GNSS Observation and Space Weather Research in Thailand

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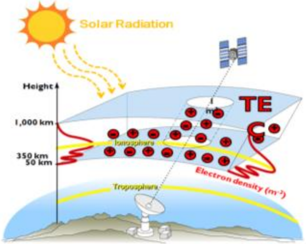
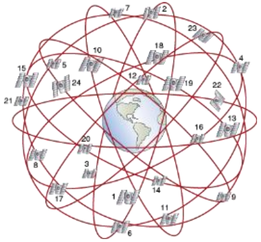
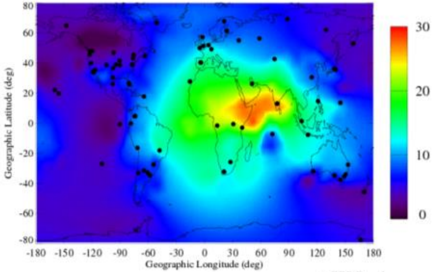
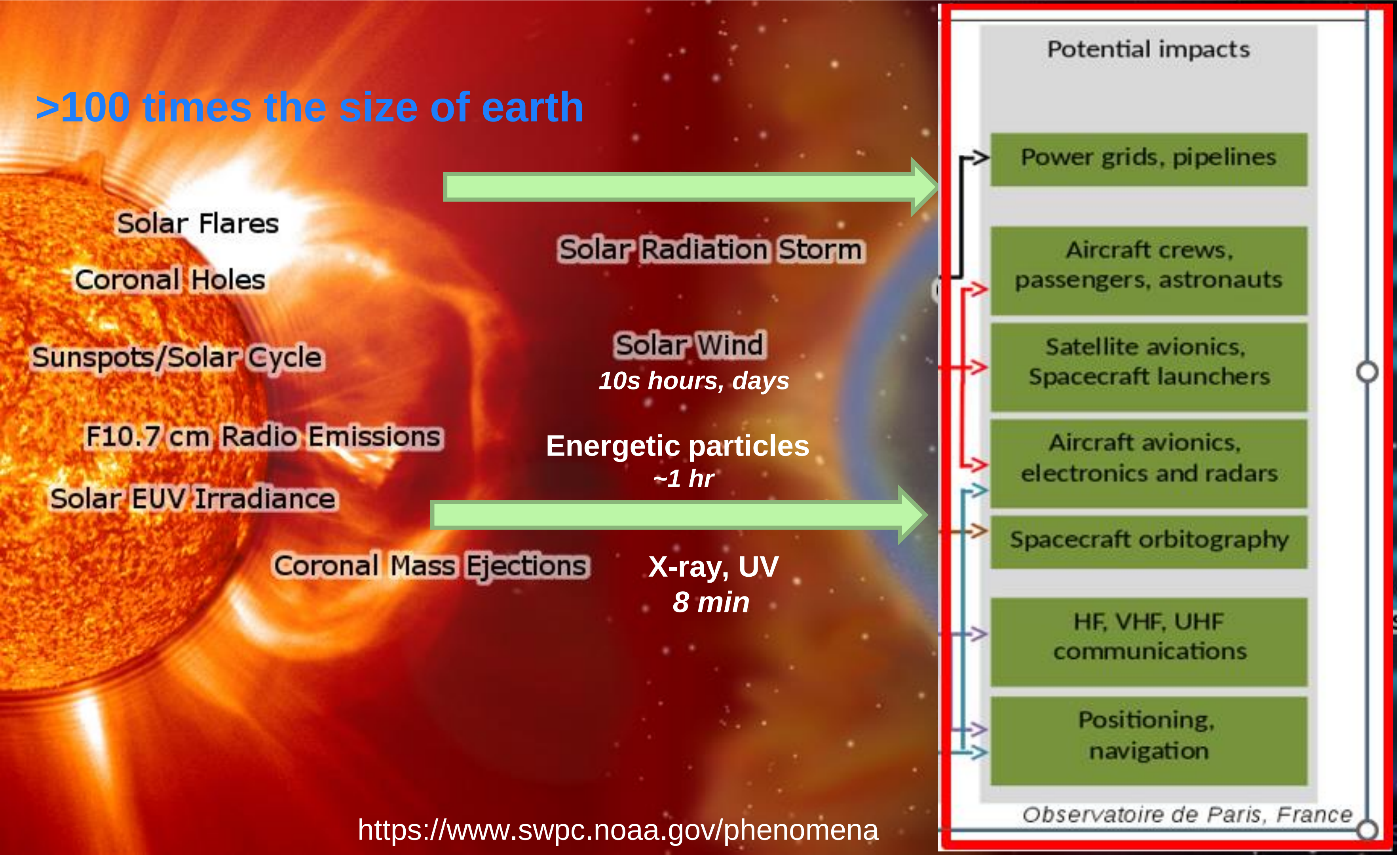






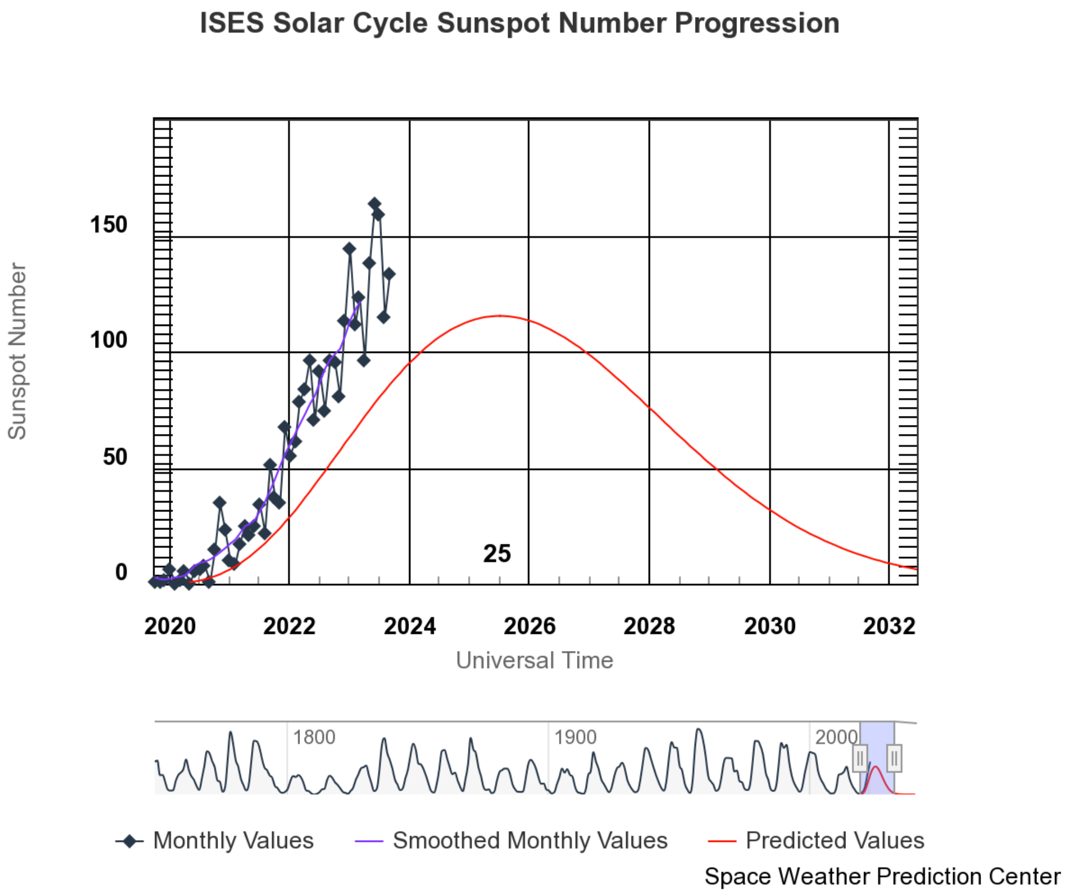
Center of Excellence in GNSS&Space Weather, KMITL



>100 times the size of earth
Solar Flares
Coronal Holes
Sunspots/Solar Cycle
F10.7 cm Radio Emissions
Solar EUV Irradiance
Coronal Mass Ejections
Solar Radiation Storm
Solar Wind
10s hours, days
Energetic particles
~1 hr
X-ray, UV
8 min
Potential impacts
Power grids, pipelines
Aircraft crews, passengers, astronauts
Satellite avionics, Spacecraft launchers
Aircraft avionics, electronics and radars
Spacecraft orbitography
HF, VHF, UHF communications
Positioning, navigation
Observatoire de Paris, France
https://www.swpc.noaa.gov/phenomena

Solar Cycles

We are entering
the solar maximum
(solar cycle #25)



https://www.swpc.noaa.gov/products/solar-cycle-progression

Space Weather Information Service - ICAO

Guidance on Crite…

3-Technical C…

a) Ability to provide the space weather information service, b… as defined in the draft SARPs for Amendment 78 of ICAO… International Air Navigation.

b) Ability to access observations (own observations and rec…
- Coronal mass ejections and high-speed streams
- Geomagnetic storms
- Solar radiation storms
- Solar flares
- Solar radio bursts
- Ionospheric activity

c) Ability to produce near real-time and forecast information… weather using numerical models capable of ingesting obs…

d) Ability to produce near real-time and forecast information… performance requirements.

e) Ability to coordinate and harmonize information with the s… adjacent areas of responsibility, as necessary.

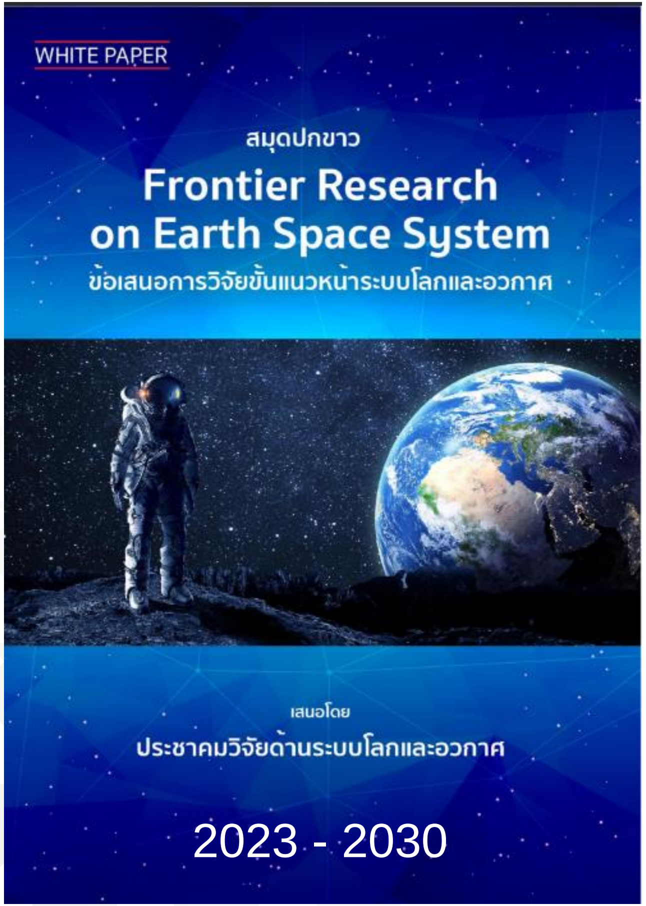
f) Ability to conduct forecast verification

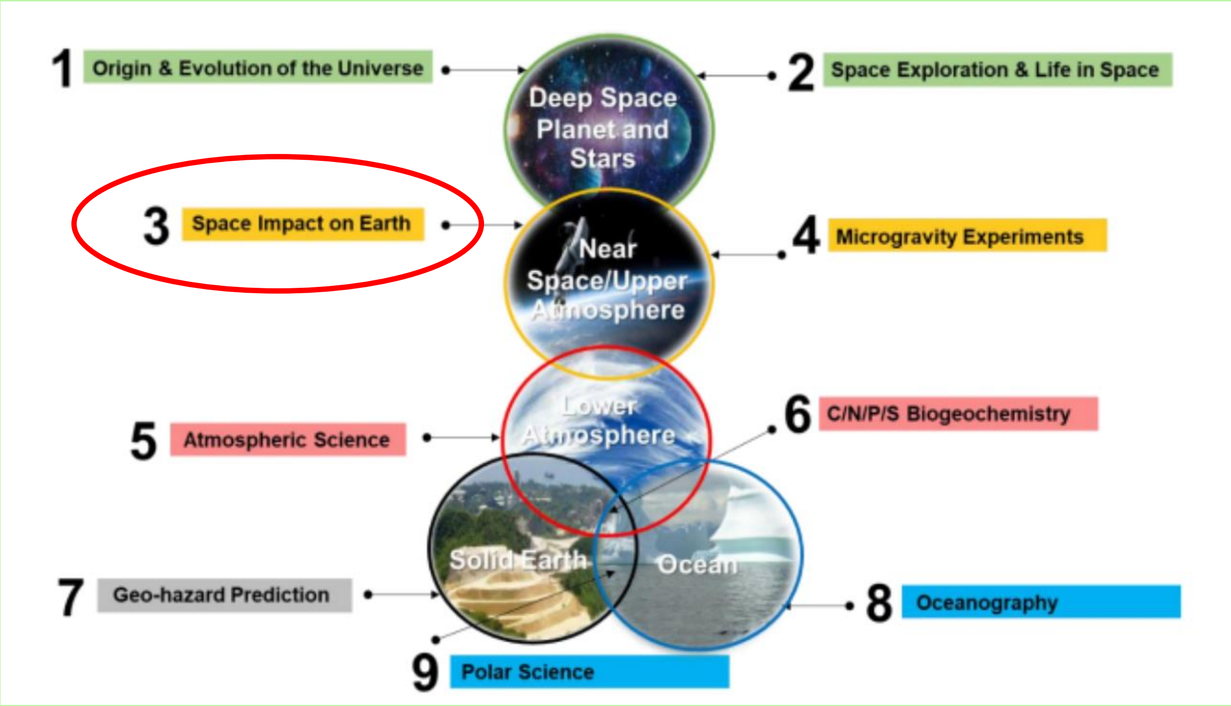
Services Within ICAO

- Services proposed for inclusion in Amendment 78 to Annex 3
  - HF Communications (propagation, absorption)
  - HF COM
  - Communications via satellite (propagation, absorption) SATCOM
  - GNSS-based navigation and surveillance (degradation) GNSS
  - Radiation at flight levels (increased exposure) RADIATION

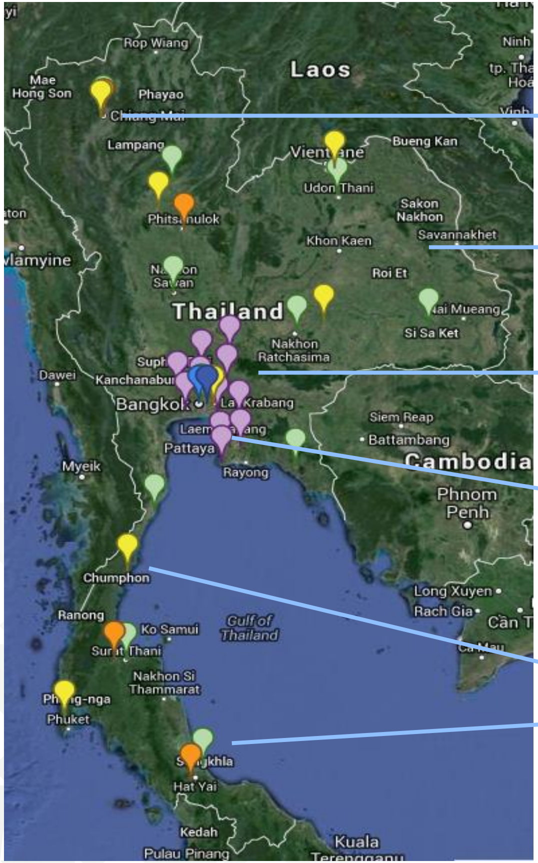
R. Romero, "Establishment of Space Weather Information Service for International Air Navigation," ***UN/USA Workshop on the International Space Weather Initiative, Boston, 31 July- 4 August 2017***.

9 focus themes





Universities/Institutes involved



CMU - Chiangmai University
NARIT - National Astronomical Research Institute of Thailand

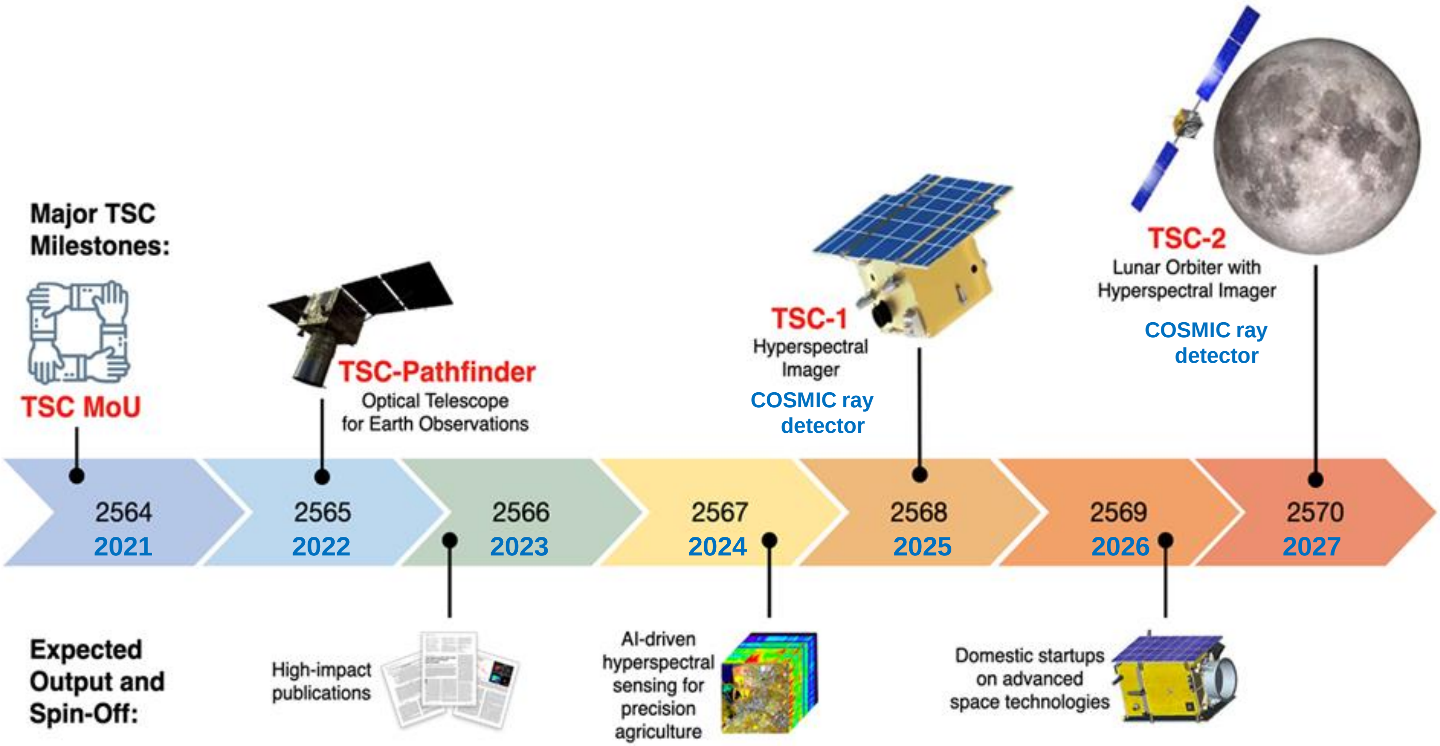
UBON - Ubonratchathani University
MSU - Mahasarakarm University

KMITL - King Mongkut's Institute of Technology Ladkrabang
MU - Mahidol University
RMUTT - Rajamangala University of Technology Thanyaburi
CU – Chulalongkorn Unviersity

Geo-Informatics and Space Technology Development Agency (GISTDA) ➔ **(future) Thailand Space Agency**

CPN – Chumphon campus, KMITL
SKU - Songklanakarin University

Thailand Space Consortium (TSC)

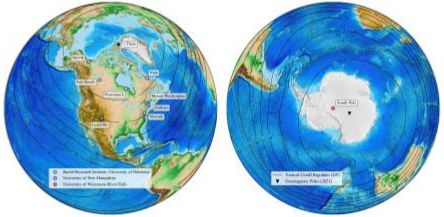


GISTDA plans to launch Thailand Space Weather Forecasting Center

Press Release – 6 October, 2022

Center of Excellence in GNSS&Space Weather, KMITL

Princess Sirindhorn Neutron Monitor station



Collaboration:

Mahidol University (Thailand)

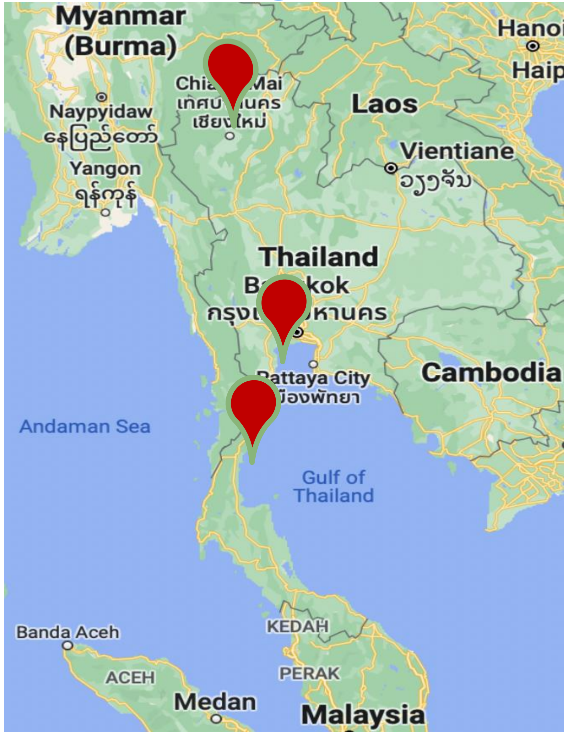
Chulalongkorn University (Thailand)

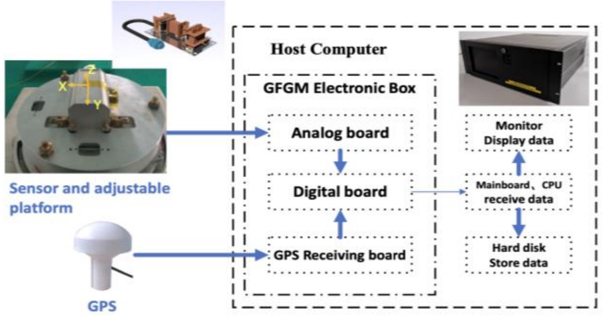
Shinshu University (Japan)

University of Delaware (United States of America)

The Asia-Pacific Space Cooperation Organization (APSCO)
The Institute of Geology and Geophysics, CAS

Geomagnetic Observation Station/Earthquake Precursor Study

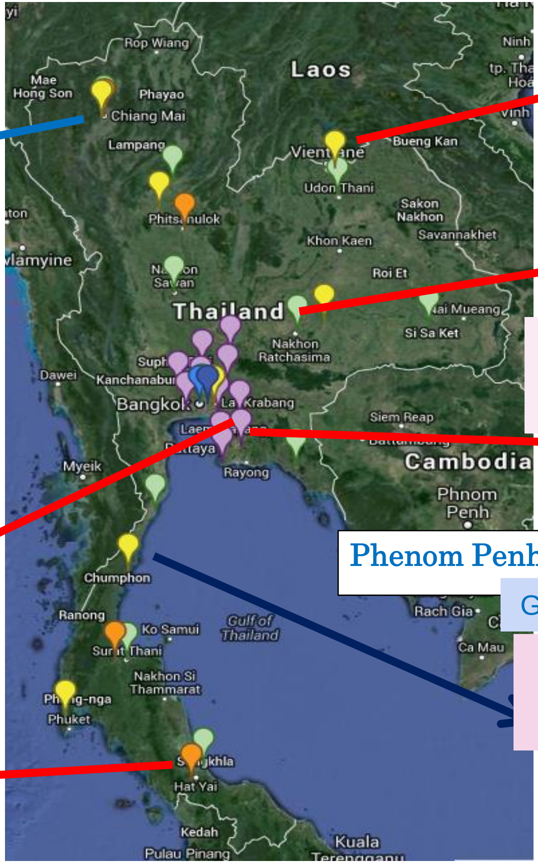




Research Facilities/Stations


Ionosonde
GNSS receiver
Beacon receiver

Chiangmai (CHM)



Vientiene (Laos)

GNSS receiver

Nakhon Ratchasima (NKR)

GNSS receiver

Bangkok (KMITL)

GNSS receiver
Beacon receiver

Bangkok (STFD)

GNSS receiver

Phenom Penh

GNSS receiver

Chumphon (CPN)

Ionosonde
GNSS receiver
Beacon receiver
VHF radar
Magnetomere

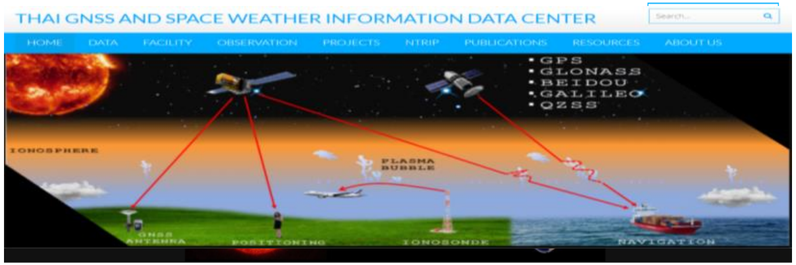


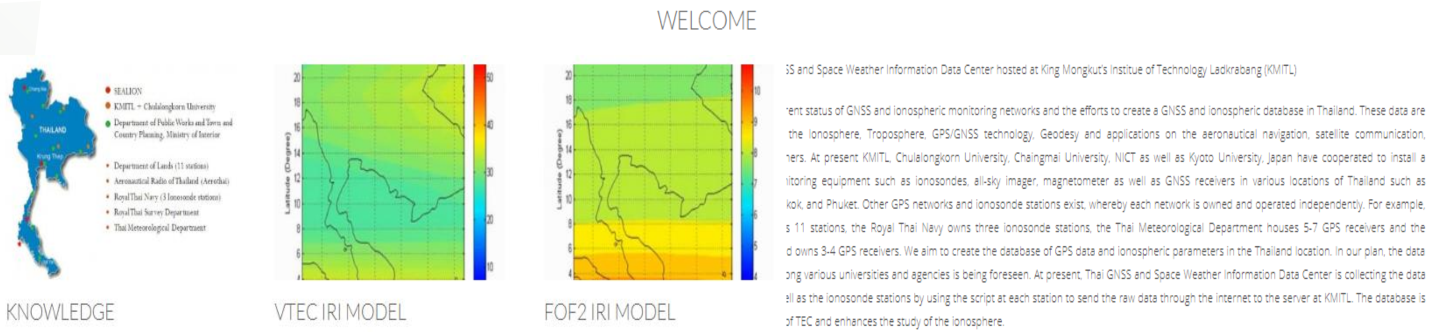
Songkla (SKLA)

Magnetometer

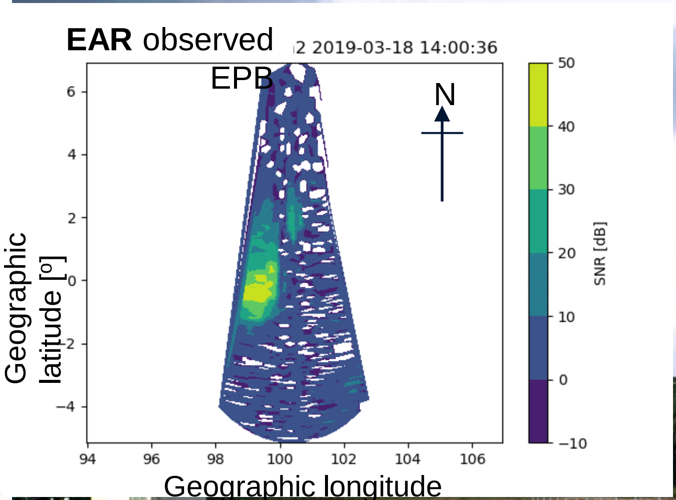
GNSS and Space Weather Information Center

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





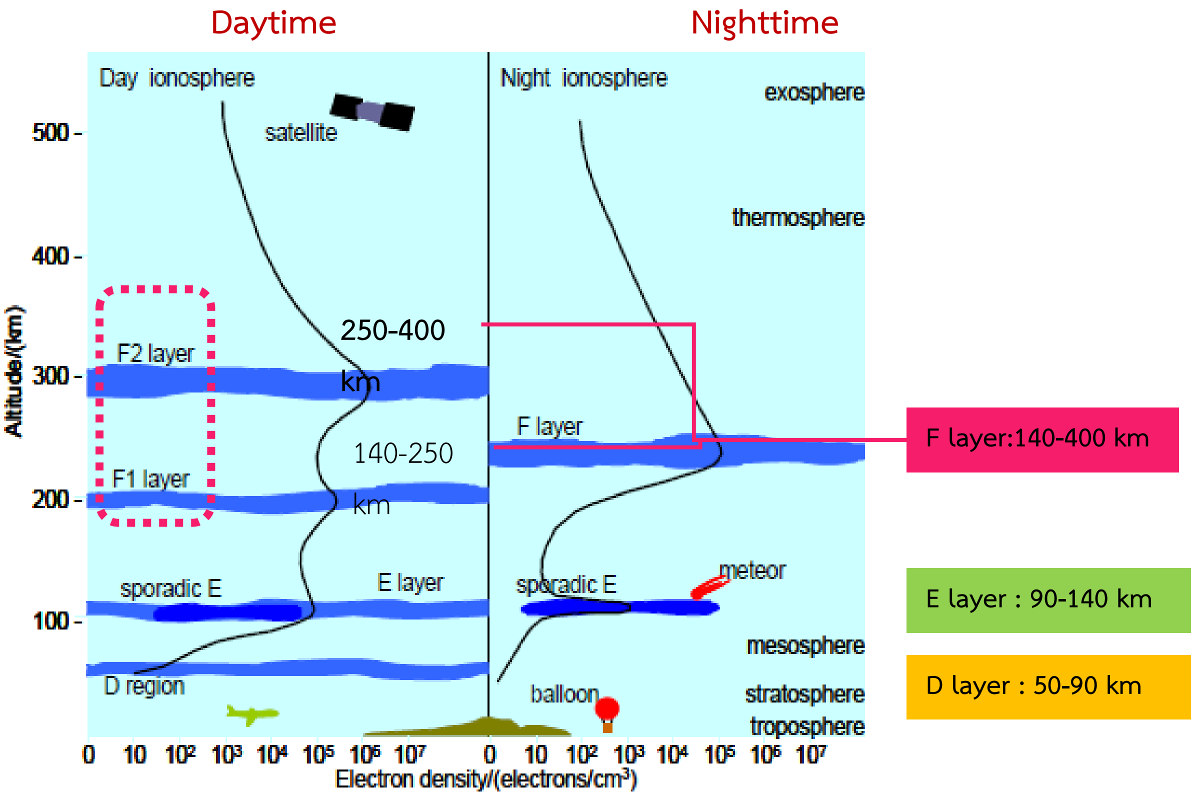
Chumphon VHF Radar station



Cost ~ $ 1 million

Since 17 Jan. 2020

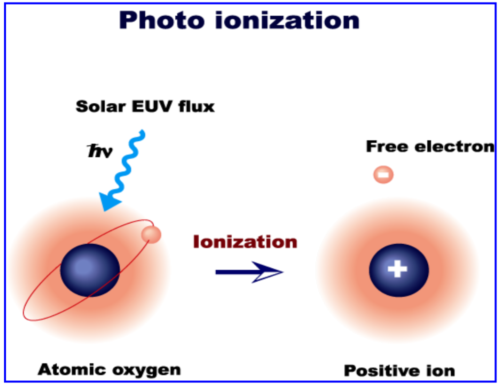
Layers of Ionosphere



- Divided into 3 layers: D, E, F
- **The F2 layer** is the uppermost layer of the ionosphere (HF comm.)

Photo Ionization and Recombination

Daytime



O_2 + hv → O_2^+ + e (E)
N_2 + hv → N_2^+ + e (E)
O + hv → O^+ + e (E, F)

or

Nighttime

Recombination

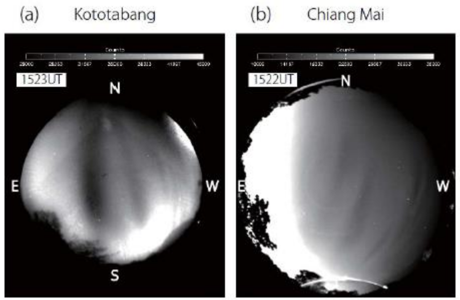
O^+ + e → O (F)

N_2^+ + O → NO^+ + N (E)
NO^+ + e → N + O (E)

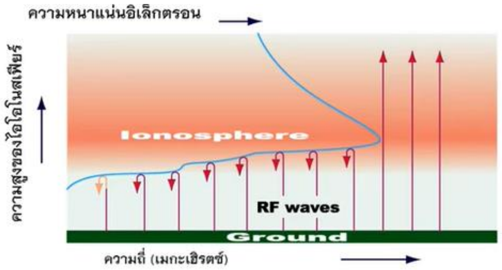
O^+ + N_2 → NO^+ + N (E)
O_2^+ + e → O + O (E)

Instruments for ionospheric study

Optical sky imagers

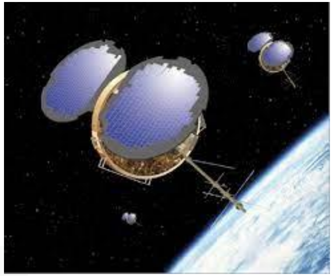


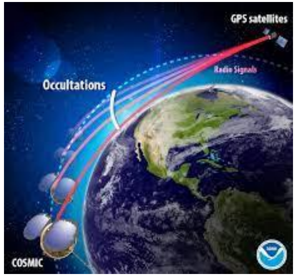
Ionosonde



Mae-hea, Chiangmai

LEO satellites (ICON, SWARM, COSMIC/Formosat, etc.)

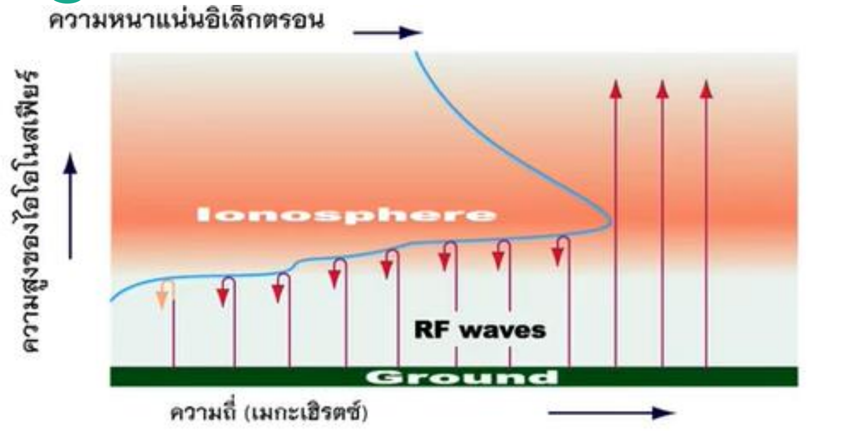


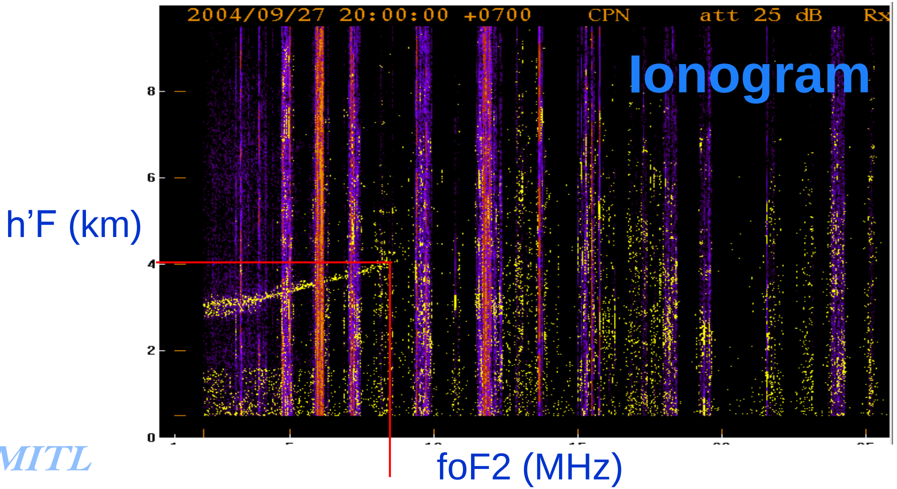


Incoherent scatter radar

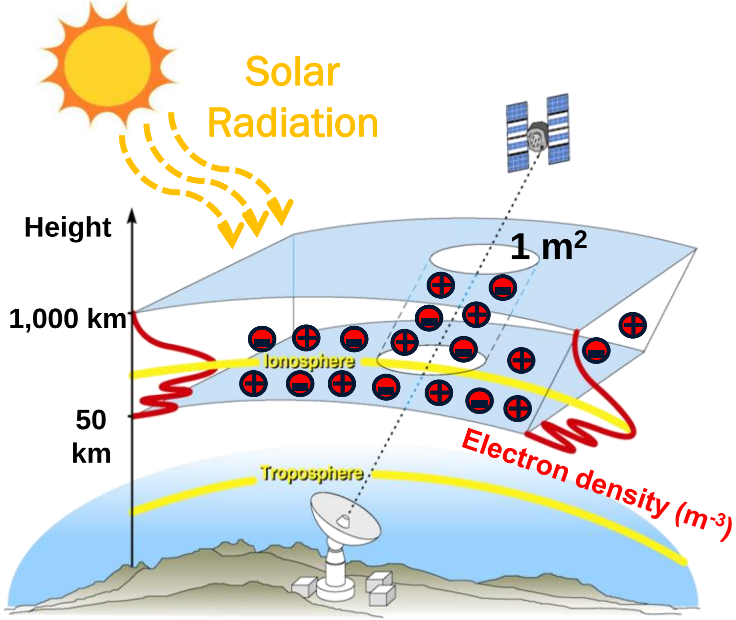
VHF radar

Ionosonde station - Chiangmai



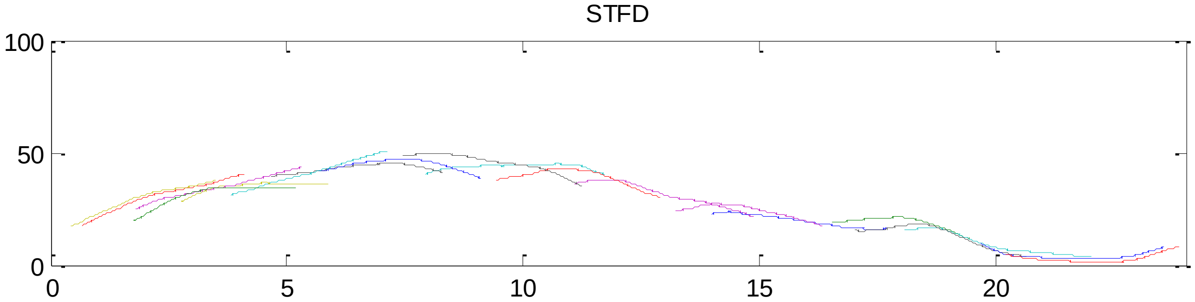


GNSS Observation
(Global Navigation Satellite System)



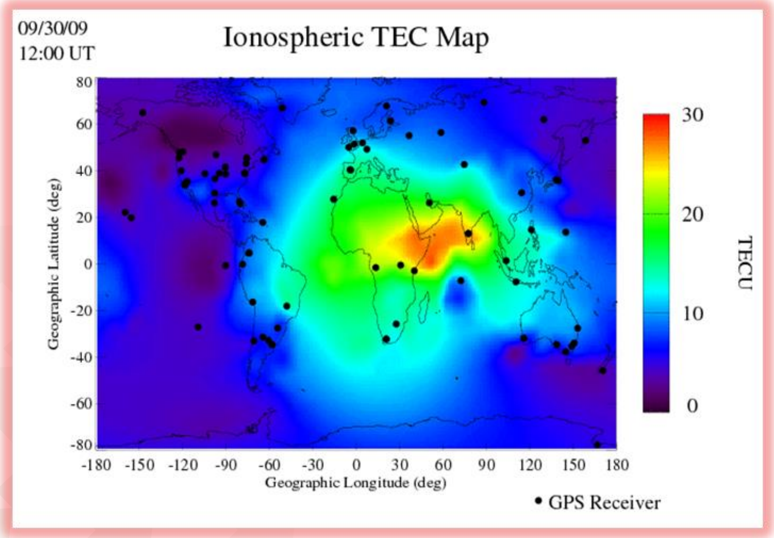
Vertical total electron content (VTEC)

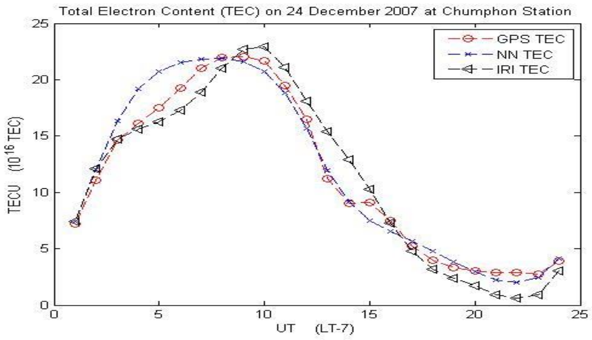
Unit : el/m²

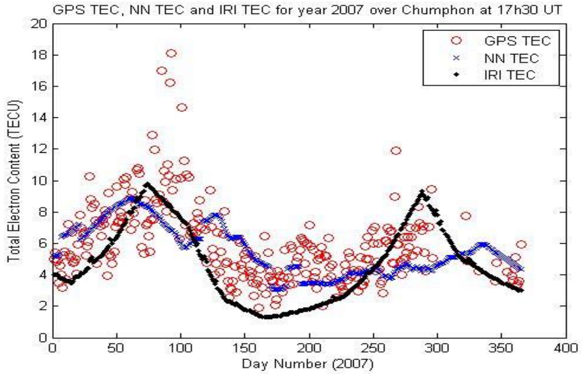


Total Electron Content (TEC)

TEC depends on
- time, location







Disturbances in Ionosphere

- The electron density in the ionosphere varies with time, location, and solar and geomagnetic activities

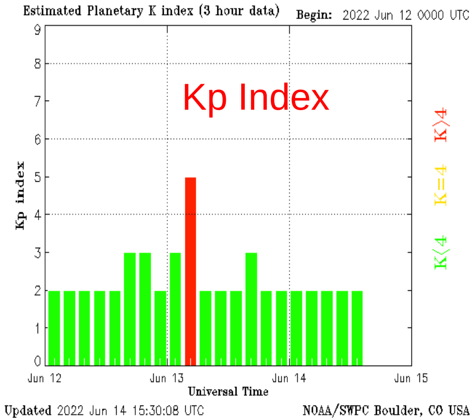
- **Global Condition (earth's geomatic activity)**
  - Kp - Planetary K-index
  - Dst – Disturbance Strom Time indices

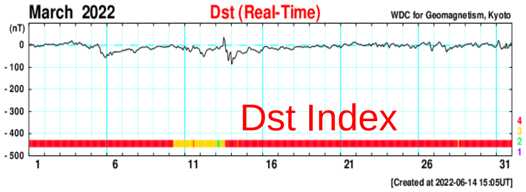
- **Local Ionospheric Conditions**

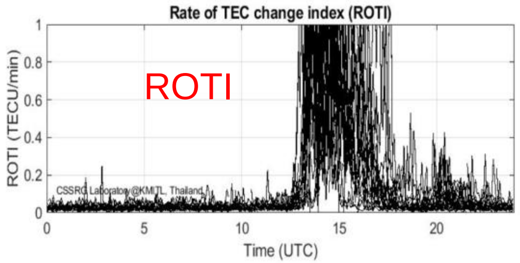
Rate of TEC Change Index (ROTI)

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

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



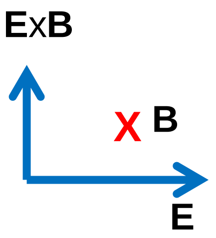


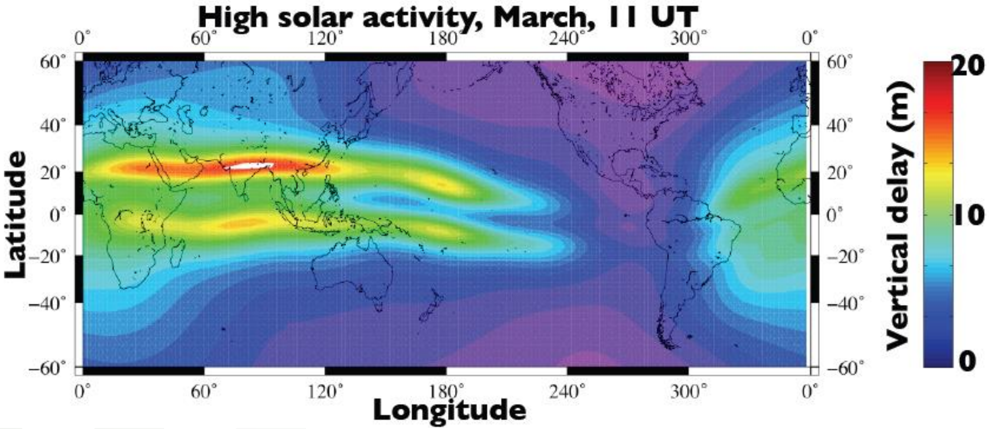


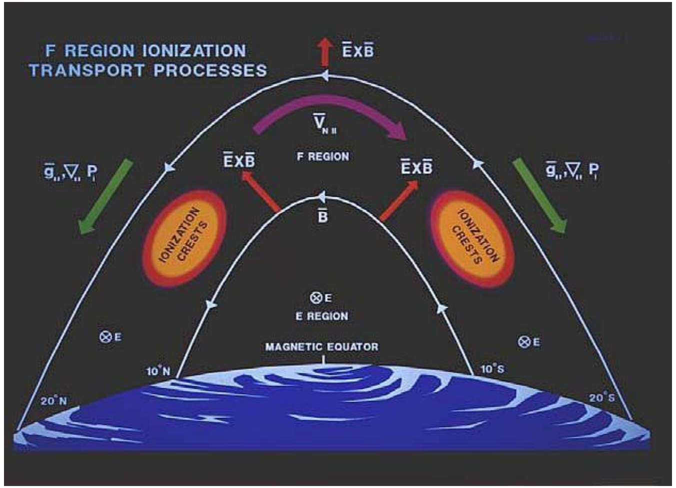
Equatorial Ionospheric Anomaly (EIA)

Large-scale ionospheric density enhancement around ±15º magnetic latitude

“Appleton Anomaly”, “The fountain effect”

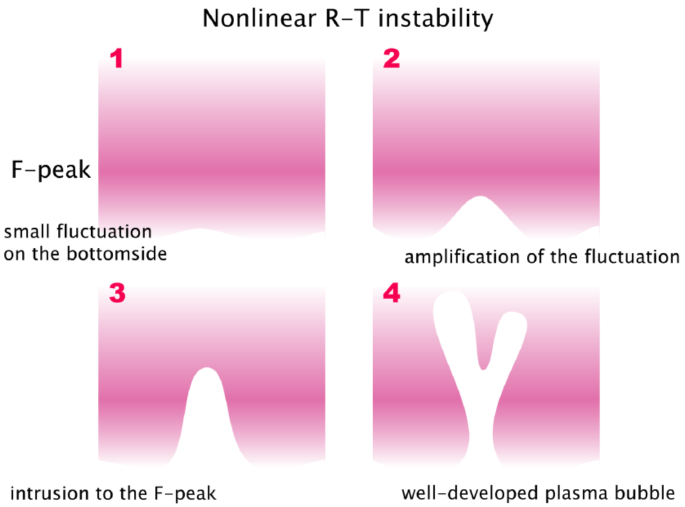


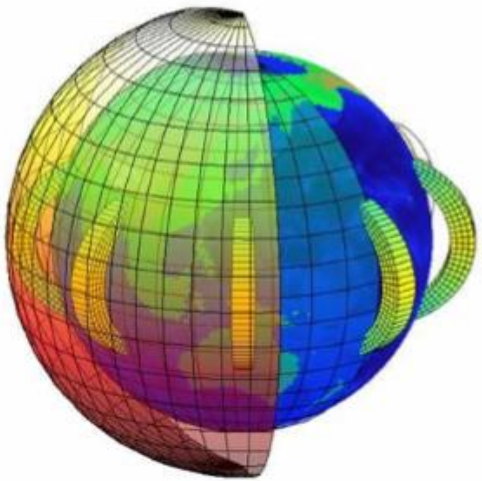




Equatorial plasma bubbles (EPBs)

- ⇨ Flux tube aligned vertically rising plasma depletions
- ⇨ Elongated along the geomagnetic field line
- ⇨ Scale sizes from tens of centimeters to 100s of km
  - The effects can be observed by means of various ranging techniques

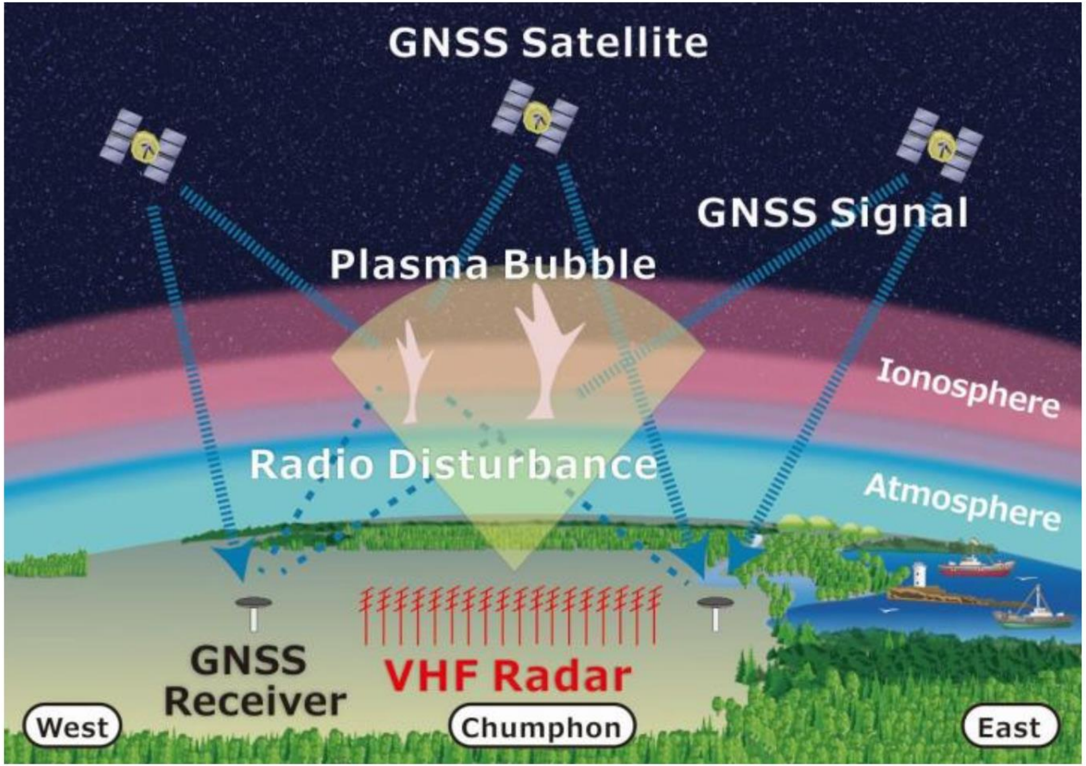




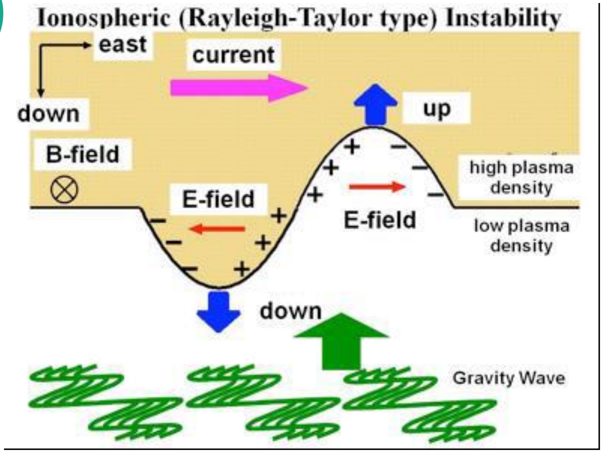
Equatorial Plasma Bubbles (EPB)

1000 km

250 km



Source: NICT



Local ionospheric disturbance

- driven by global disturbance (e.g. magnetic storms)
- local irregularity
- occurs after sunset, near magnetic equator

Linear growth rate of instability

$$\gamma = \left(\frac{E_x}{B} - W_y + \frac{g}{\nu_{in}} \right) \frac{1}{L}$$

E_x - eastward electric field

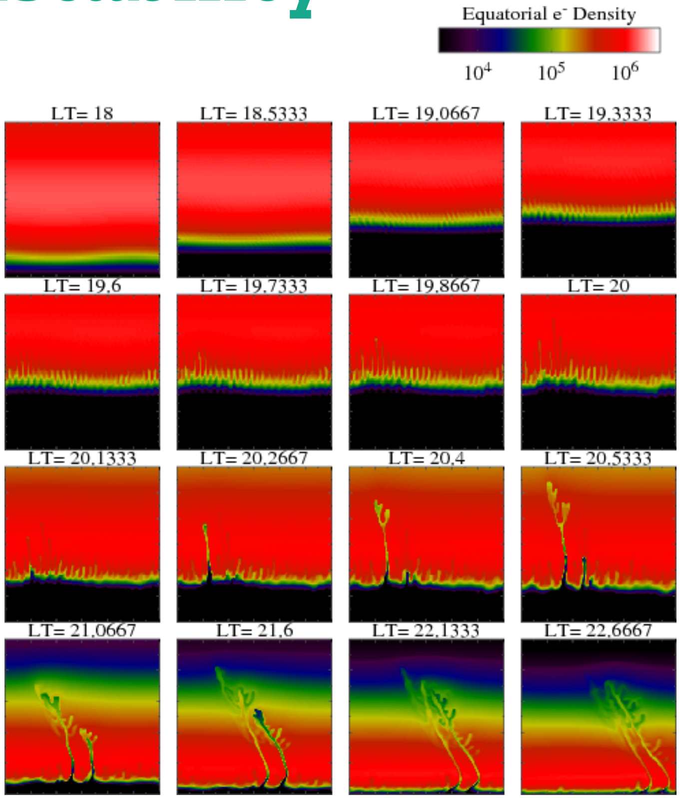
W_y – vertical neutral wind

B - geomagnetic field

g - gravity acceleration

ν_{in} - the ion-neutral collision frequency,

L - scale length of the vertical gradient of the plasma density in the F-region

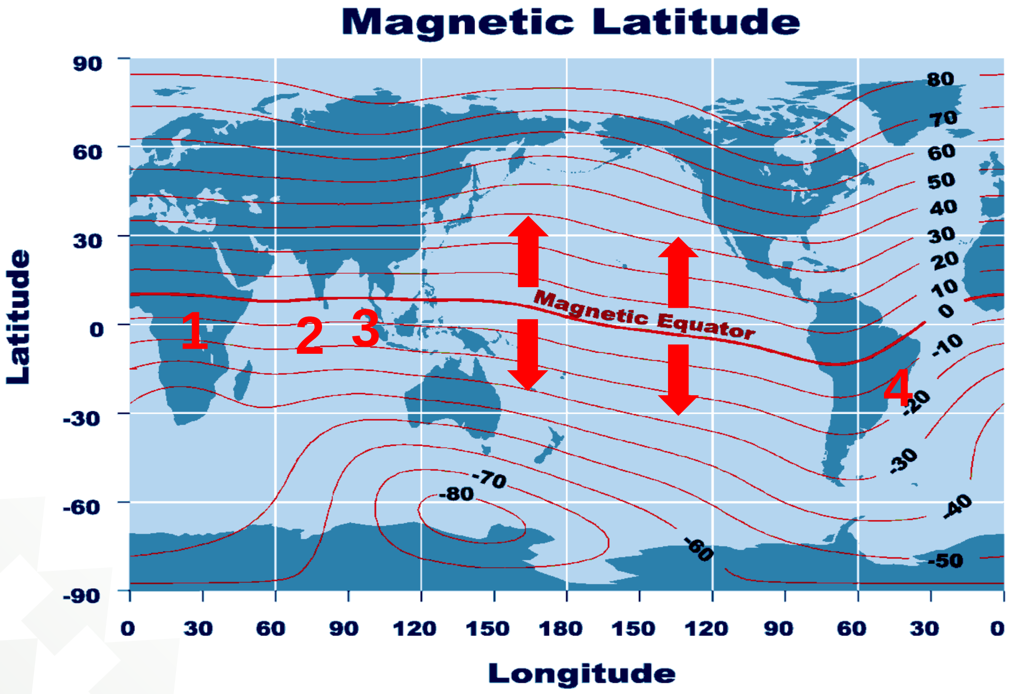


(J. Retterer, 2011)

Open research questions on EPB

- Day-to-day EPB occurrence and variations
  - seed perturbation, neutral winds, electric field
  - bottom-side structures, in-situ measurements, external f
- EPB detection and prediction
  - Multi-sensor, Artificial intelligence
- Effects of EPB on modern technology
  - Positioning
  - Navigation

Unique location of ASEAN (Ground based observation)



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 bubbles that poses a big impact on radio waves.
- 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). Phillipines

Kyoto University

Rajamangala University of Technology Isan (RMUTI)

National University of Laos (NUOL)

CADT, ITC (Cambodia)

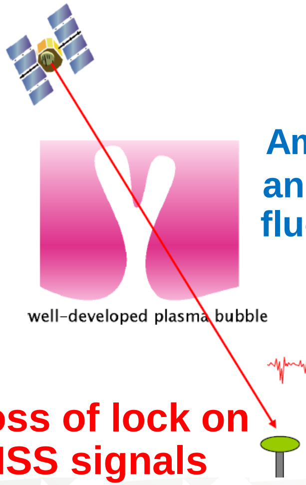
Effects of EPB (1)

VHF Comm.

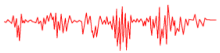

Could Plasma Bubble Have Doomed U.S. Copter in Afghanistan Battle?

A U.S. military rescue mission in Afghanistan went horribly wrong when a crucial radio message wasn't received.

Scintillation



Amplitude and Phase fluctuation



➔ Loss of lock on GNSS signals

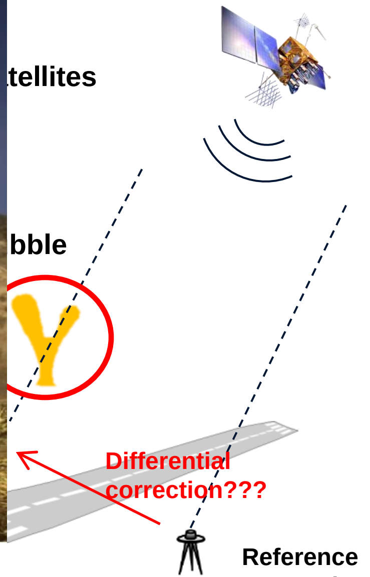
Could Plasma Bubble Have Doomed U.S. Copter in Afghanistan Battle?

A U.S. military rescue mission in Afghanistan went horribly wrong when a crucial radio message wasn't received.

tical navigation

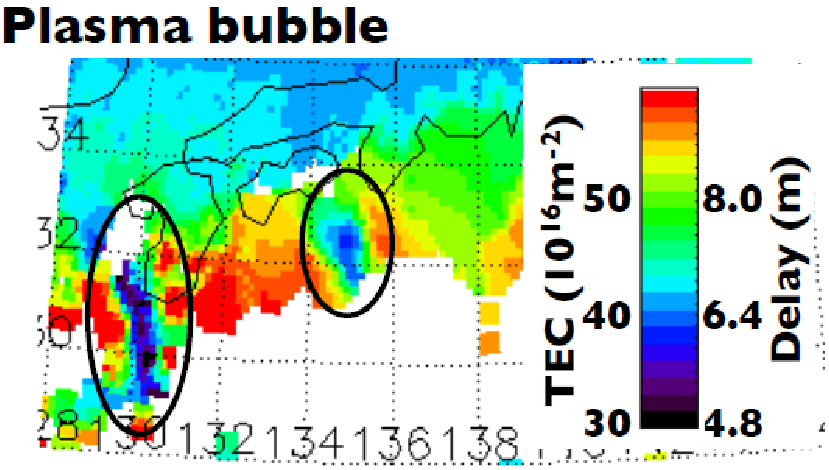
tellites

bble



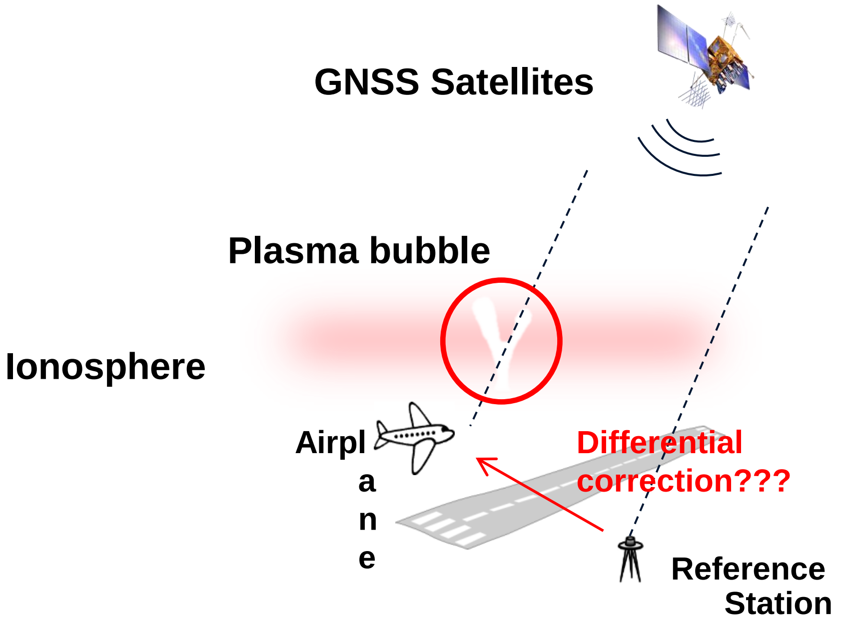
Effects of EPB (2)

Ionospheric delay gradients

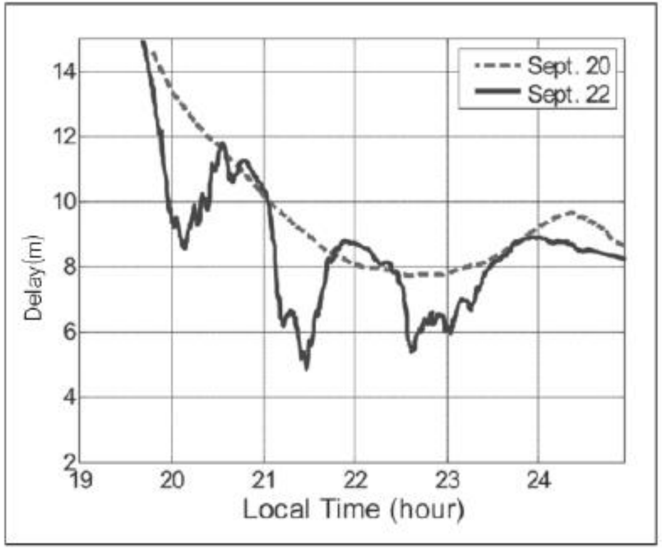


[S. Saito, 2011]

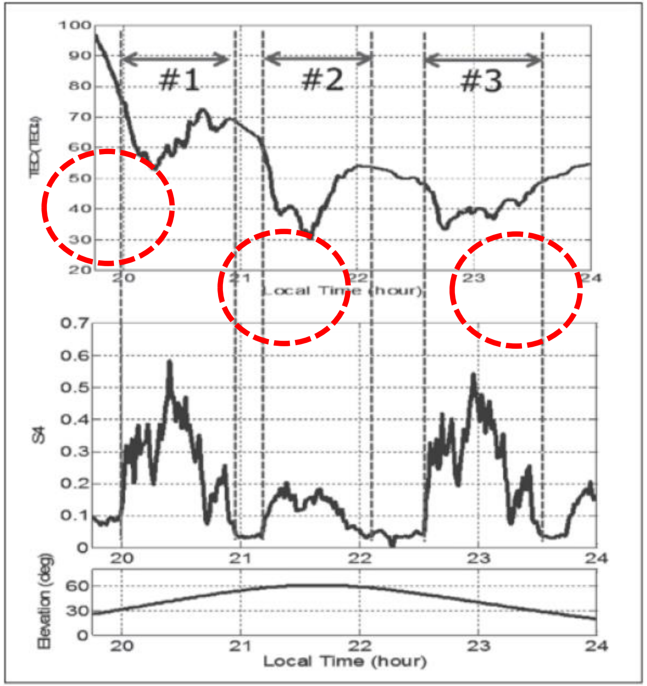
Aeronautical navigation: Ground-based augmentation system (GBAS)



Bangkok area



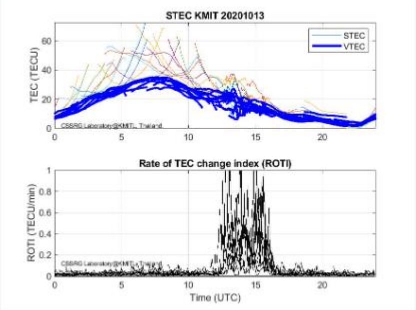
22 Sept. 2011 (uncalibrated TEC)



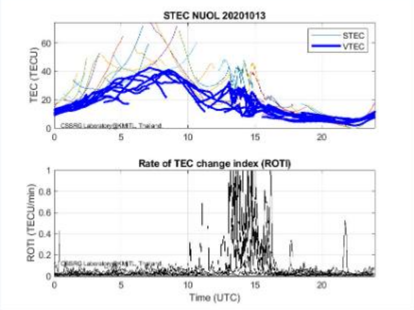
[Tsujii et al., Journal of the Korean Society of Surveying, Geodesy, Photogrammetry and Cartography, 2012]

Daily TEC and ROTI (Rate of TEC Change Index) Plots

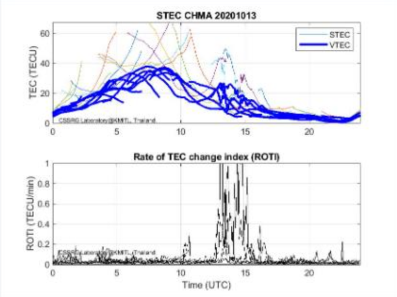
Bangkok (KMITL)



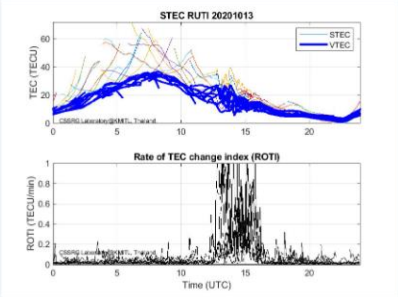
Vientiane (NUOL)



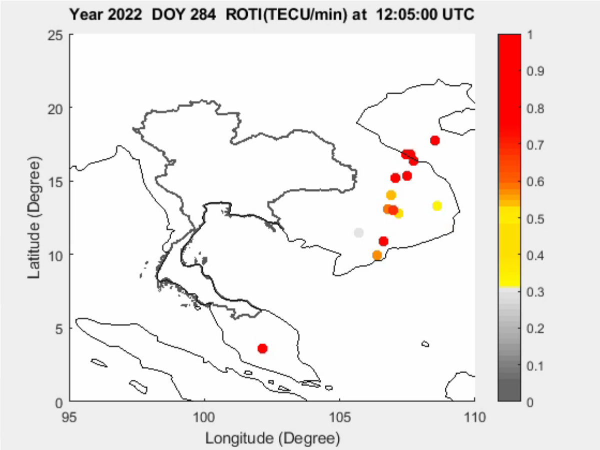
Chiangmai (CHMA)

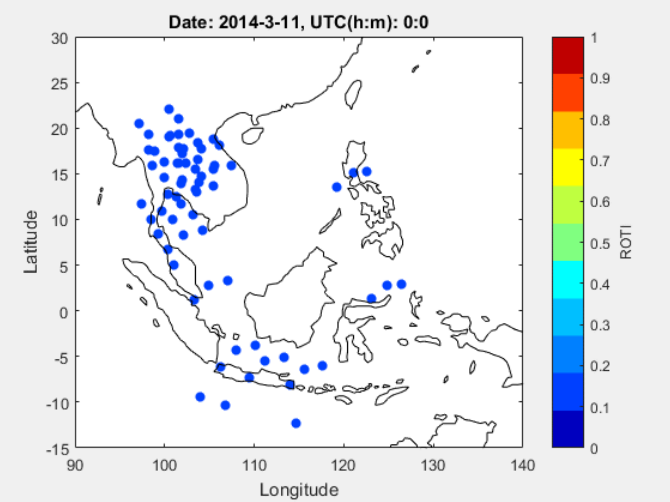


Nakhon Ratchasima (RUTI)



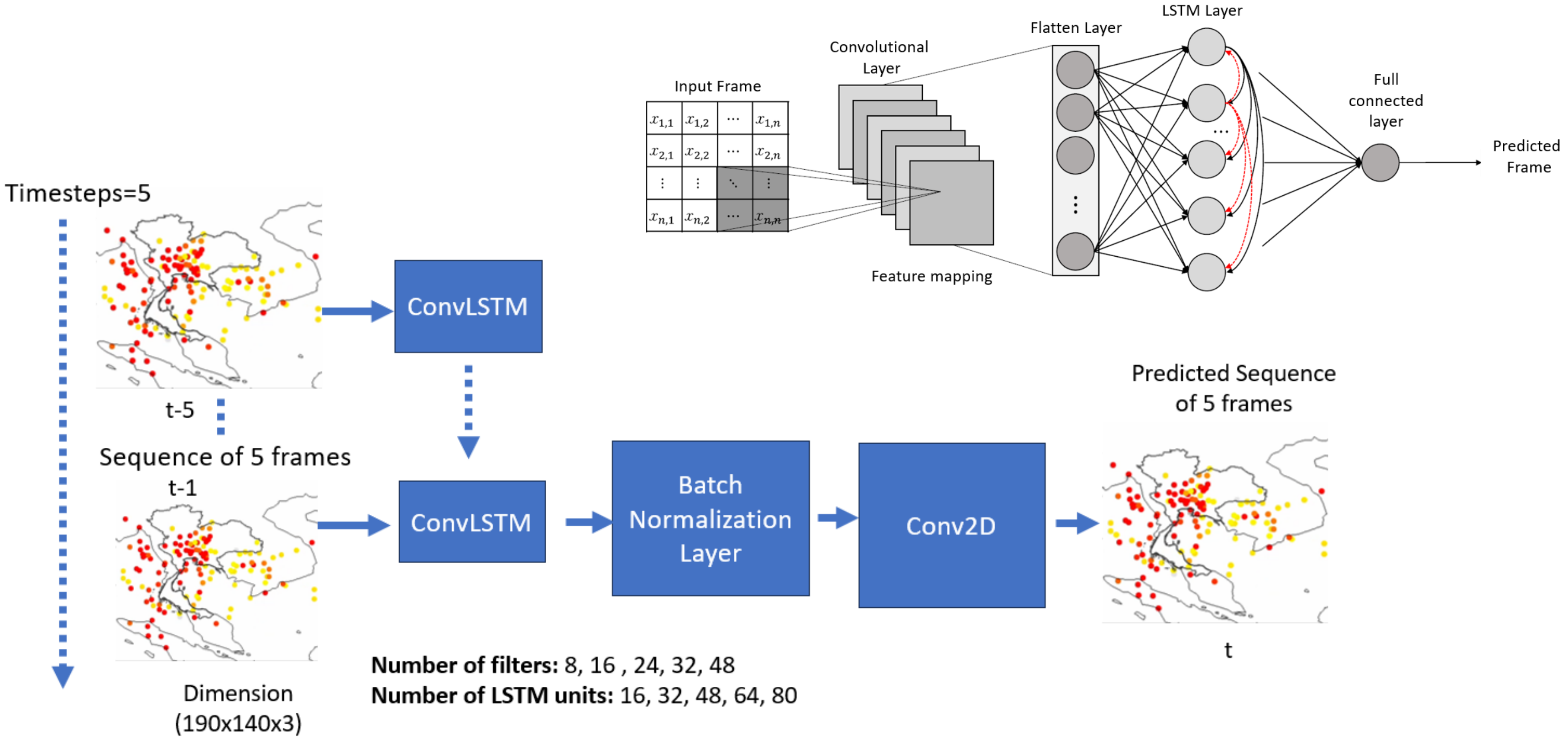
ROTI Maps





Center of Excellence in GNSS&Space Weather, KMITL

LSTM Model for ROTI Map Prediction



Number of filters: 8, 16 , 24, 32, 48
Number of LSTM units: 16, 32, 48, 64, 80

National GNSS CORS network

> 220 stations

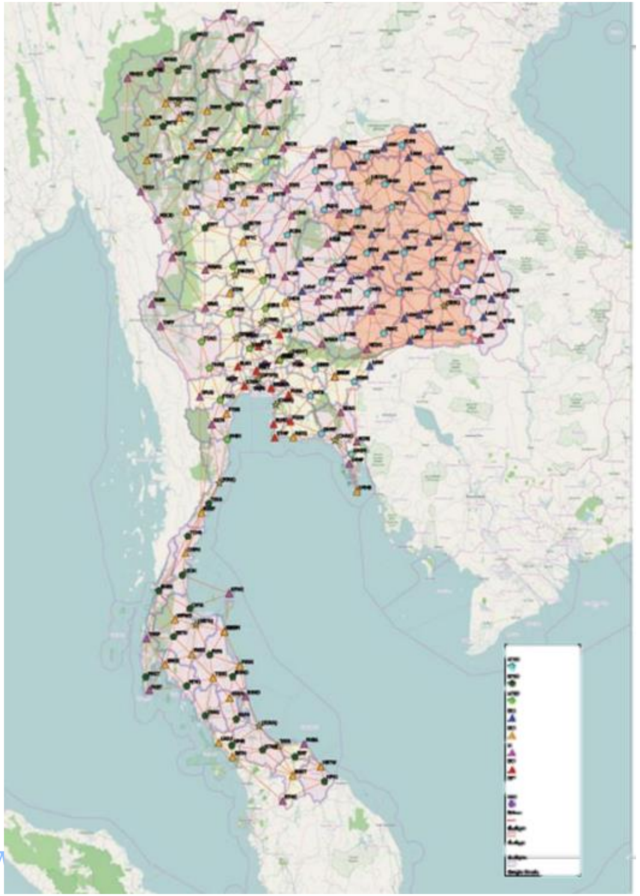
(30-80 km baseline)

➔ owned by government agencies/universities

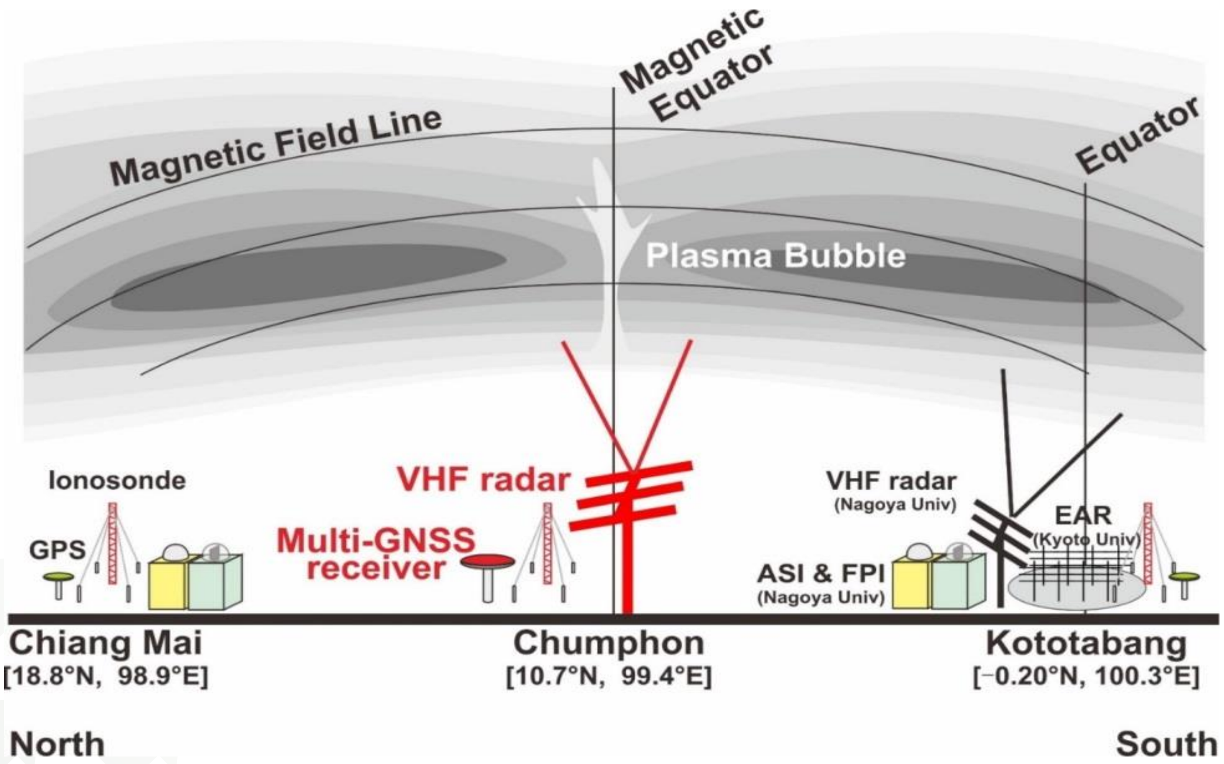
Applications:

➔ NRTK service, survey, atmospheric study, earthquake

https://gnss-portal.rtsd.mi.th/



Chumphon VHF Radar station

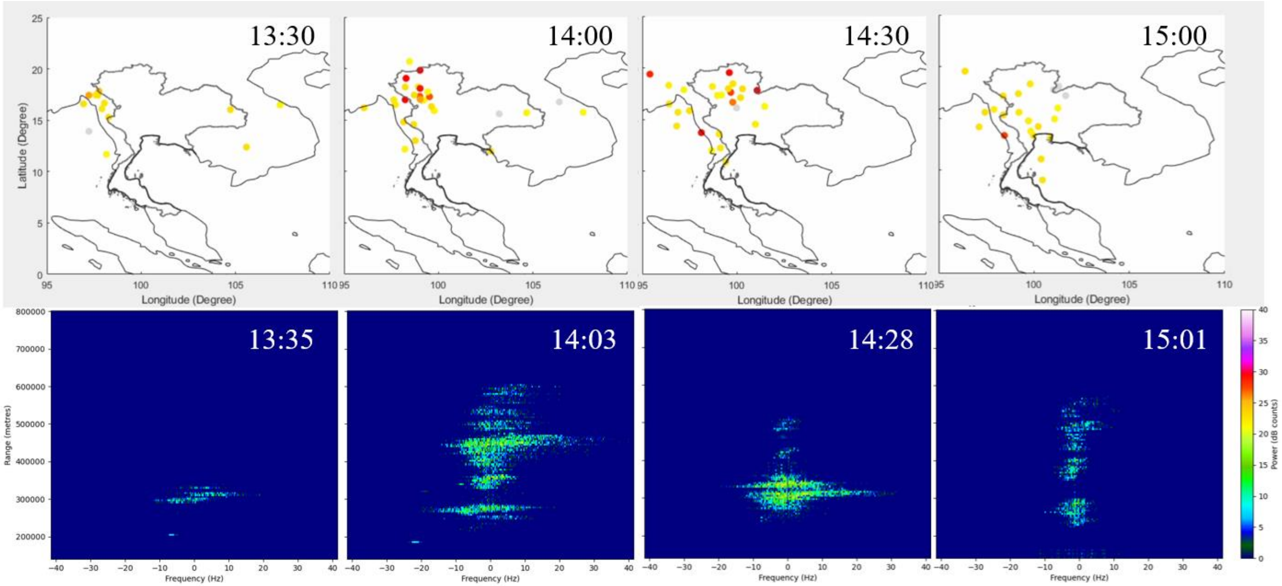


[NICT, Japan]

ROTI vs VHF radar echo image

March 18th 2020

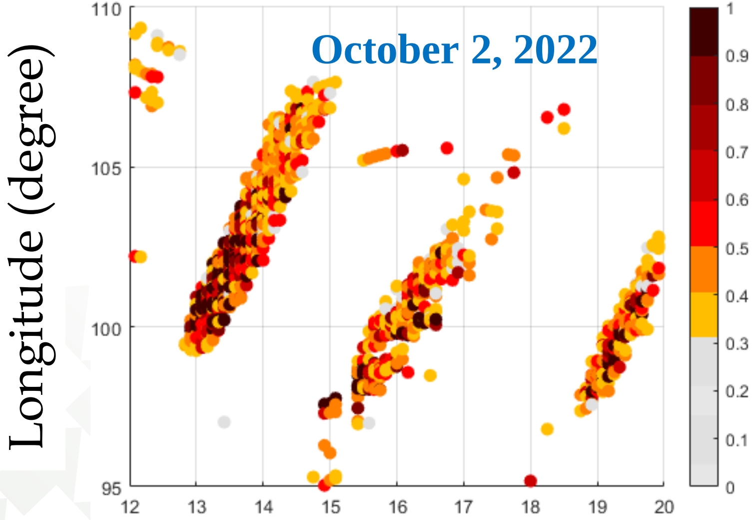
Evolution of EPB is recorded in the sequence of **ROTI 2-D maps** recorded from 13:30 to 15:00 UTC



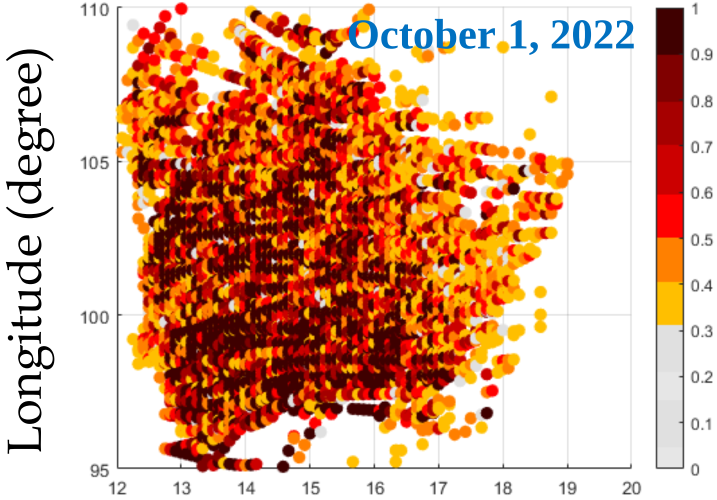
Types of irregularities

Classify the EPB type using EPB speed estimation from Longitude ROTI keogram

Case 1:



Case 2:

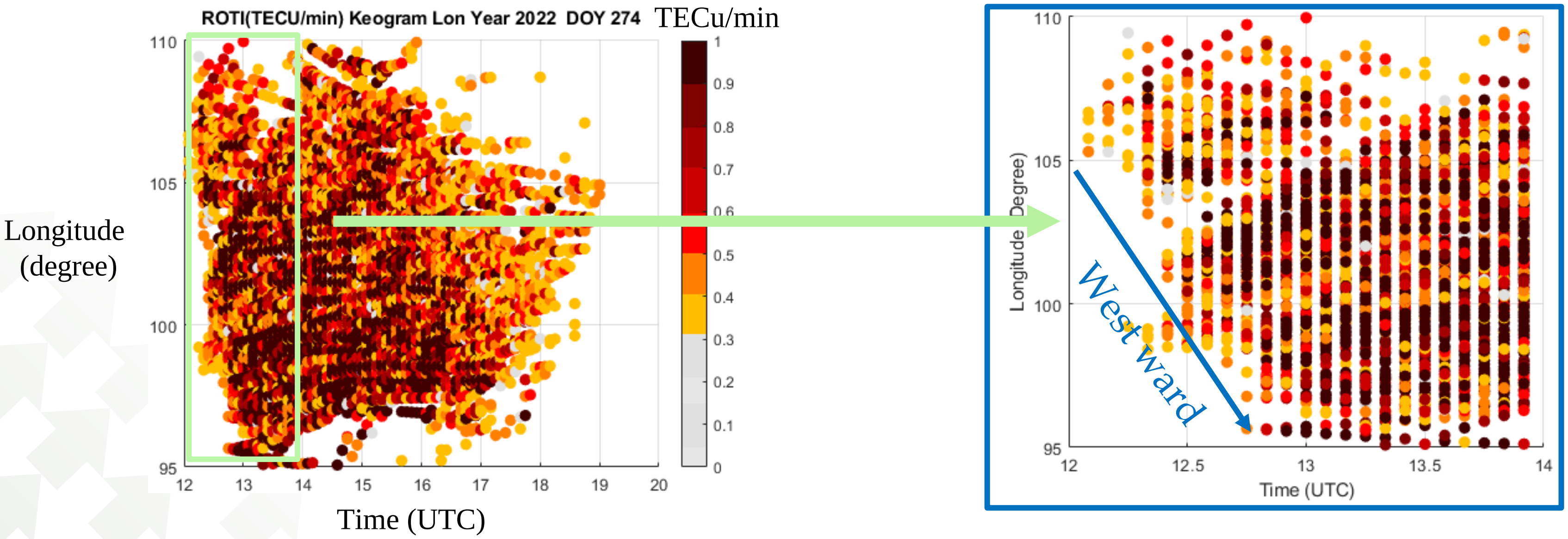


[*N. Tongkasem et al., ION GNSS+ 2023*]

Super Bubble (1st Oct 2022)

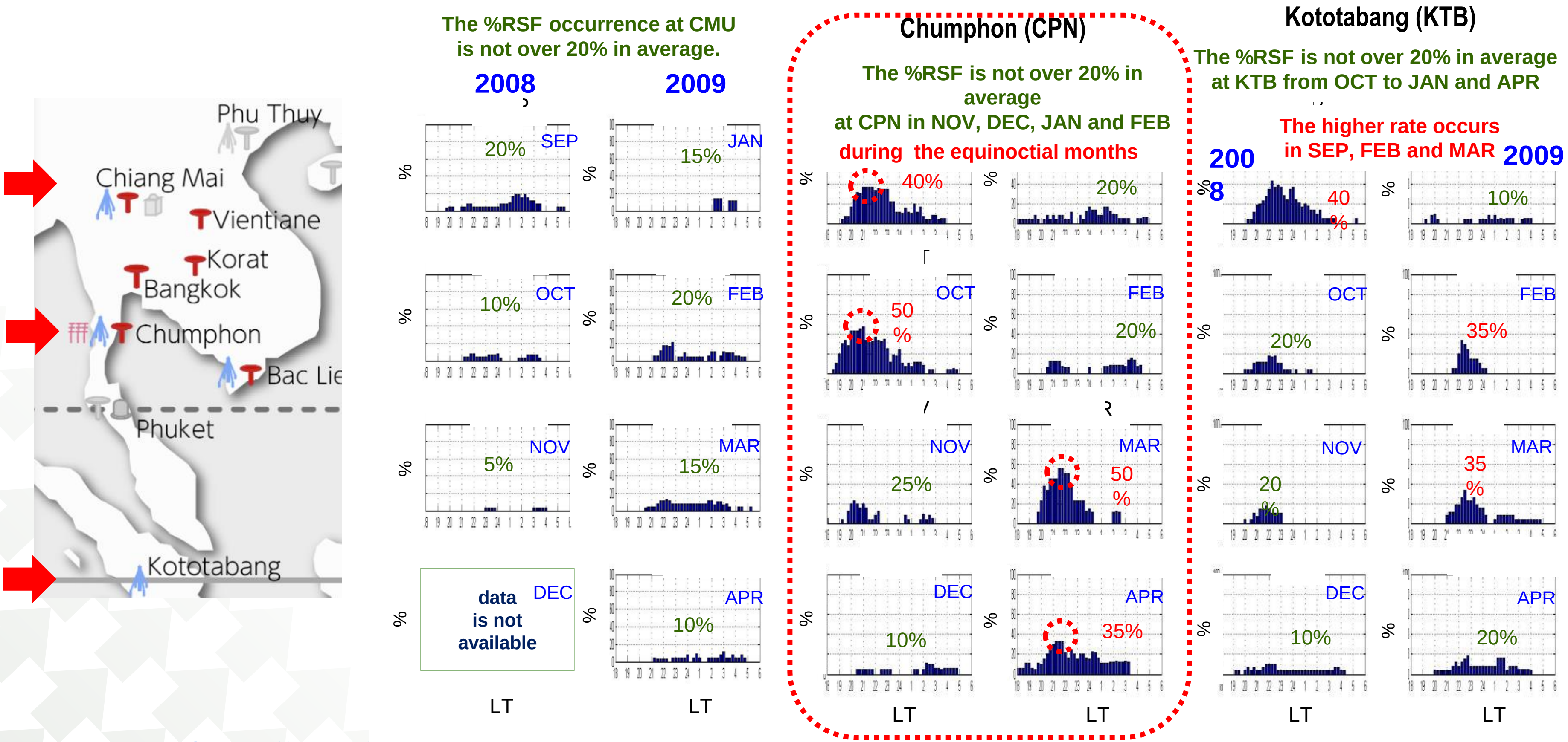
- Origin of EBP is observed from 105 longitude and move **westward** to 95 longitude

ROTI during 12-14 UTC (19-21 LT)

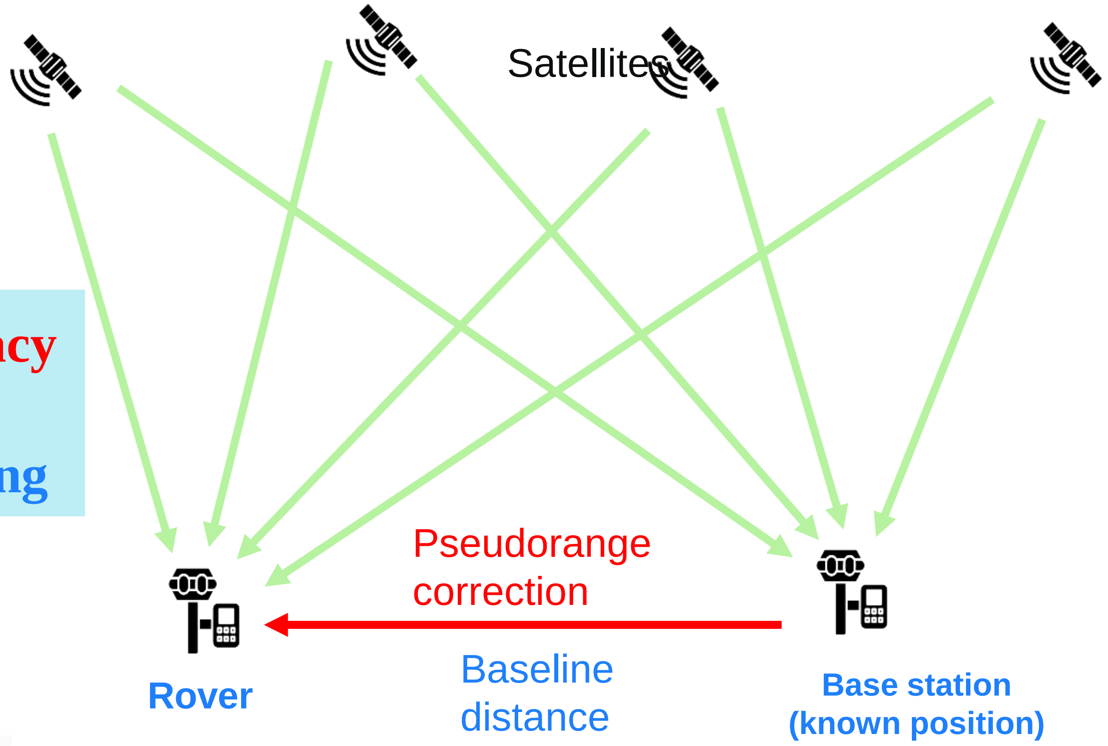


[*N. Tongkasem et al., ION GNSS+ 2023*]

EPB occurrence – 3 stations



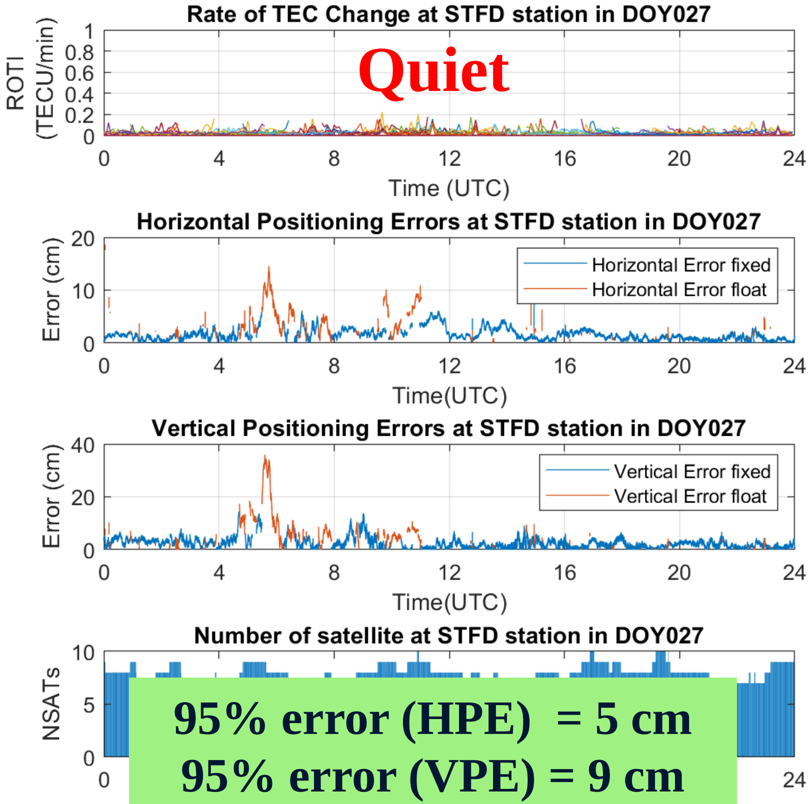
Real-Time Kinematic Positioning (RTK)



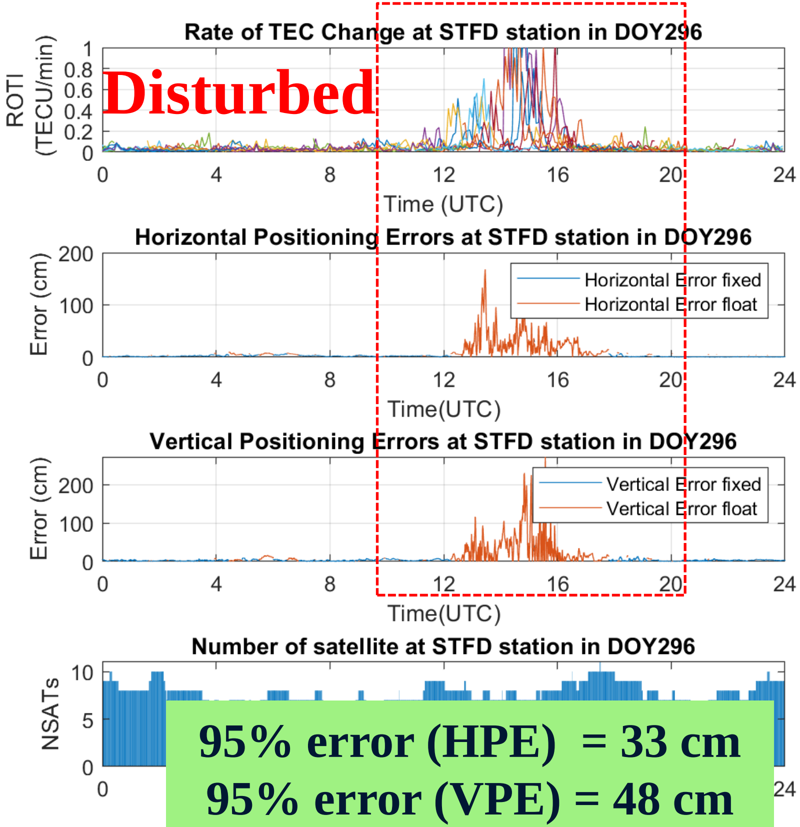
cm- level accuracy

Relative Positioning

RTK Performances (12-km baseline)



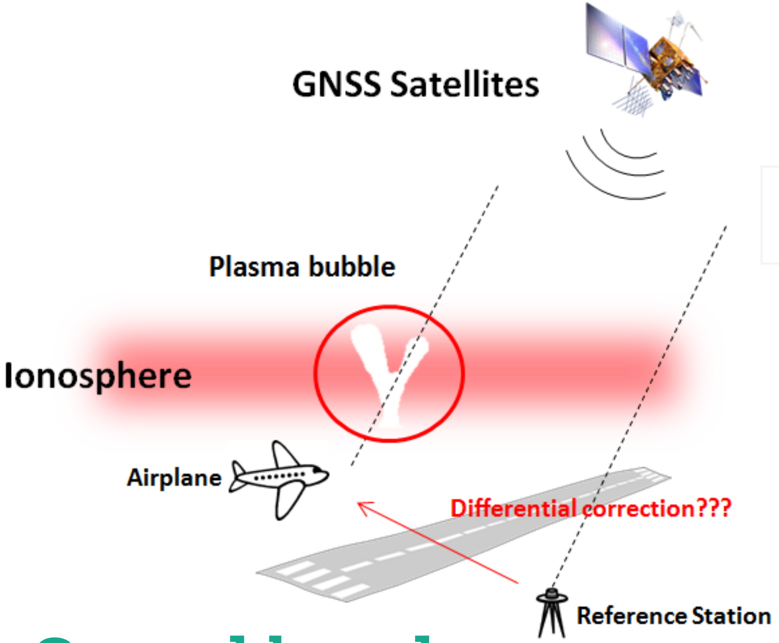
95% error (HPE) = 5 cm
95% error (VPE) = 9 cm

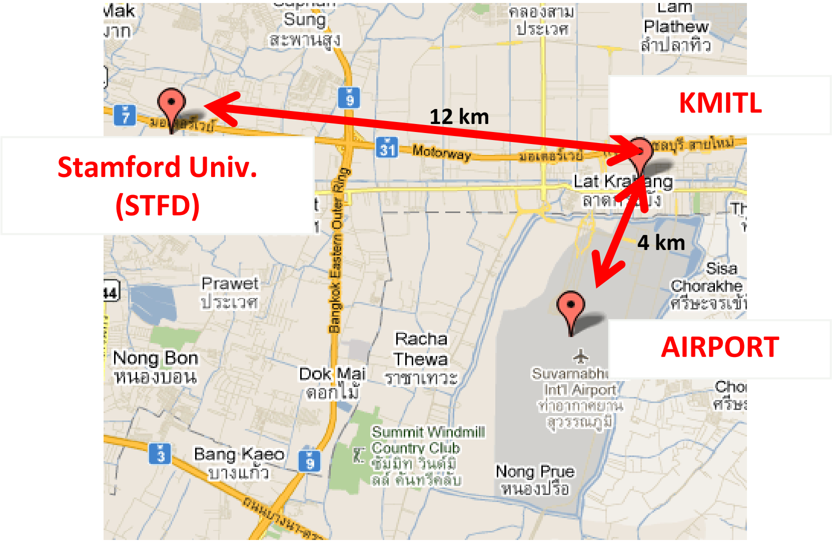


95% error (HPE) = 33 cm
95% error (VPE) = 48 cm

P.C.Thu et al.,"A study on the Relationship between the Real-Time Kinematic Positioning Performance and Ionospheric Daly Gradient," ISEA 2022, Kyoto, Sept. 2022. (Hybrid)

Iono gradient estimation Project





Ground-based Augmentation (GBAS)

Statistics of delay gradient ?
How does it affect protection limits?
How does it affect Loss-of-Lock?

Measurement Error Model

Total errors (variance) in GBAS system
are used to compute the **positioning errors**

$$\sigma_i^2 = \sigma_{pr\_gnd,i}^2 + \sigma_{pr\_air,i}^2 + \sigma_{tropo,i}^2 + \sigma_{iono,i}^2$$

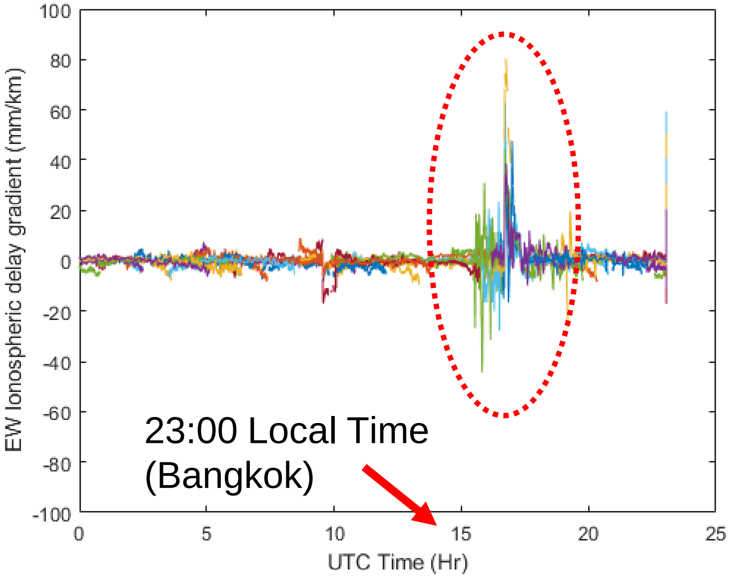
Ground facility error

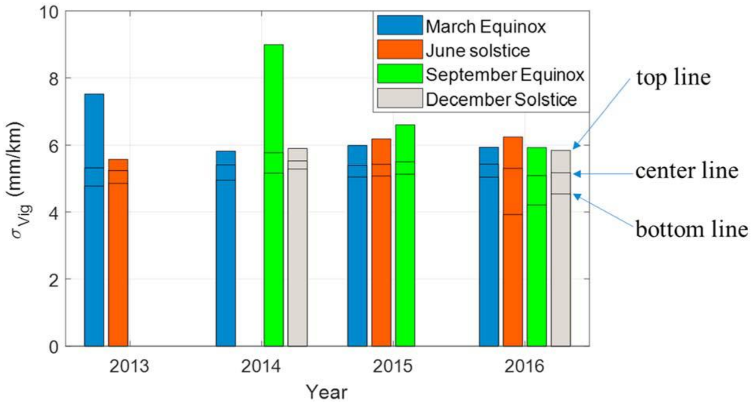
Airborne receiver error

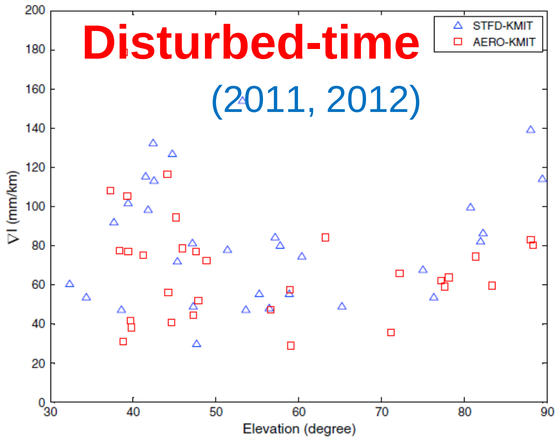
Residual tropospheric errors

Residual ionospheric errors

Iono gradient analysis







J.Budtho, P.Supnithi, S.Saito, IEEE Access, 2020.

Control Room @KMITL

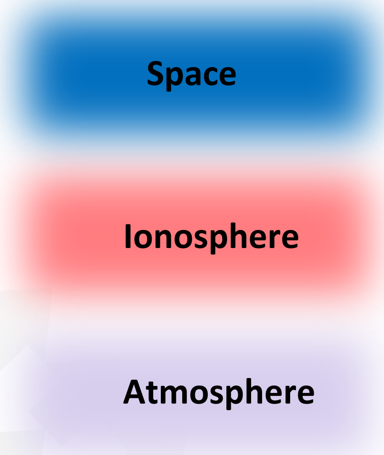
Summary

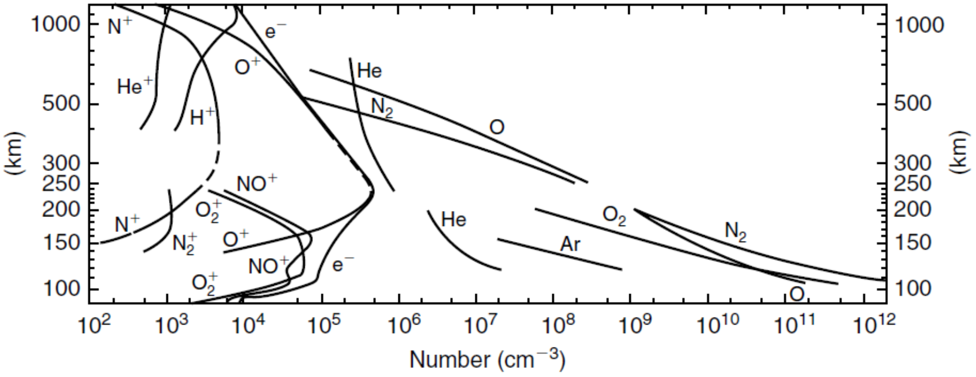
- ⇨ A number of space weather related research programs is ongoing in Thailand and neighboring partners
- ⇨ The main focus is on space weather forecasting, neutron monitor, cosmic ray study, and equatorial plasma bubbles (EPB) study
- ⇨ EPB study and prediction require the use of many types of sensors, collaboration among various countries
- ⇨ EPB effects on high-accuracy positioning and navigation are essential in modern society

Thanks!

Plasma in the ionosphere

- Ionospheric plasma consists of the electron and ion fluid immersed in the neutral gas.
- Neutral gas density > plasma density (until several thousand kilometers in altitude).
- *** Plasma: Mixture of electrons and ions that behaves as a neutral fluid with electrical properties (mobility, conductivity)





Ionospheric behavior => Plasma Physics + Fluid dynamics

M.Kelly, "The Earth's Ionosphere: Plasma Physics and Electrodynamics," 2nd Ed.

Chumphon observatory (KMITL)

Magnetometer

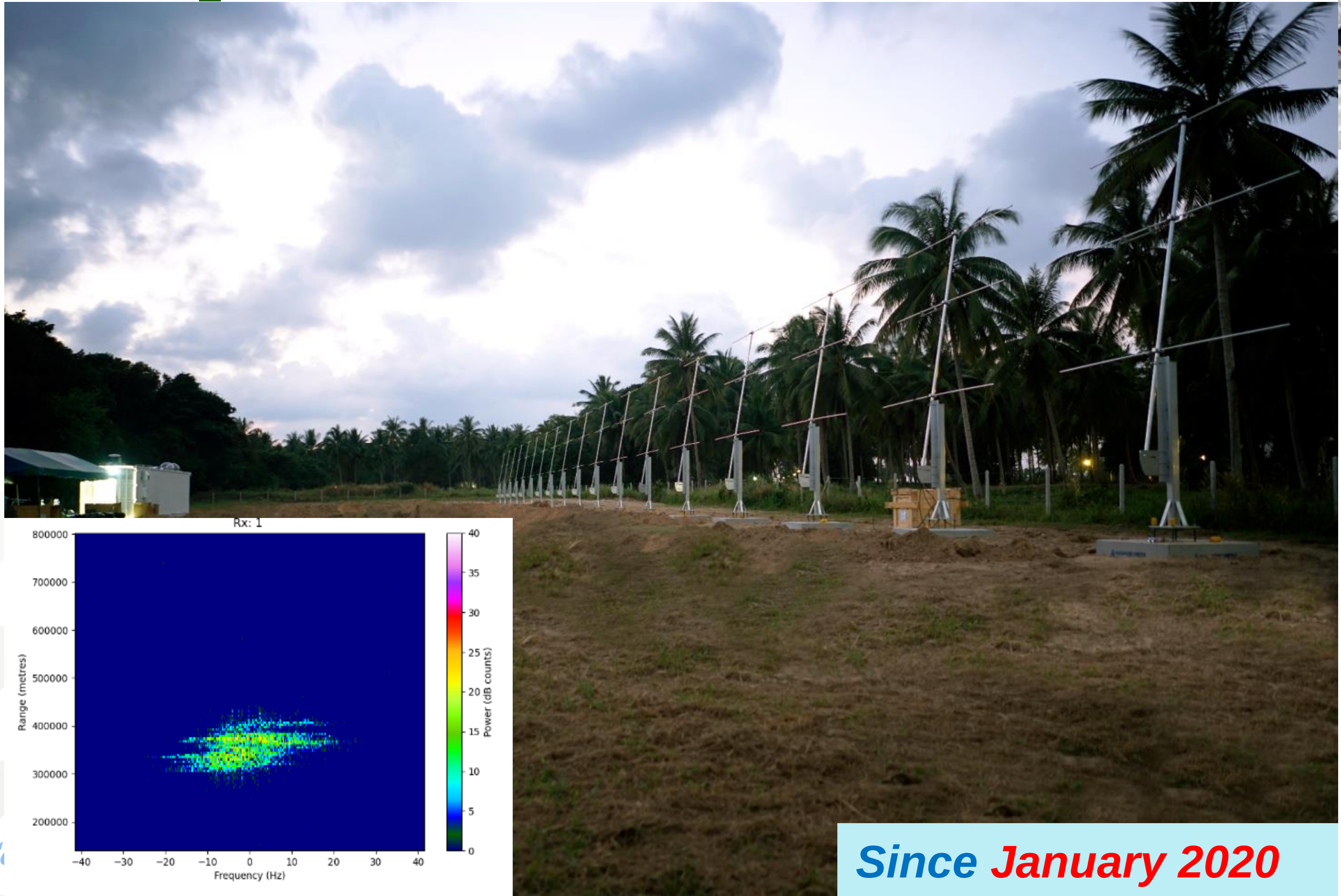
Optical Sky Imager

GNSS receiver

Ionosonde

VHF radar station

Chumphon VHF Radar station



Frequency:

39.65 MHz

Antenna:

18 yagi (Yagi)

Gain:

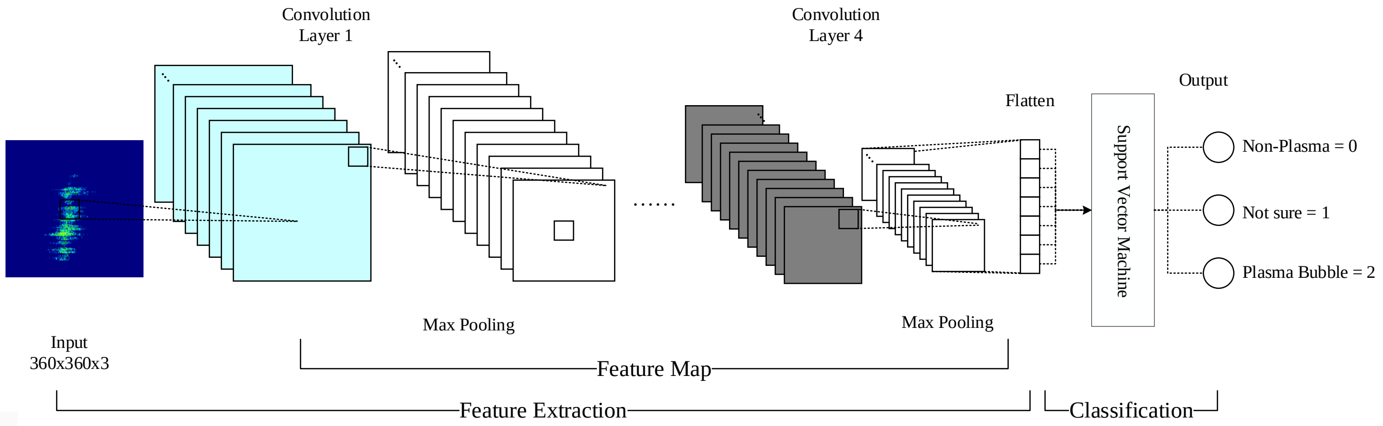
22 dBi

Range

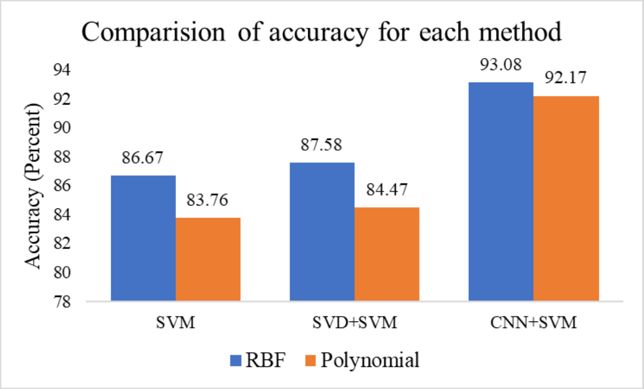
140 to 855.2 km

Since January 2020

EPB detection on VHF radar images

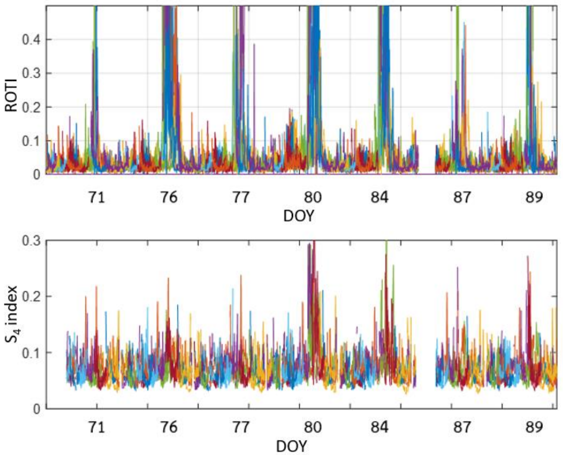


Model performance

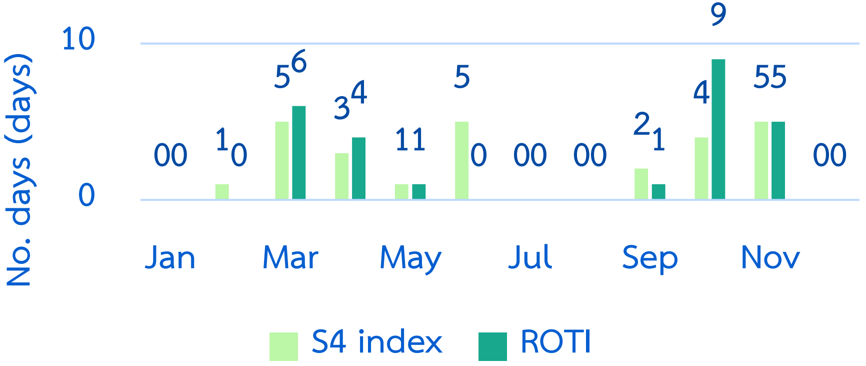


S4 index (Scintillation) vs. ROTI

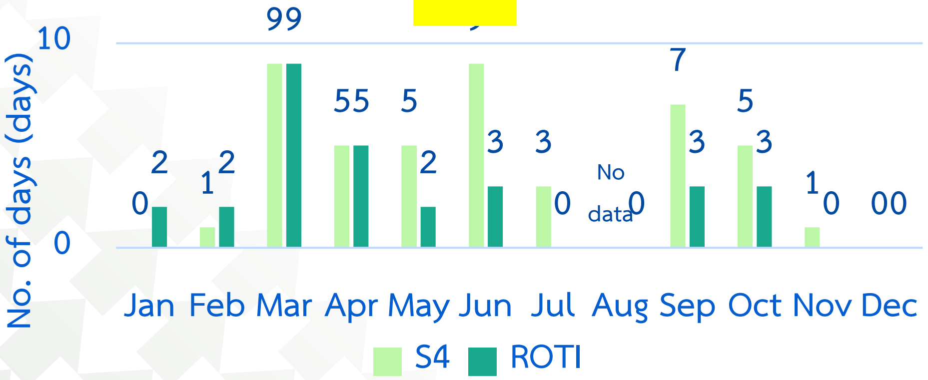
March 2021



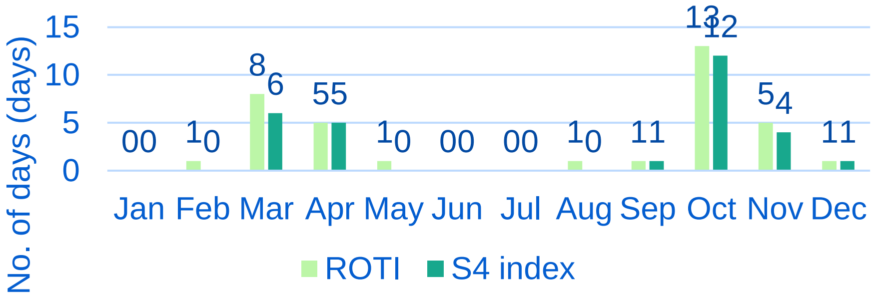
2020



2019



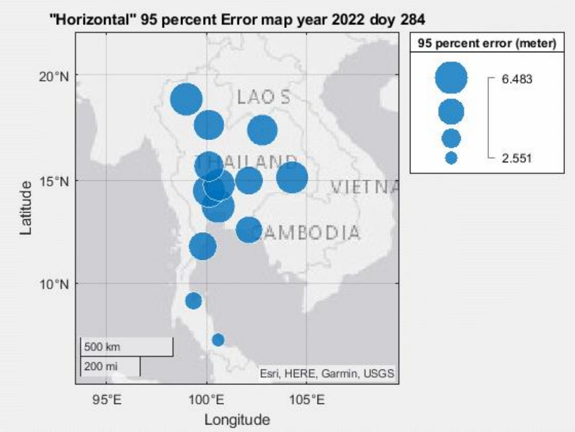
2021

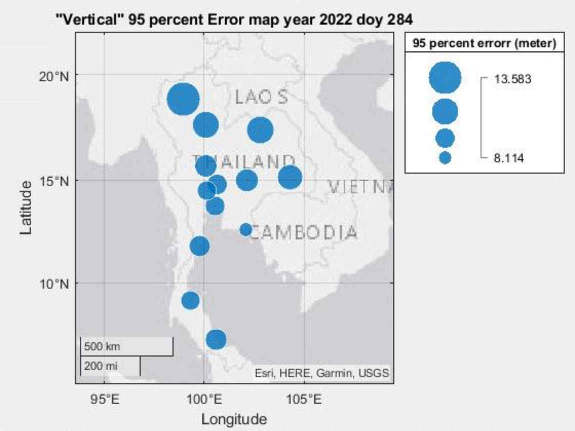


Positioning Error Map

Single-point positioning

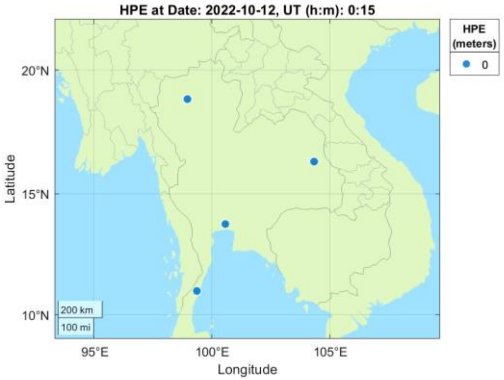
meter-scale





RTK positioning

cm-scale



EPB statistics - October 2022

Date	Number of observed EPB	Speed (meter/sec)	Date	Number of observed EPB	Speed (meter/sec)	Date	Number of observed EPB	Speed (meter/sec)
1	C*	-	**11**	4	92.58	**21**	3	123.44
2	3	154.31	**12**	C*	-	**22**	C*	-
3	3	138.88	**13**	3	129.62	**23**	3	123.44
4	4	138.88	**14**	-	-	**24**	C*	-
5	5	108.01	**15**	2	108.01	**25**	2	138.87
6	C*	-	**16**	2	108.01	**26**	C*	-
7	2	92.58	**17**	3	123.44	**27**	3	138.87
8	3	123.44	**18**	3	108.01	**28**	C*	-
9	-	-	**19**	C*	-	**29**	-	-
10	3	123.44	**20**	2	92.58	**30**	2	92.58
						31	3	92.58
Average speed								**112.71**

8 C* = non-scatter plot (Super bubble)

3 - = No EPB or quiet