Statistical Observations of Pc1 Pearl Pulsations using the Van Allen Probes

K.W. Paulson[1], C. W. Smith[1], M. R. Lessard[1], R. B. Torbert[1,2], C. A. Kletzing[3]

[1]University of New Hampshire, Durham, NH [2]Southwest Research Institute, Durham, NH [3]University of Iowa, Iowa City, IA

Abstract

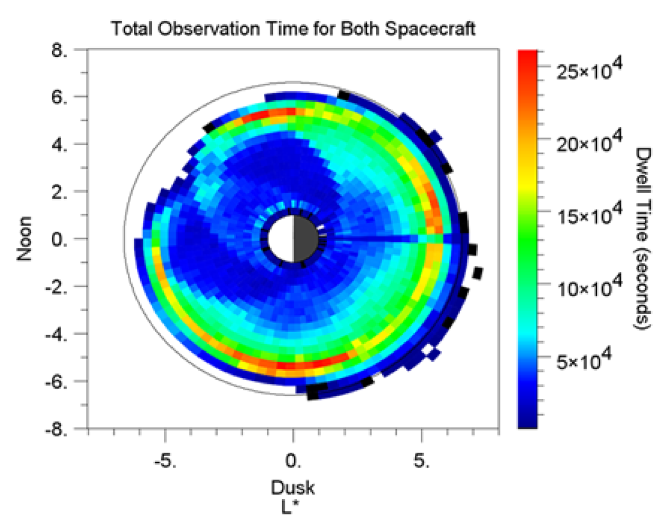
Pc1 Pearl Pulsations, time modulated magnetic field perturbations, are believed to be a subclass of electromagnetic ion-cyclotron (EMIC) waves. Pearl pulsations have often been observed using ground-based magnetometers, but the rarity of in situ observations has made the verification of theoretical explanations challenging. The Van Allen Probes mission offers an unprecedented level of observation near the magnetic equator, traditionally thought to be the generation region of EMIC waves. Using these spacecraft, we have identified over 355 hours of EMIC wave activity, of which 102 hours exhibits a pearl pulsation structure, during the period from 2012-09-08 through 2014-02-22. Comparisons between the two data sets reveal a fundamental difference in the generation of pearl pulsations versus unstructured EMIC waves.

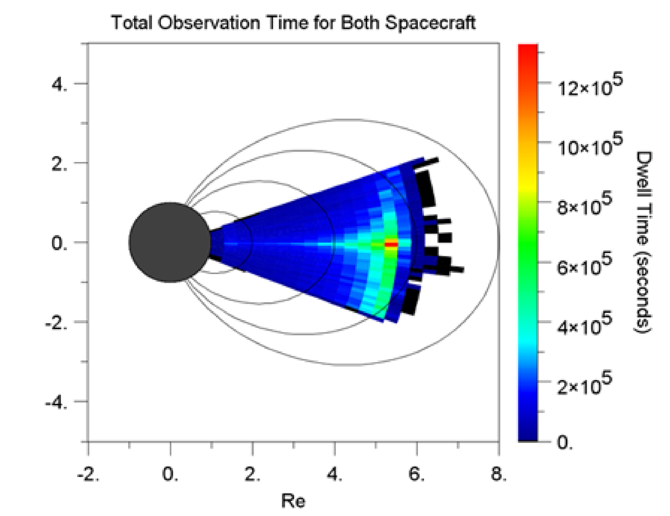
Motivation

EMIC waves serve as an important mode of energy transport within the magnetosphere, heating heavier ion species and causing pitch angle scattering of relativistic electrons. Recent work [Omura et al. 2010] has shown that the rising tones of EMIC-triggered emissions can interact with relativistic electrons through a nonlinear mechanism. The similarity in frequency sweep rate with Pc1 pearl pulsations suggests pearls could similarly scatter highly energetic electrons. The consistent differences between pearl pulsations and unstructured EMIC waves suggests that there is different mechanism acting to cause their generation.

Instrumentation

The Van Allen Probes are two identical spacecraft launched in August of 2012. They undergo elliptical ~9 hour equatorial orbits which precess at a rate of one full rotation every two years. Below can be seen the projected equatorial and meridional coverage maps.





Each spacecraft is equipped with a triaxial fluxgate magnetometer capable of measuring 64 vectors/s which we used for wave identification and polarization analysis, as well as four spin plane electric field instruments which were used for Poynting Flux measurements. We used E·B=0 in order to derive the spin axis component of the electric field, discarding data where B_x mGSE < 2 nT to avoid unphysical results. All magnetic ephemeris was calculated using the Tsyganenko 2004 magnetic field model.

Acknowledgements

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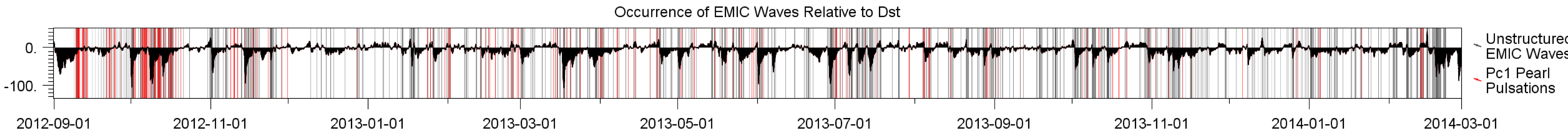
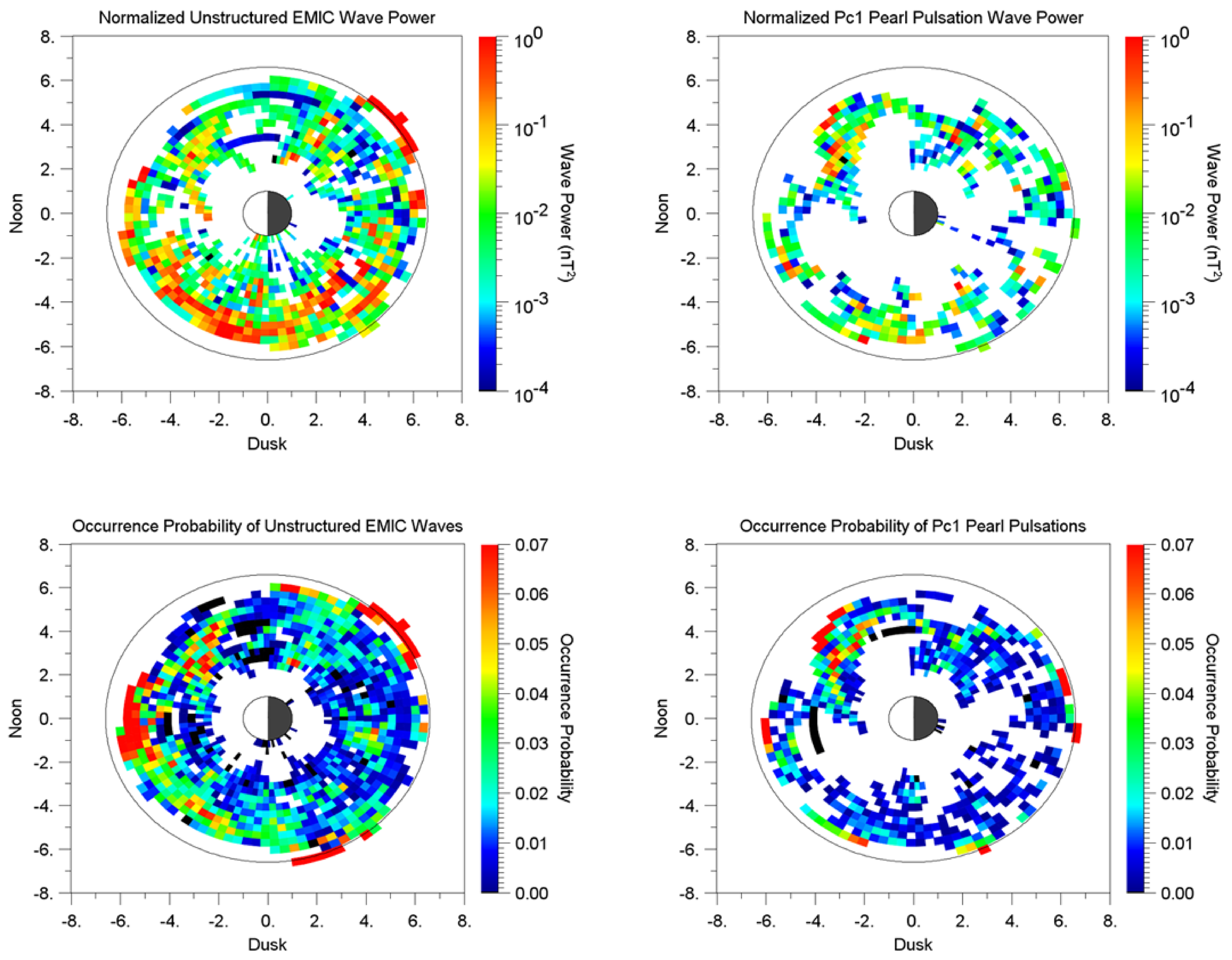


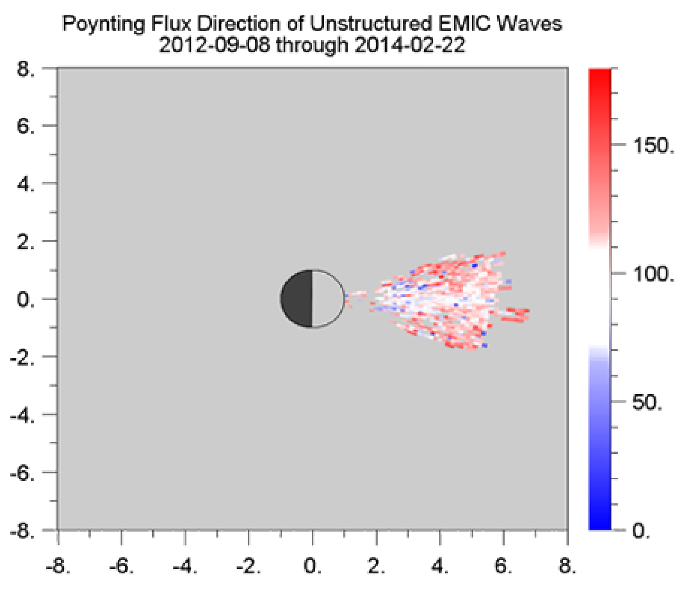
Observations

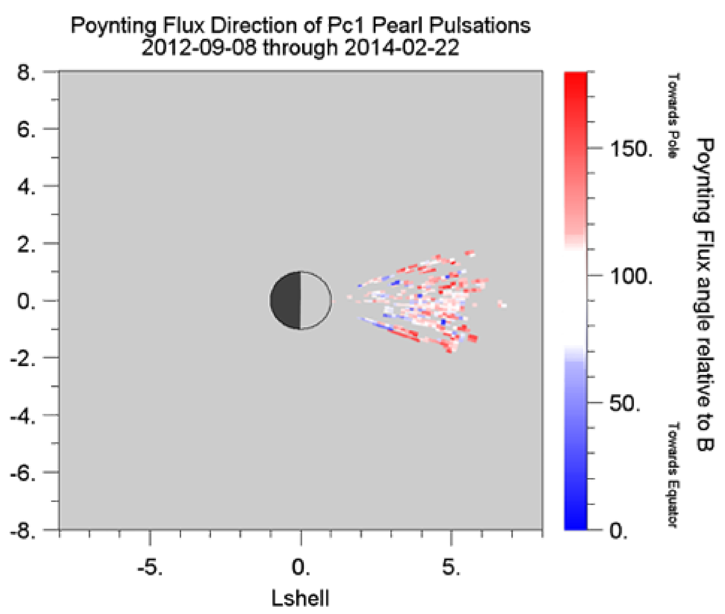
Above, we show the occurrence of both pearl pulsations (red) and unstructured EMIC waves (grey) relative to Dst. While unstructured EMIC waves are typically observed during the main phase of geomagnetic storms, pearl pulsations are observed during much quieter periods, often in the late recovery period. This pattern has been documented among pearls using ground observatories, but this observation discredits the claim that this pattern could be due to ionospheric propagation effects.



The occurrence and wave power plots below confirm previous statistical studies [eg, Min et al. 2012] showing an increase of unstructured EMIC wave power along the dusk region, though we do see an increase in the occurrence rates at noon. The pearl pulsations show a preference both in occurrence and wave power in the late dawn sector, however, due to the single precession of the spacecraft orbit, we cannot ignore the effect of the October and November storms on this result. If this were shown to be true, it would support the theory of generation of the time modulation by Pc5 ULF waves. Here Pc5 waves such as field line resonances would temporally drive particle anisotropy which leads to the ion cyclotron instability, generating time-modulated EMIC waves.

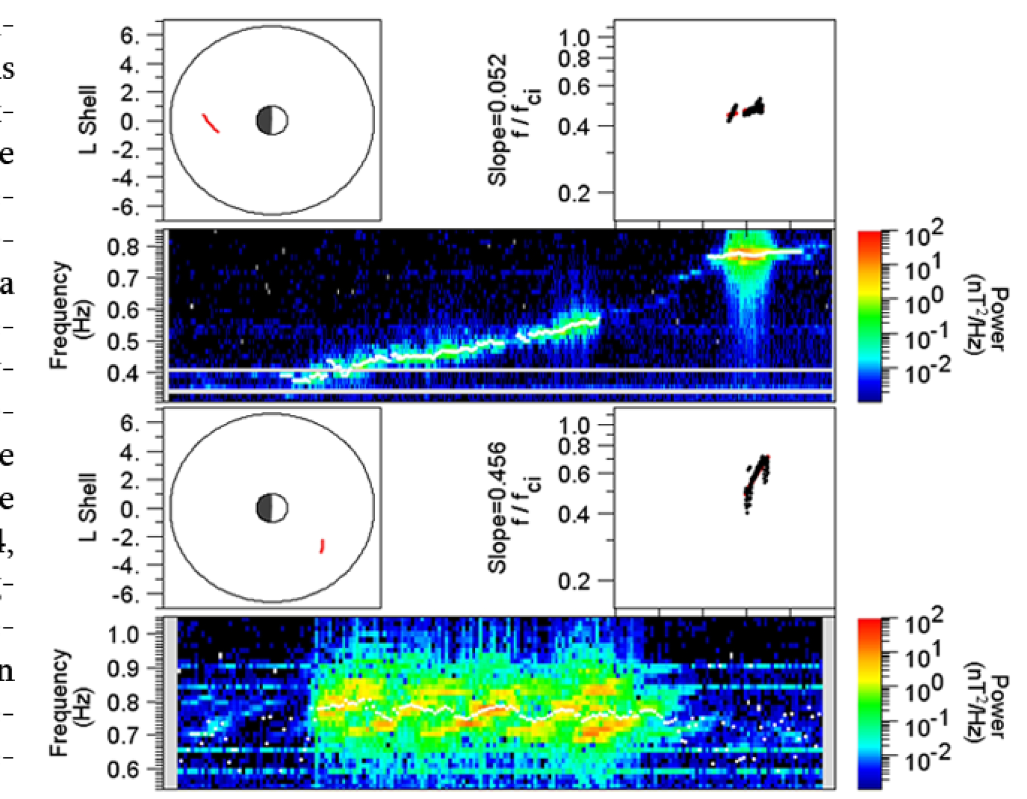
Below, we show Poynting vector analysis for both unstructured EMIC waves and Pc1 pearl pulsations collapsed to a single meridional plane. In this plot, the higher angles (red) represent propagation away from the magnetic equator, while low angles (blue) represent propagation towards the equator. The ambiguous region centered within ~5° MLat most easily visible in the unstructured EMIC waves confirms the previously shown finite width of the generation region [Loto'aniu et al. 2005]. The pearl pulsations show a higher tendency towards equatorial propagation at lower L. Previous work [Paulson et al., 2014] has shown the observation of a left-hand to right-hand mode conversion as the wave activity is seen to cross the lower bound created by the bi-ion hybrid frequency. Analysis of several case examples (not shown) demonstrate right-hand polarized modes to propagate towards the equator. This could indicate that the observed right-handed mode waves have crossed over and refracted at the boundary created by heavy ion composition and are no longer bound to the field lines.



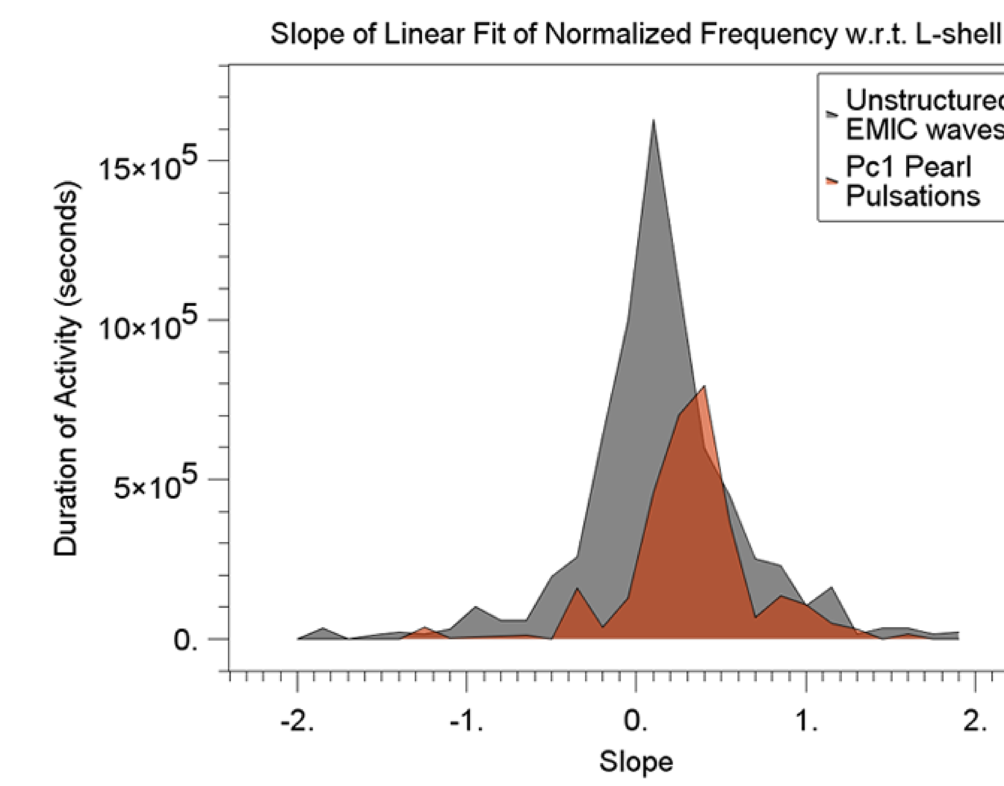


Constant Excited Frequency

A unique quality separating pearl pulsations from unstructured EMIC waves is the independence of their central excited frequency with respect to L. Since the frequency of the generated wave depends upon the local ion cyclotron frequency, we would expect to see a change in wave frequency as the spacecraft travels across Lshells. This behavior is visible at right (top), where the frequency of the unstructured EMIC wave observed on May 26th, 2013 rose as the spacecraft moved from L=5 to L=4, where it encountered a stronger magnetic field. By contrast, the mean frequency (white) of the pearl pulsation (bottom) from October 7th, 2012 remained relatively constant as the spacecraft moved from L=4.8 to L=4.2.



In order to quantify this behavior, we calculated the mean frequency of the wave event weighed by the wave power. We then normalized this frequency to the gyrofrequency of the respective ion species and fit a linear function to this normalized frequency as a function of L. The resulting slope will therefore indicate the dependence of the wave frequency on L, where a slope of 0 corresponds to a direct dependence. The histogram below shows the aggregation of this analysis using our list of wave events. The greater displacement of the pearl pulsation peak from 0 is indicative of the lack of dependence of these waves on L relative to the unstructured EMIC waves.



This constant band of excited requency would support a generation mechanism such as the theorized ion cyclotron resonator [Guglielmi et al, 2000] in which heavy ions create an opaquely bounded torus of wave activity. Here the excited frequency is determined by the size of the torus, and so might not be directly influence by local effects

Conclusions

1. Pc1 pearl pulsations are a unique subset of electromagnetic ion cyclotron waves which undergo a fundamentally different method of generation than unstructured EMIC waves. This method could be a modulation of the source particles by Pc5 ULF waves or through the heavy-ion ion cyclotron resonator mechanism.

2. Several qualities, such as their Dst dependence and their temporal modulation, which had previously been proposed to be a result from interaction with the ionospheric boundary are also shown using in situ measurements. This merits further development of a theory of generation which relies on local magnetospheric conditions.

University of New Hampshire

Kristoff Paulson
kristoffpaulson@gmail.com - 202 441 5185