Statistical Observations of Pc1 Pearl Pulsations by the Van Allen Probes and Examples of Bidirectional Poynting Flux

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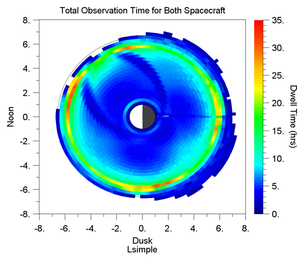
Abstract/Introduction

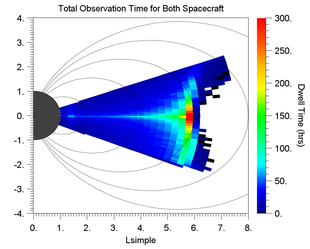
Pc1 pearl pulsations are a time-modulated electromagnetic wave in the Pc1 band of the ULF spectrum. They are believed to be a subclass of electromagnetic ion cyclotron (EMIC) waves, and so are generated through the ion cyclotron instability. However, the exact cause of their modulated structure is still a topic of debate. The previously held idea of ionospheric reflection between conjugate hemispheres has been discredited due to several observations of a similar modulation period on the ground as in the magnetosphere as well as numerous in situ observations of unidirectional poynting flux. However, there still exist examples of events exhibiting bidirectional poynting flux which would suggest a reflecting wave packet. We will show analysis from an event observed in October of 2013 using both in situ and ground-based data in addition to further examples. The Van Allen Probes spacecraft, launched in August of 2012, have offered us an unprecedented view into the equatorial magnetosphere where the generation region of EMIC waves is thought to reside. As of June of 2014, the spacecraft will have nearly undergone one full precession around Earth, allowing for observations spanning almost the full range in MLT. We therefore present here a statistical analysis of EMIC waves, both pearl pulsations and unstructured, observed within the first two years of the Van Allen Probes mission.

Instrumentation

The Van Allen Probes:

- Two identical spacecraft launched in August of 2012 into highly elliptical ~9 hr equatorial orbits
- Slightly different apogees so one laps the other, varying separation
- Apogee is just under 6 Re, so the extent of coverage in Lshell typically extends to just within geostationary orbit





- The spacecraft have nearly undergone one full precession covering the equatorial magnetosphere in all MLT.
- The range in magnetic latitude varies between +/- 20° with Earth's rotation.
- For magnetic field measurements, we have used the triaxial fluxgate magnetometer, which conitnuously records 64 vectors per second
- Electric field data for the purpose of Poynting vector analysis was obtained from the EFW spin plane booms (E·B=0 was used to determine third axis)
- The dynamic Tsyganenko 2004 magnetic field model was used to map ephemeris where available, with the 1989 model used in the case of data gaps.

Acknowledgements

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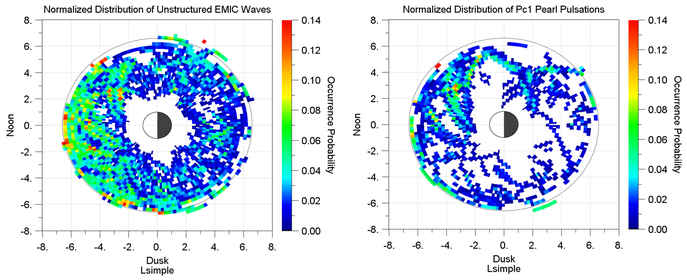
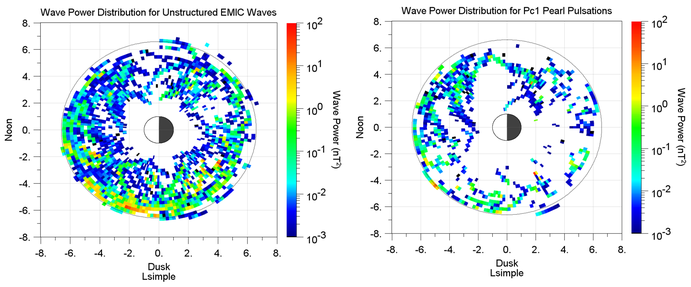
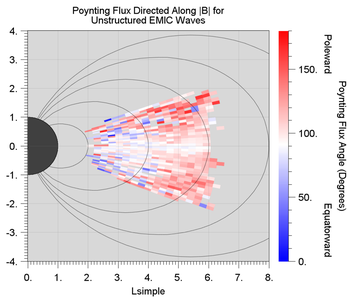
Observed Distributions

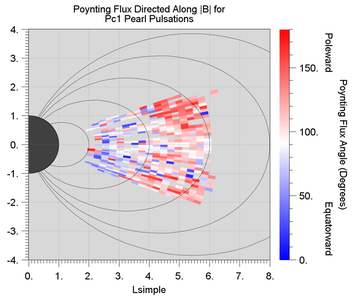


- Unstructured EMIC wave activity is seen at all MLT, but is more heavily concentrated on the dayside.
- Pc1 Pearl Pulsations are relatively uniformly distributed (concentration at ~6-11 is likely due to several strong magnetic storms in Oct. and Nov. of 2012).
- Little to no wave activity is observed within L=3.
- Out of over 880 hours of observed EMIC wave activity, 215 hours demonstrated pearl structure

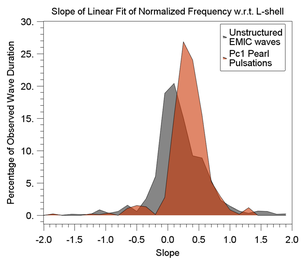
- Magnetic wave power carried by unstructured EMIC waves is strongest in the dusk/late noon sector. This agrees with previous studies which claim enhanced EMIC waves will occurr at the overlap of the plasmaspheric plume and ring current.
- Pearl pulsation wave power is evenly distributed, implying wave growth may not be influenced by the same mechanism driven by the cold dense plasma plume.







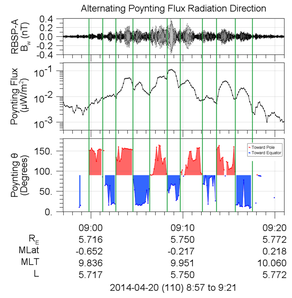
- Poynting Flux analysis shows unidirectional wave propagation away (red) from a finite equatorial source region for unstructured waves.
- This region is not well defined for pearl pulsations. Instead, we see a tendency for waves at lower L values to propagate towards (blue) the equator.
- Mean wave frequency normalized to the relevant ion gyrofrequency reveals a tendency for pearl pulsations to excite a constant central frequency as the wave is observed across different L shells.
- Previous work with Van Allen Probe data has shown polarization reversals in pearl pulsations across gyrofrequency lines as the spacecraft traveled to lower L. The right hand polarized mode would no longer be guided by the magnetic field, possibly explaining the increase in equatorward propagation.



Bidirectional Poynting Flux

Several wave events have been observed which display periodically alternatiog Poynting vector orientation along the magnetic field direction.

- These waves demonstrate comparable poynting flux within neighboring pearl elements but travel in opposite directions.
- Simultaneous observations between both Van Allen Probes spacecraft and the Oulu observatory in Finland show a similar ~2 minute modulation of the wave activity in space and on the ground.



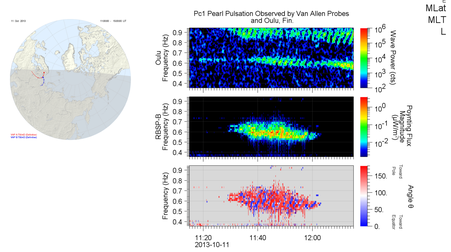
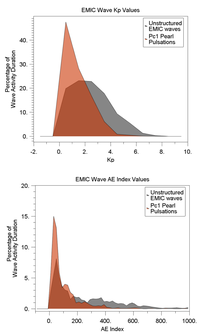


Table 1: *Events Demonstrating Alternating Poynting Vector Directions*

Start Time(UTC)	End Time(UTC)	Spacecraft	Frequency (Hz)	Average MLat (Deg.)	Average Lshell
2012-10-05 14:41	2012-10-05 15:02	A	1.27 - 1.76	0	4
2012-10-16 16:53	2012-10-16 17:04	B	2.2 - 2.65	-3.5	4.2
2012-10-17 10:53	2012-10-17 11:15	B	0.5 - 1.3	-2.2	4.3
2012-11-18 09:52	2012-11-18 10:26	B	1.91 - 2.36	-1.3	4.7
2013-01-29 13:57	2013-01-29 15:34	B	0.14 - 0.54	-4	5.2
2013-07-01 16:12	2013-07-01 17:30	B	0.32 - 0.67	0	5.5
2013-07-07 13:19	2013-07-07 13:58	A	1.45 - 2.4	-1.5	4.7
2013-07-17 11:13	2013-07-17 11:49	A	0.57 - 0.9	-0.3	4.8
2013-10-11 09:52	2013-10-11 10:04	B	0.55 - 0.68	4.5	2.5
2013-10-11 11:10	2013-10-11 12:05	B	0.45 - 0.75	-3.4	5
2013-10-11 12:14	2013-10-11 12:57	A	0.55 - 0.81	-2.1	5
2013-11-09 01:24	2013-11-09 01:40	A	0.43 - 0.55	-1.9	6
2013-11-12 23:22	2013-11-13 00:26	B	0.45 - 0.7	0.5	5.8
2013-12-12 15:08	2013-12-12 16:23	A	0.38 - 0.68	-0.9	5.3
2014-02-13 12:51	2014-02-13 13:26	B	0.67 - 0.89	-6.4	5
2014-02-24 16:49	2014-02-24 17:52	A	0.3 - 0.74	-0.1	5.1
2014-03-01 00:15	2014-03-01 00:23	A	2.8 - 3.6	0.7	4.3
2014-03-03 14:51	2014-03-03 15:17	A	0.95 - 1.38	2.5	4.6
2014-04-20 08:57	2014-04-20 09:23	B	0.62 - 0.78	-0.7	4.9
2014-05-13 06:54	2014-05-13 07:06	B	0.53 - 0.74	-0.5	5.4
2014-05-13 07:02	2014-05-13 07:32	A	0.46 - 0.87	0.5	5.1

These EMIC wave events observed by the Van Allen Probes spacecraft from October 2012 to May of 2014 demonstrated a periodically varying Poynting Flux vector component along |B|

- We have identified 20+ such events within our period of study, not all of which exhibited a sufficient temporal structure in magnetic wave power to be originally flagged as pearl pulsations.
- They are widely distributed in MLT, but are constrained to a narrow range in magnetic latitude.
- All events listed here are observed during geomagnetically quiet periods, with a minimum Dst value recorded at -30.
- Pearl elements often display closely-spaced and even overlapping rising tones, with no immediately obvious driver of frequency sweep rate.
- Alternating poynting vector direction could indicate observation of pearl pulsation generation region.



- A comparison of observed unstructured waves and pearl pulsations to geomagnetic indices such as Ae and Kp reveals a preference for the formation of pearl pulsations during magnetically quiet periods.

Conclusions/Future Work

We continue to add to our growing catalog of EMIC wave events observed by the Van Allen Probes in order to improve the statistical picture of wave generation regions within the inner magnetosphere. Results from comparisons between pearl pulsations and unstructured EMIC waves imply that there is a fundamental difference between their generation mechanisms and conditions which lead to wave growth.

The original theory of a wave packet bouncing between conjugate hemispheres is inconsistent with recent observations, and yet we see bidirectional Poynting flux similar to that of a reflected wave packet on several occasions, though constrained to a much narrower equatorial region. This may be consistent with other proposed theories such as that involving the ion cyclotron resonator, which would form a narrow region of reflection within a torus made up of heavy ions.

Of particular scientific interest is the influence of EMIC waves on energetic radiation belt particles. It remains to be seen whether the modulated structure and differing wave growth parameters of pearl pulsations allows them to more efficiently interact with the high-energy elestrons found in the outer belt.

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