Correlation of Pc 3, 4, and 5 Activity With Solar Wind Speed

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Abstract: Positive correlations of magnetic pulsation amplitude with solar wind speed are found for Pc 3, 4, and 5 at both Calgary and Leduc. The data, obtained in September and October 1970, confirm and extend similar results found in an earlier interval for Pc 3, 4 at Calgary alone, thus adding further evidence for a velocity-controlled contribution, such as the Kelvin-Helmholtz instability, to pulsation activity.

INTRODUCTION

Observations have linked occurrence and intensity of medium-period geomagnetic pulsations \((T = 10-300 \, \text{s})\) to interplanetary magnetic field (IMF) orientation and solar wind speed \((V_{SW})\). The motivation for these observations is the belief that magnetospheric pulsations are excited by perturbations brought by the solar wind to the dayside magnetopause, where they may be amplified by the Kelvin-Helmholtz instability. Data supporting these notions are not easily obtained, so new cases, augmented statistics, and fresh approaches are being actively sought. The purpose of this brief report is to show that earlier results on the velocity correlation are confirmed when the same analysis technique is extended to a new data interval, a second station, and a third band of pulsation periods.

IMF orientation has been represented by latitude and longitude angles of the IMF, \(\lambda_n, \phi_n\), in the solar ecliptic (SE) system, and by angle \(\theta_{\lambda_n}\) between the IMF and \(V_{SW}\) or between the IMF and SE \(X\) axis as an approximation to the solar wind flow direction \((\cos \theta_{\lambda_n} = \cos \lambda_n \cos \phi_n)\). Pulsations appear when \(\lambda_n \approx 0^\circ\), \(\phi_n \approx 0^\circ\), \(180^\circ\), and \(\theta_{\lambda_n} \approx 50^\circ\) [Gu'elmi, 1974], and references therein; Nourry and Watanabe, 1973; Nourry, 1976; Webb and Orr, 1976; Greenstadt and Olson, 1977] and when these angles correlated positively with \(V_{SW}\) [Singer et al., 1977]. Most recently, efforts have focused on examining \(\theta_{\lambda_n}\) and \(V_{SW}\) together [Greenstadt et al., 1979, Wolfe et al., 1979].

Various techniques for defining pulsation activity and solar wind parameters have been employed, from isolating individual events to comparing power spectra and hourly averages. Our present study has examined correlations of Pc 3 and 4 at Calgary observatory with both \(\theta_{\lambda_n}\) and \(V_{SW}\), separately and jointly, as already cited. The study has also developed the application of hourly distributions of \(\theta_{\lambda_n}\) [Greenstadt and Olson, 1979], using satellite and ground data from September, October, and November 1969.

The new data interval was September–October 1970, which satisfied the criterion that recordings were still available from Calgary, permitting a cross-check for replication of previous results. The second station was Leduc Observatory, which was recording simultaneously slightly farther north (corrected geomagnetic latitude \(61.2^\circ\); \(L = 4.2\)) than Calgary \((58.7^\circ); \(L = 3.7\)). The third band of periods was 150–300 s, corresponding to Pc 5 pulsations. It had originally been intended to examine the correlations of \(\theta_{\lambda_n}\) as well as \(V_{SW}\) by using the new data, but the natural behavior of the IMF did not support the effort, as explained below.

DATA

Measurements of horizontal and vertical field variations made at Calgary and Leduc stations were passed through digital filters separating Pc 3, 4, and 5 frequency bands, and the maximal amplitude \(\delta B\), peak to peak, for each hour was used to represent the level of occurrence of magnetic pulsation activity during the hour. The hourly \(\delta B\) from the two stations were intercompared, axis by axis, for the entire data interval, to test whether activity at the two stations was alike.

The solar wind velocity data used in this study consisted of 3-hour averages from a merged Vela data set, including Vela's 2–6, which is described by King [1977a,b]. For comparison of pulsation activity with solar wind parameters the largest \(\delta B\) in either \(X\) or \(Y\) component each hour was used. Contributions of vertical (Z) components were always smaller and were not used. Corresponding IMF data registered by Explorer 35, in lunar orbit, were analyzed to find the percentile distributions of \(\theta_{\lambda_n}\) between \(0^\circ\) and \(90^\circ\) each hour. The distributions were used to separate groups of 'IMF-favorable' hours, i.e., most \(\theta_{\lambda_n}\) near \(0^\circ\), from 'IMF-unfavorable' hours, i.e., most \(\theta_{\lambda_n}\) near \(90^\circ\), for various percentile criteria. Only two really unfavorable hours were found in which all \(\theta_{\lambda_n} > 60^\circ\), and both were at low velocity, so favorable and unfavorable IMF orientation effects on the velocity dependence of \(\delta B\) could not be contrasted. Relaxation of the criterion of unfavorable conditions failed to improve these statistics in any useful way. Similarly, no dependence of \(\delta B\) on \(\theta_{\lambda_n}\) could be developed for either high or low velocities, since the unfavorable ends of the scale had no populations. Readers interested in further details of instrumentation or data handling procedures are referred to Greenstadt and Olson [1976, 1977, 1979], Singer et al. [1977], and Greenstadt et al. [1979].
RESULTS

Station correlations. The correlations of hourly peak amplitudes of $X$ components in Pc 3 and Pc 4 bands at Leduc and Calgary are displayed in Figure 1. Correlation coefficients were 0.498 and 0.79, respectively. Similar or better results were obtained for the other components and for Pc 5. The $Y$ components of Pc 3 and Pc 4 gave correlation coefficients of 0.679 and 0.865, respectively; the $X$ and $Z$ components of Pc 5 gave coefficients of 0.942 and 0.912 respectively. Hourly averages, rather than peaks, also yielded similar correlations.

Note that the slope of the Pc 4 plot in Figure 1 is >1.0. This was true also for the $Y$ axis of Pc 4 and for both $Y$ and $Z$ axes of Pc 5. Slopes of all component correlations of Pc 3 were <1.0.

Velocity correlations. We present the data in the same 'most favourable' format used by Greenstadt et al. [1979, Figure 3]. Scatter plots of $\delta B$ versus $V_{SW}$ are displayed for hours in which 50% or more of the $\theta_{SW}$ were within 30° of the $X$ axis. Figure 2 shows the scatter plots and least square lines for hourly maximal pulsation amplitudes versus hourly average $V_{SW}$ in Pc 3 and Pc 4 period ranges at both Calgary and Leduc observatories. The dashed lines are the linear least square best fits found for the earlier data from September–November 1969 [Greenstadt et al., 1979, Figure 3]. The correlations were weaker at Calgary in the 1970 interval than in the 1969 interval, although stronger for Pc 4 than for Pc 3, just as in the earlier study. The correlations at Leduc were as strong (Pc 4) or stronger (Pc 3) than at Calgary. In fact, the present Pc 3 correlation at Leduc was stronger than the Pc 3 correlation at Calgary for the 1969 interval.

Scatter diagrams for Pc 5 are shown in Figure 3. Correlations of amplitude with velocity were clearly strong at both stations.

DISCUSSION

Both Calgary and Leduc stations are at magnetic latitudes corresponding, on average and depending on the signal period, to a strong latitude gradient in pulsation amplitude, with the maximum somewhere northward of both observatories [Samson et al., 1971; Wertz and Campbell, 1976]. Our best fit lines having slopes of >1 for Pc 4 and 5 were consistent with this latitude effect. The original choice of Calgary, the southernmost of the University of Alberta chain of stations, as the surface instrument for our earlier analysis, was based on a desire to depart no more than necessary from the latitude of Borok (53°), the station used for similar analyses by Soviet workers [Greenstadt and Olson, 1976, 1977, and references therein]. We also desired to avoid possible confusion introduced by highly geomagnetically active auroral phenomena. The rather clean results obtained here from Leduc plus the well-known increase in Pc 3, 4 amplitudes with approach to auroral latitudes, suggest that stronger correlations with solar wind parameters of the type that we are studying might be obtained by using data from stations still further north than Leduc, bearing in mind that the best station at any particular time might depend on local time [Samson et al., 1971] and overall geomagnetic activity. The data used in this report all came from relatively inactive conditions, i.e., $|A_p| \leq 19$. In fact, 7 out of 18 hours in Figures 2 and 3 were designated Q or QQ (NOAA, solar geophysical data). The position of Leduc, incidentally, is comparable to the northernmost observatory utilized by Webb and Orr [1976].

It is important to note that Pc 3 correlations of Calgary and Leduc did not show the same, let alone a more pronounced, slope effect, particularly in view of the report by Fukunishi and Lanzerotti [1974], who found Pc 3 larger than Pc 4 when
L ≥ 4. Also, the correlation of Pc 3 amplitudes with velocity was much poorer than the correlations found for the earlier data interval or for the other bands in this data interval. The limited range of Pc 3 and the smaller population of points may have combined to obscure the velocity dependence for these relatively small pulsations. However, these deficiencies and inconsistencies in the Pc 3 results probably underscore an inherent methodological difficulty in pulsation analysis: there can be multiple resonances at separate latitudes in the plasma-pause-plasmapause region for any given Pc period range, and any particular resonance will appear at different latitudes at different times, depending on magnetic activity [Orr and Webb, 1975] and local time [Orr, 1979]. Orr [1979, Figures 1 and 3] illustrates these problems clearly. It may be necessary to extract a Pc 3 'index' from recordings at several stations to obtain a quantifiable measure of signal activity comparable with itself on the same base line from one day to the next.

Certainly for the Pc 4 band the earlier B versus V sw results are confirmed here, as they have also been by Wolfe et al. [1979], who analyzed data from a station at Pittsburg, New Hampshire (L = 3.5). Thus the contribution of the velocity-dependent Kelvin-Helmholtz mechanism to pulsation generation remains consistent with measurement, on application of the previous analytic technique to a new data interval. This consistency adds to the persuasiveness of the Kelvin-Helmholtz model, at least under favorable conditions of IMF orientation, and is reinforced by the correlations obtained here in the Pc 5 band, which encompassed the periods expected from this model [Atkinson and Watanabe, 1966; Southwood, 1968; Chen and Hasegawa, 1974]. However, alternative models, less developed quantitatively than Kelvin-Helmholtz, are by no means ruled out. Russell and Elphic [1979] have proposed a dayside flux transfer process as a possible source of pulsations at the magnetopause, and of course the perverse possibility persists that elevated V sw is so correlated with reduced latitudes of the auroral edge of the closed part of the dayside magnetosphere that at any fixed station, dB rises with V sw regardless of pulsation origin, simply because of increased sensitivity of the station. Confirmation, and further study, of the dependence of dB on IMF orientation will have to await a more extensive and varied data population than was provided by the September–October 1970 interval.

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