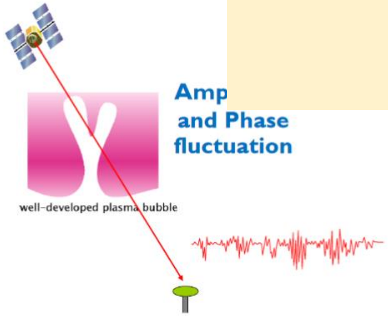
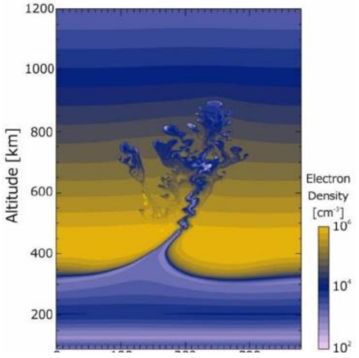
United Nations Workshop on
the International Space Weather Initiative
Vienna, Austria
26 – 30 June 2023

Equatorial Plasma Bubble (EPB) Observations at Low Latitude Regions of ASEAN





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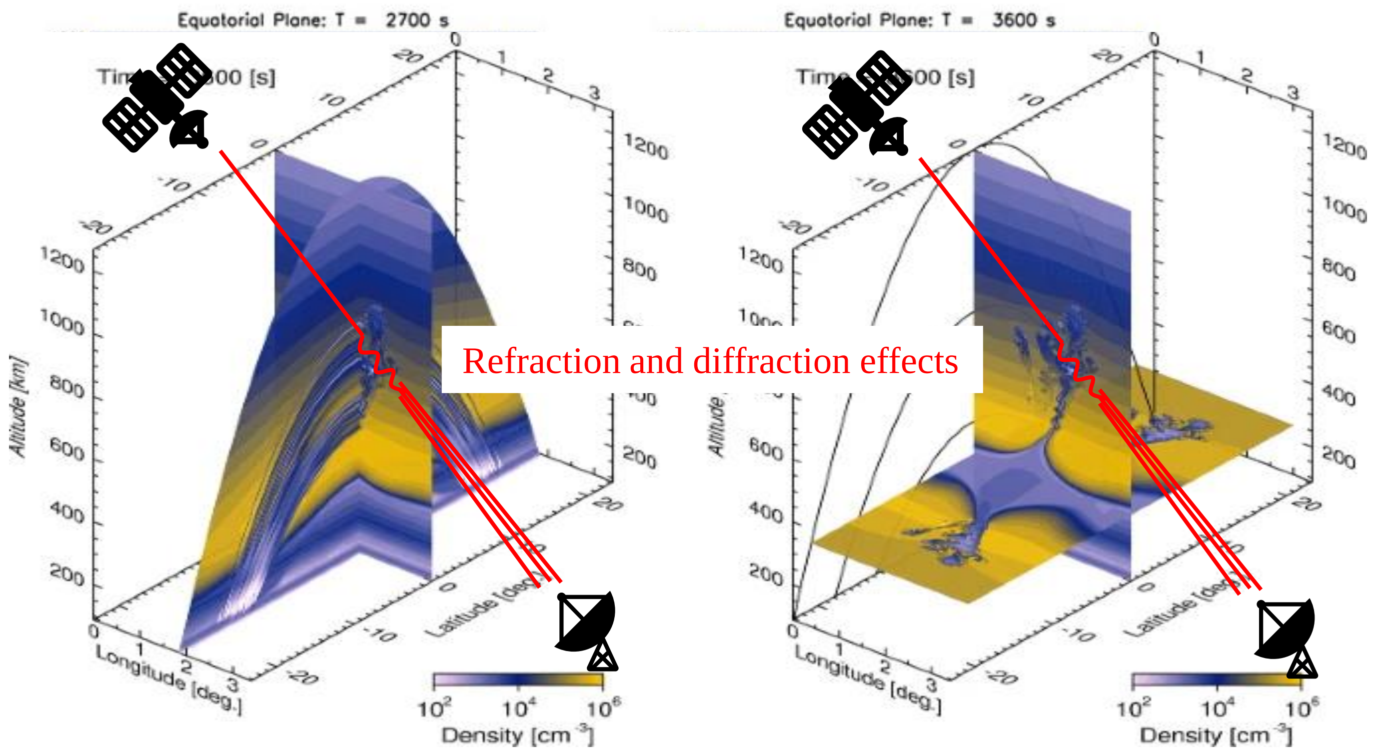
School of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand, National
National Institute of Information and Communications Technology, Koganei, Tokyo, Japan

CONTENT

- Background and Motivation
- Methodology
- Results and Discussion
  - Observations of EPB in Oct 2022
  - Summary of EPB occurrence in 2021 and 2022
- Conclusion

Equatorial Plasma Bubble (EPB)

- **The ionosphere** is the ionized layer of the earth's atmosphere, the important layer for vital technologies in our daily life such as radio and satellite communication, navigation, aviation, etc.

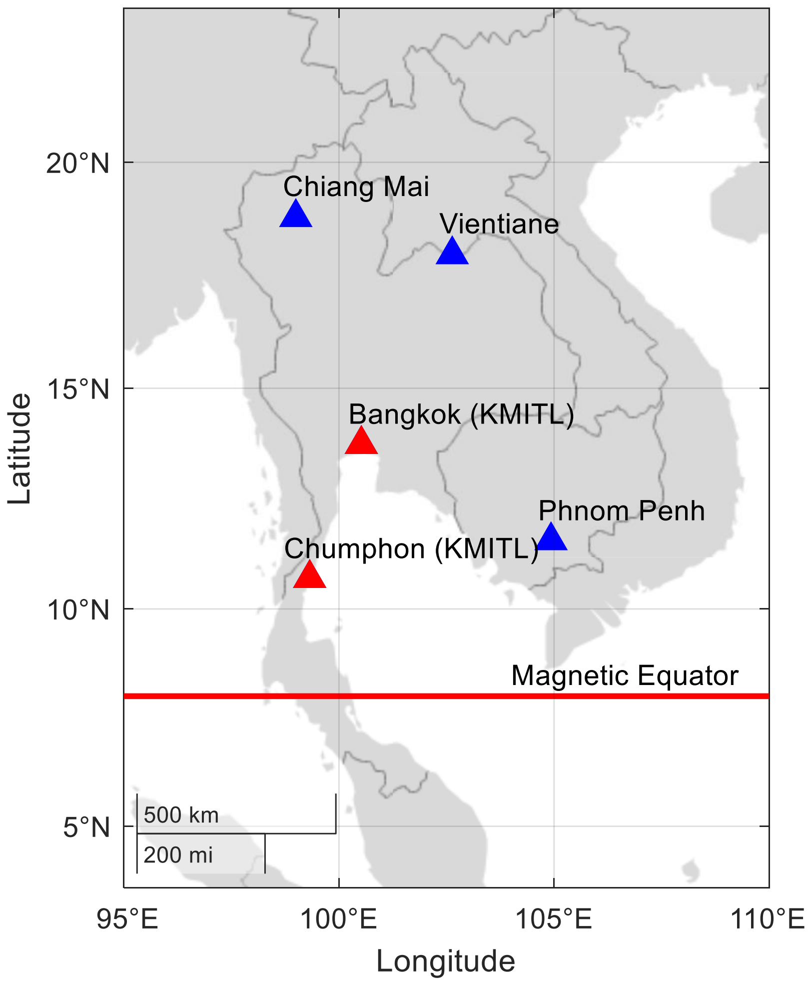


Credit: Yokoyama et al. (2014, 2015)

Equatorial Plasma bubble or a localized electron density depletion in the ionosphere,

- ✓ Origins at the bottom-side of the F region through the Rayleigh-Taylor instability after sunset.
- ✓ Generates ionospheric irregularities
- ✓ Elongate to higher latitude through the geomagnetic field lines.
- ✓ Impact on the technologies using satellite communications and navigations.

Background and Motivation



- ✓ Studying EPBs at the magnetic equator and low-latitude regions is crucial.
- ✓ KMITL's two campuses: Bangkok (the capital of Thailand) and Chumphon, near the magnetic equator.
- ✓ has been studying EPB and equatorial ionosphere characteristics based on data from various sensors instruments since 2003.
- ✓ Collaborated with many domestic and international institutes.
- ✓ Center of Excellence in GNSS and Space Weather at KMITL

SEALION Project (since 2003)

- SEALION is an ionospheric observation network in Southeast Asia conducted by NICT, Japan, and five ASEAN countries
- to monitor equatorial ionospheric disturbances, especially plasma bubble that poses a big impact on radio waves.
- SEALION is one of few observation bases in the world that is unique in having the conjugate observational points in the northern and southern hemispheres and around the magnetic equator

https://aer-nc-web.nict.go.jp/sealion/

- ❖ King Mongkut's Institute of Technology Ladkrabang (KMITL),
- ❖ Chiang Mai University (CMU)
- ❖ National Institute of Aeronautics and Space of Indonesia (LAPAN),
- ❖ Institute of Geophysics, Vietnam Academy of Science and Technology (IGP-VAST)
- ❖ University of San Carlos (USC)
- ❖ Kyoto University
- ❖ Rajamangala University of Technology Isan (RMUTI)
- ❖ National University of Laos (NUOL)

Research Facilities for Ionospheric Study

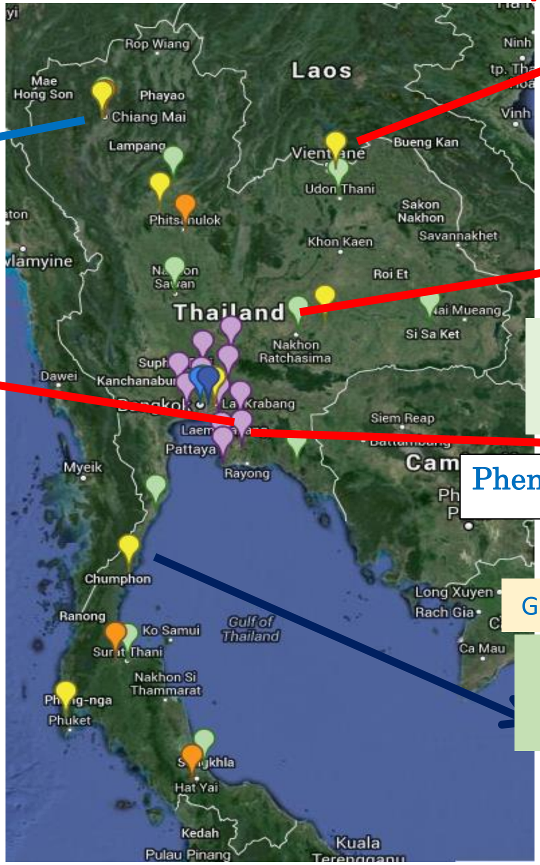
Various types of instruments

Ionosonde
GNSS receiver
Beacon receiver

Chiangmai (CHM)

Bangkok (STFD)

GNSS receiver



Vientiene (Laos)

GNSS receiver

Nakhon Ratchasima (NKR)

GNSS receiver

Bangkok (KMITL)

GNSS receiver
Beacon receiver

GNSS receiver

Chumphon (CPN)

GNSS receiver
Beacon receiver
VHF radar

CEGSW, KMITL

GNSS receivers

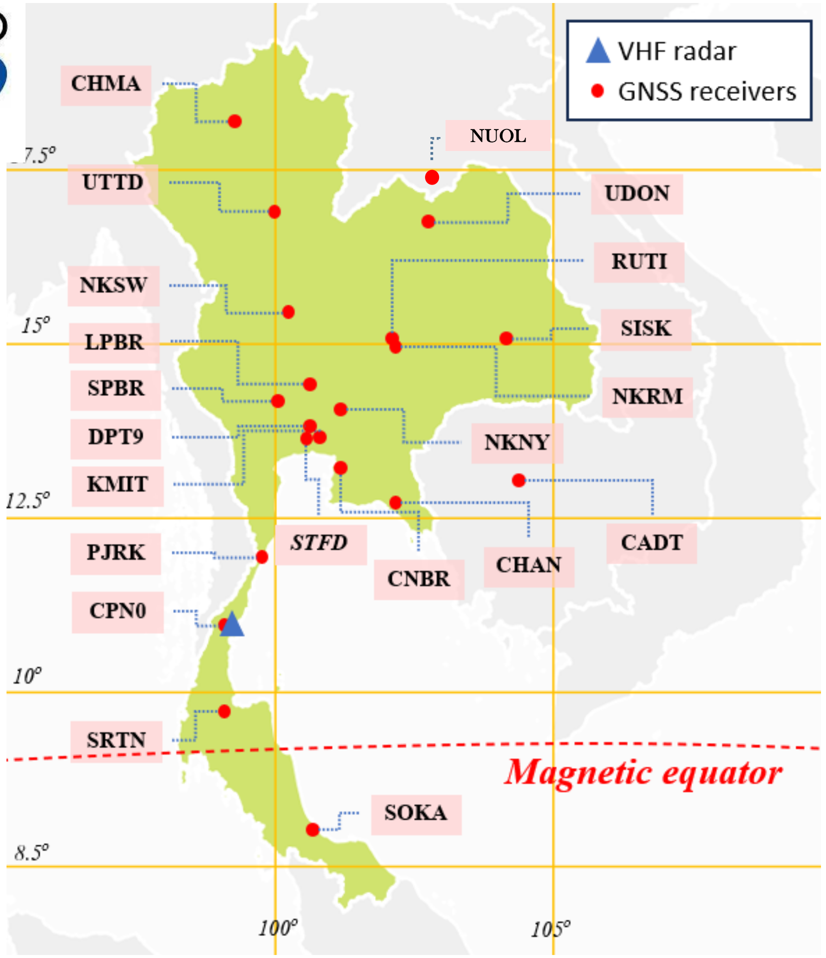
VHF radar station

Optical Sky Imager

Ionosonde

EPBs Observation System using GNSS

GNSS Station Network



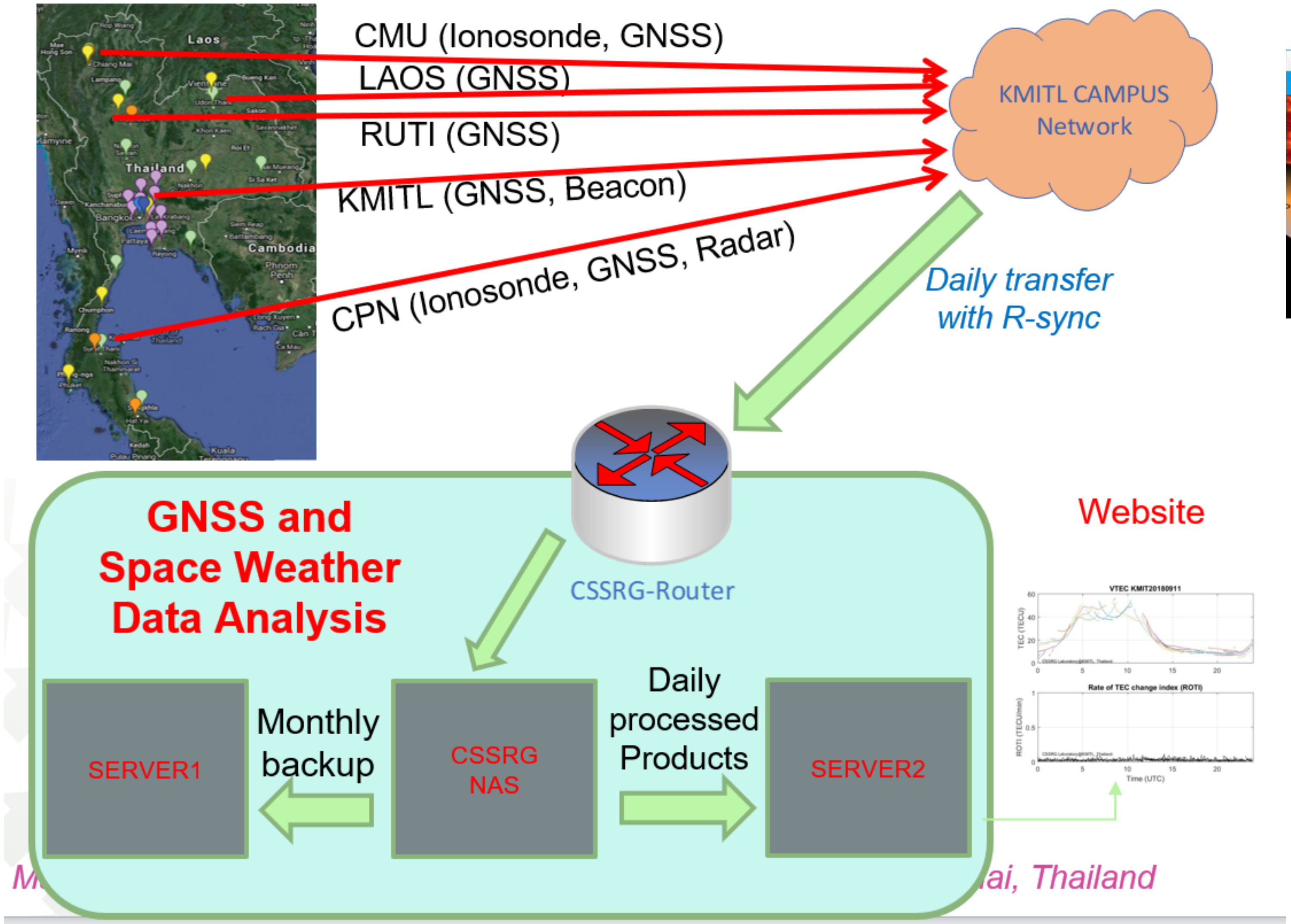
an observation system on EPB with Global Navigation Satellite System (GNSS) data from multiple receiver stations located near the magnetic equator and in low latitudes of ASEAN region, Thailand, Lao and Cambodia.

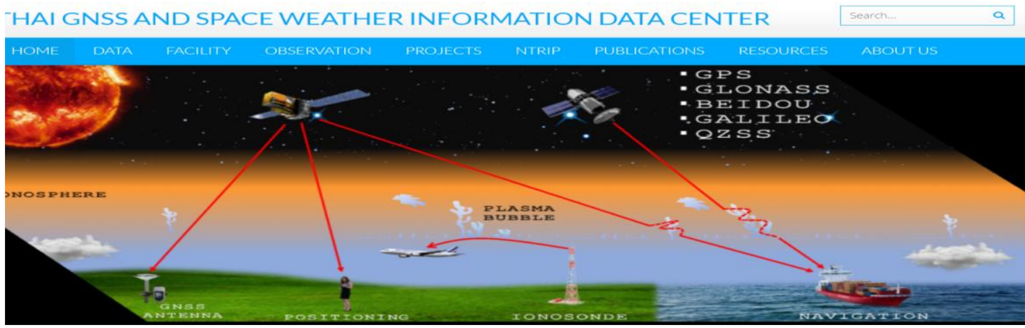
- The GNSS receivers in this study

❑ From the Excellence Center on GNSS and Space Weather (ECGSW), KMITL collaborated with the National Institute of Information and Communications Technology (NICT), Japan, the Chiang Mai University (CMU) the the National University of Laos (NUOL), and the Cambodia Academic of Digital Technology (CDAT).

❑ From the Department of Public Works and Town & Country Planning (DPT), Thailand.

Data Collection and Analysis





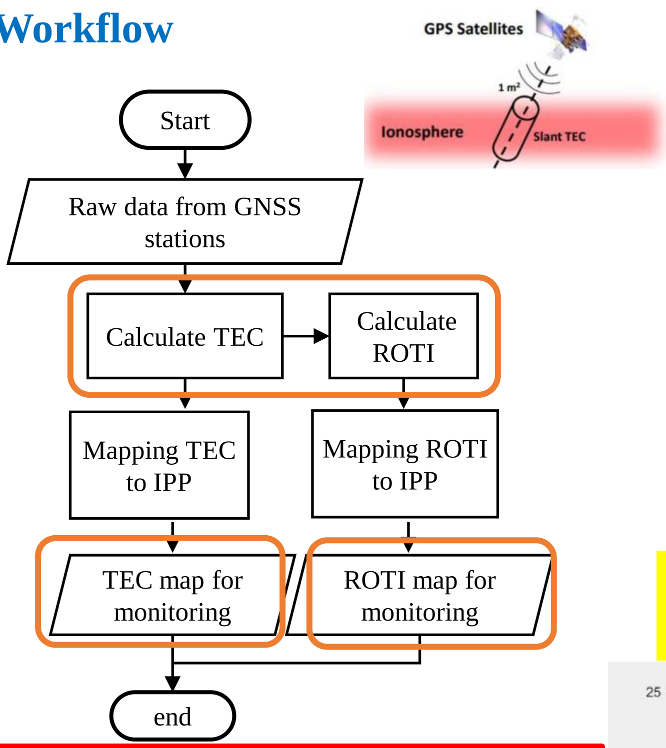
Daily Maps and Plots can be observed at KMITL's Excellence Center GNSS and SW http://iono-gnss.kmitl.ac.th/?page_id=807

EPB Observations using TEC Maps

Ionospheric Parameters

- ❑ Total electron content (*TEC*) is the total number of electrons integrated between the satellite and ground receiver.
- ❑ TEC is significant in determining the scintillation and delays of a radio wave through ionosphere.
- ❑ The Rate Of TEC Index (ROTI) is TEC's variation
- ❑ ROTI is used to characterize ionospheric disturbances due to plasma bubbles.
- ❑ TEC and ROTI are important for GNSS positioning and SW observation.

Workflow

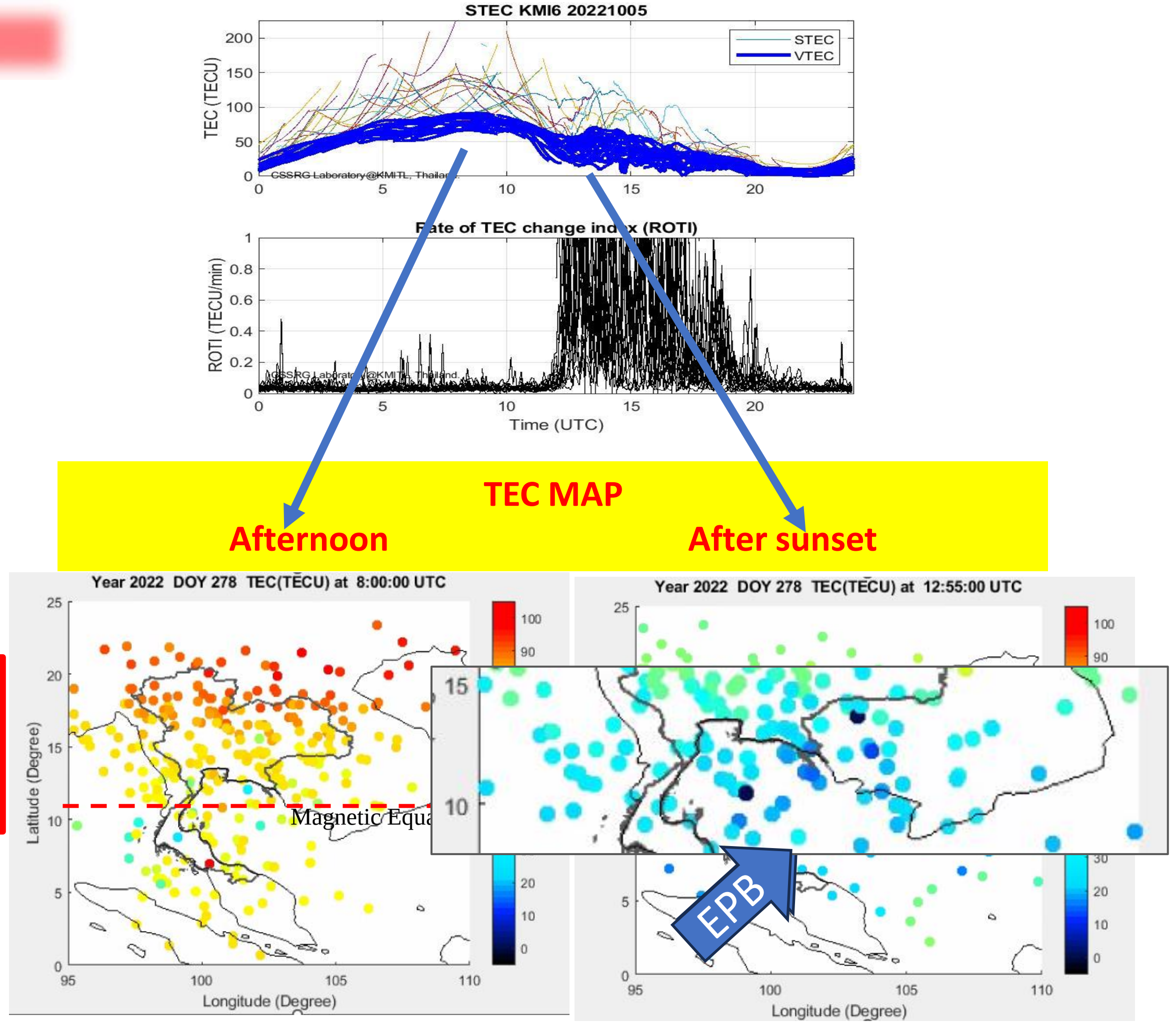


Analyze EPB occurrences using plots/maps compared with other parameters such as Kp, Solar flares

$$ROTI = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(ROT(i) - ROT)^2}$$

$$ROT(i) = STEC(i+1) - STEC(i)$$

TEC and ROTI at Each Station



EPB Observations using ROTI Maps

Ionospheric Parameters

- Total electron content (*TEC*) is the total number of electrons integrated between the satellite and ground receiver.
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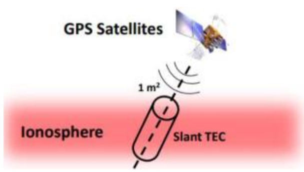

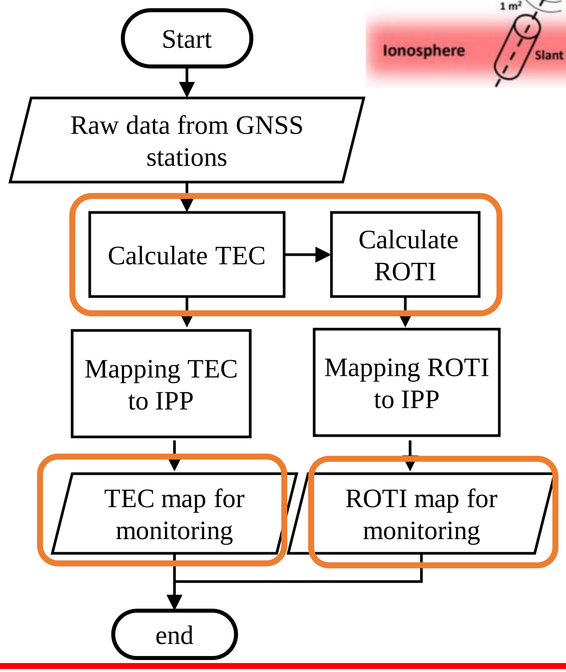

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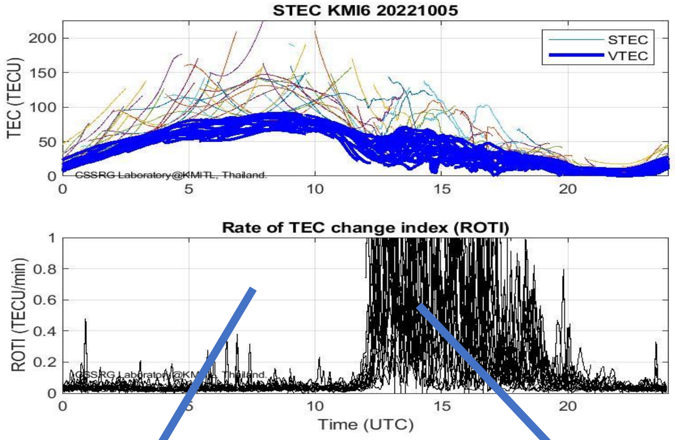
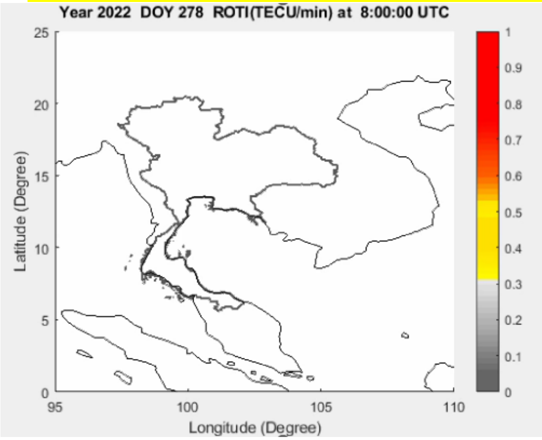
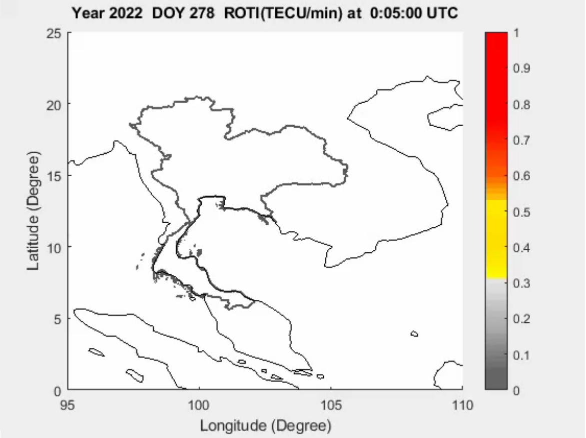
TEC and ROTI at Each Station



ROTI MAP

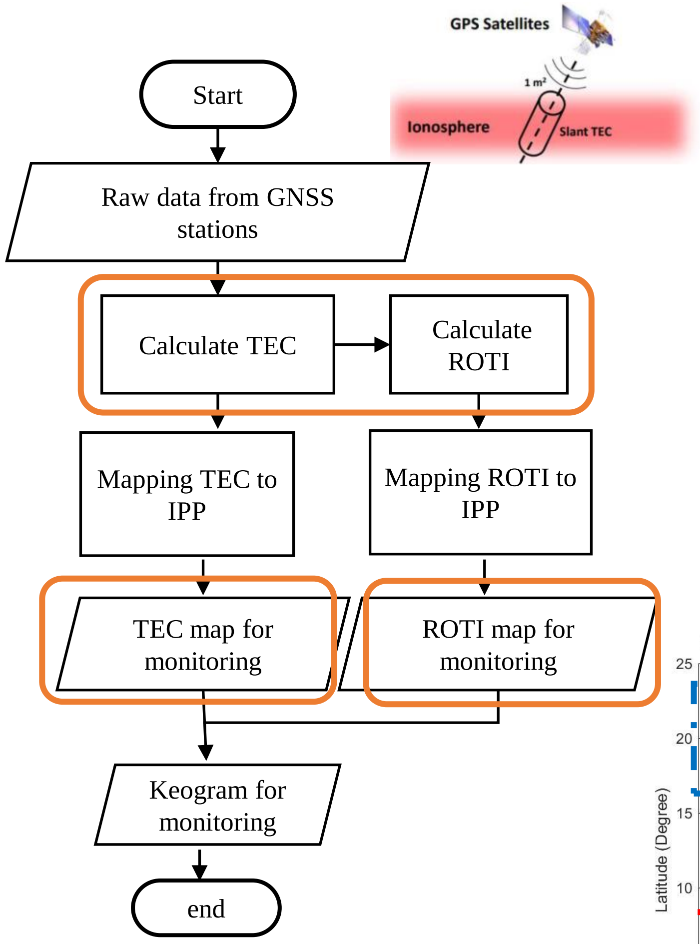
Afternoon **After sunset**





Observations using Keograms

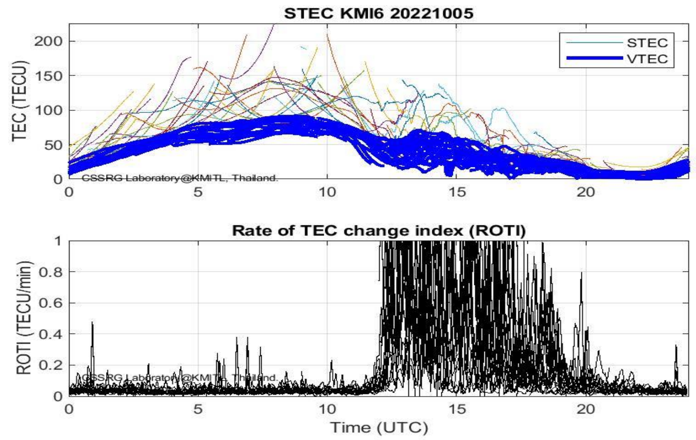
Workflow



ROTI KEOGRAM

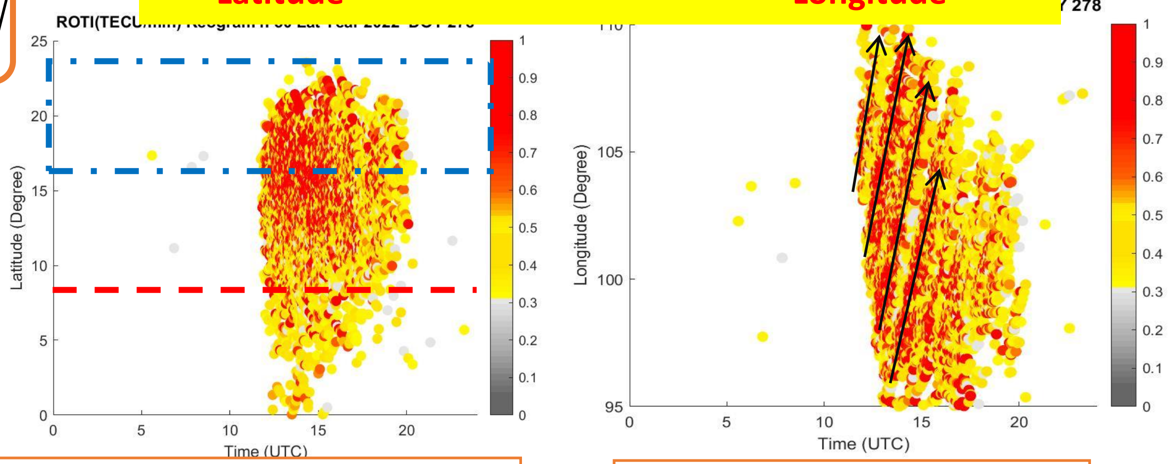
- ❑ the projections of vertical TEC values at each latitude/longitude against the time variable.
- ❑ are very helpful in monitoring the development of EPBs in their lifetime.

TEC and ROTI at Each Station



ROTI Keogram

Latitude **Longitude**



higher disturbances at higher latitudes

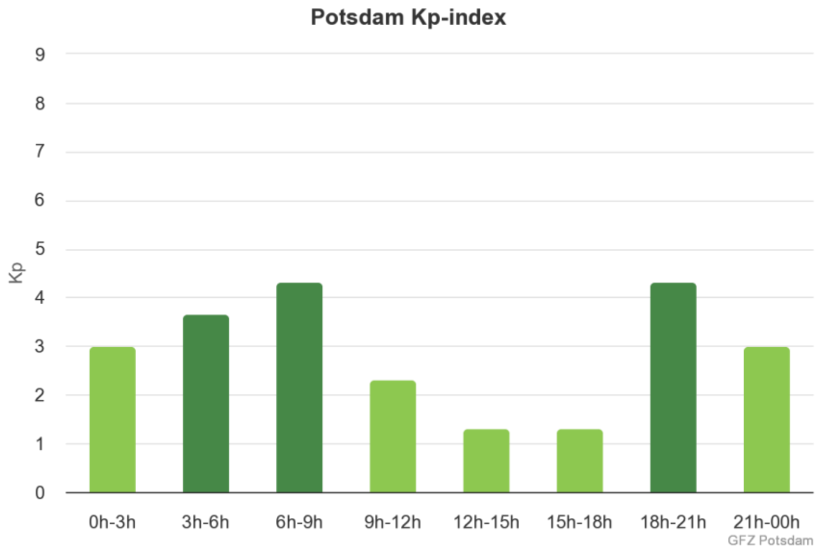
Forecast the EPB movement (Δlong/Δlat) = speed

Observation of EPB event on 4th October 2022

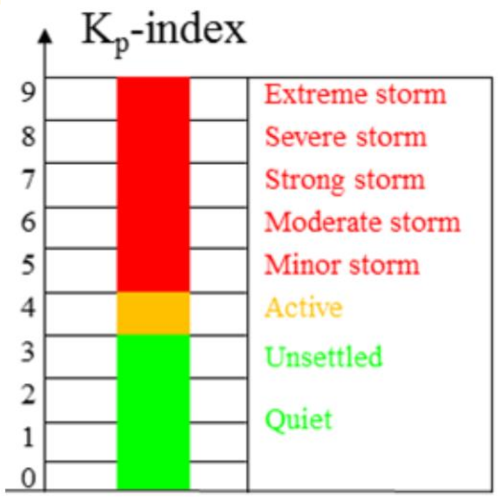
- solar and magnetic active day.

©NOAA SWPC - SpaceWeatherLive.com

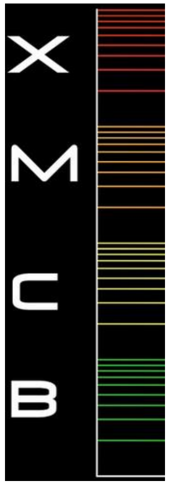
Sunspot number	New regions	Background flux	Maximum flux	C
153 ↑9	0 ↓-3	C1.14	M1.61	5



Credit: https://www.spaceweatherlive.com/



solar flare



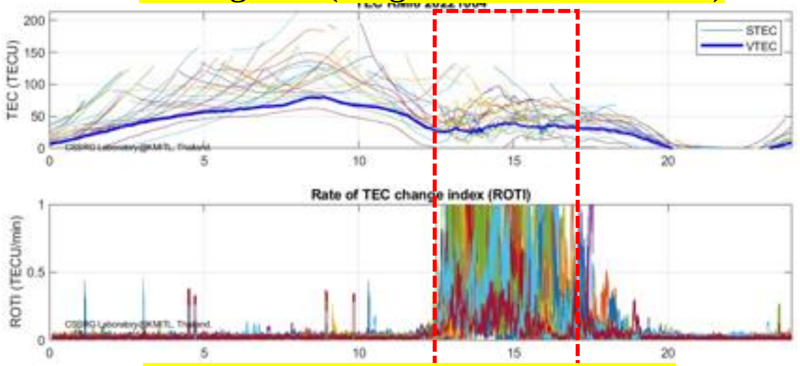
Solar flares

Region			Start	Maximum	End
3112	C4.4		00:37	00:43	00:56
3112	C2.1		04:21	04:27	04:31
3112	C1.6		05:24	05:32	05:39
3110	C2.5		12:25	12:44	12:48
3110	M1.6	1 2 3	12:48	13:15	13:51
3110	C1.5		19:26	19:36	20:02
3112	C1.5		22:47	22:56	23:12

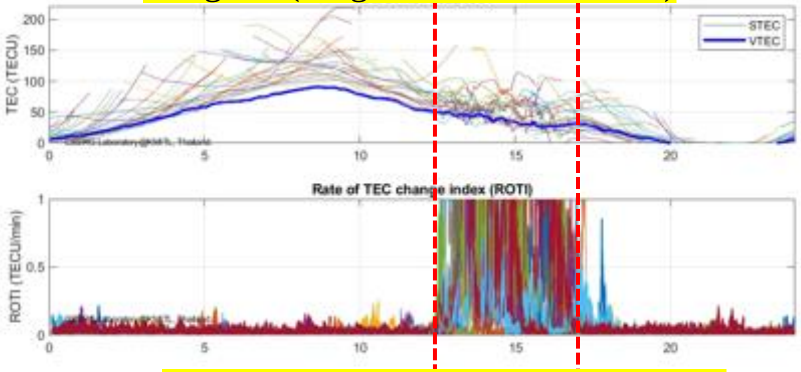
TEC/ROTI 1-D Plot Observations on 4th October 2022

Different TEC's characteristic and disturbed period at each station.

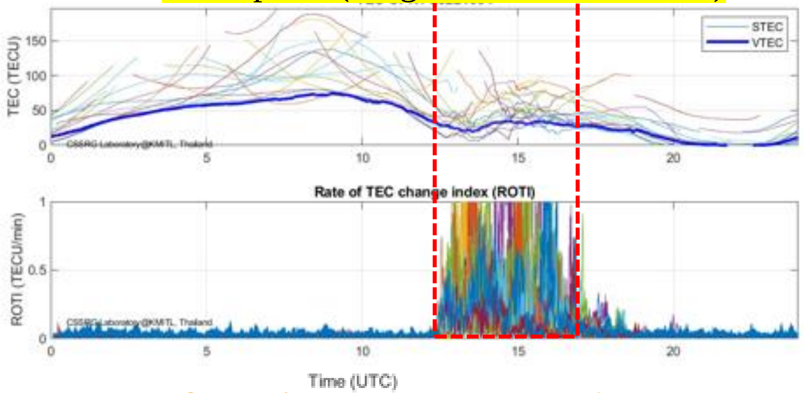
Chiang Mai (Mag.:12.72°N, 171.96°E)



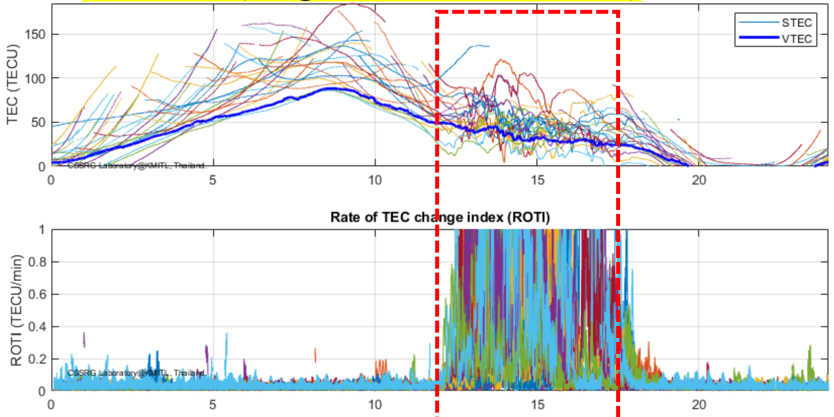
Bangkok (Mag.:7.42°N, 173.36 °E)



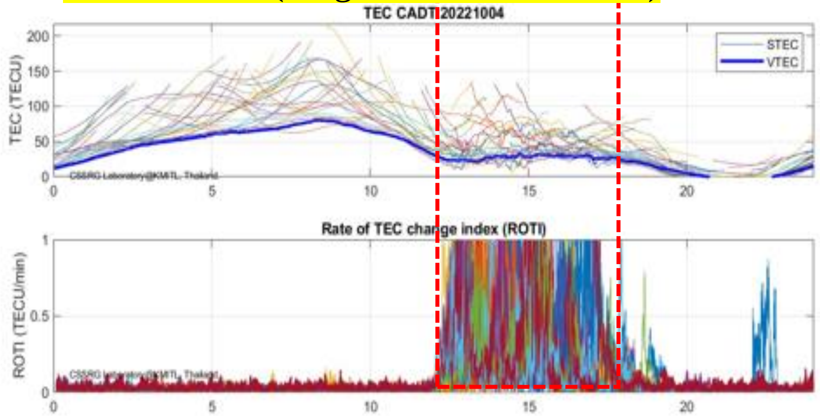
Chumphon (Mag.:3.92°N, 171.94 °E)

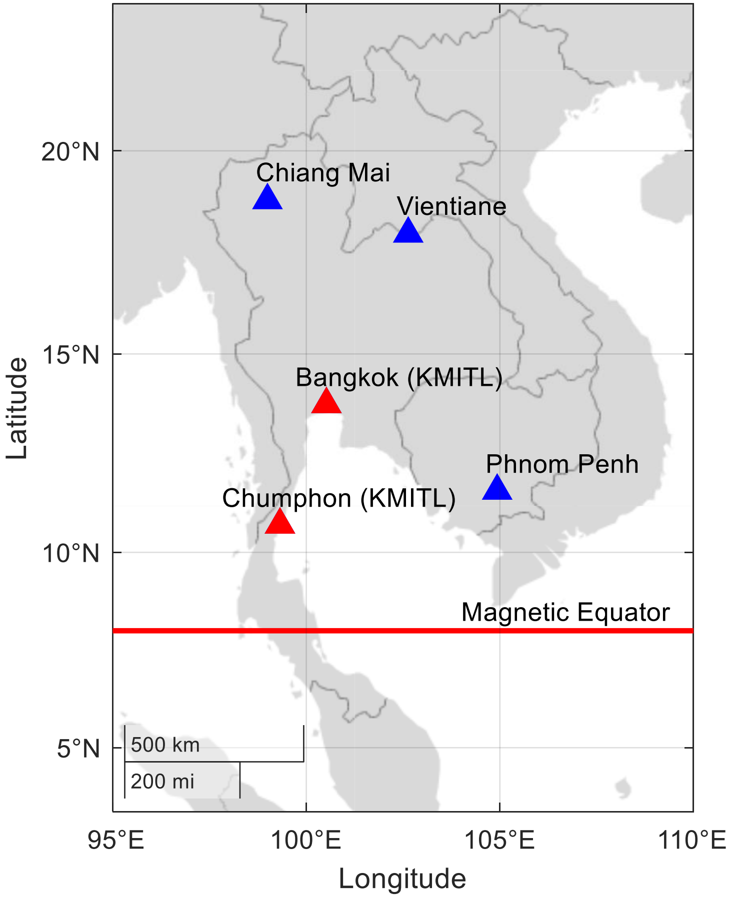


Vientiane (Mag.:12.02°N, 175.56 °E)



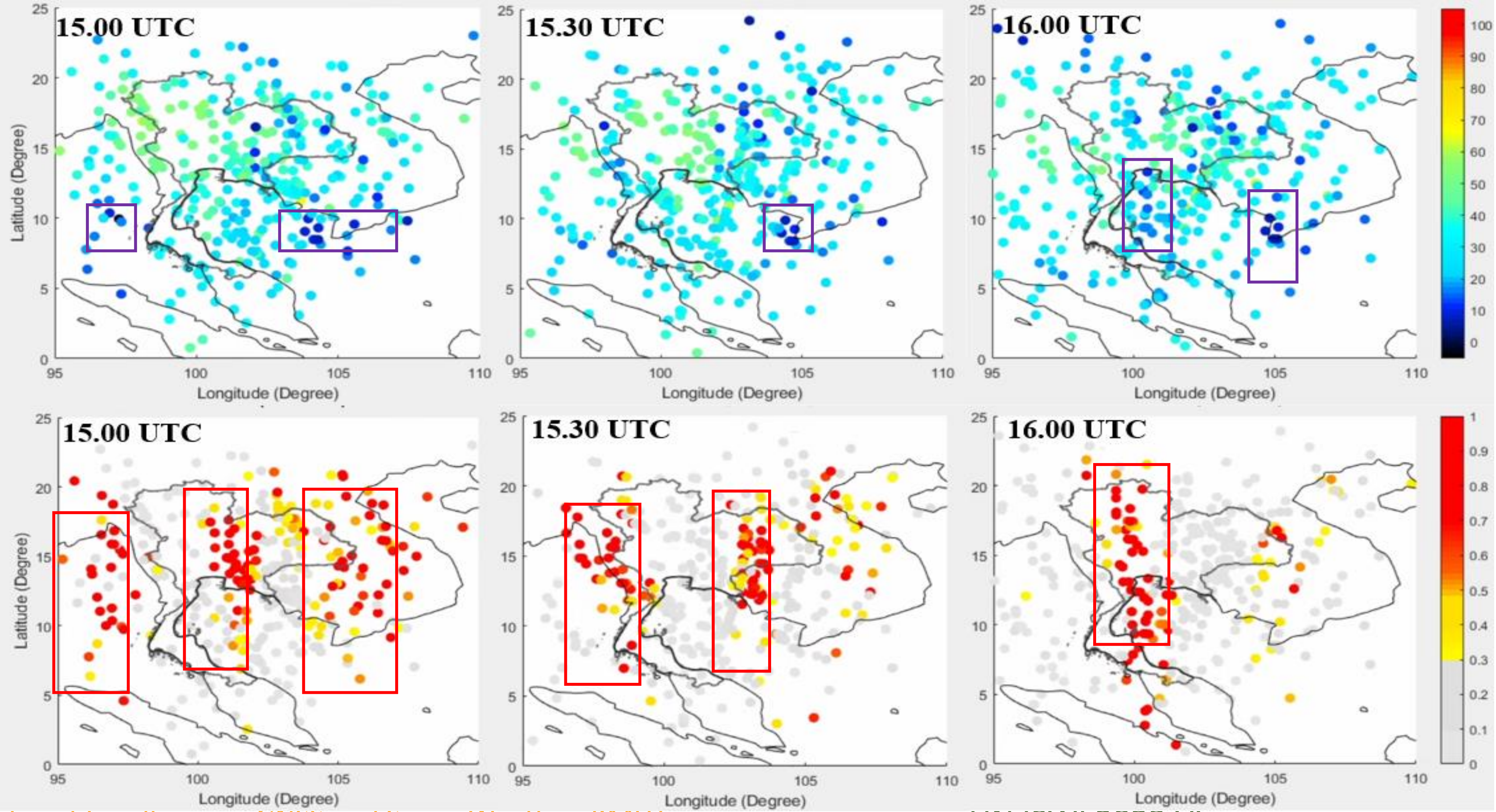
Phnom Penh (Mag.:5.12°N, 177.69 °E)



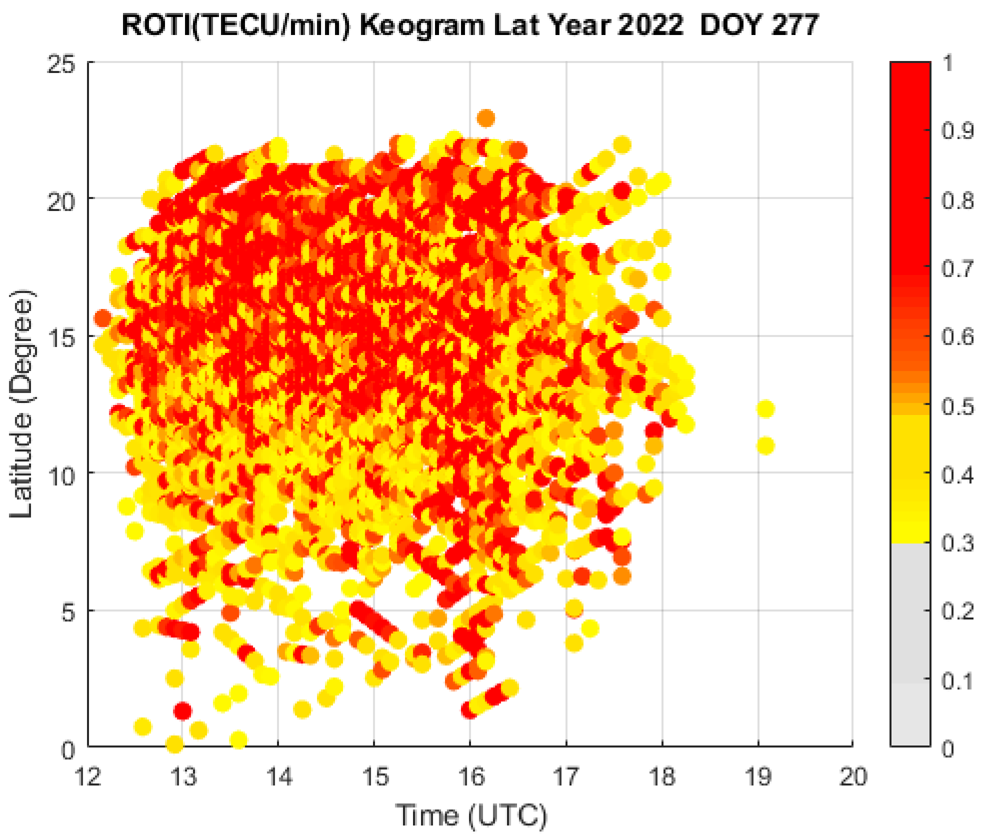


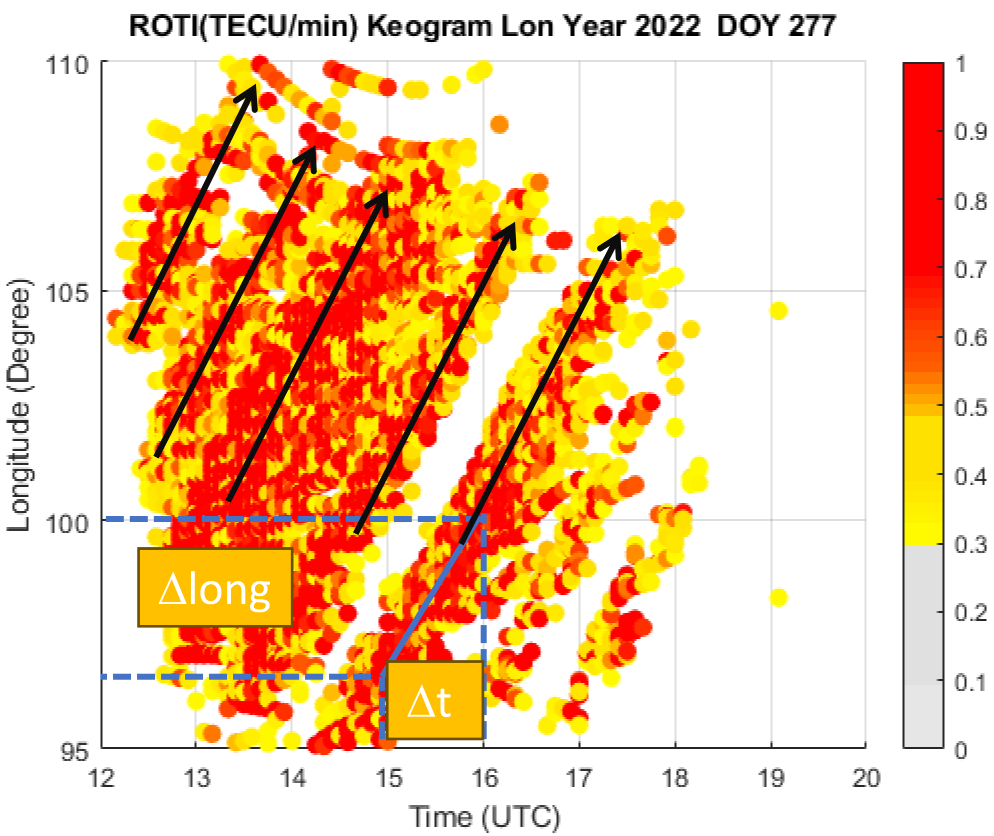
TEC/ROTI Maps Observations on 4th October 2022

TEC depletion, but not significant; however, disturbances are observed



ROTI KEOGRAM from 4th October 2022





Low ROTI value at near magnetic equator mostly, but higher value at higher latitude

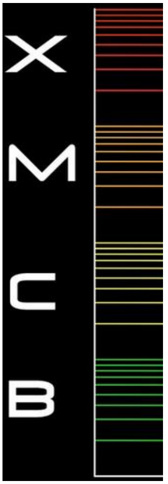
Various EPBs occurs at different longitudes, shifting to the eastward direction almost the same speeds

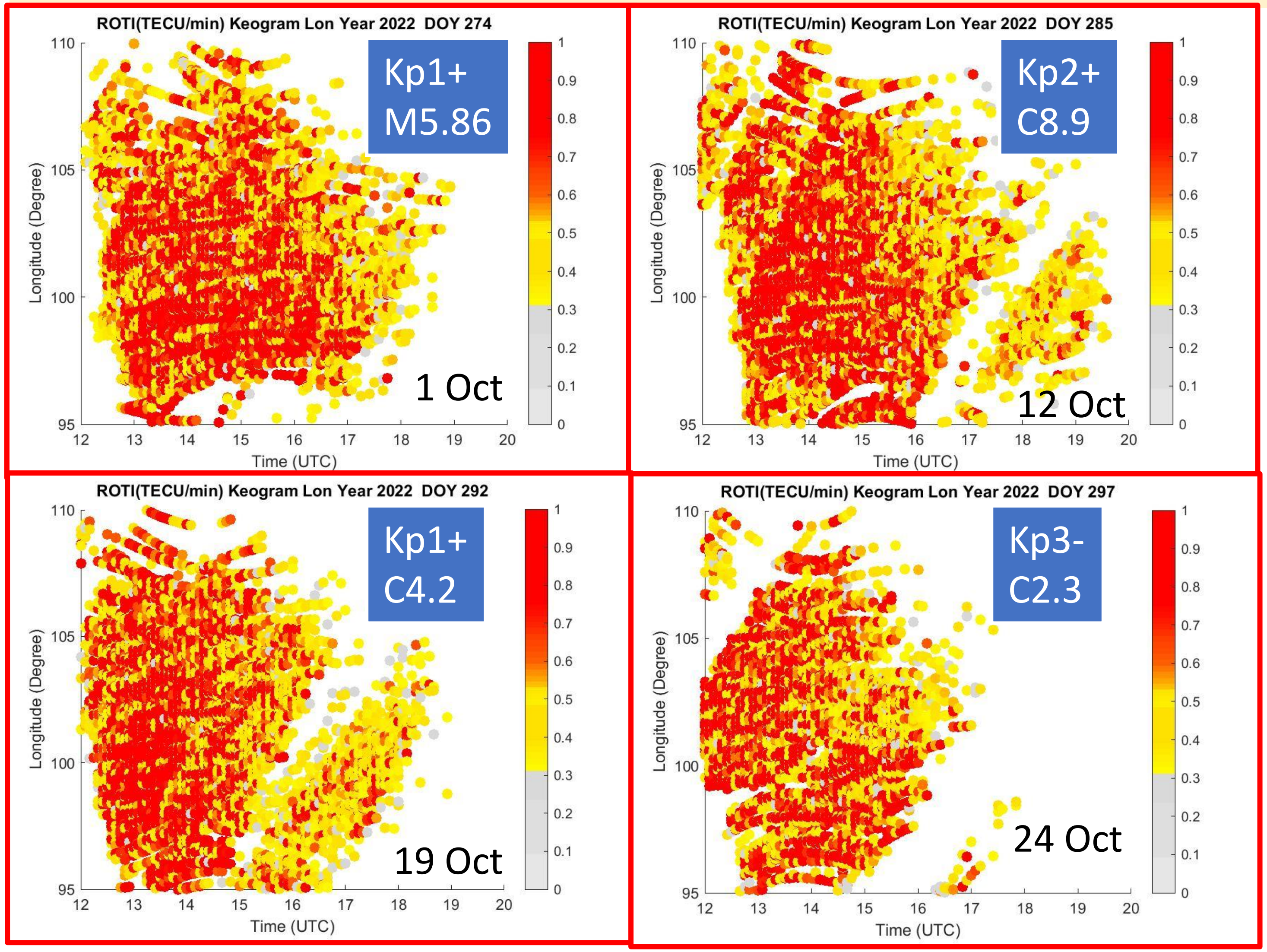
EPBs Observation in October 2022

- EPBs were observed almost everyday in October
- Different temporal and spatial structures of EPBs
- Occurrence of EPBs even in low Kp and solar flare
- Therefore, we are interested to study EPBs with
  - Large zonal width disturbances
  - Occurrences after mid night
  - Scattered

Large Zonal Width EPBs in October 2022

solar flare

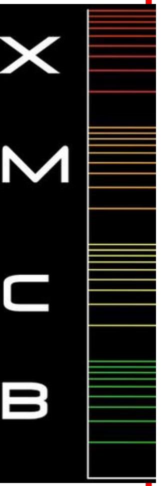


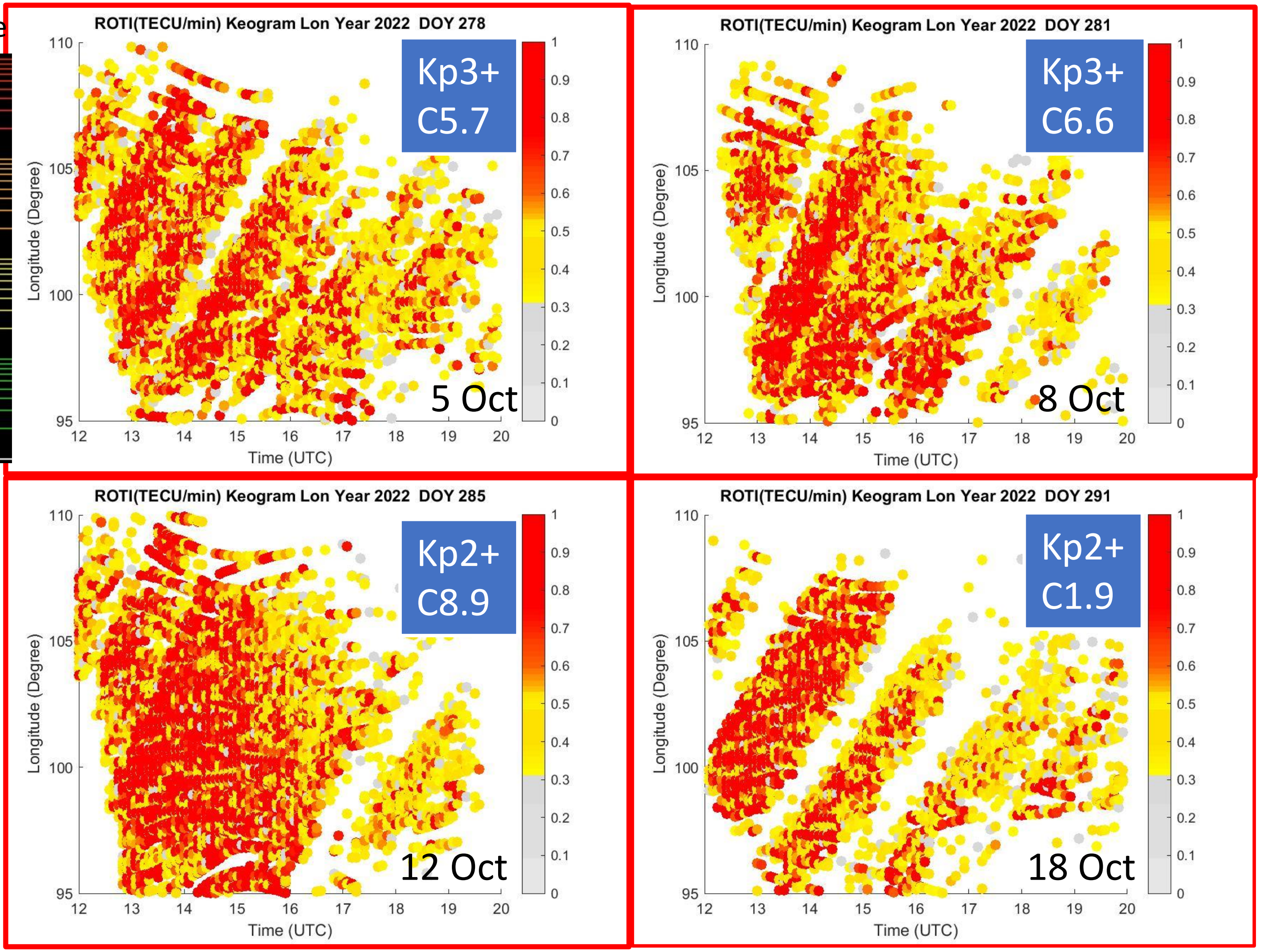


- Disturbances appears almost all longitudes.
- No easy identity separate EPBs
- Perceive that a large TEC depletion region occurs.

EPB Existence after Midnight in October 2022

solar flare

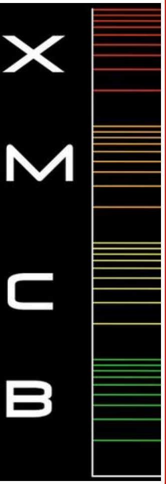


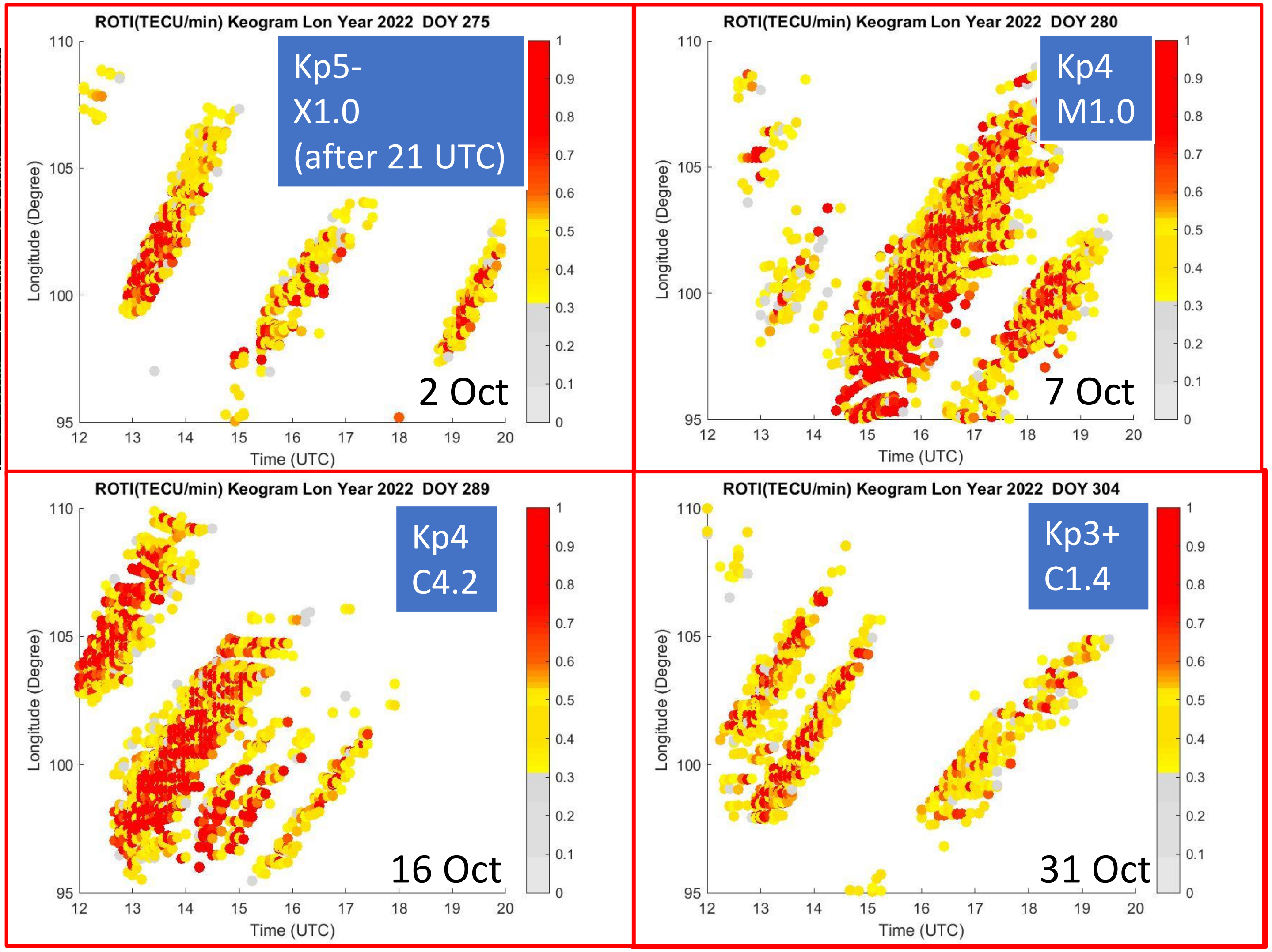


- EPB still exist after mid night
- EPB appears almost all longitudes.
- Can identity separation between EPBs in some events
- Can track EPB's movement

Scattered EPBs in October 2022

solar flare



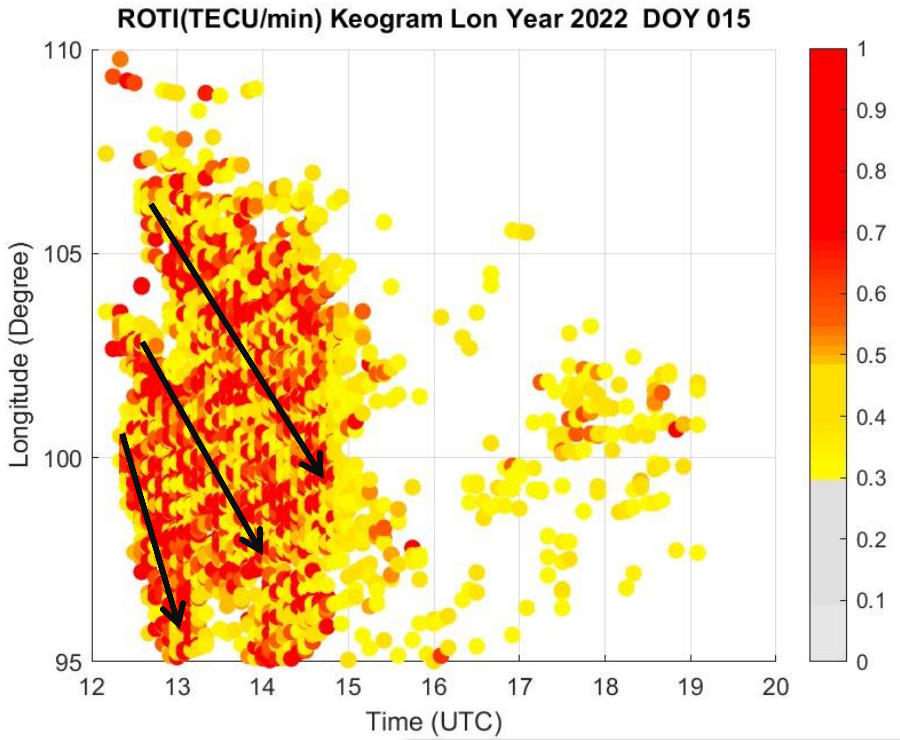


- EPBs occurs separate time and different longitudes.
- Can identity separation between EPBs in events
- Can track EPB's movement

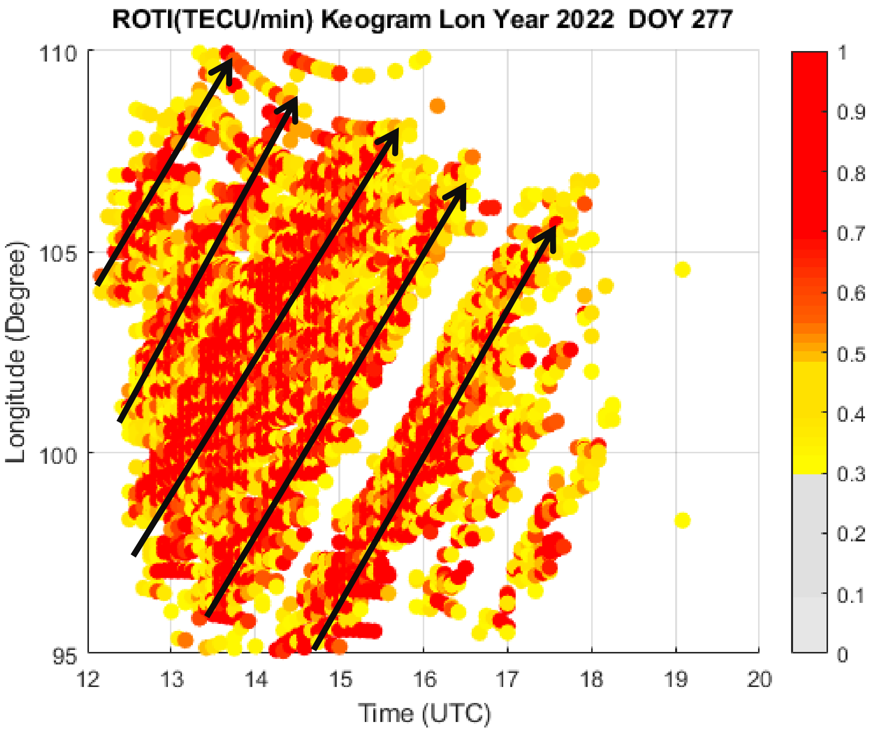
2022 Hunga Tonga Volcano

The volcanic eruption in Tonga on 15 January 2022 created waves in the upper atmosphere and impacted GPS across Australia and Southeast Asia.

Tonga Volcano Day (15th January 2023)

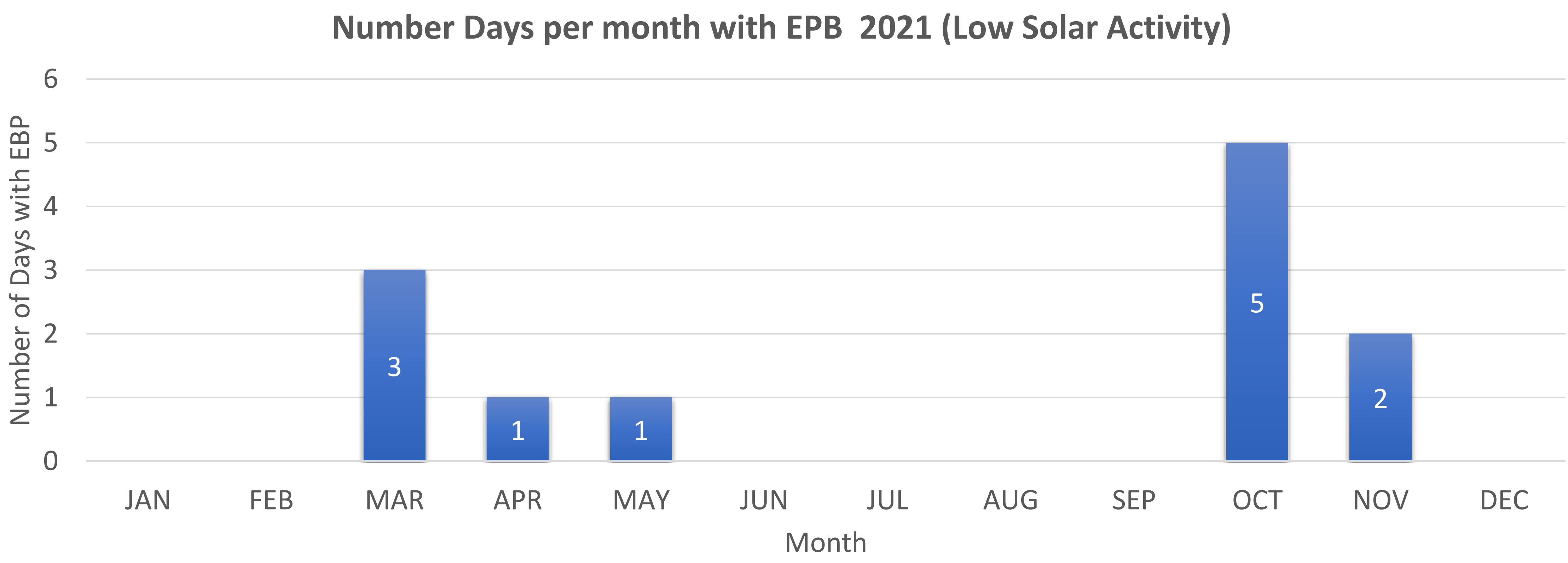


Normal Disturbed Day (4th October 2022)



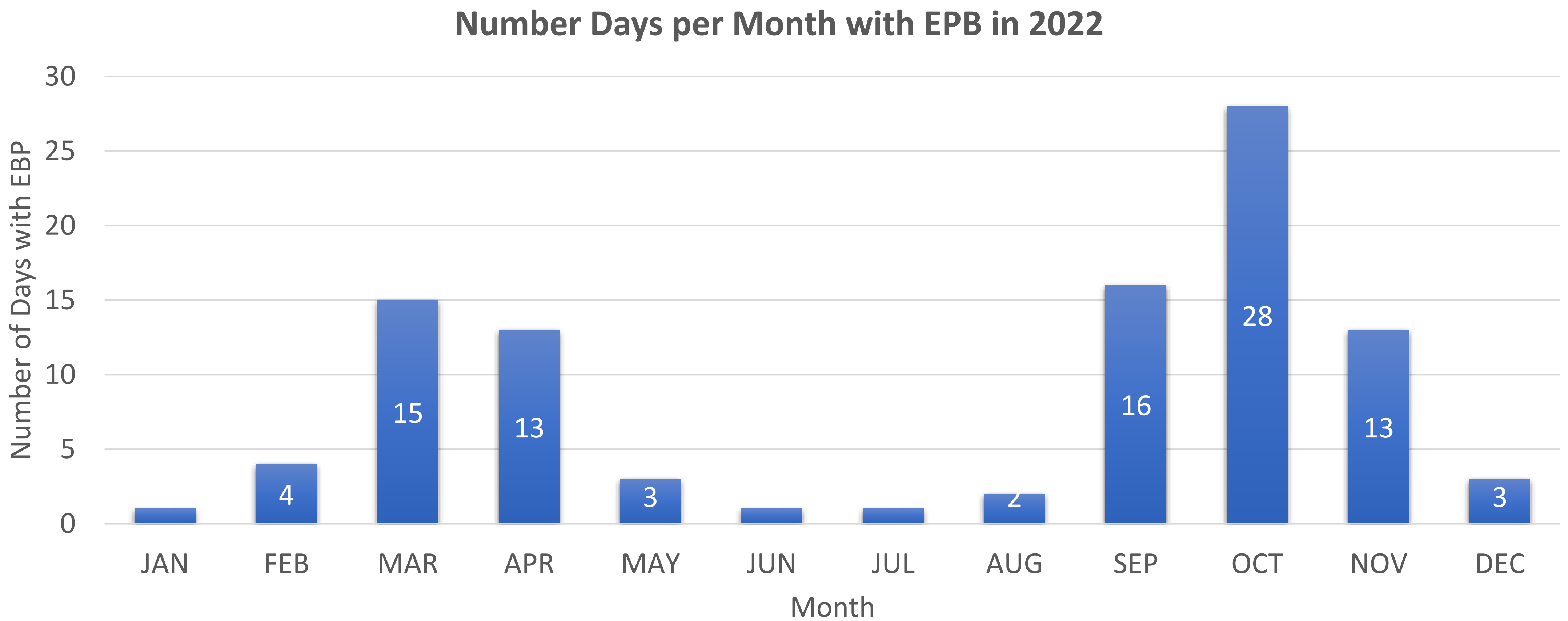
EPBs occurred for 4 hours and shifted toward west ward direction.

EPB Occurrences in 2021 in KMITL Station



EPB occasionally occurred in 2021 and the highest number of EPB occurred days with 5 is observed in October.

EPB Occurrences in 2022 in KMITL Station



EPB frequently occurred in 2022 and the frequent occurrence of EPB happened in equinox months.

Summary

- In this study, we examine the spatial and temporal changes of EPBs using the spatial ROTI map, latitudinal/longitudinal keogram plots developed from the GNSS receiver network in ASEAN's northern hemisphere low latitudes.
- According to the results, the location of the EPB can be detected by the spatial ROTI maps and their spatial-temporal variation is monitored using the keogram plots for forecasting their occurrence and movement.
- We planned to expand the coverage of the observation network into other ASEAN countries.
- We will analyze EPB images using AI and machine learning technique.

King Mongkut's Institute of Technology Ladkrabang (KMITL)

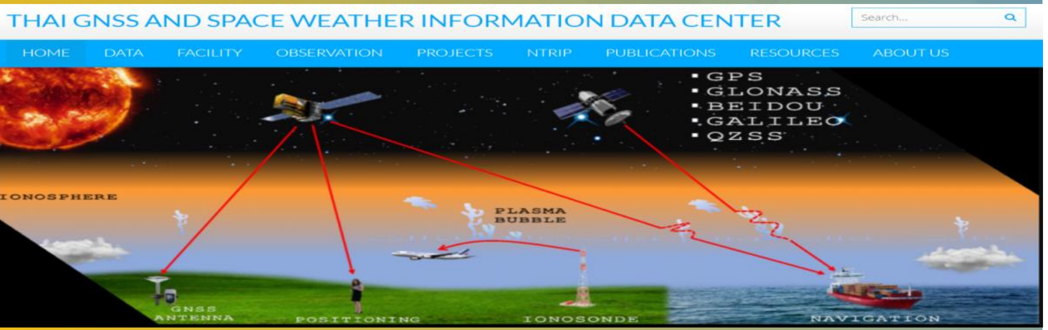
- One of top research and educational institutions in Thailand.
- Has about 8,000 (Inter/domestic) students studying in under/graduate programs.
- Has two campuses: Bangkok (capital of Thailand) and Chumphon which is near the magnetic equator.

Thanks!

GNSS and Space Weather Information Center:

Center of Excellence in GNSS and Space Weather:

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



Recent Publications from CEGSW, KMITL

- G.B. Soares, Y. Yamazaki, A. Morschhauser, J. Matzka, K.J.Pinheiro, C.Stolle, P. ALken, A. Yoshikawa, K. Hozumi, A. Kulkarni, P. Supnithi," Using Principal Component Analysis of Satellite and Ground Magnetic Data to Model the Equatorial Electrojet and Derive Its Tidal Composition," Journal of Geophysical Research: Space Physics, 127, 9, Sept. 2022. DOI: 10.1029/2022JA030691.
- N. Tongkasem, L.M.M.Myint, P. Supnithi, "Estimation of Ionospheric Delay using Standalone Single-Frequency observations," IEEE Access, vol. 10, pp. 103485-103495, 2022, doi: 10.1109/ACCESS.2022.3208102.
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- S. Sophon, P. Supnithi, L.M.M.Myint and S.Saito,"Performance Improvement of the GAGAN Satellite-Based Augmentation System Based on Local Ionospheric Delay Estimation in Thailand, " GPS Solutions, 2022. https://rdcu.be/cTIKT
- L.M.M. Myint, P. Supnithi, K. Hozumi and S. Saito, "Analysis of Local Geomagnetic Index Under the Influence of Equatorial Electrojet (EEJ) at the Equatorial Phuket Geomagnetic Station in Thailand ," Advances in Space Research, June 2022. https://doi.org/10.1016/j.asr.2022.06.024
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- T. Maruyama, K. Hozumi, G. Ma, P. Supnithi, N. Tongkasem and Q. Wan"Double-thin-shell approach to deriving total electron content from GNSS signals and implications for ionospheric dynamics near the magnetic equator," Earth, Planets and Space, 2021. https://doi.org/10.1186/s40623-021-01427-y. Download
- P. Kenpankho, A. Chaichana, K. Trachu, P. Supnithi, K. Hozumi, "Real-time GPS receiver bias estimation," Advances in Space Research, 2021, https://doi.org/10.1016/j.asr.2021.01.032.

Q/A