Intense geoelectric field perturbations driven by magnetospheric ULF waves

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Background and Motivation

- Geomagnetic perturbations (GMDs) related to various phenomena in the geospace system can induce geoelectric fields within the Earth.
- These geoelectric fields can drive geomagnetically induced currents (GIC) that can cause potential damage to critial infrastructure.
- The geoelectric field is an important link between phenomena in geospace and GICs in grounded electricity transmission networks.
- Ultra-Low Frequency (ULF: ~1mHz to several Hz) waves couple to GMDs, geoelectric fields, and GICs (e.g., Hartinger et al., 2020, Yagova et al., 2019, Heyns et al., 2021).
- Though numerous past studies have examined ULF wave related GMDs from a space weather perspective, few studies have directly linked ULF waves with geoelectric fields due to limited direct measurements of these fields.
- There is a lack of comparison from past work on nominal geoelectric field amplitudes driven by different sources, e.g., ULF waves & substorms.

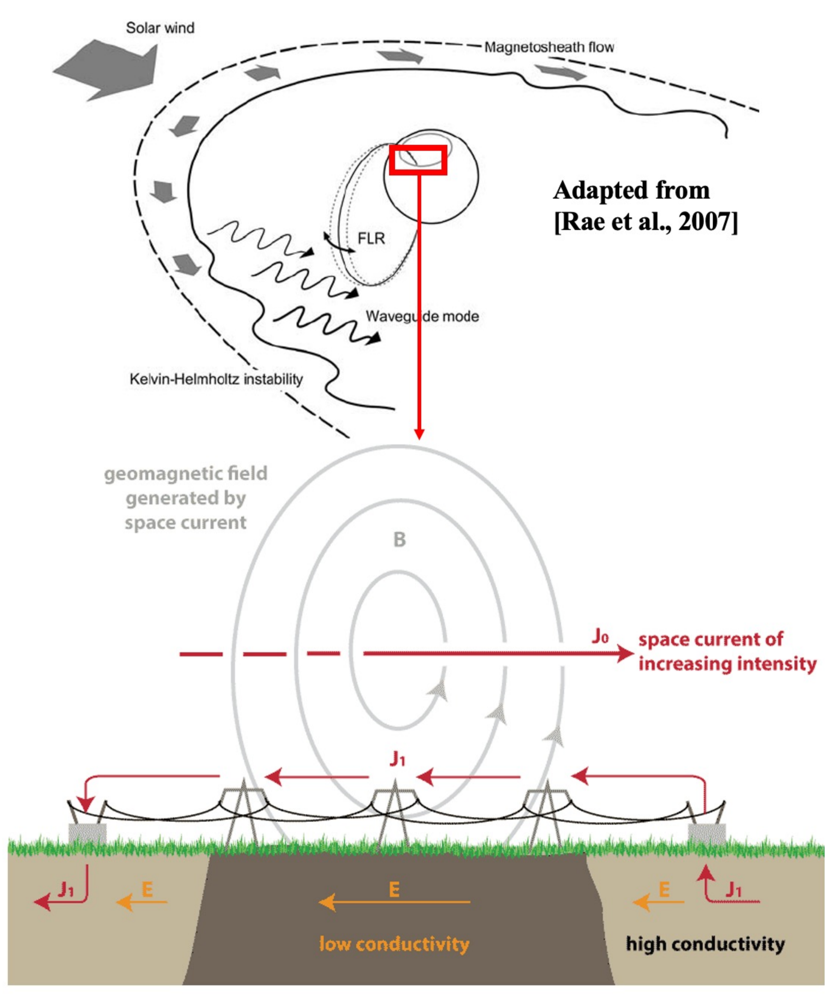
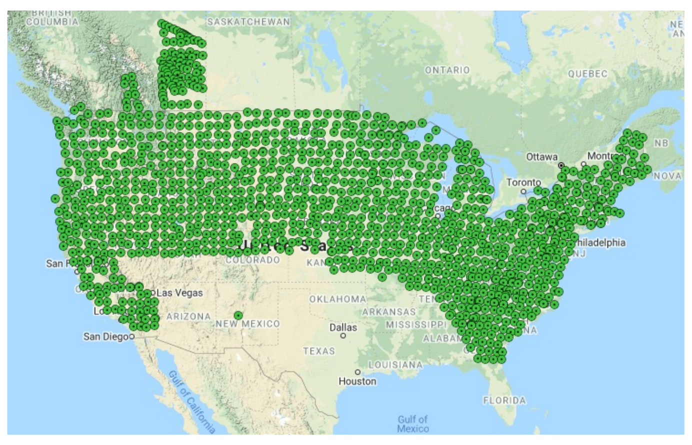


Image source: https://www.usgs.gov/media/images/powerlines

Data Sets and Methodology

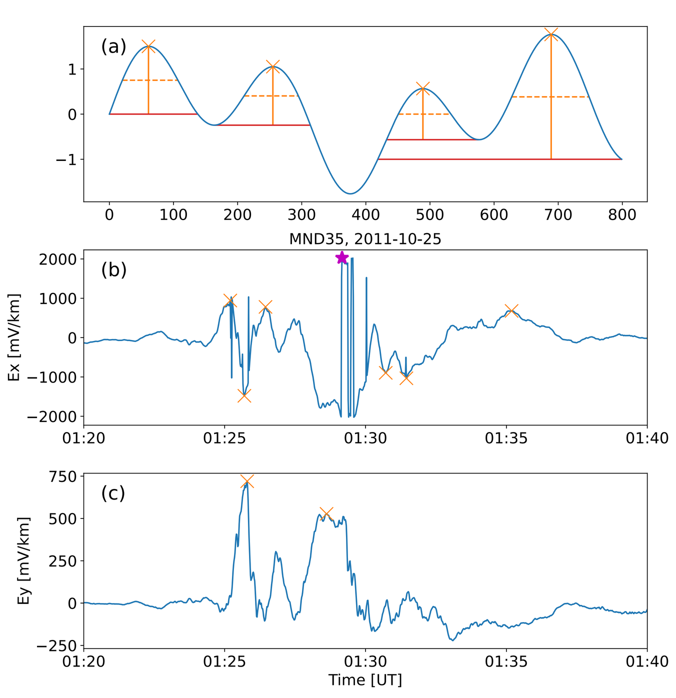
- Use 1-sec geoelectric field measurements ($\mathbf{E_{geo}}$) made at recently available EarthScope magnetotelluric (MT) survey sites distributed widely across the United States.
- OMNI solar wind data and geomagnetic indices (AE, SYM-H) are used to investigate typical sources that drive intense geoelectric fields.
- 16 geomagnetic storms with Dst_{min} < - 100 nT are selected when EarthScope $\mathbf{E_{geo}}$ data are available from 2006 to 2019.

[Shi et al., 2022]

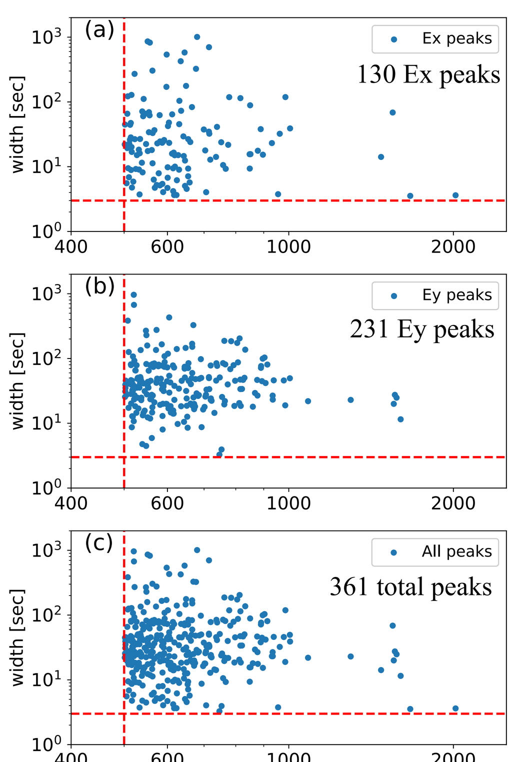


Identify temporally-localized peaks in measured 1-second geoelectric field time series:

- We take absolute values of the geoelectric fields in order to find peaks and valleys.
- We require that the peak be prominent above the surrounding signal by at least **0.5 V/km**.
- A peak must have a minimum width of 3 sec and peaks must be separated by at least 30 sec.



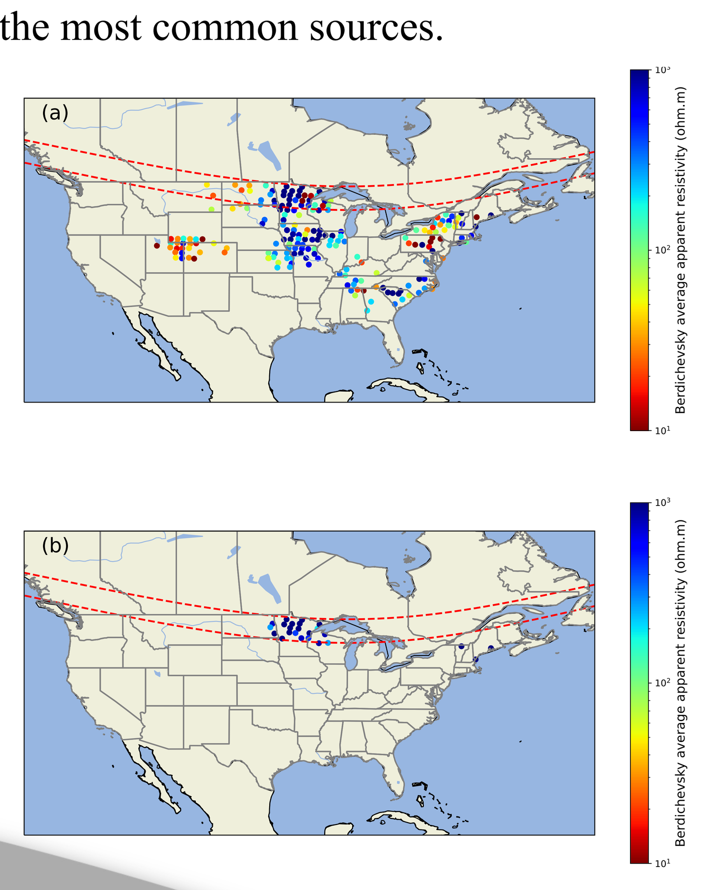
Statistical Results



- In total, 361 intense geoelectric field peaks were identified from 24 EarthScope sites during six geomagnetic storms.
- Extreme events have a prominence up to 1-2 V/km, comparable to thresholds commonly used to identify hazardous events.
- 73.4% of the events have a width less than 60 s and thus are difficult to resolve with 1-min resolution data.
- Most of the intense geoelectric fields were observed in **resistive** regions with magnetic latitudes greater than 55°.
- The causes of intense geoelectric fields differ from storm to storm due to dependence on multiple factors. ULF wave activity is one of the most common sources.

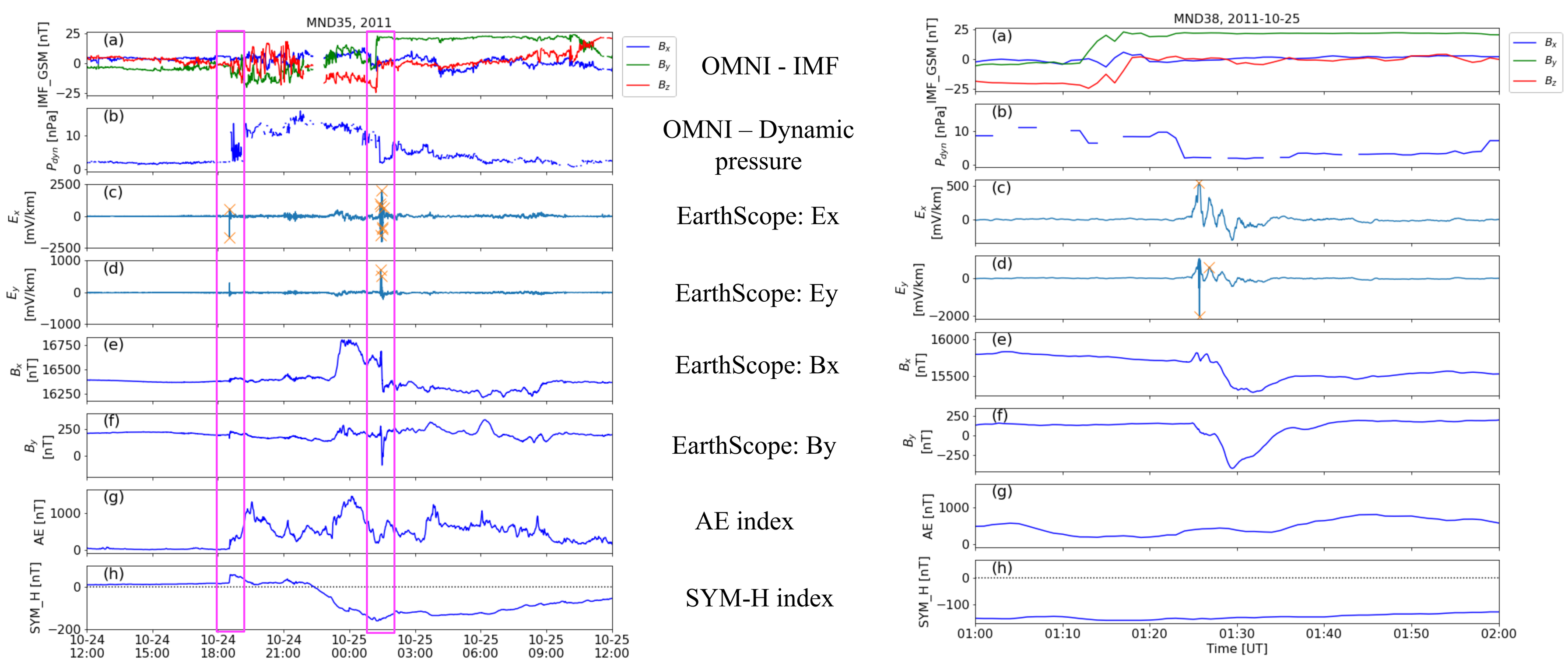
[Shi et al., 2022]

Storm date (Dst_{min})	IP shock C1	IMF turning C2	Substorm C3	ULF wave C4	Others C5
2011-09-26 (-118 nT)	09-26/12:36 MLT: 6.4 h	09-26/19:37 MLT: 13.4 h		09-26/12:39 MLT: 6.4 h	09-26/20:54 MLT: 14.6 h
2011-10-25 (-147 nT)	10-24/18:31 MLT: 12.3 h	10-25/01:30 MLT: 19.2 h		10-24/18:32 MLT: 12.3h	
2012-07-15 (-139 nT)	07-14/18:12 MLT: 11.6 h		07-15/07:00-12:00 MLT: 0-5 h	07-15/04:58 MLT: 22.3	07-15/00:43 MLT: 18.4 h
2013-06-29 (-102 nT)			06-29/04:00-12:00 MLT: 22-06 h		
2017-05-28 (-125 nT)				05-28/03:00-05:00 MLT: 23-01 h	
2017-09-08 (-124 nT)	09-07/23:02 MLT: 16.4 h		09-08/00:00-02:00 MLT: 19-21 h		09-08/13:00-15:00 MLT: 6.3-8.3 h

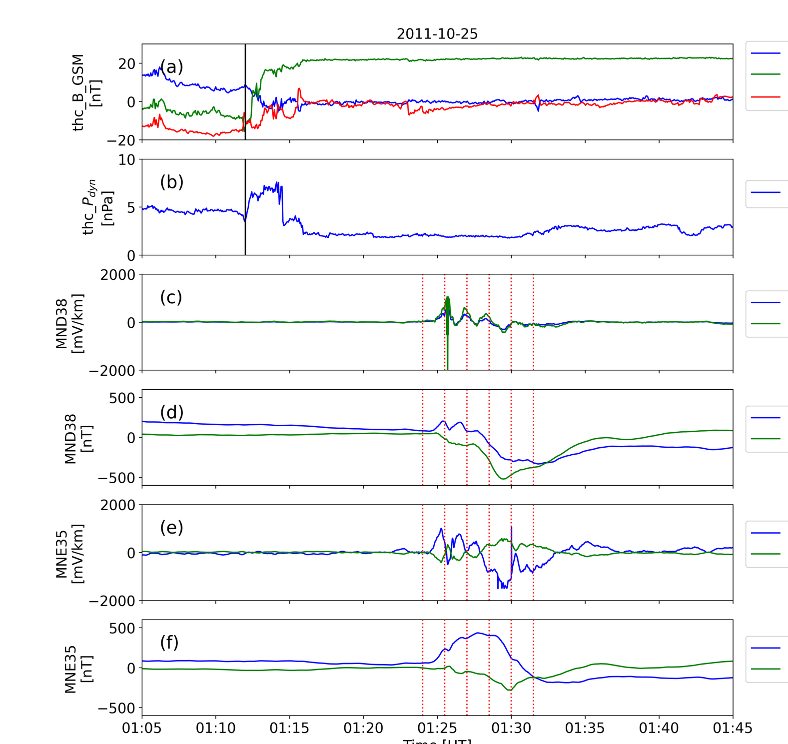


ULF Wave driven Intense E_{geo} Events

Intense E_{geo} driven by ULF waves together with other drivers such as IP shock and IMF turning.



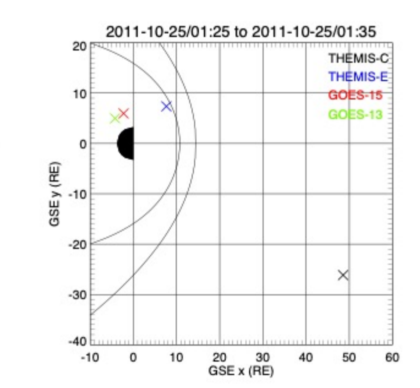
Coordinated space and ground investigation on the driving mechanism of intense E_{geo} perturbations:

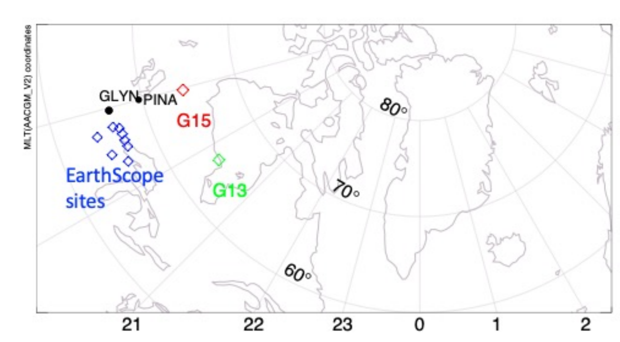


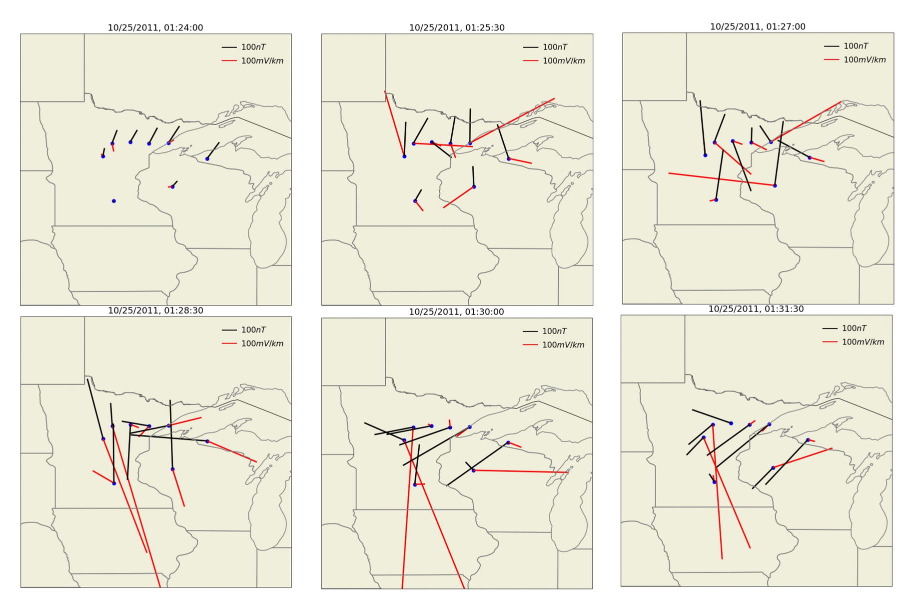
EarthScope site MNE35 at MLT = 19.2h, MLAT=56.3°

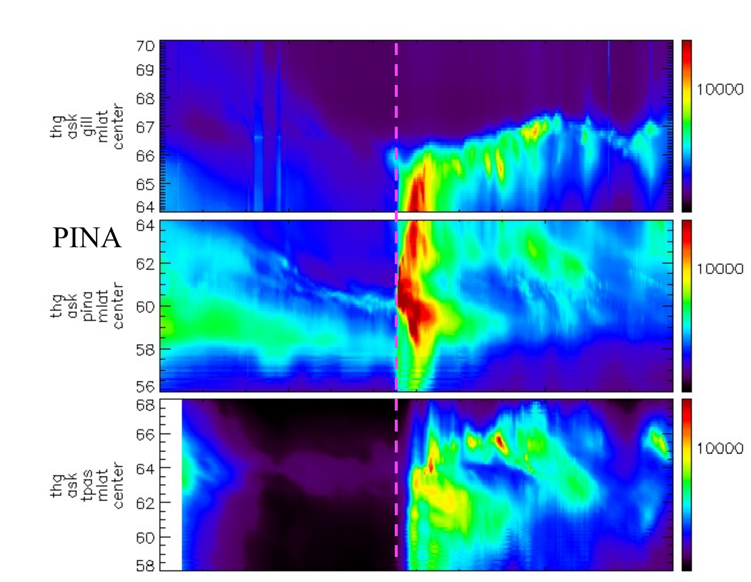
ΔE~1.5V/km & ΔB ~ 300 nT

Shorter-period (~ 1 min) ULF waves are superposed within longer period (~10 min) perturbations.









- Both geomagnetic and geoelectric field perturbations are nonuniform and localized.
- Localized ionospheric currents associated with substorm auroral activity after the IMF turning are most likely the driver of the longer-period $\mathbf{E_{geo}}$ and **B** field perturbations.
- The solar wind dynamic pressure impulse may be the driver of the shorter-period ULF perturbations.

Summary

- **ULF wave activity** is a common driver of intense geoelectric fields (>0.5 V/km) during geomagnetic storms.
- There is considerable variability in the causes of intense geoelectric fields due to dependence on multiple factors, including **regional ground conductivity** and sources from the geospace system (**amplitude and frequency content**).
- A detailed case study shows that the combination of sources from ionospheric currents and ULF waves as well as the Earth's spatially varying conductivity drive the intense geoelectric fields of ~ 1.5 V/km at mid-latitudes.
- More collaboration is needed between MT and space physics communities, and more satellite conjunction studies are needed to understand how different phenomena couple to geoelectric fields (e.g., ULF waves and other fine structure in the aurora).

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