Solar wind velocity and its control on low latitude Pc3 geomagnetic pulsations

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Abstract. Energy for the Earth's magnetospheric processes is provided by solar wind. Pc3 Geomagnetic pulsations are quasi-sinusoidal variations in the Earth's Magnetic field in the period range 10-45 seconds. The magnitude of these pulsations ranges from fraction of a nT (nano Tesla) to several nT. These pulsations can be observed in a number of ways. However the application of ground based magnetometer arrays has proven to be one of the most successful methods of studying the spatial structure of hydromagnetic waves in the Earth's magnetosphere. With few exceptions, the Pc3 studies undertaken in the past have been confined to middle and high latitudes. The spatial and temporal variations observed in Pc3 occurrence are of vital importance because they provide evidence which can be directly related to wave generation mechanisms both inside and external to the magnetosphere. At low latitudes ($L < 3$), wave energy predominates in the Pc3 band and the spatial characteristics of these pulsations have received little attention in the past. An array of four low latitude induction coil magnetometers was established in south-east Australia over a longitudinal range of 17 degrees at L=1.8 to 2.7 for carrying out the study of the effect of the solar wind velocity on these pulsations. Digital dynamic spectra showing Pc3 pulsation activity over a period of about six months have been used to evaluate Pc3 pulsation occurrence. Pc3 occurrence probability at low latitudes has been found to be dominant for the solar wind velocity in the range 400-700 km/sec. The results suggest that solar wind controls Pc3 occurrence through a mechanism in which Pc3 wave energy is convected through the magnetosheath and coupled to the standing oscillations of magnetospheric field lines.

Index Terms. Magnetospheric physics, Pc3 magnetic pulsations, Pc3 occurrence, solar wind velocity.

1. Introduction

Geomagnetic pulsations recorded on the ground are the signatures of the integrated signals from the magnetosphere. The solar wind provides the energy for the Earth's magnetospheric processes. Pc3-5 geomagnetic pulsations can be generated either externally or internally with respect to the magnetosphere. Examples of the external sources are the surface waves produced at the magnetopause by the Kelvin-Helmholtz instability, and waves generated at the bow shock or in the magnetosheath, all of which eventually propagate into the magnetosphere. The internal generation occurs by means of plasma instabilities within the magnetosphere. To date there is no comprehensive theory of internal excitations that could explain the external control which is compatible with observations and generally models for the external excitations are favoured. Greenstadt et al. (1983) have presented the first direct evidence for propagation of external Pc3 wave energy into the magnetosphere. They have shown that similar wave frequencies were observed simultaneously by ISEE-1 and ISEE-2 spacecraft in the magnetosheath and the outer magnetosphere respectively while lower power was seen within the magnetosphere. Furthermore using the data from GOES-2 satellite, Yomoto et al. (1984) have proposed that Pc3-4 wave energy is convected through the magnetosheath to the magnetopause, transmitted deep into the magnetosphere without significant changes in spectra, and then couple with various hydromagnetic wave modes in the magnetosphere.

There is ample evidence that the solar wind velocity controls some of the properties of Pc3-4 pulsations (Saito, 1964; Singer et al., 1977). In addition the direction of IMF also plays an important role in controlling these pulsations (Bolshakova and Troistakaya, 1968; Takahashi et al., 1981). Studies of the joint effect of the solar wind velocity (V_{sw}) and the angle of the interplanetary magnetic field from the sun-earth line (θ_{XB}) have shown that the amplitude (occurrence) and energy of Pc3-4 pulsations are positively and negatively correlated with V_{sw} and θ_{XB} respectively (Greenstadt et al., 1979; Wolfe, 1982).

The present study describes the dependence of low latitude Pc3 occurrence on V_{sw} over the period range of March 25 to May 11, 1982. Since IMF data was not available, the Pc3 occurrence dependence on θ_{XB} and the frequency dependence on the IMF magnitude could not be studied.

2. Data and analysis

Data acquisition involved the use of induction coil magnetometers employing digital analysis techniques. Four recording stations, three spaced in longitude and the two in latitude, were used. A geomagnetic longitudinal range of 17° was covered at L=1.8 and a latitudinal range of 10° over L=1.8 to 2.7. The stations were situated at Woomera (WM)

(41.7°S, 209.1°E geomagnetic), Broken Hill (BH) (42.4°S, 214.5°E), Newcastle (NC) (42.0°S, 226.3°E) and Launceston (LN) (52.4°S, 231.1°E).

The geomagnetic north-south (X) and east-west (Y) components of Pc3-4 wave signals in the 5-100 mHz were recorded using slow speed analog magnetic tapes employing frequency modulated recording system. Brief details of the recording and analysis instrumentation have been given by Ansari et al., (1985). Data from March 25 to September 21, 1982 were digitised in the laboratory with a 5 sec. sample rate using the recorded time channel pulses and providing a Nyquist frequency of 100 mHz. Digital sonagrams from the X(t) and Y(t) time series of all the data for each recording station over one day (25 hour) intervals were constructed using the Maximum Entropy Method (MEM) on 10 minute subsets overlapping by 5 minutes. A detailed analysis of the digital sonagram characteristics was then carried out and the duration of Pc3 occurrence to the nearest five minutes and the signal frequencies were determined for each station. This information was used to calculate the Pc3 occurrence probability and consequently study the control of V_{SW} on Pc3 pulsations.

3. Results

The hourly occurrence probability of Pc3 is defined in Fig. 1 and is based on a method developed by Saito et al., (1979). The daytime intervals from 0500 to 1900 hr AEST in the digital sonagrams are divided into fourteen hourly domains to eliminate local time effects. The hourly value of Pc3 occurrence probability, $P_{H,}$ is defined by the formula based on the shaded area A_S and hourly area A_H in the frequency time domain. The solar wind velocities were taken from IMP-8 data (King (1978-1982)). There were only 18 out of 48 days which provided common solar wind velocity and Pc3 occurrence.

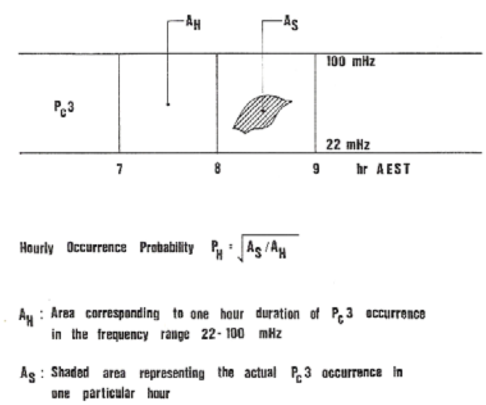
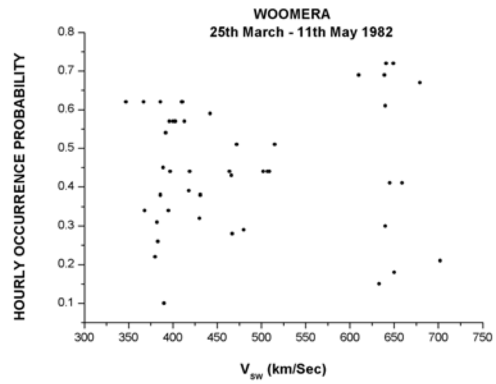
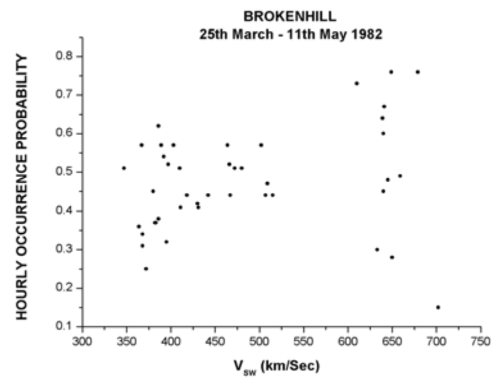


Fig. 1. Hourly occurrence probability of Pc3

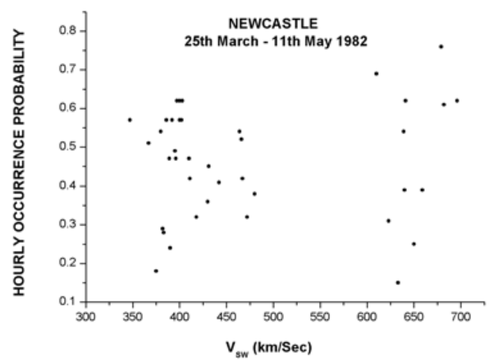
The dependence of Pc3 occurrence probability on the solar wind velocity at all the four stations over the 18 days is shown in Fig. 2. The results show a variable pattern with Pc3 occurrence at a value of V_{SW} ~ 400 km/sec followed by a gap between 520 and 610 km/sec and no occurrence over 700



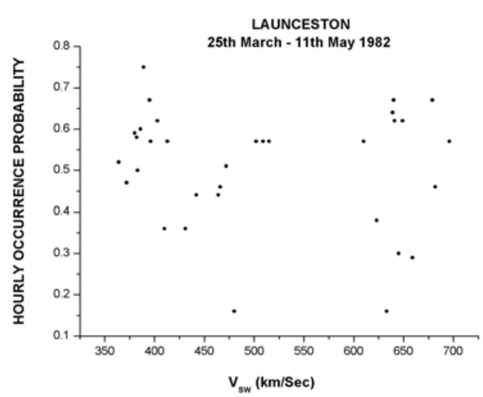
2.(a)



2. (b)



2. (c)



2. (d)

Fig. 2. The dependence of Pc3 occurrence probability on the solar wind velocity (V_{SW}) over 18 days in the duration March 25 to May 11, 1982 in the 0500-1800 hr AEST interval at WM (a), BH (b), NC (c), and LN (d).

km/sec. Over all velocity ranges, the Pc3 occurrence probability is uniformly high (≥ 50 %). The lack of Pc3 activity around V_{SW} = 600 km/sec may be due to the low occurrence of V_{SW} in this velocity range as illustrated in V_{SW} distribution shown in Fig. 3.

4. Discussion and conclusion

The dependence of Pc3 occurrence on V_{SW} found in the present study, based on a small data sample is in general agreement with previous studies on the ground (Greenstadt et al., 1979; 1980) and in space (Takahashi et al., 1981). Greenstadt et al. (1979) examined the maximum amplitude of Pc3 for solar wind parameter correlations, while the definition of occurrence of Pc3 pulsations in this study was based on the shape of the spectra. Gugliel'mi and Potapov (1994) have also reported similar results.

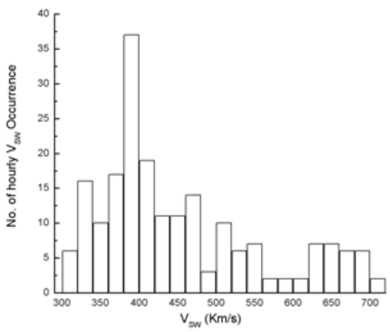


Fig. 3. Hourly occurrence of solar wind velocity (V_{SW}) over the period March 25 to May 11, 1982 in the 0500-1900hr AEST interval.

There are two possible locations for the external origin of pulsations, at the magnetopause, and upstream from the magnetopause. Surface waves generated by the K-H instability are important at the magnetopause (Southwood, 1968; Boller and Stolov, 1973). Upstream from the magnetopause large amplitude waves in the quasi parallel bow shock are swept back into the magnetosheath and then penetrate the magnetosphere and couple to the standing oscillations of the magnetospheric field lines (Greenstadt, 1972). This coupling may occur at all latitudes (Yumoto and Saito, 1983).

The characteristics of the waves excited by the K-H instability are dependent on the length of the field lines and the plasma density at the magnetopause (Chen and Hasegawa, 1974). The association of westward propagation of Pc3 waves with left hand (LH) ellipticity pre noon and eastward propagation with right hand (RH) ellipticity after noon for the azimuthal pair of stations (Ansari and Fraser, 1986) are consistent with the waves generated at the magnetopause by the K-H instability. The Pc3 noon peaks in occurrence (Ansari and Fraser, 1985), however, cannot be explained by this mechanism. It is also difficult to see how the externally excited evanescent surface waves with large damping rates can propagate deep into the magnetosphere and through the plasma pause to couple with the field line resonance at low latitudes. In addition the threshold velocity for the K-H instability involves the angle between the magnetic fields across the magnetopause. Hence on a statistical basis it is likely that the magnetopause is more unstable for higher solar wind velocity which is consistent with the present results, the contribution of θ_{XB} to Pc3 occurrence cannot be interpreted in the absence of IMF data.

The quasi-parallel shock transition has been found to be highly turbulent (Greenstadt et al., 1977). Furthermore the amplitude of bow-shock-associated waves seems to be dependent on the magnetosonic Mach Number (Formisano et al., 1973) and therefore on the solar wind velocity. The association of higher probability of Pc3 occurrence at low latitudes with higher solar wind velocity is therefore more likely to be a consequence of bow-shock associated waves. The results of Yumoto et al. (1984) support this mode of Pc3 wave generation and resonance. More recently Chugunova et al. (2003), using the data of search coil magnetometers from two Antarctic stations (sub-auroral Pc3), have found that the suggested idea about the possibility of two channels of the penetration of primary upstream turbulence, i.e., via the cusp and via the lobe flanks is statistically feasible. It is however obvious that further studies are needed, which include IMF data, in order to uniquely determine the external and internal contributions to the generation of Pc3 waves observed at low latitudes.

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