Analytical results of ionospheric delay gradient based on GPS monitoring stations near Suvarnabhumi airport in Thailand

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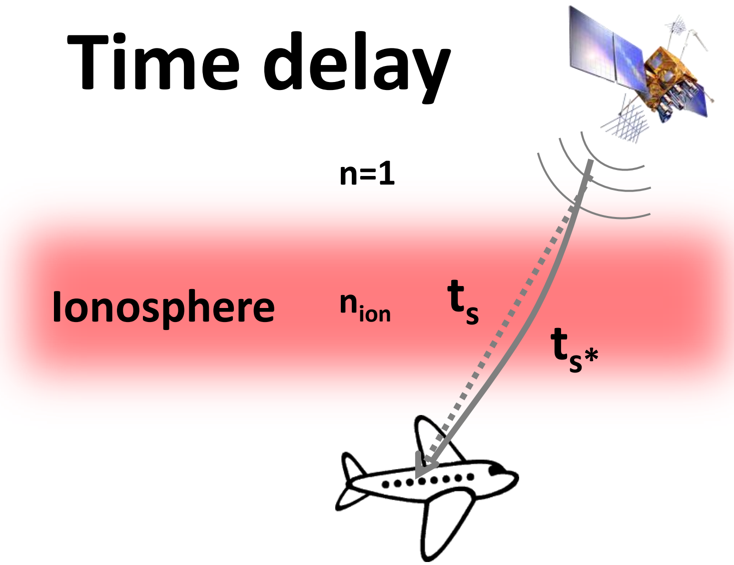
Outline

- Introduction
  - Ionospheric effects on GNSS signals
  - Ionospheric delay gradient effects on GBAS
- Experimental Setup
- Results and Discussions
- Conclusions

Ionospheric effects on GNSS signals

Time delay



- The extra time delay produced by the ionosphere is given by,

$$\delta t = t_{s*} - t_s = \frac{40.3}{cf^2}\int_{s*} N_e ds \qquad \text{(second)}$$

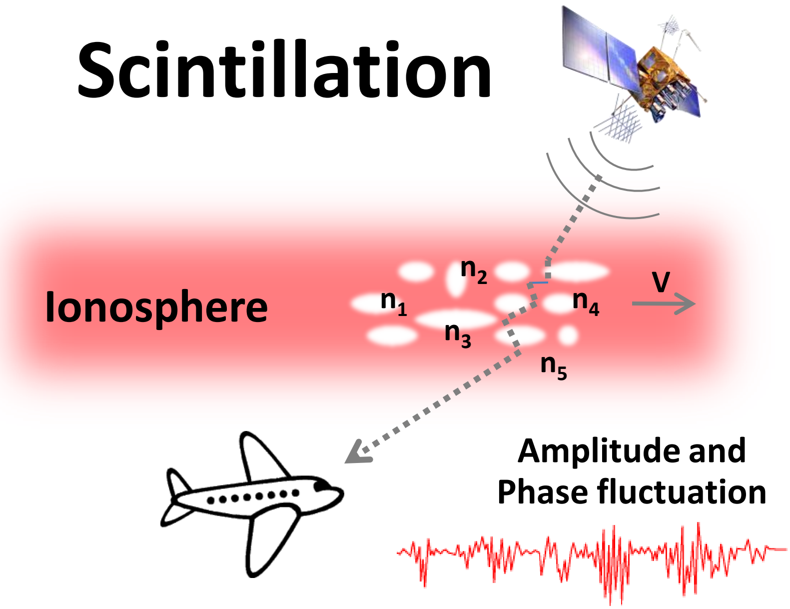
Ionospheric delay

$$I = c \times \delta t = \frac{40.3}{f^2} TEC \qquad \text{(meter)}$$

t_{s*} : Traveling time with an ionosphere

t_s : Traveling time without an ionosphere

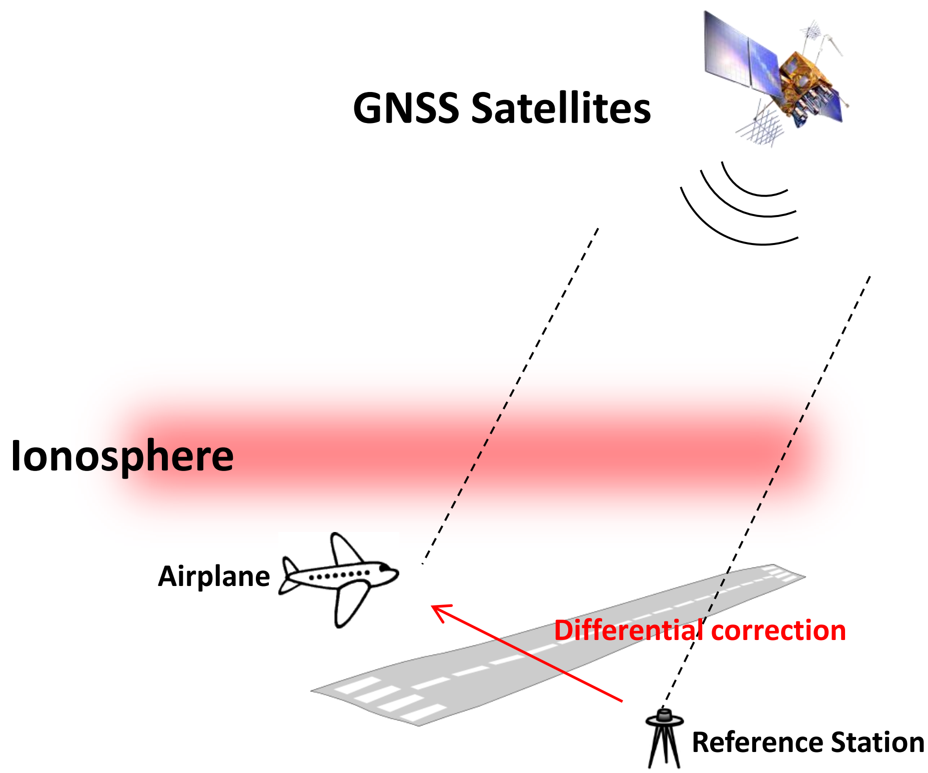
Scintillation



- The ionospheric irregularities cause the fluctuations in the refractive index (n).
- It causes the rapid fluctuations in amplitude and phase of GNSS signals.
- In the worst case, the receiver loss of lock the satellite signal.

Ionospheric effects to GBAS

GBAS (Ground-Based Augmentation System)



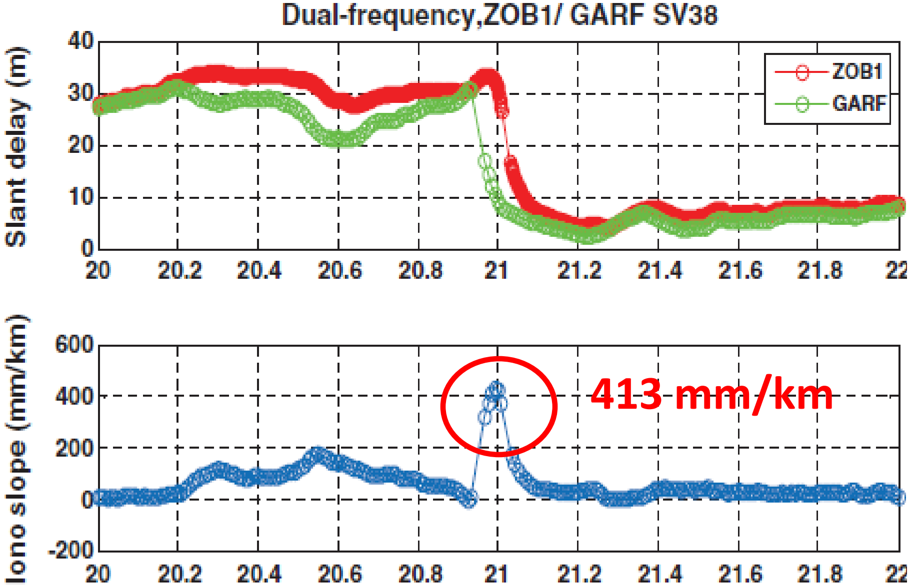
- The reference stations provide the differential corrections to the receiver that are equipped in the aircraft in the nearby area.

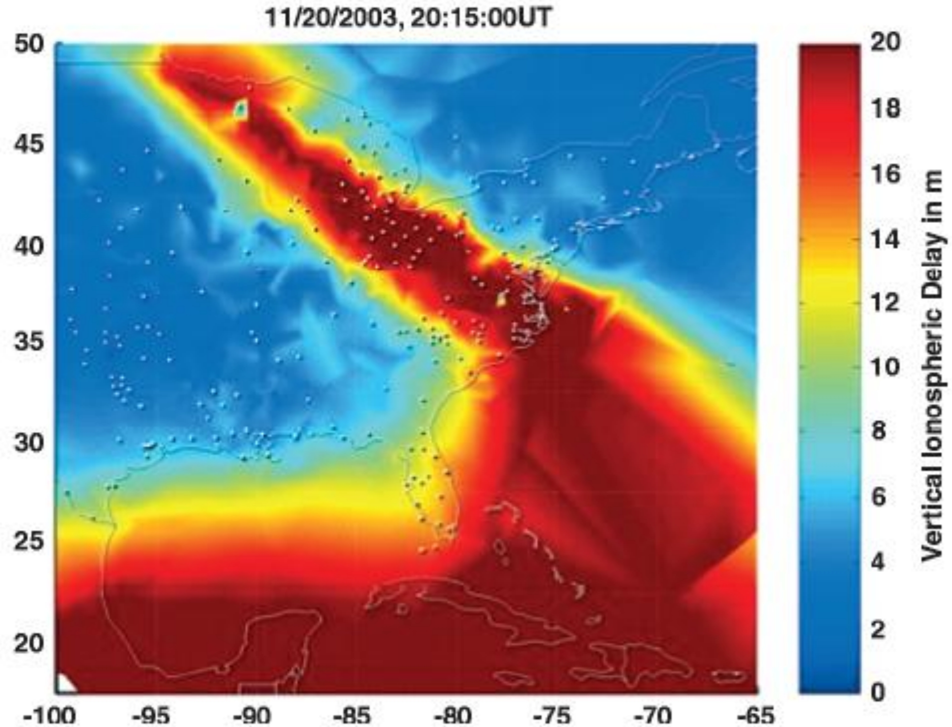
- However, the ionospheric irregularities cause the error of the differential correction information that broadcast to the aircraft.

- For the GAST-D (GBAS Approach Service Type D), the error of differential corrections shall be less than 1.5 m within 5 km of the runway threshold (300 mm/km).

Ionospheric effects to GBAS

20 November 2003



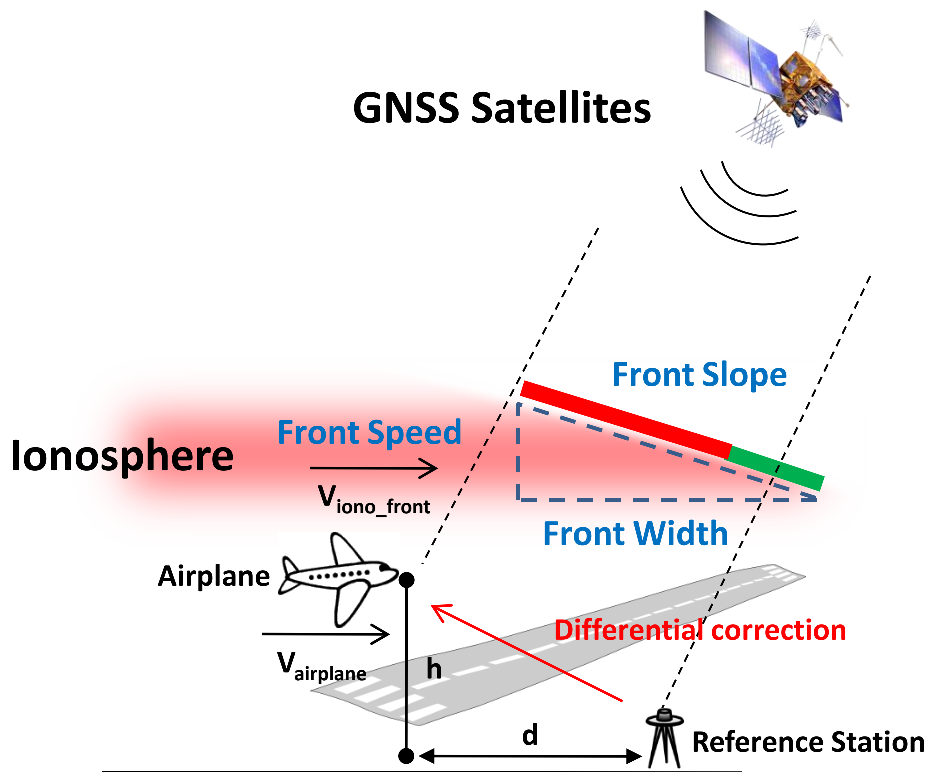


The extreme ionospheric delay gradient observed in US.

S. Datta-Barua, et al., 2010.

Ionospheric effects to GBAS

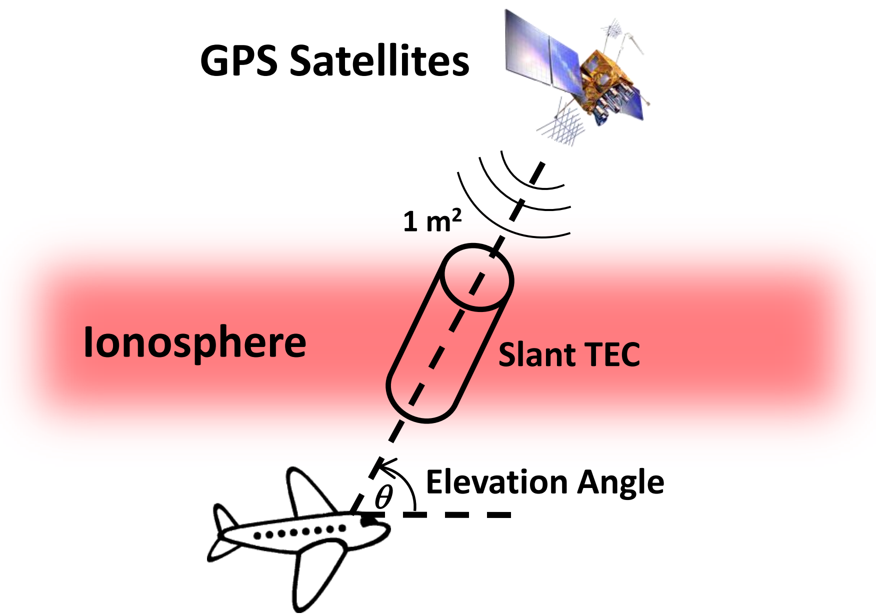
Simplified ionosphere wave front model



- Here, we focus on the Front Slope or "Ionospheric delay gradient".
- Ionospheric delay gradient problems
  1. Due to the physical ionospheric separation between aircraft and reference station.
  2. Due to the ionospheric irregularities (plasma bubbles, SED).
- Q : How large of the ionospheric delay gradient in the low latitude regions can be?

In this study, we focus on the ionospheric delay gradient associated with plasma bubbles in Thailand, which is located in low- latitude region

How to derive TEC from GPS data?



- Since the $STEC_P$ is nosier than $STEC_L$ but the $STEC_L$ still has an initial ambiguity which frequently causes the $STEC_L$ to have negative values.
- Generally, $STEC_L$ is adjusted to $STEC_P$ level.

$$STEC_{adj} = STEC + B_S + B_R$$

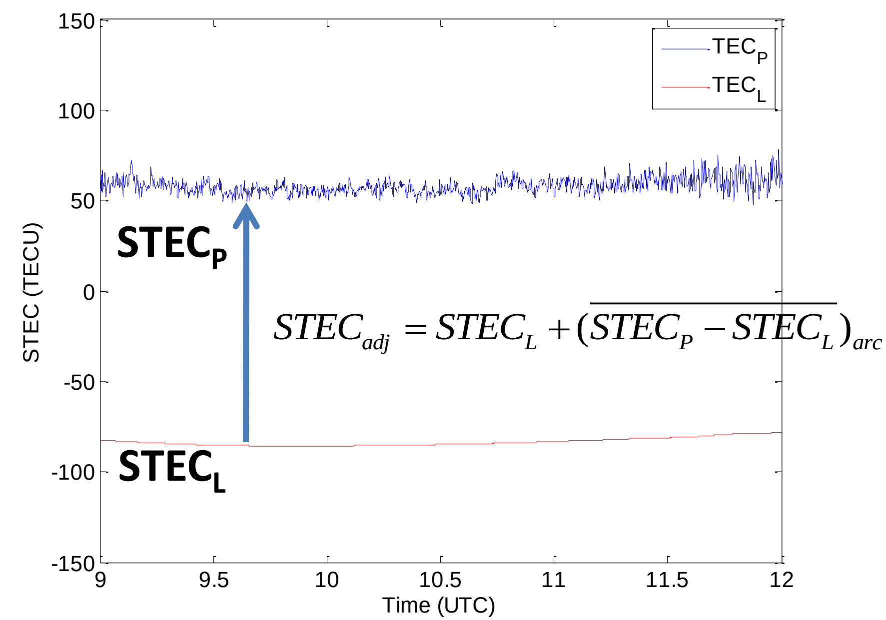
Satellite IFB   Receiver IFB

- For dual-frequencies GPS receiver, the Slant TEC can be derived by both psedorange and carrier phase linear combinations.

Pseudorange : $STEC_P = k(P_2 - P_1)$

Carrier phase : $STEC_L = k(L_1 - L_2)$

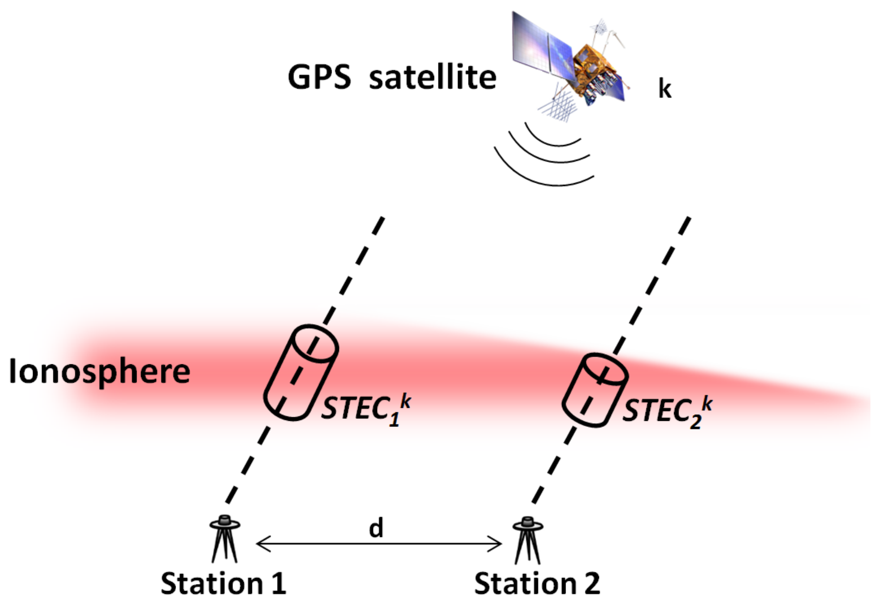
where k=9.5196 for TEC expressed in TECU.

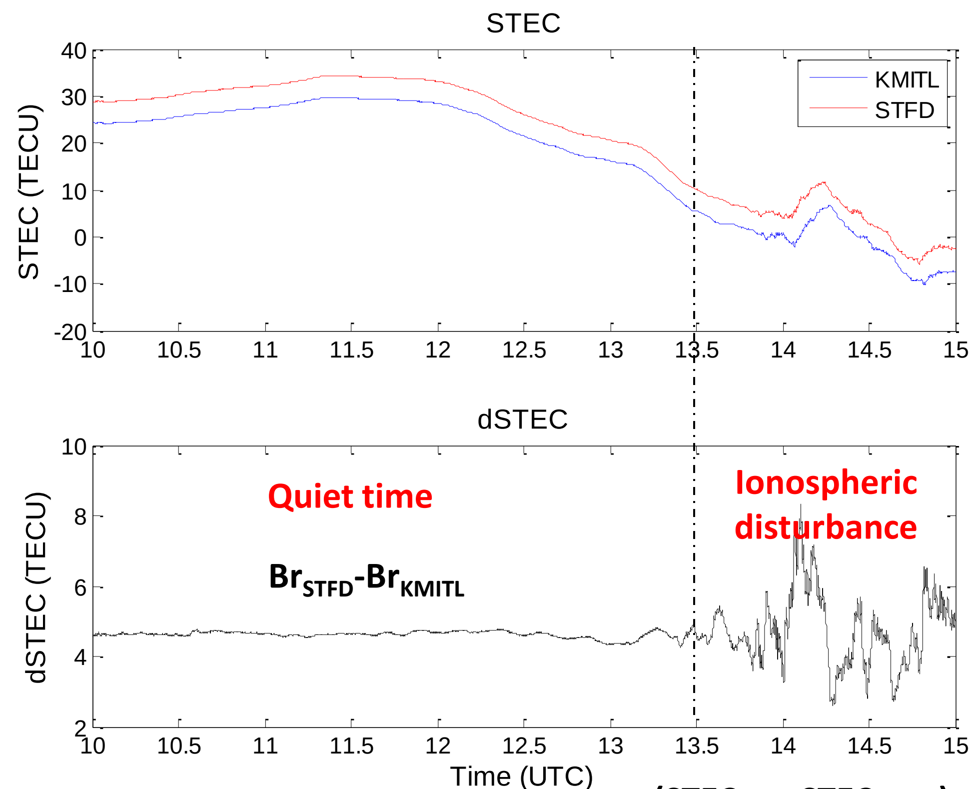


Receiver bias calibration

Single difference method

1 September 2011





$(STEC_{STFD}$-$STEC_{KMITL})$ + $(Br_{KMITL}$-$Br_{STFD})$

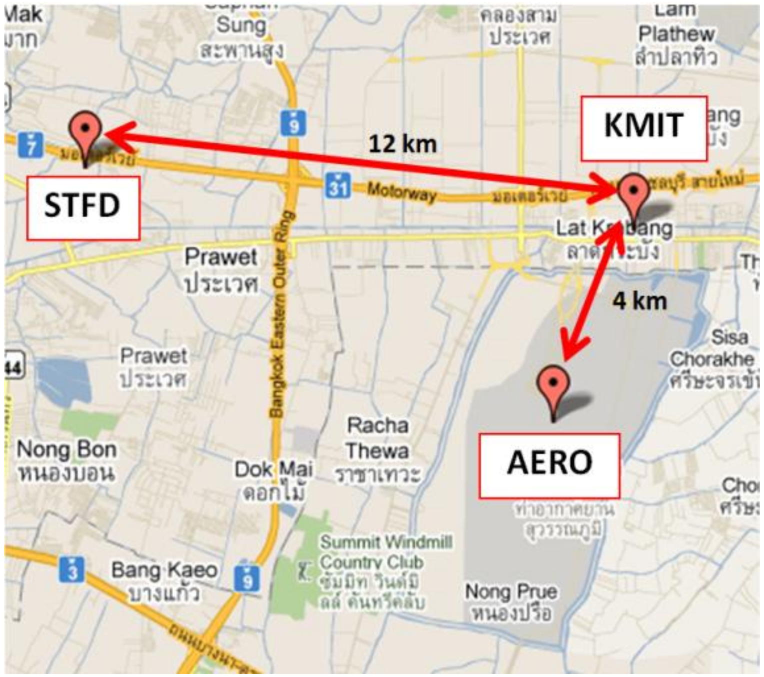
$$STEC^k_{adj\_1} = STEC^k_1 + B^K_S + B_{R\_1}$$

$$STEC^k_{adj\_2} = STEC^k_2 + B^K_S + B_{R\_2}$$

$$dSTEC^k = STEC^k_{adj\_1} - STEC^k_{adj\_2}$$

$$= (STEC^k_1 - STEC^k_2) + (B_{R1} - B_{R2})$$

Short baseline experiments



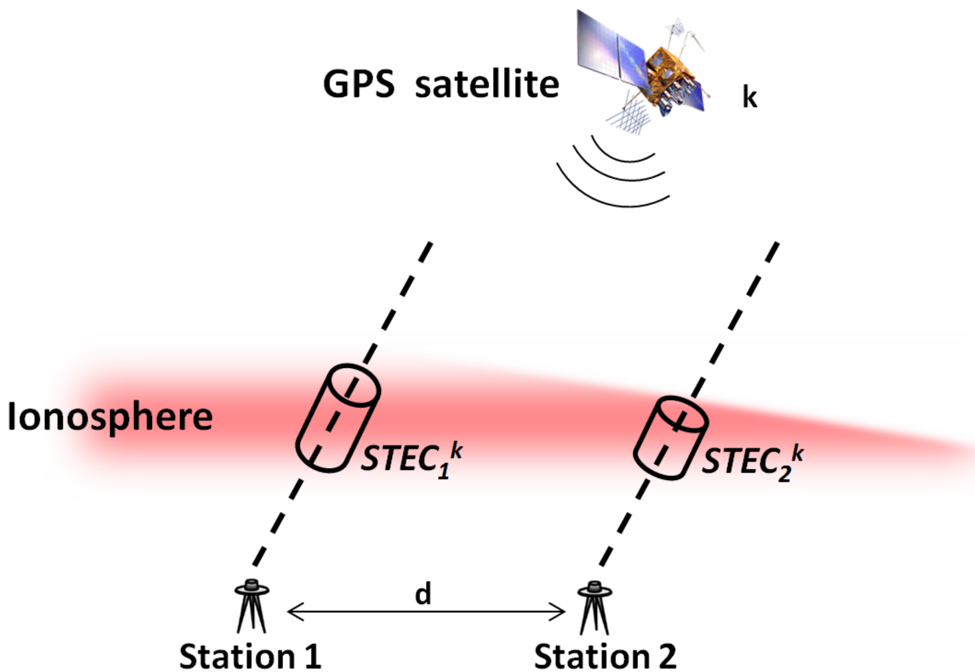
• Short baseline experiment needs to be carried out to monitor the ionospheric delay gradients near Suvarnabhumi international airport.

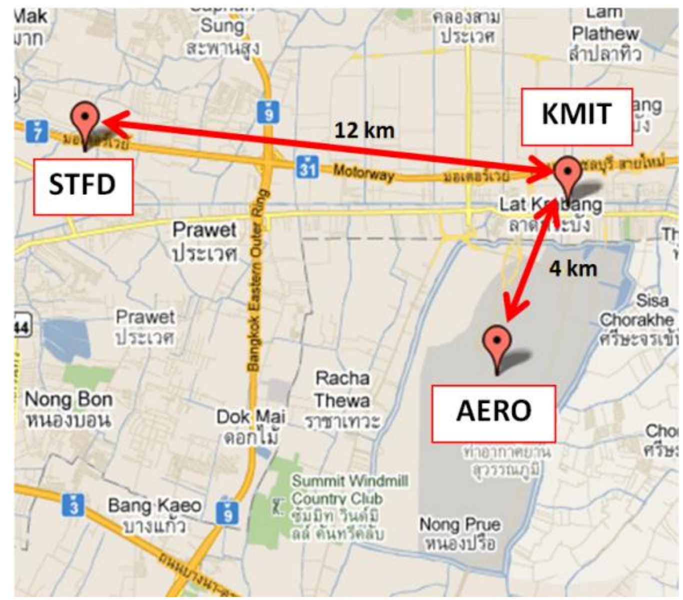
• Three dual-frequency GPS receivers have been installed as part of a cooperation project of

1. King Mongkut's Institute of Technology Ladkrabang (KMITL)
2. Electronic Navigation Research Institute (ENRI), Japan
3. Aeronautical Radio of Thailand Ltd. (AEROTHAI)
4. Stamford International University

• This project started July 2011.

Short baseline experiments



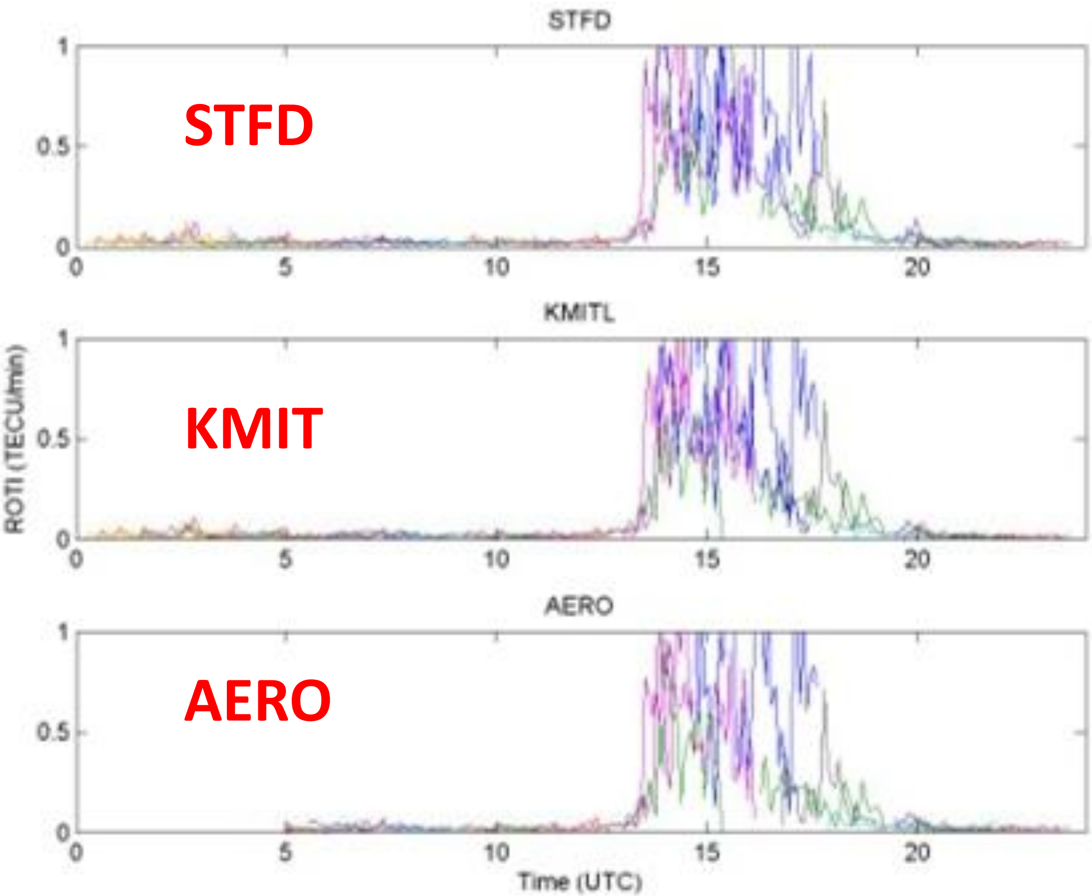


$$dSTEC^k = (STEC_1^k - STEC_2^k) + (\cancel{B_{R1} - B_{R2}})$$

$$\nabla I(t) = \frac{40.3}{f^2}\left(\frac{STEC_1^k(t) - STEC_2^k(t)}{d}\right)$$

Ionospheric delay gradient (mm/km)

ROTI (Rate of TEC change index)



1st September 2011

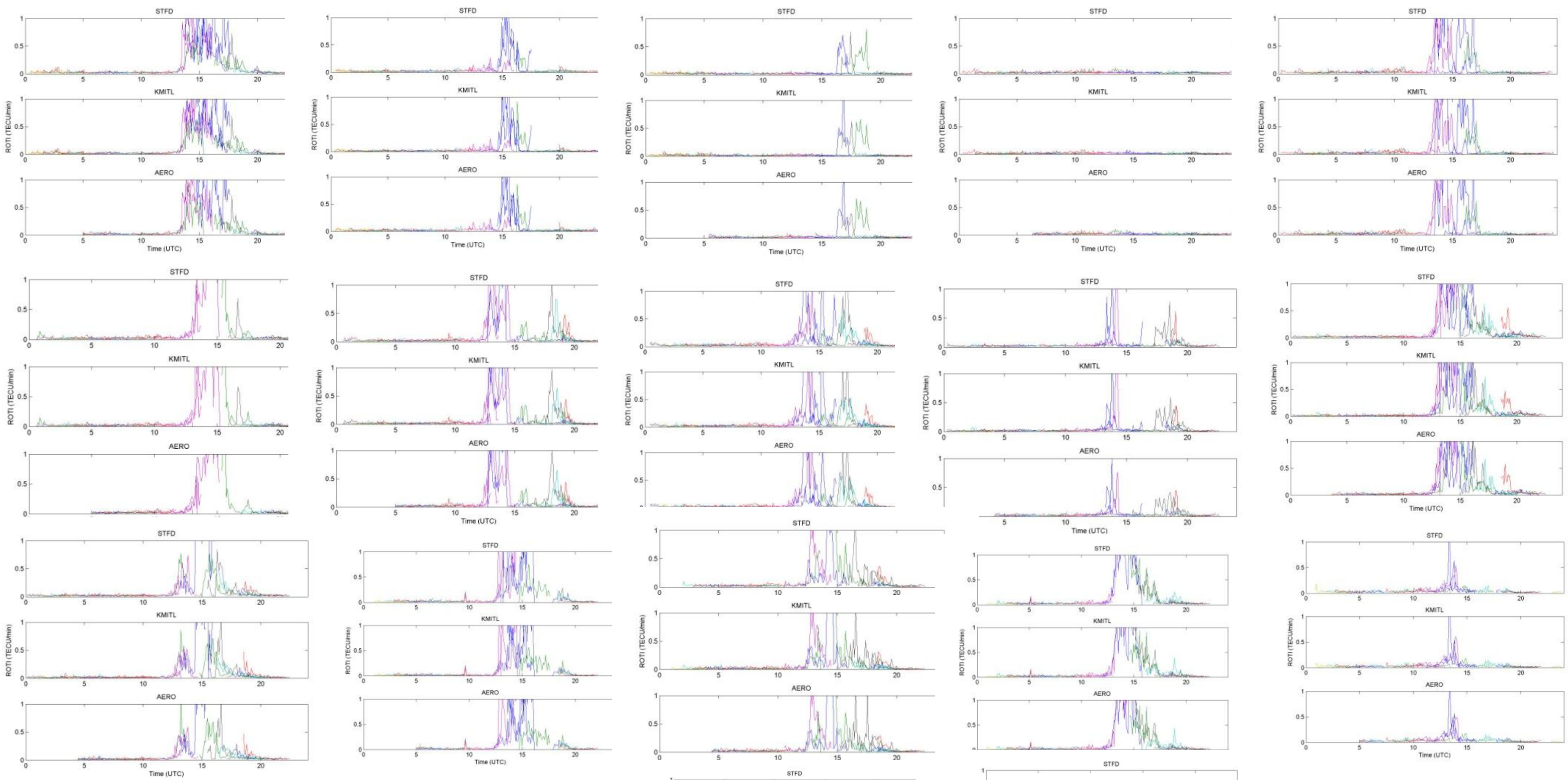
- In order to check the ionospheric irregularities, we use the rate of TEC change index or ROTI to indicate whether the plasma bubbles occur or not.

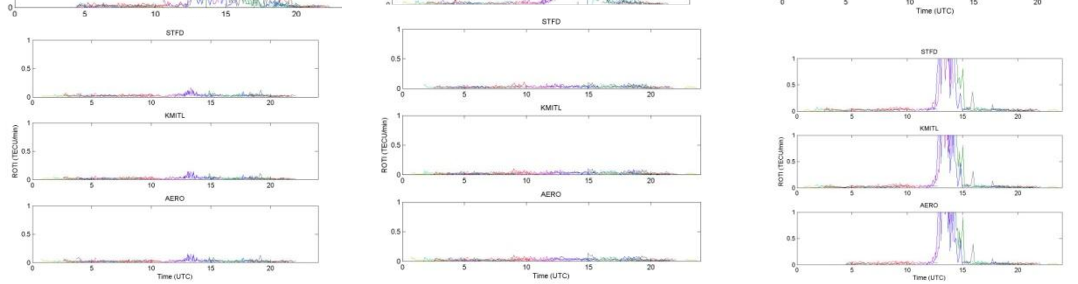
$$ROT(i) = STEC(i+1) - STEC(i)$$

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

- The ROTI is defined by Standard deviation of rate of TEC change with 5-minute window.

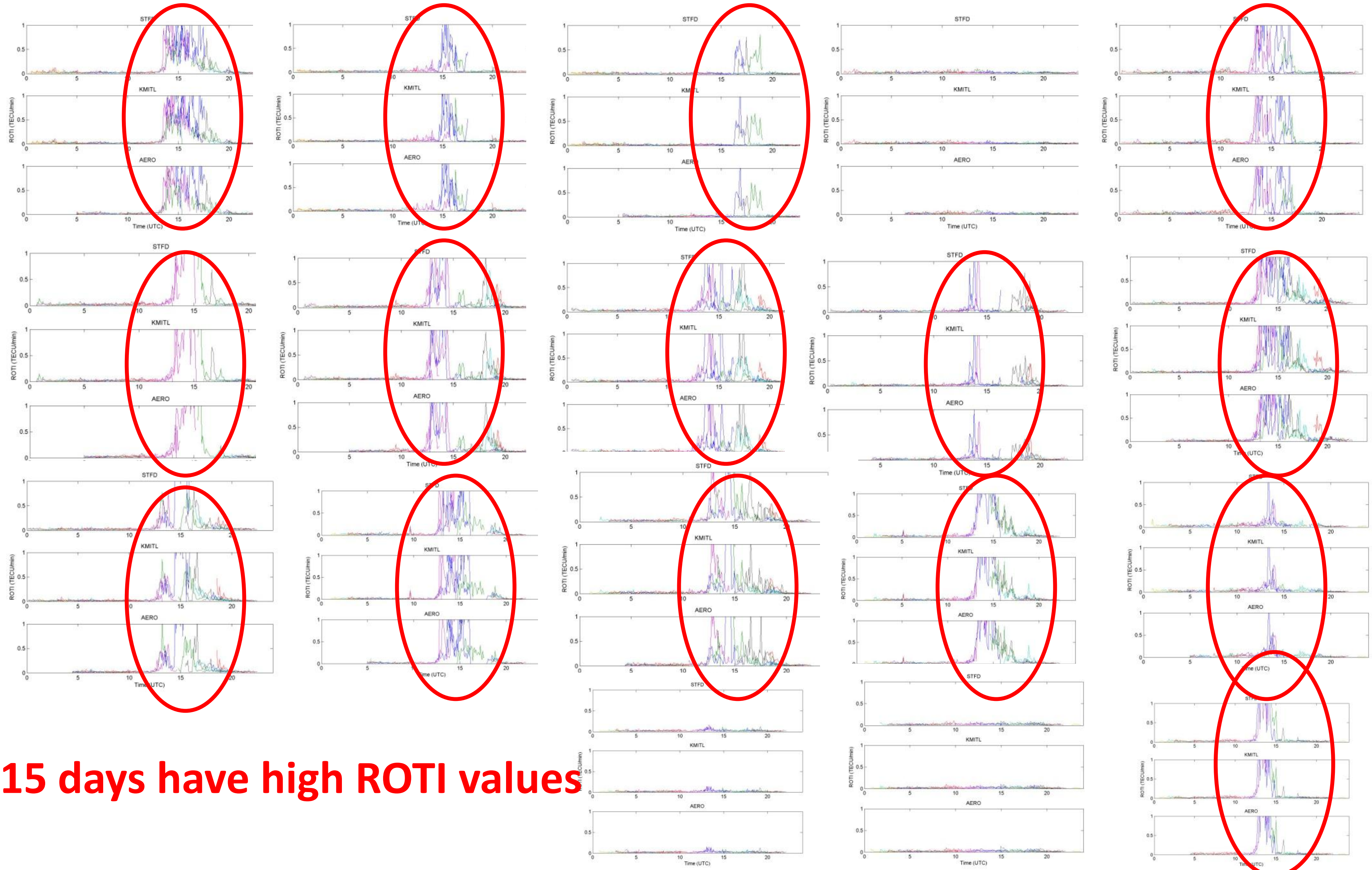
ROTI (Rate of TEC change index)





ROTI (5 minute window) of 18 days of September 2011

ROTI (Rate of TEC change index)

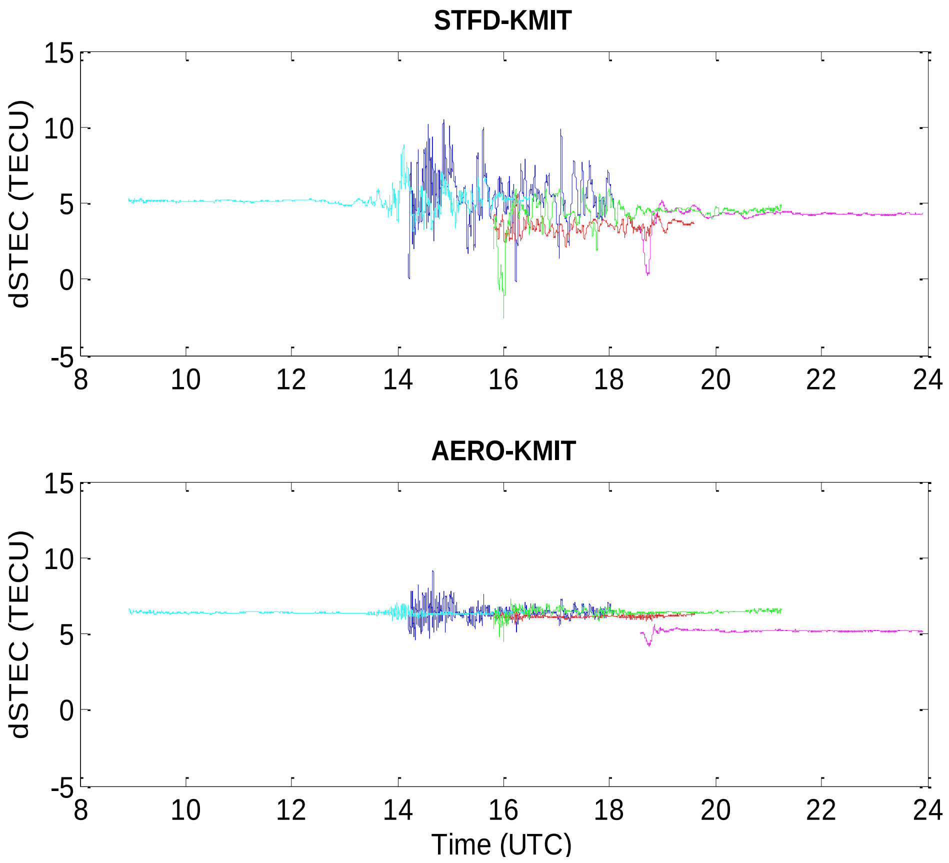


15 days have high ROTI values

Results and Discussions

1st September 2011

dSTEC



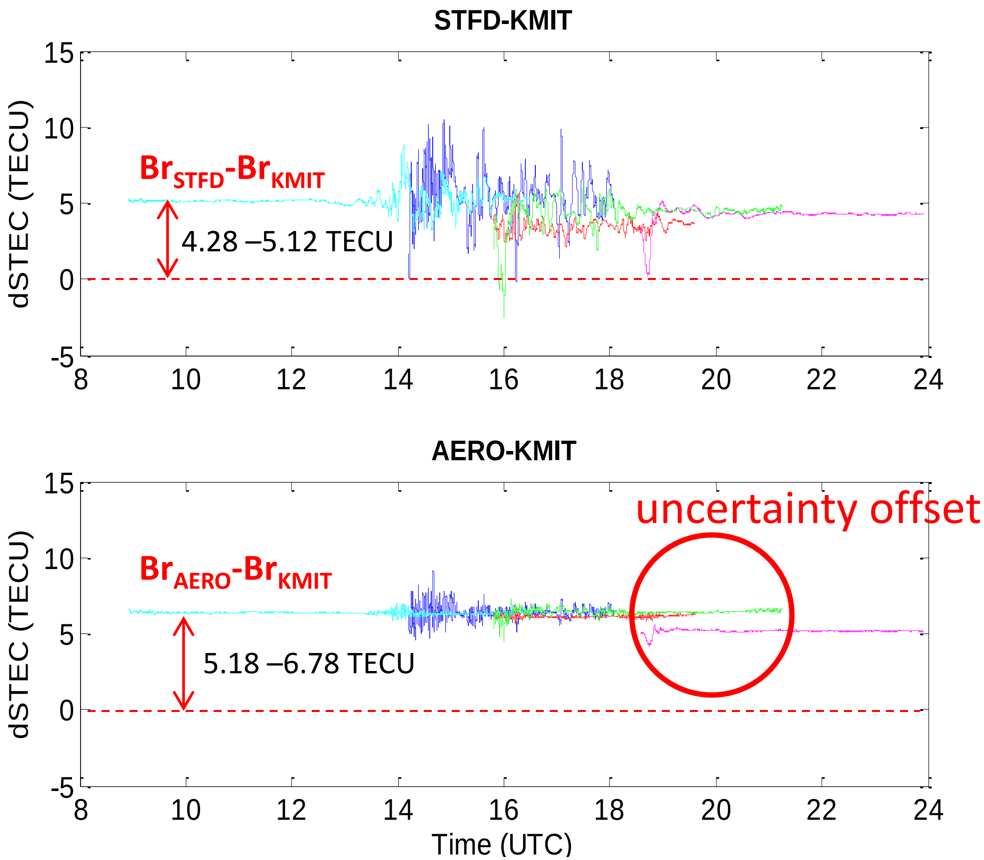
- **In the results, we selected the data on 1 September 2011 to analyze.**
- **The constant level can be considered as the differential receiver biases.**

PRN2, 9, 14, 21, 29

Results and Discussions

1st September 2011

dSTEC



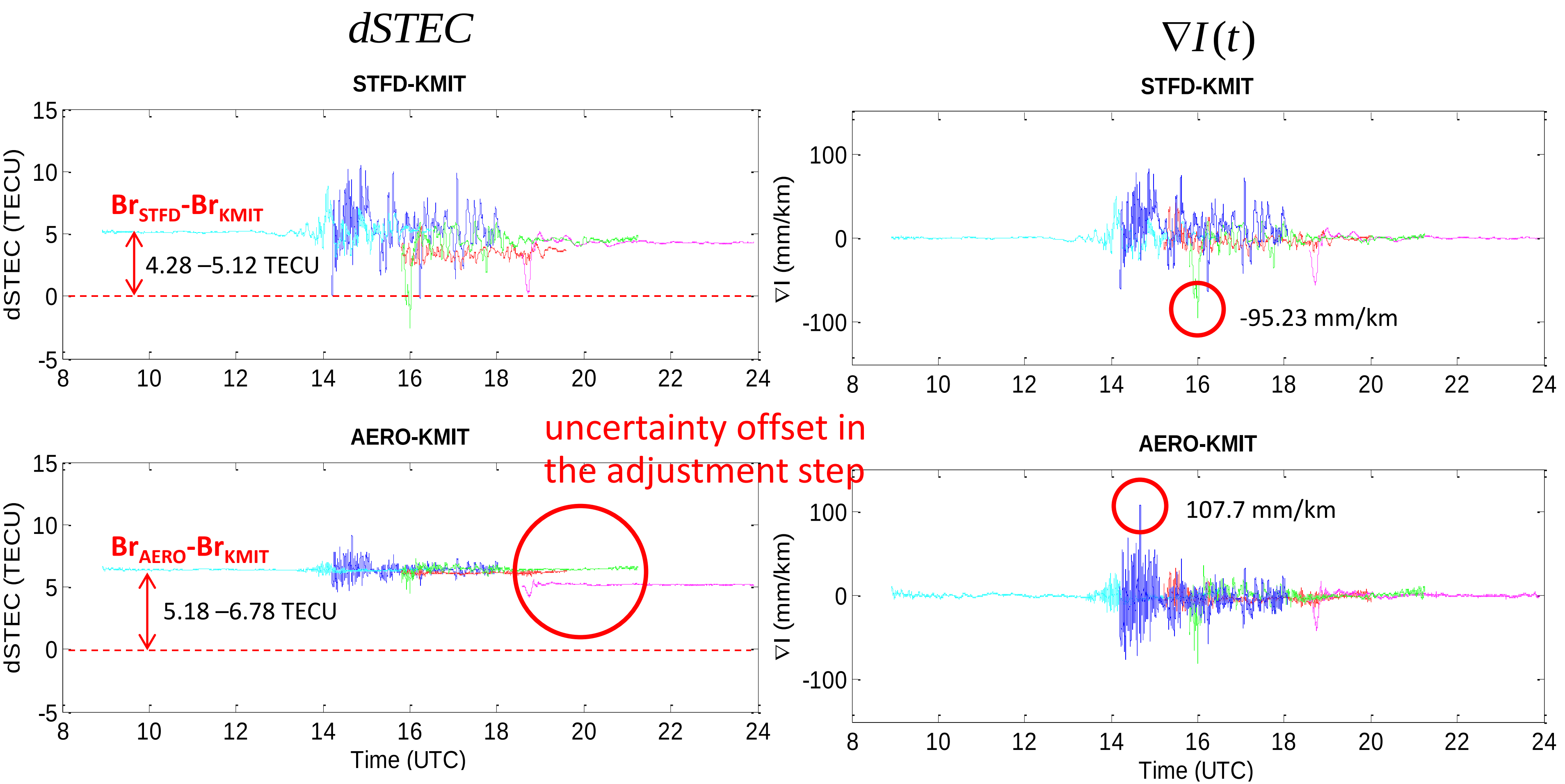
- **However, we found a slight offset exist in AERO-KMIT direction due to the uncertainty offset in the adjustment step (L. Ciraolo, et al., 2007).**
- **Therefore, we consider the differential receiver biases for each satellite.**

L. Ciraolo, et al., 2007.

PRN2, 9, 14, 21, 29

Results and Discussions

1st September 2011



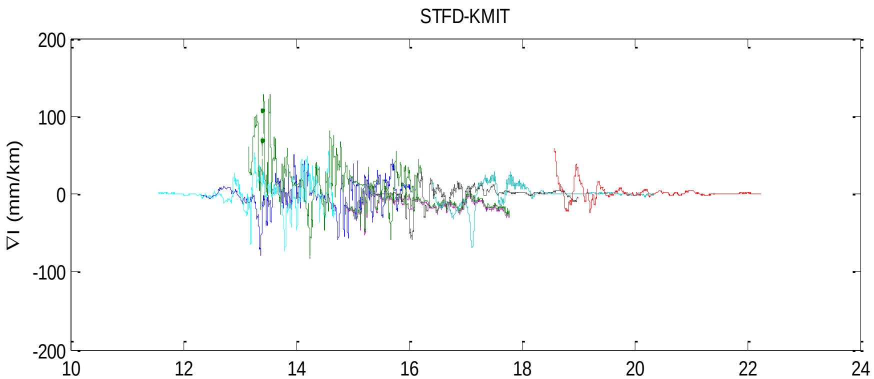
PRN2, 9, 14, 21, 29

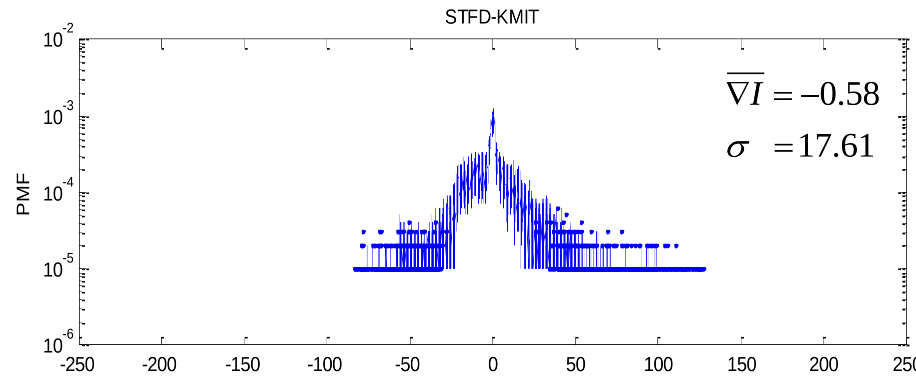
Results and Discussions

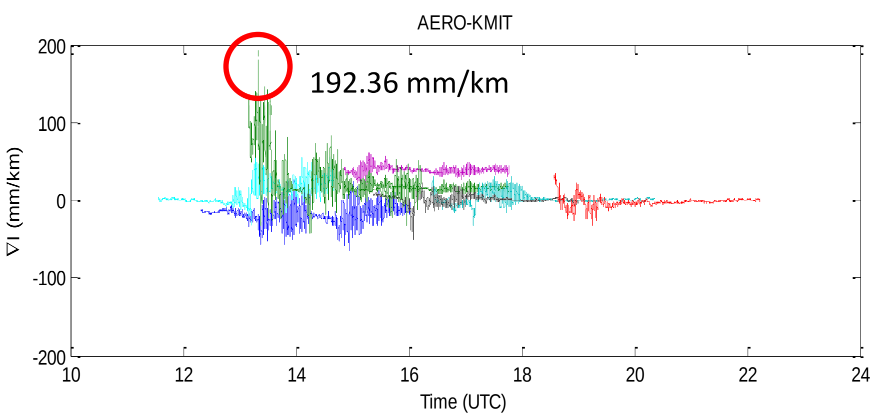
22nd September 2011

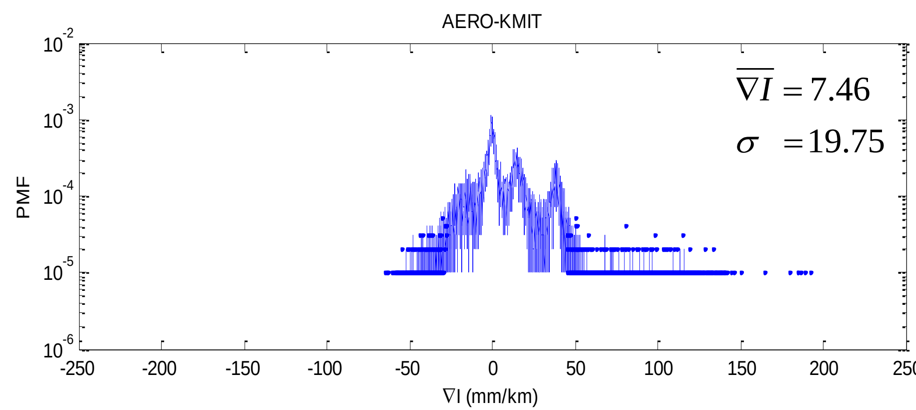
$\nabla I(t)$

PMF









Conclusions

- **From this study, we show the ionospheric delay gradients near Suvarnabhumi airport, Thailand, in September equinox 2011.**
- **Based on 15-day observation, we found that the maximum ionospheric delay gradient can reach 192.36 mm/km on 22nd September 2011.**
- **For the GBAS implementation in this area, the local ionospheric threat model should consider the maximum ionospheric delay gradient.**

Thank you for your attention!

Question?