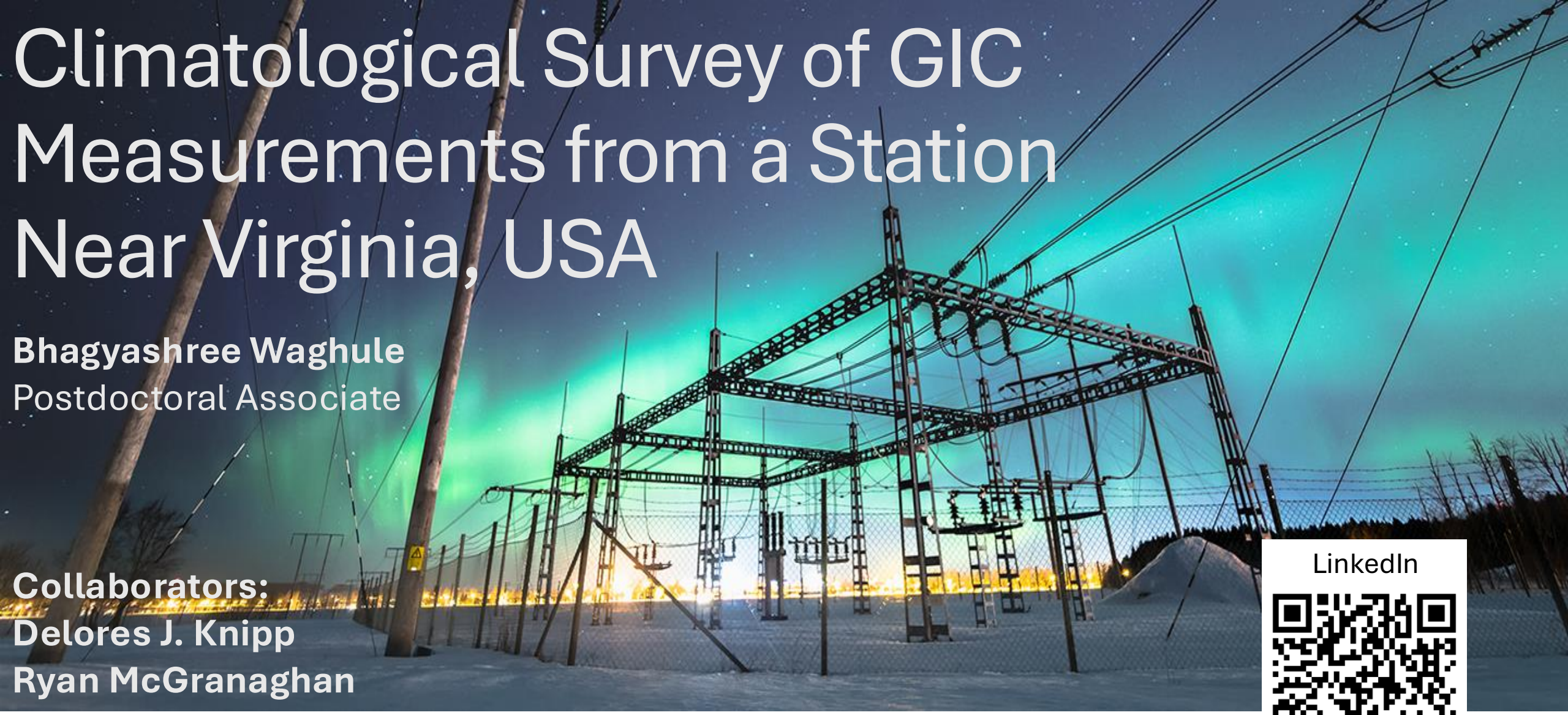
Climatological Survey of GIC Measurements from a Station Near Virginia, USA



Bhagyashree Waghule
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Delores J. Knipp
Ryan McGranaghan

LinkedIn

Questions? Comments?

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Eddy Symposium

Wednesday, May 06, 2026

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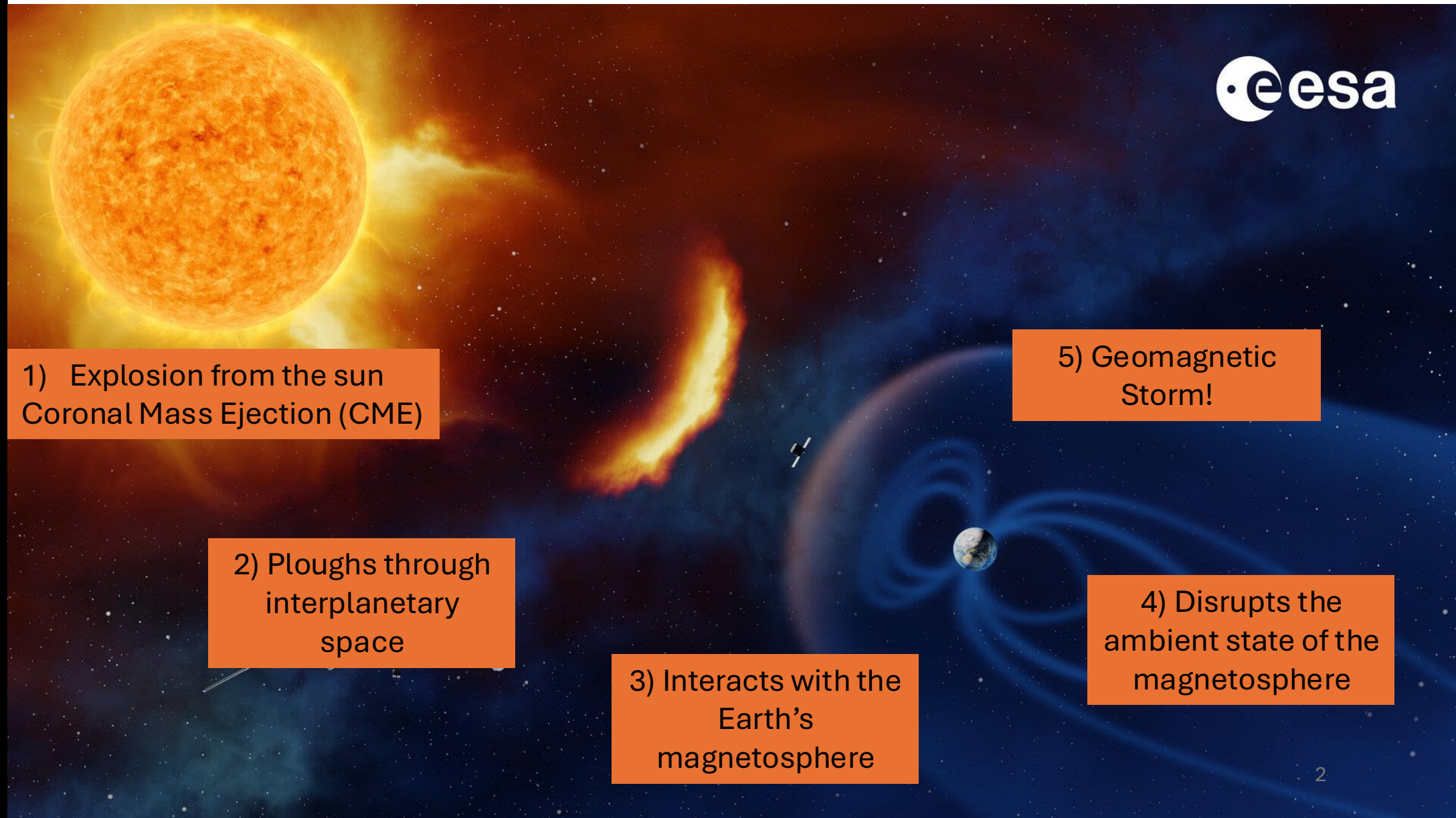
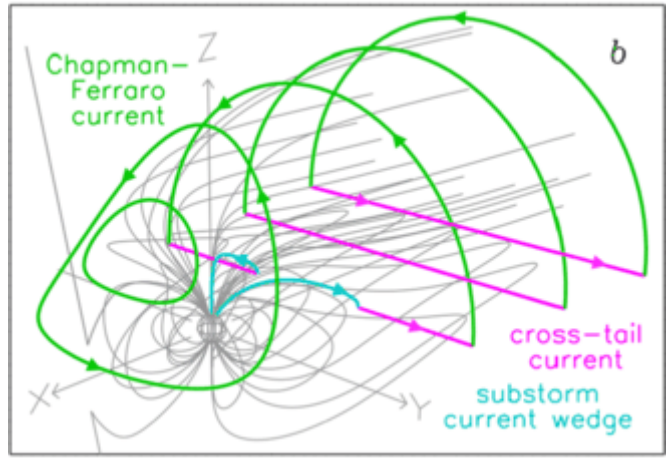
Earth Resides in the Sun's Heliosphere



Geomagnetically Induced Currents

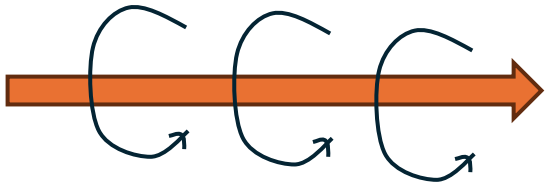
- What are GICs?
  - Currents generated in long conducting systems such as pipeline, powerlines, etc. due to change in magnetic flux (dB/dt) (Faraday's law)
- What changes the magnetic flux?
  - Change in overhead ionospheric currents changes the associated magnetic field with it (Ampere's law)
- What changes the ionospheric currents?
  - Currents from the magnetosphere that couple with the ionosphere, during **geomagnetic storms**
- What drives the magnetospheric currents?
  - Mass, Momentum, Energy from Solar wind, especially from a Coronal Mass Ejection (CME)



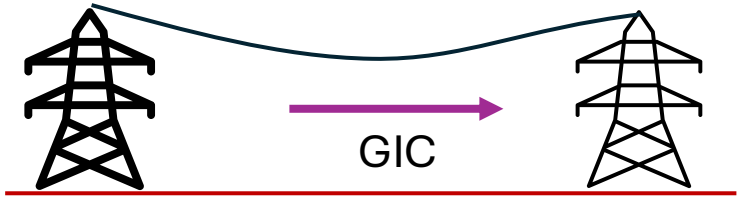
Solar wind

Magnetospheric Currents

Ionospheric Current



Associated dB



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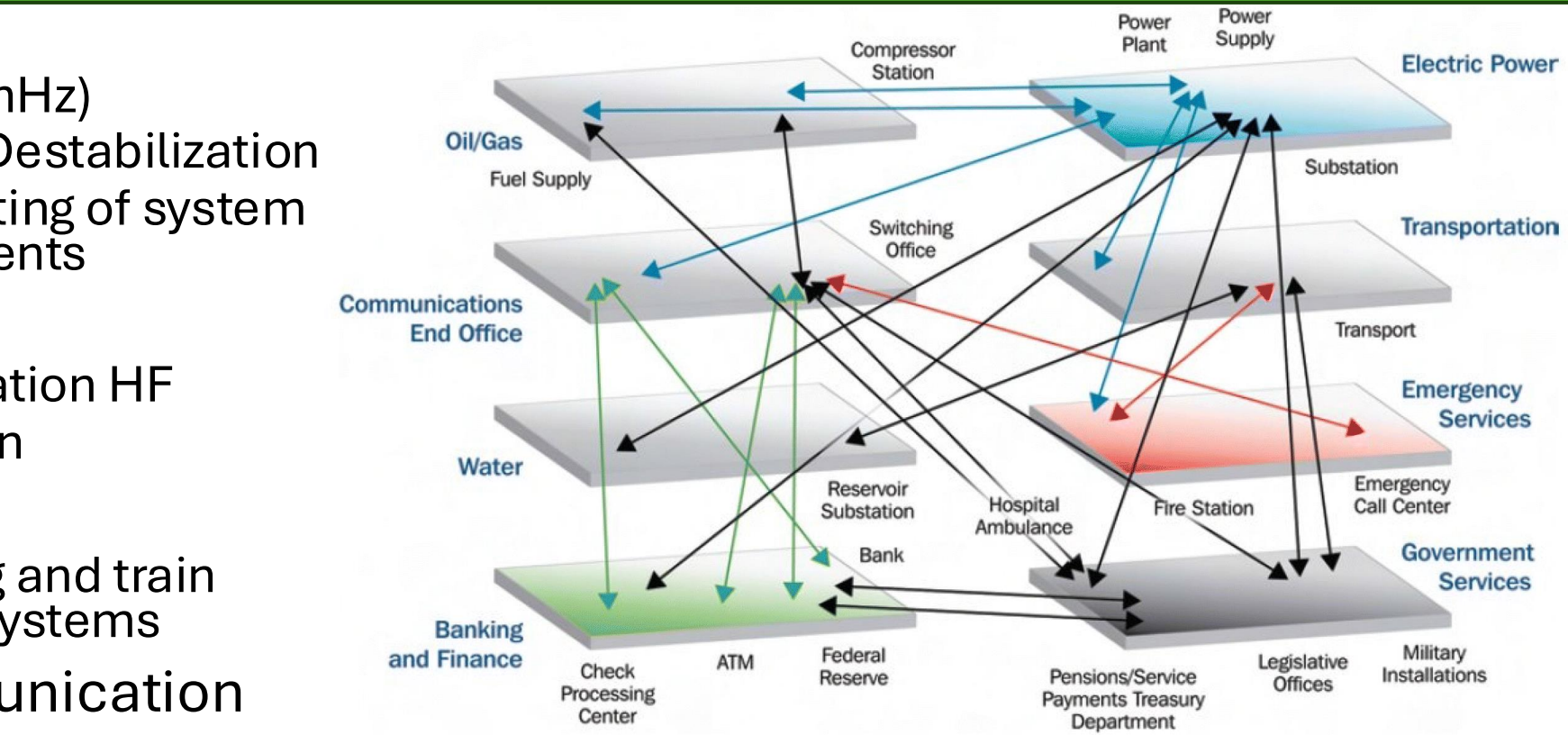
Why are GICs Important?

GICs affect critical ground-based infrastructure.

Damage to these systems can lead to large economic losses and day-to-day operations.

- Power grid
  - ULF (<1mHz)
  - Voltage Destabilization
  - Overheating of system components
- Pipeline
  - long duration HF
  - Corrosion
- Railroad
  - Signaling and train control systems
- Telecommunication cables



Thaduri+(2020)

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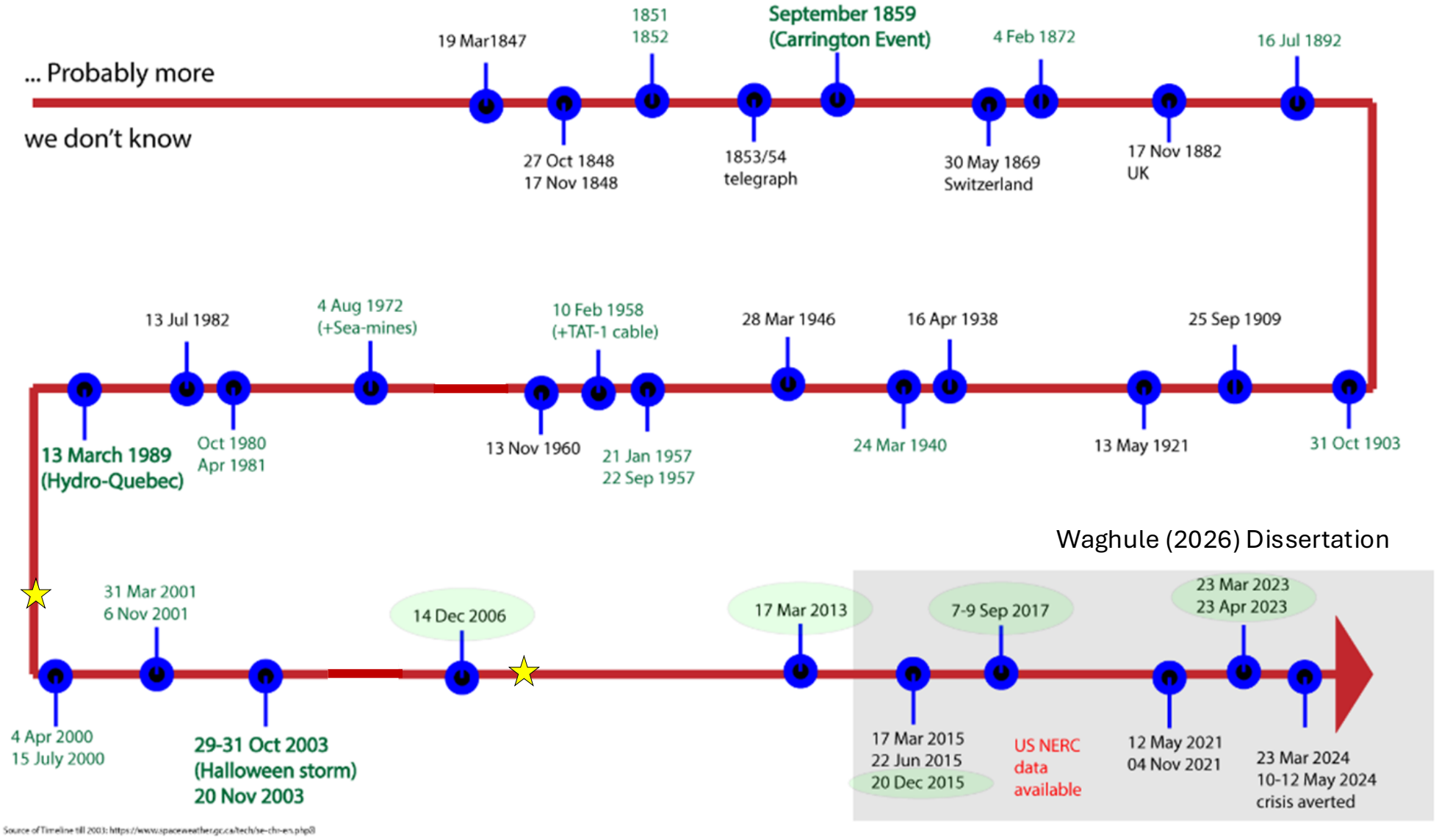
History of Ground Impacts of Space Weather



Waghule (2026) Dissertation

Source of Timeline till 2003: https://www.spaceweather.gc.ca/tech/se-ch-es.php#

★ Established: Space Environment Center[SEC]
Later became Space Weather Prediction Center [SWPC]

Mantsala pipeline GIC data available

Events that affected infrastructure in the US

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Power Grid Impacts

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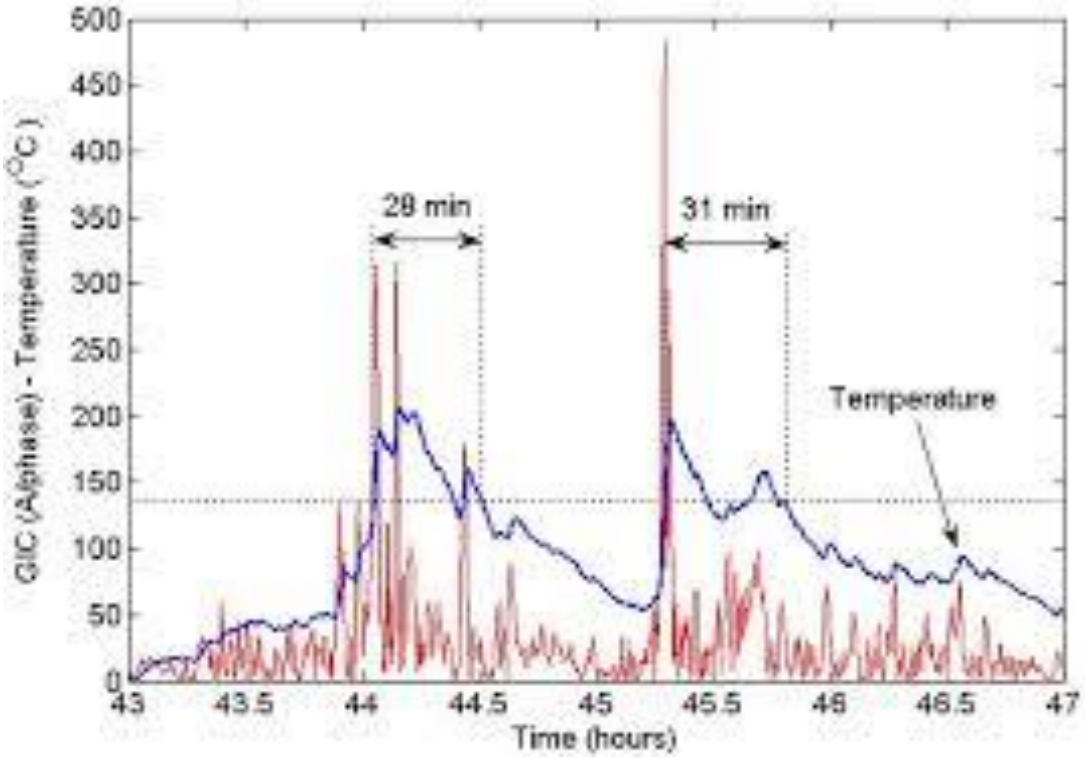
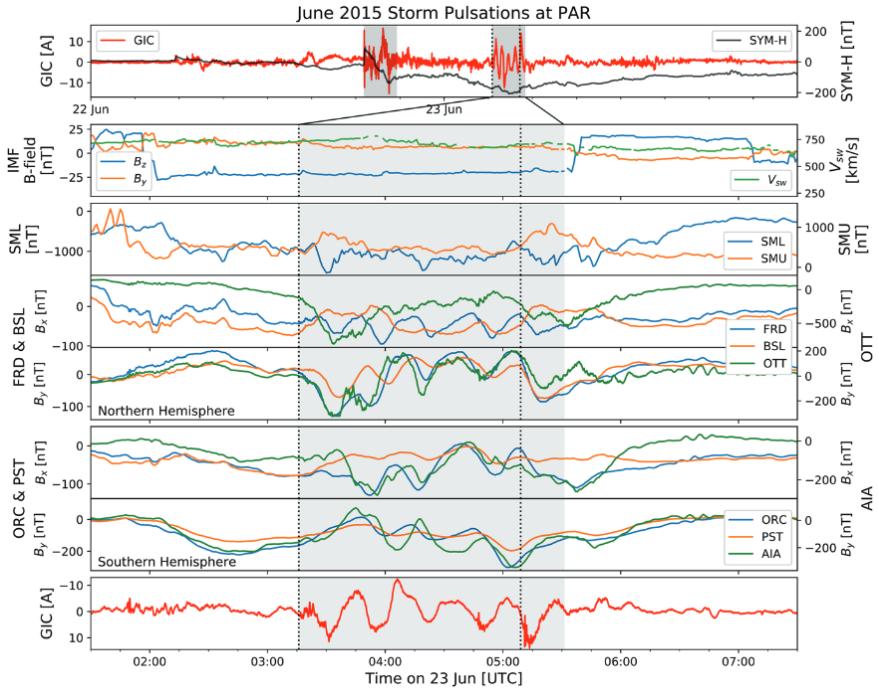
Local hot spots | Voltage destabilization | Harmonics | Transformer failure

The focus of GIC research has been on understanding spikes, but long duration pulsations have also been of interest



Marti et al. (2013)



Heyns et al. (2021)

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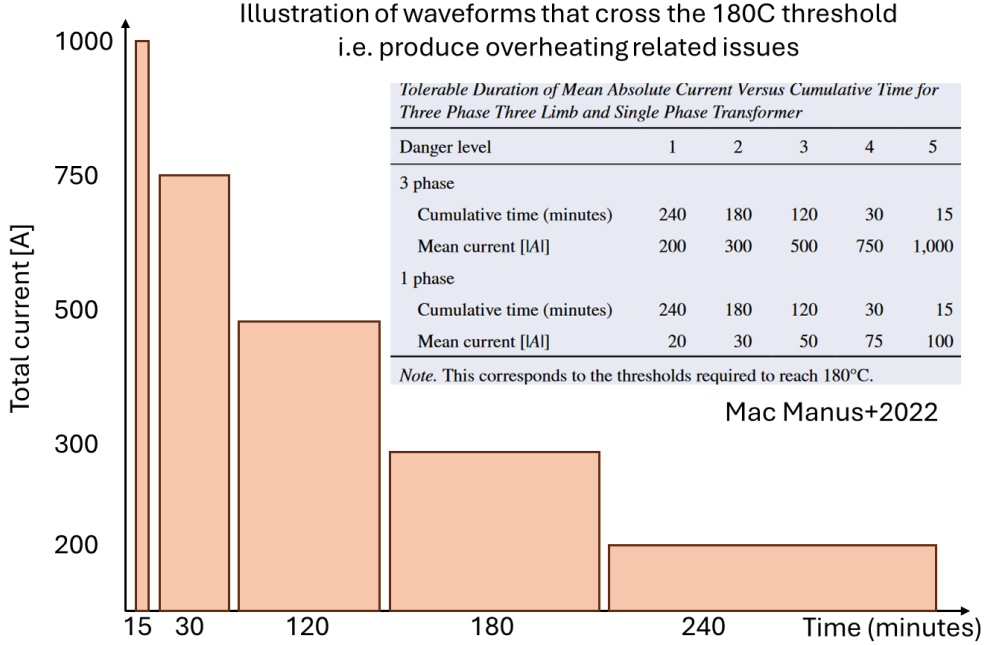
Example of Waveforms

Local hot spots | Voltage destabilization | Harmonics | Transformer failure

Area under the GIC curve may determine the temperature increase

Illustration of waveforms that cross the 180C threshold
i.e. produce overheating related issues



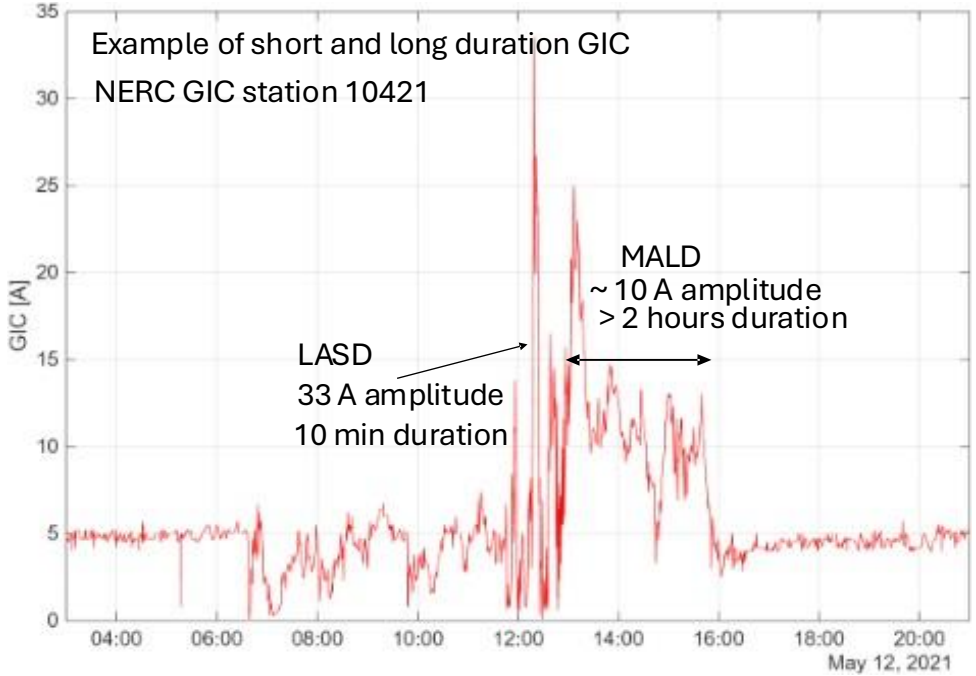
Tolerable Duration of Mean Absolute Current Versus Cumulative Time for Three Phase Three Limb and Single Phase Transformer

Danger level	1	2	3	4	5
3 phase					
Cumulative time (minutes)	240	180	120	30	15
Mean current [|A|]	200	300	500	750	1,000
1 phase					
Cumulative time (minutes)	240	180	120	30	15
Mean current [|A|]	20	30	50	75	100

Note. This corresponds to the thresholds required to reach 180°C.

Mac Manus+2022

No temperature data, so cannot comment on the impact; (Dr. Gannon's find)



Waghule (2026), Knipp & Waghule (2025)

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Where is this data coming from?

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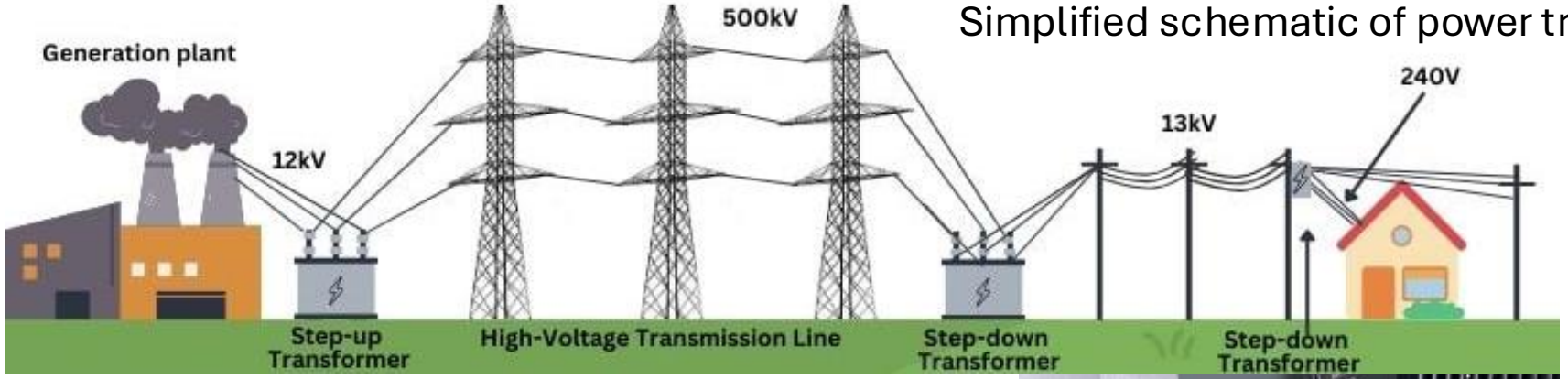
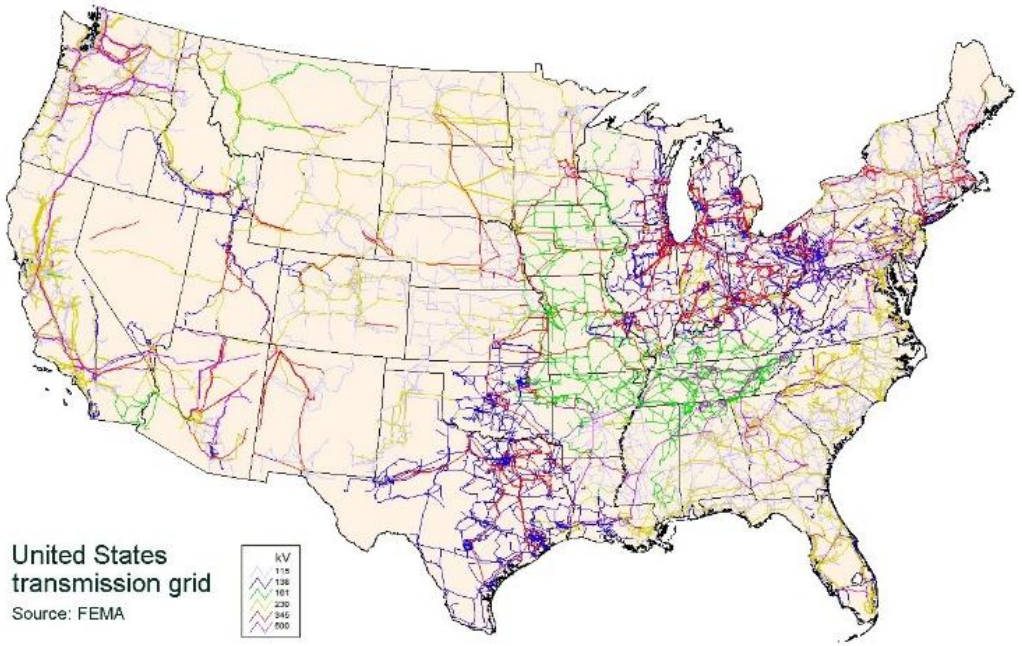
Simplified schematic of power transmission





GIC sensor

https://www.dynamicratings.com/products/sensors/geomagnetic-induced-current-sensor/

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North American Electric Reliability Corporation (NERC) GMD Database

Event	Start Date	Start Time	End Date	End Time
2025E07	12/3/2025	6:00	12/3/2025	23:59
2025E06	11/12/2025	15:00	11/13/2025	23:59
2025E05	11/6/2025	18:00	11/6/2025	23:59
2025E04	9/30/2025	18:00	9/30/2025	23:59
2025E03	09/15/2025	9:00	09/15/2025	23:59
2025E02	06/01/2025	9:00	06/03/2025	23:59
2025E01	04/15/2025	15:00	04/17/2025	23:59
2024E12	12/31/2024	3:00	01/01/2025	23:59
2024E11	10/10/2024	0:00	10/11/2024	23:59
2024E10	10/07/2024	0:00	10/08/2024	23:59
2024E09	09/16/2024	12:00	09/17/2024	23:59
2024E08	09/12/2024	23:59	09/12/2024	23:59
2024E07	08/11/2024	23:59	08/13/2024	23:59
2024E06	08/04/2024	23:59	08/04/2024	23:59
2024E05	06/28/2024	23:59	06/28/2024	23:59
2024E04	05/10/2024	00:00	05/12/2024	23:59
2024E03	05/02/2024	00:00	05/02/2024	23:59
2024E02	04/19/2024	00:00	04/19/2024	23:59
2024E01	03/23/2024	00:00	03/25/2024	23:59

30+ Events from 2013 to 2026

Event	Date	Start Time	End Date	End Time
2023E04	12/01/2023	00:00	12/02/2023	23:59
2023E03	04/23/2023	00:00	04/24/2023	23:59
2023E02	03/23/2023	00:00	03/24/2023	23:59
2023E01	02/26/2023	12:00	02/28/2023	23:59
2022E01	04/09/2022	00:00	04/10/2022	23:59
2021E02	11/03/2021	15:00	11/04/2021	23:59
2021E01	05/12/2021	00:00	05/13/2021	12:00
2018E01	08/25/2018	18:00	08/27/2018	00:00
2017E03	09/27/2017	15:00	09/29/2017	00:00
2017E02	09/07/2017	21:00	09/09/2017	03:00
2017E01	05/27/2017	15:00	05/28/2017	15:00
2015E06	12/20/2015	03:00	12/21/2015	09:00
2015E05	10/06/2015	18:00	10/09/2015	09:00
2015E04	09/19/2015	18:00	09/20/2015	18:00
2015E03	09/11/2015	03:00	09/11/2015	18:00
2015E02	06/22/2015	03:00	06/23/2015	15:00
2015E01	03/17/2015	03:00	03/18/2015	06:00
2013E02	10/02/2013	00:00	10/03/2013	03:00
2013E01	05/31/2013	15:00	06/01/2013	15:00

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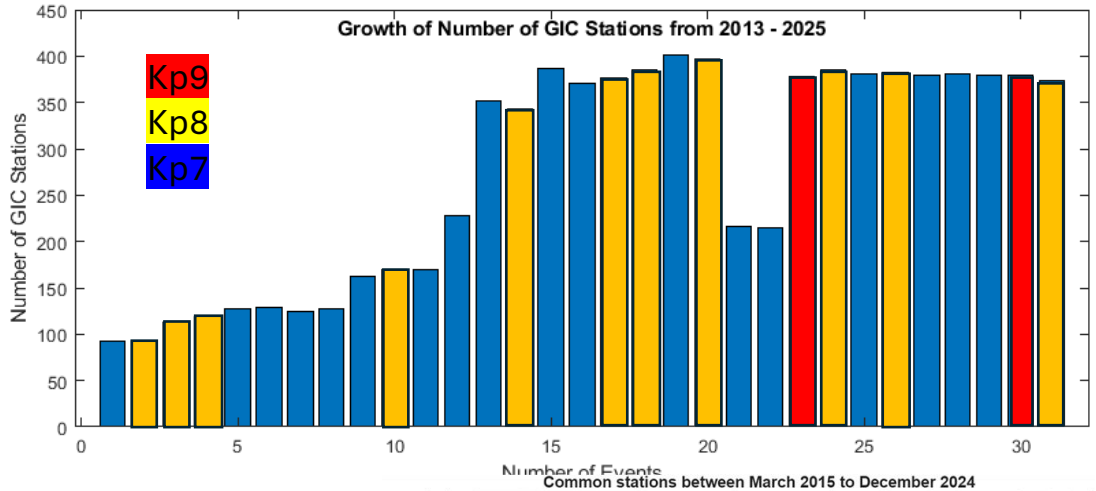
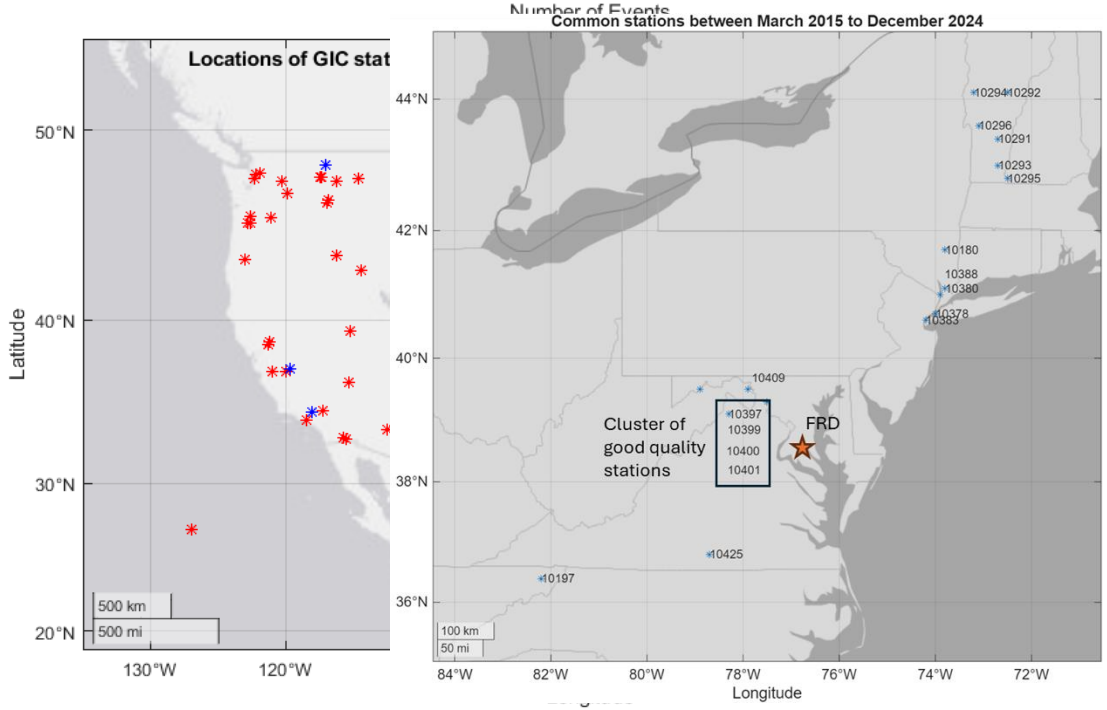
Data from NERC GMD database

- Growing number of GIC stations
- 350+ stations after 2020
- 2 Kp=9 Storms
- 11 Kp=8 Storms
- 18 Kp=7 storms
- Sensors are spread across the US
  - More measurements near eastern and central US

- * NERC GIC
- * NERC MAG





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NERC GIC station 10397 data

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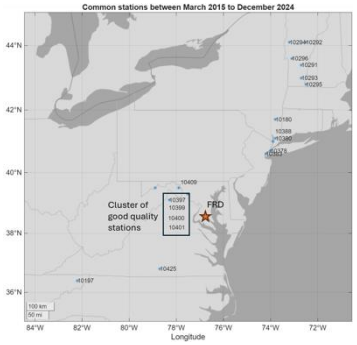

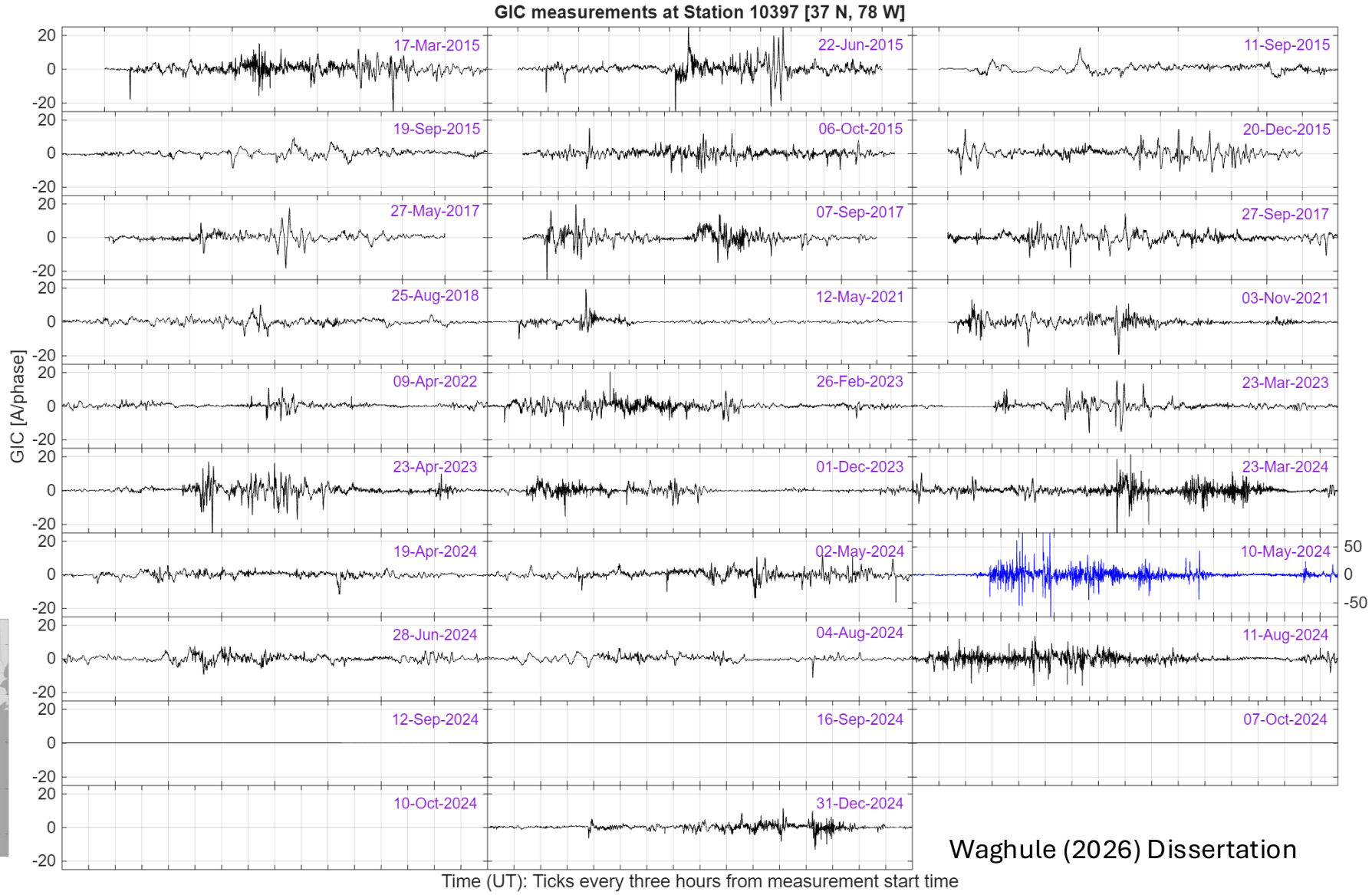

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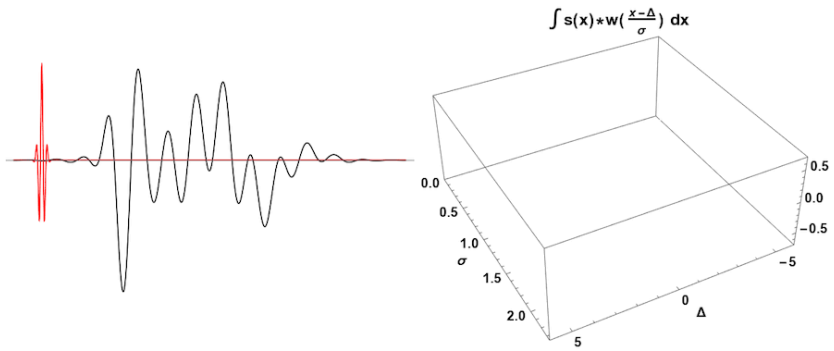
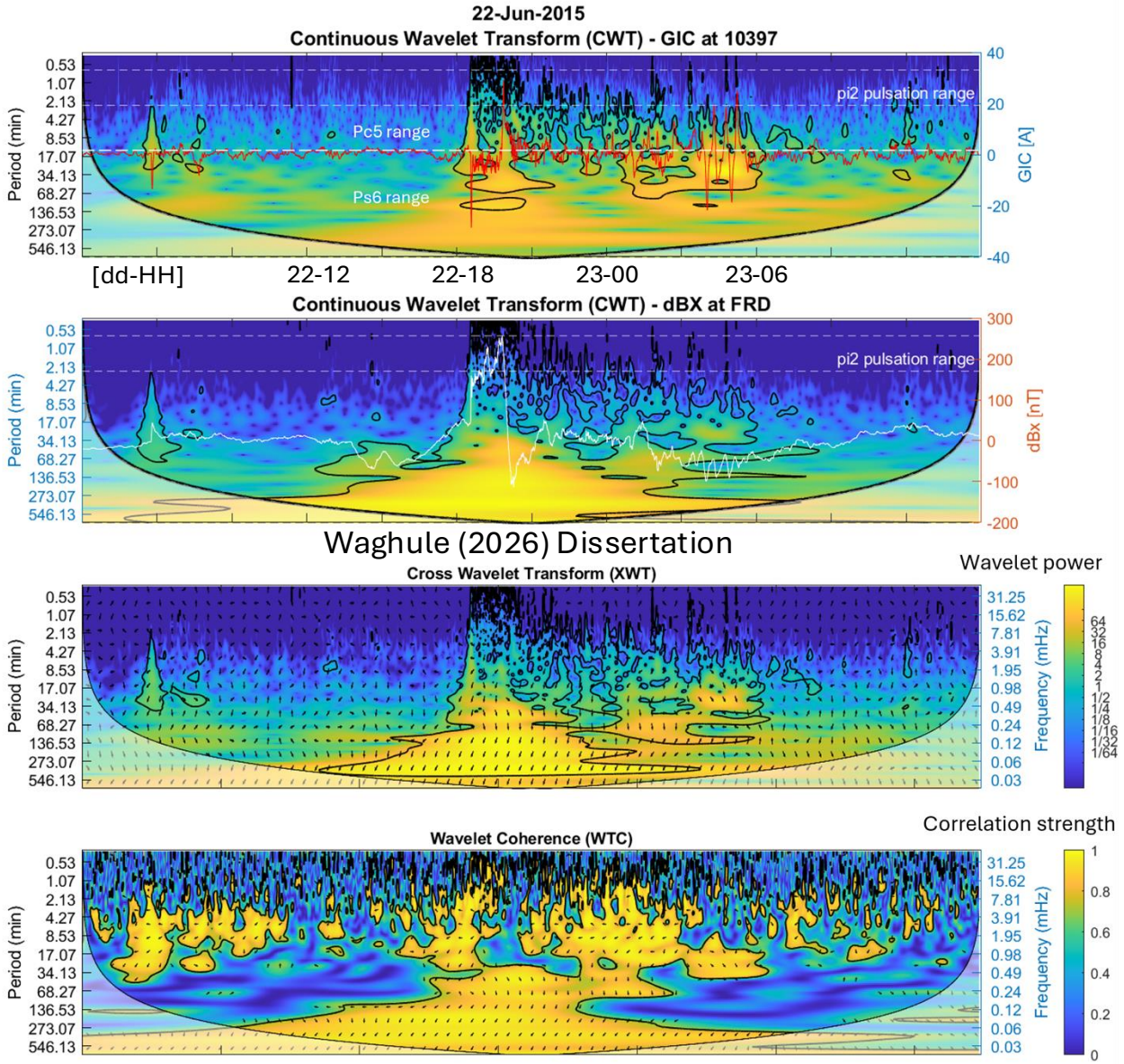
Is the GIC data geophysical?

- Continuous Wavelet transform decomposes timeseries into different periodicities



- Cross wavelet transform identifies similarity in data and whether one timeseries leads or lags the other
- Coherence shows where the frequency-wise correlation is the highest

Yellow: High wavelet power
Black outline: significant power above noise



Code: Grinstead et al. (2004) http://grinsted.github.io/wavelet-coherence/

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Where in local time do peak GICs occur?

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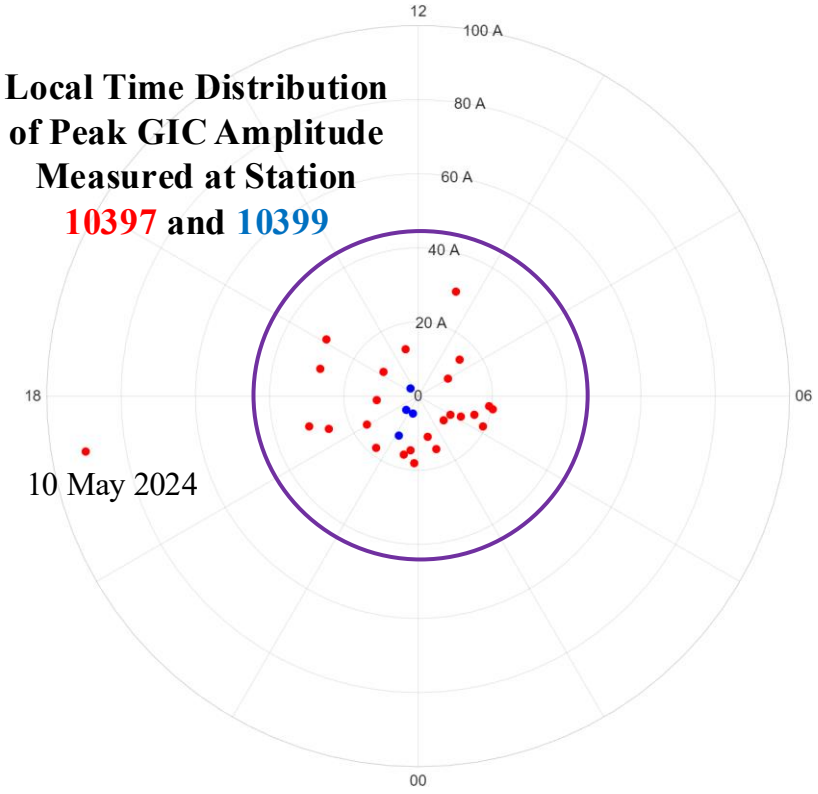

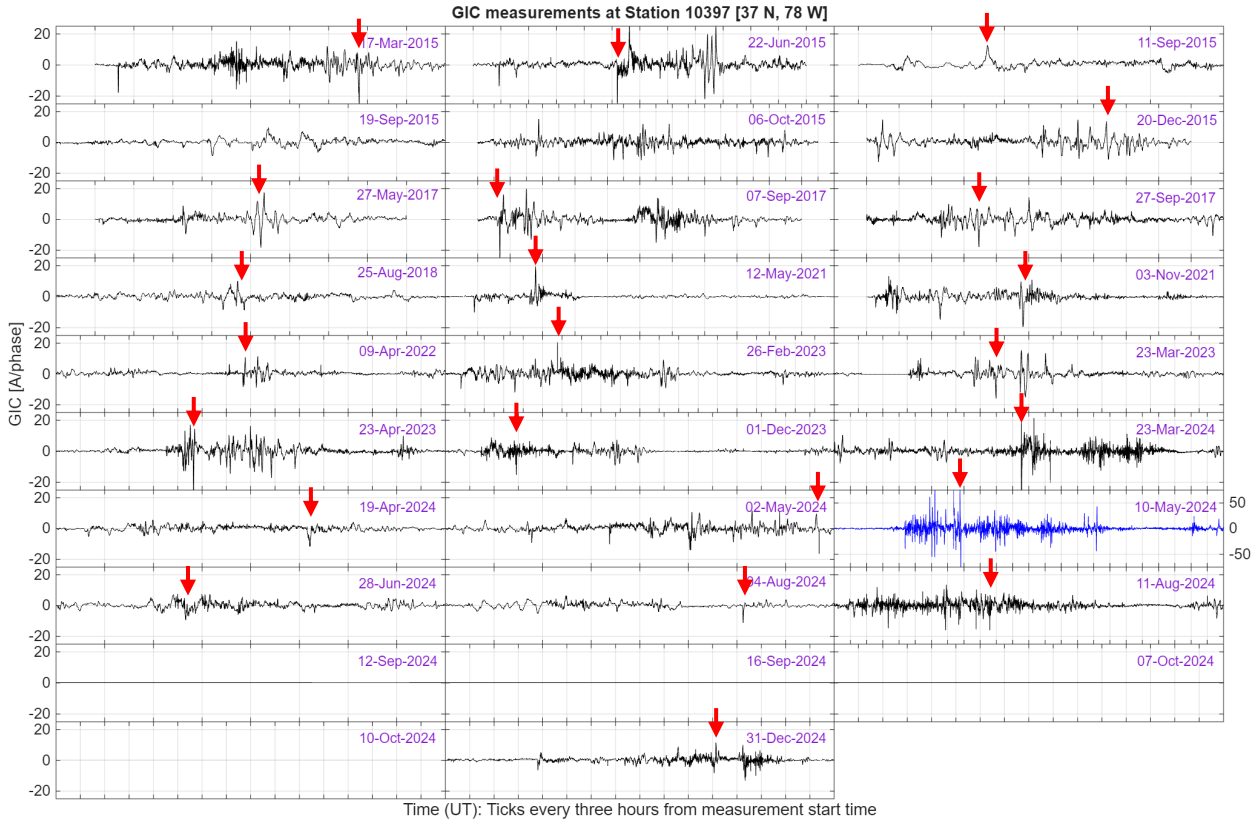

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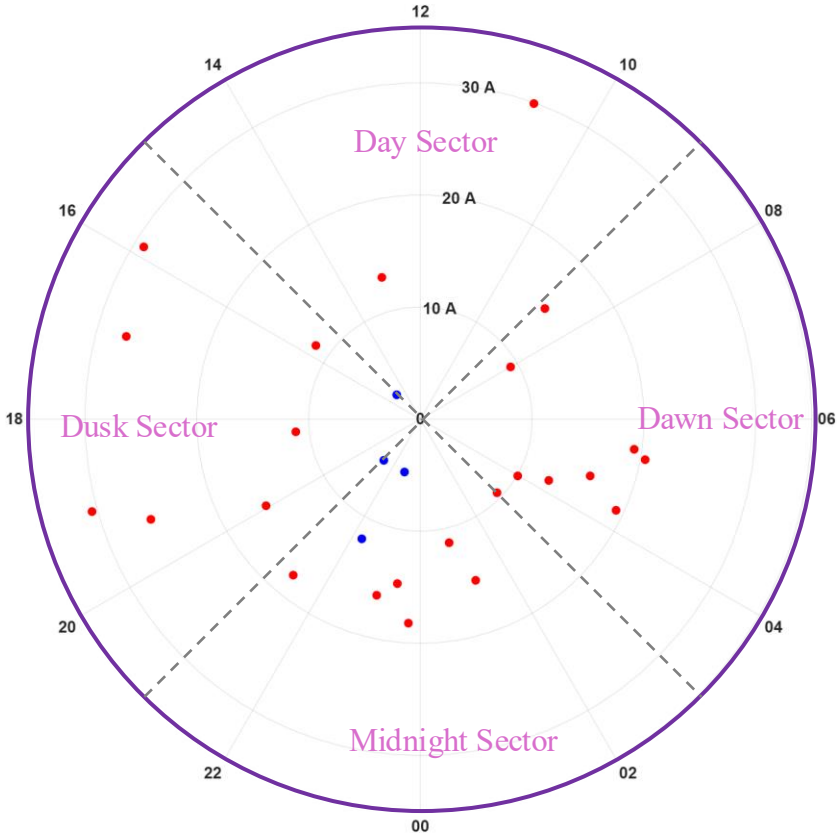
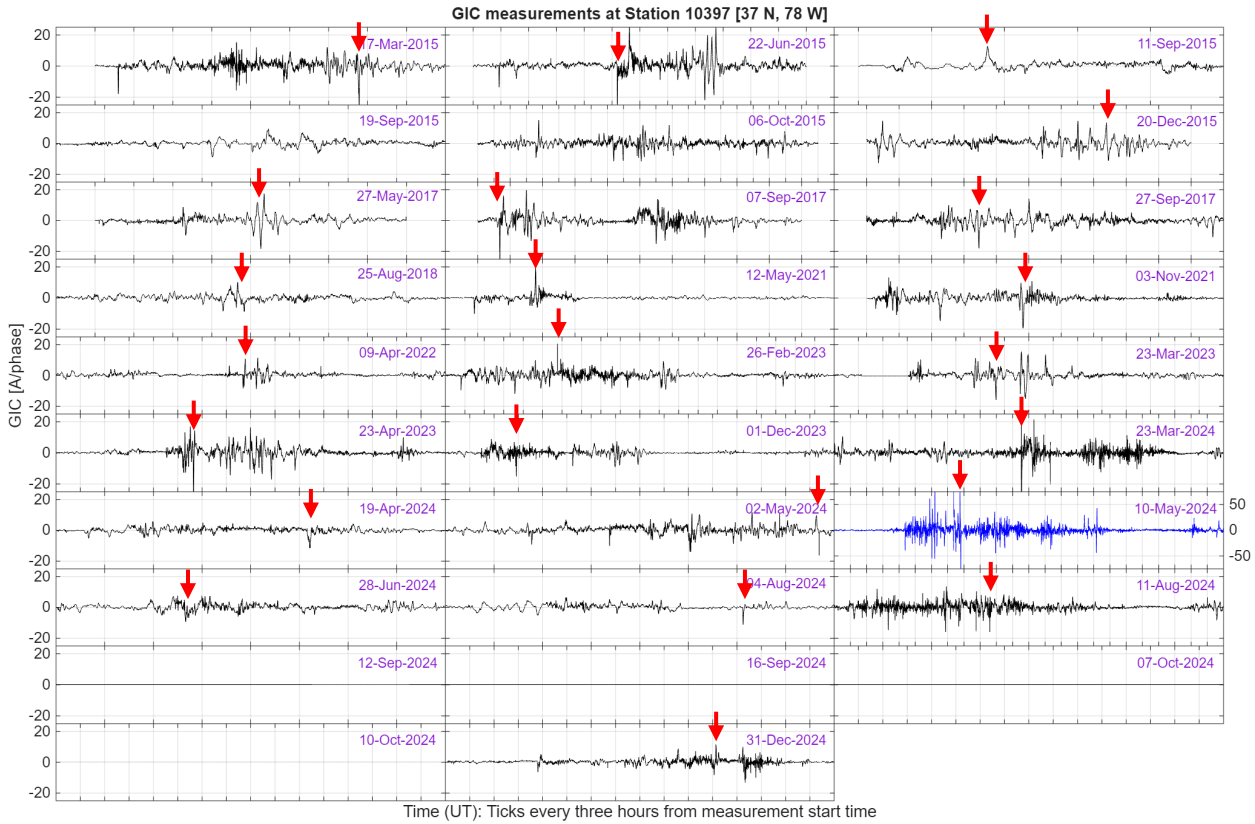


Max GIC distribution

Dusk:9 Midnight:9 Dawn:9 Day:2



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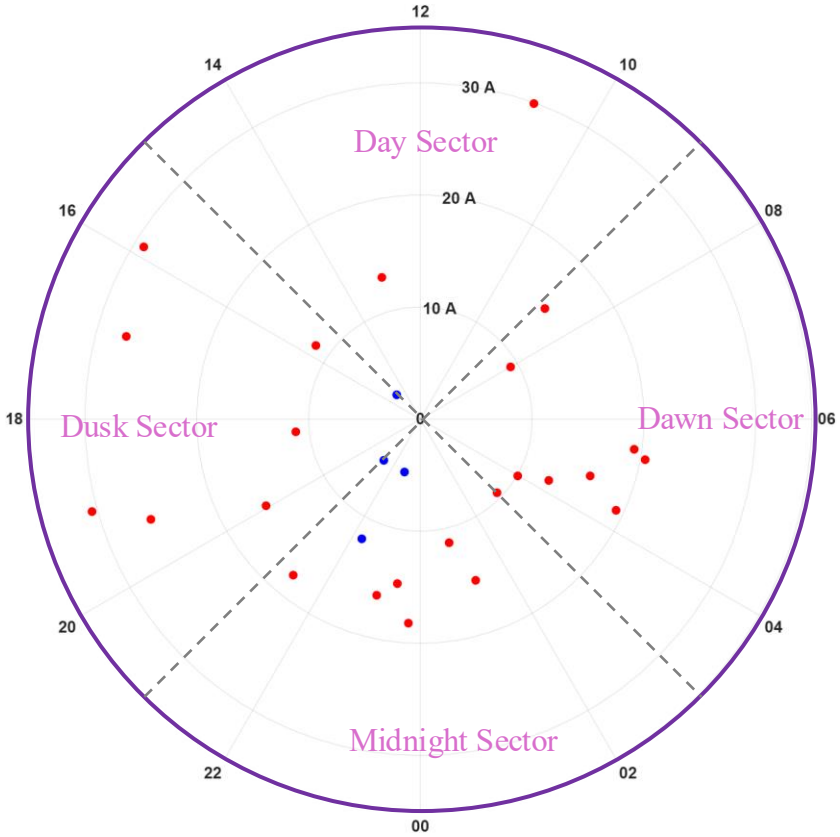
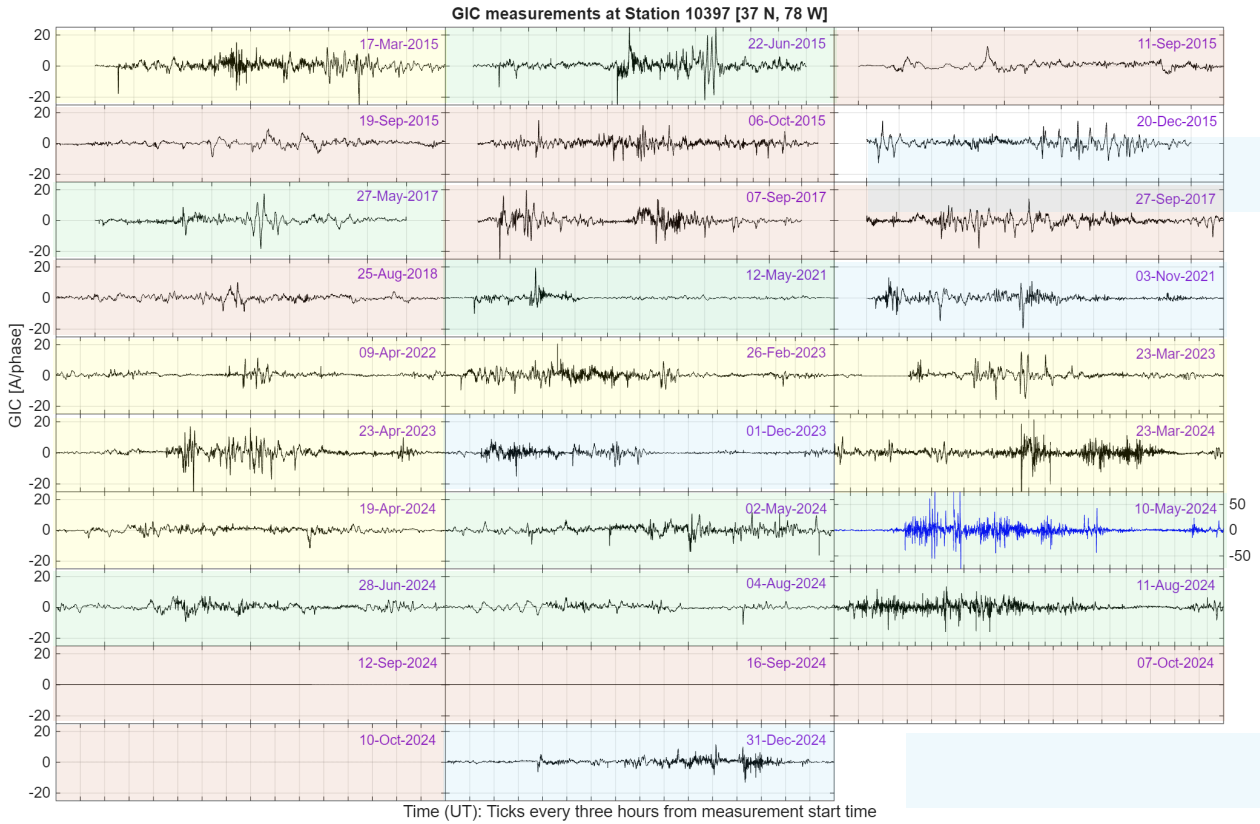
Seasonal distribution

Local Time Distribution of Peak GIC Amplitude Measured at Station 10397 and 10399



Seasonal Kp7+ occurrence distribution

Spring:7	Summer:8	Fall:10	Winter:4



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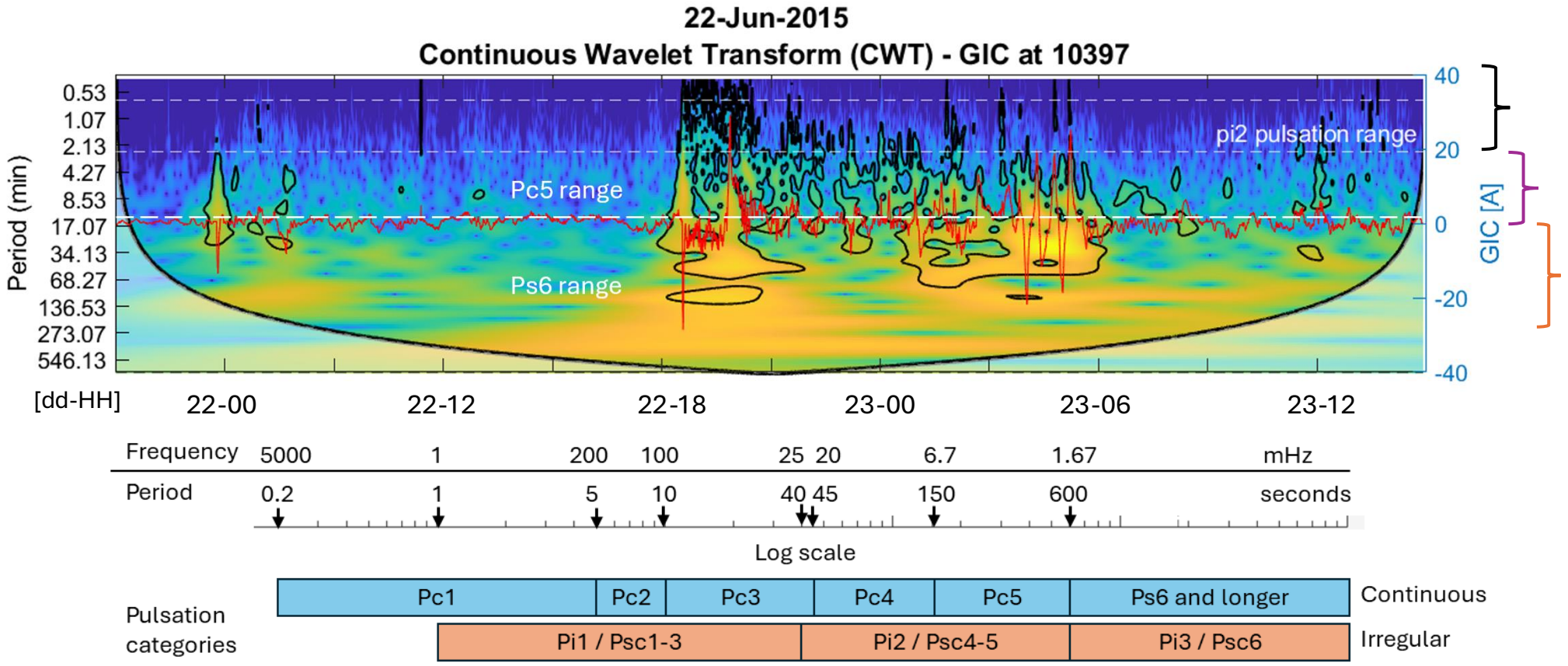
When in storm time do GIC waveforms occur? GIC and Associated Pulsations



Substorm injection / ICME arrival

Damped oscillations or steady magnetospheric convection

The GIC measurement has a 10-second sampling period.
As a result, the upper period-limit is 20-seconds
Brace brackets show the corresponding periods in the CWT plot

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GIC and Associated Pulsations

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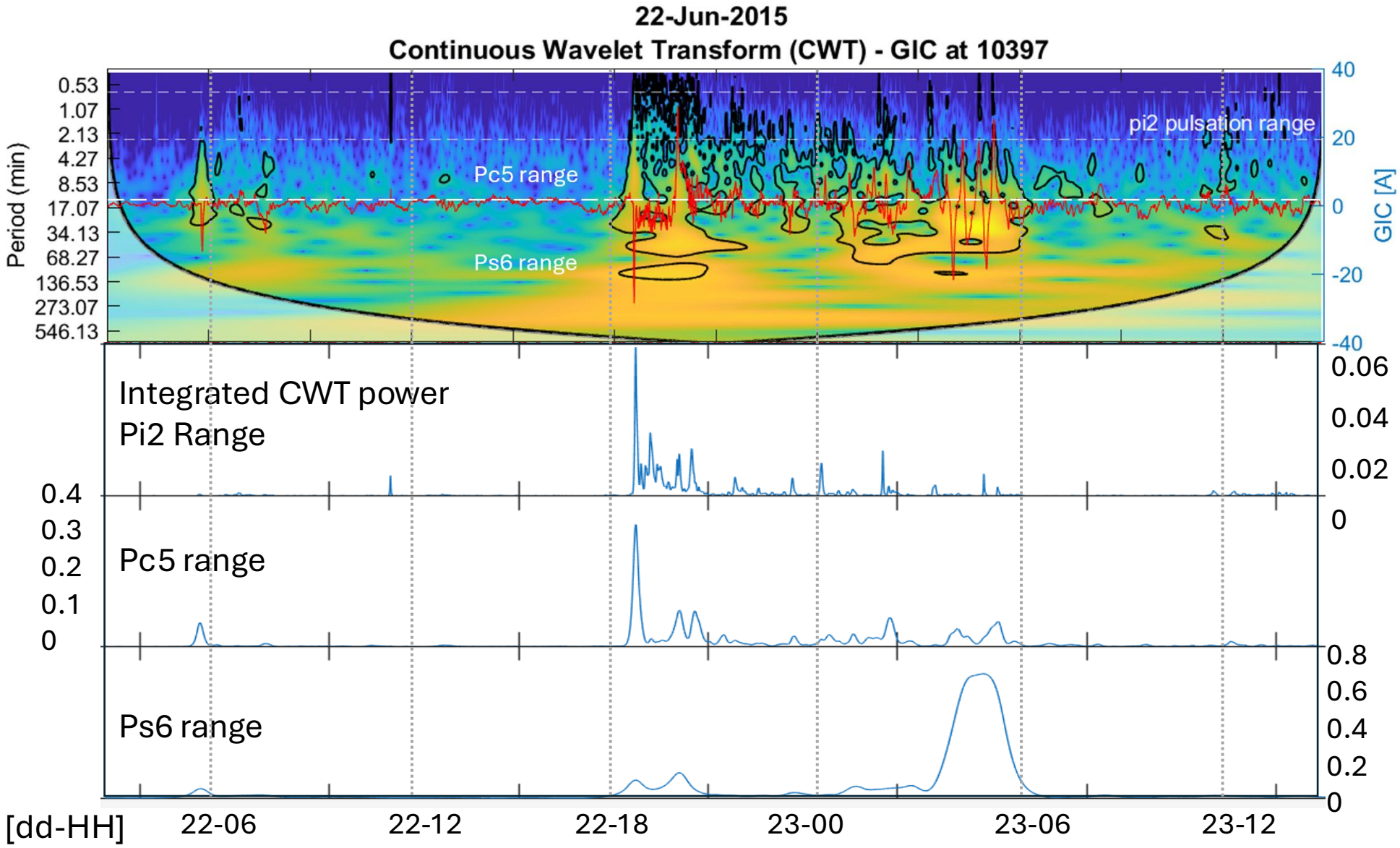

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Where in Local time do different GIC waveforms occur?

LHS: 29 events stacked horizontally
RHS: binned-average for every local time hour

High frequency fluctuations

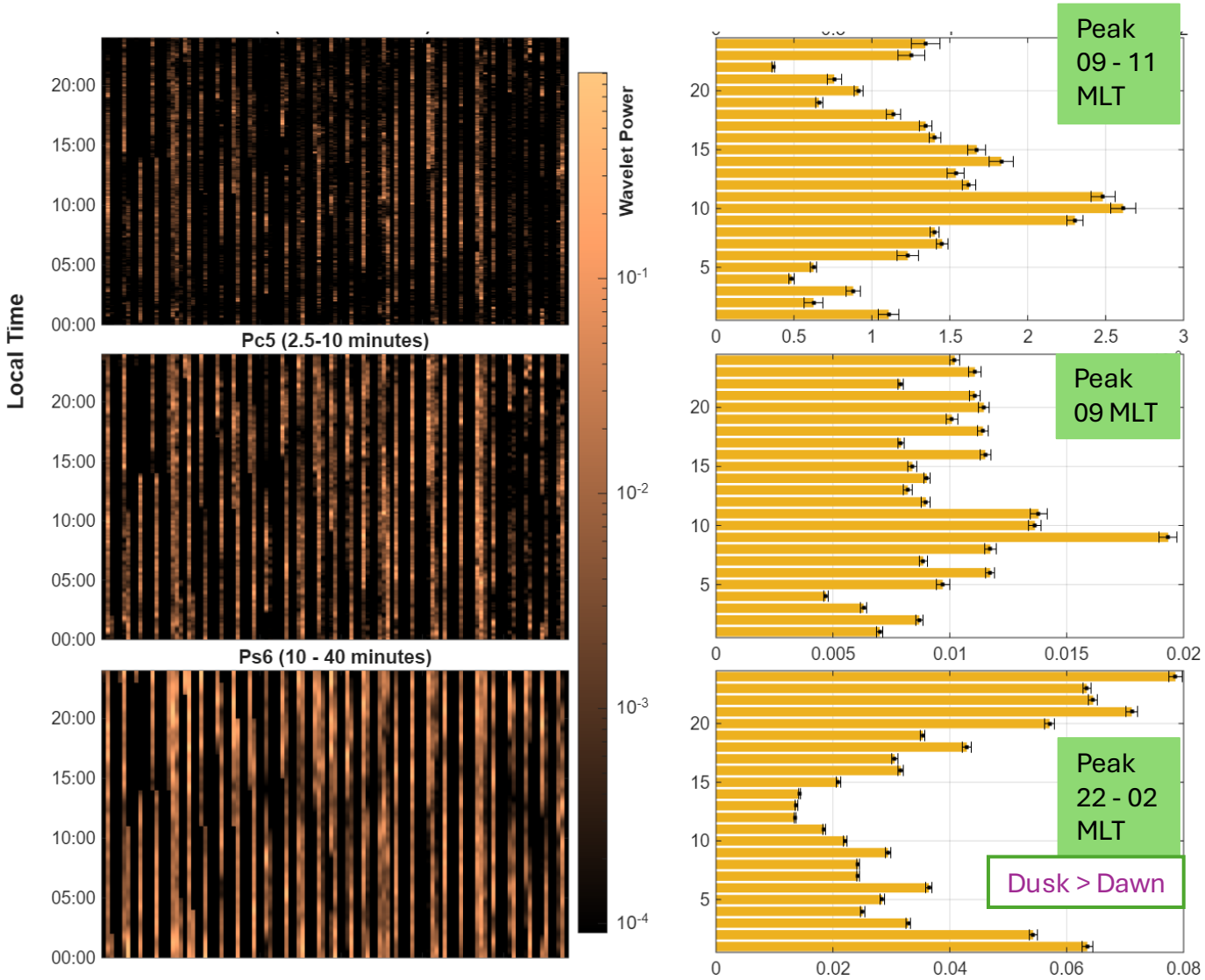
- Peaks in the morning sector

Slow varying disturbance

- Peaks in the midnight sector

Duration

- Average : 40 hours
- Median : 36 hours
- Minimum : 15 hours
- Maximum : 71 hours



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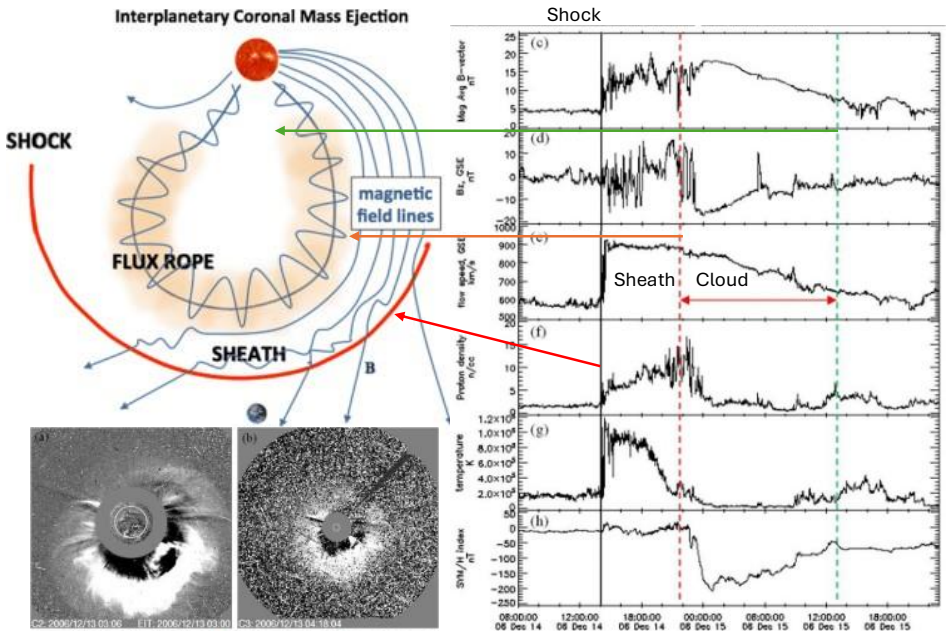
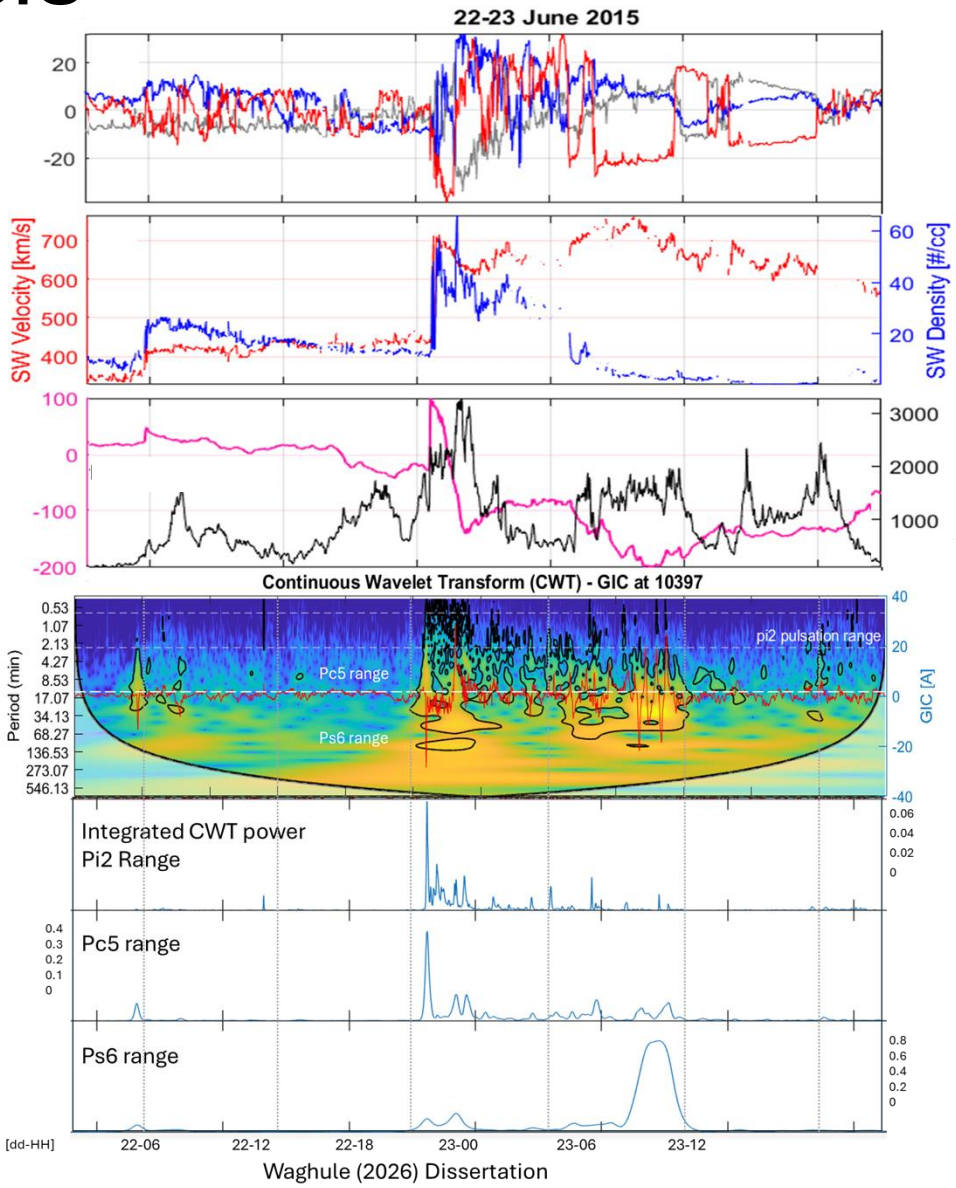
When in storm time do they occur? Superposed Epoch Analysis

Parameters that show the nature of transient solar wind
Most of the 29 events were CMEs but some were HSS (High Speed Streams)





Source: OMNIweb data

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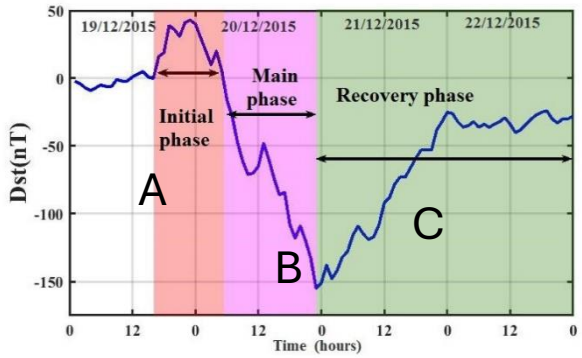
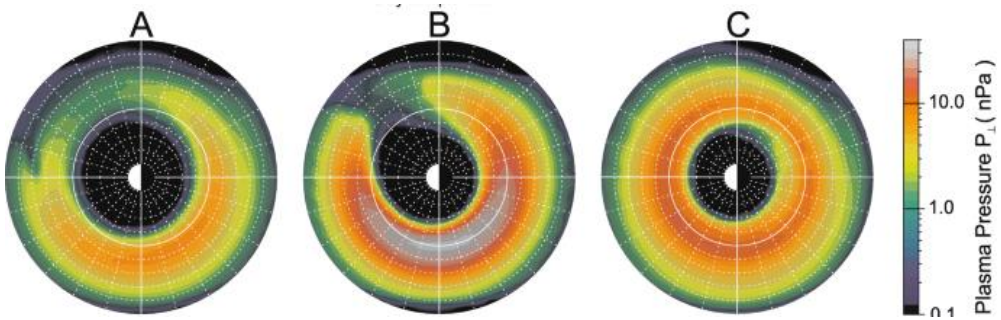
When in storm time do they occur? Superposed Epoch Analysis

Source: OMNIweb

Sym-H shows the intensity of the ring current

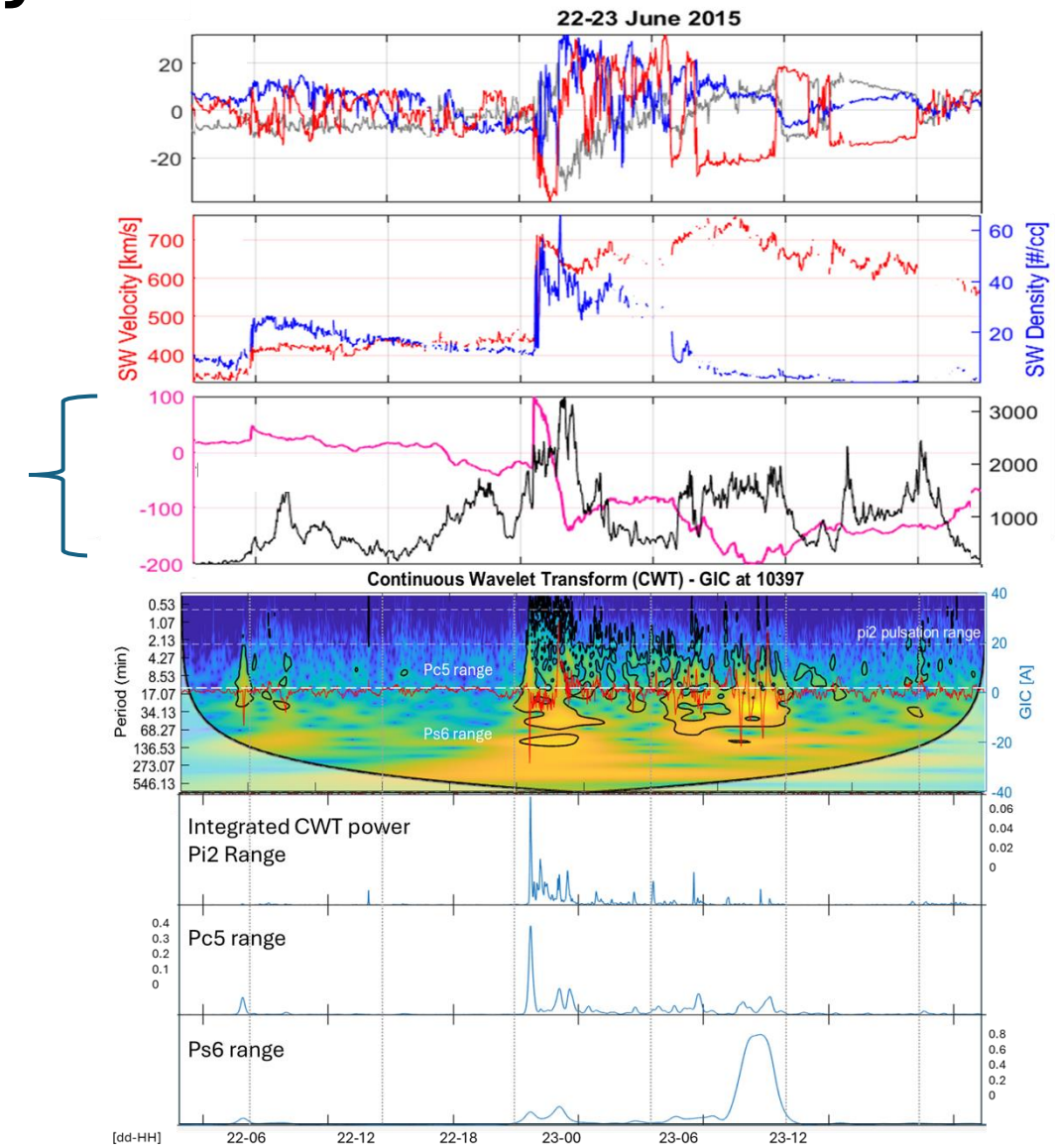


Singh (2019)



Storm-phase-wise Ring current distribution

Ebihara et al. (2019)



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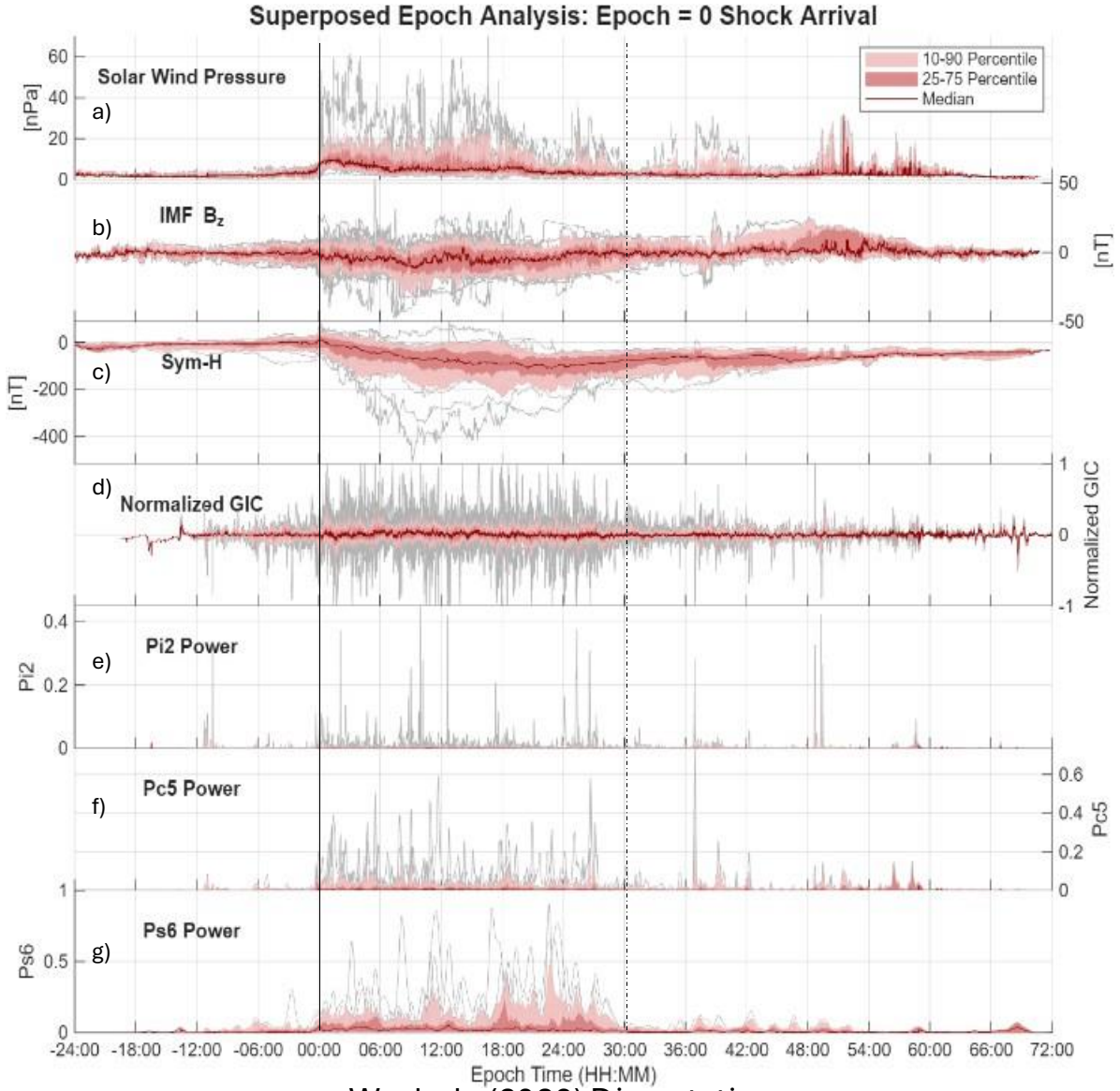
SEA of GIC and associated disturbance Shock arrival



Waghule (2026) Dissertation

Epoch 0: Psw = 8nPa

Largest GIC variability in the 30 hours

Spikes < 2.5 min long co-occur with pressure pulses

Spikes < 10 minutes are omnipresent

Long duration disturbances occur more often after 12 hours from shock arrival

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Introduction Background

NERC GIC Data

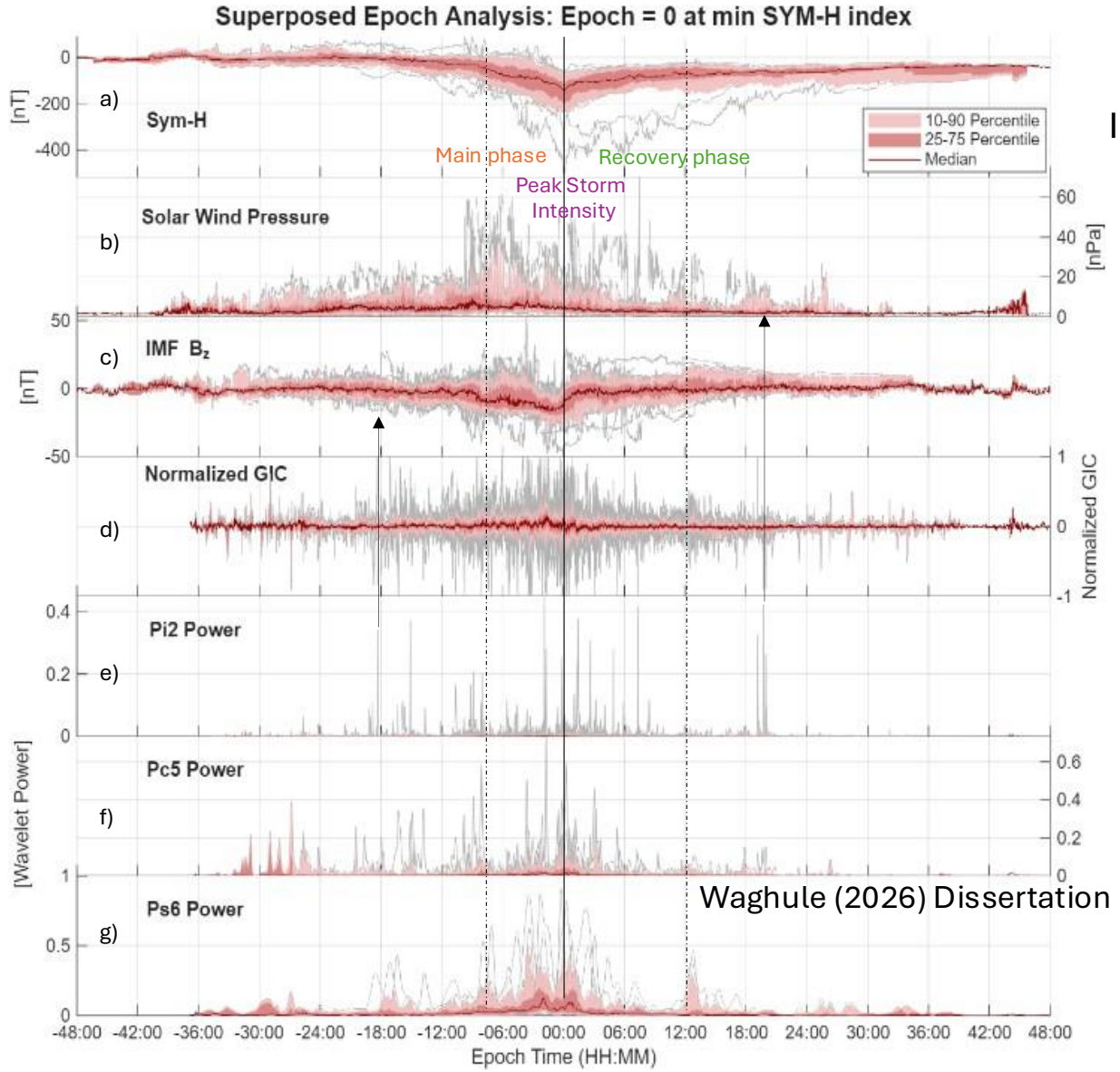
Climatology survey

- Method

➢ Results

Concluding remarks

SEA of GIC and associated disturbance Peak Storm Intensity



Waghule (2026) Dissertation

Epoch 0: Sym-H = minimum

ICME shocks line up with initial phase

Ring current intensification during southward Bz and recovery during northward Bz

Median GIC peak: 2 hours before peak storm intensity

Spikes < 2.5 min long co-occur with pressure pulses

Spikes < 10 minutes more in main phase than recovery

Long duration disturbances clustered around +/- 6 hours

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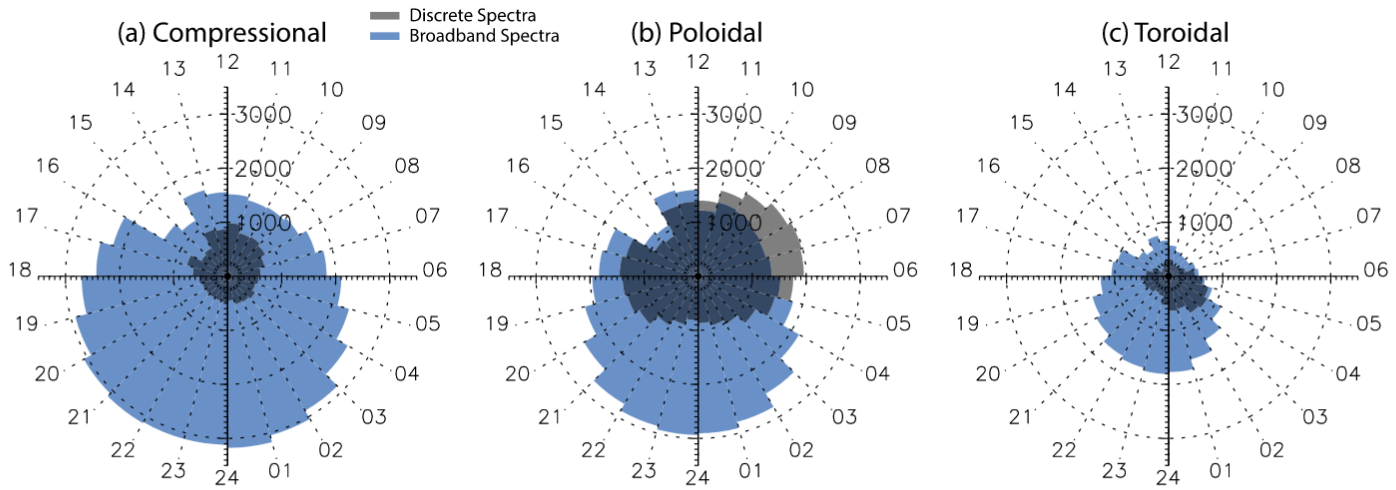
Concluding Remarks

First of its kind analysis of GIC timeseries (Manuscript and Research data in prep)

	GIC peak	**Pi2**	**Pc5**	**Ps6**
Local Time	Dusk	9-10 MLT	9 MLT	22-02 MLT
SEA, CME phase	No clear pattern	Pressure enhancement	Persistent	18-24 hours
SEA, Storm phase	More in main phase	No pattern	Main phase	Near peak storm intensity



GOES distribution of short and long period disturbances

Murphy et al. (2020)

Figure 2. Polar histograms showing the occurrence of discrete and broadband ULF intervals as a function of MLT. The radial axis shows the number of counts in each MLT bin as a function of magnetic field component (top) and wave band (bottom). From left to right are the distributions of (a) compressional, (b) poloidal, and (c) toroidal magnetic field components; discrete and broadband intervals are shown by the gray and blue histograms, respectively.

Thank you!

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