Spatial Extent of Electromagnetic Ion Cyclotron Waves in Earth's Magnetosphere during Geomagnetic Storms

Taylor Whitney Aegerter[1,2] **& Lauren Blum**[1,2]

[1]University of Colorado Boulder, Department of Astrophysical and Planetary Sciences, Boulder CO, United States

[2]Laboratory for Atmospheric and Space Physics, Boulder CO, United States

Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**

Abstract

Geomagnetic storms often trigger electromagnetic waves in the Earth's magnetosphere that can further influence wave-particle interactions. However, the spatial variability of these wave signatures throughout the magnetosphere is not well understood. This study will characterize the spatial extent of electromagnetic ion cyclotron (EMIC) waves throughout the magnetosphere during periods of geomagnetic storming from March 2015 - October 2019. This will be done using simultaneous magnetic field measurements from the Magnetospheric Multiscale (MMS), Time History of Events and Macroscale Interactions during Substorms (THEMIS), Van Allen probes, and Geostationary Operational Environmental Satellite (GOES) missions. Results of this study reveal the regions of the magnetosphere over which EMIC waves span throughout geomagnetic storms.

Introduction

Plasma waves drive energetic particle movements throughout the magnetosphere, impacting natural phenomena as well as electronic systems. One type of these waves are electromagnetic ion cyclotron (EMIC) waves, which are generated in the inner magnetosphere by anisotropic ions [4]. These waves interact with particles, causing losses for ring current ions and radiation belt electrons [4].

Method

Magnetospheric observations are available from four satellite missions: Van Allen probes, MMS, THEMIS, and GOES. Data from these satellites are used to determine the presence of EMIC waves in response to geomagnetic storms, as identified by Pedersen et al. [2].

Initial methods were applied to the EMIC wave observations of November 6, 2015. A coronal mass ejection (CME) from November 4, 2015 arrived at Earth on November 6 and simultaneous observations from the magnetospheric satellite missions show wave generation throughout the evolution of the geomagnetic storm [1, 3].

Results

During the initial phase of the geomagnetic storm, EMIC waves are primarily concentrated on and spanning the entirety of the dayside. In the main phase, the prevalence of EMIC waves spreads out into the nightside. While in the recovery phase, EMIC waves are observed throughout the magnetosphere. However, given the long time range of the recovery phase, it is not clear how the waves propagate throughout this phase.

Future Work

This study will be expanded to include all events in the list from Pedersen et al. [2] that fall within the overlapping years of the four satellite missions. This time range is between March 12, 2015 and October 18, 2019 and covers 102 geomagnetic storms. This larger sample size will allow for stronger conclusions to be drawn regarding the instantaneous spatial distribution of EMIC waves in the magnetosphere in response to geomagnetic storming.

Additionally, EMIC wave instances are currently identified by eye, which will likely be inefficient and subjective for a larger event list. Possible methods for automating this process will be explored.

Acknowledgments

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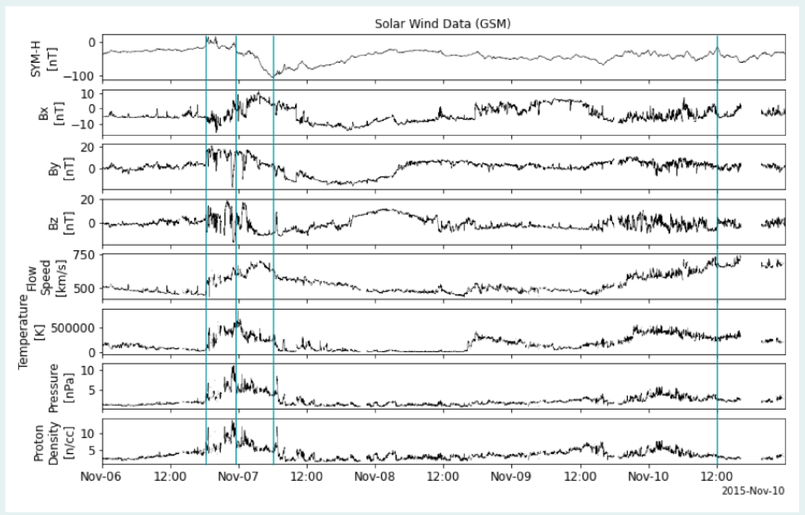
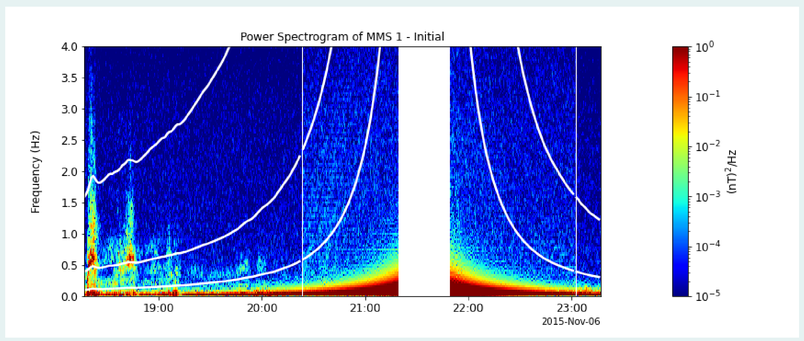


Figure 1: Space weather data for the geomagnetic storm starting on November 6, 2015. The storm phases, as identified by Pedersen et al. [2] are indicated by the vertical (initial phase beginning, main phase beginning, recovery phase beginning, and storm end).



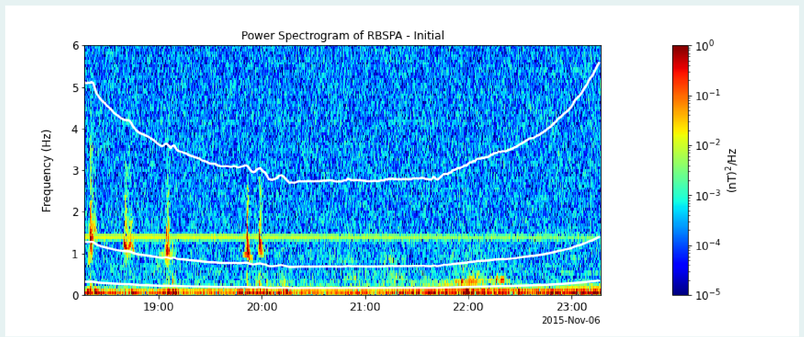


Figure 2: Spectrograms from the MMS-1 and Van Allen Probe A satellites during the initial phase of the geomagnetic storm. Multiple EMIC waves can be seen within the first two hours, as identified by eye for this study.

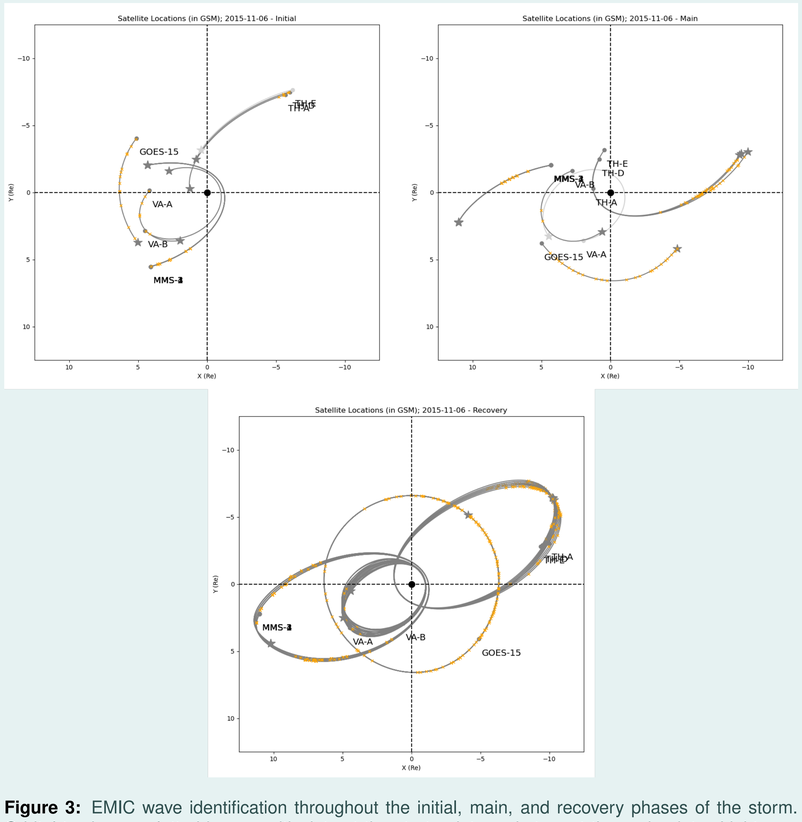


Figure 3: EMIC wave identification throughout the initial, main, and recovery phases of the storm. Orbital tracks are plotted in gray with dots at the start points and stars at the end points. Light gray orbits did not have data during the time period. Orange x markers indicate observed EMIC waves.

References

[1] Blum, L. W., Koval, A., Richardson, I. G., Wilson, L. B., Malaspina, D., Greeley, A., and Jaynes, A. N. (2021). Prompt Response of the Dayside Magnetosphere to Discrete Structures Within the Sheath Region of a Coronal Mass Ejection. *Geophysical Research Letters*, 48(11):e2021GL092700.

[2] Pedersen, M. N., Juusola, L., Vanhamäki, H., Aikio, A. T., and Viljanen, A. (2024). Rapid Geomagnetic Variations During High-Speed Stream, Sheath and Magnetic Cloud-Driven Geomagnetic Storms From 1996 to 2023. *Journal of Geophysical Research: Space Physics*, 129(10):e2024JA032656. e2024JA032656 2024JA032656.

[3] Space Weather Prediction Center (2015). G1 (Minor) Geomagnetic Storms Expected on 06 November 2015. https://www.swpc.noaa.gov/news/g1-minor-geomagnetic-storms-expected-06-november-2015. Accessed: 4 March 2025.

[4] Usanova, M. E., Mann, I. R., and Darrouzet, F. (2016). EMIC Waves in the Inner Magnetosphere. In *Low-Frequency Waves in Space Plasmas*, chapter 5, pages 65–78. American Geophysical Union (AGU).