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KMITL
พระจอมเกล้าลาดกระบัง

Effects of equatorial plasma bubbles on RTK positioning in low-latitude region

Session F4a – Atmospheric Effects on GNSS Thursday, Sept 14, 1.45 pm -5.30 pm

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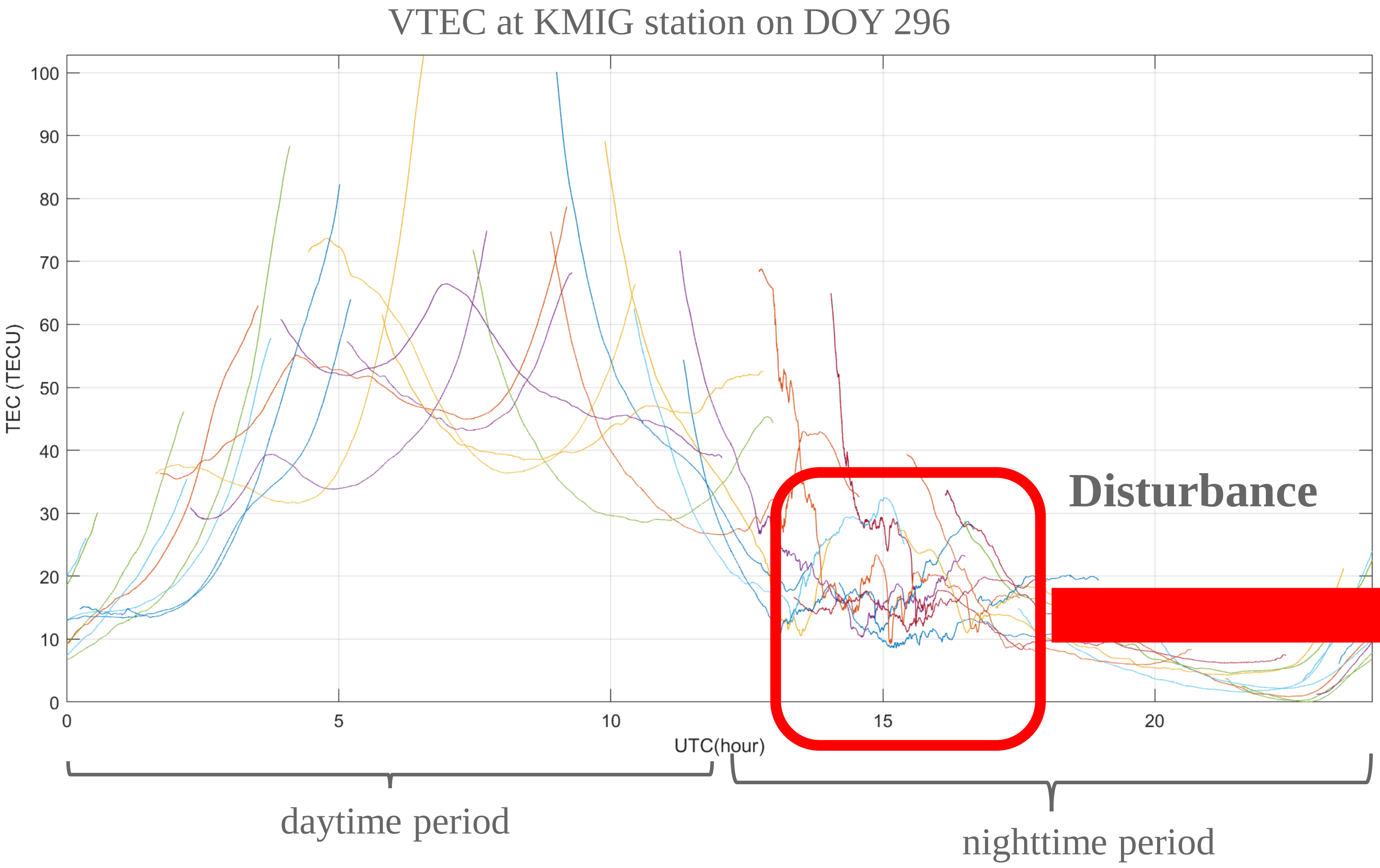
Outline

- Motivation and Literature Review
- Objectives
- Background on Equatorial plasma bubbles and disturbance index
- Methodology and Experimental Setup
- Results and Discussions
- Conclusions

GNSS Positioning and Ionospheric Delays

Fluctuation in electron density due to ionospheric disturbance can degrade the positioning performance



$$\delta_{ion} = \frac{40.3}{f^2} TEC$$

Ex. $f_1 = 1575.4$ Mhz , $TEC = 20$ TECu
1 TECu = 10^{16} electron/m^2
$\delta_{ion} = 3.2475$m

Degraded Positioning accuracy

National GNSS CORS network

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

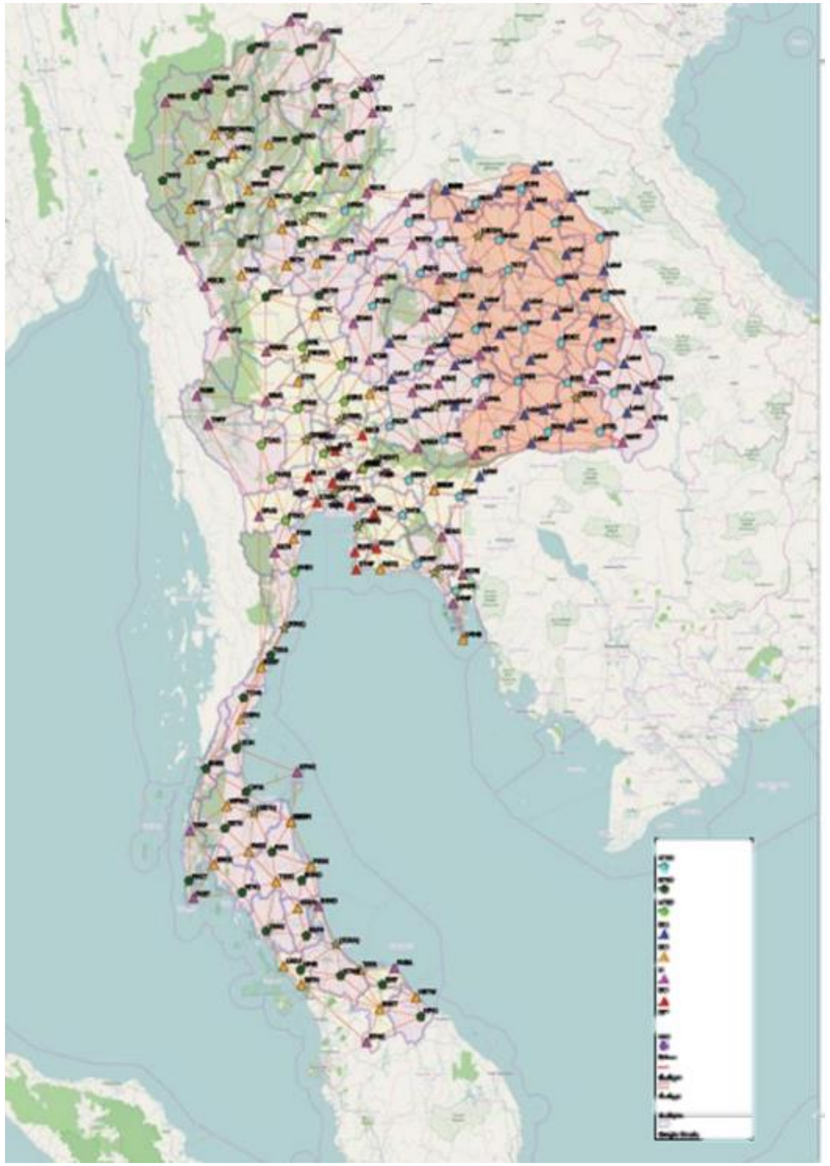
> 220 stations

(30-80 km baseline)

➔ owned by government agencies/universities

Applications:

➔ NRTK service, survey, atmospheric study, earthquake



Recent research works

- **Effects of ionospheric irregularities on precise positioning**
  - Middle and high latitudes
    - Jacobsen and Schäfer 2012; Luo at al. 2018; Yang et al. 2020; Zakharenkova and Cherniak 2021; Paziewski Jacek et al. 2022
  - Low-latitudes
    - A.L. Christovam et al. 2023; Ning and Tang 2018; Guo et al. 2019; Veettil et al. 2020; Li et al. 2022a

There are not many research works on effects of EPB on RTK technology at low-latitude region over long period !!

Objectives

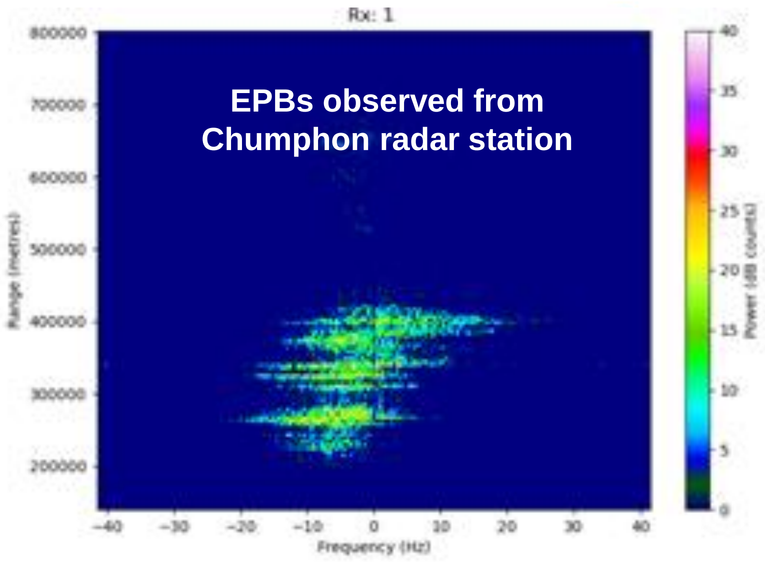
- To analyze the performances of (GPS) RTK positioning during ionospheric disturbed periods **in 2020 and 2022**
- To evaluate RTK positioning performances at **short, medium and long baselines**.
- To analyze the relationship between ROTI index and RTK positioning performances

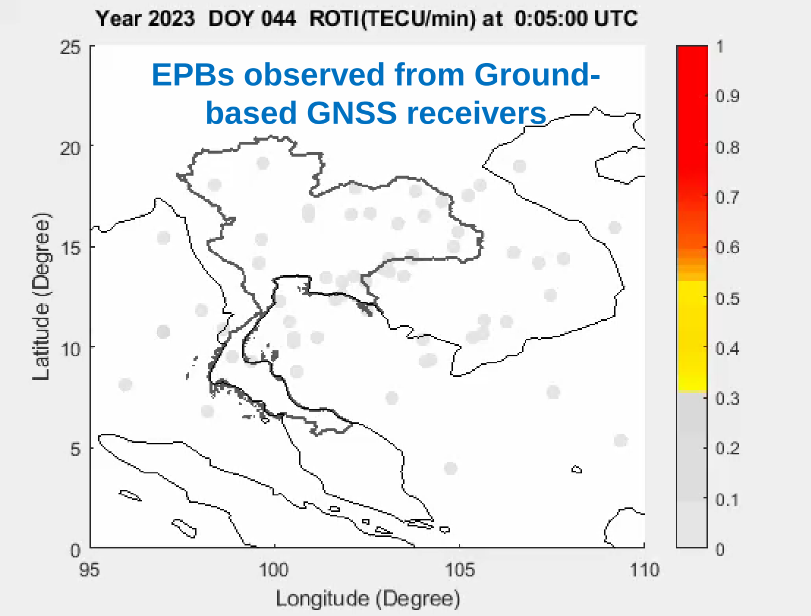
Equatorial Plasma Bubbles (EPB)

- EPBs are local ionospheric disturbances which originate near magnetic equator; low density inside the EPB

- EPBs occur after sunset and disappear before sunrises

- EPBs can be observed by various methods including VHF radar, Ionosonde, in-situ satellites and ground based GNSS receivers among others





GNSS Positioning and Ionospheric Delay

Code pseudorange

$$P_i = \rho + c(dt - dT) + c(b_i^r + b_i^s) + \delta_{ion,i} + \delta_{trop,i} + \varepsilon_{P_i}$$

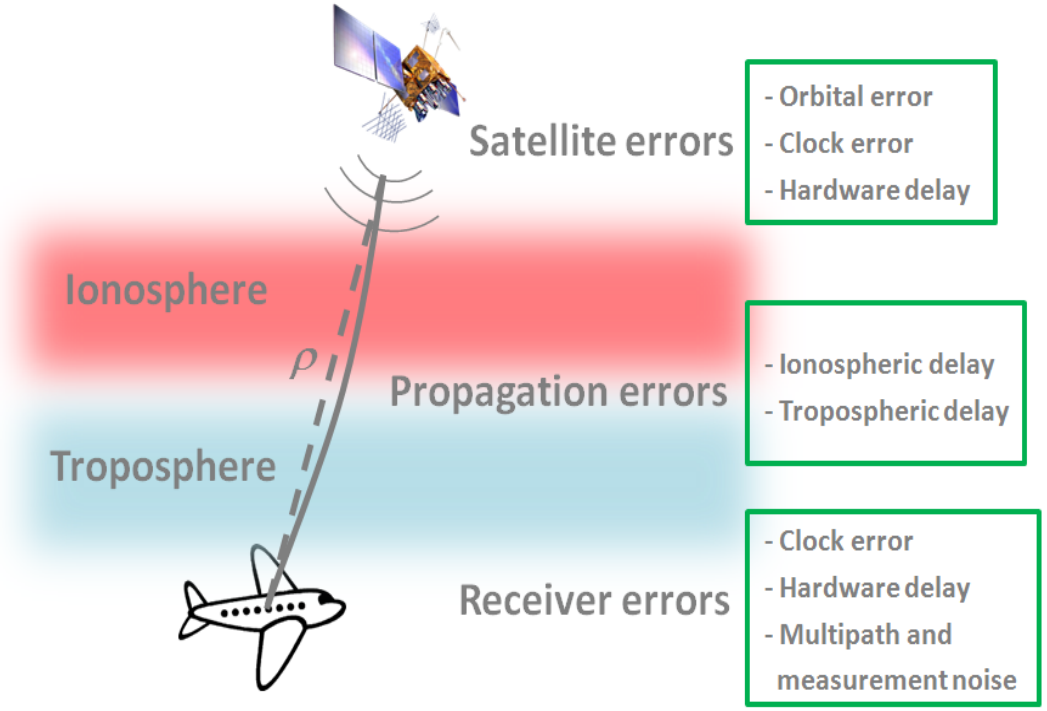
True distance | Clock offset | Hardware delay | Ionospheric delay | Tropospheric delay | Multipath and measurement noise

Carrier-phase pseudorange

$$L_i = \rho + c(dt - dT) + c(b_{r,i} + b_{s,i}) - \delta_{ion,i} + \delta_{trop,i} + \lambda_i N_i + \varepsilon_{L_i}$$

Initial phase ambiguity

$$\delta_{ion,i} = \frac{40.3}{f^2} \int N_e ds$$

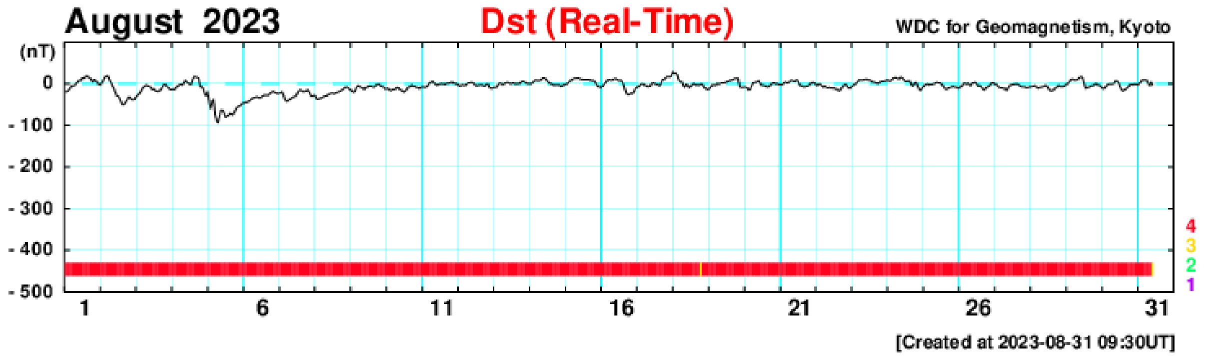


N_e is the electron density in ionosphere which can vary with solar activity.

Ionospheric irregularities such as equatorial plasma bubbles (EPB)
At low-latitude can degrade the positioning performance

Ionospheric disturbance Indices

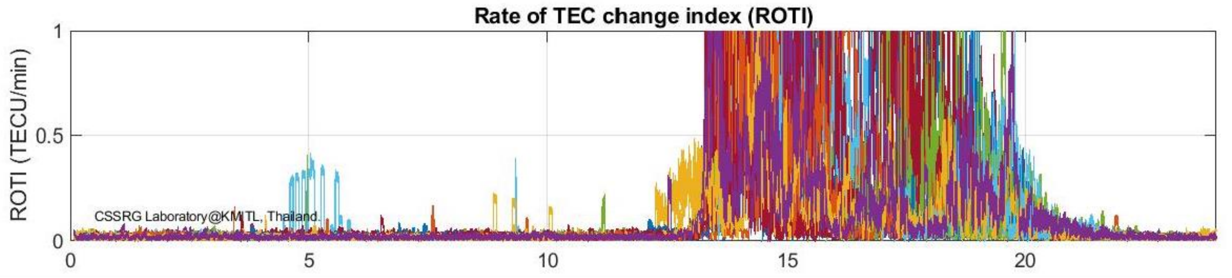
- **Global Condition** (earth's geomagnetic activities)
  - K_p - Planetary K-index
  - Dst – Disturbance



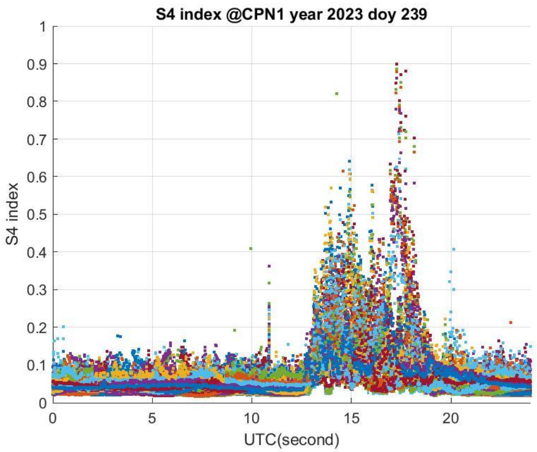
- **Local Ionospheric Conditions**
  - Rate of TEC Change Index (ROTI)

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

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

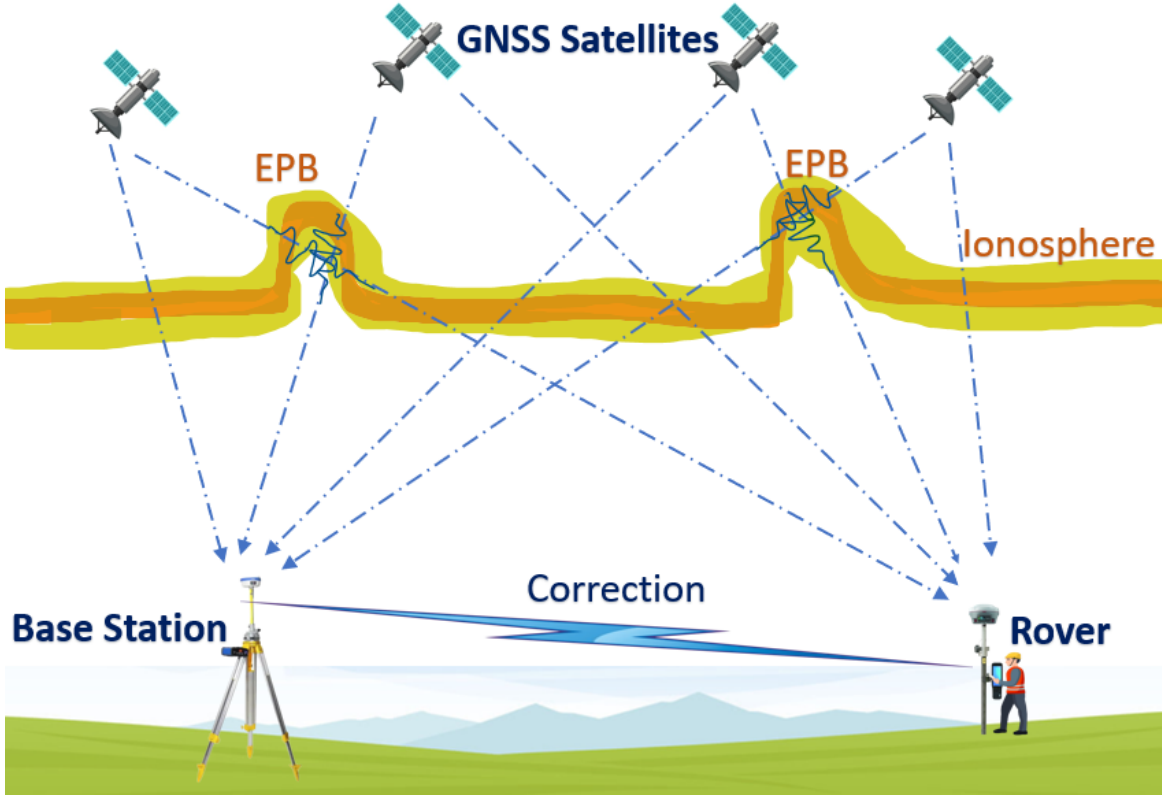


  - Scintillation (S4 index)



Real-Time Kinematic (RTK) Positioning

- RTK can provide cm-level accuracy.
- RTK require at least two station: Base station and Rover station
- **Base station** – stationary receiver with known coordinates and send corrections
- **Rover station** – rover station compute its position based on measured psudoranges and corrections from base station
- Nowadays, virtual reference station (VRF) based on network of base stations are also used.
- RTK positioning is widely used for land surveying, mapping, agriculture, unmanned aerial vehicles and so on.



Real-Time Kinematic (RTK) Positioning

- RTK positioning model is based on double-difference code and carrier-phase measurement

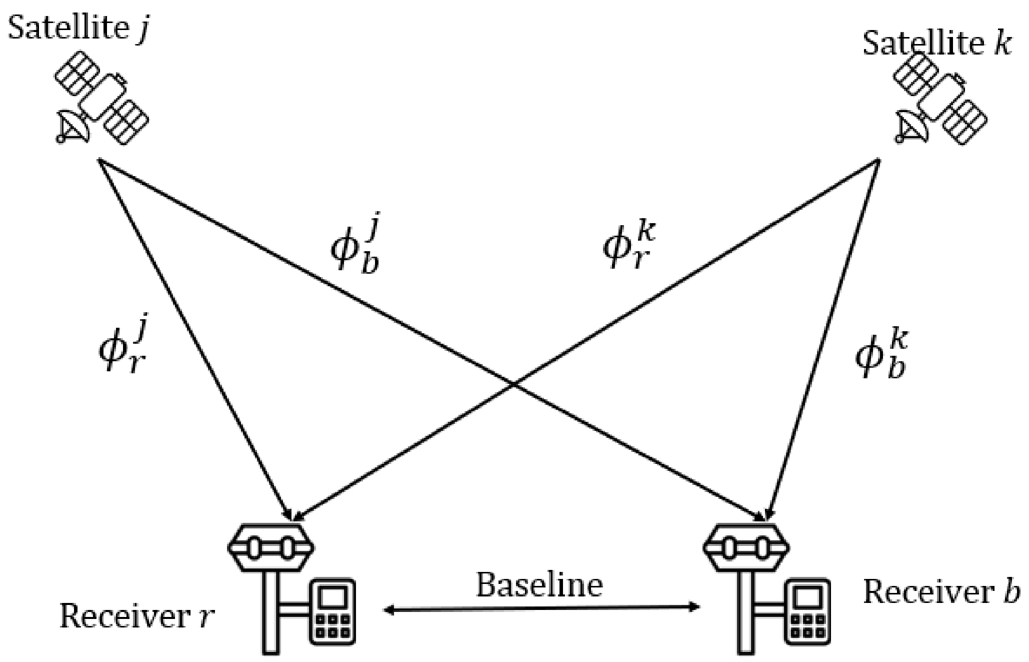
$$\phi_{rb,i}^{jk} = \rho_{rb}^{jk} - I_{rb,k}^{jk} + T_{rb}^{rk} + \lambda_i (B_{rb,i}^{j} - B_{rb,i}^{k}) + d\phi_{r,i}^{s} + \varepsilon_{\phi}$$

$$P_{rb}^{jk} = \rho_{rb}^{jk} - I_{rb,k}^{jk} + T_{rb}^{rk} + \varepsilon_{\phi}$$

- Extended Kalman Filter is used to obtain unknown state vector **x**

$$\mathbf{x} = (r_r^T, v_r^T, Z_r, G_{E,r}, Z_b, G_{E,b}, I^T, B_1^T, B_2^T)^T$$

- **LAMBDA** method is used to fix the float solution by ratio test.
- **Fixed solution** – integer ambiguities can be solved and reliable.
- **Float solution** – integer ambiguities cannot be solved.



National GNSS CORS network

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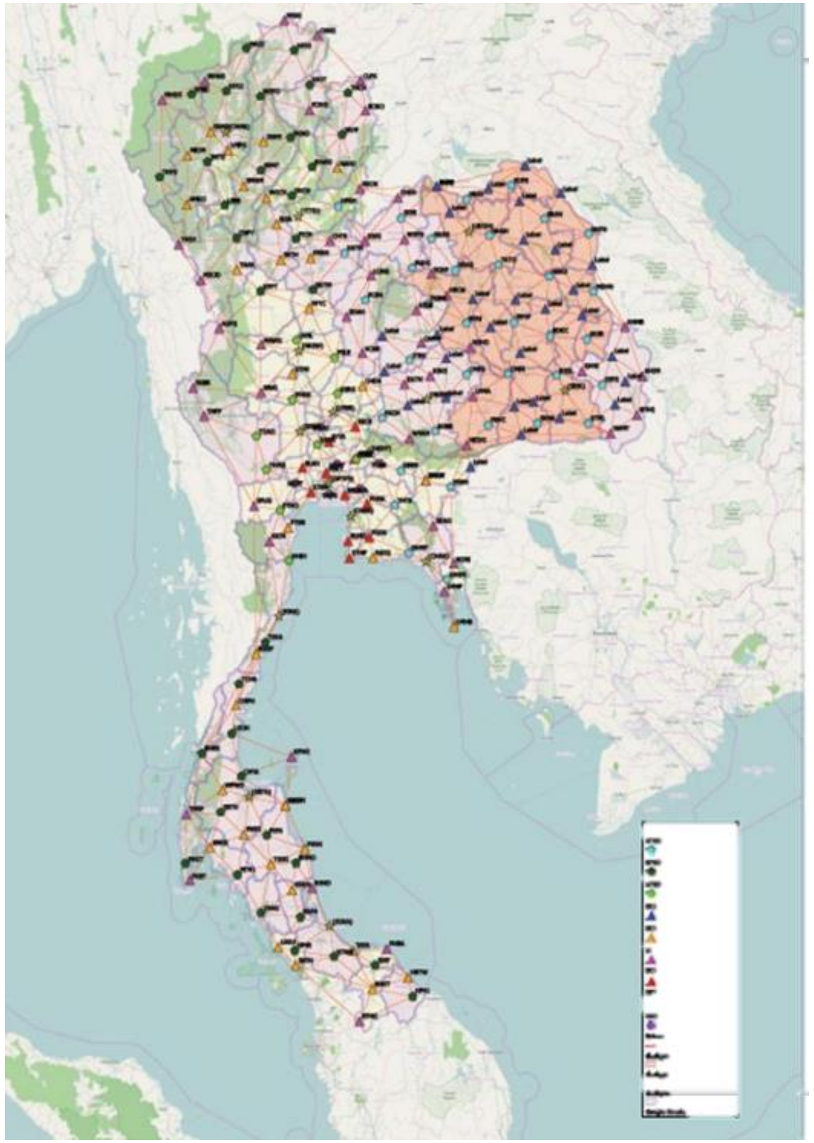
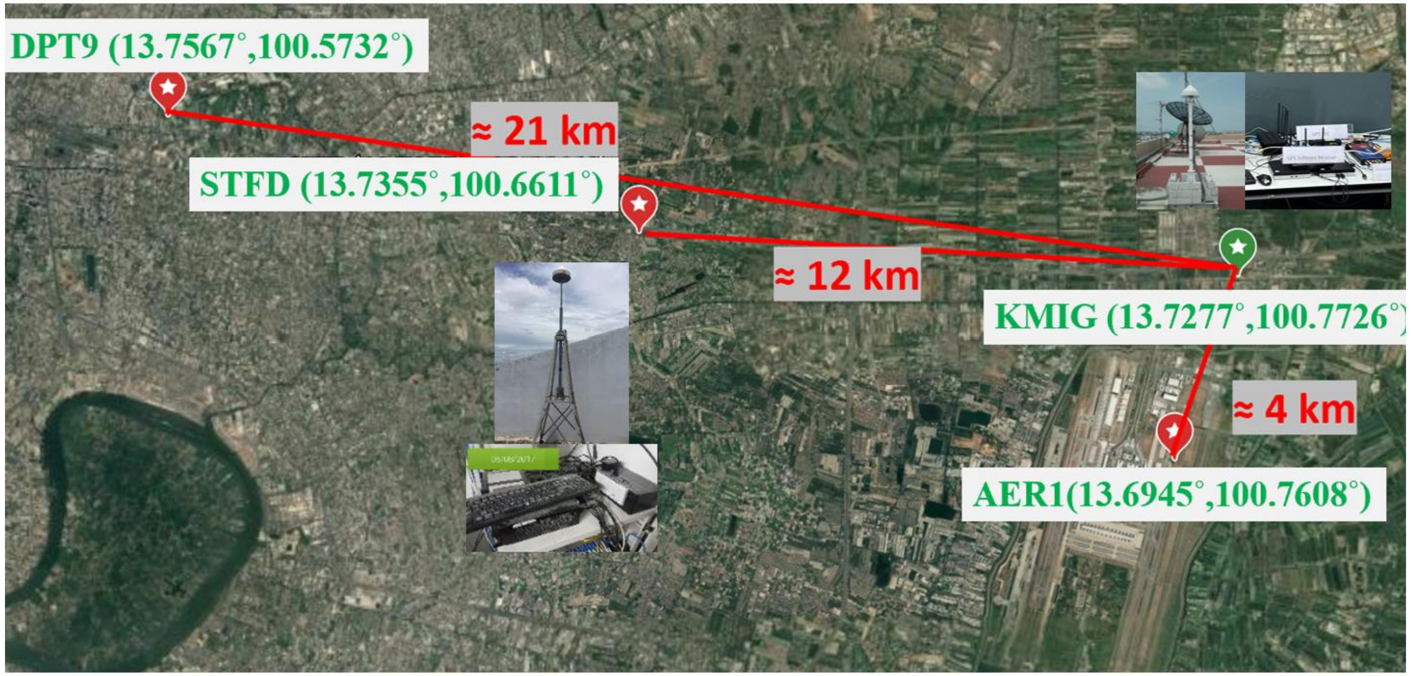


Experimental Setup - Stations



Station Pairs:

- **Base station**: KMIG (13.72º, 100.77º, Magn.Lat. 4º)
- **Rover station**:
  - AER1 (Rover) **– 4 km**
  - STFD (Rover) **– 12 km**
  - DPT9 (Rover) **– 21 km**

This study is performed over two years

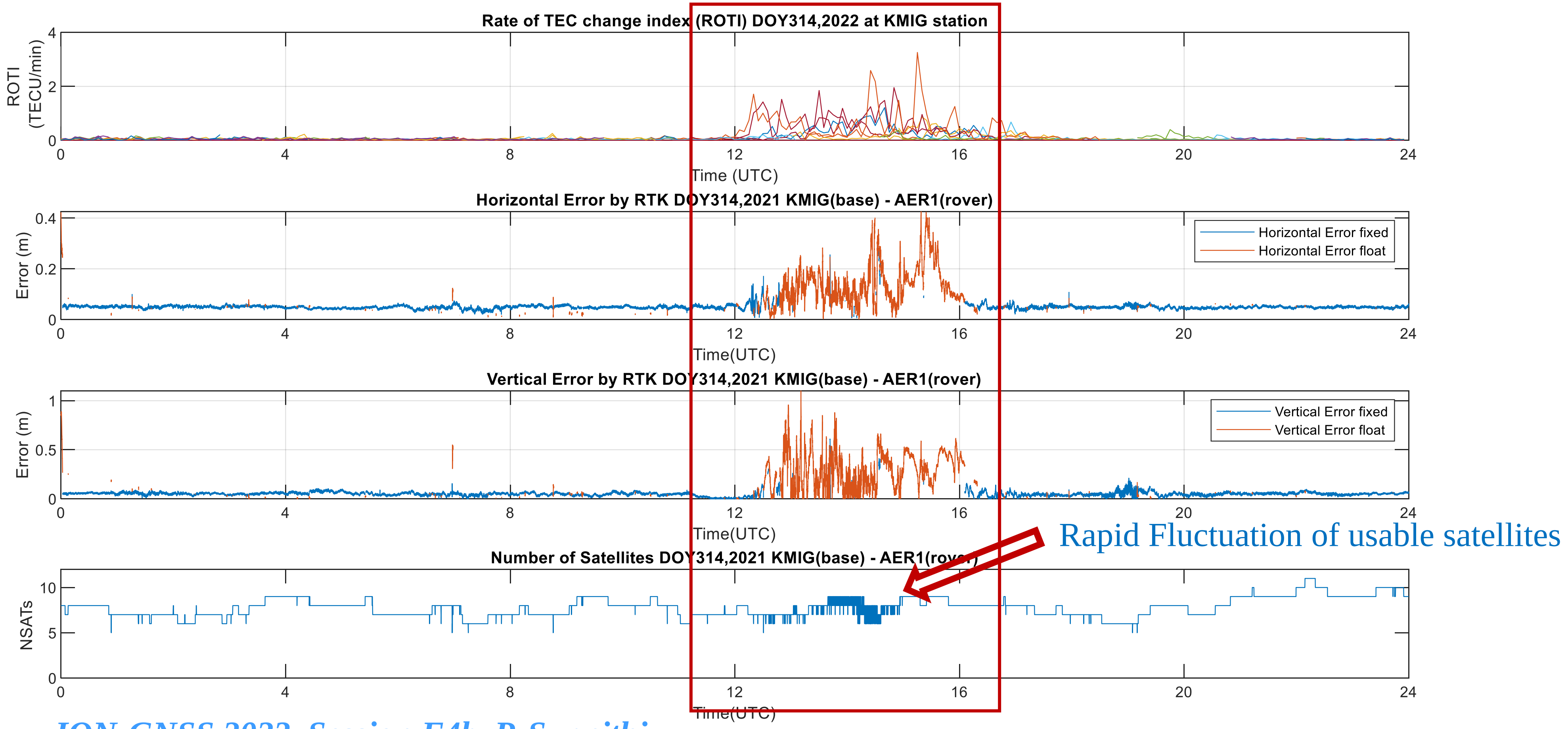
- **2020 (solar minimum of cycle #25)**
- **2022 (ascending phase of cycle #25)**

RTKLib (2.4) Parameters

Constellation	GPS
Frequency	L1+L2
Filter Type	Forward
Elevation Mask	15˚
Constellation	GPS
Integer Ambiguity Resolution	Continuous

Results and Discussions - Positioning errors (4 km)

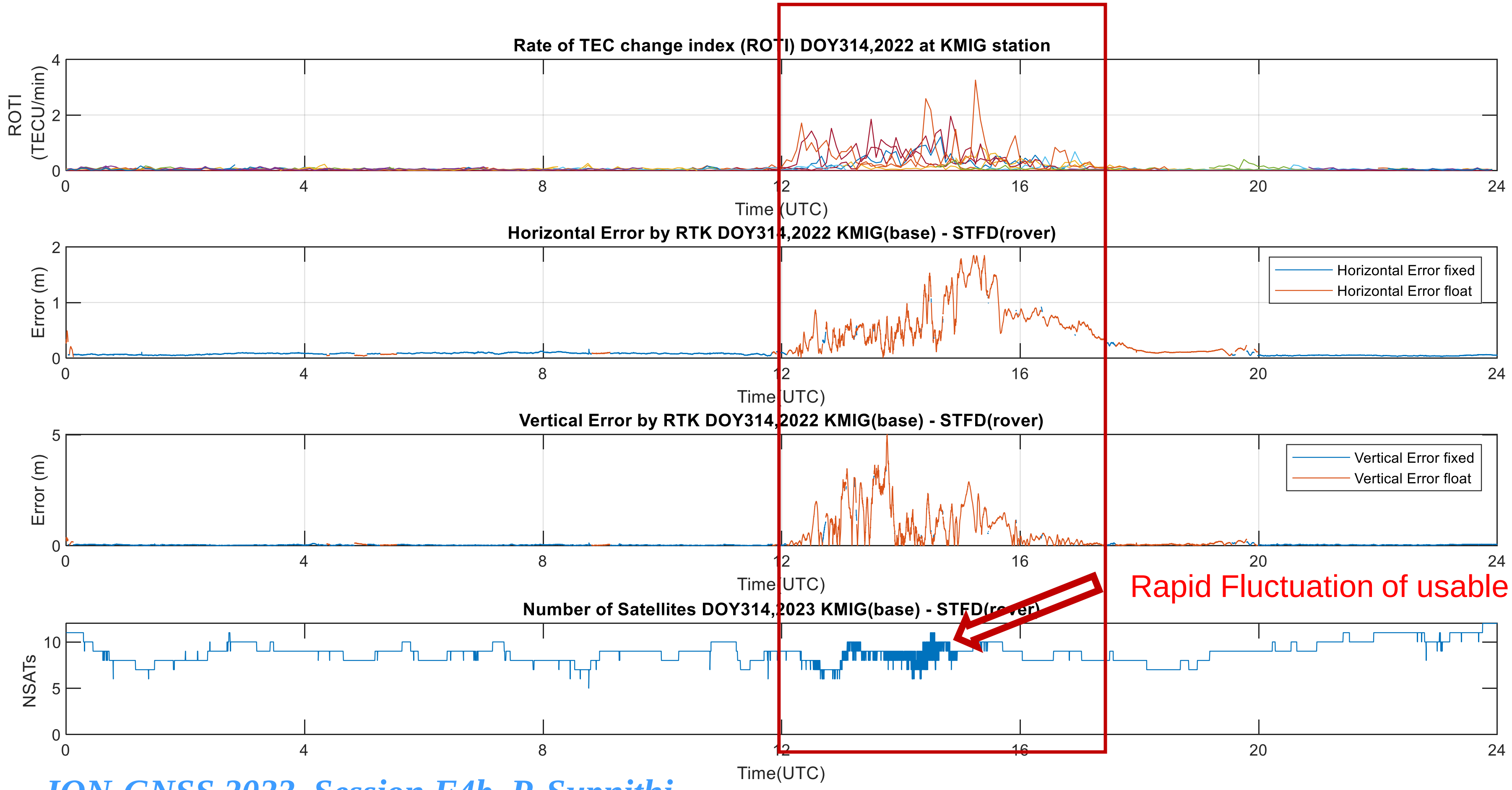
Positioning Errors - DOY 314, 2022
KMIG – Base, AER1 - Rover



4-km baseline

Results and Discussions – Positioning errors (12 km)

Positioning Errors - DOY 314, 2022
KMIG – Base, STFD - Rover (12 km baseline)

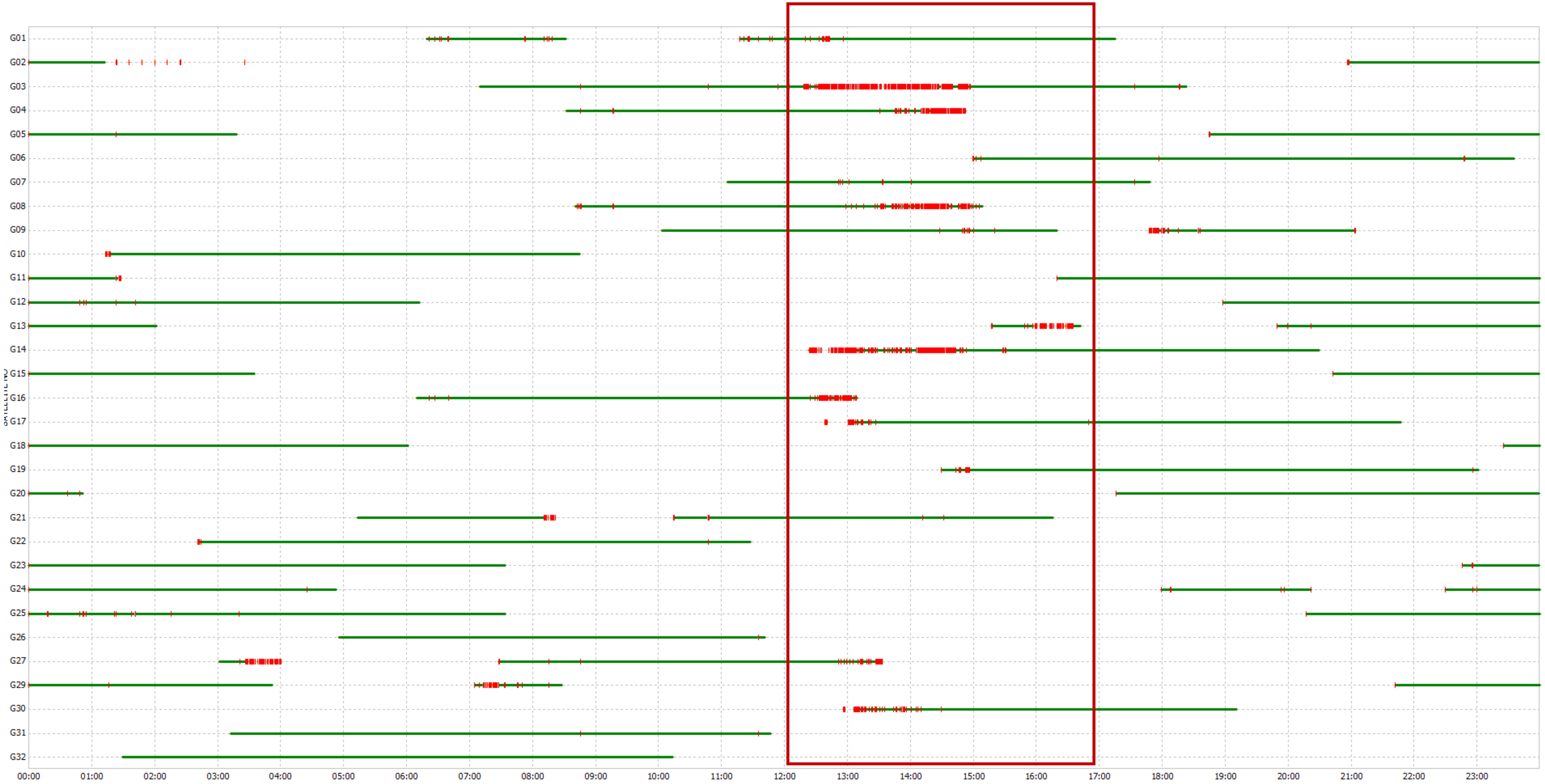


Rapid Fluctuation of usable satellites

12-km baseline

Results and Discussions – Cycle slips

Cycle-slip occurrence on DOY 314, 2022 on KMIG station

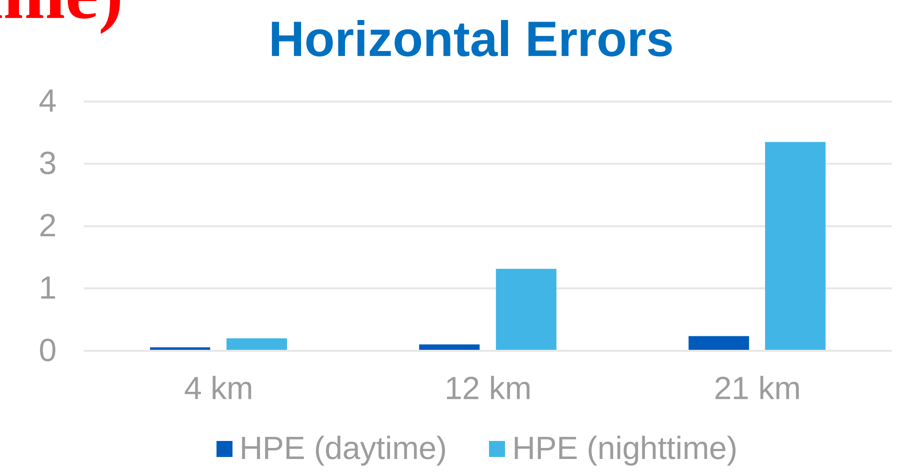


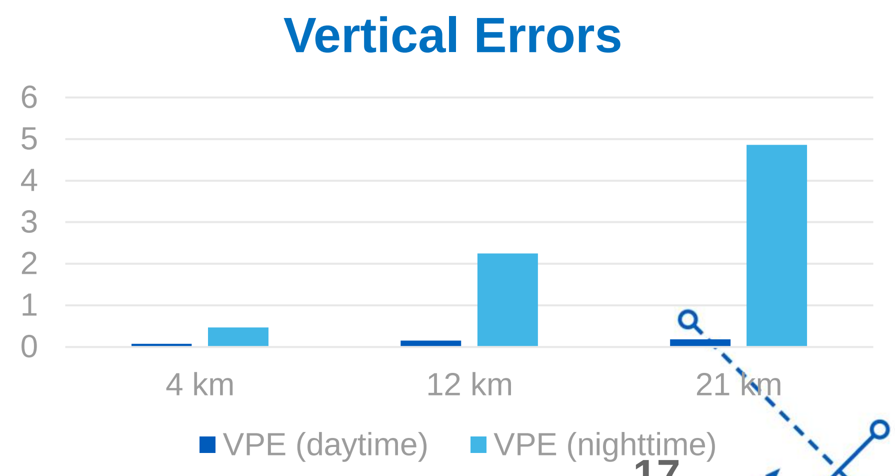
Results and Discussions

Summary results on DOY 314, 2022 (Nighttime)

- Vertical positioning errors are higher than horizontal positioning error
- Positioning errors are higher during disturbed period (night-time)
- Positioning errors are higher a longer baseline

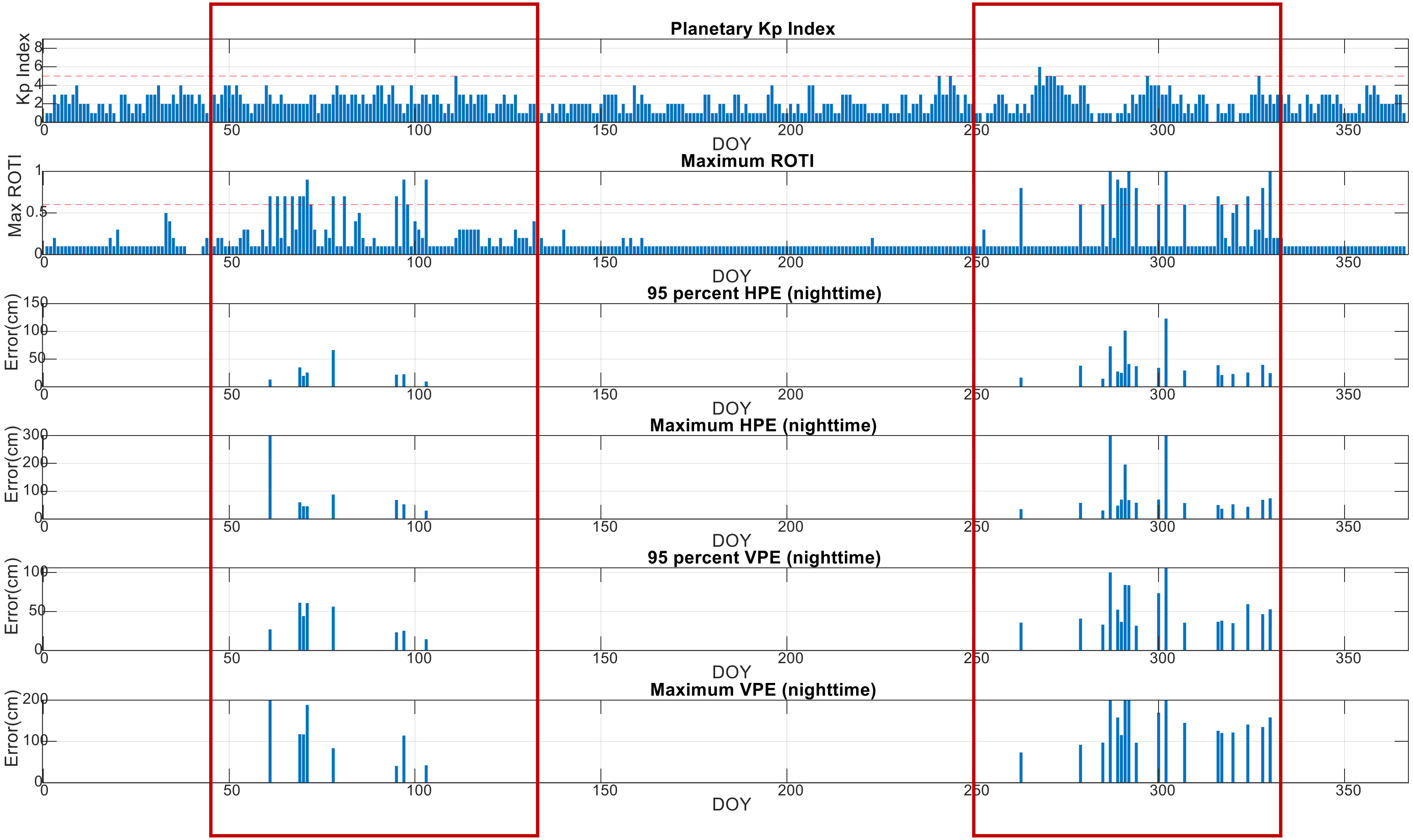
Baseline length	Percent of fixed/float solution		Positioning Error (meters)			
			Quiet Period (daytime)		Disturbed Period (nighttime)	
	fixed	float	HPE	VPE	HPE	VPE
AER1 (4 km)	90.8	9.2	0.0579	0.0759	0.1995	0.4664
STFD (12 km)	68.5	31.5	0.1038	0.1528	1.3154	2.2486
DPT9 (21 km)	46.6	53.4	0.2380	0.17943	3.3514	4.8587





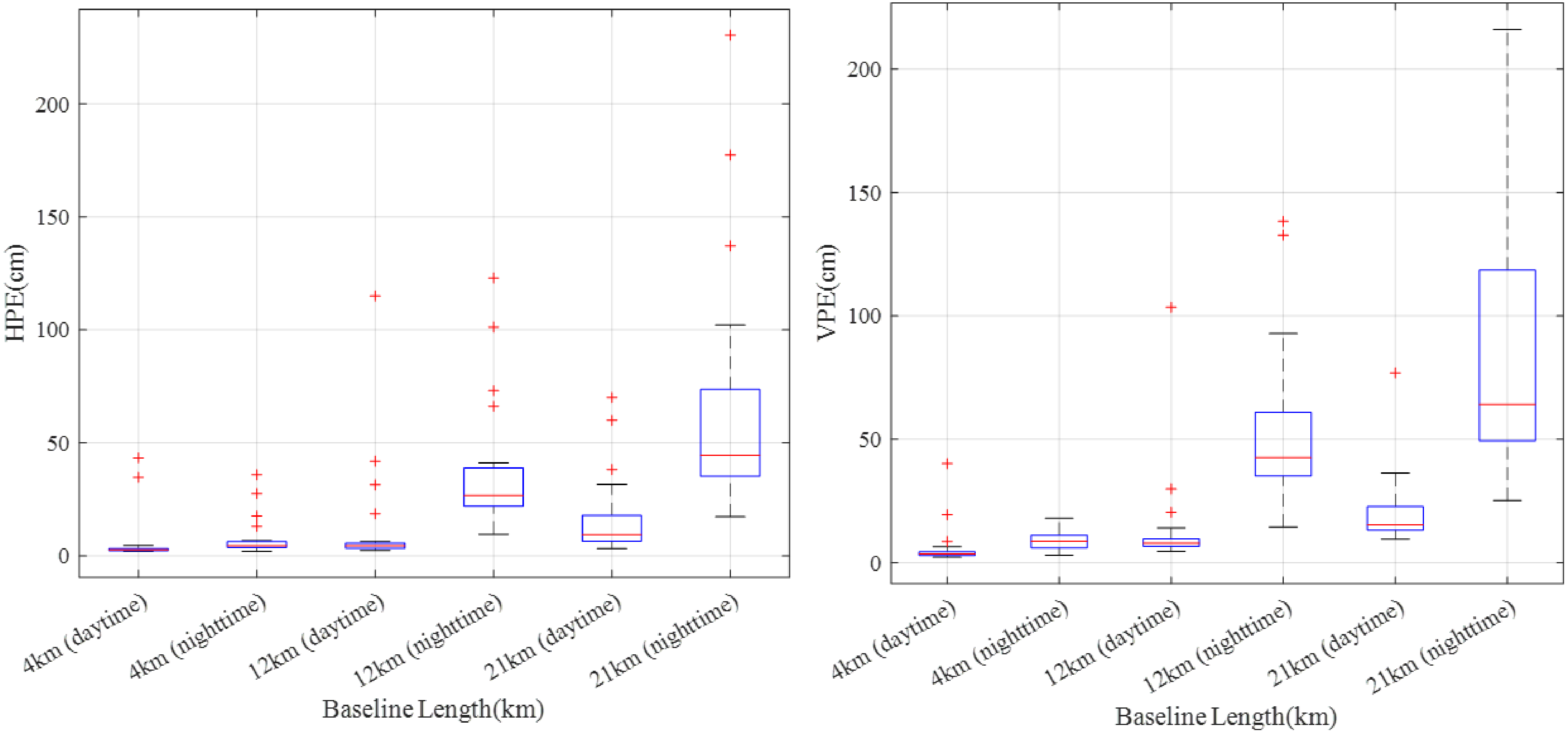
Results and Discussions - Daily positioning errors (2020)

Daily positioning errors in 2020 (medium baseline 12km)



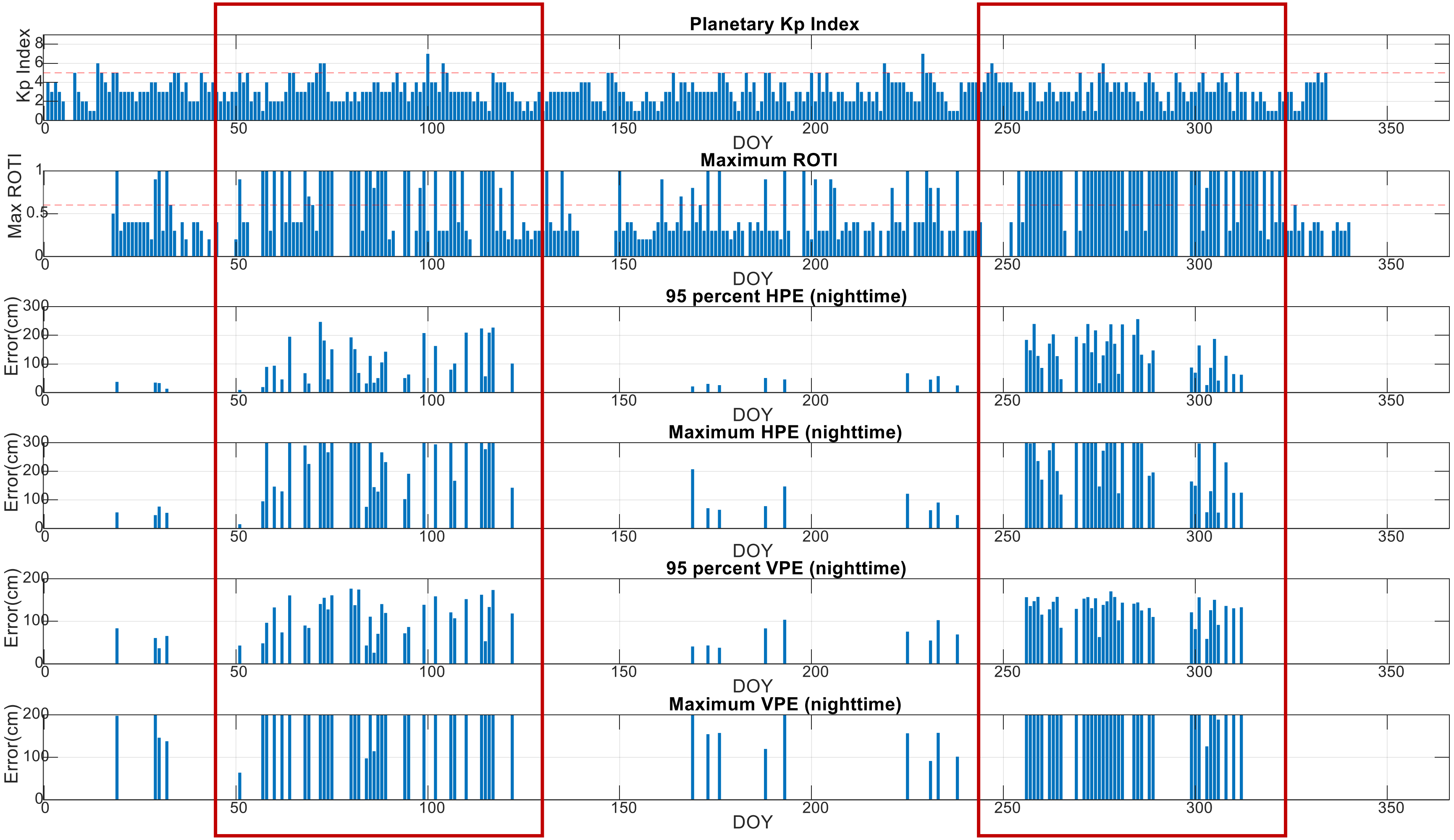
Results and Discussions

Box plots of positioning errors in 2020



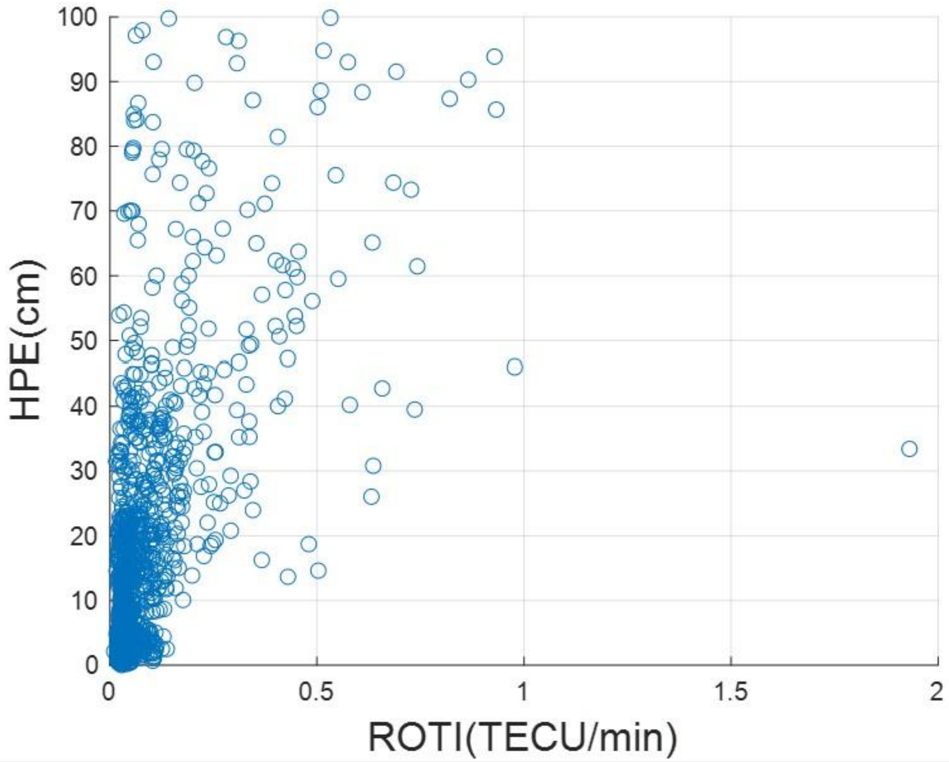
Results and Discussions - Daily positioning errors (2022)

Daily Positioning errors by RTK at 2022 (medium baseline 12km)

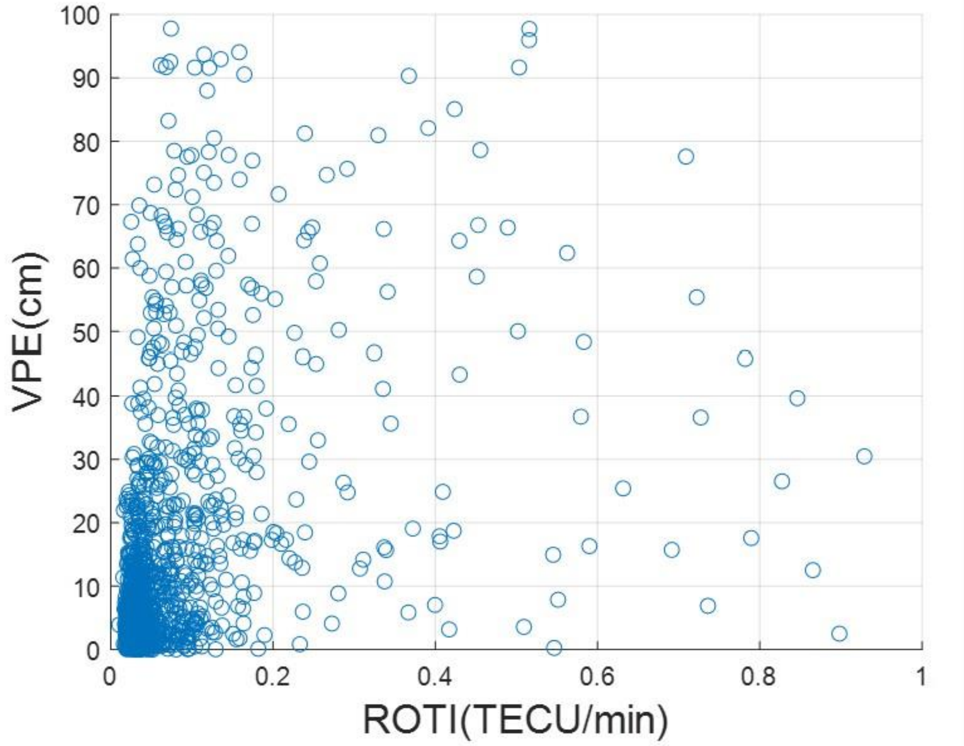


Results and Discussions - HPE,VPE vs. ROTI

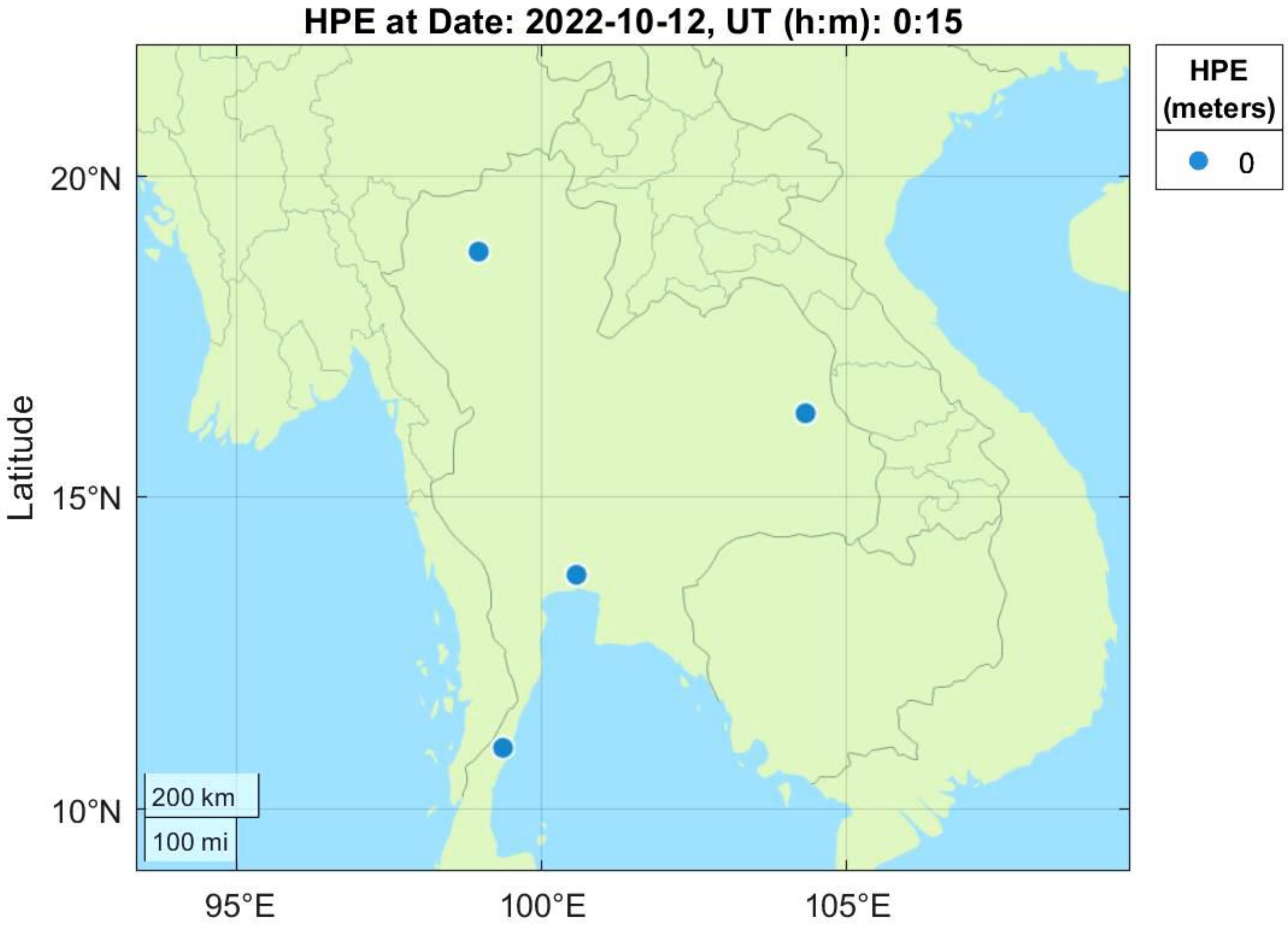
HPE vs. ROTI (2020)



VPE vs. ROTI (2020)



RTK Map Demo


HPE at Date: 2022-10-12, UT (h:m): 0:15
HPE (meters)
0
20°N
15°N
10°N
Latitude
95°E
100°E
105°E
200 km
100 mi

Conclusions

- Horizontal and vertical positioning errors
  → Higher during disturbed periods (nighttime) quiet periods (daytime)
  → increase with longer baselines between the rover and base station
  → Occurs more during equinoxes

- During severe ionospheric disturbed periods
  → rapid fluctuation in no. of usable satellites
  → lots of cycle slips

- Most of high RTK positioning errors are caused by local ionospheric disturbances such as EPBs rather than global events.

Acknowledgement

Funding

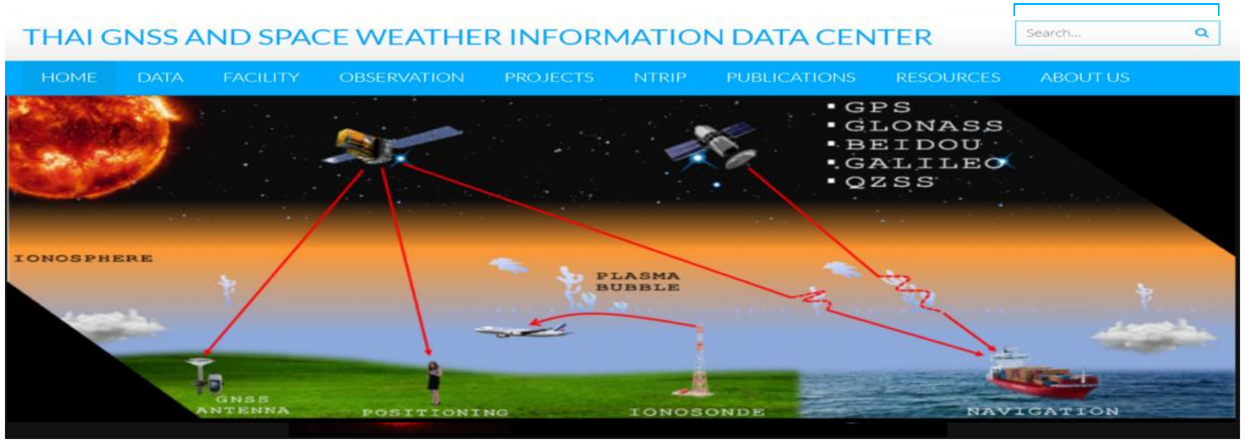
- King Mongkut's Institute of Technology Research Fund
  - Grant no. KREF016422 , RE-KRIS/FF65/35
- NICT ASEAN-IVO (Phase II)
  - GNSS and Ionospheric Data Products for Disaster Prevention and Aviation in Magnetic Low- Latitude Regions (Phase II)

Data Provider

- King Mongkut's Institute of Technology Ladkrabang, Thailand
- Stamford International University, Thailand
- Department of Public Works, Town & Country Planning (DPT), Thailand
- Aeronautical Radio Thailand
- Electronic Navigation Research Institute, Japan
- National Institute of Information and Communications Technology (NICT), Japan

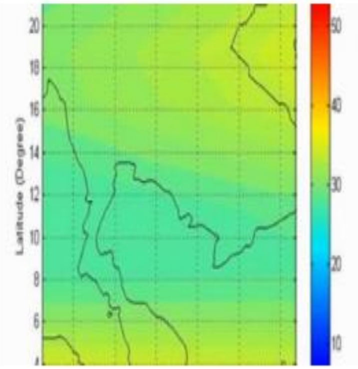
Thai GNSS and Space Weather Information Center

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

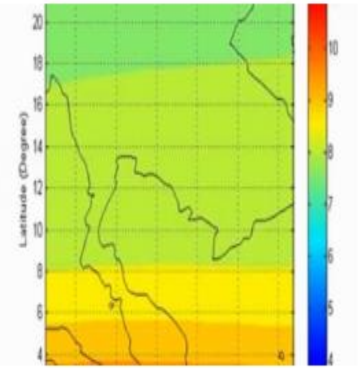


WELCOME

KNOWLEDGE



VTEC IRI MODEL



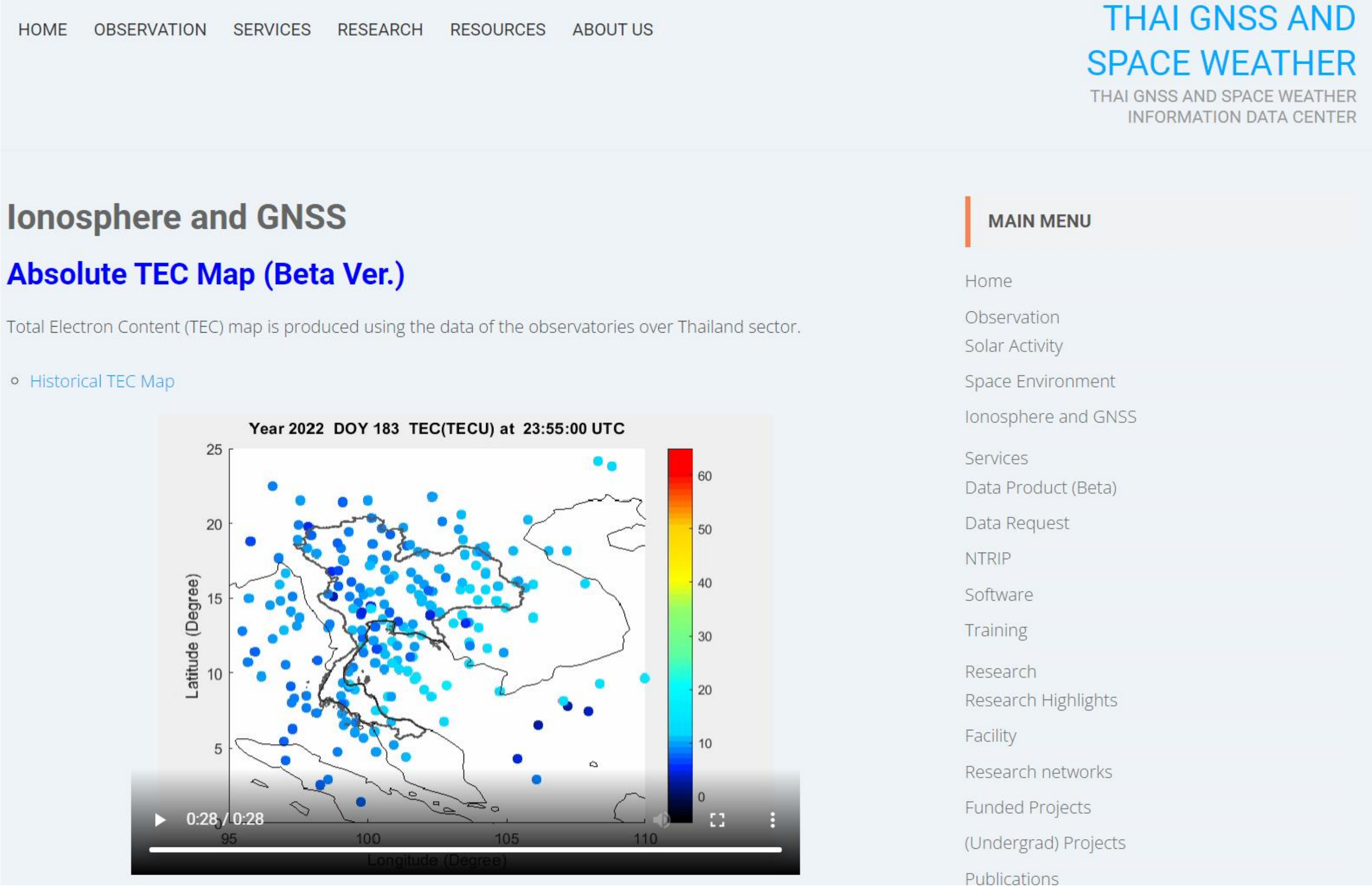
FOF2 IRI MODEL

SS and Space Weather Information Data Center hosted at King Mongkut's Institue of Technology Ladkrabang (KMITL)

rent status of GNSS and ionospheric monitoring networks and the efforts to create a GNSS and ionospheric database in Thailand. These data are the Ionosphere, Troposphere, GPS/GNSS technology, Geodesy and applications on the aeronautical navigation, satellite communication, hers. At present KMITL, Chulalongkorn University, Chaingmai University, NICT as well as Kyoto University, Japan have cooperated to install a itoring equipment such as ionosondes, all-sky imager, magnetometer as well as GNSS receivers in various locations of Thailand such as kok, and Phuket. Other GPS networks and ionosonde stations exist, whereby each network is owned and operated independently. For example, s 11 stations, the Royal Thai Navy owns three ionosonde stations, the Thai Meteorological Department houses 5-7 GPS receivers and the d owns 3-4 GPS receivers. We aim to create the database of GPS data and ionospheric parameters in the Thailand location. In our plan, the data ong various universities and agencies is being foreseen. At present, Thai GNSS and Space Weather Information Data Center is collecting the data ell as the ionosonde stations by using the script at each station to send the raw data through the internet to the server at KMITL. The database is of TEC and enhances the study of the ionosphere.


Thank you!

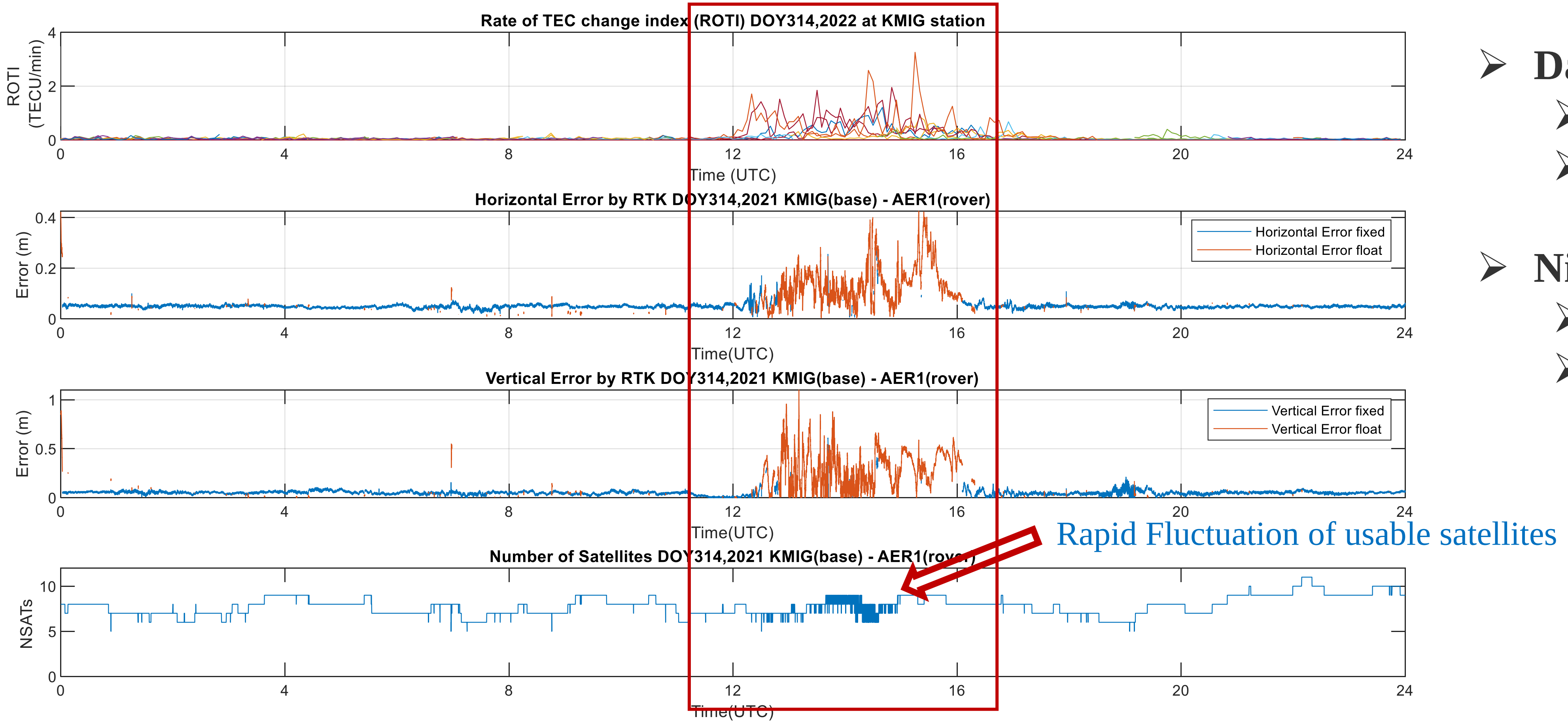
Thai GNSS and Space Weather Information Center



SCAN ME

Results and Discussion

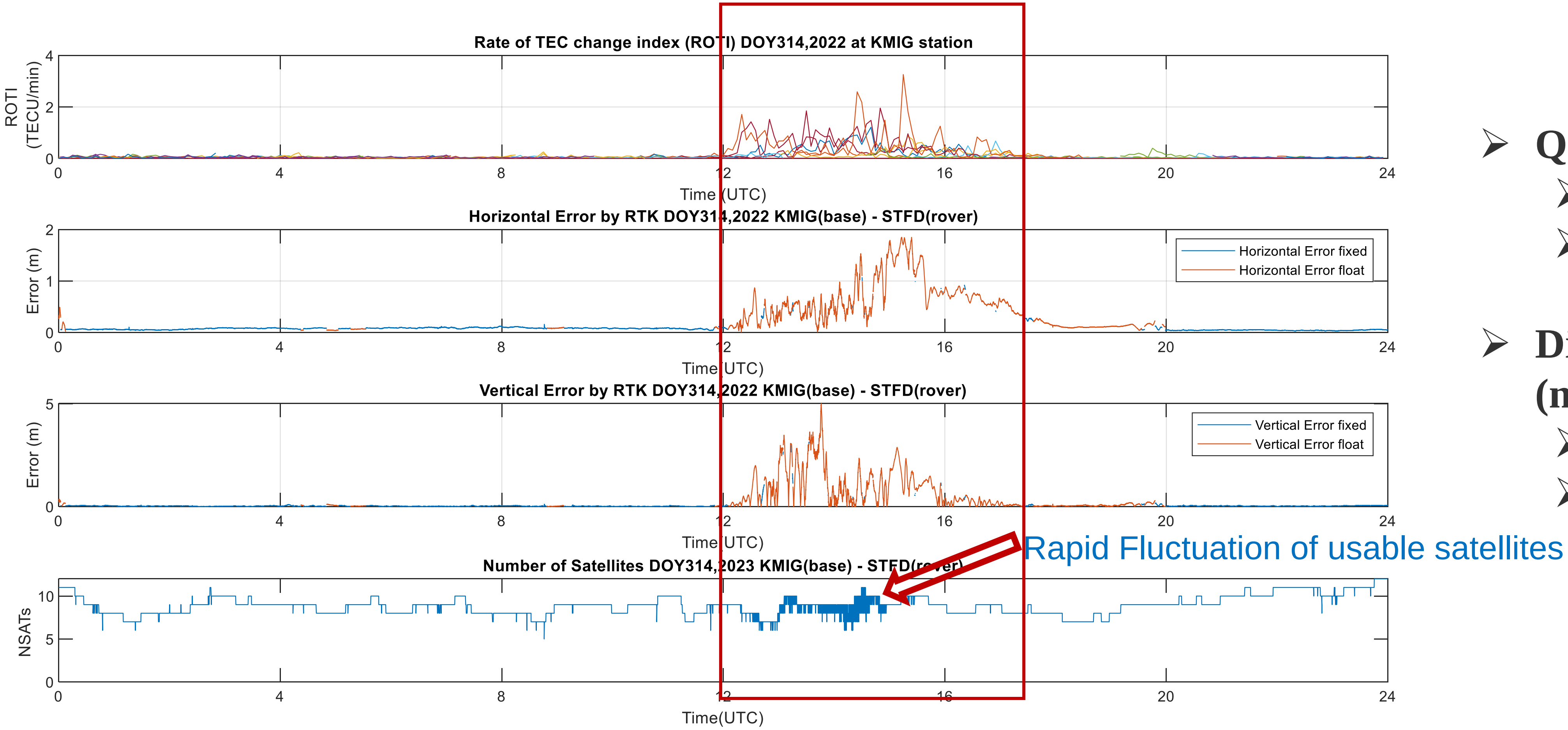
Positioning Errors at DOY 314, 2022 using KMIG as Base and AER1 at Rover (4 km baseline)



- Daytime
  - 0 to 12 UTC
  - 7 AM to 7 PM LT
- Nighttime
  - 12 to 24 UTC
  - 7 PM to 7 AM LT

Results and Discussions

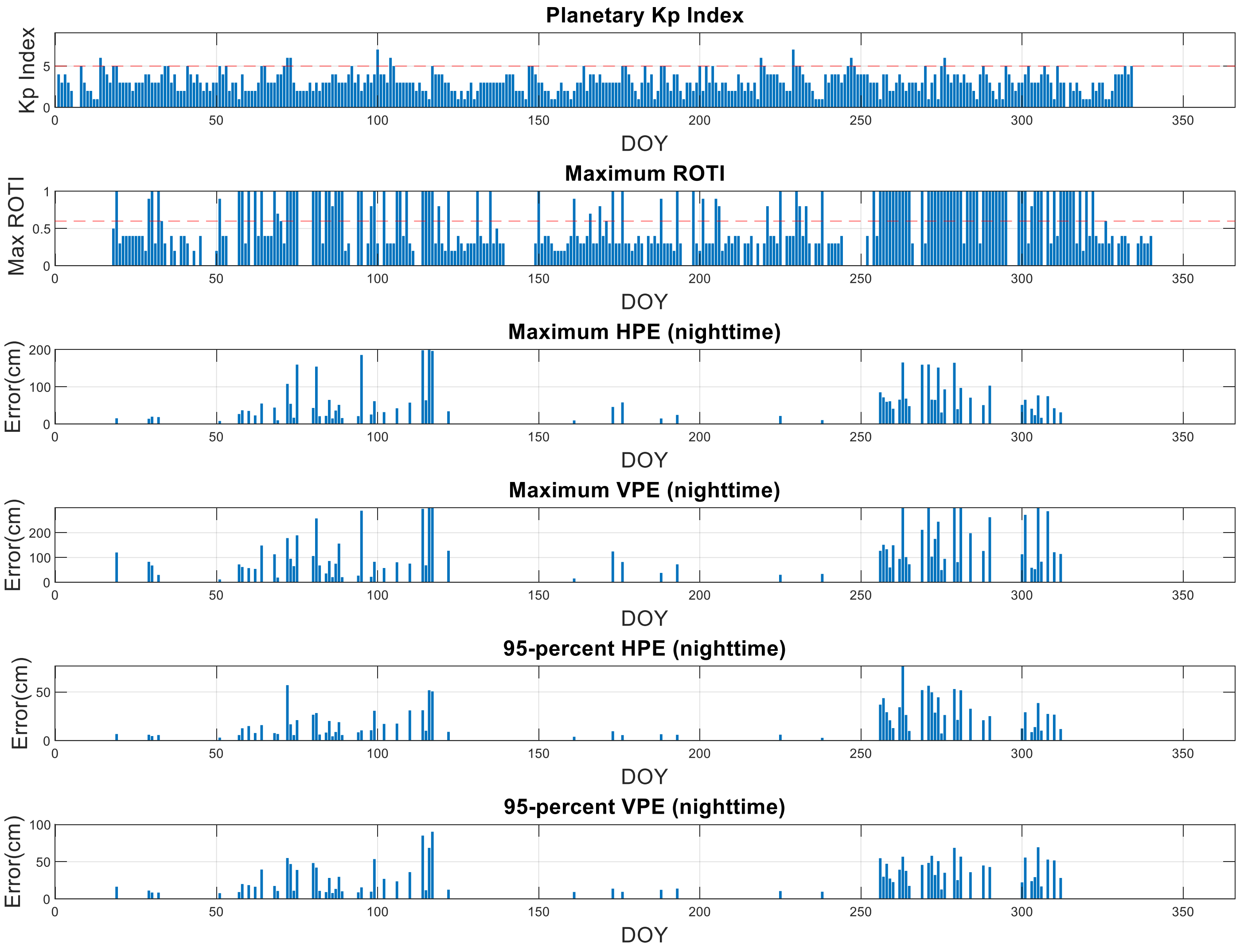
Positioning Errors at DOY 314, 2022 using KMIG as Base and DPT9 at Rover (21 km baseline)



- **Quiet Time (daytime)**
  - **0 to 12 UTC**
  - **7 AM to 7 PM LT**
- **Disturbed Time (nighttime)**
  - **12 to 24 UTC**
  - **7 PM to 7 AM LT**

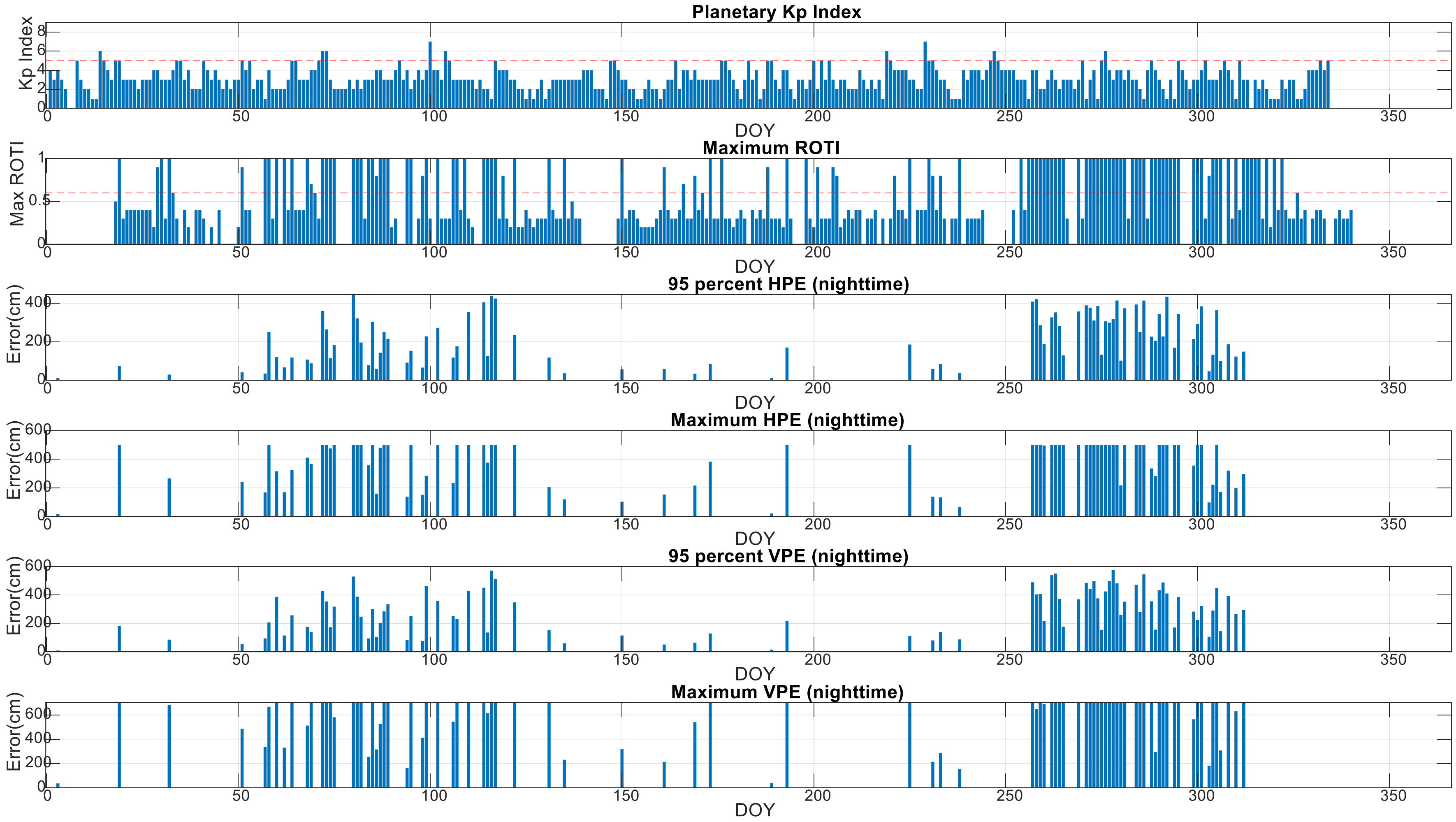
Results and Discussions

Summarized Positioning errors by RTK at 2022 (short baseline)



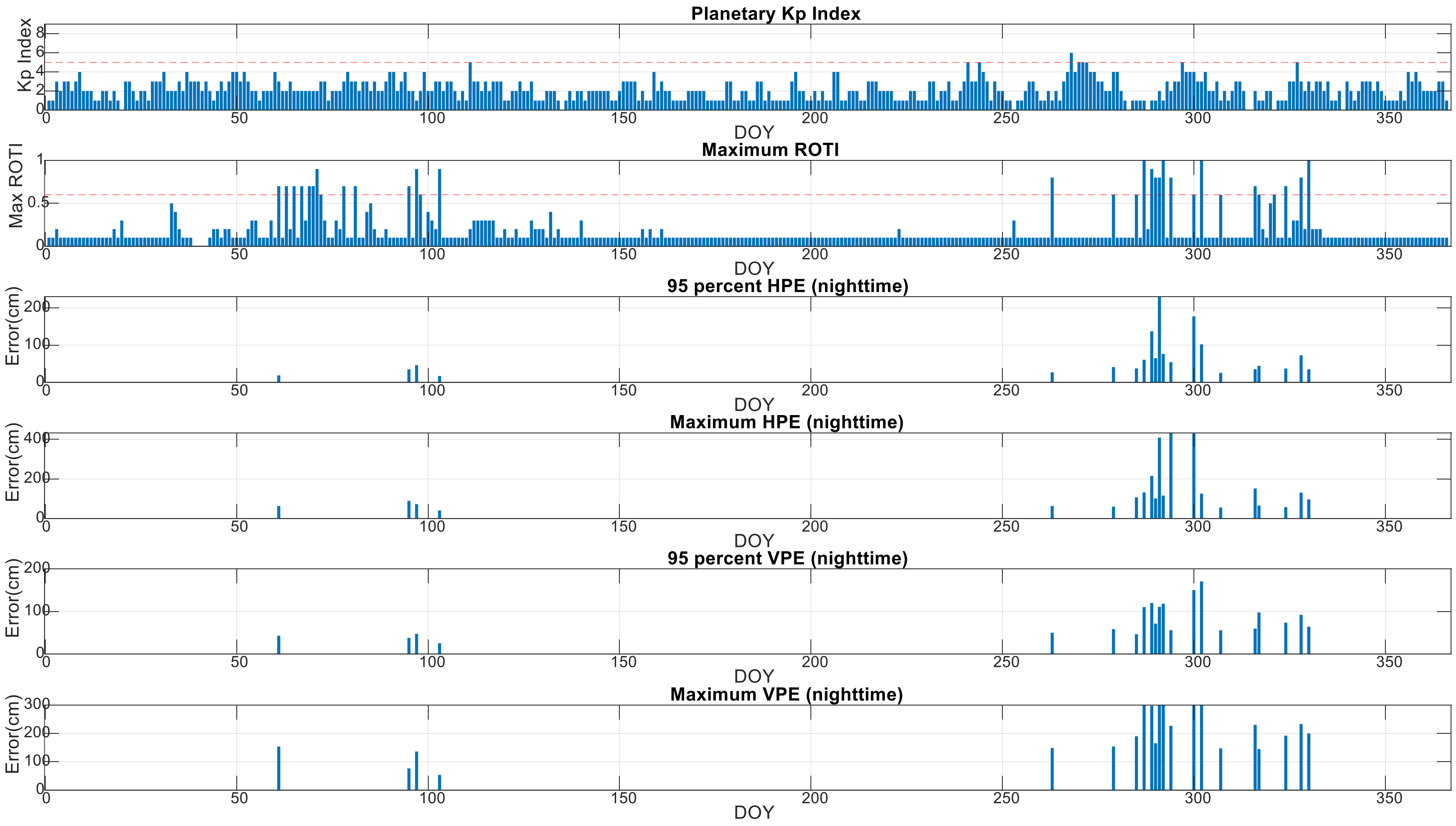
Results and Discussions

Summarized Positioning errors by RTK at 2022 (long baseline)



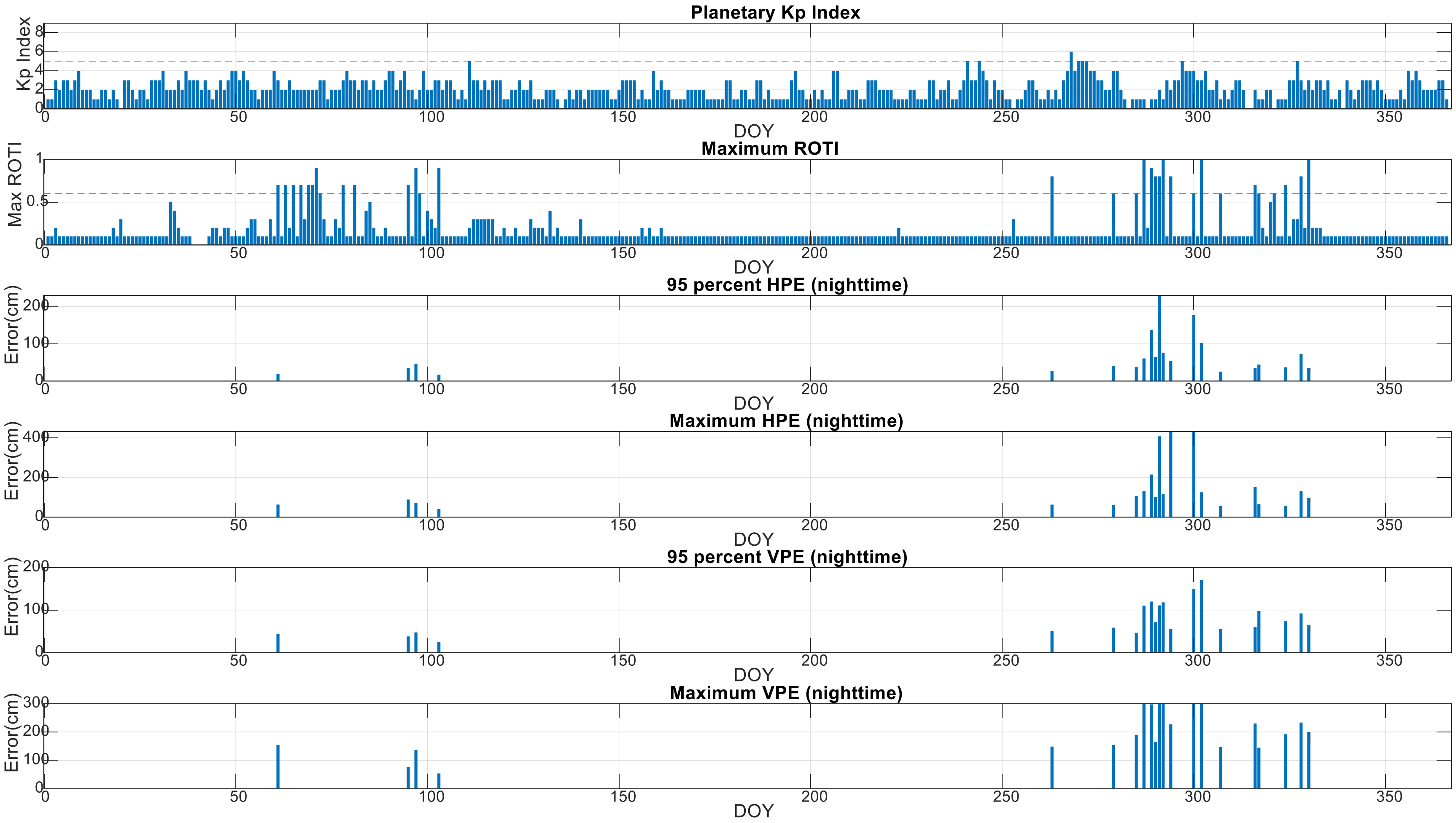
Results and Discussions

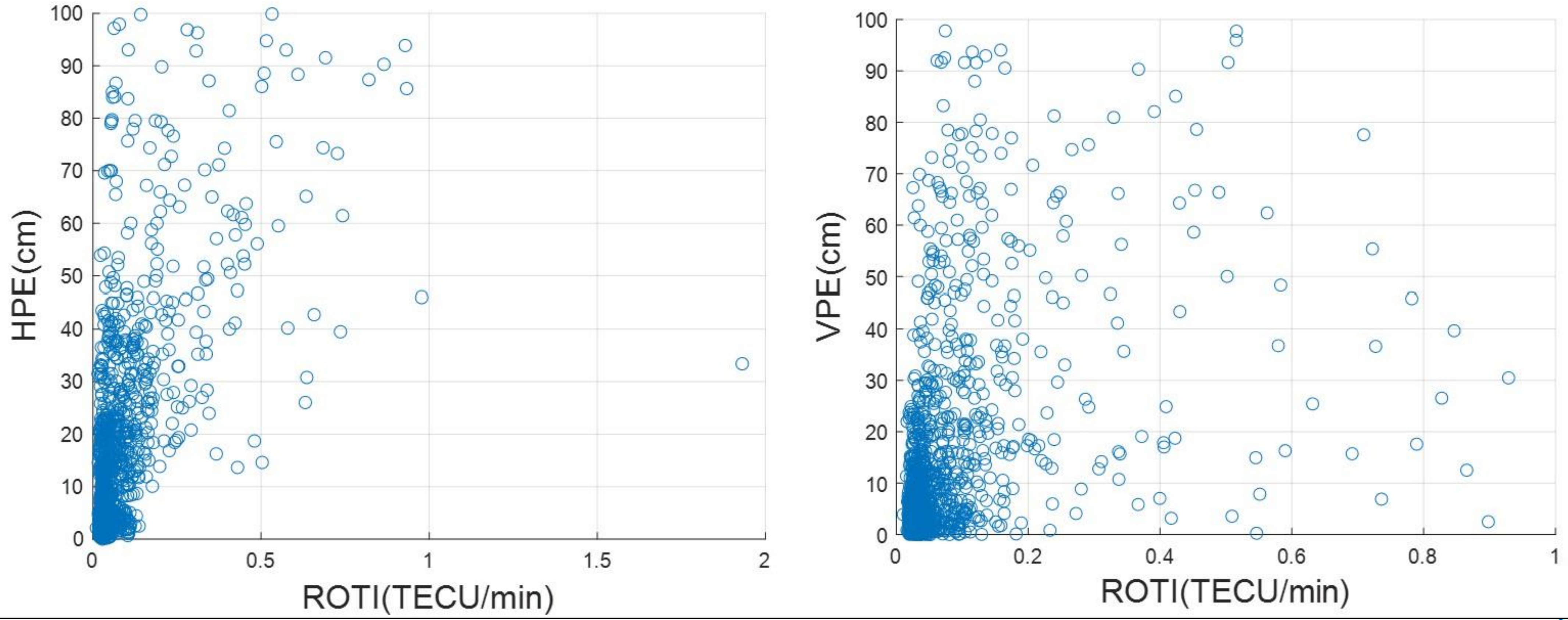
Summarized Positioning errors by RTK at 2020 (short baseline)



Results and Discussions

Summarized Positioning errors by RTK at 2020 (long baseline)




HPE(cm)
ROTI(TECU/min)
VPE(cm)
ROTI(TECU/min)