A comprehensive survey of auroral latitude Pc5 pulsation characteristics

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[1] We surveyed 10 years of CANOPUS Churchill line magnetometer data for Pc5 pulsations and catalogued over 4500 hours of pulsation activity (3334 Pc5 pulsation intervals). Many previously observed Pc5 pulsation characteristics are evident in our data including the dawn/dusk occurrence asymmetry, antisunward propagation patterns, strong correlations between Pc5 band power spectral density (PSD) and solar wind flow speed, increased Pc5 pulsation occurrence during times of high solar wind speeds, and statistical evidence for Pc5 pulsation polarization sense reversals in latitude and local time (across local noon). Our investigation also revealed some as of yet unreported results such as a good correlation between solar wind speed/Pc5 band PSD in all MLT sectors, increased Pc5 pulsation occurrence with IMF Bz northward conditions (for all MLTs), and the prevalence of Pc5 pulsations under all Pc5 band relative power values. We used a subset of 800 data intervals which contained Pc5 pulsations in at least three Churchill line stations to search for pulsations that exhibit classic FLR characteristics. Four hundred and fifty of these pulsations matched the FLR criteria and we discovered that the FLR MLT occurrence distribution is asymmetric about local noon with more pulsations occurring in the morning sector (0600–1200 MLT) than the afternoon sector (1200–1800 MLT), and an absence of FLRs at local noon. We also found that the MLT occurrence distribution for the remaining 350 “non-FLR” pulsations is symmetric about local noon and has a (nonzero) local minimum at noon. In contradiction with the results of some previous studies, we find no evidence of stable, recurring, discrete Pc5 pulsation frequencies in our data set. Instead, our statistics show a continuous distribution of central frequencies and a general lack of frequency stability throughout the course of individual Pc5 pulsation events.

INDEX TERMS: 2784 Magnetospheric Physics: Solar wind/magnetosphere interactions; 2752 Magnetospheric Physics: MHD waves and instabilities; 2431 Ionosphere: Ionosphere/magnetosphere interactions (2736); 2435 Ionosphere: Ionospheric disturbances; KEYWORDS: ULF waves, solar wind/magnetosphere interactions, field line resonance, magnetospheric cavity modes, Kelvin-Helmholtz instability, magnetometer data


1. Introduction

[2] Ground-based magnetic pulsations in the Pc5 frequency band (1.67–6.67 mHz) are produced by magnetospheric ULF (ultra-low frequency) waves. They are thought to play a role in mass and energy transport and in the production of discrete auroral arcs [Samson et al., 1996]. As the characteristics of these waves are determined to a large extent by the length of and plasma distribution along magnetic flux tubes, they often provide a quantitative means of remote-sensing magnetospheric parameters, such as the radial distribution of the inner-magnetospheric equatorial plasma density [Waters et al., 1995]. For all of this, Pc5 pulsations have attracted significant attention and have been explored through theory, simulation, and observation.

[3] Here, we report on the results of an extensive survey of Pc5 waves in the CANOPUS (Canadian Auroral Network for the OPEN Unified Study) magnetometer data set. In this study, we carried out a detailed search of the CANOPUS magnetometer data and identified 3334 clear examples of quasi-monochromatic Pc5 pulsations according to the criterion described in section 2. To the best of our knowledge, this is the most extensive such survey ever undertaken, and the resulting data set of Pc5 pulsations provides us with an excellent tool with which to study essentially all properties of Pc5 pulsations. In particular, we focus our attention on the latitude and MLT (magnetic local time) distributions of properties of Pc5 pulsations that shed light on the source of these waves. We also report on the distribution of frequencies of these pulsations.
[4] In the remainder of the introduction, we provide a review of the literature that forms the framework for the interpretation of our results. We begin with the body of work related to the existence (or lack thereof) of discrete, stable, recurring pulsation frequencies and end with a review of studies related to the source or sources of these pulsations. In sections 2 and 3 we describe our data analysis and results, respectively. In section 4 we discuss our results within the context of the material presented in the introduction.

1.1. Stable, Recurring Pulsation Frequencies

[5] In the FLR (field line resonance) model [Southwood, 1974; Chen and Hasegawa, 1974], compressional mode magnetic waves propagating in the near-Earth magnetosphere mode couple into transverse magnetic standing waves on closed magnetic field lines. Each field line has its own set of discrete resonant frequencies which are inversely proportional to the field line “length” (observationally confirmed by Takahashi and Russell [1982] and Takahashi et al. [1984] with in situ measurements). Band energy inputs should produce higher-frequency pulsations for decreasing field line lengths (decreasing magnetic latitude). Satellite observations have demonstrated the existence of such broadband energy, but Pc5 pulsations observed in ground-based magnetometer and HF (high frequency) radar data rarely exhibit this frequency spreading [McDiarmid and Allan, 1990; Ziesolleck and McDiarmid, 1995]. A possible solution to this inconsistency was offered by Kivelson et al. [1984], who suggested that the magnetosphere might ring as a whole with its own set of eigenfrequencies (the cavity mode model). Kivelson and Southwood [1985, 1986] further developed this idea, postulating that a frequency-dependent turning point and the magnetopause form the inner and outer boundaries of this cavity, respectively. The model predicts energy transport from the magnetopause to the turning point for waves that propagate with the cavity eigenfrequencies (which are determined by magnetospheric boundary conditions). Compressional waves that reach the turning point are partially transmitted, and the transmitted portion evanescently decays in the region beyond the turning point before coupling into transverse magnetic waves. Cavity eigenfrequency estimates were made during these studies, but they yielded values above the Pc5 frequency range.

[6] Samson et al. [1991] used ground-based magnetic field and HF radar data and a box model of the magnetosphere to further explore the cavity mode mechanism. They used data from six 7-hour intervals that spanned local midnight in the CANOPUS magnetometer data and the early morning sector in the Goose Bay HF radar data. Their analysis of these intervals demonstrated the existence of four frequency bands which contained discrete, recurring frequencies with stabilities of ±5% over several hours (1.3, 1.9, 2.6, and 3.4 mHz). They constrained the magnetospheric box model with data from a previous study [Samson and Rostoker, 1972] (to incorporate the relation between FLR frequency and magnetic latitude) and found that the first four cavity mode harmonics predicted by the model corresponded to their observed frequencies. These are the “CMS frequencies” (cavity mode model of Samson et al. [1991]) [Ziesolleck and McDiarmid, 1994, 1995; Mathie et al., 1999].

[7] Samson et al. [1992a] and Walker et al. [1992] modified the cavity mode model further, postulating that the magnetopause is a semi-infinite, open-ended waveguide and used one event from those analyzed by Samson et al. [1991] to demonstrate that the new model remained consistent with the CMS frequencies. Harrold and Samson [1992] proposed a model where the bowshock was used as the outer boundary of the waveguide and demonstrated that their model was also consistent with the CMS frequencies. Samson et al. [1992b] and Xu et al. [1993] provided additional evidence of CMS frequencies with periodic fluctuations in auroral arc intensity. Further support for the CMS frequencies was provided by Fenrich et al. [1995] who studied 12 FLR events with SuperDARN data. Their results indicated that the CMS frequencies were prevalent at all magnetic local times.

[8] Ziesolleck and McDiarmid [1995] conducted a statistical study that addressed the repeatability of FLR frequencies. In contrast to the event studies listed above, their results demonstrated that while FLRs occur with the same frequency at all latitudes, they do not preferentially occur at the CMS frequencies. In fact, Ziesolleck and McDiarmid [1995] proposed three new sets of discrete frequencies which might be more prevalent. More recent Pc5 pulsation studies have also addressed the subject of stable, repeatable, discrete frequencies. Mathie et al. [1999] found that the CMS frequencies were prominent in their 137 pulsation events but were unable to confirm that the frequencies were stable. Chisham and Orr [1997] found no evidence of the CMS frequencies in their 129 events but did find a set of recurring frequencies that were consistent with one of the frequency sets proposed by Ziesolleck and McDiarmid [1995].

[9] Despite the large body of work that has been conducted on Pc5 pulsation characteristics the issue of stable recurring frequencies remains controversial. It seems reasonable that the magnetospheric cavity can support its own eigenfrequencies and that the CMS frequencies or other discrete frequency sets could be a specific realization of the waveguide modes. However, pulsations are observed under a large range of solar wind conditions and thus a large set of magnetospheric configurations. Varied magnetospheric topologies correspond to varied boundary conditions applied to the waveguide and should in turn change the eigenfrequency solutions.

1.2. Pulsation Source Mechanisms

[10] One likely source mechanism for Pc5 pulsations is surface wave activity at the magnetopause, which is a possible consequence of Kelvin-Helmholtz instabilities (KHI) [Southwood, 1968; Olson and Rostoker, 1978; Rostoker and Sullivan, 1987; Engebretson et al., 1998]. The Pc5 pulsation polarization pattern identified by Samson et al. [1971] and Samson [1972] can be explained by KHI-generating compressional mode waves that propagate through the magnetosphere and couple to FLRs [Southwood, 1974; Chen and Hasegawa, 1974]. The cavity mode model provided a mechanism to convert broadband compressional mode waves generated by KHI processes into monochromatic waves (with the cavity eigenfrequency) and reconciled the broadband KHI energy inputs with the monochromatic pulsations observed on the ground. KHI processes can also explain the dependence of
Pc5 pulsation characteristics on solar wind parameters. For instance, Miura [1995] used a two-dimensional model to show that magnetopause KHI activity is more likely to occur under conditions of northward, rather than southward, IMF. More recently, Engebretson et al. [1998] demonstrated the presence of increased Pc5 band power during high-speed solar wind streams and explained their results through a simple KHI simulation. KHI activity also offers an explanation for the dawn/dusk asymmetry in Pc5 pulsation occurrence which was first observed by Gupta [1975]. Lee and Olson [1980] suggest that the infrequency of duskside KHI processes is due to the IMF Parker spiral angle at the Earth which yields larger magnetic field of duskside KHI processes is due to the IMF Parker spiral ward, IMF. More recently, they demonstrated the presence of increased Pc5 band power during high-speed solar wind streams and explained their results through a simple KHI simulation. KHI activity also offers an explanation for the dawn/dusk asymmetry in Pc5 pulsation occurrence which was first observed by Gupta [1975]. Lee and Olson [1980] suggest that the infrequency of duskside KHI processes is due to the IMF Parker spiral angle at the Earth which yields larger magnetic field tensions (on average) at the dusk flank. As well, Miura [1992] asserted that KHI activity could be preferentially excited on the dawn flank due to the more turbulent dawnside magnetosheath flows.

A recent study has incorporated both the waveguide/cavity mode theory and magnetopause instabilities into a single model [Mann et al., 1999]. They treated the magnetopause as a freely moving (outer) boundary to the magnetospheric waveguide cavity and postulated that the ability of the cavity to trap waveguide modes is strongly dependent on the magnetosheath flow speed. With this model they simulated the development of waveguide modes in the magnetospheric cavity under three magnetosheath flow regimes. Low magnetosheath flow speeds resulted in an inability of the magnetopause to completely reflect waves back into the cavity, and as a result, waveguide modes were rarely trapped. This low flow speed feature accurately predicts the observed rarity of Pc5 pulsations at local noon [Olson and Rostoker, 1978]. Moderate flow speeds led to stable conditions where the magnetopause became a good reflector, and the magnetospheric cavity consistently trapped waveguide modes. High flow speed conditions gave rise to what Mann et al. [1999] call “overreflected waveguide modes,” which result when the magnetopause becomes unstable to shear flow instabilities. Their simulations also showed that overreflected waveguide modes yield much larger amplitudes than the waveguide modes trapped under lower flow speed conditions.

Mann et al. [1999] asserted that the dawn/dusk asymmetry could be explained in the context of their model by a depletion of duskside overreflected waveguide modes (which they supported with the stability arguments of Lee and Olson [1980] and Miura [1992]). They also estimated the lower cutoff for magnetosheath flow speeds leading to overreflected waveguide modes to be 500 km/s. Spreiter and Stahara [1980] have indicated that magnetosheath flow speeds near the magnetospheric flanks are reasonably approximated by the solar wind radial flow speed. As a result, the overreflected waveguide mode pulsations should occur predominantly during high solar wind speed events. Moderate flow speeds on the other hand, should produce a symmetric pulsation occurrence distribution about local noon within this model if the condition for magnetopause reflection is independent of IMF angle.

2. Data Analysis

The CANOPUS magnetometer array consists of 13 fluxgate magnetometers deployed across northern Canada (Figure 1). Each instrument records the magnetic field strength in the X (geographic north-south), Y (geographic east-west), Z (vertical) coordinate system eight times per second with a resolution of 0.025 nT. Owing to telemetry bandwidth restrictions, the 8 Hz data is filtered and averaged to yield a 0.2 Hz (5 s) data set. There is one magnetically east–west aligned array of magnetometers (five stations) and one magnetically north-south aligned array (seven stations, called the “Churchill line”). Table 1 contains the station names, geodetic coordinates, and PACE geomagnetic coordinates for the East–West and Churchill line stations.

We assembled a 1870 day data subset from 10 years of CANOPUS magnetometer data (1989–1999). Each day contained 24 hours of data (0000–2400 UT) that was free of data gaps, steps, and spikes in at least five of the seven Churchill line stations. For each 45 min data window in this subset we calculated the Pc5 band power spectral density (PSD) and relative power. Pc5 band relative power values were obtained by performing the Fourier transform of a Hanning windowed data interval and calculating the ratio of the integrated power in the Pc5 spectral band (1.67–6.67 mHz) to the integrated power across all frequencies up to the Nyquist frequency (0.1 Hz). Similarly, Pc5 band PSD values were found by dividing the integrated power in the Pc5 band by the Pc5 band spectral bandwidth (5 mHz).

For each day of data we plotted an exponential of relative power as a function of UT and identified the (two to

Table 1. PACE Geomagnetic Coordinates and Geodetic Coordinates (in Brackets) for the CANOPUS East-West Line and Churchill Line Magnetometer Stations

<table>
<thead>
<tr>
<th>Station Code</th>
<th>Station Name</th>
<th>Latitude (deg)</th>
<th>Longitude (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pin</td>
<td>Pinawa</td>
<td>61.2 (50.2)</td>
<td>328.4 (264.0)</td>
</tr>
<tr>
<td>idl</td>
<td>Island Lake</td>
<td>64.9 (53.9)</td>
<td>329.7 (265.3)</td>
</tr>
<tr>
<td>gil</td>
<td>Gillam</td>
<td>67.4 (56.4)</td>
<td>329.1 (265.4)</td>
</tr>
<tr>
<td>chu</td>
<td>Fort Churchill</td>
<td>69.7 (58.8)</td>
<td>329.2 (265.9)</td>
</tr>
<tr>
<td>esk</td>
<td>Eskimo Point</td>
<td>71.9 (61.1)</td>
<td>328.4 (266.0)</td>
</tr>
<tr>
<td>ran</td>
<td>Rankin Inlet</td>
<td>73.7 (62.8)</td>
<td>331.0 (267.9)</td>
</tr>
<tr>
<td>tal</td>
<td>Taloyoak</td>
<td>79.7 (69.5)</td>
<td>323.6 (266.5)</td>
</tr>
<tr>
<td>daw</td>
<td>Dawson</td>
<td>65.9 (64.1)</td>
<td>269.9 (220.9)</td>
</tr>
<tr>
<td>sim</td>
<td>Fort Simson</td>
<td>67.6 (61.8)</td>
<td>290.1 (238.8)</td>
</tr>
<tr>
<td>smi</td>
<td>Fort Smith</td>
<td>67.9 (60.0)</td>
<td>302.7 (248.1)</td>
</tr>
<tr>
<td>rab</td>
<td>Rabbit Lake</td>
<td>67.8 (58.2)</td>
<td>315.0 (256.3)</td>
</tr>
</tbody>
</table>
four) time intervals which contained the highest relative power levels during that day. We performed this procedure independently for each station and manually inspected the selected data intervals in the time domain (which ranged from 20 min to 8 hours in length) for Pc5 pulsations. Before classifying a magnetic disturbance as a Pc5 pulsation we required that (1) it have an amplitude of greater than 0.5 nT and a frequency in the Pc5 spectral range (1.67–6.67 mHz), (2) it execute at least four complete cycles, and (3) its amplitude not be monotonically damped or growing in time (as is the case for some irregular pulsations [Saito, 1978]). In total, we identified 3334 Pc5 pulsations from the Churchill line data that satisfied these selection criteria. We used this manually identified pulsation data base in conjunction with the automatically calculated Pc5 band PSD and relative power values to investigate the feasibility of utilizing Pc5 band PSD and relative power as proxies for Pc5 pulsation activity (section 3).

[16] In addition, we were able to determine the polarization characteristics of 2698 Pc5 pulsation events (in the XY-plane) using the pure state filtering technique of Samson [1973]. To specify a single set of polarization parameters for each pulsation, we determined a characteristic frequency for each event. To do this we defined the “pulsation spectral band” to be a range of frequencies (that at least partially overlaps with the Pc5 spectral band) whose power spectrum rises significantly (at least two orders of magnitude) above the background power curve (see the bottom panel of Figure 14). The frequency that we used to calculate pulsation polarization characteristics was identified by the global power maximum within the pulsation spectral band. We refer to this as the “central frequency” of the pulsation. All of the pulsation intervals used in our polarization analysis exhibited a single, well characterized central frequency (i.e., the 636 pulsation events excluded from this polarization analysis either (1) exhibited multiple frequency components or (2) did not contain a localized region of significantly increased power).

[17] Pc5 pulsation azimuthal propagation characteristics can be determined using azimuthal wavenumbers or “m numbers.” In order to obtain a reliable m number estimate from ground-based magnetometer data three (or more) stations that are unevenly spaced along a line of constant magnetic latitude are required. Owing to possible spatial aliasing, there is always uncertainty in m number determinations [Chisham and Mann, 1999]. However, previous studies with station spacings similar to any three adjacent CANOPUS East-West line stations have shown that ground-based pulsations are primarily a low m number phenomenon [Chisham and Orr, 1997; Mathie et al., 1999]. In addition, Yeoman et al. [1990] have shown that lower m number events lead to more effective coupling to FLRs and thus should be observed on the ground more often than high m number events. Therefore we presumed that all events are low m number events (i.e., N = 0 in equation (2) of Chisham and Mann [1999]) and used three adjacent East-West line stations (not the same ones in each case) to obtain three m number estimates (one per station pair) for each event. We only accepted the m number determinations if the dispersion of the three station pair estimates was less than 2. From each set of acceptable m number estimates we took the median value to be the “true m number” for that event. This and the East-West line station spacing imposes a constraint on the largest m number that we can confidently resolve (|m| ≤ 15, see Chisham and Mann [1999]).

[18] We selected intervals from our pulsation data base for which there was pulsation activity in three adjacent East-West line stations. There were 515 such intervals that could potentially yield pulsation m numbers, and we were able to calculate reliable m numbers for 255 of these intervals. We also determined an ionospheric phase speed for each m number using $v_{ph} = 2\pi f R_e \cos(\lambda)/m$, where $\cos(\lambda)$ is the cosine of the magnetic latitude, and f is the central frequency.

3. Observations

3.1. Pc5 Pulsation Occurrence Characteristics

[19] The 1870 day data subset described at the beginning of section 2 is comprised of 24 hour data intervals which start at 0000 UT and end at 2400 UT. As a result of this and our requirement that all Pc5 pulsations execute at least four complete cycles, there is a region of time spanning 2400 UT where we could not identify short duration pulsations. To avoid misrepresenting Pc5 pulsation characteristics in this region, we omitted a half-hour interval on either side of 2400 UT from our analysis.

[20] Figure 2 is a plot of Pc5 pulsation occurrence as a function of magnetic local time and latitude. The top left panel indicates the probability of observing a pulsation in at least one Churchill line station during a specified minute of the day. The dawn/dusk occurrence asymmetry reported by Gupta [1975] is clearly evident in this plot. The bottom left panel displays the probability of observing (at least) one pulsation per day at each Churchill line station. Pc5 pulsation occurrence peaks at (or near) Fort Churchill and tapers off asymmetrically with latitudinal distance from Fort Churchill. The asymmetric shape of the histogram is a result of rapidly increasing L-values for higher-latitude stations. The absence of pulsations at Taloyoak is due to the fact that the station is almost always poleward of the open/closed field line boundary.

[21] The sequence of panels on the right side of Figure 2 are the autoscaled (to unit area) Pc5 pulsation occurrence distributions as a function of MLT for each station (Taloyoak is omitted due to the absence of Pc5 pulsations). Two general trends are present: (1) there is a convergence of the occurrence peaks towards local noon with increasing latitudes (starting at Gillam), and (2) there is a general reduction in the statistical scatter of the MLT distributions with increasing latitude (note that more pulsations are observed at Island Lake than Rankin Inlet (see bottom left panel)).

3.2. Relative Power and Pc5 Band PSD

[22] The top panel of Figure 3 shows the autoscaled (to unit area) relative power distributions, compiled from all stations, for data intervals strictly containing Pc5 pulsations, as well as for the intervals that do not contain the pulsations. In the absence of Pc5 pulsations the relative power values are usually quite small. Conversely, the relative power for pulsation intervals is generally quite large. However, both distributions (pulsation times and nonpulsation times) have nonnegligible probabilities of obtaining the opposite out-
come. Thus high relative power by itself is an imperfect proxy for Pc5 pulsation activity. This property is accentuated in the bottom panel of Figure 3, where morning sector pulsations (0600–1200 MLT) tend toward large relative power values as predicted in the top panel, but afternoon sector pulsations (1200–1800 MLT) are almost as likely to have low relative power values as high ones.

Figure 4 displays dial plots of Pc5 band PSD for (a) all hourly data intervals in the 1870 day data subset, (b) hourly data intervals containing Pc5 pulsations only, and (c) hourly data intervals without Pc5 pulsations. Local noon is located at the top of the page, MLT labels are present on the outside of the outer circle in each dial plot, and magnetic latitude labels are given by the smaller numbers on the inner edge of every second circle. We remind the reader at this point that the data used in this study extends from 61° to 79° magnetic latitude. The presence of a premidnight peak and the absence of an afternoon sector PSD peak in Figure 4a demonstrates the limitations of this quantity as a proxy for the occurrence of Pc5 pulsations. Pc5 band PSD does however convey useful information about the amplitude of Pc5 pulsations.

Vennerstrøm [1999] produced a dial plot similar to our Figure 4a using magnetometer data from 20 stations in Greenland, Scandinavia, and Canada. She attributed the premidnight PSD peak to substorm activity and the morning sector peak to a combination of Pc5 pulsation activity and “transient signatures” such as magnetic impulse events (MIEs). We have confirmed the latter half of this claim empirically. Figure 4b shows that the largest amplitude Pc5 pulsations occur in the morning sector. Figure 4c demonstrates that in the absence of Pc5 pulsations the morning sector Pc5 band PSD disappears, with the exception of a region between 65 and 70 degrees geomagnetic latitude near 0500 MLT. We examined the 30 data intervals which contributed the most power to this region and found transient events that include rapid increases which form step-like structures in the magnetic data (up to 600nT over 10 min), irregular pulsations, and bipolar signatures (i.e., travelling convection vortices) that have periods in the Pc5 spectral band.

In order to obtain a magnetospheric context for Pc5 pulsation excitation regions, we mapped the PSD and pulsation occurrence distributions into the equatorial plane using the T87 model [Tsyganenko, 1987]. We subdivided the Pc5 pulsation occurrence statistics (right side of Figure 2) and the PSD distributions for all data intervals (Figure 4a) into three $K_p$ groups: low ($0 < K_p < 2$), middle ($2 < K_p < 3$), and high ($K_p > 3$). We mapped the low, middle, and high $K_p$ data into the equatorial plane using $K_p = 1, 3, 5$ models, respectively. The results are shown in Figure 5. The dotted contours show the equatorial projection of the geomagnetic latitudes for, with increasing distance from the Earth, Pinawa, Gillam, Fort Churchill, and Rankin Inlet.

Figure 2. Pc5 pulsation MLT and latitude occurrence distributions. The panels on the right display the autoscaled (to unit area) MLT distribution for each Churchill line station.

Figure 3. Normalized histograms of Pc5 relative power (1.67–6.67 mHz) are shown for pulsation and non-pulsation times (top) and morning/afternoon sector pulsation times (bottom).
Afternoon sector pulsations are seen to occur primarily during low $K_p$ conditions, while morning sector pulsations exist under all $K_p$ conditions. This $K_p$ trend is not an artifact of our search technique, as we did not set an (arbitrary) minimum relative power threshold for the data intervals investigated for Pc5 pulsations. This means that small-amplitude pulsations occurring during magnetically active times are not systematically removed from our survey. The morning sector results in Figure 5 are suggestive of Pc5 band power on closed field lines which are excited by compressional energy transmitted from disturbances on the dawnside magnetopause.

3.3. Solar Wind Influences

[26] As mentioned in section 1.2, the source mechanism that has received the most attention is surface instabilities occurring at the magnetopause (such as KHI) [Southwood, 1968; Olson and Rostoker, 1978; Rostoker and Sullivan, 1987; Engebretson et al., 1998]. If ground-based pulsations are the result of this instability activity, then it is likely that Pc5 pulsation characteristics would depend on solar wind conditions.

[27] To investigate the possibility of relationships between pulsation occurrence and solar wind parameters, we sorted each hour of data from the CANOPUS subset into categories corresponding to different concurrently measured solar wind conditions. We obtained the probability of a pulsation occurring during a given set of solar wind conditions by identifying all pulsation hours within a given MLT hour that occur during the specified solar wind conditions, determining the total number of hours within the same MLT hour with the same solar wind conditions, and dividing the number of pulsation hours by the total number of hours for each hourly MLT bin. We investigated many different solar wind parameters (i.e., IMF components, dawn/dusk electric field magnitude, flow speed components, and solar wind dynamic pressure, etc.) and found that of the parameters we analyzed, only the radial flow speed, proton number density, and IMF $B_z$ had any affect on Pc5 pulsation occurrence. Further investigation revealed that the solar wind proton number density dependence resulted from an anticorrelation between number density and solar wind radial flow speed. Figure 6 shows the results of the other two pulsation occurrence dependencies. The top panel of Figure 6 demonstrates that morning sector pulsations occur during high solar wind speed conditions while afternoon sector pulsation occurrence is virtually independent of solar wind speed. The results in the bottom panel show that pulsations are more likely to occur when IMF is northward, rather than southward, at all local times. The results of Junginger and Baumjohann [1988], who observed a correlation between morning sector Pc5
pulsation occurrence and high solar wind speeds, and Rostoker and Sullivan [1987], who found that afternoon sector pulsations occurred more frequently for IMF \(B_z\) northward conditions, are consistent with, and a subset of, our results.

[28] In addition to Pc5 pulsation occurrence, we investigated the dependence of Pc5 band PSD on the same solar wind speed parameters for all magnetic local times. The only independent parameter that correlated well with PSD was the solar wind radial flow speed (Figure 7). Using data from Fort Churchill we obtained a linear correlation coefficient of \(r = 0.72\) in the morning sector (0600–1200 MLT) which is consistent with the previously reported results of Engebretson et al. [1998] \((r = 0.74)\) and Vennerstrøm [1999] \((r = 0.73)\). Our afternoon sector (1200–1800 MLT) correlation coefficient was similar \((r = 0.67)\), and our nightside (1800–0600 MLT) value was somewhat lower \((r = 0.48)\). We found comparable correlation coefficients at the other Churchill line stations as well. The nightside scatter plot in Figure 7 differs from the dayside plots in that there is a substantial number of points with large PSD and low solar wind speeds. A more detailed investigation of the high power/low flow speed points revealed that they are predominantly the result of magnetic substorms. Together, this fact and the moderate nightside correlations leads us to believe that increases in Pc5 pulsation amplitude with increasing solar wind speed are not intrinsic to Pc5 pulsations but rather are general increases in power common to all long period magnetospheric processes.

3.4. Polarization and Propagation Characteristics

[29] We calculated the standard polarization characteristics [Fowler et al., 1967] and pure state characteristics [Samson, 1973] for 2698 pulsation events. Most pulsations had a degree of polarization greater than 0.7, which is consistent with the search criteria applied by Ziesolleck and McDiarmid [1995] to identify FLR intervals. The pure state filtering technique rotates pulsation data into a coordinate system where the X axis coincides with the polarization ellipse semimajor axis, and the Y axis coincides with the semiminor axis. The polarization azimuth (angle of polarization ellipse semimajor axis relative to magnetic north) distributions of our pulsation subset are shown in Figure 8. Negative angles indicate pulsations that are tilted west of north, zero values indicate north-south orientations, and positive angles indicate pulsations tilted east of north.
Morning sector pulsations are largely oriented in a north-west direction at Rankin Inlet and progressively move towards north-south orientations with decreasing latitude until Gillam. South of Gillam the morning sector polarization azimuths spread into a more uniform distribution. Afternoon sector azimuths on the other hand, consistently tend towards smaller angles with decreasing latitude. If we extrapolate these trends to midlatitude stations, then the results would be consistent with those reported by Chisham and Orr [1997] (uniformly distributed morning sector azimuths and more clustered afternoon sector azimuths centered at $\pm 30^\circ$). Rostoker and Sullivan [1987] reported that afternoon sector pulsations observed with the University of Alberta array of magnetometers were mostly oriented in a north-south direction. However, for the majority of their events the most poleward station was Fort Smith, which is at the same magnetic latitude as Gillam (see Table 1). Consequently, their data set did not include enough high-latitude pulsations to observe the polarization azimuth drift seen in this study. We point out that the polarization azimuth distributions of the four most poleward stations show less scatter than those at Island Lake and Pinawa.

Figure 9 shows the ellipticity distributions for 3.4 mHz ($\pm 5\%$) pulsations as a function of MLT for each Churchill line station. Positive (negative) ellipticities denote a counterclockwise (clockwise) rotation of the magnetic vector in the horizontal plane, looking down from above. A polarization reversal across noon is clearly evident in the Rankin Inlet data. These polarization distributions are consistent with the polarization patterns reported by Samson et al. [1971] and Samson [1972] (i.e., see Figure 9 in the work of Samson et al. [1971]).

This polarization pattern is also consistent with magnetospheric waves propagating azimuthally about the Earth in an antisunward direction. These propagation patterns were deduced in previous studies with azimuthal wavenumber distributions [Olson and Rostoker, 1978; Chisham and Orr, 1997; Mathie et al., 1999]. Our wavenumber results are consistent with these studies (top panel of Figure 10). Positive $m$ numbers indicate eastward propagation while negative $m$ numbers indicate westward propagation. The majority of $m$ numbers have magnitudes less than 10 and are evenly distributed throughout the range. Ionospheric phase speeds (bottom panel of Figure 10) are clustered about $v_{ph} = 9.5$ km/s in the morning sector and are more scattered in the afternoon sector. This morning sector phase speed value ($v_{ph} = 9.5$ km/s) is consistent with previous FLR event studies [Olson and Rostoker, 1978; Ziesolleck and McDiarmid, 1994; Ziesolleck et al., 1998; Mathie and Mann, 2000].

### 3.5. Field Line Resonances

Ground-based field line resonances (FLRs) are pulsations that exhibit a single amplitude maximum as a
function of latitude and an ellipticity reversal (180° phase shift) across the latitude of the amplitude maximum [Chen and Hasegawa, 1974; Ziesolleck and McDiarmid, 1994]. Using this definition we separated CANOPUS pulsations into two groups: pulsations that exhibit these characteristics (FLRs) and those that do not (non-FLRs). Figure 11 shows a typical FLR event. The left panel displays the filtered, polarization ellipse major-axis component for each Churchill line station. The panels on the right show an amplitude peak at Fort Churchill with an ellipticity reversal at the same latitude. We also observed many pulsations with other polarization patterns (i.e., more than one amplitude maximum, ellipticity reversals that do not coincide with amplitude maximums, or no ellipticity reversal at all) which we classified as non-FLRs.

Eight hundred pulsation intervals containing pulsation activity in at least three Churchill line stations were selected from our 2698 event polarization subset for this analysis, 450 of which we classified as FLRs. The top panel of Figure 12 shows the occurrence statistics for both pulsation subclasses. FLRs occur primarily in the morning sector. They occur less frequently in the afternoon sector, and are completely absent at local noon. Non-FLRs, on the other hand, occur symmetrically on either side of local noon with a smaller but still substantial occurrence rate near local noon. We also investigated the location of the FLR ellipticity reversal/amplitude maximum as a function of latitude (bottom panel). Using the same techniques as applied in sections 3.2–3.4, we investigated the characteristics of each pulsation subclass and present the results in Table 2.

3.6. Pulsation Frequencies

We investigated the frequency characteristics of Pc5 pulsations on two different time scales: within individual events and on an event by event basis. For the latter we assigned a single frequency to each pulsation (central frequency), while the former involved looking at the frequency of wave packets within a given pulsation.

Figure 10. Azimuthal wavenumbers (top) and ionospheric phase speeds (bottom) calculated from the CANOPUS East-West line magnetometers.

Figure 11. FLR event observed on 12 February 1994.
We present our results on the subject of recurring frequencies first. To remain consistent with the literature, we report pulsation frequency occurrence in terms of the number of pulsation frequencies that occur within ±5% of the central value of each frequency bin. This percentage conversion introduces a bias towards higher frequencies, since the sampled frequency range grows larger with increasing frequency bin values. To account for this bias, we divided each frequency bin by the width of its associated frequency range. As a result, our observations are provided in terms of “frequency number densities.”

Figure 13 displays our results for all pulsations, FLRs, and non-FLRs. There is no evidence of preferred frequency bands in any panel. To convince ourselves that the distributions in Figure 13 are not a statistically unlucky arrangement, we shifted the center of each frequency bin by 0.01 mHz (while holding the bin spacings constant) and reevaluated the distributions. We repeated this procedure until our shifts covered the entire range of the initial frequency bin. We also adjusted the bin spacings in a similar fashion. Several of the new distributions yielded localized number density concentrations near some frequencies (CMS and others), but shifting away from these bin configurations removed these peaks. In other words, prevalent frequencies appear and disappear with small changes in the binning arrangement, and our results indicate that there is no statistically significant sets of discrete, recurring frequencies.

In addition to investigating the recurrence characteristics of Pc5 pulsation frequencies, we examined the spectral stability of fifty extended pulsation intervals (duration >1.5 hours). This event subset contained both FLRs and non-FLRs. We were able to identify at least three distinct wave packets from each pulsation interval. To determine the frequency of each wave packet, we identified an MLT for each trough (or crest) within the packet and evaluated the mean separation between them. Figure 14 shows a sample FLR pulsation on 15 October 1992. The top panel shows the unfiltered, major-axis components from the Churchill line together with dashed lines that indicate the MLT locations of wave packet troughs (or crests) in the Gillam data. In general, the phase of a pulsation can change across the Churchill line; however, the dashed lines that indicate troughs at one station will cross a different station waveform at the same phase each cycle. This trend of a latitude independent central frequency held for all 50 events.

Another characteristic that is evident in Figure 14 is that the pulsation frequency changes from wave packet to wave packet. Frequencies of FLR and non-FLR pulsations tend to drift equally as much and with no apparent systematic behavior. In fact, the only trait that we were able to identify was that the pulsation frequencies are confined to drift within the pulsation’s spectral band. For instance, in Figure 14 the pulsation spectral band extends from 4.15 to 5.70 mHz with a central frequency of 4.60 mHz (bottom panel). All of the wave packet frequency estimates (listed in top panel) fall within this range. We did find a few pulsation events that exhibited stable frequencies (within the ±5% error margin) over several hours, but they are not representative of most pulsations. Our observations of frequency drifting within individual pulsation events are consistent with the findings of Mathie et al. [1999].

<table>
<thead>
<tr>
<th></th>
<th>Pulsation Characteristic</th>
<th>FLRs</th>
<th>Non-FLRs</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>MLT occurrence</td>
<td>asymmetric (about noon)</td>
<td>symmetric (about noon)</td>
</tr>
<tr>
<td>3.1</td>
<td>latitude occurrence</td>
<td>high latitudes</td>
<td>all latitudes</td>
</tr>
<tr>
<td>3.1</td>
<td>duration</td>
<td>longer (mean: 2 hours, median: 1.5 hours)</td>
<td>shorter (mean: 1.2 hours, median: 1 hour)</td>
</tr>
<tr>
<td>3.3</td>
<td>solar wind speed (dawn)</td>
<td>high flow speed</td>
<td>no dependence</td>
</tr>
<tr>
<td>3.3</td>
<td>solar wind speed (dusk)</td>
<td>no dependence</td>
<td>northward</td>
</tr>
<tr>
<td>3.3</td>
<td>IMF ( B_z ) (dawn)</td>
<td>northward</td>
<td>same as FLRs</td>
</tr>
<tr>
<td>3.3</td>
<td>IMF ( B_z ) (dusk)</td>
<td>no dependence</td>
<td>northward</td>
</tr>
<tr>
<td>3.2</td>
<td>pulsation PSD (dawn)</td>
<td>large (10^n T²/Hz)</td>
<td>small (10^nT²/Hz)</td>
</tr>
<tr>
<td>3.2</td>
<td>pulsation PSD (dusk)</td>
<td>small (10^nT²/Hz)</td>
<td>same as FLRs</td>
</tr>
<tr>
<td>3.4</td>
<td>ellipticity</td>
<td>same as Figure 9</td>
<td>same as FLRs (more scatter)</td>
</tr>
<tr>
<td>3.4</td>
<td>polarization azimuth</td>
<td>same as Figure 8</td>
<td>same as FLRs (more scatter)</td>
</tr>
</tbody>
</table>

The numbers in the leftmost column refer to the subsection where we previously investigated each pulsation characteristic (without splitting Pc5 pulsations into subgroups).
time. Note that this drift might be due to an azimuthal or MLT variation rather than a temporal evolution.

3.7. Summary of Results

[40] Our results show the following properties of Pc5 pulsations: (1) the dawn/dusk occurrence asymmetry; (2) Pc5 pulsations occur under a large range of relative power values; (3) morning sector Pc5 band PSD is primarily due to pulsation activity; (4) high correlations exist for Pc5 band PSD and solar wind speed at all magnetic local times; (5) Pc5 pulsation occurrence depends on solar wind flow speed and Pc5 band PSD is independent of local time and that Pc5 pulsations at all MLTs occur preferentially during IMF Bz, northward conditions. Our polarization azimuth distribution covers all local times at geomagnetic latitudes between 61° and 74°. The azimuth distributions are consistent with the auroral zone observations of Rostoker and Sullivan [1987] and Ziesolleck and McDiarmid [1994] and can be reasonably extrapolated to be consistent with the midlatitude results of Chisham and Orr [1997]. The morning sector phase speed clustering has not previously been observed, and it allowed us to make an estimate of the characteristic morning sector phase speed that is consistent with previous event studies [Olson and Rostoker, 1978; Ziesolleck and McDiarmid, 1994; Ziesolleck et al., 1998; Mathie and Mann, 2000]. Finally, we followed the lead of previous studies [Ziesolleck and McDiarmid, 1995; Chisham and Orr, 1997; Mathie et al., 1999] by assigning a single frequency to each pulsation event, and we found no evidence for the existence of the CMS frequencies or any other preferential set of recurring frequencies.

[41] Some of the results summarized above have been previously seen with less extensive data sets. The dawn-dusk occurrence asymmetry was first identified by Gupta [1975], and the overall Pc5 band PSD distribution (Figure 4) is in agreement with that found by Vennerstrøm [1999]. Engebretson et al. [1998] and Vennerstrøm [1999] obtained similar correlation values for morning sector Pc5 band PSD with solar wind speed, and Junginger and Baumjohann [1988] demonstrated the dependence of morning sector pulsation occurrence on solar wind speed. The pulsation polarization sense reversals were discovered by Samson et al. [1971], and the antisunward propagation patterns were seen in the azimuthal wave number distributions of Olson and Rostoker [1978], Chisham and Orr [1997], and Mathie et al. [1999].

[42] This is the most comprehensive ground-based Pc5 pulsation study that has been conducted to date, and to the best of our knowledge several of the above listed results are new. Our finding that pulsations occur over a large range of relative power values indicates that there is no lower limit for relative power below which one can say that no Pc5 pulsations occur. We found that the strong correlation between solar wind speed and Pc5 band PSD is independent of local time and that Pc5 pulsations at all MLTs occur preferentially during IMF Bz, northward conditions. Our polarization azimuth distribution covers all local times at geomagnetic latitudes between 61° and 74°. The azimuth distributions are consistent with the auroral zone observations of Rostoker and Sullivan [1987] and Ziesolleck and McDiarmid [1994] and can be reasonably extrapolated to be consistent with the midlatitude results of Chisham and Orr [1997]. The morning sector phase speed clustering has not previously been observed, and it allowed us to make an estimate of the characteristic morning sector phase speed that is consistent with previous event studies [Olson and Rostoker, 1978; Ziesolleck and McDiarmid, 1994; Ziesolleck et al., 1998; Mathie and Mann, 2000]. Finally, we followed the lead of previous studies [Ziesolleck and McDiarmid, 1995; Chisham and Orr, 1997; Mathie et al., 1999] by assigning a single frequency to each pulsation event, and we found no evidence for the existence of the CMS frequencies or any other preferential set of recurring frequencies.

[43] In addition, based on a rigorous application of the definition of an FLR, we split the pulsations into two subclasses: FLRs and non-FLRs. This separation and the

Figure 13. Central frequency number density distributions determined for all pulsations (top), FLRs (middle), and non-FLR pulsations (bottom) using pulsation data from all stations. The shaded regions indicate the CMS frequency bands within the Pc5 spectral range (1.9, 2.6, 3.4 mHz ±5%).

Figure 14. An example of our wave packet frequency determination method being applied to an FLR event on 15 October 1992. The dashed lines (top) indicate pulsation troughs (or crests) at Gillam. The wave packet frequencies (grey boxes in top panel) change but remain within the pulsation spectral band (bottom).
size of our data set allowed us to elucidate different characteristics for the two pulsation populations. We have shown that FLR pulsations tend to occur preferentially in the morning sector at high latitudes while non-FLR pulsations are more ubiquitous and occur symmetrically on either side of noon. Morning sector FLRs have significantly larger amplitudes (higher PSD) than non-FLRs and afternoon sector FLRs. The afternoon sector FLRs show no dependence on IMF $B_z$, while all other pulsations are more likely to occur during northward rather than southward IMF conditions. FLRs have longer durations than non-FLRs, and non-FLR pulsation characteristics tend to be more scattered than the FLR characteristics. The distribution of pulsation polarization characteristics, on the other hand, are the same for FLRs and non-FLRs.

4. Discussion

[44] In this final section, based on our observations, we comment on the idea of stable recurring Pc5 pulsation frequencies and on possible source mechanisms for Pc5 pulsations. In both cases, we refer the reader to the review material presented in the introduction specifically related to these two topics and to the relevant results in section 3. We finish with several future directions for research that could follow this work, based on our extensive pulsation data set.

4.1. Stable, Recurring Pulsation Frequencies

[45] As discussed in section 1.1, whether or not there are recurring, stable pulsation frequencies in the Pc5 band (i.e., the CMS frequencies) is an open question. The results we presented in section 3.6 show that the distribution of pulsation central frequencies does not exhibit significant occurrence peaks at any particular frequency or set of frequencies. Our analysis indicates that there is a continuum of frequencies and, moreover, that the frequencies can drift during long duration pulsations. Our data and our analysis are consistent with the idea that the pulsation frequencies vary with changing solar wind and magnetospheric conditions. In other words, the magnetospheric cavity supports discrete frequency eigenmodes, the frequencies of which naturally change with changes in the cavity topology (size and shape) and magnetospheric magnetic field strengths and plasma characteristics (i.e., mass density).

4.2. Pulsation Source Mechanisms

[46] The results of this study are largely consistent with both the waveguide/cavity mode model and the traditional FLR model. However, there is one observation that is inconsistent with the FLR model: the occurrence of nonpropagating Pc5 pulsations at local noon. We estimated azimuthal propagation characteristics for a handful of noontime Pc5 pulsations (many of the noontime pulsations occurred in less than three East-West line stations) and found that they typically have low m-numbers and very high phase speeds (see Figure 10). These characteristics are consistent with nonpropagating disturbances and, consequently, with an energy source at the nose. Flow speeds are quite small in this region of the magnetosheath [Spreiter and Stahara, 1980], and it is unlikely that magnetopause KHI could develop often enough to drive the observed noontime Pc5 pulsations.

[47] Our observations of FLR and non-FLR pulsation characteristics are consistent with those predicted for overreflected, trapped, and leaky waveguide modes (see section 1.2), and they lend observational support to the waveguide model. Overreflected waveguide modes energized by KHI can explain both the observed MLT occurrence distribution for FLRs and their solar wind dependencies (Table 2). Similarly, trapped waveguide modes can explain the symmetric MLT occurrence distribution of non-FLRs, and evidence of leaky waveguide modes can be obtained indirectly through our observations of non-FLR pulsations. According to Mann et al. [1999], the magnetopause becomes less reflective with increased proximity to local noon and is nearly transparent at noon. This nonreflection condition at the nose would have produced a discrepancy between our observations and the waveguide/cavity mode theory if it were not for the work of Harrold and Samson [1992]. The authors of that study demonstrated that the bowshock is a reflecting surface that is capable of supporting cavity modes that have eigenfrequencies within the Pc5 spectral band. Given that magnetosheath flow speeds near the nose are small and that the magnetopause is a poor reflector under low flow speed conditions, it is plausible that the bowshock would form the outer cavity boundary for an MLT range centered about local noon. The MLT extent of this region should be larger during low solar wind speed intervals as compared with high solar wind speed intervals because magnetopause reflectance deteriorates with decreasing magnetosheath flow speeds [Mann et al., 1999]. Observationally, we would expect to see a shift towards lower pulsation frequencies in this region (due to the increased distance between the inner and outer boundaries of the cavity [Harrold and Samson, 1992; Samson et al., 1992a]). Non-FLRs, as observed in this study, tend to occur during lower solar wind speed conditions than FLRs (see Table 2). They also have a non-zero frequency of occurrence at local noon (Figure 12). As a result, we expect non-FLRs to, on average, have lower pulsation frequencies than FLRs (since we are asserting FLRs arise from overreflected waveguide modes and are bounded by the frequency dependent turning point and the magnetopause). This expectation is consistent with the frequency distributions shown in Figure 13.

[48] The presence of nonpropagating Pc5 pulsations at local noon, together with evidence for KHI involvement at times away from local noon (Figure 6), leads us to believe that there are (at least) two distinct energy sources which give rise to magnetospheric cavity modes. Additional support for multiple Pc5 pulsation source mechanisms can be found from differences in FLR and non-FLR pulsation characteristics. The MLT occurrence distribution of FLRs is asymmetric about local noon with a larger likelihood of occurrence in the morning sector, and an absence of pulsations at local noon (Figure 12). This MLT distribution and the correlations between solar wind conditions and dawnside FLR occurrence (Table 2) provides a strong case for FLRs being generated through magnetopause KHI activity [Miura, 1995; Engebretson et al., 1998]. Duskside FLRs do not exhibit the same solar wind dependencies as dawnside FLRs. However, it is possible that the infrequent appearance of turbulence in duskside magnetosheath flows might overrule the systematic depen-
dencies that are observed with dawnside FLRs. Non-FLRs, on the other hand, have a MLT distribution that is symmetric about local noon with a rarity of pulsation activity at noon (Figure 12). As discussed earlier, this is inconsistent with magnetopause driven KHI. The low m-numbers associated with non-FLRs suggest that these pulsations are not driven by plasma instabilities or wave/particle interactions either [Chisham and Orr, 1997]. Therefore we propose that non-FLRs arise from more irregular (or impulsive) energy sources such as travelling indentations on the magnetopause [Mathie and Mann, 2000] or solar wind buffeting.

[48] If FLRs and non-FLRs are indeed generated through magnetopause KHI and irregular deformations of the magnetopause (as indicated above), then one major curiosity remains in our observations: Why are the polarization characteristics of FLRs and non-FLRs so similar? We feel that it is unreasonable to assume that the proposed source mechanisms would yield such consistently similar polarization characteristics. Instead, we favor an explanation where the coupling from compressed mode waves into field line resonances could determine the polarization characteristics of Pc5 pulsations. More specifically, we think that the field line length, MLT location, and mode of oscillation constrain the polarization behavior. Satellite observations indicate that morning sector pulsations are primarily toroidal oscillations [Kokubun et al., 1989; Anderson et al., 1990]. The later study [Anderson et al., 1990] reported an increased likelihood of occurrence for toroidal pulsations with increasing L-shell. They also noted the presence of a smaller toroidal pulsation population in the duskside magnetosphere (with the same L-shell dependence). The occurrence distribution of toroidal mode pulsations, as determined from in situ measurements, is consistent with the high-latitude occurrence and MLT distribution observed for ground-based FLRs in this study. These independent observations suggest that FLRs are the ground-based signatures of toroidal mode resonances, and it is our belief that the more ubiquitous non-FLRs are the ground-based signatures of poloidal mode resonances (arising from poloidally polarized low m-number cavity/waveguide modes). We further speculate that a waveguide mode amplitude threshold might exist for coupling into toroidal mode resonances directly. This is plausible, since simulations of overreflected waveguide modes [Mann et al., 1999] yielded much larger amplitudes than those for trapped waveguide modes, and our observations of morning sector FLRs indicate substantially larger amplitudes than non-FLRs.

4.3. Future Work

[50] We have developed an extensive set of near-monochromatic Pc5 pulsations. Future work could utilize this data set to explore a number of questions. For example, there is solar wind data available for 60% of the pulsation events. This opens up the possibility of exploring the connection between solar wind dynamic pressure variations and Pc5 pulsations. Further, detailed examination of long duration events from our list would elucidate whether pulsation frequency drifts result from spatial or temporal variations, or both. If the frequency drifts could be linked to systematic changes in the solar wind, it would provide further observational evidence for the existence of cavity modes.

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References


