Storm time magnetic field variations at low latitude and its association with solar wind parameters

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Abstract. It is known that interplanetary plasma has significant influence on the storm time magnetic field variations observed on the surface of the earth. It has been well observed that the southward component of interplanetary magnetic field is a strong candidate in triggering and controlling the geomagnetic storm. However, apart from this, the solar wind parameters such as plasma density, velocity etc. could also have considerable contribution to the ground magnetic field variations and the present study aims to identify this association. Thus, to investigate the influence of solar wind parameters on the magnetic field variations at low latitude, we use one-minute observations of the horizontal component of the magnetic field variations at Alibag (Geomagnetic latitude = 9^o N), and onboard ACE satellite measurements of plasma parameters during intense storm events. During the development and decay stage of geomagnetic storms, close correspondence of rapid changes observed at the low latitude magnetic field with solar wind parameters leads to further extended investigation using filter analysis techniques, which reveals that the bursts of solar wind density have clear marks at low latitude magnetic field measurements. Cross correlation analysis shows that the solar wind dynamic pressure has significant correlation with surface magnetic observations, which provides direct evidence of solar wind impact at low latitude magnetic field variations.

Index Terms. Geomagnetic storm, Low latitude magnetic field, magnetospheric ULF waves, solar wind parameters.

1. Introduction

The horizontal component of magnetic field at low latitude exhibits typical signatures during geomagnetic storm periods. In the case of a classic magnetic storm, the H-component shows a sudden increase, corresponding to the storm sudden commencement, and then decreases sharply as the ring current intensifies, recognized as main phase; IMF is southward during this time interval. Once the IMF turns northward again and the ring current begins to recover, the low latitude H-component begins to rise slowly, back to its quiet time level called the recovery phase. However, besides this, it is often observed that ground magnetograms also show some oscillatory structures during magnetically disturbed periods, which can be categorized as pulsations and further, can be classified depending on its frequency and character. Till date there are various mechanisms proposed to explain the observed intricate features of the ultra-low frequency (ULF) pulsations, obtained with dense network of ground- based techniques and satellite in earth's environment. There exists one group of researchers who believe that the discrete magnetospheric pulsations might arise directly from oscillatory sources inherent in the solar wind (Matsuoka et al 1995, Korotova and Sibeck 1995). Recently, Kepko et al. (2002, 2003) and Stephenson and Walker (2002) established that pulsations are at least some times directly driven by density oscillations of solar wind, whereas Singer et al. (1977) found that pulsation activity is proportional to solar wind velocity.

The main focus of present paper is to examine the influence of solar wind parameters on the magnetic field measurements at low latitude station.

2. Observations

In the present paper, we analyze intense storm events by means of one-minute observations of ground horizontal magnetic field at Alibag (Geomag lat = 9^0 N) and onboard ACE satellite measurements of solar wind parameters.

2.1 Event on 21-22 October 1999

Forty hours of un-processed ground magnetic observations and solar wind parameters along with Dst index, during 21-22 October 1999, are shown in Fig. 1. Local noon is denoted by blue solid circle. It should be noted that throughout this paper, red color is used for solar wind density/dynamic pressure. We observe that major density peaks at ~ 3 UT on 21 Oct and ~ 6 UT on 22 Oct has clear impact on magnetic field measurements at Alibag. Solar wind velocity is also increasing during enhanced density. Since the magnetospheric ring current and diurnal variation associated with quiet day ionospheric currents, can masquerade the ground observations, it is necessary to discard its effect by eliminating Dst and quiet-day diurnal variation from actual measurements.

Fig. 2 depicts the time series after systematic removal of each factor for the event on 21-22 Oct 99. Fig. 2a, and 2b show the variation of the H-component of the magnetic field at Alibag, during the disturbed event under study and the first quiet day of the month, respectively. Fig. 2c represents 2a-2b. Dst index is shown in Fig. 2d, and 2c-2d, called residual magnetic field, is depicted in Fig. 2e. The magnitude scale for 2a to 2d is the same, whereas the scale for 2e is enlarged by 50%. Below that, solar wind density variations are also plotted in Fig. 2f. In the first conjecture, we see some association between 2e and 2f, which motivates us for the further detailed investigation.

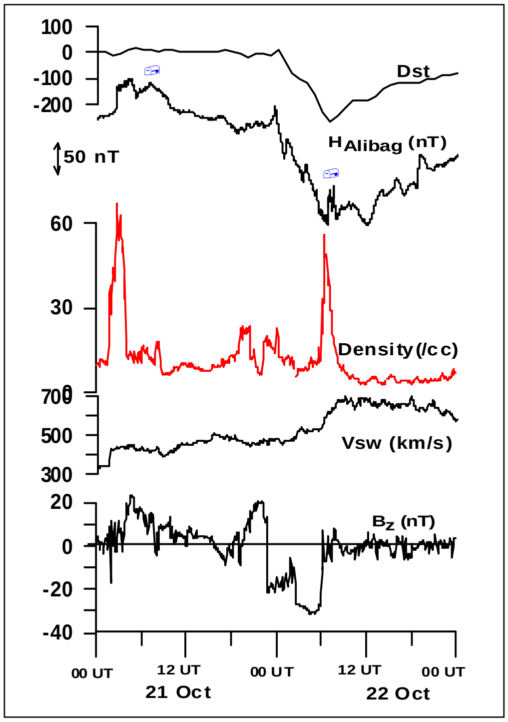

Fig. 1. Variation of Dst and H component at Alibag along with solar wind parameters during 21-22 October 1999.

2.2 Event on 11-12 August 2000

Fig. 3 shows untreated data during 11-12 August 2000. Fluctuating structure is observed at Alibag, and in solar wind parameters as well. Southward turning of IMF essentially develops westward ring current around the Earth and results in the decrease of the H-component at low latitude, during the main phase of the storm. The major density impulse at ~ 13 UT on 12 Aug, which takes place during recovery phase of the storm, is clearly perceived at low latitude, whereas the wind velocity does not show any abrupt changes during this density peak. Other density peaks at ~ 3 UT on 11 Aug and between 0 UT to 5 UT on 12 Aug, also find corresponding signatures in the H component at Alibag. Thus, the fluctuations recorded at Alibag seem to be well correlated with solar wind density changes.

2.3 Event on 6-7 April 2000

Fig. 4 shows various solar wind parameters, such as IMF components Bx, By, Bz, total field B, temperature, velocity, dynamic pressure, and density of solar wind, along with the residual magnetic field at Alibag, after eliminating Dst and quiet time diurnal variations. We observe that the ground magnetic field has similar fluctuations as that of density and

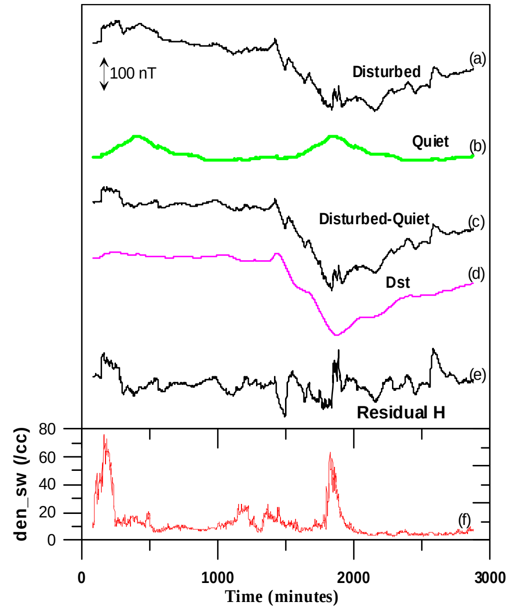

Fig. 2. Alibag H-component on 21-22 Oct 99 with one minute sampling interval. Time series after successive removal of each component. Bottom plot shows solar wind density fluctuations.

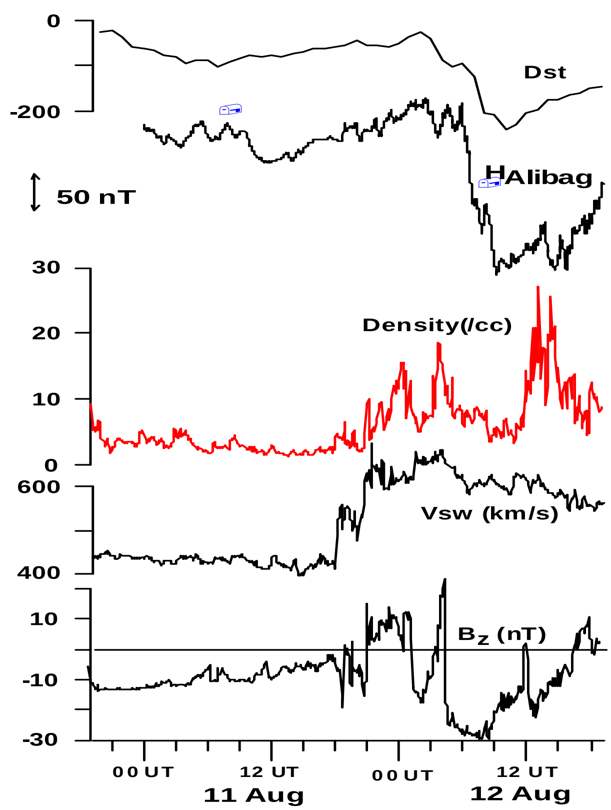

Fig. 3. Same as fig. 1, during 11-12 August 2000.

dynamic pressure. Though the IMF and solar wind temperature are also oscillating, during that time, the ground variations resemble the density and hence correlate with solar wind dynamic pressure. The southward turning of IMF is denoted by the shaded area. It is interesting to note that, even after removing Dst from Alibag data, the residual field does show decreasing trends, similar to a ring current. In other words, the Dst index does not account for a complete ring current observed at Alibag. Then, we redid the analysis with pressure corrected Dst value, Dst*, but leakage of the ring current persisted; i.e. decreasing trend at ~ 1200 minute, remained unchanged. Since Dst values are hourly averaged, we also carried out the above exercise with SymH and SymH* values, which too fail to account for the entire ring current.

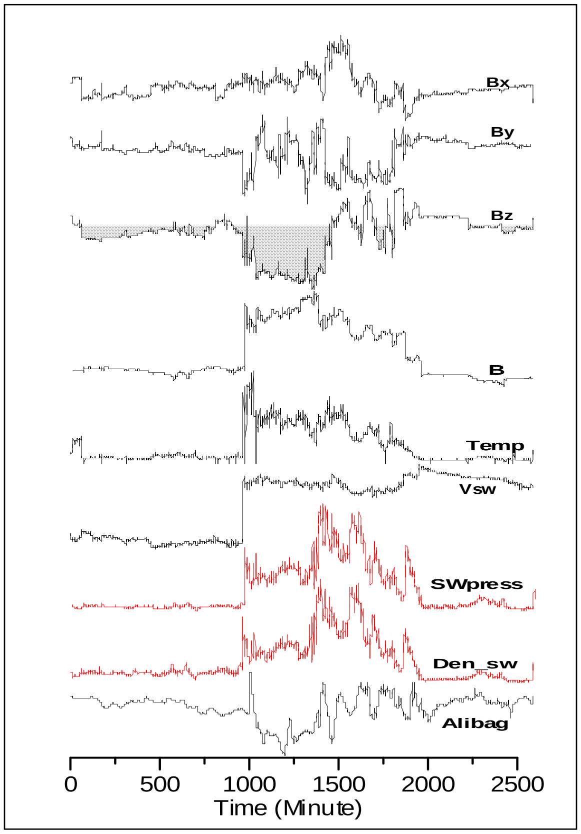

Fig. 4. Solar wind parameters and residual horizontal field at Alibag, during 6-7 Apr 2000.

3. Analysis

We use the fast Fourier transform (FFT) method with a time window of 48 hours (1-minute sampling, 2880 data) to calculate spectra of the ground magnetic field and solar dynamic pressure. Fig. 5 shows the power spectra for all three events, which signifies the presence of discrete frequencies.

Earlier researchers attributed these discrete frequencies observed in ground spectrum to the properties of the magnetosphere, such as size of the magnetospheric cavity, global Alfven wave speed profile, magnetic field profiles, mass density distributions, field line lengths, etc. However, we observe that these frequencies are also present in solar wind data, which is far upstream from the earth and hence can not be considered as dependent of magnetospheric features. These are solely inherent properties of solar wind.

The coherence (not shown here) is above 0.9 for the common peaks, particularly between 0.5 and 1 mHz. Global

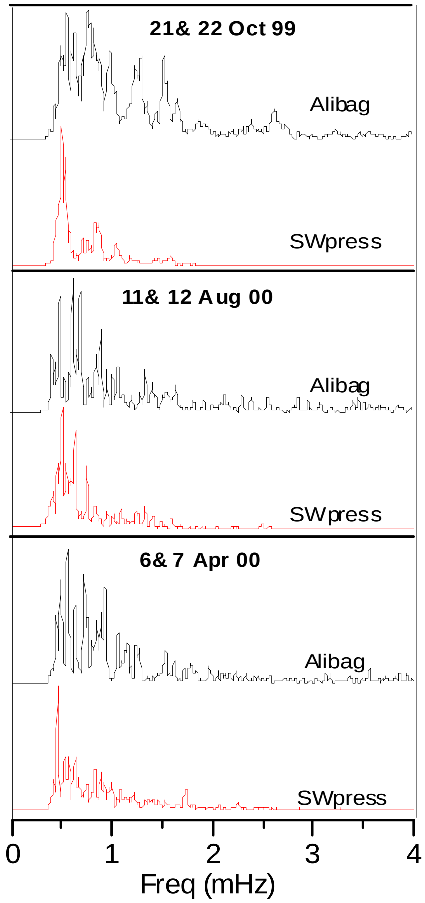

Fig. 5. Power spectra of H-component at Alibag and solar wind dynamic pressure for all three events.

magnetospheric oscillations with frequencies below 1 mHz are not uncommon and have been observed in both ground and radar measurements (Herron, 1967; Rinnert, 1996; Huang et al., 2001) and in magnetosphere (Nikutowski et al., 1996; Chen and Kivelson, 1991; Lessard et al., 1999). Therefore, we decided to use a narrow band-pass filter with the above two limits. One-minute observations were band-pass filtered using a zero phase infinite-duration impulse response (IIR) filter. Fig. 6 shows the time series of filtered solar wind dynamic pressure and geomagnetic H-component at Alibag, for all three events. Filtered time series in figure 6 shows a high degree of resemblance, suggesting that the bursts of solar wind density have clear marks at low latitude magnetic field measurements. While it is obvious from the Fig. 6 that the same source of oscillations are seen at ACE and ground, it is possible to get a quantitative confirmation by taking the correlation between the ACE solar wind parameters and ground magnetic field time series at various time lags. There are standard test for testing the significance for the level of peak correlation obtained in each event. This is better than 99 % in all the cases. The peak correlation is around 0.4. The time lag required for the maximum cross correlation (~ 40 minutes) indicates how much the filtered ground data has to be shifted backward in time to get the best correlation with the corresponding solar wind data.

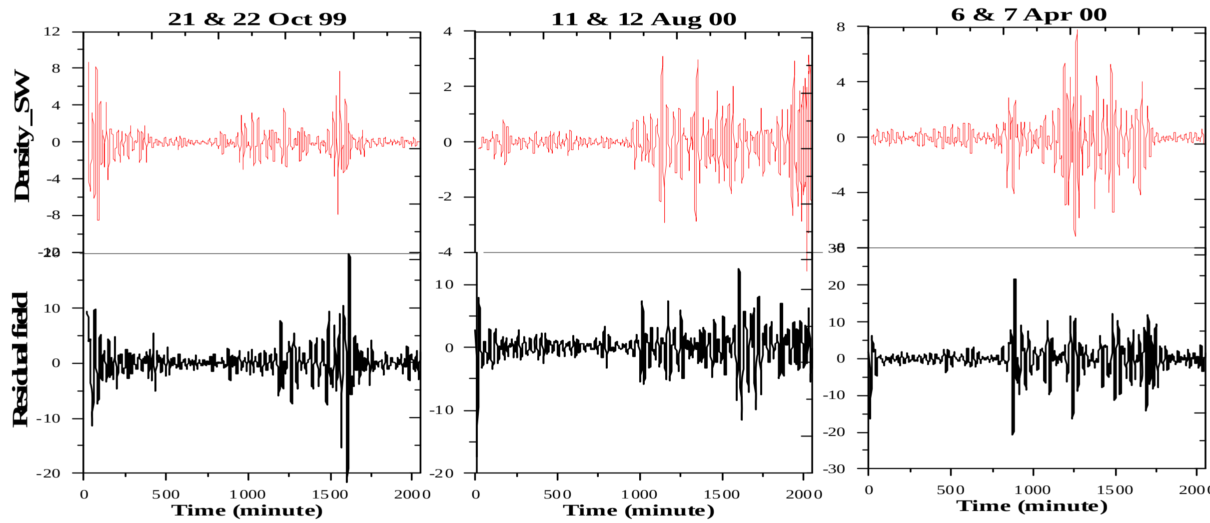

Fig. 6. Filtered time series of solar wind density and ground magnetic field for the band between 0.5-1 mHz.

4. Results and discussion

A high degree of correlation between the solar wind dynamic pressure computed using outer magnetospheric ACE satellite measurements and low latitude ground oscillation is found during the development and decay of geomagnetic storms. The duration of each event comprises two complete days, and hence the ground station moves through day and night globes. Despite this, in general, the correlation of low latitude ground magnetic fields with solar wind parameters is significant, which is a striking result of present analysis. The power spectrum reveals the presence of discrete frequencies, which are common for both solar wind parameters as well as the ground magnetic field. According to the global magnetospheric cavity and waveguide models (Kivelson and Southwood 1986; Harrold and Samson 1992; Walker et al. 1992), the discrete frequencies of oscillations recorded near earth are due to the properties of the magnetosphere. However, we observe that these frequencies are also present in solar wind data, which is far upstream from the Earth and hence can not be considered dependent on magnetospheric features. Hence, we can argue that discrete frequencies observed in the ground pulsations are due to solar wind pressure, which has nothing to do with any internal property of the magnetosphere. These findings are in accordance with, Kepko et al. (2002; 2003), which have also reported association of ULF pulsations with solar wind density. Filter analysis techniques illustrate that the bursts of solar wind density have clear marks at low latitude magnetic field measurements. Thus, provides direct evidence of solar wind impact at low latitude magnetic field variations.

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