Statistical Study of the Occurrence of POES Relativistic Electron Precipitation (REP) in Correlation with Electromagnetic Ion Cyclotron (EMIC) Waves

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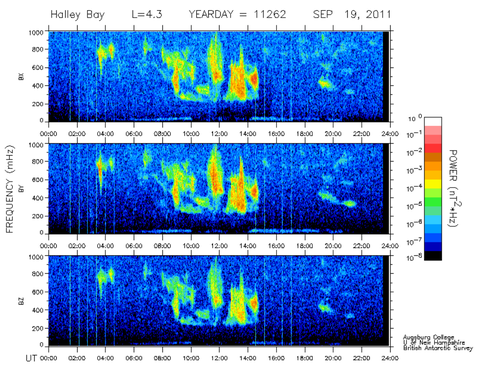
Abstract

Electromagnetic Ion Cyclotron (EMIC) waves are phenomena that exists within the Earth's magnetosphere caused by an ion temperature anisotropy. The ideal conditions for EMIC wave growth occur during solar storms. In this statistical study, Polar Orbiting Environmental Satellites (POES) relativistic electron precipitation (REP) data is compared to EMIC wave data from Halley Bay in the years ranging from 2008-2010. This statistical study will consider a specific type of EMIC wave events known as Intervals of Pulsations of Diminishing Periods (IPDP) to see whether this type of EMIC wave causes a statistically greater occurrence of REP.
In this study, different types of IPDP are characterized based on the increase in frequency over time of each wave form. Another considered characteristic of the IPDP waves is whether the wave is continuous or appears to form discrete packets. The discrete packets may actually be separate events. IPDP events are cataloged and then compared to REP events from the POES data set. This study is complementary to a study done by Aaron Hendry et al. who compared REP from POES data to the presence of EMIC waves at Halley Bay.

Background

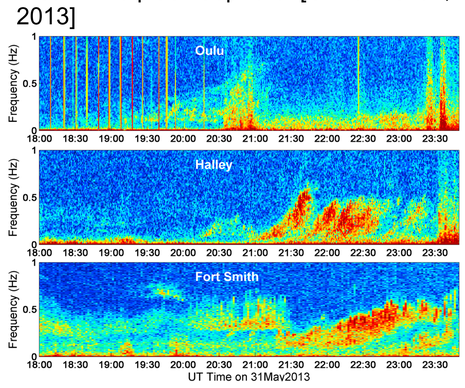


What are EMIC waves?

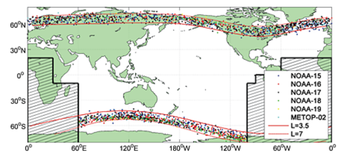
EMIC waves are Ultra Low Frequency (ULF) waves in the Pc1-Pc2 range occurring in the equatorial region of the magnetosphere. An ion temperature anisotropy is created, causing the generation of these waves.

What are IPDP waves?

An IPDP is a type of structured EMIC wave which is a geomagnetic pulsation. IPDP's have been recently been associated with electron precipitation. IPDP waves are created as a result of substorms. IPDP generation is shown to occur when injected protons move westward and meet a densely populated area of the plasmasphere. [Clilverd et al., 2013]



The figure above is an example of an IPDP observed by three different ground based observatories. [Clilverd et al 2015]



The figure above is a map of events detected by the POES satellite. [Carson et al 2013]

How is electron precipitation generated?

Relativistic electron precipitation (REP) generated outside of the plasmapause is potentially generated by EMIC waves. [Carson et al 2013] REP occur more frequently during geomagnetic disturbances.

The Department of Physics at the University of Otago in New Zealand, developed an algorithm to sort POES data into EMIC wave driven associated electron precipitation. [Carson et al., 2013] In order to find EMIC associated REP events, peaks in the flux of relativistic electrons were matched with peaks in the flux of protons.

How can relativistic electron precipitation be related to IPDPs?

Observational studies showing a closed connection between EMIC waves and precipitation of radiation belt electrons include Sandanger et al. [2007]; Clilverd et al. [2007]; Miyoshi et al. [2008], and Rodger et al. [2008].

In a study by Hendry et al from 2015 the POES database of REP was compared to ground based measurements of IPDPs. 85% of POES events within +/- 2 degrees of Halley correlated with EMIC wave observation at Halley. In our complementary study we will first catalog IPDP waves based on certain characteristics and then use the data of REP from POES to see if there is a positive correlation.

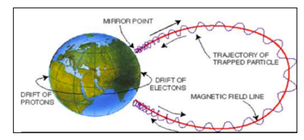
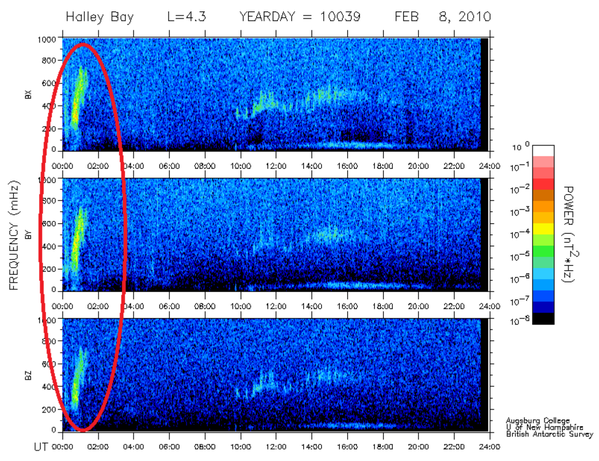
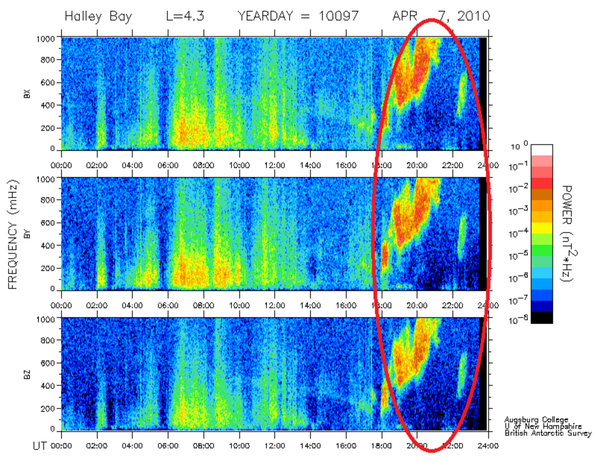


Image courtesy of:
http://ccar.colorado.edu/asen5050/projects/projects_2010/blum/

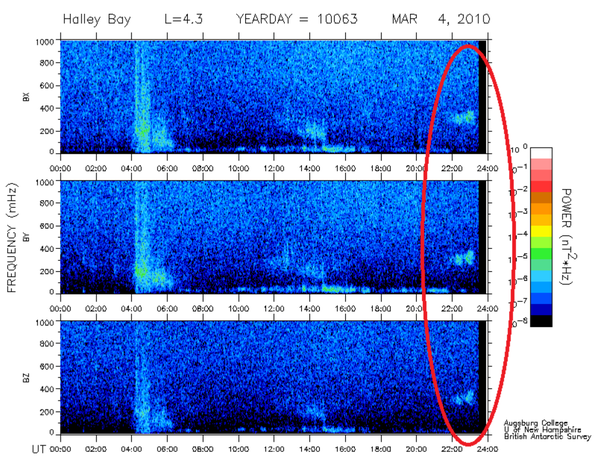
IPDP events



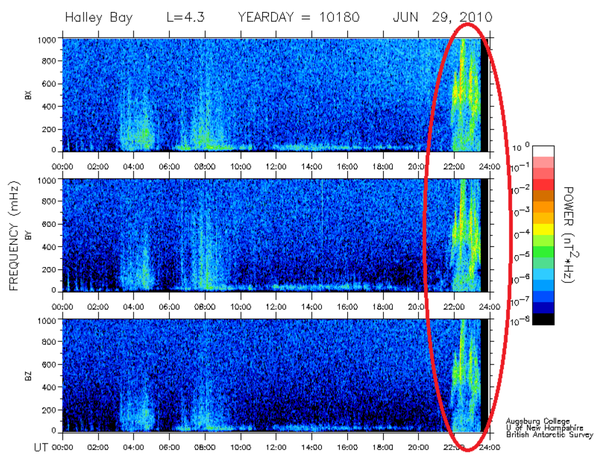
This event is an IPDP event from February 8th 2010 as recorded at the Halley Bay station. There is a clear rise in frequency in a short period of time which is characteristic of an IPDP wave.



This event is a possible IPDP event from April 7th 2010. This event has a clear rising tone signature. The wave may possibly be broken up into separate IPDP events that are not necessarily related. This event may be too long to be classified as an IPDP according to how IPDP waves are defined in a paper by Pikkarainen et al. 1983. See IPDP definition below for further details.



This event is a possible low power IPDP event from March 4th 2010 as recorded at the Halley Bay station. The possible event occurs from 22:15 UT- 23:15 UT. The slope of this event is not as prominent as most of the other events recorded. Shallow slope events are also considered based on how IPDP waves are defined in a paper on IPDP waves by Pikkarainen et al. 1983.



This event is an IPDP event from June 29, 2010. This event which occurs between 22:00 -24:00 UT is associated with an REP event occurring at 21:59 UT at an MLT of 18.13. There is a positive correspondence between the UT and MLT of this IPDP event and an REP from the POES database.

Halley Bay

Halley Bay station is located in Antarctica at Lat. 75°35'0"S, Long. 26°39'36"W. In collaboration with the British Antarctic Survey and Augsburg College, the University of New Hampshire has a ULF search coil magnetometer system installed at Halley Bay. EMIC waves are measured from the ground using search coil magnetometers that are placed near Earth's magnetic poles, where the magnetic field lines are stongest.

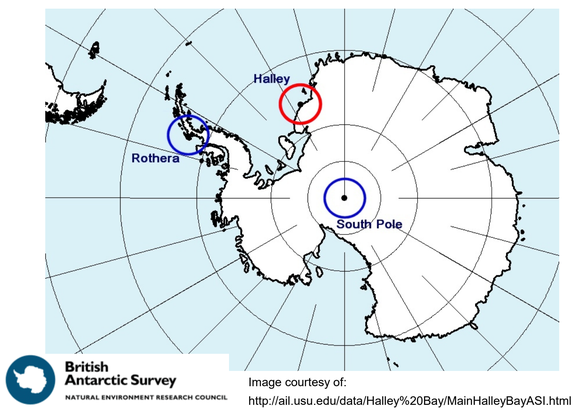


Image courtesy of:
http://ail.usu.edu/data/Halley%20Bay/MainHalleyBayASI.html

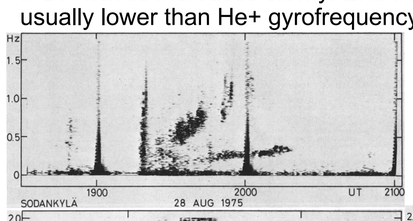
Conclusions

The purpose of this study is to consider IPDP wave events and compare to the POES database of REP events to see if IPDP waves cause a statistically greater occurrence of REP. This study differs from Hendry's 2015 study "POES Detected EMIC Precipitation Survey". In Hendry's study, data points from POES were considered first and then compared to Halley data to see if an EMIC event occurred. In this study, first a list of all IPDP events is complied and then compared to the POES REP data. Unlike Hendry's study, IPDP events with no associated REP will be recorded.

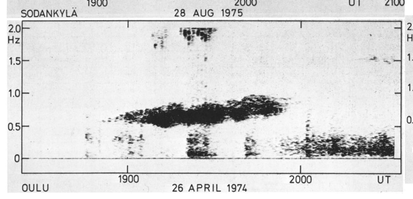
For this study, 98 unique IPDP events from 2010 were included in a database. From the POES database, we considered events within +/- 15 degrees magnetic longitude of Halley which is located at 304.4 degrees magnetic longitude. In conclusion, for 2010, our database contained 98 IPDP events, 3 which were associated with REP. ~3% of IPDP at Halley Bay were associated with REP events within a +/- 15 degree latitude. In Hendry's study, he discovered that 65% of REP event within a +/- 15 degree latitude occurred during a wave. He concluded that REP events were positively correlated with IPDP or EMIC waves. ***Our preliminary conclusion, in contrast to Hendry's study, is that IPDP waves do not have a positive correlation to REP events, meaning that IPDP events can occur independently of relativistic electron precipitation.***

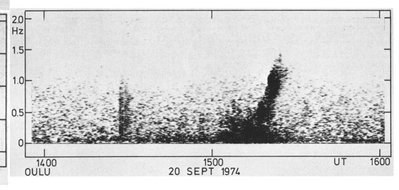
IPDP Definition

In a paper from 1983 by Pikkarainen, IPDP waves were categorized by LT and latitude. They found waves measured at low latitude stations can extend beyond 1 Hz. Auroral stations observed IPDP waves occurring up to 1 Hz. IPDP waves are defined as waves that start at a frequency of .1 Hz to 1-2 Hz over the span of 30 minutes to 2 hours. However, some waves defined as IPDP do not start at that low of a frequency. IPDP waves more frequently occur between noon and midnight MLT. IPDP waves occur during injections of energetic protons. [Yahnin et al 2009] IPDP waves that occur in the dusk sector are steeper. Sometimes, consecutive IPDP waves occur. These consecutive events could be caused by an echo due to the westward drift of protons. In the evening and midnight sector the frequency of IPDP waves increases slowly. End frequencies of IPDP waves are usually lower than He+ gyrofrequency of field line of occurrence.



These three figures are from the 1983 paper by Pikkarainen et, al. which helped inform the characteristics to define what the signature of an IPDP wave is.





EMIC Wave Generation

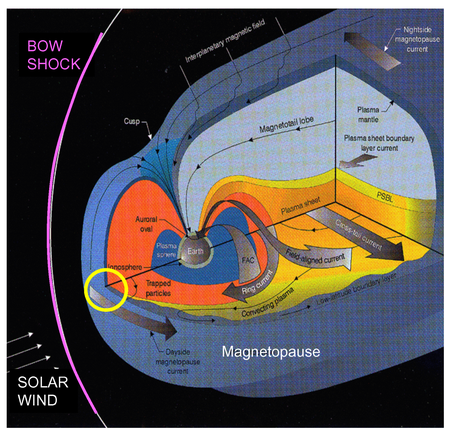


Image courtesy of: http://www.mssl.ucl.ac.uk/www_plasma/sci_nug/msphere.png

EMIC waves are an important phenomena in the magnetosphere. Not only do these waves couple the ring current and the ionosphere, they create a dynamic change in the RC-ionosphere system as a whole. EMIC waves create non adiabatic pitch angle scattering of ring current ions. During storm time, the proton precipitation caused by EMIC waves changes the distribution of field aligned currents and can change the ionosphere-thermosphere system by changing conductance or gas velocity of the system.

References:
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