study of the solar-terrestrial interaction. Magnetic field data collected at Bharati proved to be important for addressing substorms localized poleward of the standard auroral latitudes. Moreover, our study also throws light on the limitation of the standard AE index in precisely monitoring substorm occurrence which have been a key parameters in the field. The network of closely-spaced Svalbard magnetic observatories along the magnetic meridian of Bharati in the northern hemisphere provides additional opportunity to address inter-hemispherical characteristics of the space weather events.

Long period geomagnetic pulsation activity at Bharati observed to exhibit clear diurnal pattern. The pulsation activity maximizes around local noon hours and the amplitude of pulsation shows dependence on the flow speed of the solar wind. Observations clearly suggest that the source of pulsations lies on the dayside and possibly generated by the instabilities on the magnetopause due solar wind flow.

During XXVI and XXVII expeditions, magnetic data could be collected only for selected days during austral summer seasons. However, after the start of year around operation of the station, magnetometer would collect data for entire year and future studies would address seasonal characteristics of various space weather processes. Moreover, long-term data from Bharati would be analyzed in conjunction with satellite data to establish the morphology of cusp over Bharati.

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