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Geomagnetically Induced Currents (GICs) during space weather events in May and October 2024

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Geomagnetically induced currents (GICs)

GICs are induced by electric fields generated by any rapid changes in the magnetic field during various space weather events

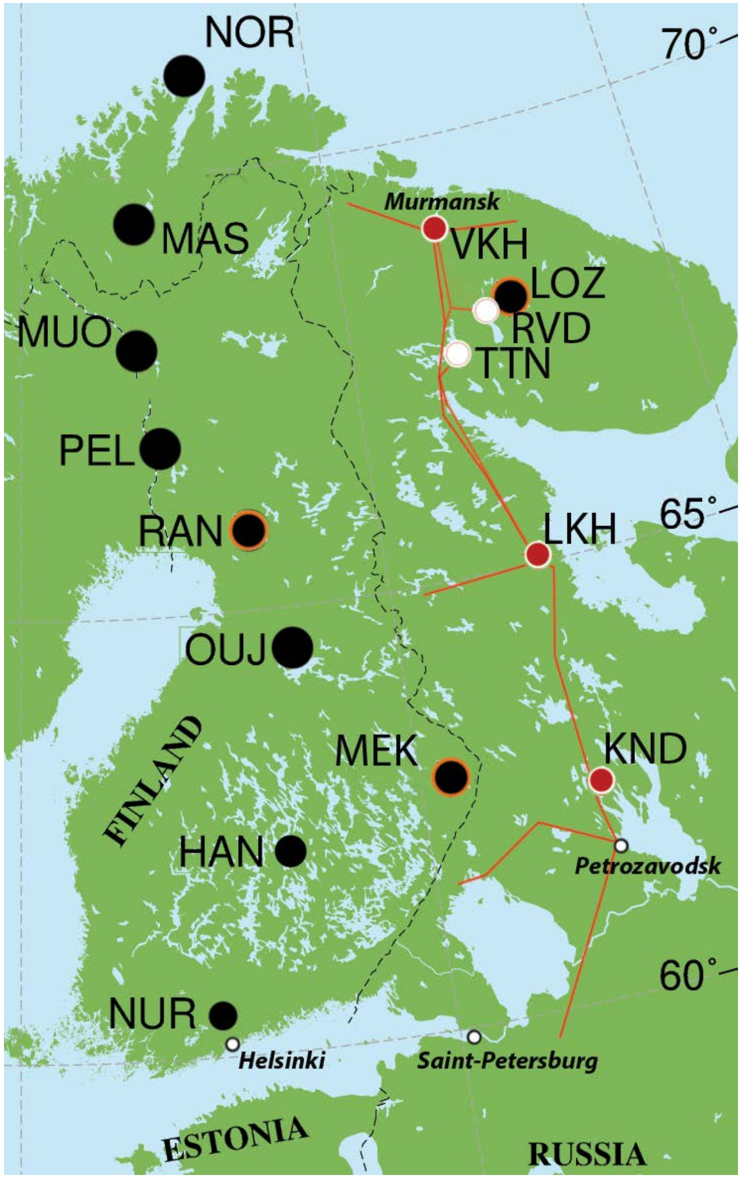
$$\nabla \times \mathbf{E} = -\partial \mathbf{B} / \partial t$$

Such events include the development of
a **sudden storm commencement** (SSC) pulse (*Zhang et al., 2015*),
a sharp increase in the **ring current** (*Gil et al., 2023*),
an intensification of **auroral electrojets** (*Boteler, 1999; Despirak et al., 2022*),
the generation of **low-frequency pulsations** (*Apatenkov et al., 2020; Yagova et al., 2021; Setsko et al., 2022*).

The magnitude of GICs depends not only on the intensity of magnetic disturbances,
but also on **ground conductivity** and the **configuration of the technological systems** (e.g. *Viljanen and Pirjola, 2017; Love et al., 2018a 2018b; Ingham et al., 2023).*

- The conductivity values for the region where the Karelian-Kola power line is located are almost the same.
- a direct comparison of GIC is not possible because transmission lines undergo outages, upgrades, or the addition or replacement of transformers.

• direct GIC`s measurements in Russian electrical circuits



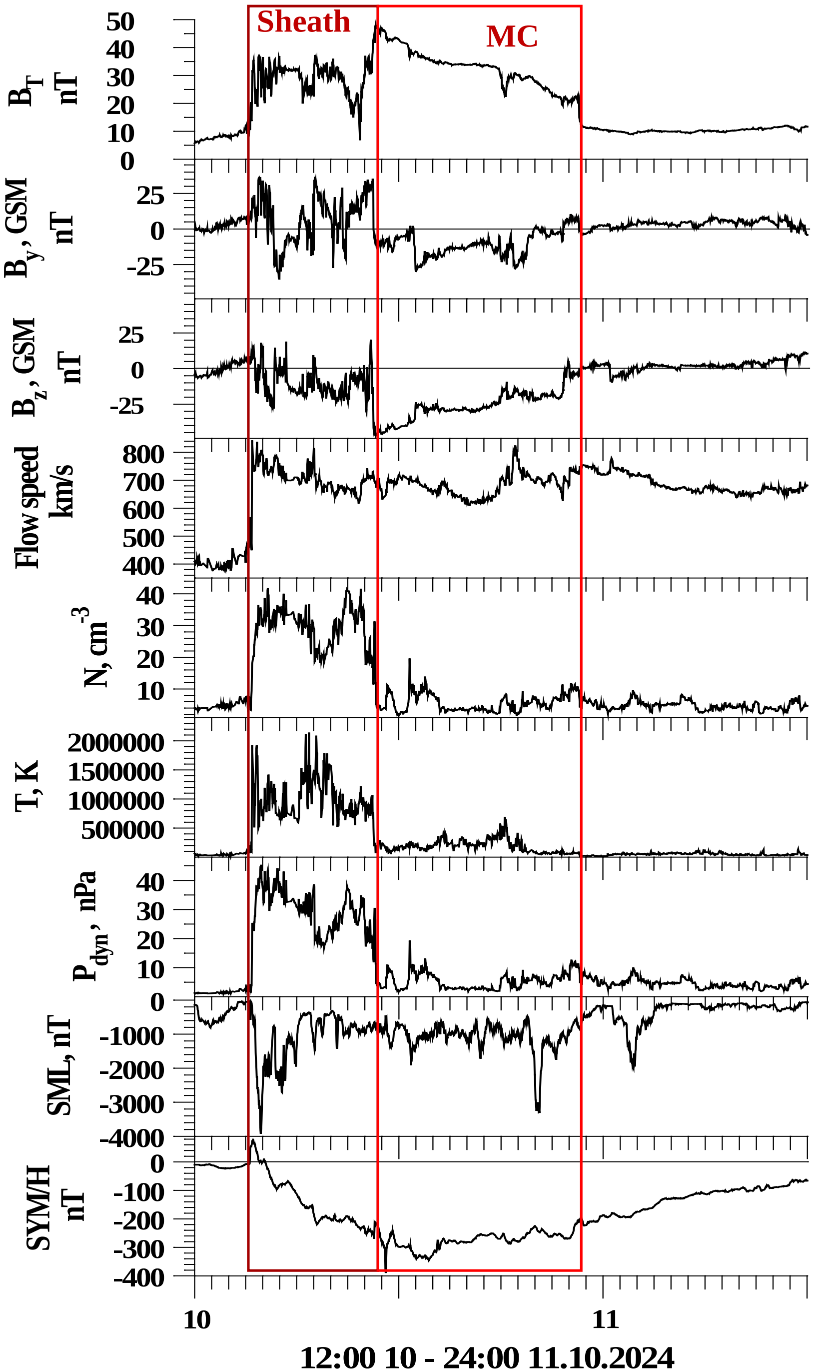
Geographic coordinates:
Vykhodnoy (VKH) (68.8° N, 33.1° E),
Loukhi (LKH) (66.08° N, 33.12° E),
Kondopoga (KND) (62.2° N, 34.3° E)

System for monitor GICs in the existing Karelian-Kola power transmission line with a length of over 800 km (http://eurisgic.ru/).
“Vykhodnoy”, “Revda”, “Titan” (Murmansk region), **“Loukhi”** and **“Kondopoga”** (Republic of Karelia)

The power transmission line stretched from south to north. Acording to Faraday's law, the variations of the Y-component of the geomagnetic field play a major role in GIC generation (Setsko et al., 2023; Selivanov et al., 2023).

VKH is a node station that collects GIC, according to Kirchhoff's law, from both the East-West and North-South lines, so the GIC at VKH is the sum of the currents induced by variations in the X- and Y-components of the magnetic field.
VKH station has two autotransformers, and an additional transformer nearby, i.e. three autotransformers for VKH node.
LKH station has two autotransformers,
KND station has only one.
Since the GIC is measured on a single grounded line of one autotransformer at each station, the total current in each node can be estimated by multiplying the measured value by the number of grounding points
(1 at KND, 2 at LKH and 3 at VKH).

Solar wind and IMF conditions



Large magnetic storm (Dst = − 333 nT).

The differences from the May 2024 storm are;
the color of aurora (predominantly red)
the phase of magnetic storm (early main phase just after the sudden commencement).

The origins of the storm are the disk-center X1.8 flare at ~ 02:00 UT on October 9, 2024 and the full-halo coronal mass ejection (CME) with an initial speed of ~ 1000 km/s. ***(Kataoka et al., 2025)***

The interplanetary shock was observed at ~ 15:00 UT on October 10, 2024.
Just after the shock arrival or sudden commencement at the Earth at ~ 15:20 UT,
an extremely large substorm occurred, so- called supersubstorm (SSS), ~ 4000 nT at ~ 16 UT.
This is associated with a strong southward directing Bz of − 20 nT, a high solar wind density of 30/cc, and a high solar wind speed of ~ 700 km/s

Several intense substorms ~17:00, ~18:30, ~20:30, ~22:30 UT were recorded after SSS, during Sheath

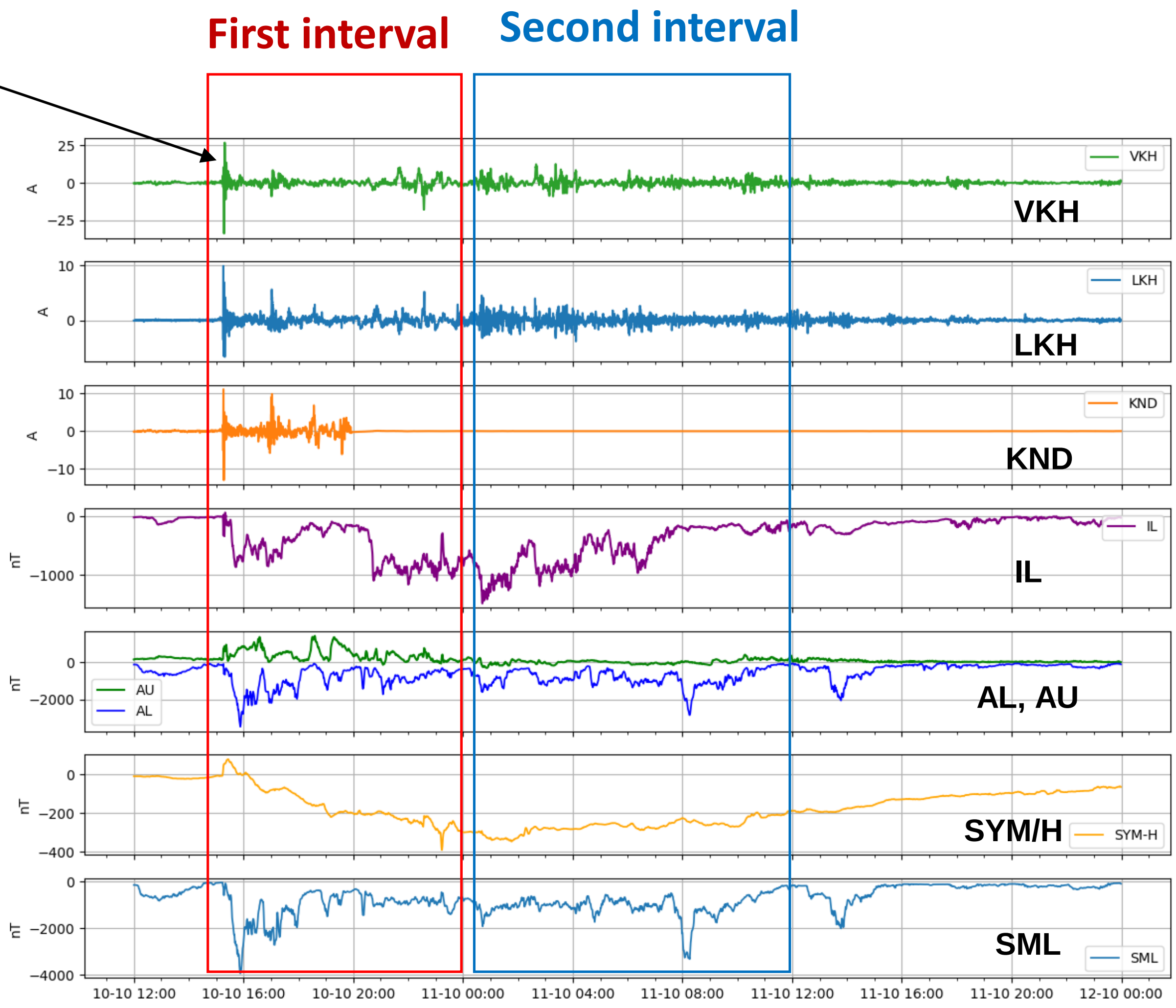
In the morning sector, during the magnetic cloud (MC), there were also several substorms ~00:40, 02:30, 03:30, 05:50 UT

GICs and geomagnetic indexes

~15:20 UT,
~30A (VKH)
~10A (LKH)
~12A (KND)

~17:00 UT,
~7A (VKH)
~6A (LKH)
~10A (KND)

~22:40 UT,
~12 A (VKH)
~5A (LKH)



~00:40 UT,
~10A (VKH)
~4A (LKH)

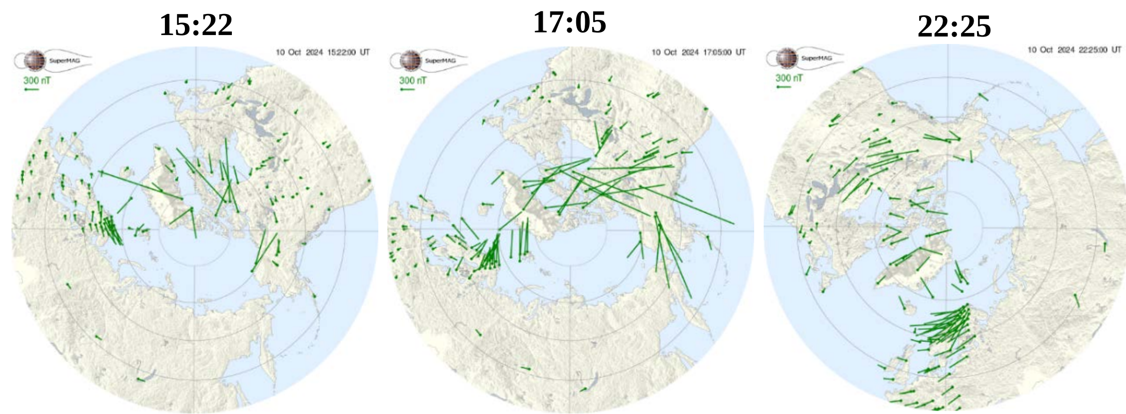
~02:40 UT,
~12A (VKH)
~4A (LKH)

~06:00 UT,
~8A (VKH)
~3A (LKH)

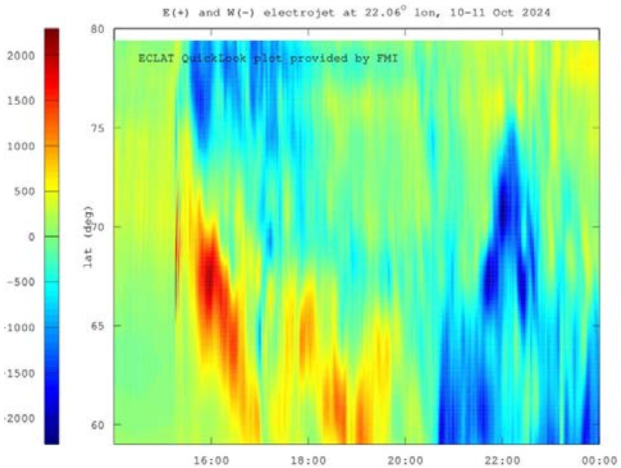
- **GIC sources in the First interval: Interplanetary Shock wave and substorms**

First interval

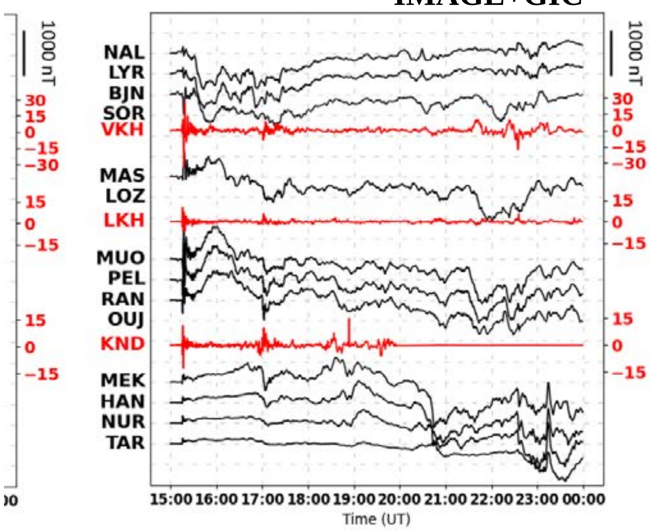
SuperMAG



MIRACLE



X **IMAGE+GIC**



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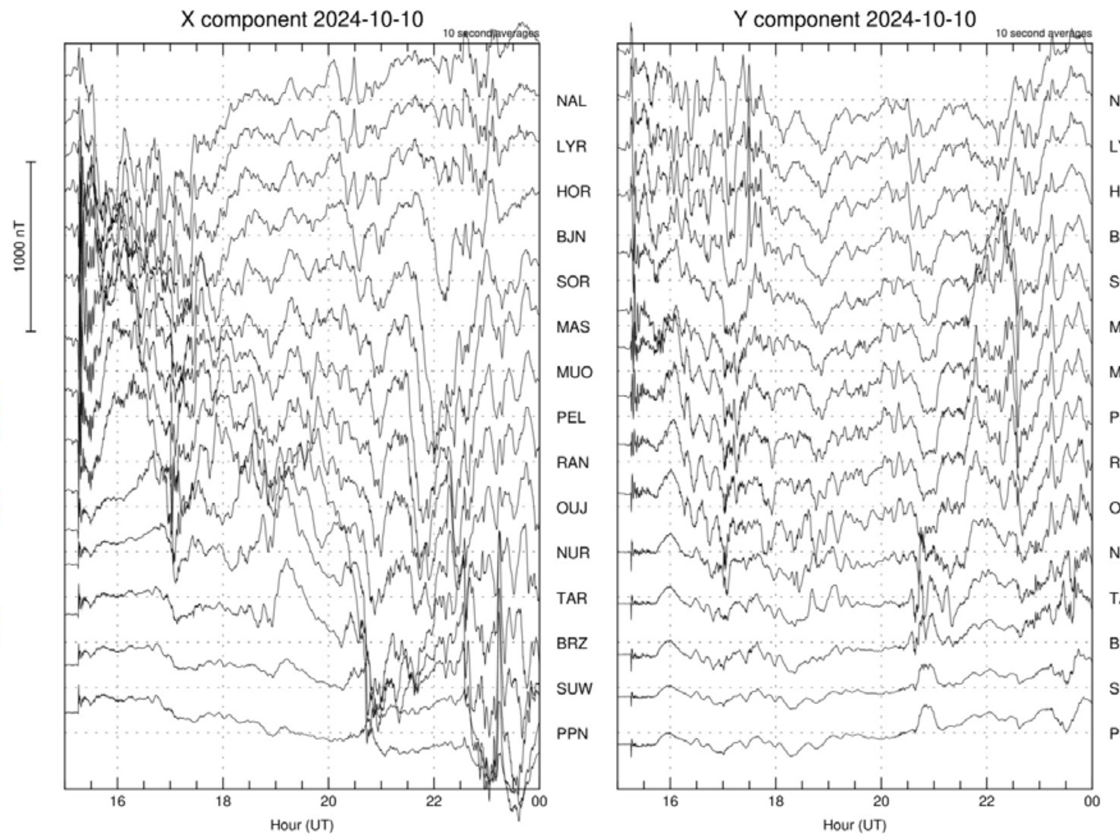
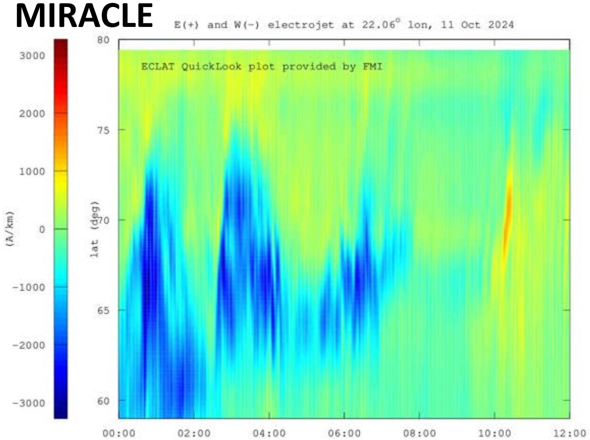


- **GIC sources in the Second interval: Pc5/Pi3 geomagnetic pulsations and substorms at the morning sector**

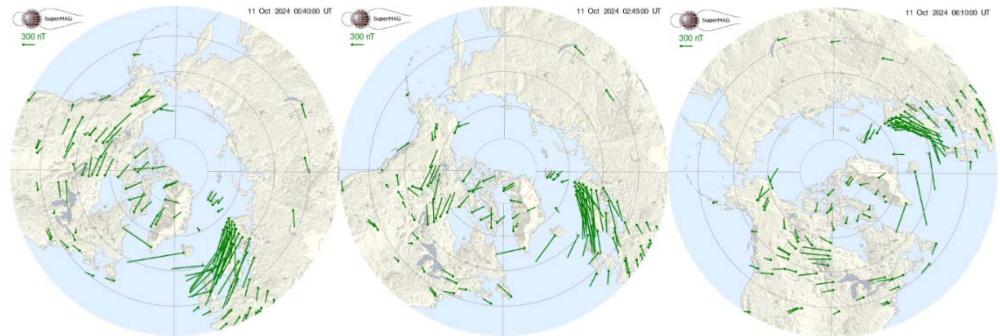
Second interval

MIRACLE



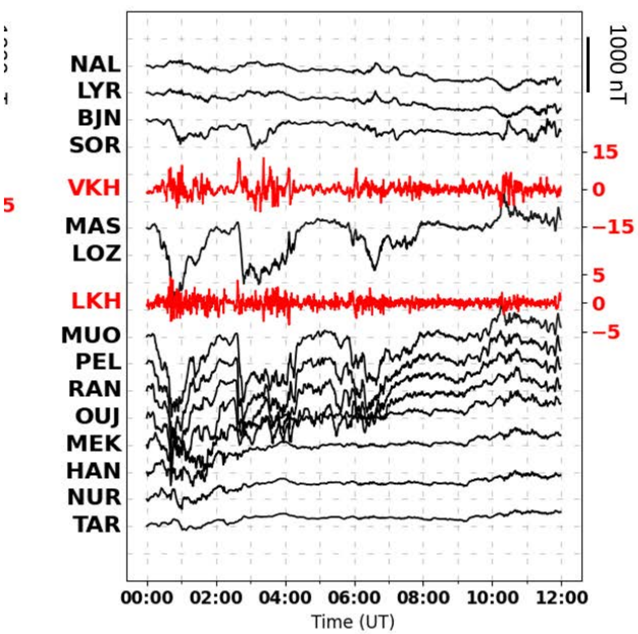
SuperMAG

00:40 **02:45** **06:10**



X

IMAGE+GIC



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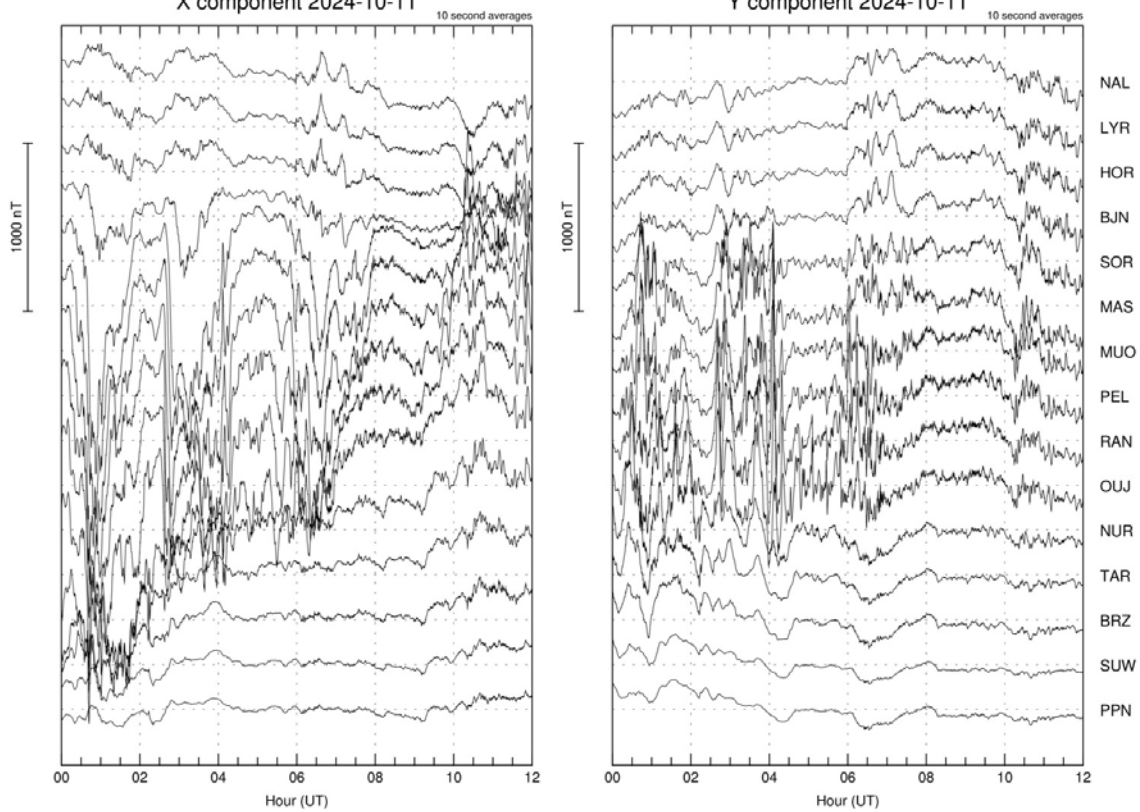
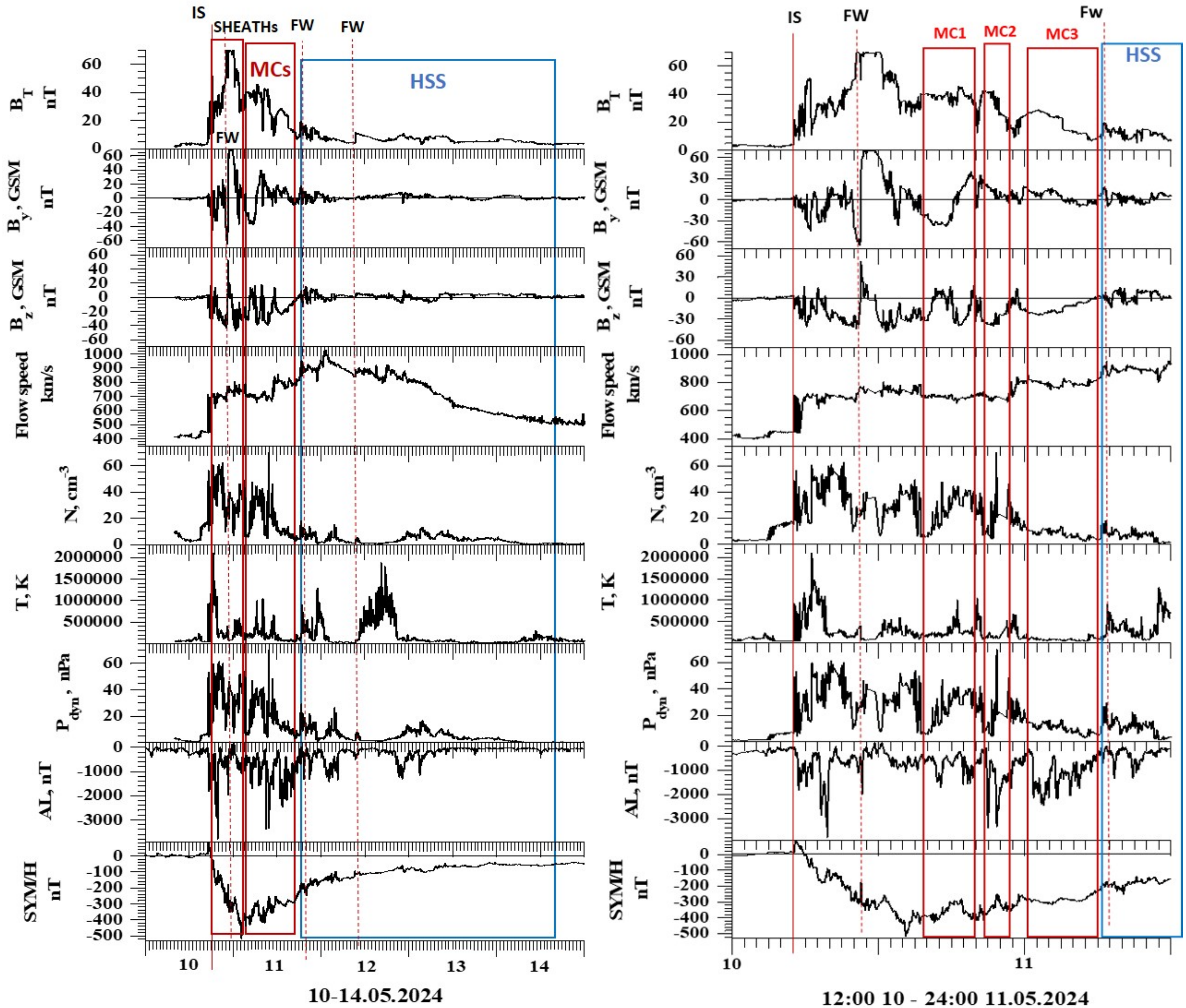


Solar wind/interplanetary and geomagnetic conditions during the 2024 May, 10-12 superstorm (SYM/H~-518 nT)



Interplanetary shock wave arrived at L1 at 16:45 UT on May 10 (*Gonzales-Esparza et al. 2024; Hajra et al. 2024*).

three-stage strong magnetic storm : SYM/H ~-183nT; -354 nT; -518 nT

MCs

1) ~03:28 to 07:54 UT,
2) ~08:25 to 10:36 UT,
3) ~11:19 to 17:17 UT on May 11

GICs and geomagnetic indexes registered in 10- 13 May 2024

Night sector, 10 May :

~18:30 UT, ~62A (80A) (KND)
~20:20 UT, ~26A (KND)
~22:10 UT, ~25A (KND)

Morning and day sector, 11 May:

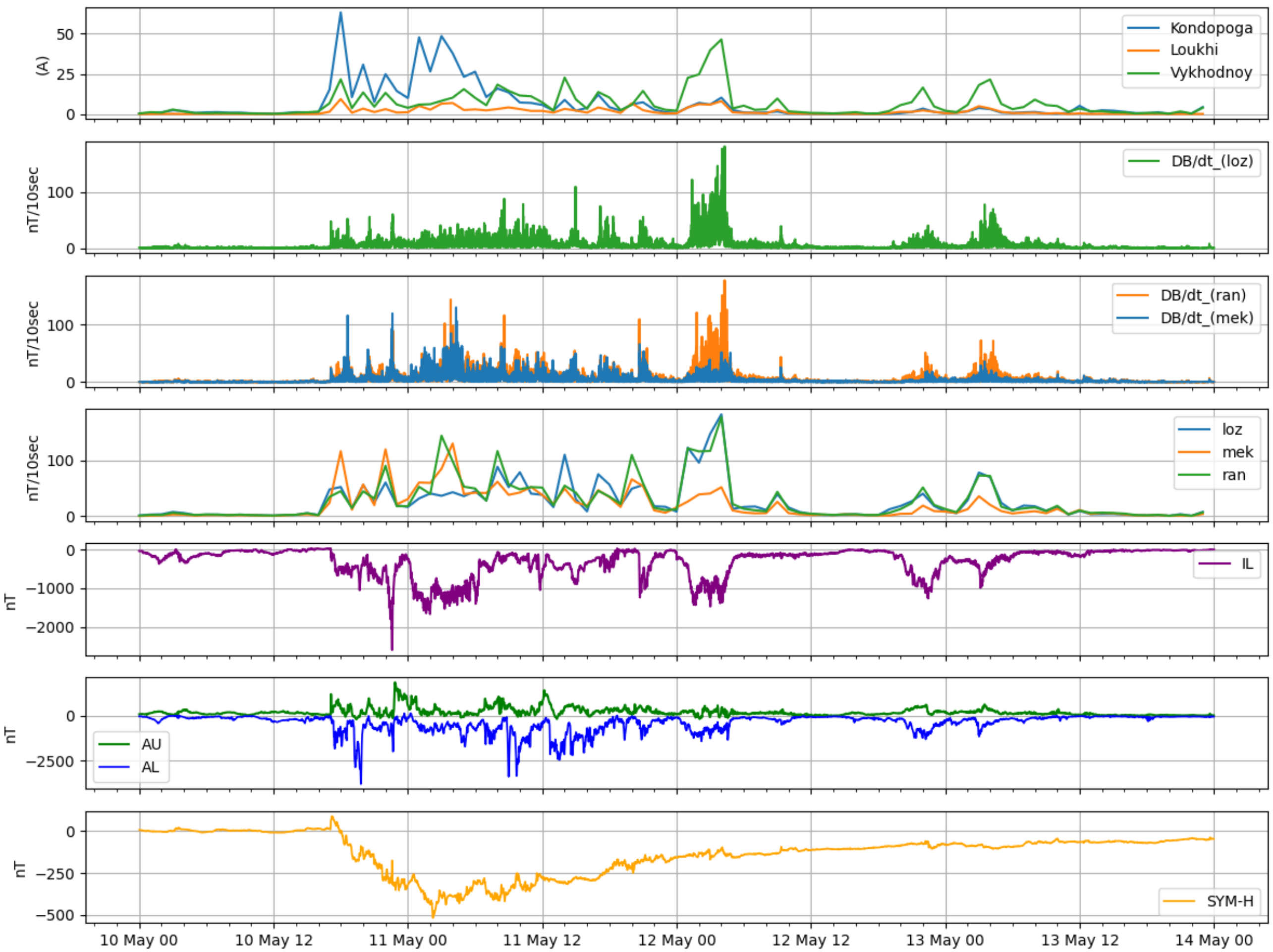
~01:40 UT, ~50A (KND)
~03:20 UT, ~50A (KND)
~08:40 UT, ~20A (VKH)

Evening sector, 11 May:

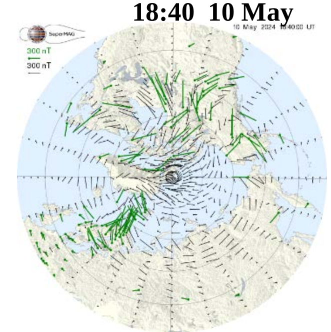
~15:00 UT, ~22A (VKH)
~17:00 UT, ~12A (VKH)
~20:40 UT, ~~12A (VKH)

Morning sector, 12 May:

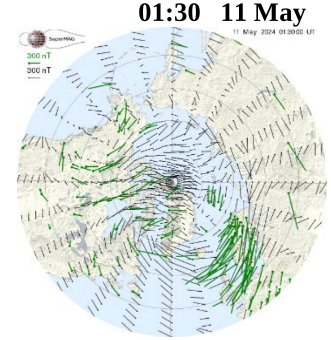
~01:30 UT, ~20A (VKH)
~01:50 UT, ~25A (VKH)
~04:00 UT, ~50A (VKH)



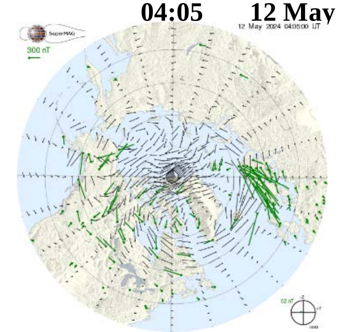
18:40 10 May



01:30   11 May

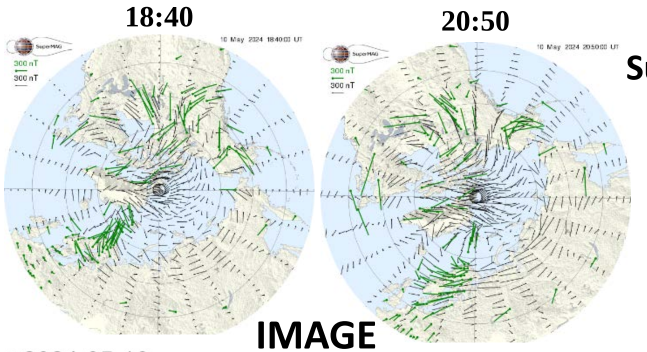


04:05   12 May



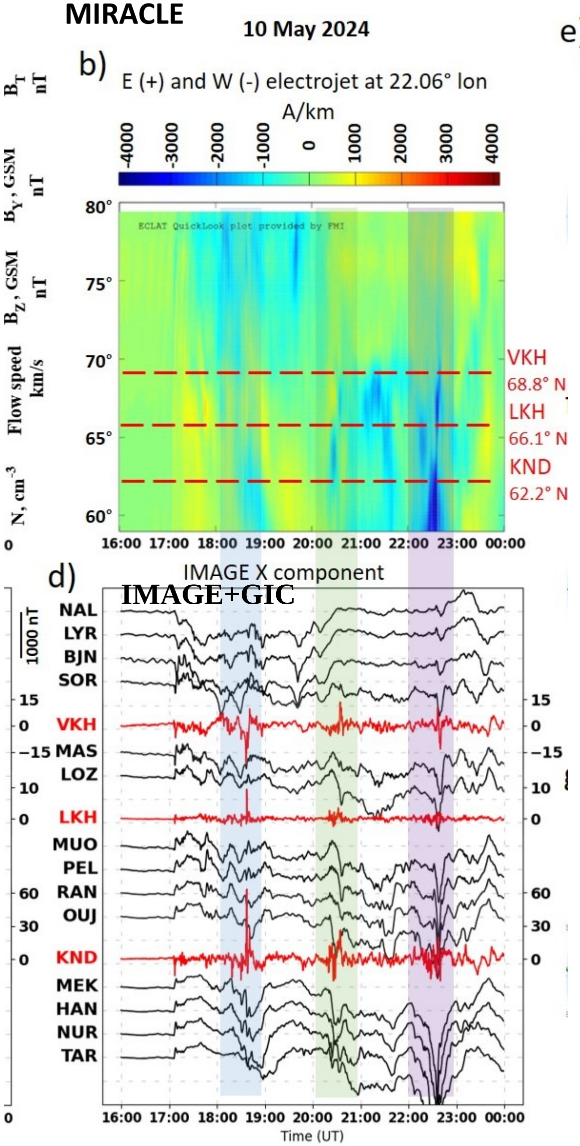
Evening and pre-midnight sectors on 10 May

- **GIC sources in the evening sector:**
 the superposition of the substorm development and a local magnetic disturbance caused by a large solar wind pressure jump.



SuperMAG

MIRACLE



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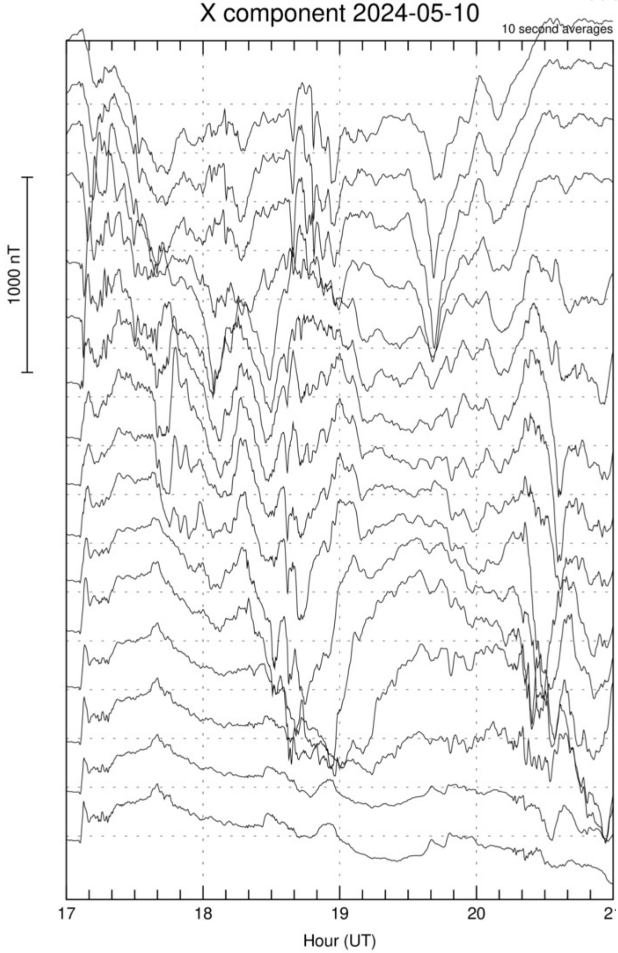
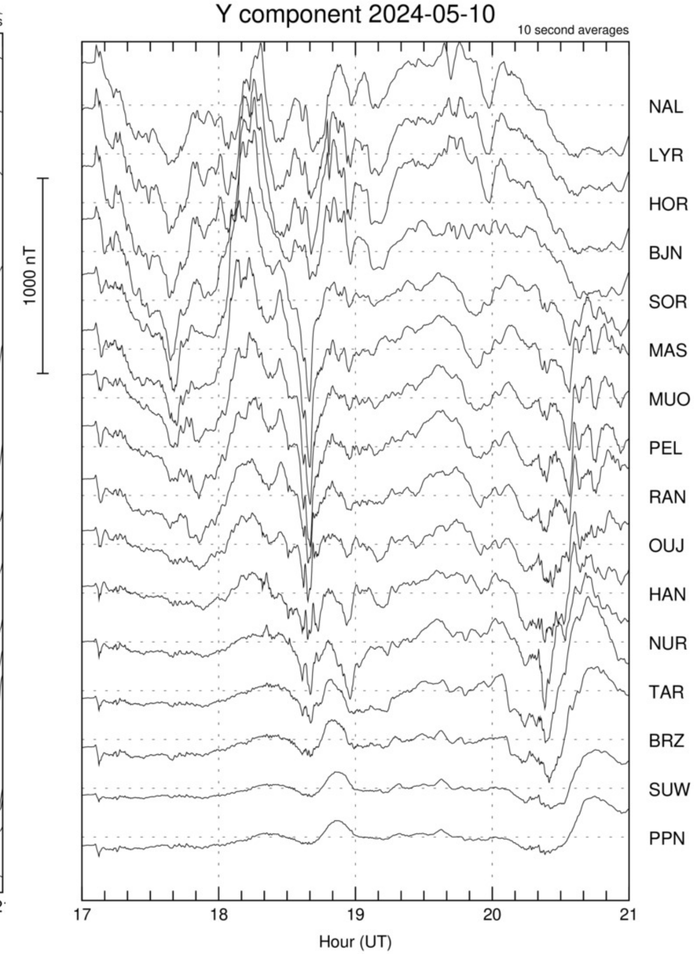


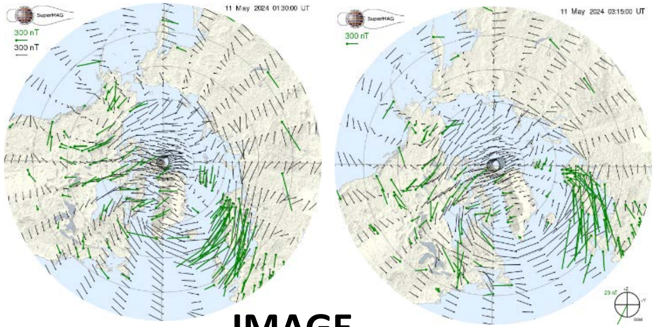


Morning interval on 11 May

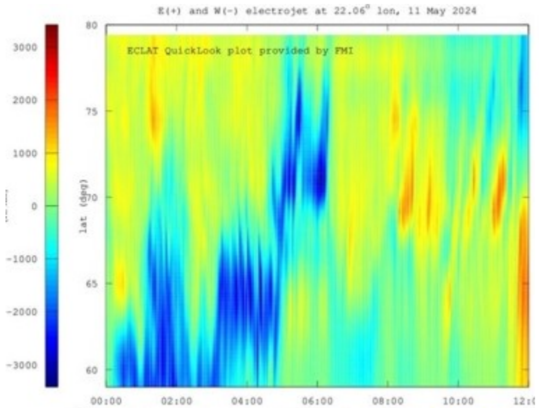
- **GIC sources in the morning sector: Pc5/Pi3 geomagnetic pulsations and substorms**

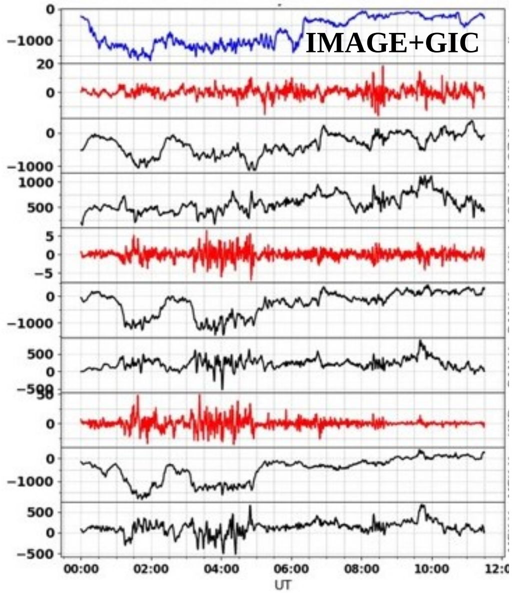
SuperMAG

01:30 **03:15**



MIRACLE





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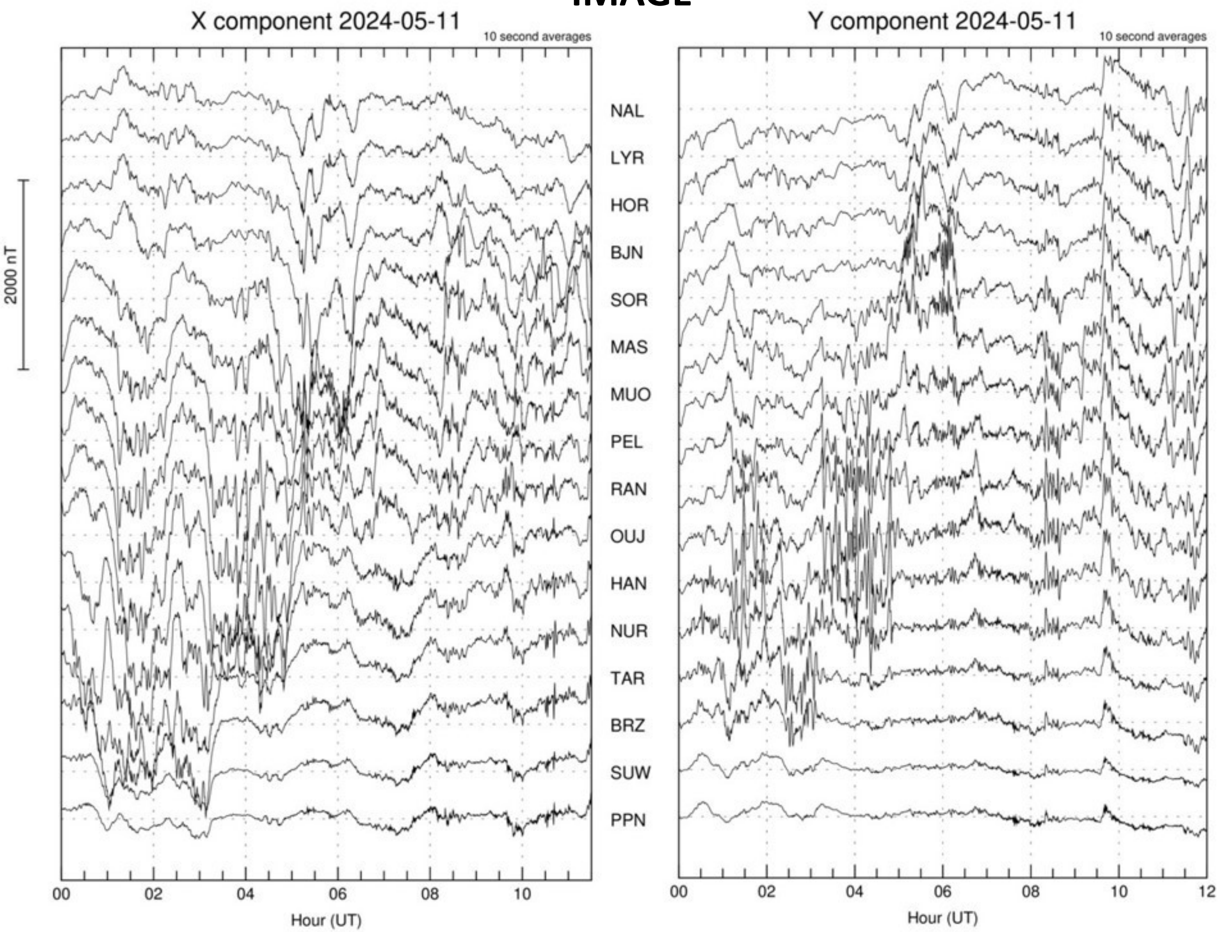
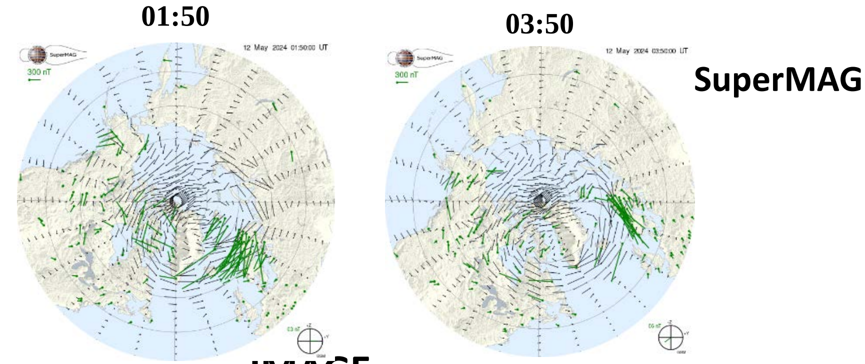
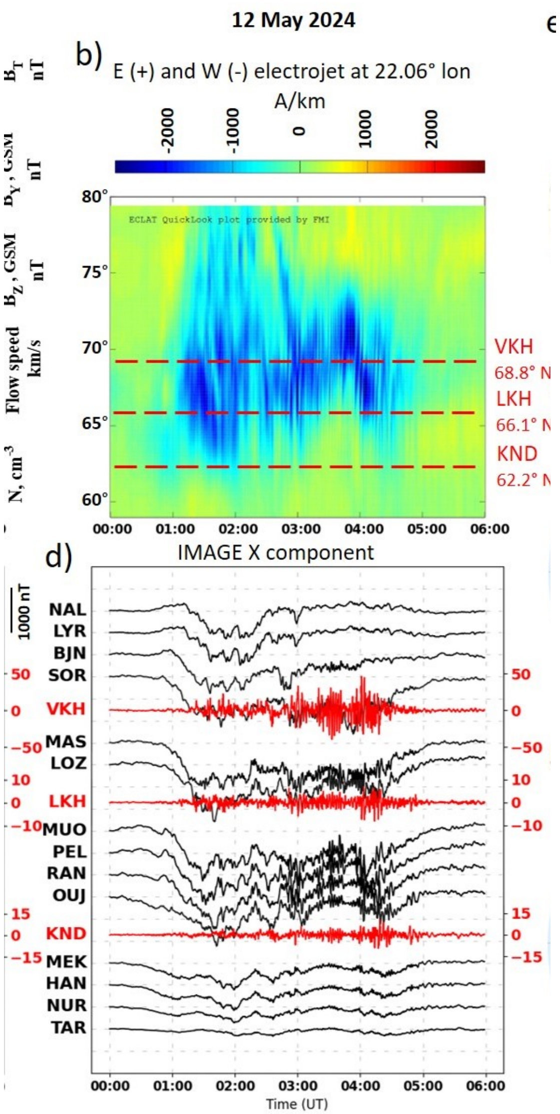


Morning interval on 12 May

- **GIC sources in the morning sector:**
- **the superposition of Pc5/Pi3 geomagnetic pulsations and the substorm development**





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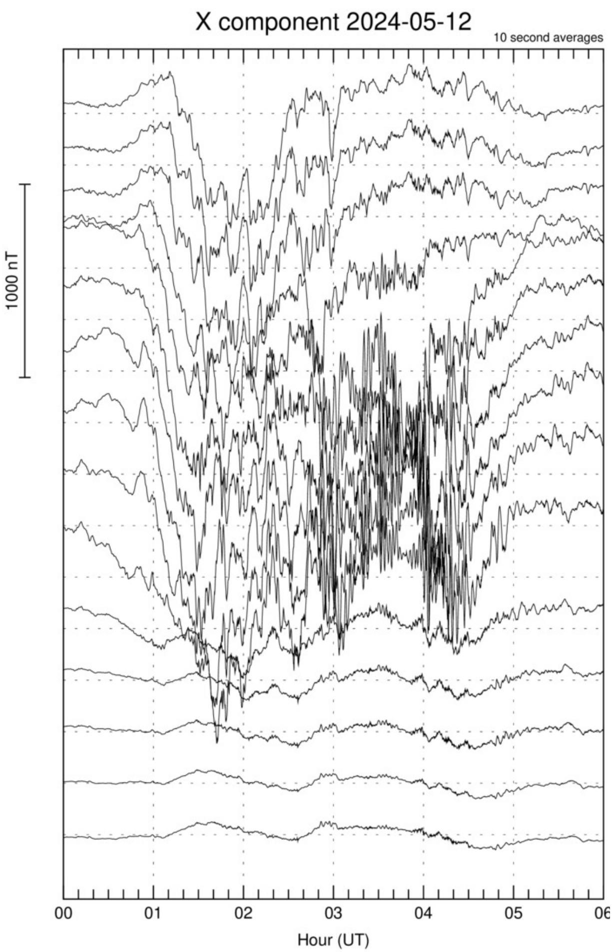

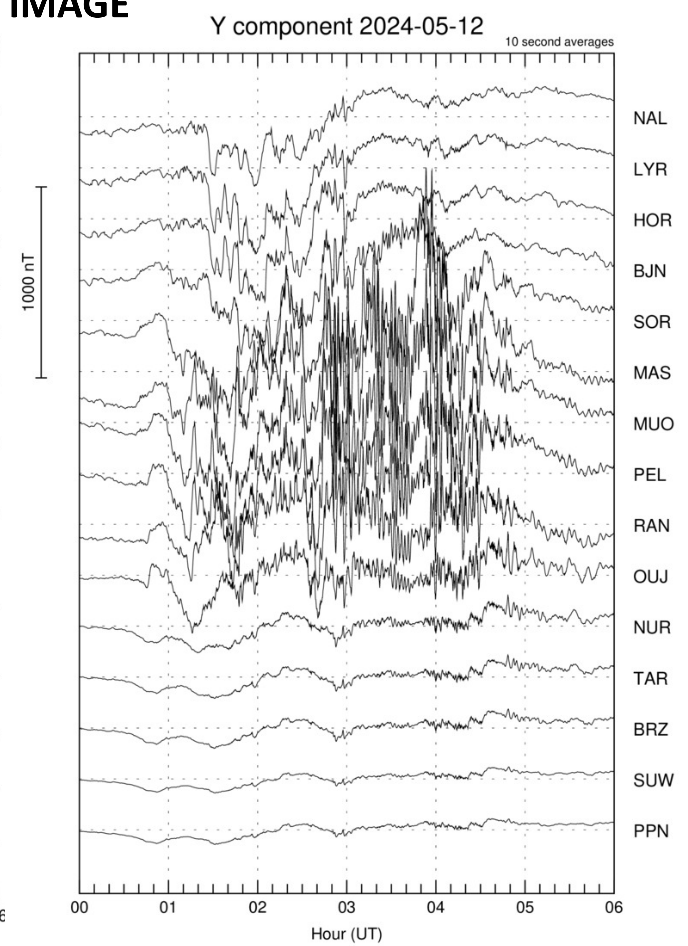

Conclusions

GIC sources are distributed over MLT sectors:
an intense GICs **(~10–30A)** in the evening and night sectors were caused by **substorms,** while intence GICs in the morning sectors were caused by **Pc5/Pi3 geomagnetic pulsations.**

One strongest GIC peak was recorded during storm on **10-11 October 2024**:
- **GIC peak of ~30 A** at **VKH** station was ~ 15:20 UT at the beginning of the magetic storm and was probably associated with the **IS** or **SC.**

Three strongest GIC peaks were identified during superstorm on **10-12 May 2024**:
Three strongest GIC peaks of **~50-62 A** - one in the night and two in the morning sectors- were associated with the superposition of two different geophysical sources:
- First strongest GIC **(~62A)** registered at~18:40 UT on 10 May at KND was caused the superposition of the substorm development and a local magnetic disturbance caused by a large solar wind pressure jump.
- Second strongest GIC peaks **(~50 A)** at ~03:30 UT on May 11 at KND were associated with the superposition of Pc5/Pi3 geomagnetic pulsations and negative bays of subsequent substorms.
- Third strongest GIC peak **(~50 A)** at ~04:00 UT on May 12 at VKH was associated with strong Pc5/Pi3 geomagnetic pulsations recorded at the recovery phase of substorm recorded during HSS.