Pc3 pulsations during low density solar wind events

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Abstract

We study the generation of Pc3 geomagnetic pulsations (22 – 100 mHz) measured at Tihany, Hungary (THY: 42.44° E, 92.39° N; $L \approx 1.84$) during intervals of very low solar wind density (low density events - LDE's), when $N_p \lesssim 2$ cm^{-3}. The main driver of Pc3 pulsations of the geomagnetic field is ULF waves generated upstream of the bow shock (upstream waves - UW's) by a plasma instability set up due to the reflection of ion beams from the bow shock. A statistical investigation into the dependence of Pc3's on solar wind density is made, and it is found that SW density only influences Pc3 generation during LDE's. Furthermore, we derive the growth rate of the instability responsible for upstream waves, and show that damping occurs for low density, thereby inhibiting the generation of UW's and Pc3's.

1 Introduction

Geomagnetic pulsations are low frequency oscillations of the geomagnetic field, observable on the ground and in near-Earth space, caused by ultra-low frequency (ULF) magneto-hydrodynamic (MHD) waves occurring in the magnetosphere. These pulsations are classified [1] according to form and waveform as either continuous (Pc1 − Pc5) or irregular (Pi1, Pi2). We study the Pc3 class of quasi-sinusoidal pulsations that fall in the $22 - 100$ mHz frequency range.

The magnetosphere acts as an obstacle to the supersonic natural flow of solar wind plasma from the solar corona. This causes a shockwave (the bow shock) to be formed upstream of the magnetopause. Through specular reflection [2] or leakage from the dense shock wave region, beams of ions may propagate upstream along IMF field lines at around $2 - 3$ times the solar wind speed ($V_b \sim 2 - 3V_{sw}$) [3]. Due to the counter streaming of the ion beam with the downstream propagating solar wind, an ion-ion beam instability is set up which excites ULF waves in the foreshock region[4]. Depending on the orientation of the interplanetary magnetic field (IMF) with respect to the solar wind direction, these waves may propagate across the turbulent sheath region and penetrate the magnetosphere. In the magnetosphere the waves may (i) couple to a cavity mode, (ii) excite a resonant mode with geomagnetic field lines (field line resonance - FLR), or (iii) propagate up to the ionosphere; and is subsequently measured as ULF oscillations in the poloidal/toroidal modes in the magnetosphere and in the horizontal component of the surface magnetic field.

It has been observed that during conditions where the solar wind density is extremely low ($N_p < 1\mathrm{cm}^{-3}$) that Pc3 activity observed on the ground all but ceases. Figure 1 below illustrates the pause in Pc3 activity during the low density event (LDE). This occurs even while other conditions are favourable for the excitation of UW-generated Pc3's. For example, low cone angle (ϑ_{xB}) normally yields increased pulsation activity as UW's gain easier access to the magnetosphere for a quasi-parallel shock [5]. However, we see that this is not the case while N_p is very low (see Figure 1).

2 Statistical Investigation

We investigate the relationship between Pc3 occurrence and solar wind density by a statistical analysis where we compute the conditional probability of observing Pc3's at different levels of solar wind density. We find that low solar wind density implies low pulsation activity, but that low Pc3 activity does not necessarily result from low SW density. In other words, N_p above a certain level is a necessary, but not sufficient

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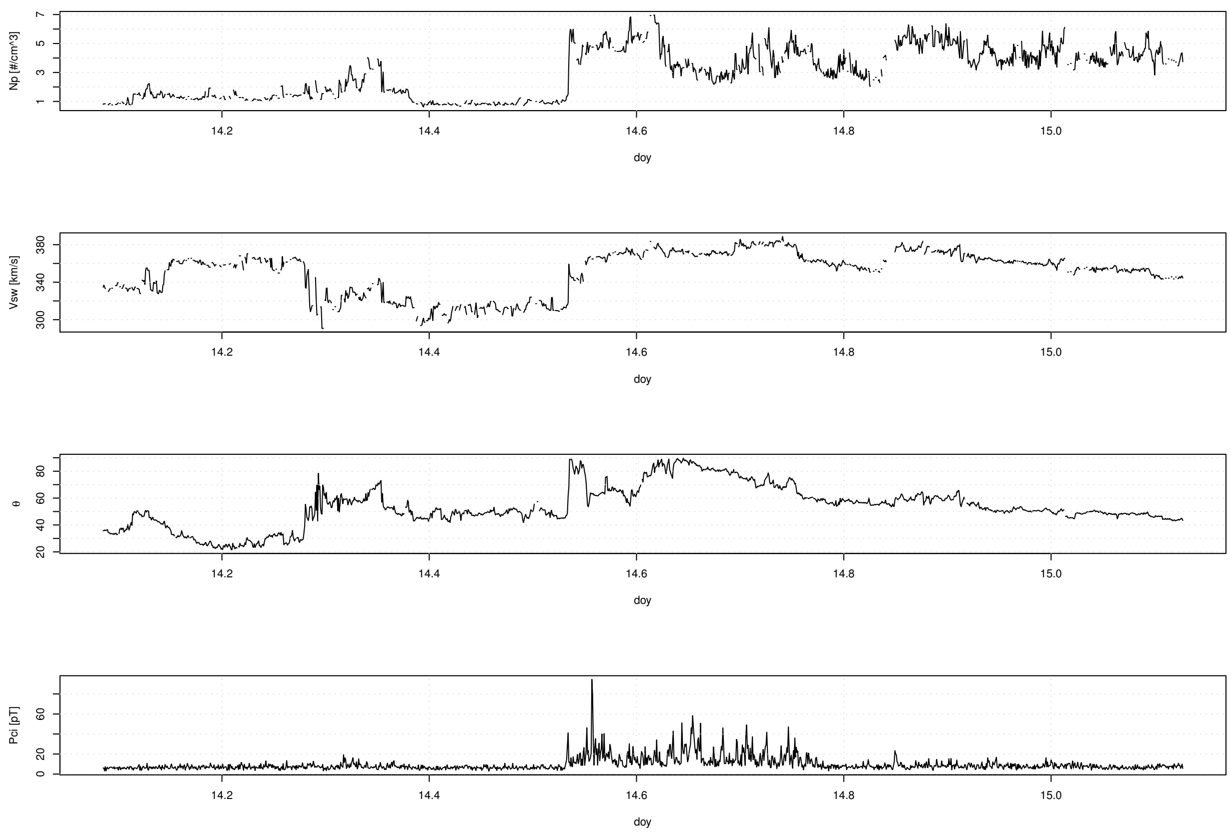

Figure 1: LDE on day 14 of 2007 (UT). Solar wind density and speed, cone angle and a pulsation index, the root-mean-square of Pc3 amplitude, is plotted for the same interval. Pulsation activity remains extremely low while $N_p \sim 1$ cm^{-3}, even with small cone angle, and returns to normal along with the step up in N_p.

condition for Pc3's. Figure 2 below illustrates the dependence of pulsation activity on solar wind density. A pulsation index Pci, which is just the root-mean-square of pulsation amplitude [6], is computed for daytime pulsation observations measured at Tihany, Hungary from 2002 to 2007. We count the number of occurrences of $Pci \in [x_0,\, x_1]$ for different levels of solar wind density and normalise it to a conditional probability. It is clear from Figure 2 that solar wind density is only influential to pulsation activity when N_p is low.

3 Analytical Investigation

The dependence of Pc3 on N_p may be due to a number of factors: (i) low Alfvénic Mach number of the bow shock wave inhibits the reflection of solar wind particles so that beam formation is not possible; (ii) ion beam density is dependent on the density of background ions (i.e. solar wind density), and low beam density reduces the free energy available to drive the instability that excites UW's; (ii) under low N_p the solar wind may become sub-Alfvénic, meaning that ULF waves travelling upstream cannot be convected downstream by the solar wind to penetrate the magnetosphere; (iv) the increased size of the magnetosphere due to the drop in solar wind pressure results in higher attenuation of waves as the propagate into the magnetosphere. Any or all of the mechanisms listed above may be responsible for the pause in Pc3 activity during LDE's. To test this, we derive the dispersion relation and growth rate of the ion-ion instability responsible for upstream waves and show that growth is damped under low densities, thus inhibiting Pc3 generation through upstream waves. This seems to suggest that factor (ii) is the main reason for the lack of pulsations during low density

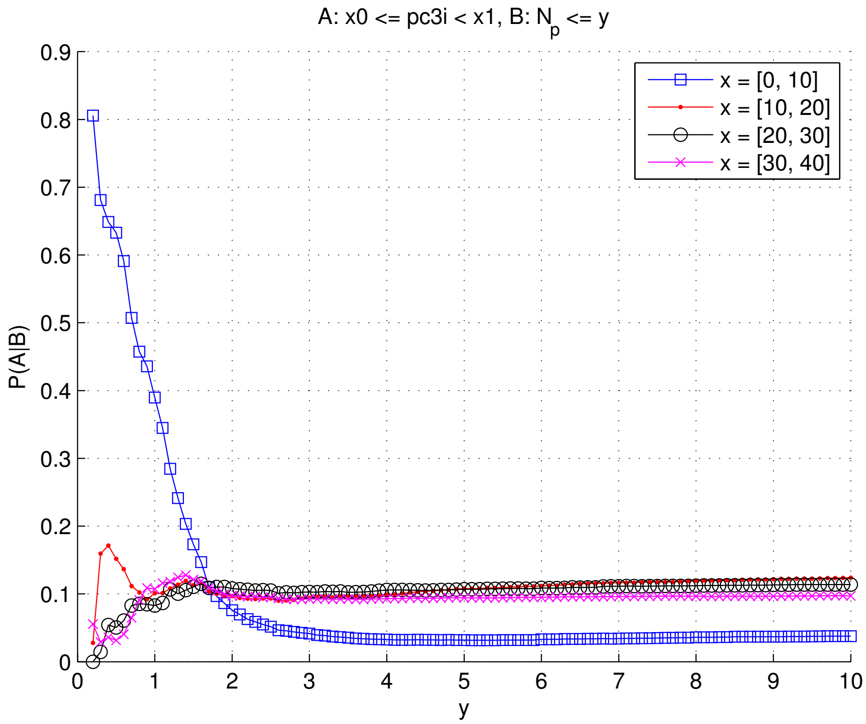

Figure 2: Conditional probability of finding $x_0 < Pc3_i \leq x_1$ cm^{-3} when $N_p < y$. Data from 2002 to 2007 was used. It is clear that N_p only has an influence on pulsation activity at low densities.

events, however further investigation of the beam generation mechanism need to be considered, since beam generation precludes all other factors (ii – iv).

4 Conclusion

The generation of Pc3 pulsations in the geomagnetic field is studied during intervals of low solar wind density. Through a statistical analysis we see that solar wind density only has an appreciable influence on Pc3 activity when N_p is very low. By deriving the growth rate of the ion instability responsible for ULF waves in the foreshock, we conclude that the reason why we observe the pause in pulsation activity during low density events is that the instability cannot develop due to the lack of free energy available when the solar wind density, and hence the beam density, is very low. This work provides further evidence of the importance of the upstream wave mechanism in the generation of dayside Pc3's.

5 References

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