Giant GIC Undulations During the 22-23 June 2015 Geomagnetic Storm Driven by Magnetosphere-Ionosphere Coupling Dynamics

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INTRODUCTION

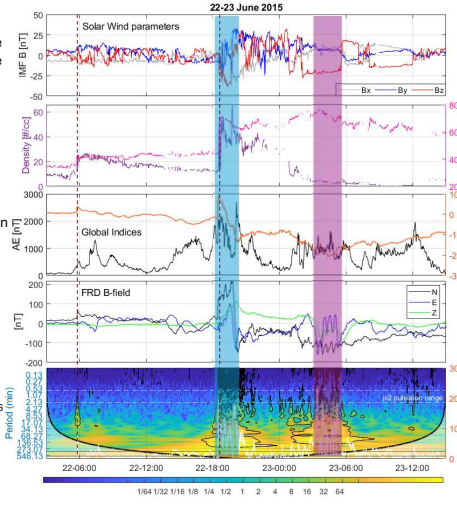
- Geomagnetic storms arise when Earth's magnetic field is disturbed by eruptions from Sun called Coronal Mass Ejection (CMEs)
- This creates **Geomagnetically Induced Currents (GICs)**, which are excess ground currents capable of **damaging critical ground infrastructure** such as powerlines, pipelines, etc.
- Since GICs depend on magnetic field (B-field) fluctuations and ground conductivity (∇xEg = -dB/dt; I = σgEg), **local meso-to-small scale activity** that drives B-field fluctuations become important.
- The B-field fluctuations on the ground are driven by the currents in the geospace, that is, magnetospheric currents flowing in and out of the ionosphere.
- Datasets are available to analyze various parts of the geospace. **Systematic data fusion** of these observations can provide useful insights into location-specific dynamics.

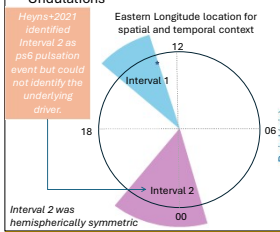
22-23 June 2015 Event

Double CME event
- Shock 1 arrived @ 05:45 UT on 22 June
- Shock 2 arrived @ 18.33 UT on 22 June

Global geoeffectiveness
- High substorm (>1000 nT) after 18 UT
- Double dip in ring current index
  - Interval 1: 108 nT @ 20:30 UT on 22 June
  - Interval 2: 210nT @ 04:30 UT on 23 June

Local Response – Eastern US
- Interval 1: High frequency fluctuation on periodic 10A GICs
- Interval 2: Smooth +/- 20A GIC Undulations

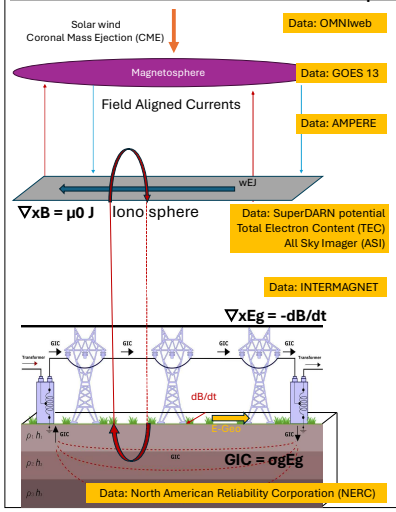




Motivating Question: What M-I coupling produced the periodic pulsations on the ground response?

METHOD AND DATA

Data Fusion of Observations from Ground to Space



Keograms – 70-80W Geographic Longitude

Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE)-derived FACs are often presented in Geomagnetic coordinates. Herein we use a novel perspective in Geographic coordinates to trace the M-I coupling (FAC activity) poleward (80-40GLAT) of the Eastern US.
- *Time Resolution: 10-minute average, every 2 minutes.*

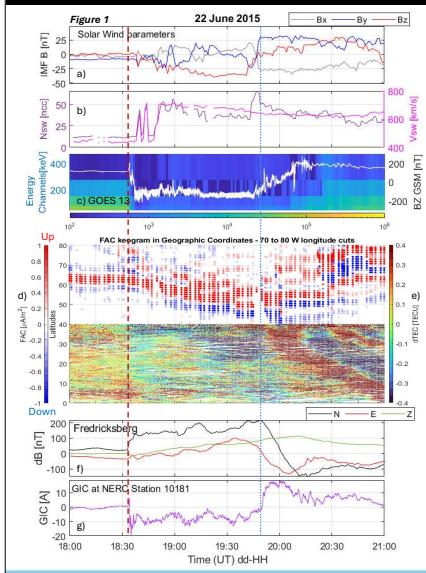
Global Navigation Satellite System (GNSS) differential TEC (dTEC) is presented from 40 GLAT to equator.
- *Time Resolution: few seconds.*

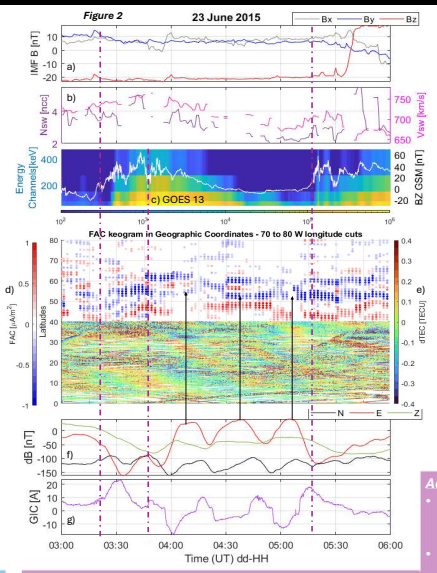
Ground-based All Sky Imager (ASI) at Goose Bay, Canada is presented between (70-50 MLAT or ~60-40 GLAT)
- *Time Resolution: <10 seconds.*

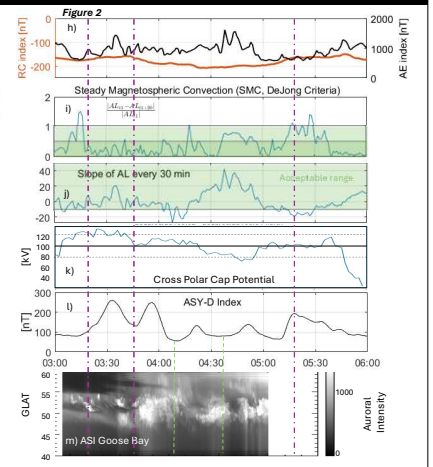
Trough Detection (Starr+2022) is used to identify the location and extent of the nightside electron depletion.

Continuous Wavelet Transform is used to understand the underlying fluctuations

RESULTS and DISCUSSION







Key Takeaways for Interval 1:

- **CME arrived at 18:33 UT**
  - Strong southward IMF Bz (sBz, Fig.1a) high n_{sw} and v_{sw} (1b)
- Geosynchronous Magnetopause Crossing **(GMC)** due to high solar wind pressure (Psw = n_{sw}-v_{sw}^2)
  - Sharp -100nT drop in GOES13 Bz and Electron Flux (1c)
- **Rapid FAC intensification** upon shock arrival. FAC system extends equatorward corresponding to sBz (1d)
  - Lowest Latitude: 38GLAT
- Large scale TID (**LSTID**, diagonal deep red/deep blue) propagates equatorward from 19:45 UT (1e).
  - Movie reveals two auroral disturbances originate at 19:30 UT and merge at 19:45 UT
- **FACs poleward retreat**, responding to IMF Bz rotating northward rotation at 19:45 UT.
  - Max Fac: 2..5microA/m at 20:00 UT appears to trigger mid-scale TID (MSTID)
- Three periodic **Eastward Electrojet enhancements** ~25 minutes apart (dBN rise in 1f).
- **Sustained 10A GIC for ~2 hours.**

Underlying Mechanism: GMC and Joule Heating

Key Takeaways for Interval 2:

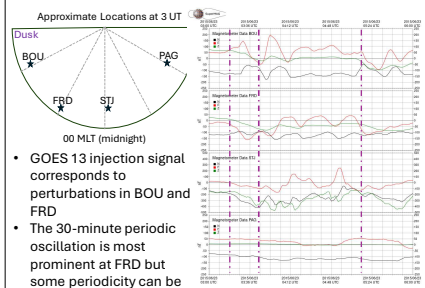
- **Magnetic Cloud arrives at ~12:45 UT**
  - sBz stabilizes to -23nT (Fig.2a) with ambient nsw, but high vsw (2b).
- **Two large injections with smaller embedded structures**
  - GOES13 Bz and electron flux – 3:15 and 5:20 UT.
  - Smaller injection at 3:45 UT (2c)
- **Quasi-periodic upward FACs at 60 GLAT** (2d)
  - Likely Substorm Current Wedge dynamics
- **Sustained dTEC depletion around 40 GLAT** (2e)
  - Accompanied with Mid-scale TIDs (MSTIDs)
- **Westward dB intensification correspond to injections**
  - Undulations appear in all dB components suggesting east-west and north-south oscillations of auroral currents.
- **+/-20A GIC oscillations persist for 3 hours**

- GMC produced high frequency fluctuations on the ground.
- FACs are found to heat the topside ionosphere (Giannattasio+2022) and increase the electron density.
- LSTIDs can be generated from Poynting Flux (S=(1/μ_0)E x dB) where dB is related to FACs and E is the convection Electric field (Valladares+2025).

Additional analysis
- Stable Dayside sBz, and steady Sym-H ring current index and AE auroral index at ~180nT and 1000nT respectively (2h) suggest Steady Magnetospheric Convection (SMC)
- DeJong's SMC Criteria (2i,j) is met for all but two instances – they are related to the injections.
- Cross polar cap potential (CPCP) shows periodic rise and fall of 100kV
- ASI keogram from Goose Bay shows quasi periodic intensifications

Underlying Mechanism: Periodic Expansion and Contraction of the Auroral Oval due to SMC

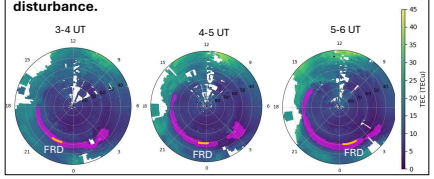
How Localized is Interval 2?



- GOES 13 injection signal corresponds to perturbations in BOU and FRD
- The 30-minute periodic oscillation is most prominent at FRD but some periodicity can be seen at BOU and STJ

Why?

The sustained dTEC depletion indicates **ionospheric trough**. The trough detection algorithm shows electron depletion over FRD for the three hours. Troughs are often associated with sub-auroral ion drift (SAID) and polarizing streams (SAPS), which **could explain the localized nature of the periodic dB disturbance.**



SUMMARY

- 22-23 June 2015 storm generated significant GICs at mid-latitude for prolonged duration in two intervals.
- Both interval had ~30-minute periodicity but the first was superposed with high frequency fluctuations driven by solar wind compression and the later with injection-type signals.
- Data fusion of observations suggest that the 30-minute period in Interval...
  - 1 was likely driven by joule heating.
  - 2 was likely driven by the expansion and contraction of the auroral oval. The effect may have been confined due to the ionospheric trough.
- Additional analysis is required to confirm the exact underlying mechanism

Acknowledgement and Key References

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