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

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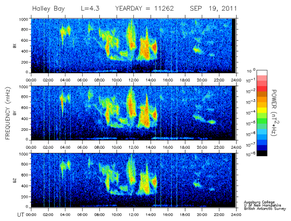
Sponsored by NSF

Abstract

Electromagnetic Ion Cyclotron (EMIC) waves are phenomena that exist 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

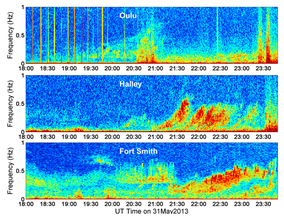


What are EMIC waves?

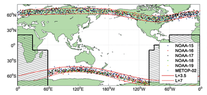
EMIC waves are Ultra Low Frequency (ULF) waves in the Pc1-Pc2 range occurring in the equatorial region of the magnetosphere. An ion temperature anisotropy is created, causing the generation of these waves.

What are IPDPs?

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 to the left is a map of events detected by the POES satellite. [Carson et al 2013]

How is electron precipitation driven?

Relativistic Electron Precipitation (REP) driven 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 drive 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 close 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 triggers within +/- 2 degrees of Halley correlated with EMIC wave observation at Halley. When events within +/- 15 degrees magnetic longitude were considered, they found that 64.8% of these events corresponded to an EMIC wave event at Halley. Of these corresponding events, 63% were IPDP wave Events. 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.

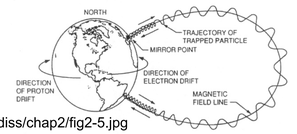
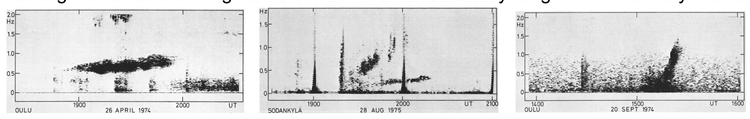


Image courtesy of: http://galileo.ftecs.com/stone-diss/chap2/fig2-5.jpg

Statistical Study

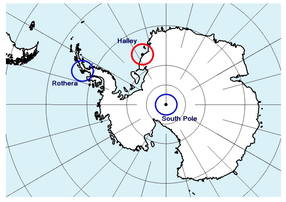
For this statistical study, we determined the correlation between REP and EMIC waves three different ways: firstly correlation in time and location, secondly correlation in time only, and lastly correlation in location only. For both events to be correlated in both time and location with each other, they must occur at the same time: within 1 hour UT(Universal Time) from one another and they must occur at the same location: within 1 hour MLT(Magnetic Local Time) from one another. For both events to have a correlation in time only they must occur within 1 hour UT from one another at different locations. For both events to have a correlation in location only they must occur within 1 hour MLT from one another at different times within a 24 hour UT window.

Using these three different correlations, we compared REP events to IPDP events starting with a list of REP events, REP events to non-IPDP EMIC wave events, starting with a list of REP events and IPDP events to REP events starting with a list of distinguishable IPDP events. Our study ranges from January 1. 2008 to December 31, 2010. During this time period 219 IPDP events are recorded and 449 REP events are recorded.

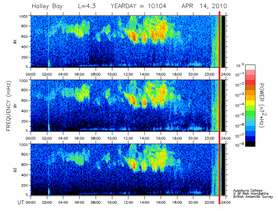


In a paper from 1983 by Pikkarainen, IPDP waves were categorized by LT and latitude. They found waves measured at low latitude stations can extend beyond 1 Hz. Auroral stations observed IPDP's occurring up to 1 Hz. IPDP waves are defined as waves that start at a frequency of .1 Hz to 1-2 Hz over the span of 30 minutes to 2 hours. 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.

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. The Magnetic Local Time(MLT) at Halley Bay, which measures location, is ~3 hours behind the Universal Time(UT) at Halley Bay.

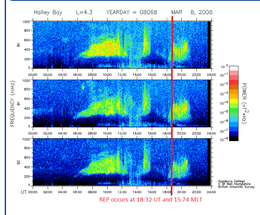


REP to IPDP Waves Comparison



- REP occurs at 23:39 UT/20.53 MLT
- Correlated in time and location with midnight IPDP events
- REP occurs at 23:34 UT/17.84 MLT and 24:07 UT/15.52 MLT respectively
- Both correlated in UT only with midnight IPDP events
- REP occurring at 24:07 UT/15.52 MLT correlated in MLT only with earlier non-IPDP EMIC wave

REP to Non-IPDP EMIC Waves Comparison

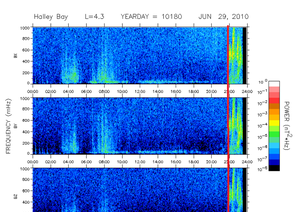


- Six other REP events occur
- Other non-IPDP EMIC events occur earlier in the day
- Three REP correlate to a non-IPDP EMIC wave in time only
- One REP correlates to a non-IPDP EMIC wave in location only

- REP event occurs at 18:32 UT/15.74 MLT
- Correlated in both time and location with the non-IPDP EMIC wave occurring between 18:00 UT & 21:15 UT /15:00 MLT & 18:15 MLT

DATE	UT	MLT	Correlation
03/08/08	9:47	.59	none
03/08/08	11:46	.26	none
03/08/08	13:30	22.95	UT only
03/08/08	13:46	19.98	UT only
03/08/08	14:01	20.48	UT only
03/08/08	17:55	1.87	MLT only (from the next day)
03/08/08	18:32	15.74	UT and MLT

IPDP Waves to REP Comparison



In the Hendry et al study, the list of REP events from the POES database was compared to EMIC wave events at Halley Bay.

For our study, we compiled a list of distinct IPDP EMIC wave events to compare and correlate with REP events, in order to see what percentage of IPDP events correspond to REP. This part of the study goes beyond the comparisons made in in the Hendry et al. study.

- Four IPDP events occur between 21:45 UT & 23:30 UT/18:45 MLT & 20:30 MLT
- REP event occurs at 21:59 UT/18.13 MLT
- Correlated in both time and location with one IPDP wave
- REP event occurs at 21:29 UT/21.04 MLT
- Correlated in time only with two other IPDP waves
- Correlated in location only with last IPDP of the day

References:

Carson, Bonar R. et al. "POES Satellite Observations of EMIC-wave Driven Relativistic Electron Precipitation during 1998-2010." J. Geophys. Res. Space Phys. Journal of Geophysical Research: Space Physics 118.1 (2013): 232-43.

Clilverd, Mark A. et al. "Electron Precipitation from EMIC Waves: A Case Study from 31 May 2013." J. Geophys. Res. Space Physics Journal of Geophysical Research: Space Physics 120.5 (2015): 3618-631.

Hendry, Aaron T. et al."Confirmation of EMIC wave driven relativistic electron precipitation." Journal of Geophysical Research: Space Physics.(2015)

Pikkarainen, T. et al. "Type IPDP Magnetic Pulsations and the Development of Their Sources - Pikkarainen - 1983 - Journal of Geophysical Research: Space Physics.

Yahnin, A. G. et al."Proton aurora related to intervals of pulsations of diminishing periods". Journal of Geophysical Research: Space Physics. (2009)

Three Cases

Case A: Spatially and Temporally Correlated
- Event 1 is within 1 hour MLT of Event 2
- Event 1 is within 1 hour UT of Event 2

Case B: Only Temporally Correlated
Event 1 is within 1 hour UT of Event 2
Event 1 is NOT within 1 hour MLT of Event 2

Case C: Only Spatially Correlated
- Event 1 is within 1 hour MLT of Event 2
- Event 1 is NOT within 1 hour MLT of Event 2
- Event 1 occurs within +/- 12 hours UT of Event 2; within a 24 hour UT window

Conclusions

	Of all REP events, what percent correlate to IPDP waves?	Of all REP events, what percent correlate to Non-IPDP EMIC waves?	Of all IPDP waves, what percent correlate to REP events?
Case A: Spatially and Temporally Correlated	*2.7%*	*5.4%*	*6.4%*
Case B: Only Temporally Correlated	*5.1%*	*36.8%*	*14.6%*
Case C: Only Spatially Correlated	*3.8%*	*29%*	*9.6%*

Unlike the study done by Hendry et al., we used MLT to determine if the REP events considered were near Halley Bay. In Hendry et al., they used longitude to determine if a REP event was correlated in position with Halley Bay. Only events within 15 degrees magnetic longitude were considered. They found that 64.8% of these events corresponded to an EMIC wave event at Halley. Of these corresponding events, 63% were IPDP wave events. ***The percentage of corresponding events in the Hendry et al. study is significantly higher than the percentage of events corresponding in our study.***

We find that for all REP events, 2.7% are correlated in both time and location with an IPDP event. To be considered correlated, the EMIC event must occur within 1 hour UT and 1 hour MLT of the REP event. For all REP events, 5.1% are correlated with IPDP in time but not location; the EMIC event must occur within 1 hour UT but not within 1 hour MLT of the REP event For all REP events, 3.8% are correlated with IPDP in location but not time within a 24 hour UT window.

We find that for all REP events, 5.4% are correlated in both time and location with non-IPDP EMIC events. To be considered correlated, the EMIC event must occur within 1 hour UT and 1 hour MLT of the REP event. For all REP events, 36.8% are correlated with non IPDP EMIC waves in time but not location; the EMIC event must occur within 1 hour UT but not within 1 hour MLT of the REP event. For all REP events, 29% are correlated with non-IPDP EMIC events in location but not time within a 24 hour UT window.

We find that for all IPDP events, 6.4% are correlated in both time and location with a REP event. To be considered correlated, the REP event must occur within 1 hour UT and 1 hour MLT of the IPDP event. For all IPDP events, 14.6% are correlated with REP in time but not location; the REP event must occur within 1 hour UT but not within 1 hour MLT of the REP event. For all IPDP events, 9.6% are correlated with a REP event in location but not time within a 24 hour UT window.

Acknowledgment: Research at the University of New Hampshire was supported by NSF grant PLR 1341677.