EIWAC 2013

THE THIRD ENRI INTERNATIONAL WORKSHOP ON ATM/CNS

~DRAFTING FUTURE SKY~

Statistical characteristics of background ionospheric total electron content (TEC) in Bangkok, Thailand

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P. Supnithi[1], S. Rungraengwajiake[1], S. Saito[2], N. Siansawasdi[3], A. Saekow[4]

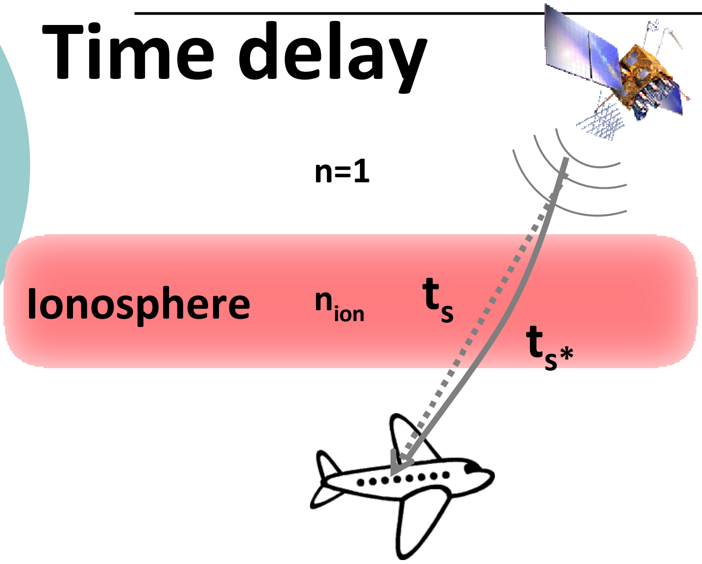
[1]Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand
[2]Electronic Navigation Research Institute (ENRI), Japan
[3]Aeronautical Radio of Thailand (AEROTHAI), Thailand
[4]Stamford International University, Thailand

Outline

- Introduction
- Ionospheric effects on GNSS and GBAS
- Receiver bias computation
- 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

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

t_{s*} : Traveling time with an ionosphere
t_s : Traveling time without an ionosphere

- The refractive index of the radio wave in the ionosphere can estimate by using Appleton-Hartree equation (Kintner, 2005) :

$$\boxed{n_{ion}^2 = 1 - \frac{\omega_p^2}{\omega^2}}$$

Plasma frequency

$$\omega_p^2 = \frac{N_e e^2}{\varepsilon_0 m_e} = 80.6 N_e$$

Radio wave frequency

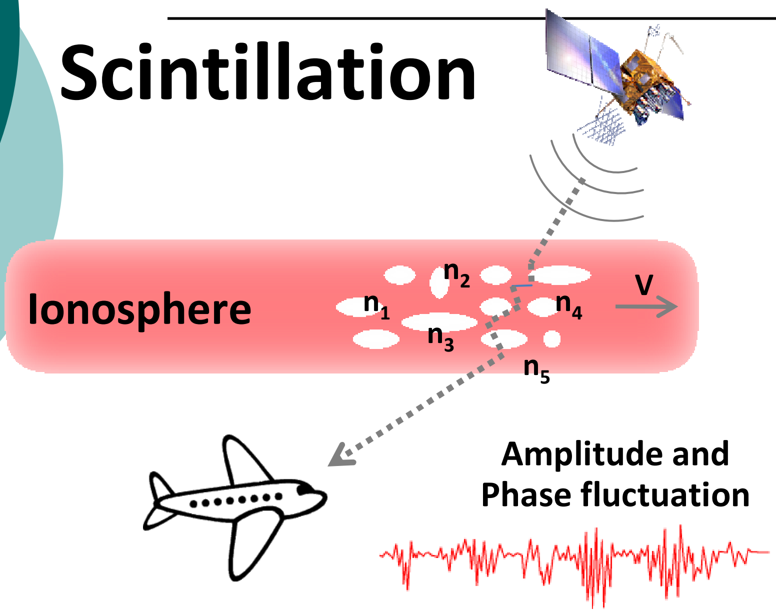
- Since the plasma frequency is less than the radio wave frequency (GPS L1 signal is 1.5 GHz).

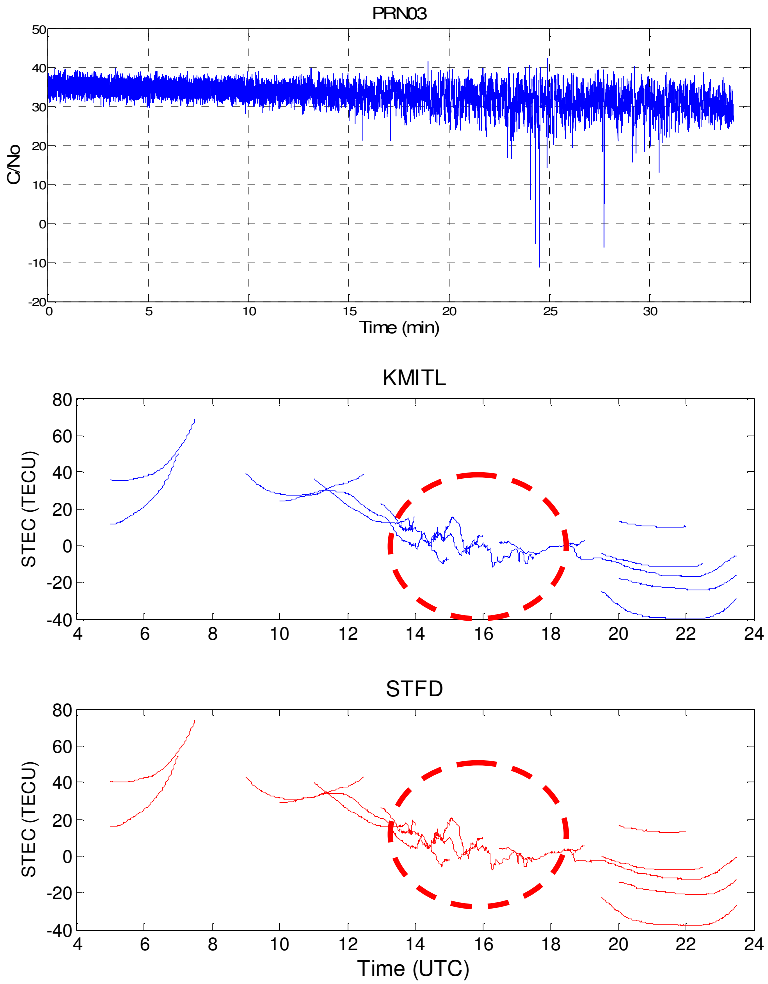
$$n_{ion} = \sqrt{1 - \frac{\omega_p^2}{\omega^2}} \approx 1 - \frac{\omega_p^2}{2\omega^2} \approx 1 - 40.3\frac{N_e}{f^2}$$

ω_p : Plasma frequency
N_e : Electron density
e : Electron's charge
f : Radio wave frequency (Hz)
ε_0 : Permittivity of free space
m_e : Electron mass
ω : Radio wave frequency (rad/s)

Ionospheric effects on GNSS signals

Scintillation



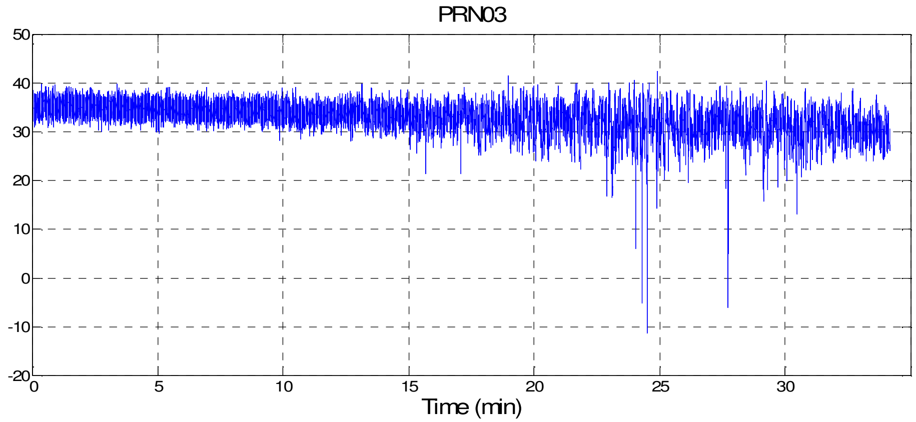


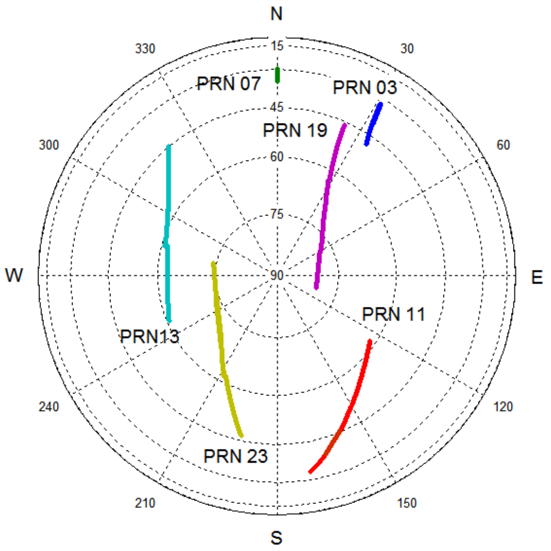
- **The ionospheric irregularities cause the fluctuations in the refractive index (n).**
- **It causes the rapid fluctuations in amplitude and phase of GPS signals.**
- **In the worst case, the receiver loss of lock the satellite signal.**

Scintillations – 22 March 2012

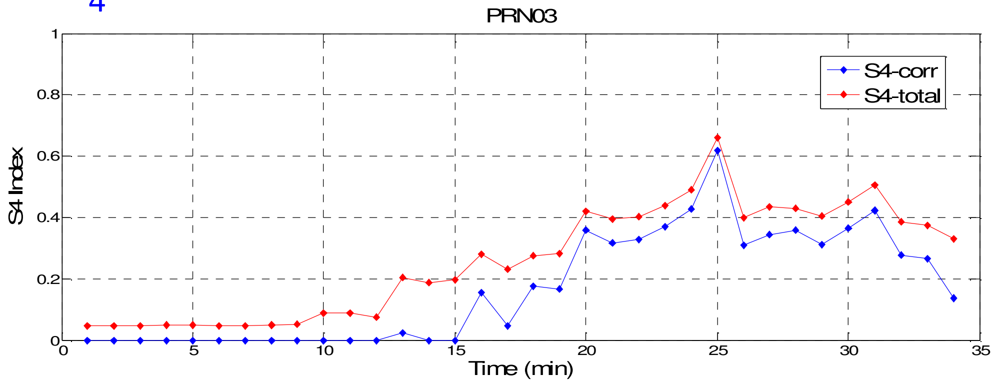
[The raw GPS satellite signal from the software receiver is provided with the courtesy of JAXA (Dr. Toshiaki Tsujii)]

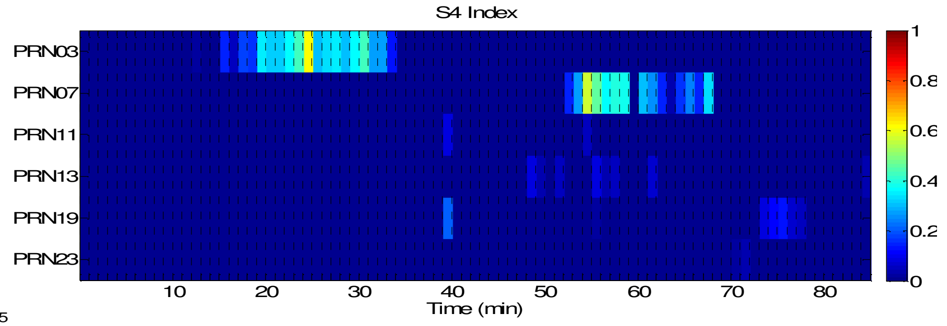
C/N_0





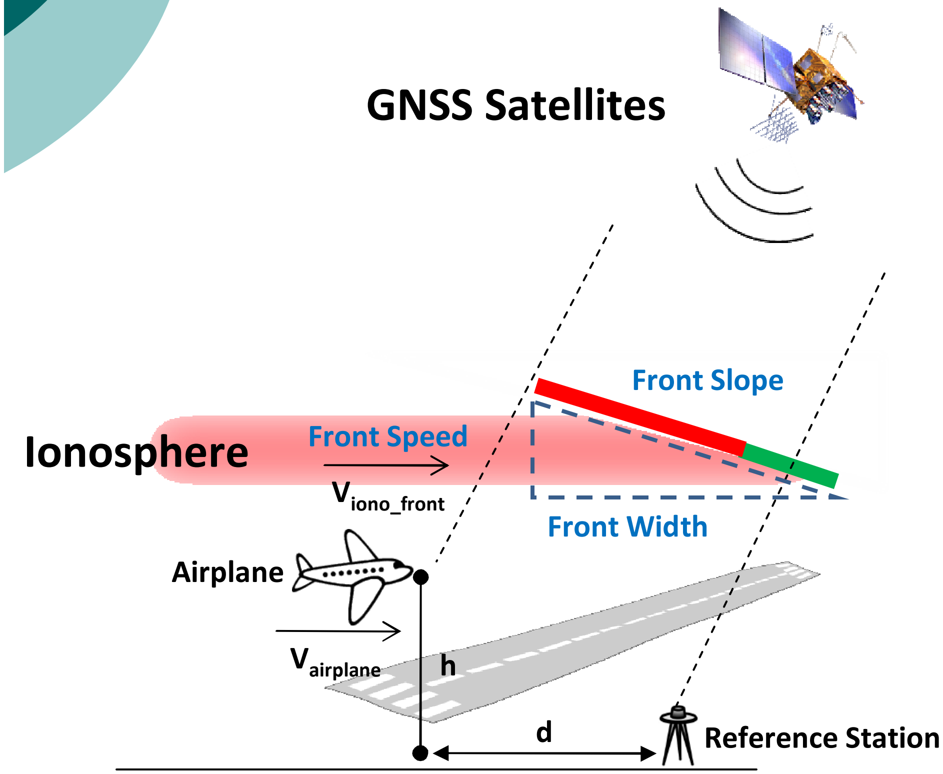
S_4 index





Ionospheric Effects to GBAS

Simplified ionosphere wave front model



Ionospheric delay gradients

1. Delay gradients with ionospheric disturbance
2. Background delay gradients (quiet time)

In this study, we focus on the background ionospheric delay gradient (quiet-time).
The approach is to use the 'minimum variance' method

Previous works

- [Fujita et al., 2010] uses ‘single difference method’ together with Kalman filter to determine integer ambiguities and then compute the ionospheric delays. The TEC levels at each station is not computed.
- [J. Lee et al.,2010] suggests using Maruyama’s method in the long-term ionospheric monitoring as a simpler way to estmate the receiver bias in “Simple Truth” solutions.

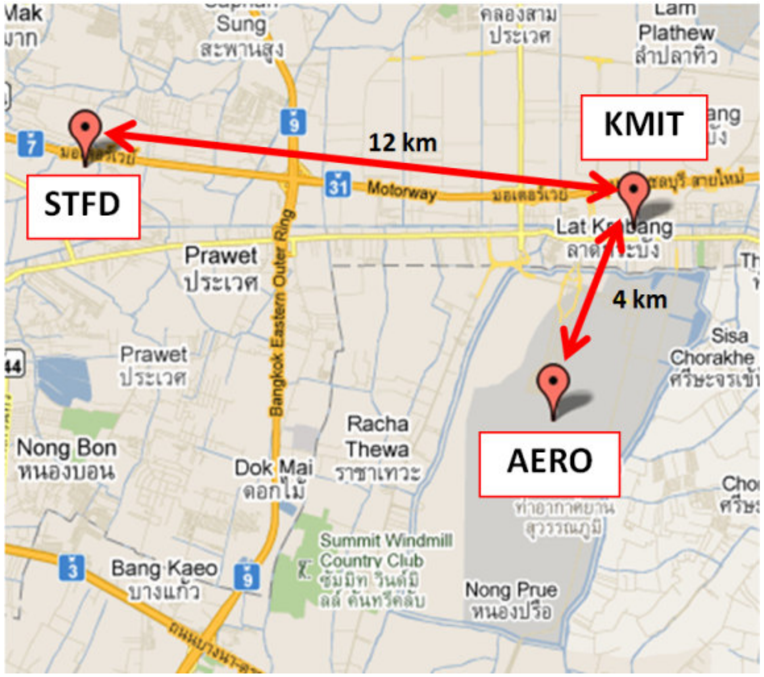
S.Fujita, T. Yoshihara, S. Saito, “Determination of Ionosphere Gradient in Short Baselines by Using Single Frequency Measurements,” Journal of Aeronautics, Astronautics and Aviation, Series A, vol. 42, no. 4, pp. 269 – 276 (2010),

J.Lee, S.Jung, E.Bang and S.Pullen, “Long Term Monitoring of Ionospheric Anomalies to Support the Local Area Augmentation System ,” ION GNSS 2010, Sept. 20-24, Oregon, USA.

Objectives

- Preliminary study of the background delay gradient near Suvarnabhumi airport, Thailand
- To estimate the receiver bias using the minimum variance method in [Ma and Maruyama, 2003]

Short baseline experiments



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**
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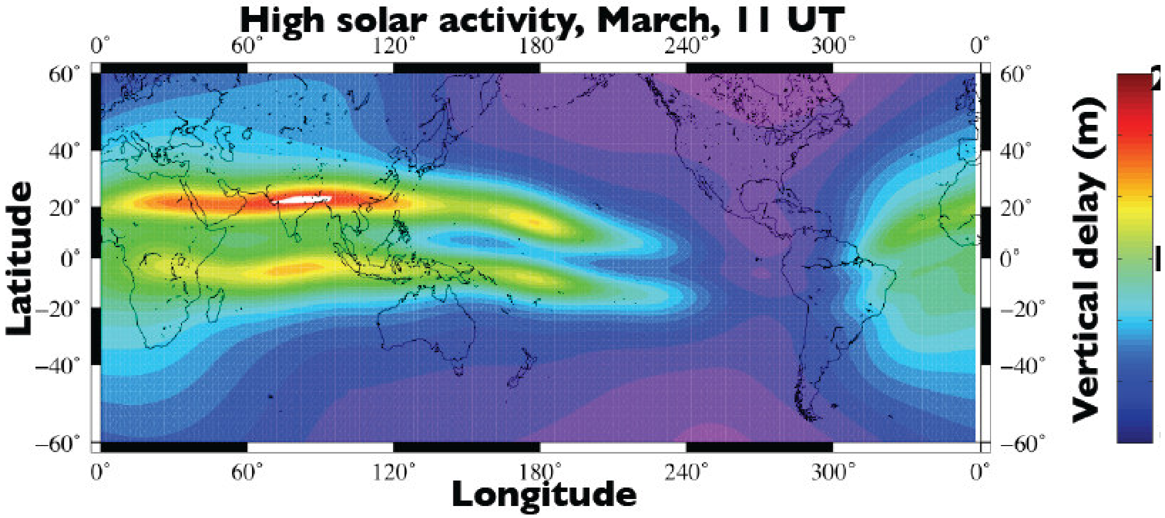
Causes of Delay Gradients

Low and Equatorial Latitudes

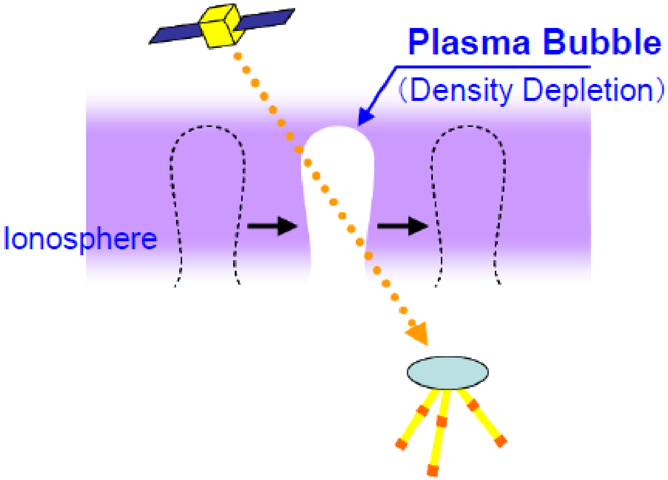
- Equatorial Ionospheric Anomaly (EIA) : Large-scale ionospheric density enhancement around ±15º magnetic latitude
- Plasma Bubble: area of depletion of TEC at night time, typically generated from the equator due to pre-reversal enhancement

Equatorial Ionospheric Anomaly (EIA)



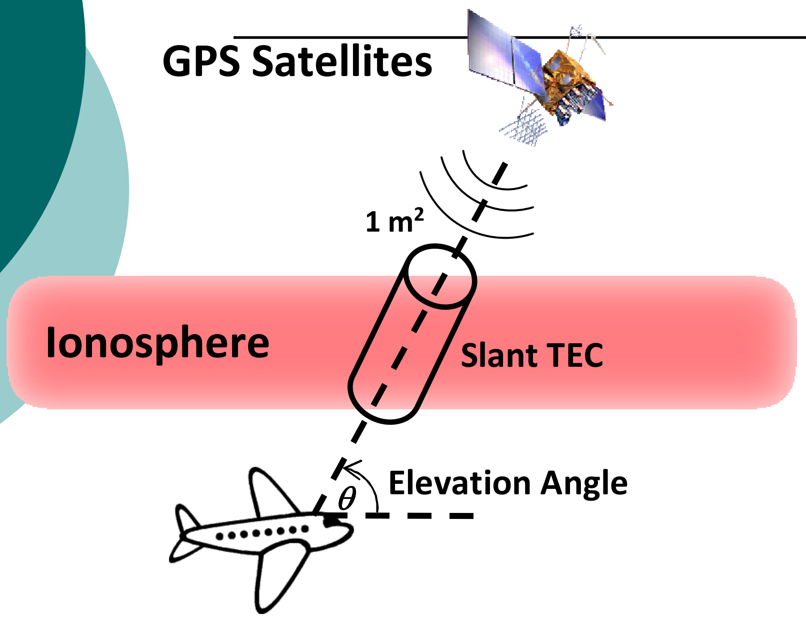
[S.Saito, 2011]

Plasma Bubble



[Tsujii, 2010]

Slant TEC

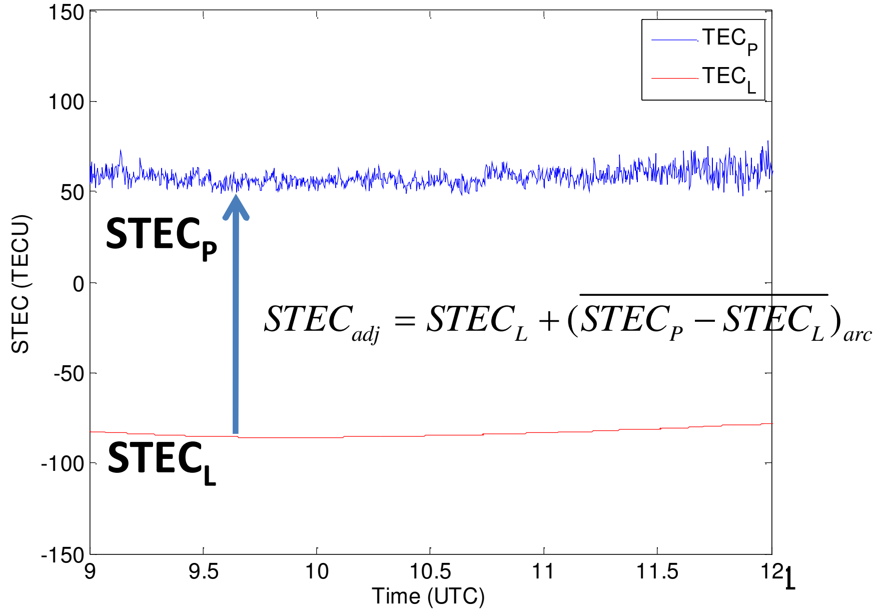


- For dual-frequencies GPS receiver, the Slant TEC can be derived by both psedorange and carrier phase linear combinations.

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.



$$STEC_{adj} = STEC_L + \overline{(STEC_P - STEC_L)}_{arc}$$

- Since the $STEC_P$ is nosier than $STEC_L$ but the $STEC_L$ still has an initial ambiguity which frequently lead the $STEC_L$ to negative value.

- Generally, $STEC_L$ is adjusted to $STEC_P$ level.

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

Satellite IFB   Receiver IFB

Satellite and receiver biases

Observed Value **Absolute Value** **Satellites Bias** **Receiver Bias**

$$STEC_1 = STEC + B_S + B_R$$

The satellite biases obtained from IGS, determined by CODE (Center for Orbit Determination in Europe)

$$STEC_2 = STEC + B_R$$

[Ma and T. Maruyama, 2003]

- The VTEC computed from low elevation angle data should not be different from VTEC compute from high elevation angle data.

- The expected receiver bias that gives the minimum σ of VTEC is the corrected receiver bias

Example

$$VTEC_{adj} = STEC \cdot \cos\chi + (B_R - B_R^{'}) \cdot \cos\chi$$

Earth radius

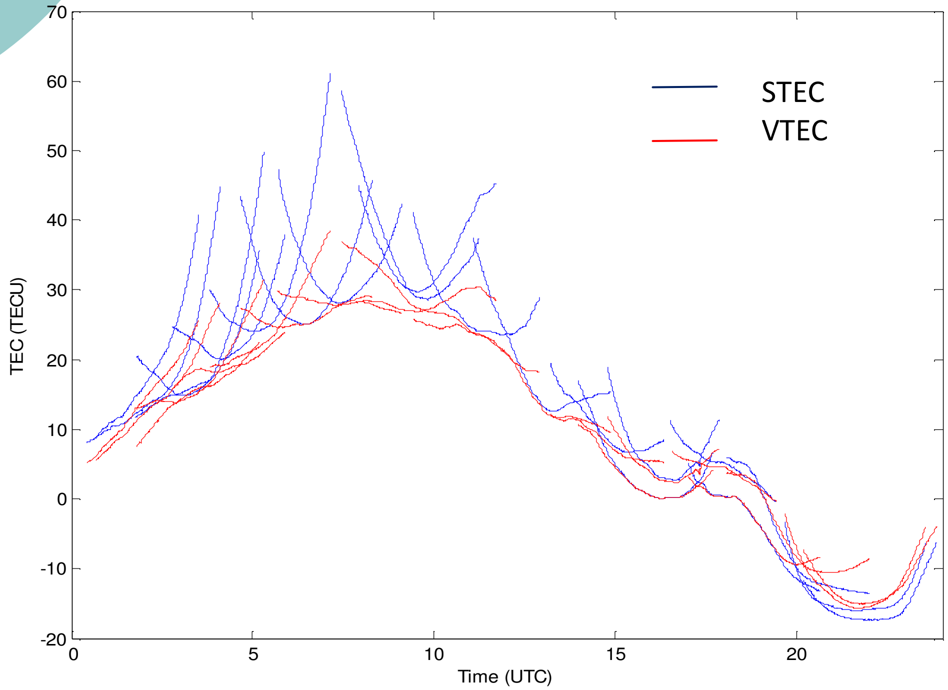
elevation angle

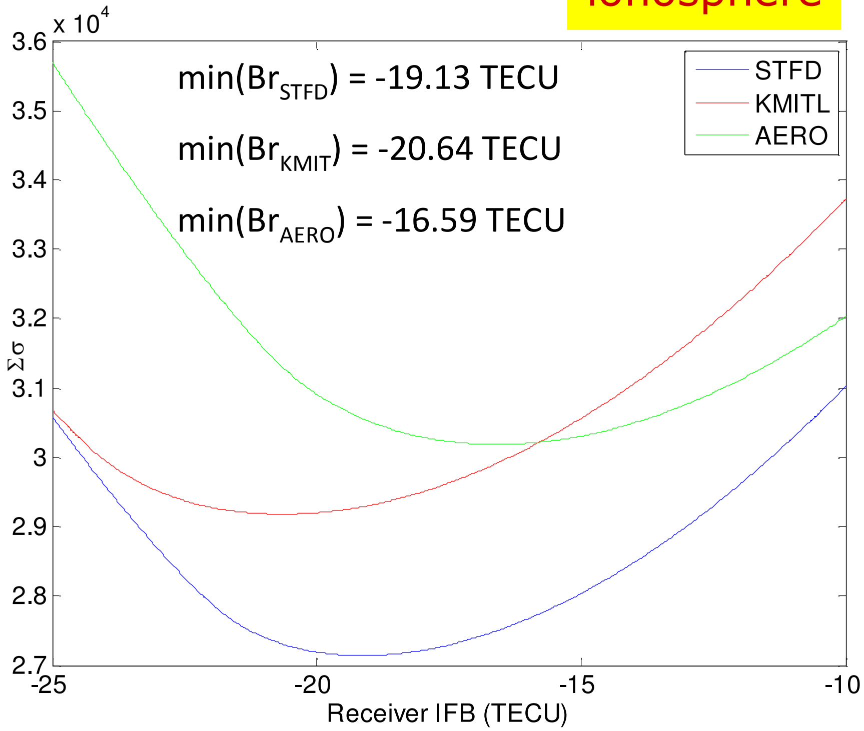
$$\chi = \arcsin(\frac{R_e \cos\theta}{R_e + h})]$$

Height of ionosphere

Conditions on data used for receiver bias computation:

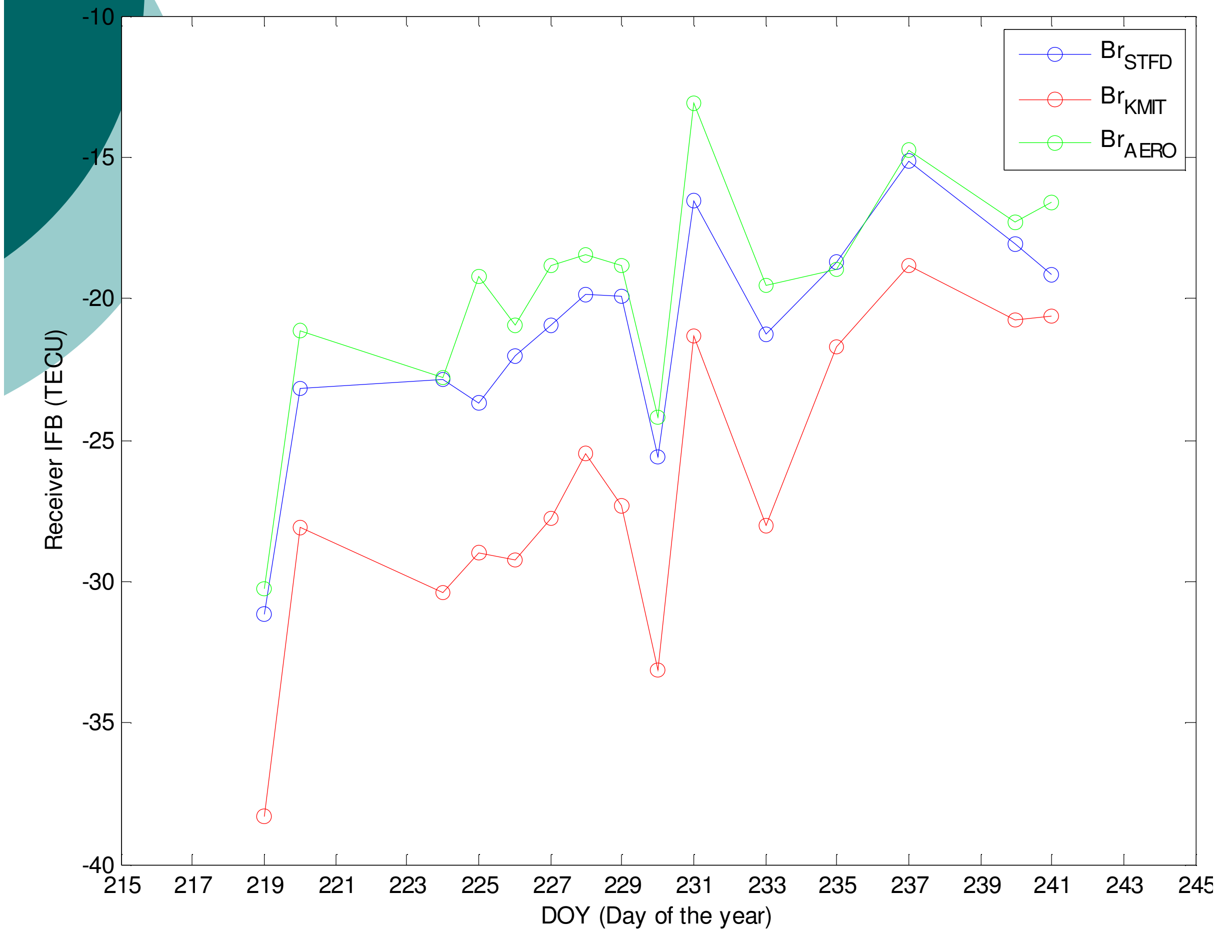
- Elevation > 35◦
- The ionospheric height h = 350 km





Receiver Bias

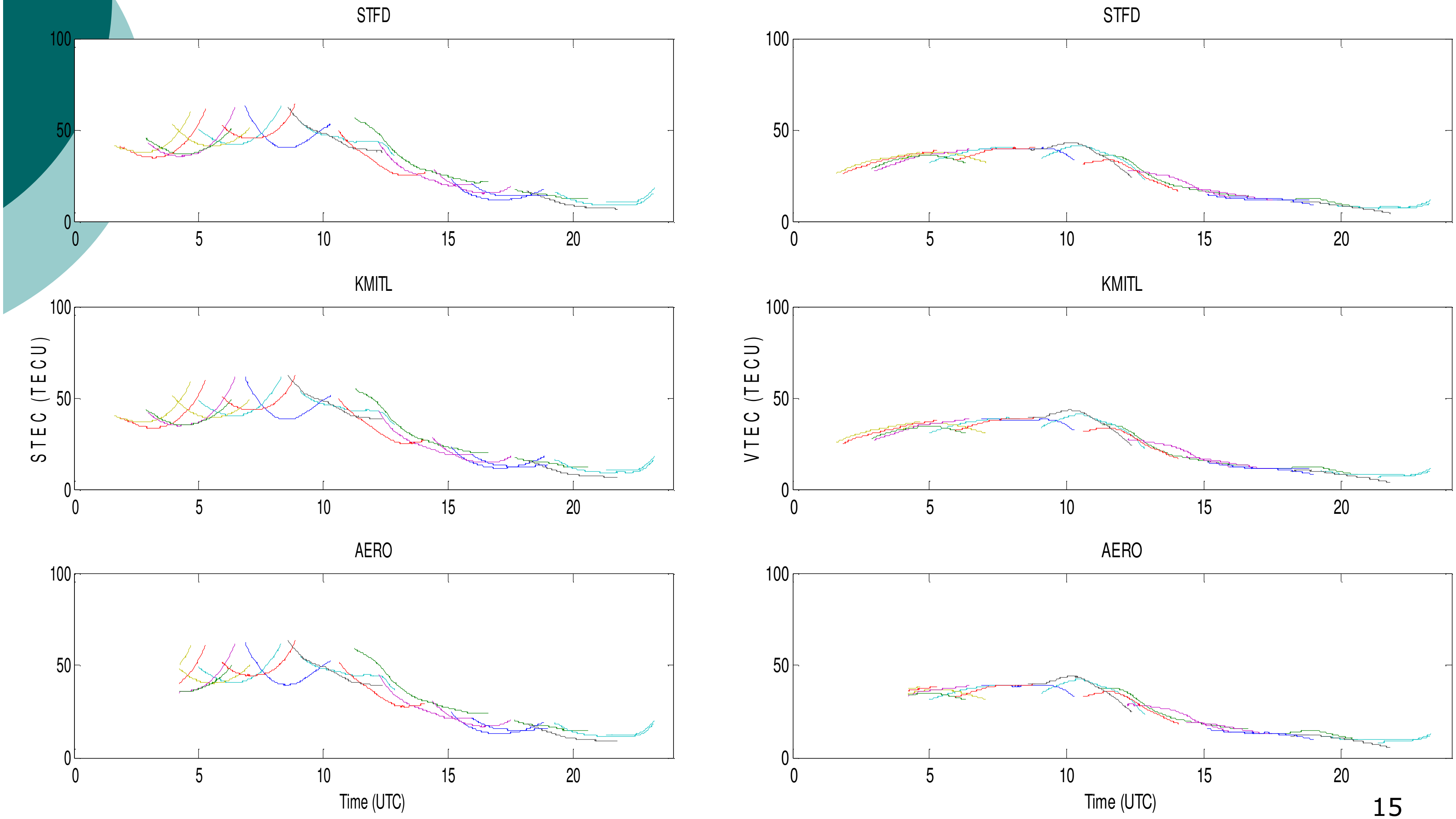
August, 2011



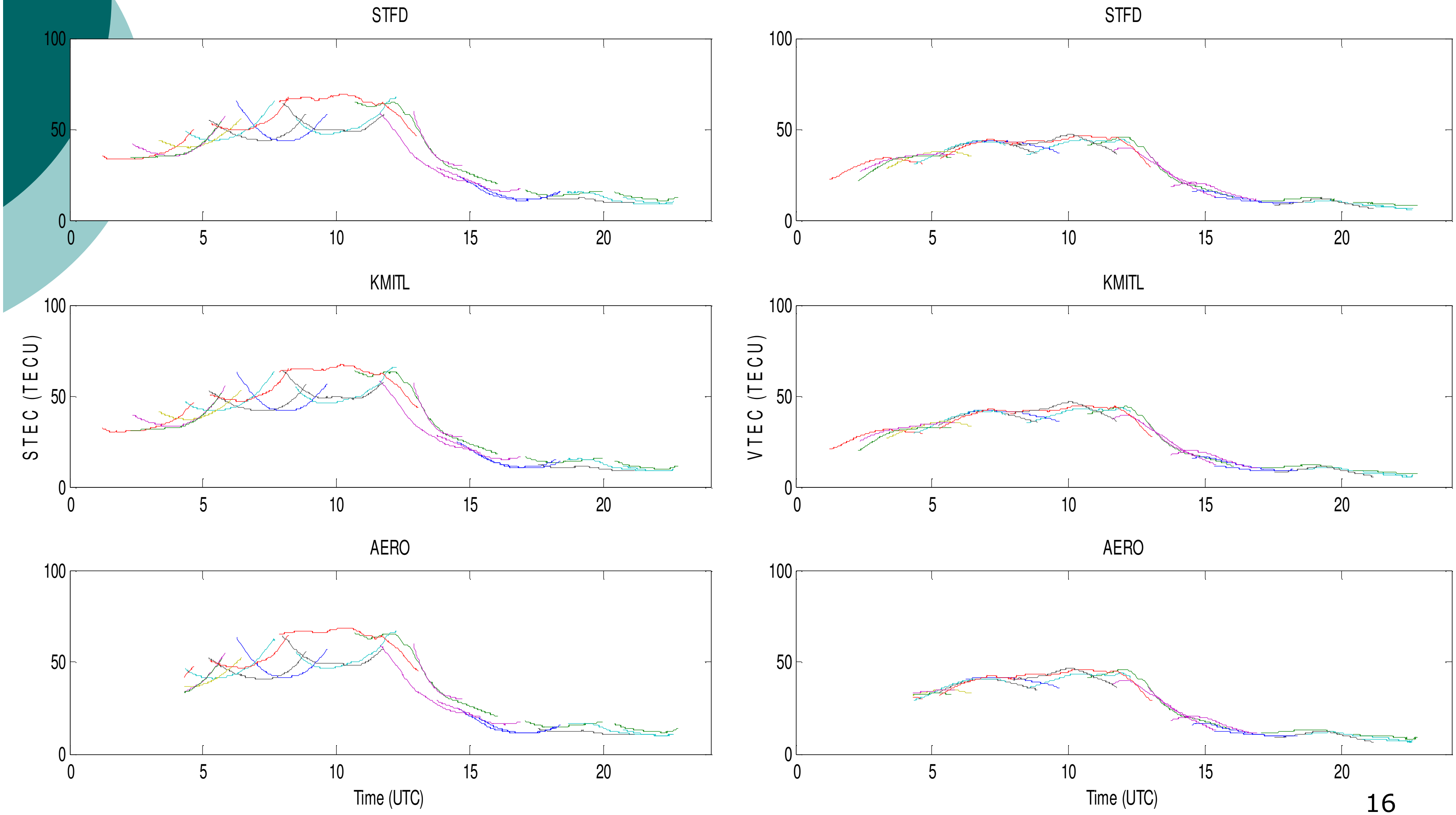
DOY	Br_stfd	Br_kmit	Br_aero
219	-31.14	-38.28	-30.25
220	-23.17	-28.1	-21.13
224	-22.86	-30.37	-22.79
225	-23.69	-28.99	-19.23
226	-22.00	-29.24	-20.96
227	-20.92	-27.8	-18.86
228	-19.86	-25.50	-18.46
229	-19.94	-27.32	-18.85
230	-25.58	-33.17	-24.22
231	-16.55	-21.34	-13.11
233	-21.24	-28.01	-19.53
235	-18.71	-21.70	-18.97
237	-15.12	-18.83	-14.75
240	-18.09	-20.75	-17.28
241	-19.13	-20.64	-16.59

A jump in the receiver bias is partially due to omission of some satellite data with remaining cycle slips after the cycle slip correction.

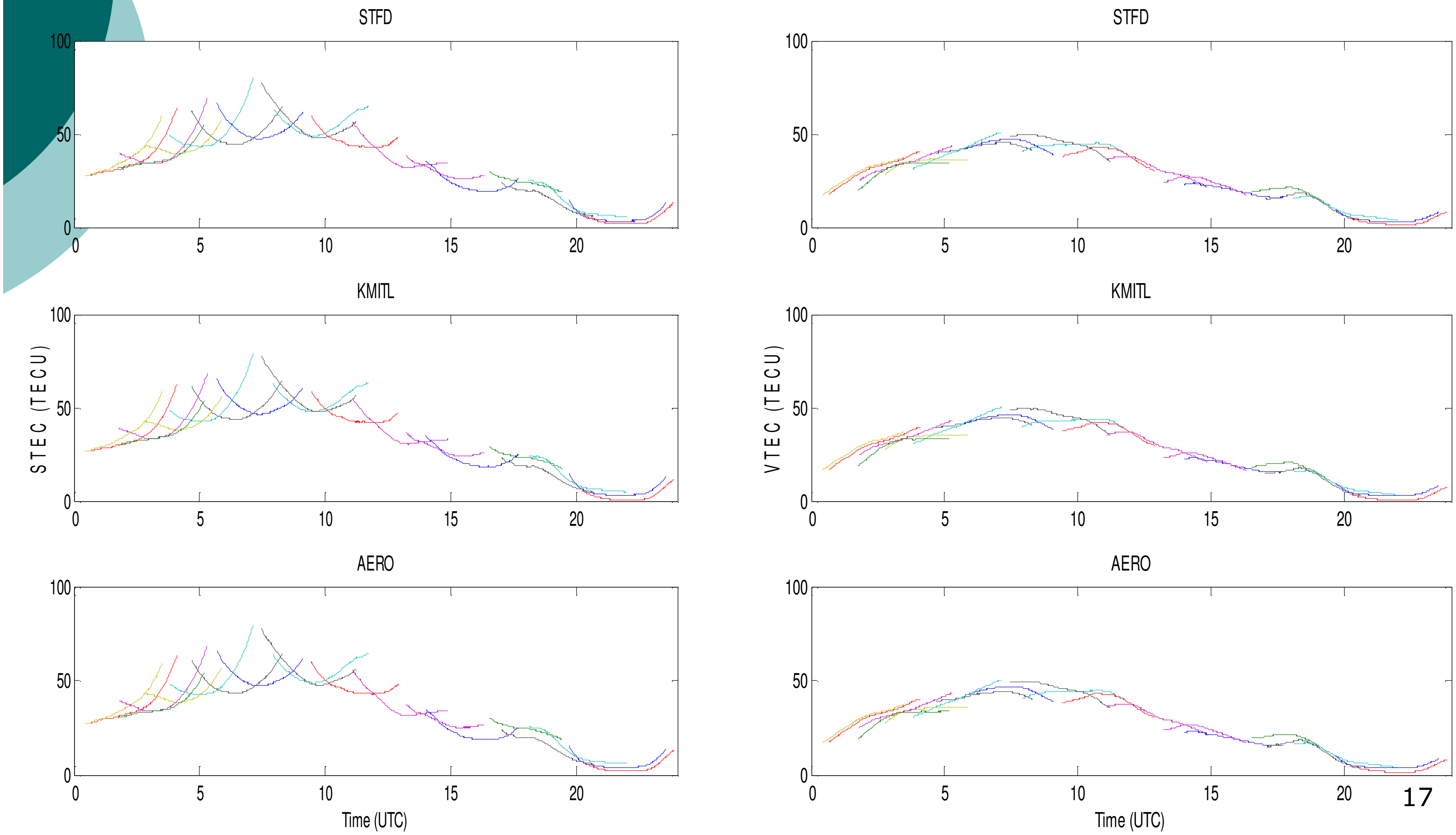
STEC and VTEC (Day 224)



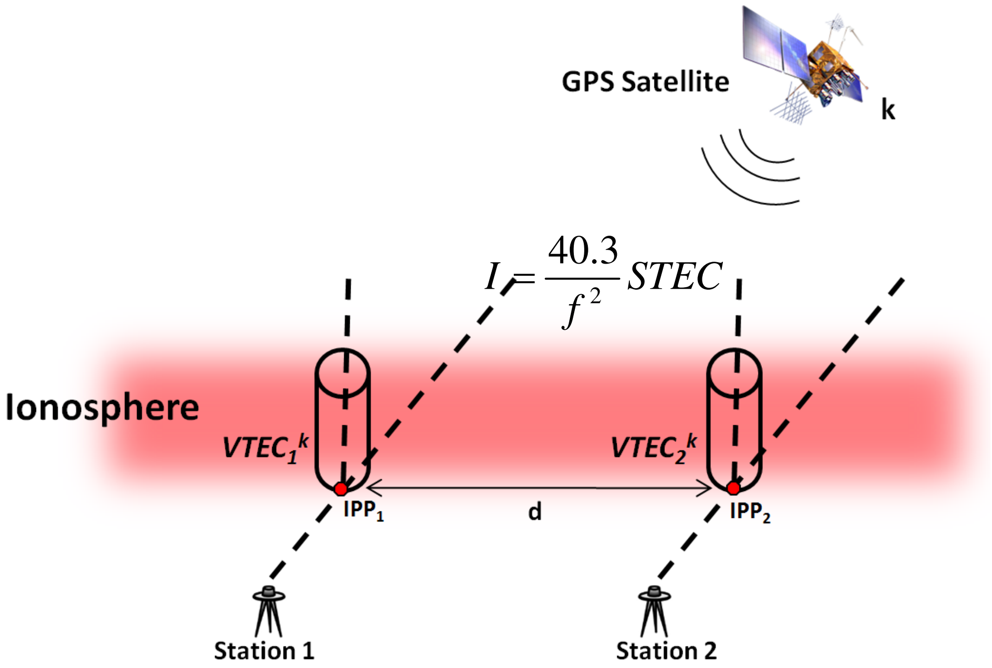
STEC and VTEC (Day 233)

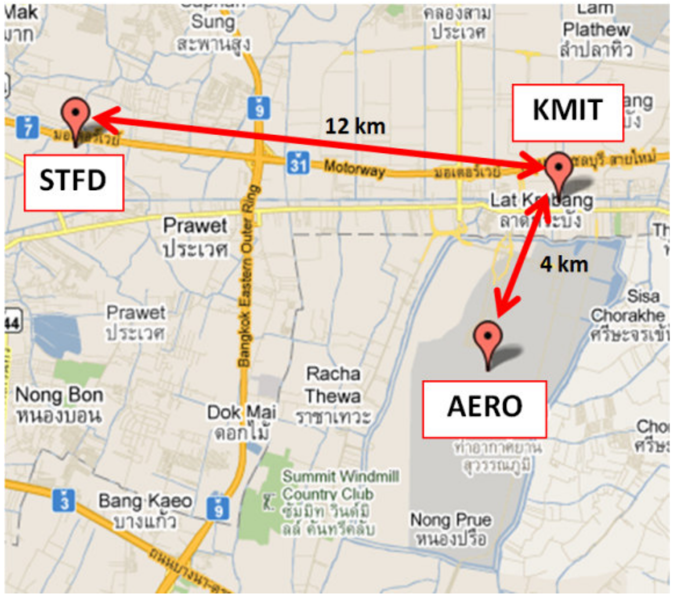


STEC and VTEC (Day 241)



Delay Gradients





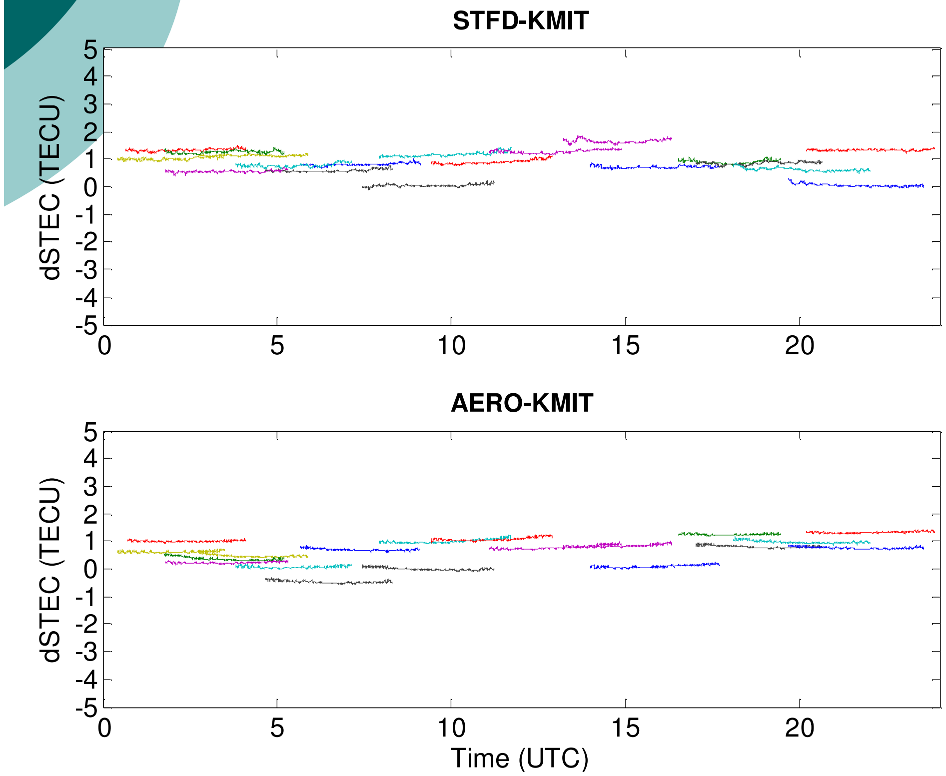
$$\nabla I_{vertical}(t) = \frac{40.3}{f^2}\left(\frac{VTEC_1^k(t) - VTEC_2^k(t)}{d}\right)$$

d = distance between the IPPs

Results

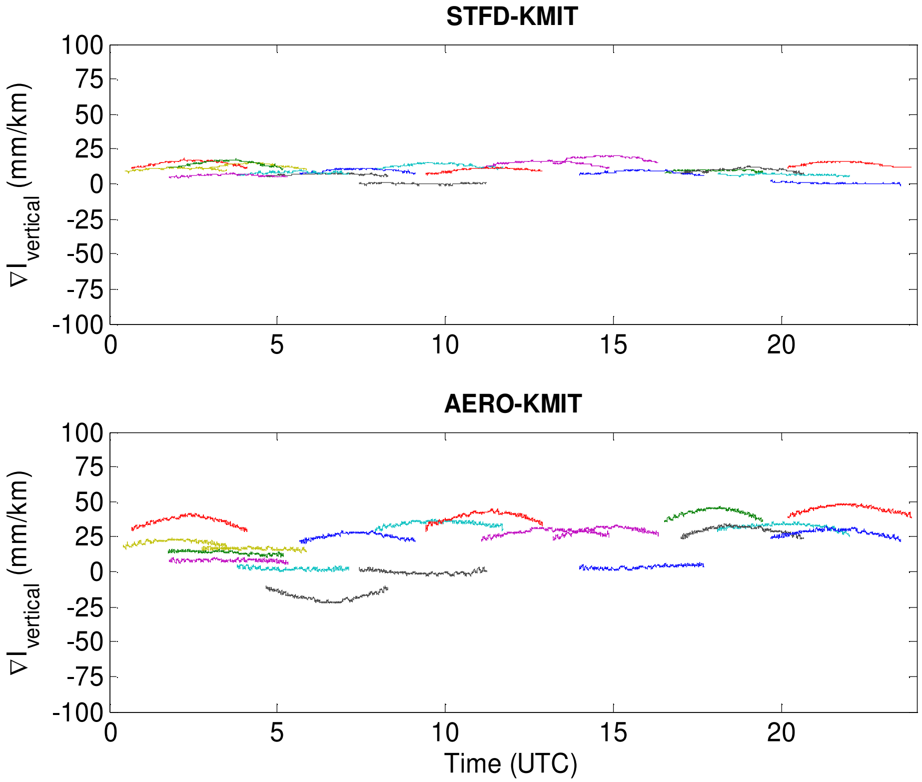
29th August 2011

Differential STEC (dSTEC)



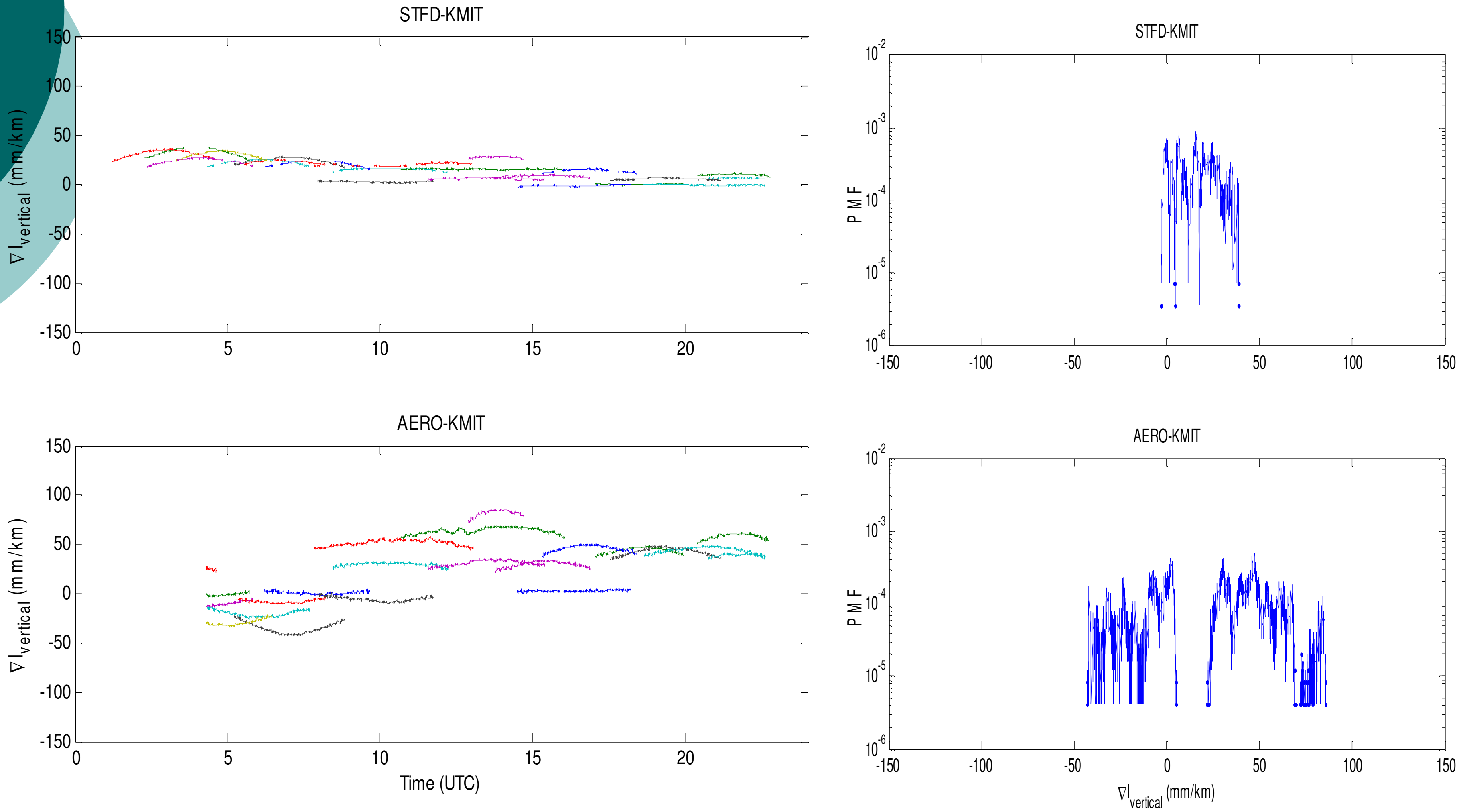
d ~ 11.5 km

Vertical ionospheric delay gradient



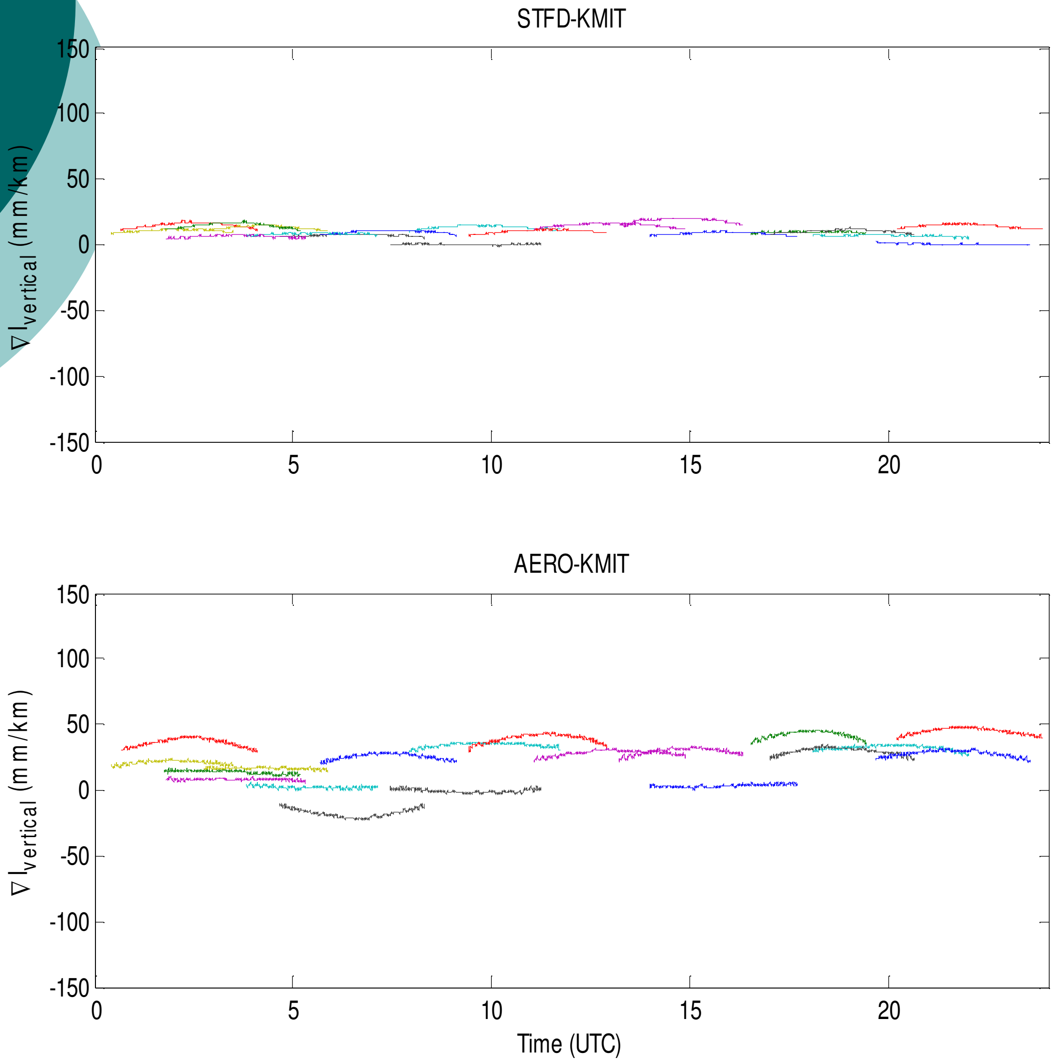
d ~ 3.5 km

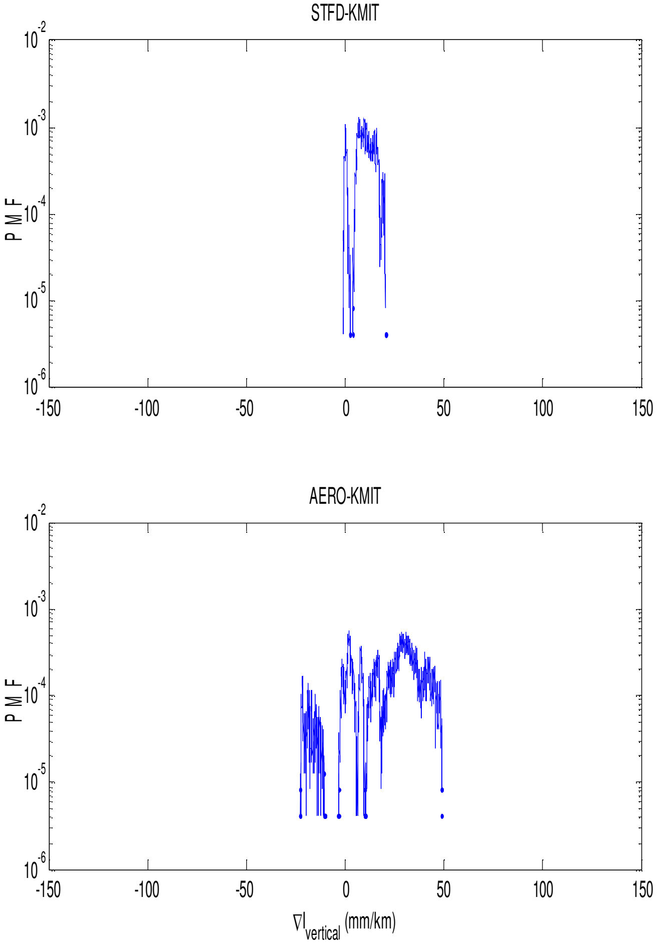
Ionospheric Delay Gradient (Day 233)


STFD-KMIT

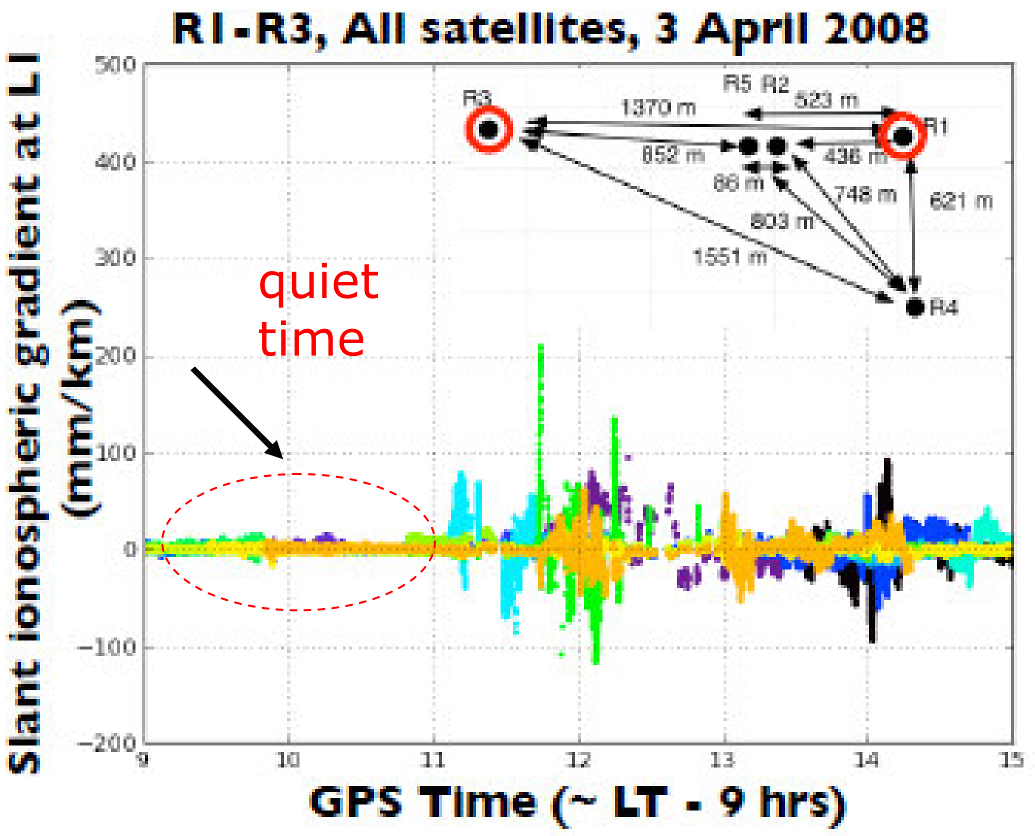
AERO-KMIT

Ionospheric Delay Gradient (Day 241)



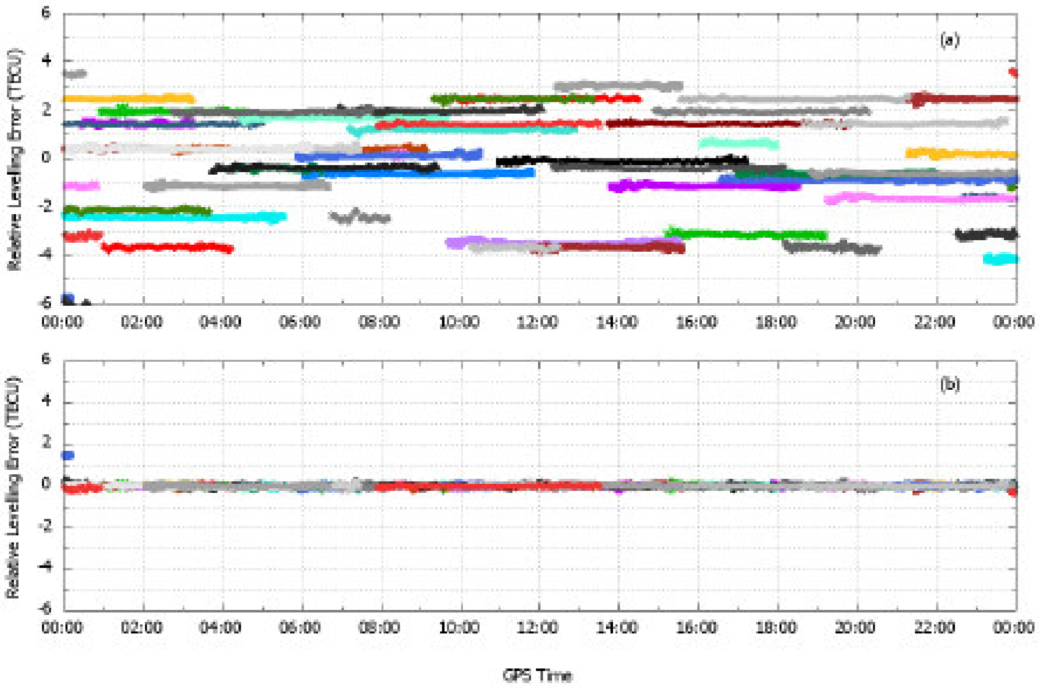


[Fujita et al., 2011]



During quiet time, the TEC gradient is computed with the mean around 0 mm/km.

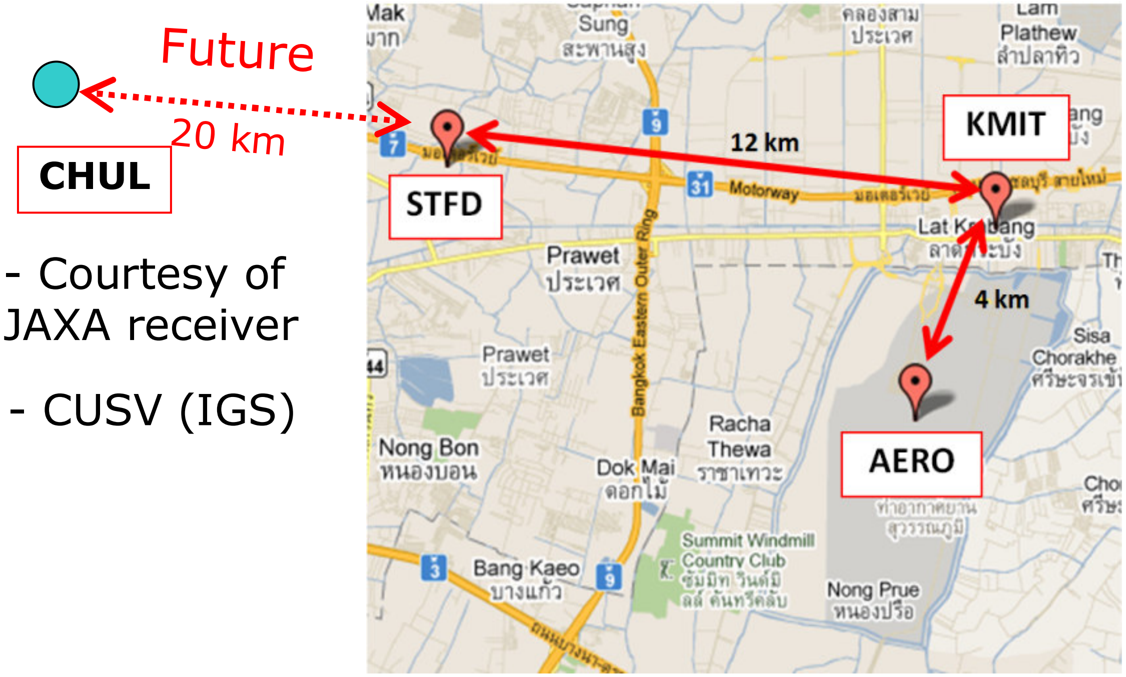
Discussions



The leveling errors from the standard leveling technique can drastically reduced by the “integer leveling” whereby the integer ambiguities are obtained through PPP processing and introduced to the geometric-free equation

S. Banville et al.,”Ionospheric Monitoring Using Integer-Levelled Observations,” ION GNSS 2012, Tennessee, USA, 17-21 Sept, 2012.

Short baseline experiments



- Courtesy of JAXA receiver

- CUSV (IGS)

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Conclusions

- The preliminary results show that using Minimum variance method, which is suitable for a few single stations, the background ionospheric delay gradient is within +,- 50 mm/km for STFD-KMIT baseline, but have higher values for the KMIT-AERO baseline.
- The use of minimum variance method will need to be further modified to account for the integer ambiguities.

Thank you for your attention
Q&A