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# Effects of Geomagnetic Storms on Equatorial Ionization Anomaly and Equatorial Ionospheric Plasma in Thailand

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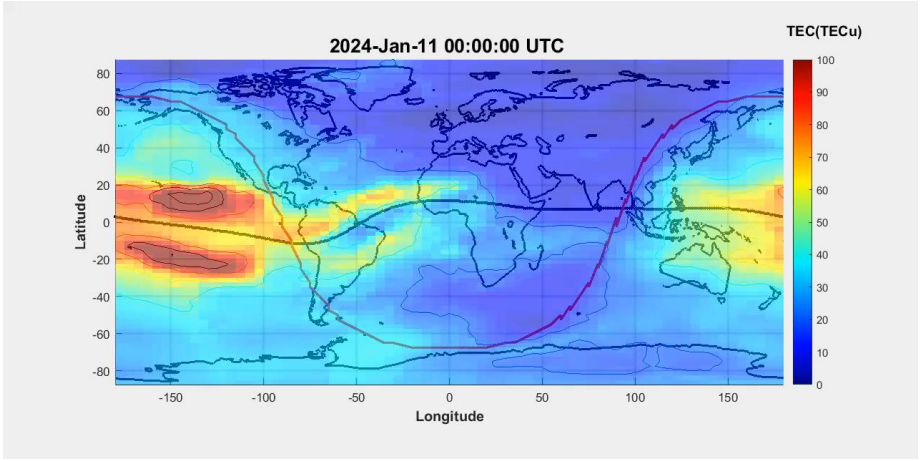
# Motivation

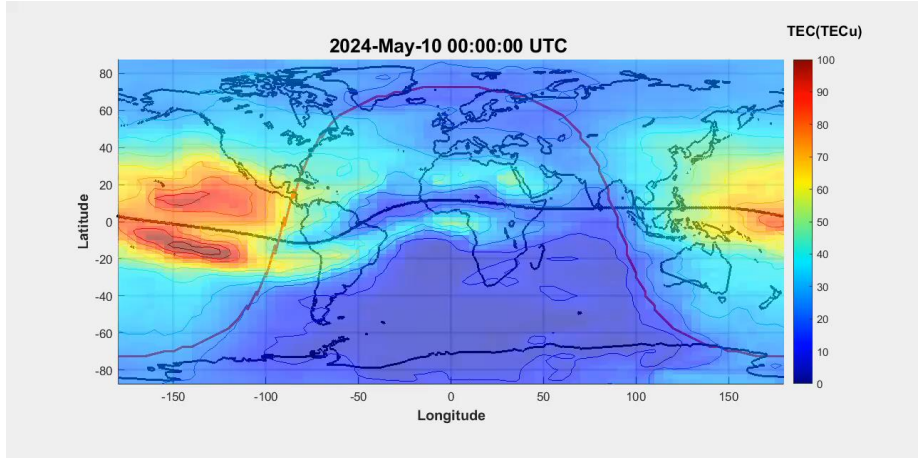
- The **Equatorial Ionization Anomaly (EIA)** is characterized by **two peaks of ionospheric electron density** of the magnetic equator.
- The **EIA formation** varies with **time, days, longitude, and season.**
- Its **formation** during **quiet periods** has been intensively studied.
- **Geomagnetic storms** cause significant disturbances in the ionosphere, affecting EIA and ionospheric irregularities.

- The research investigates **intense geomagnetic storm-time EIA formations** at the longitude 100 °E, over Thailand.
- We want to study relationship **between EIA formation and Equatorial Plasma Irregularity** using local data.

Quiet Time



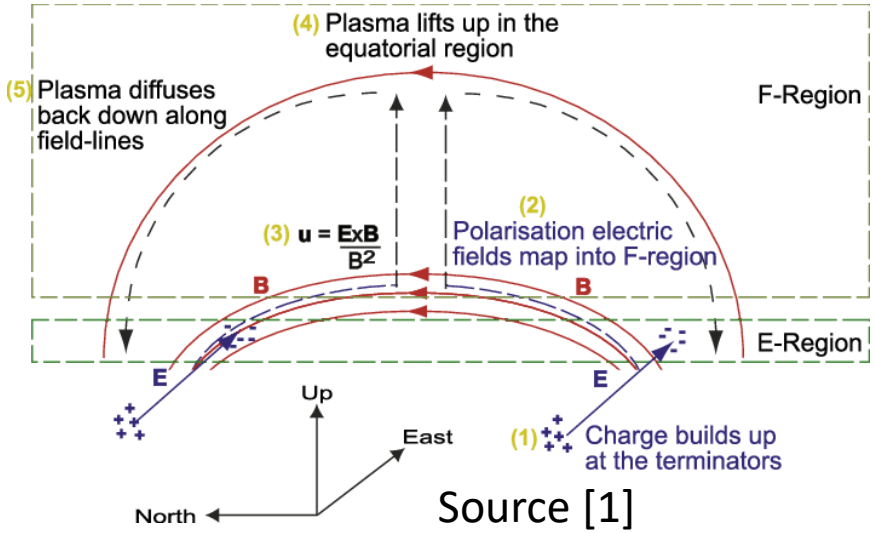

Storm Time



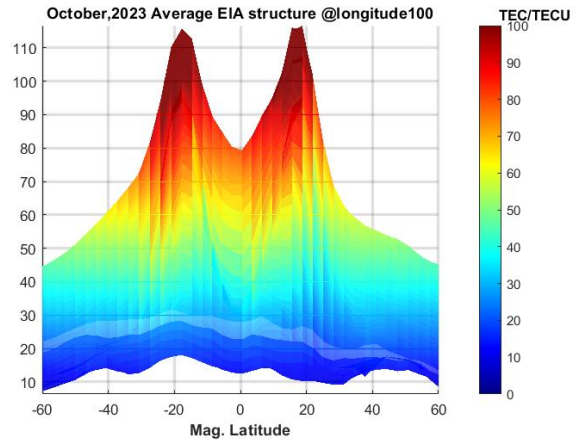

Source: http://cdaweb.gsfc.nasa.gov

# Equatorial Ionization Anomaly (EIA)

- The EIA forms in regions where the Earth's magnetic field (**B**) is nearly parallel to the surface.
- During daytime, the **dynamo electric field** in the ionospheric E layers, is directed eastward, influencing the behavior of ionospheric plasma.
- The **ExB drift** causes the F layer ionospheric plasma to uplift at the magnetic equator.
- The plasma eventually diffuses and falls back down along the field line under **pressure gradient and gravity**.
- Finally, it results in **two** TEC **maxima (crests) at 15/20° north and south** of the magnetic equator and one **minimum (trough) at the equator**.
- The **electric field and neutral wind** are main factors among others that shape the geometry and characteristics of EIA

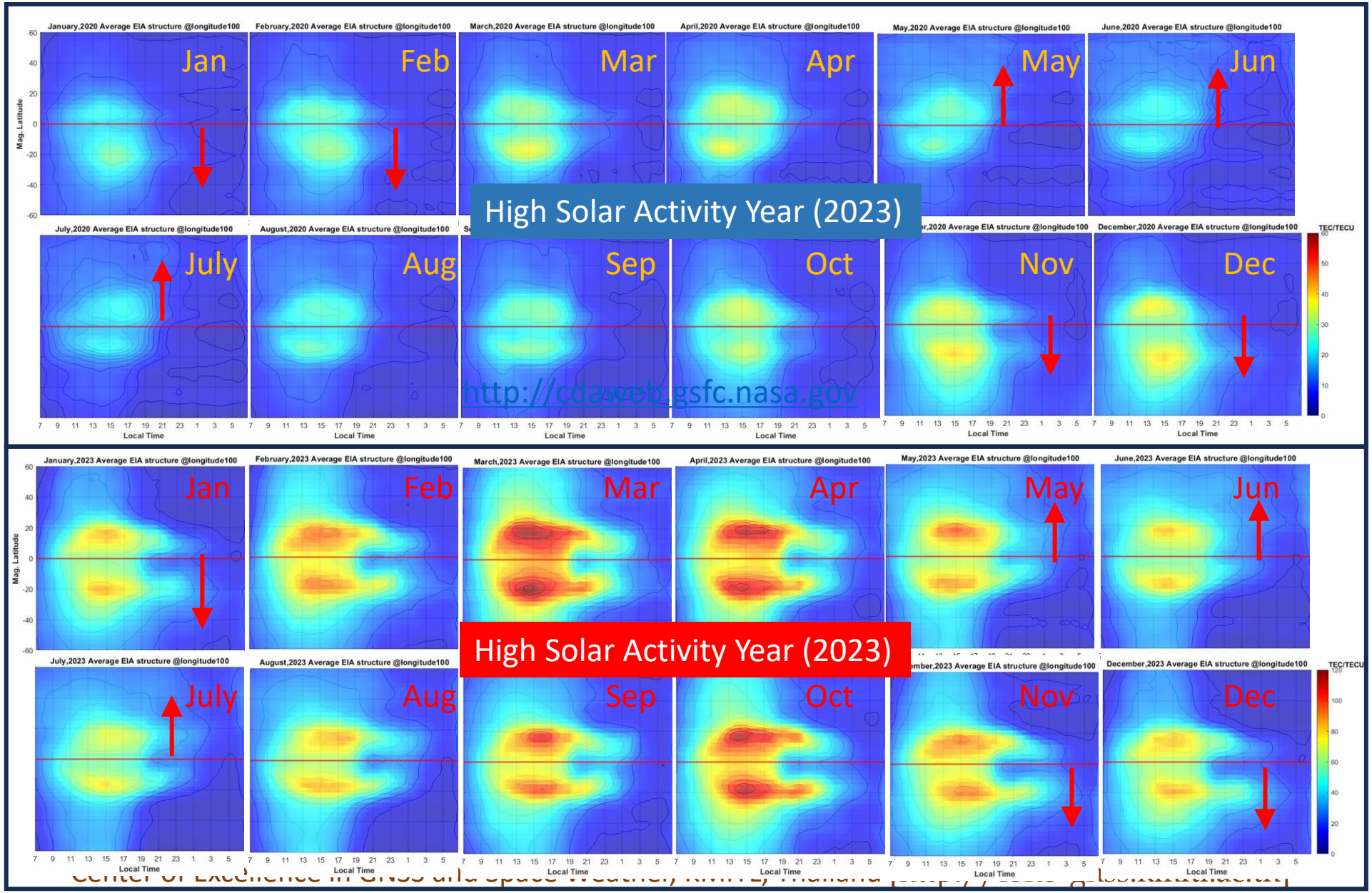



Source [1]




[1] Immel et al. (2006), Control of equatorial ionospheric morphology by atmospheric tides, Geophys. Res. Lett., 33, L15108, doi:10.1029/2006GL026161.

# Monthly Average EIA Formations at Long 100°E




Arrow = drifted direction

- **Similar seasonal variations** between high and low solar activity.
- **Significant symmetric EIA** during the **equinoxes** (March and September) due to solar radiation **evenly distributed** across both hemispheres.
- Asymmetric **EIA** during the solstices (drifted to summer hemisphere).

http://cdaweb.gsfc.nasa.gov

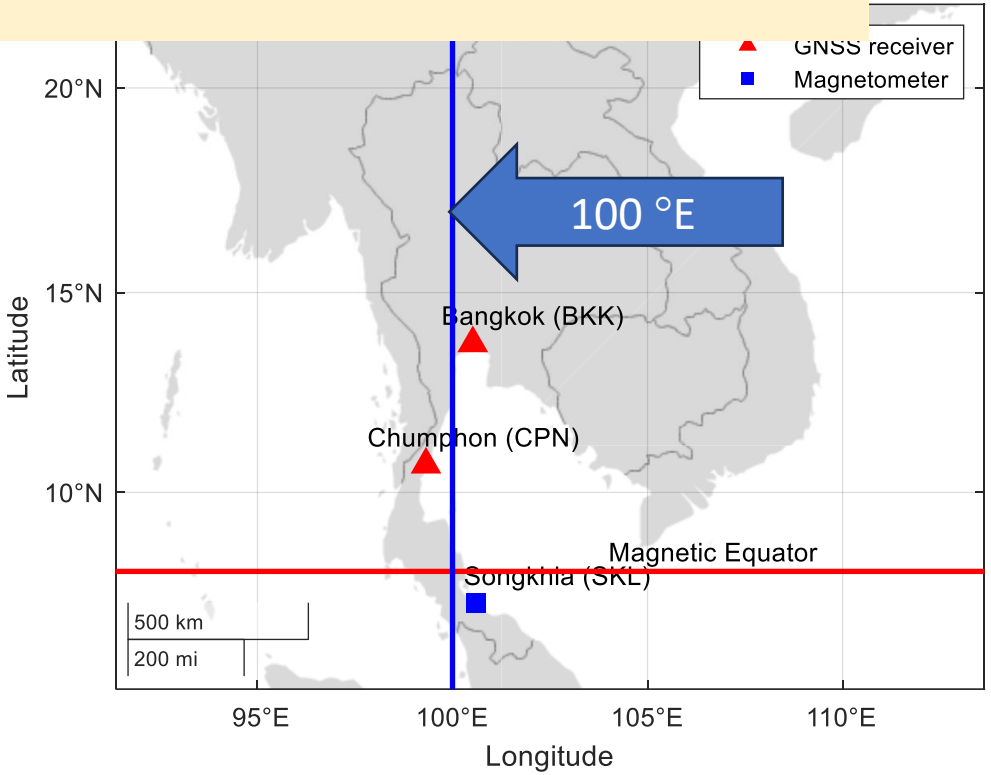
# Experiment Setup and Data

## Ionospheric total electron content (TEC)

- **GNSS** data were collected from the receivers under the Excellence Center in GNSS and Space Weather, at KMITL, Thailand http://iono-gnss.kmitl.ac.th/ and NICT.
- Rapid TEC global map data from the CDAWeb data service http://cdaweb.gsfc.nasa.gov.

## Other Parameters

- Interplanetary magnetic field (IMF) and solar wind https://omniweb.gsfc.nasa.gov/ .
- Disturbance storm time (Dst) index https://wdc.kugi.kyoto-u.ac.jp
- Songkhla geomagnetic station Data https://aer-nc-web.nict.go.jp/sealion/index.html from NICT and GISTDA.




| Station | Geog. Coord. | Mag. Lat. |
|---|---|---|
| Bangkok | 13.73°N, 100.78°E | 4.29°N |
| Chumphon | 10.7°N, 99.4°E | 1.33°N |
| Songkhla | 7.2° N,, 100.59°E | -2.05 °N |

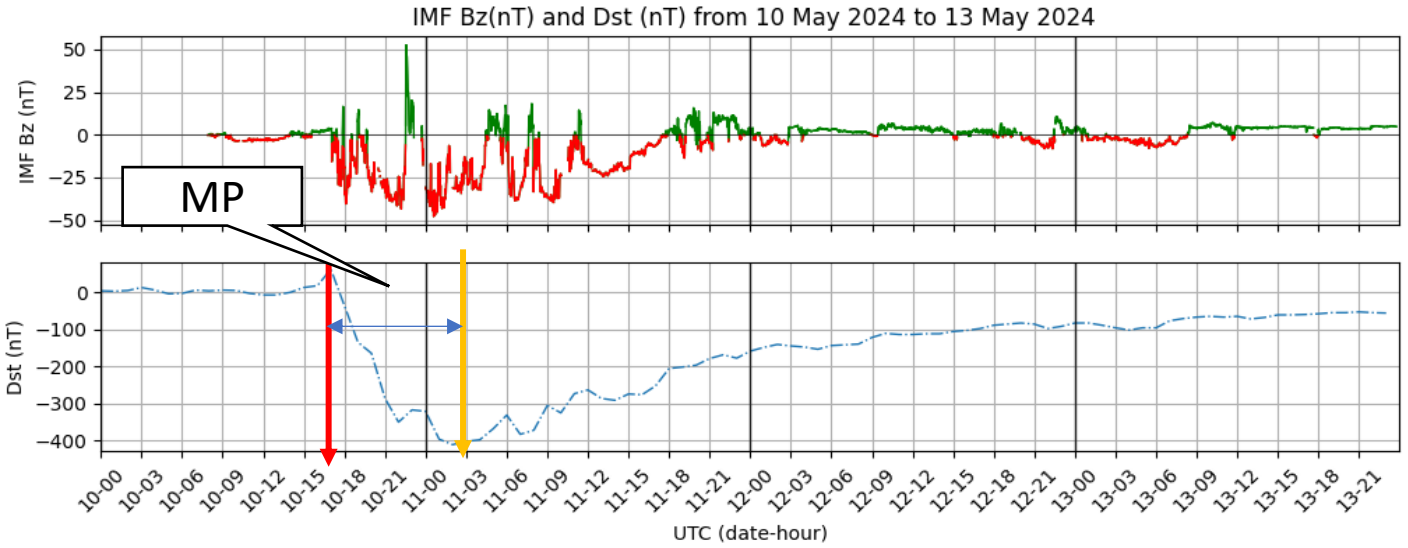
# Intense Geomagnetic Storms in SC # 24 and 25

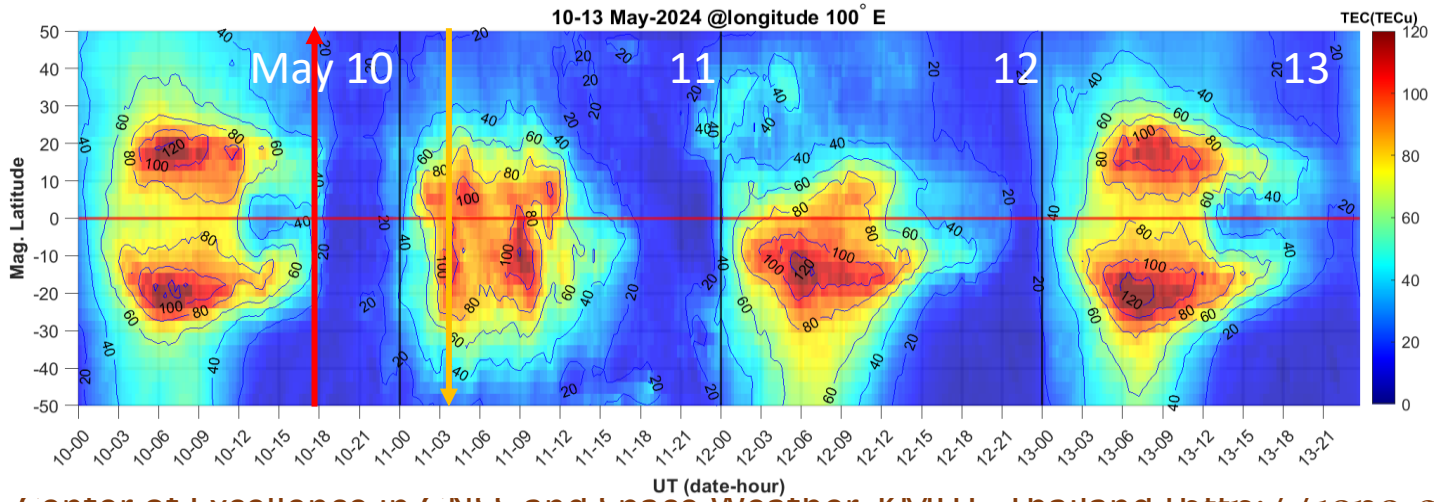
| No. | Date | Dst min | Kp max | Onset Time (UTC) |
|---|---|---|---|---|
| 1 | 10-12/May/2024 | -412nT | 9 | ~17:00 |
| 2 | 23-25/Mar/2024 | -128nT | 8+ | ~3:00 |
| 3 | 4-6/Nov/2023 | -172nT | 7+ | ~10:00 |
| 4 | 23-25/Apr/2023 | -213nT | 8+ | ~09:00 |
| 5 | 23-25/Mar/2023 | -163nT | 7 | ~10:00 |
| 6 | 26-28/Feb/2023 | -132nT | 7- | ~20:00 |
| 7 | 26-29/Aug/2018 | -175nT | 7+ | ~17:00 |
| 8 | 7-9/Sept/2017 | -148nT | 8+ | ~21:00 |
| 9 | 20-21/Dec/2015 | -166nT | 7- | ~4:00 |
| 10 | 22-24/Jun/2015 | -198nT | 8+ | ~11:00 |
| 11 | 17-18/Mar/2015 | -234nT | 8- | ~6:00 |

https://www.spaceweatherlive.com/

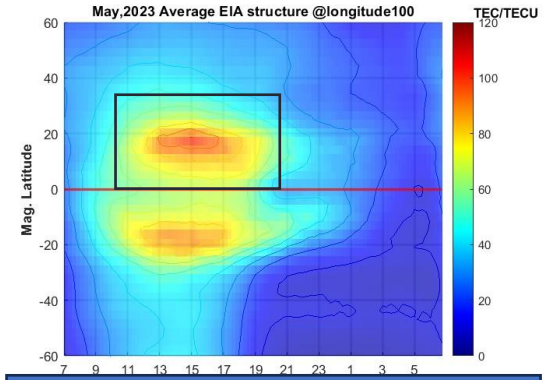
- Only intense geomagnetic storms **(Dst <-120)** during solar **cycle 24 and 25** were considered.
- We categorized the storm based on Dst Index
  - ❖ Intense Storm < -120 nT = 3 storms
  - ❖ Very Intense Storm <- 160 nT= 5 storms
  - ❖ Extreme Intense Storm <-200 nT = 3 storms
- We investigated EIA formation and ionospheric irregularities during these geomagnetic storms.

# EIA in May 2024 Extreme Intens. Storm



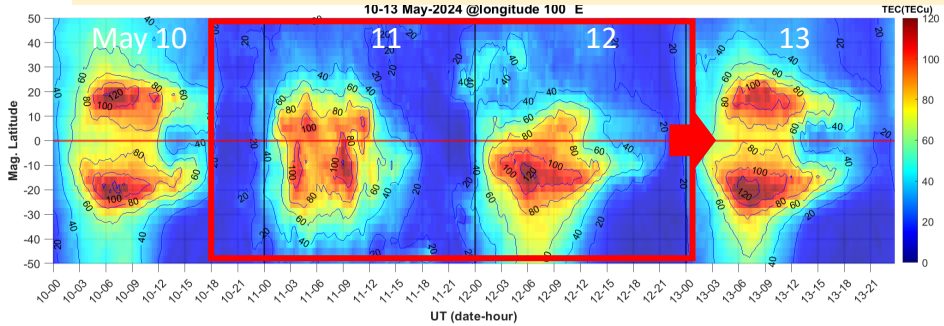




- The geomagnetic storm started at ~17:00 UTC (24 LT) on 10 May.
- The storm (Dst ~ -400 nT) significantly disturbed the EIA formation.
- This event led to higher TEC in the Southern H. (SH) -winter side, although TEC is typically higher in the Northern Hemisphere (NH), but .
- It extended TEC southward, creating an unusual hemispheric imbalance on 12.




Average TEC in May 2024

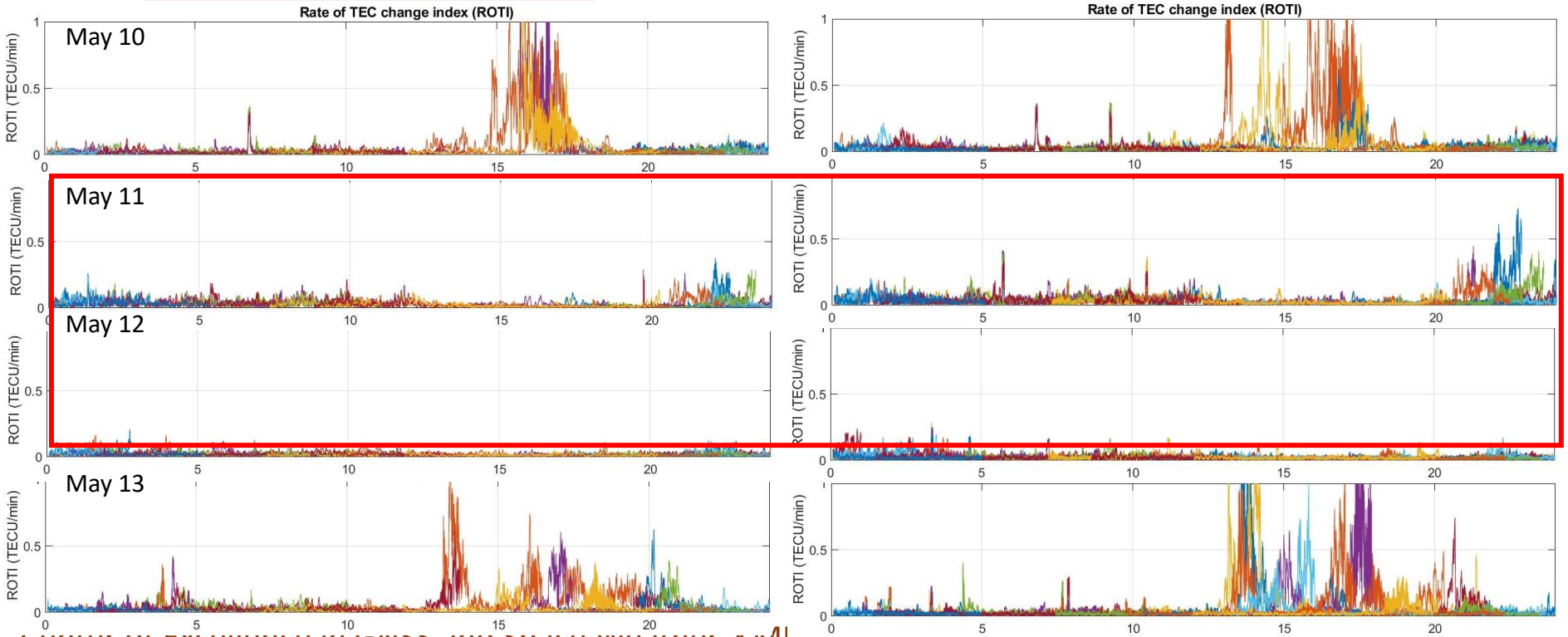
# Ionospheric Irregularity in May 2024 Storm




- The storm suppressed irregularity events, leading to a TEC drop along the longitude.
- **Pre-sunrise irregularity** occurred during the recovery phase on 11.
- No irregularity was observed on the day with a single crest EIA.

**Chumphon Station (Mag. Lat: 1.33°N)**

**Bangkok Station (Mag. Lat: 4.29°N)**



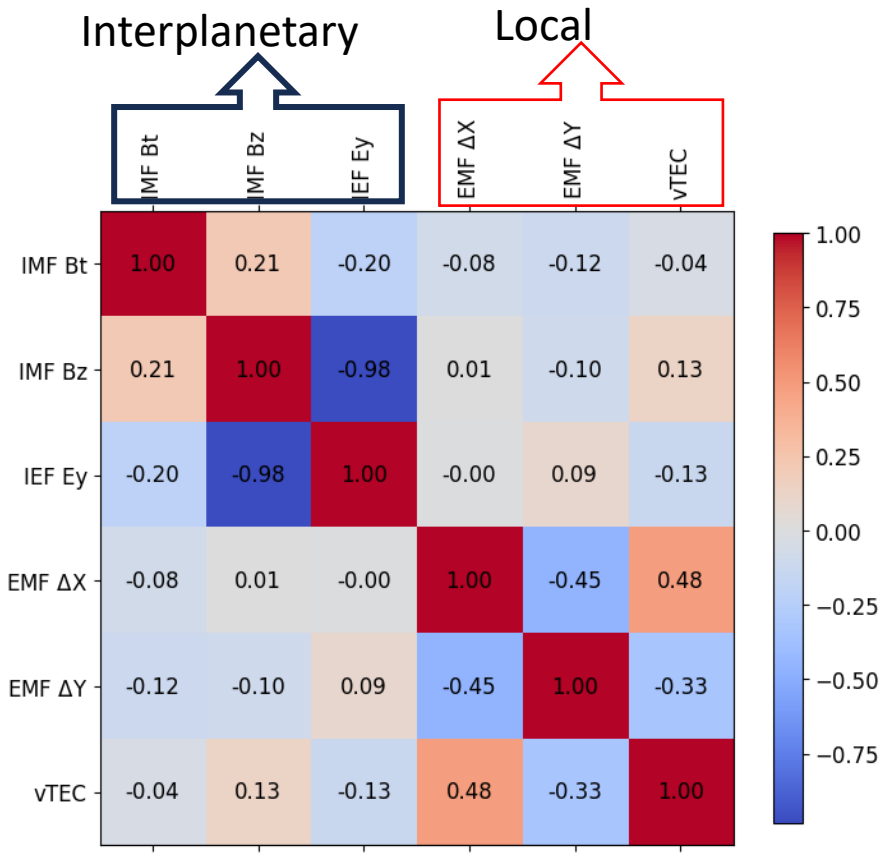

- Higher ROTI at higher latitude.

# Correlation between Interplanetary and Local

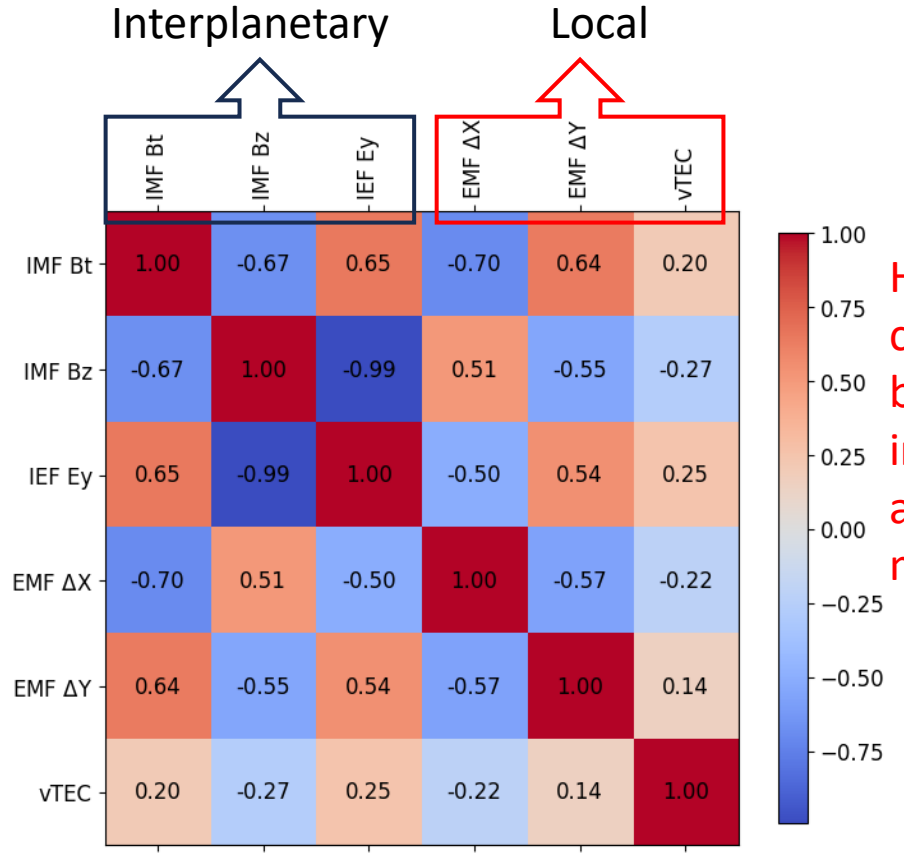
Pearson's correlation coefficients among components of interplanetary magnetic and electric fields, and equatorial magnetic and TEC.

High correlation coefficients between interplanetary and equatorial (local) parameter during the storms.

Low correlation between interplanetary and local magnetic field.



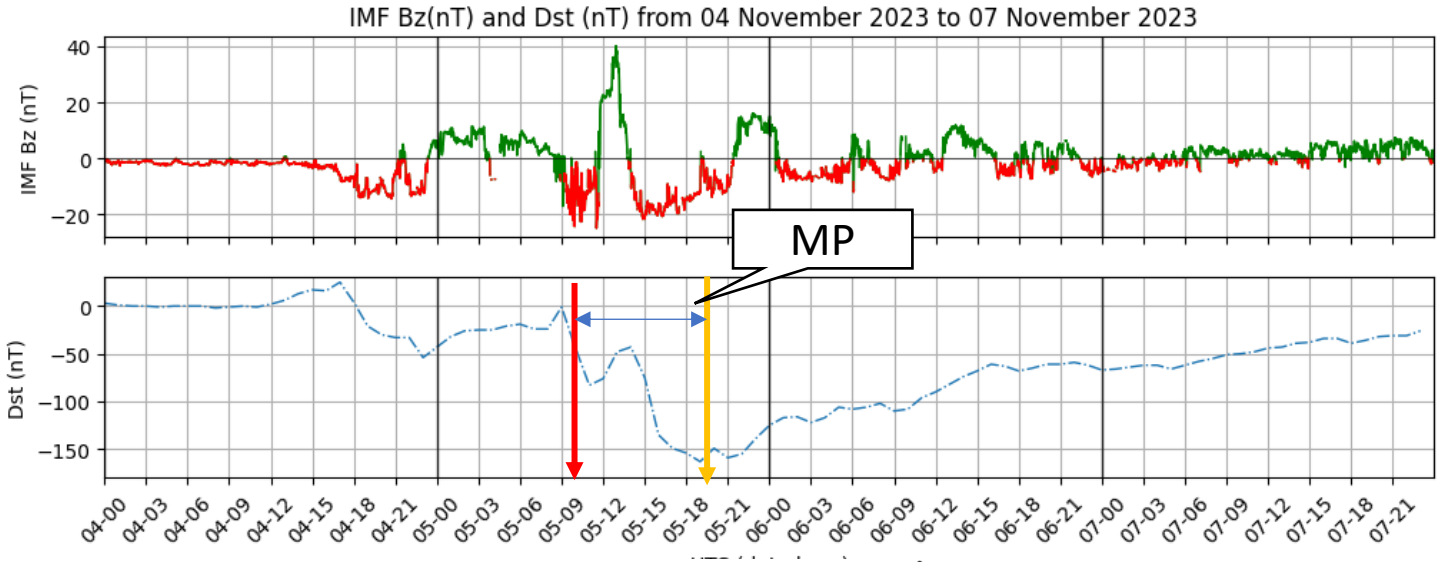

Quiet period during 4-9 May

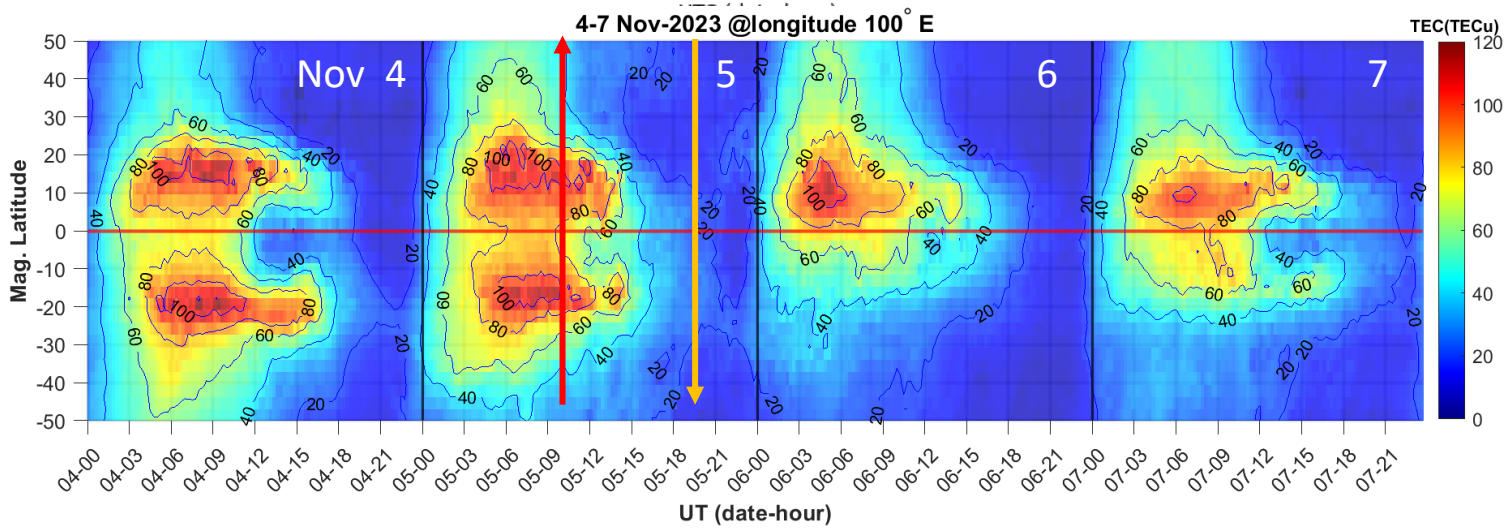



Storm period during 10-13 May 2024

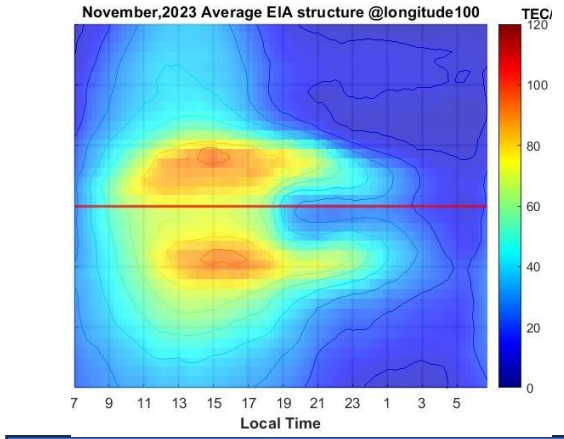
High correlation between interplanetary and local magnetic field.

# EIA In November 2023 Very Intens. Storm



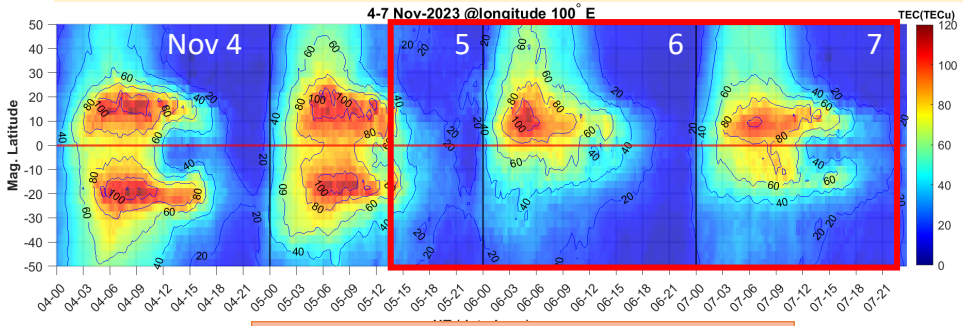




- The geomagnetic storm started at ~10:00 (~17:00) UTC on 5 Nov 2023.
- The storm (Dst ~ -170 nT) caused major EIA disturbed formation on the recovery phase.
- EIA formed with a single crest at NH-winter side on November 6 and 7.



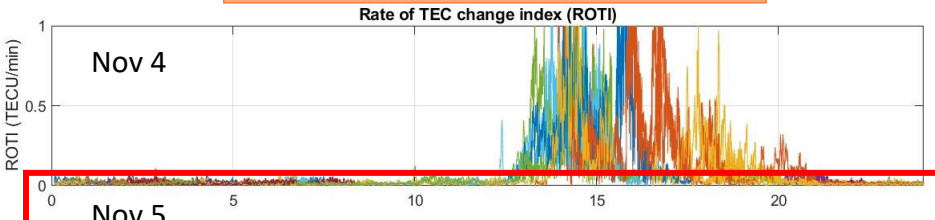

Average TEC in Nov 2023

# EIA during November 2023 Geomagnetic Storm



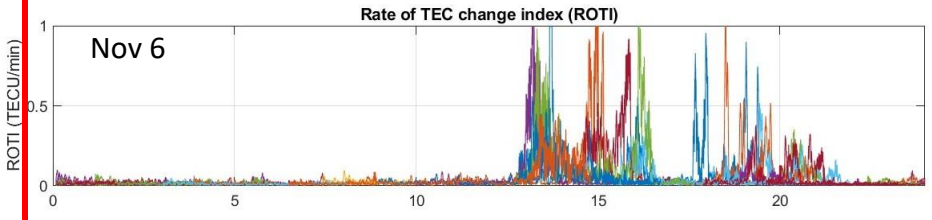

- Irregularity was experienced as the Storm started local daytime
- Irregularity events were detected during the storm period
- **Pre-sunrise irregularity** was observed on Nov 7, 2023.

**Chumphon Station (Mag. Lat: 1.33°N)**




Nov 5

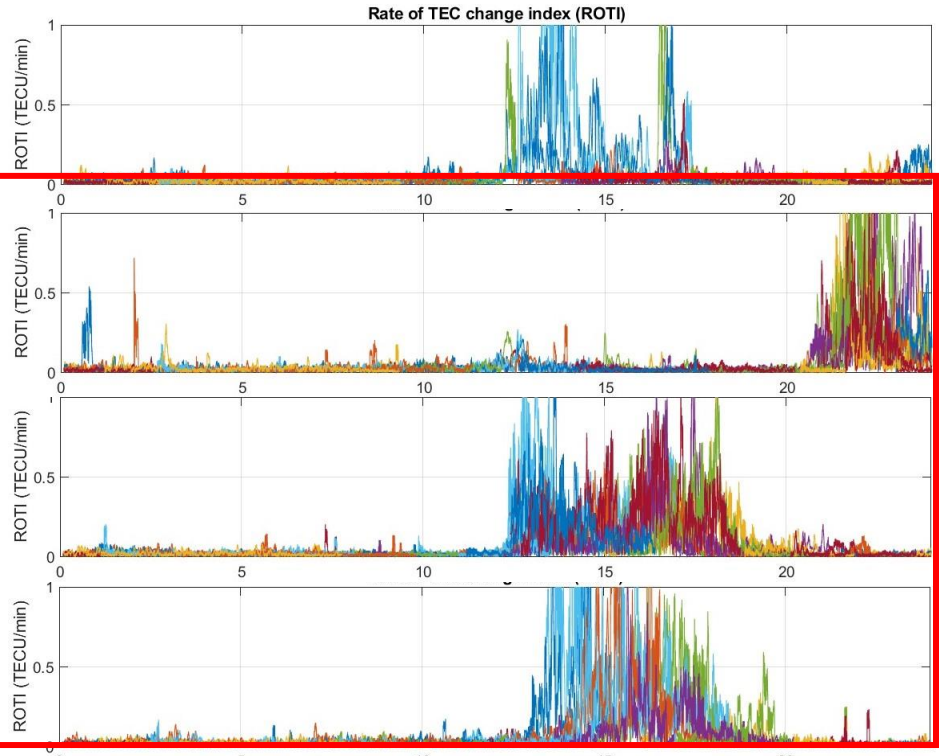
No Data




Nov 7

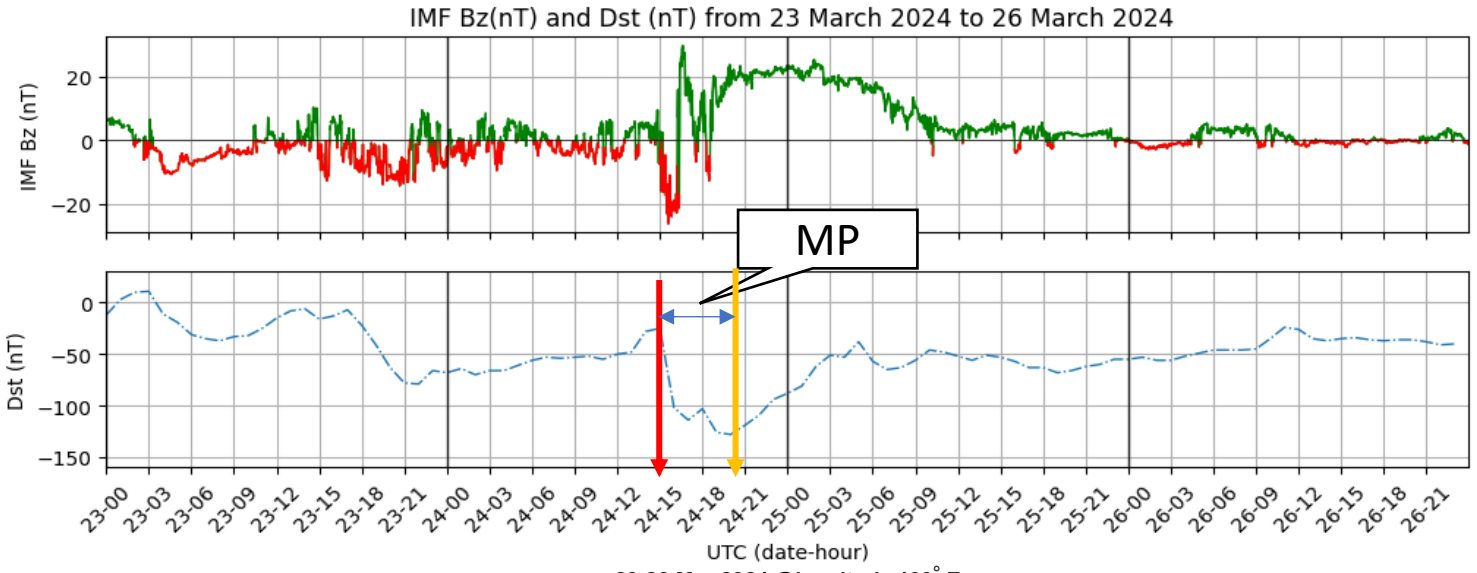
No Data

**Bangkok Station (Mag. Lat: 4.29°N)**

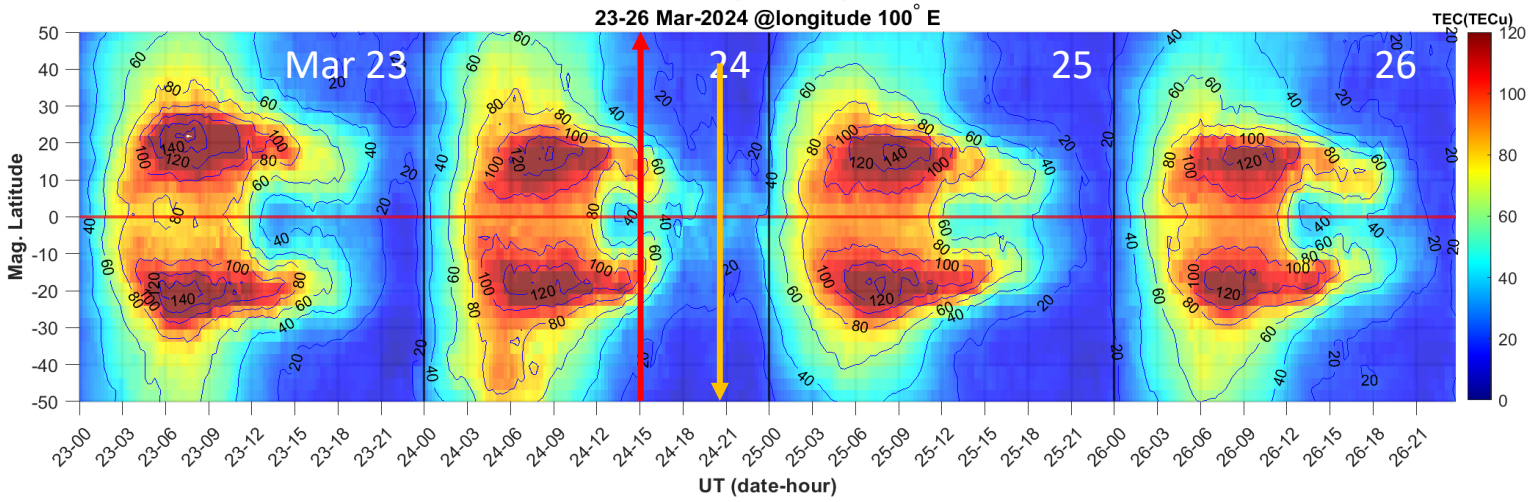


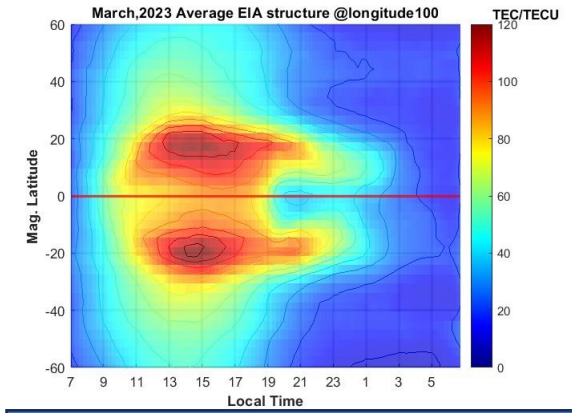

- More significant ROTI at higher latitude.

# EIA in Intense March 2024 Storm



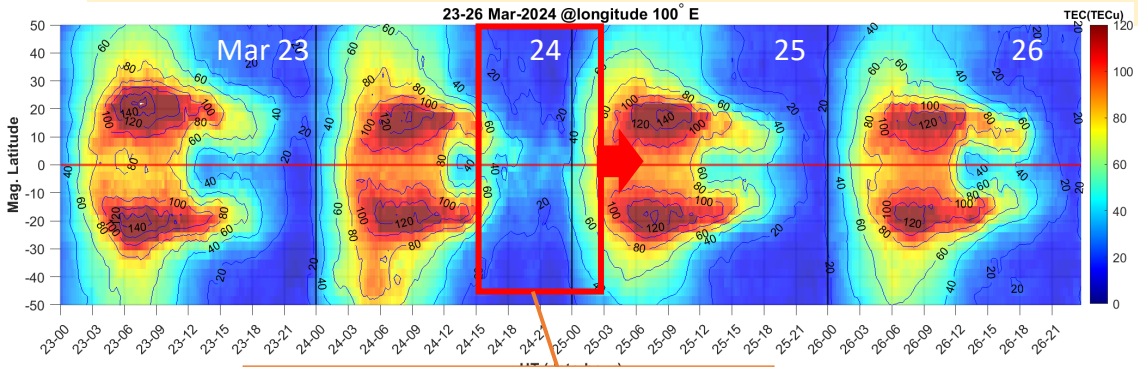

- The Dst dropped multiple times before the storm.
- The storm began around 15:00 UTC (22 LT) on March 24.
- Despite reaching Dst ~ -130 nT, the storm had minimal impact on the EIA due to its short duration.
- The symmetric structure of the EIA remained intact.




Average TEC in March 2024

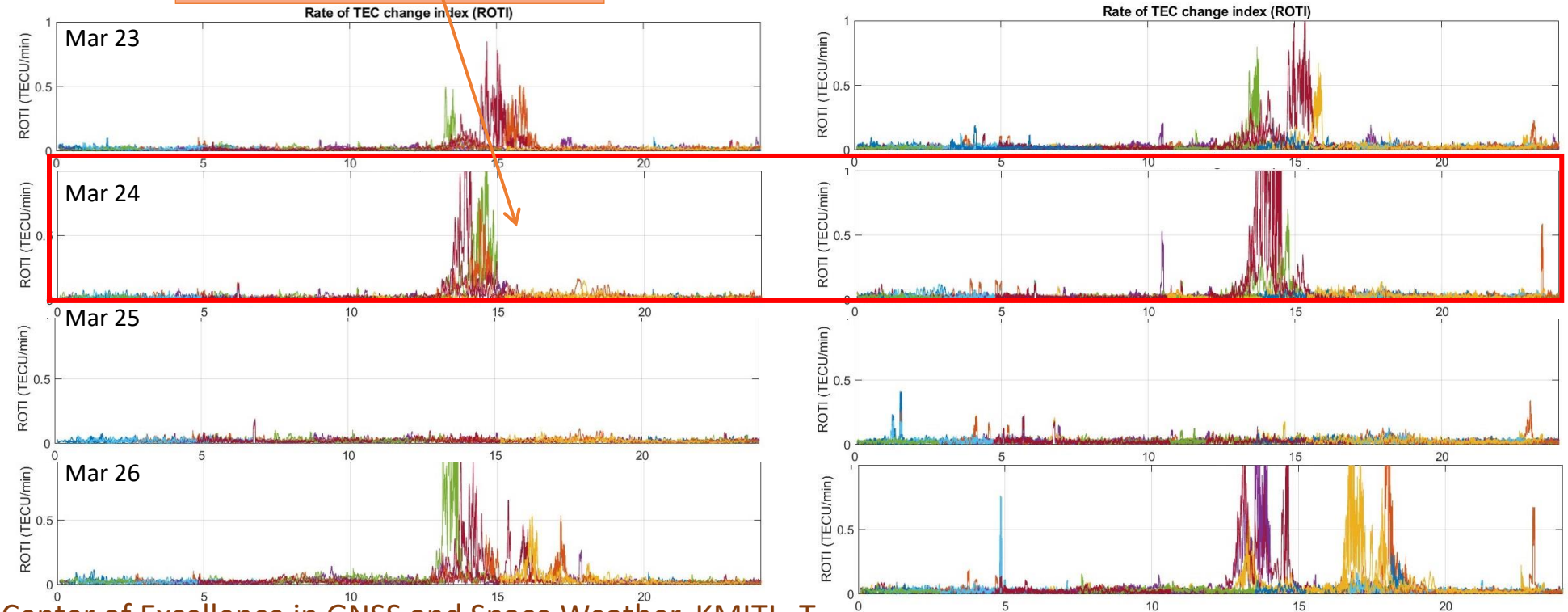
# Ionospheric Irregularity in March 2024 Storm




- The storm suppressed irregularity events, similar to May 2024 event.

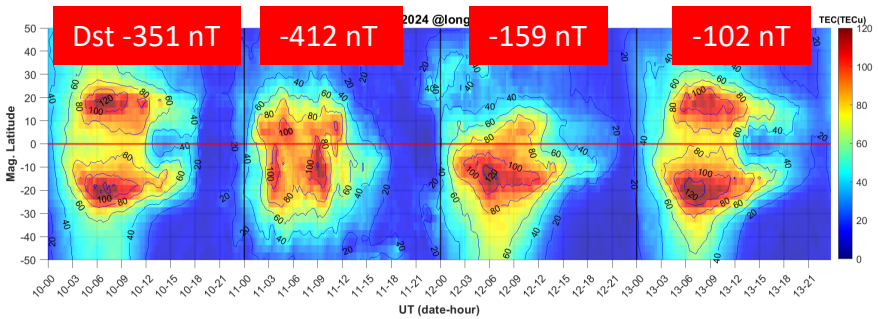
Chumphon Station (Mag. Lat: 1.33°N)

Bangkok Station (Mag. Lat: 4.29°N)

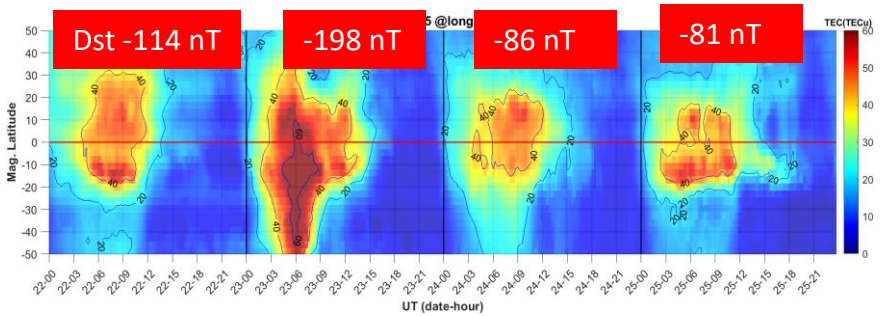


# EIA Formations vs. Dst Index (<-160)

May 2024 (SC #25)

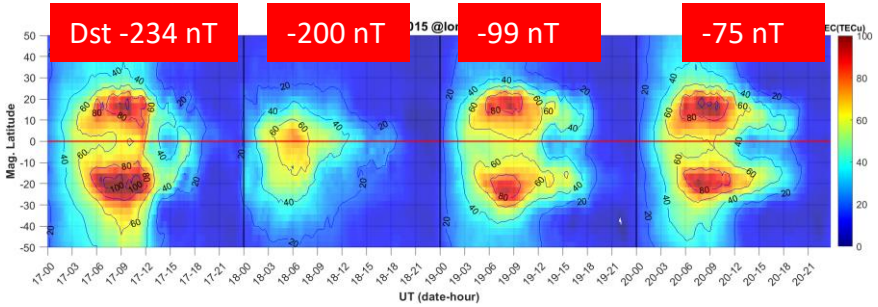



June 2015 (SC #24)

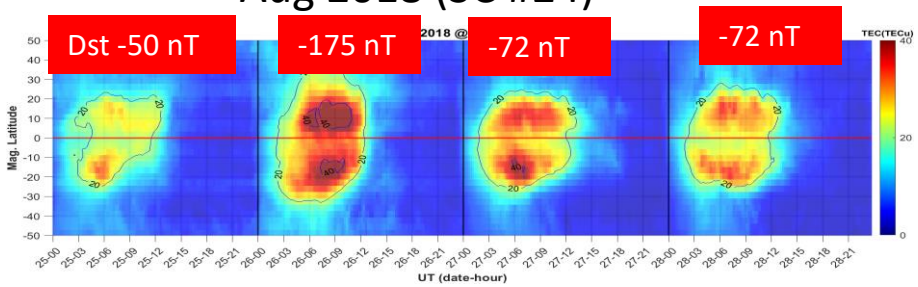



**Storms according to Dst ascending order.**

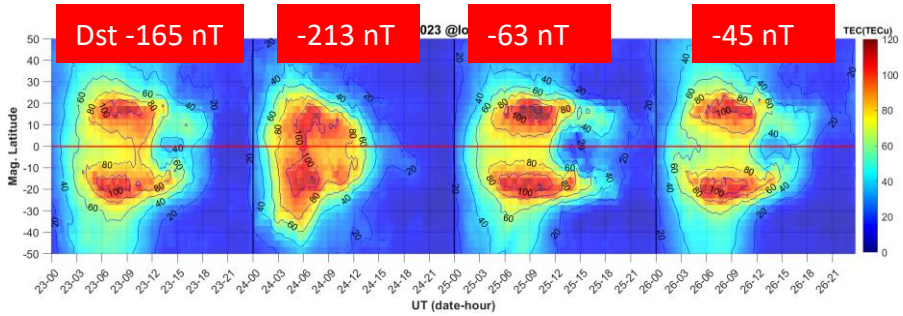
Mar 2015 (SC #24)



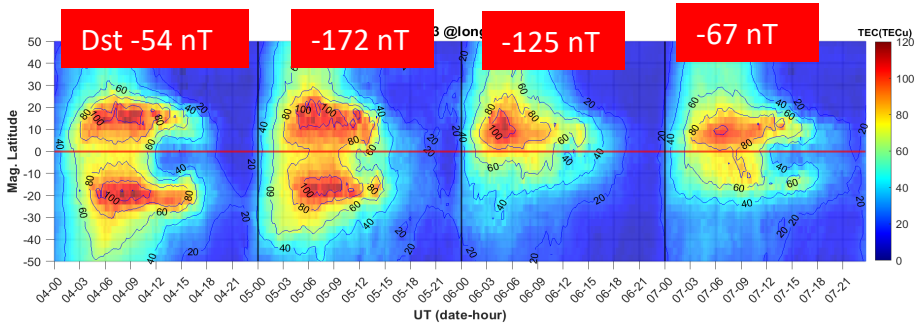

Aug 2018 (SC #24)




Apr 2023 (SC #25)




Nov 2023 (SC #25)

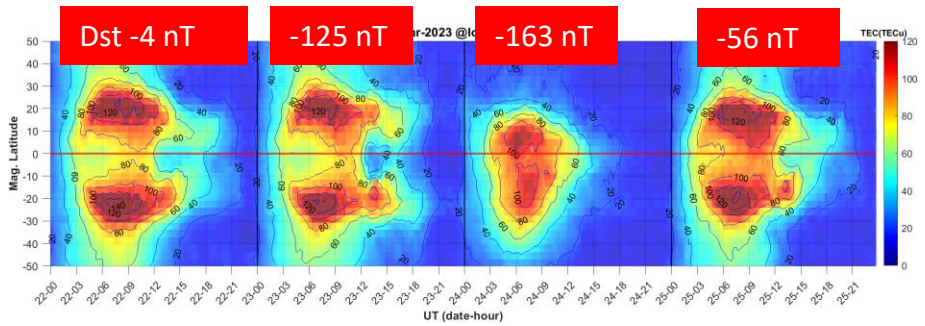



**Single Crest EIA**

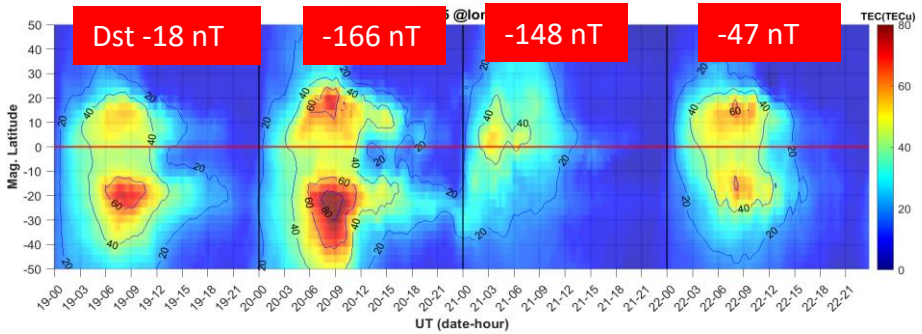
- ❑ Mostly during recovery phase
- ❑ Extended to winter hemisphere in May and Nov storms.
- ❑ At the mag. Equator in other storms
- ❑ Depending on season

# EIA Formations vs. Dst Index

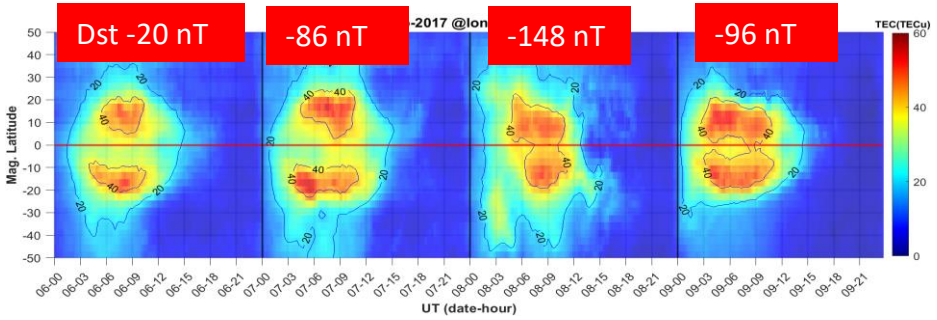
Mar 2023 (SC #25)




Dec 2015 (SC #24)

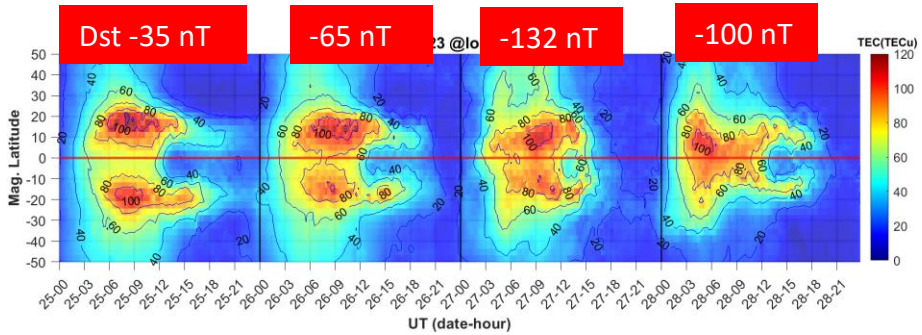



Sept 2017 (SC #24)

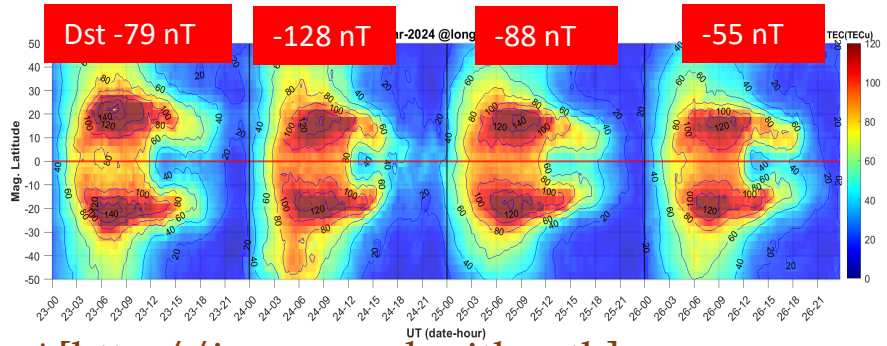



- Short-time storms with high Dst typically don't modify EIA formation.

Feb 2023 (SC #25)




Mar 2024 (SC #25)



# Conclusion and Future Work

- Significant geomagnetic storms lead to substantial disturbances in the Equatorial Ionization Anomaly (EIA), resulting in increased ionospheric irregularities.
- Geomagnetic storms occurring during high solar activity years have a more pronounced effect on ionospheric plasma dynamics, impacting both the intensity and symmetry of the EIA.
- In most cases with Dst ≤ -160 nT, a single crest EIA formed near the magnetic equator during the recovery phase of the storm.
- The development of ionospheric irregularities is highly dependent on the onset time of the storm, with variations observed in both timing and location of irregularities.
- **Future Work**
- Further analysis is needed to investigate the relationship between storm-time electric fields and neutral winds and their combined influence on EIA disturbances.

# Acknowledgement

This work is partially funded by the NSRF via the Program Management Unit for the Human Resources & Institutional Development, Research and Innovation (grant no. B05F640197 and B39G660029).

The ASEAN IVO (http://www.nict.go.jp/en/asean_ivo/index.html) project, Research and development for precise positioning with Artificial Intelligence (AI) during ionospheric disturbances in low-latitude region in ASEAN, was involved in the production of the contents of this work and financially supported by NICT (http://www.nict.go.jp/en/index. html).

# Thanks!

GNSS and Space Weather Information Center:

Center of Excellence in GNSS and Space Weather:

http://iono-gnss.kmitl.ac.th