International collaboration on space weather forecast

Paper: SCT1.9
Slant TEC gradient analysis during 12-13 September, 2014

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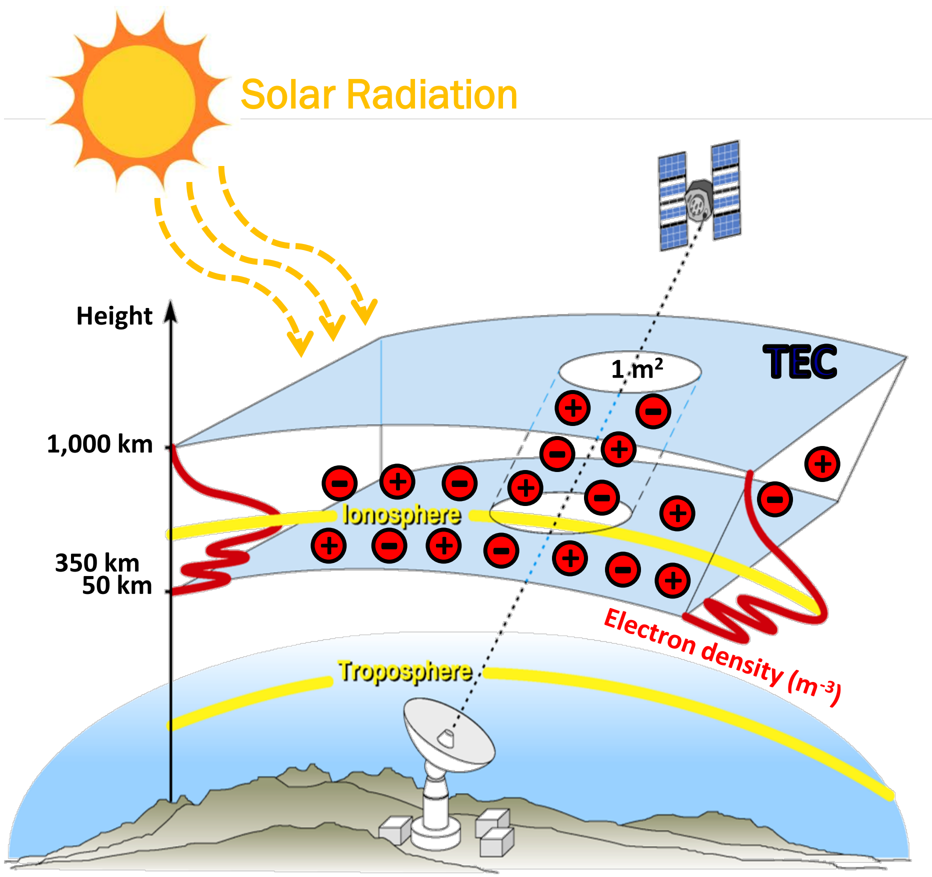
Outline

- Ionospheric delay gradient effects on Ground-Based Augmentation System (GBAS)
- Experimental Setup
- Results and Discussions
- Conclusions

Total Electron Content (TEC)

- The ionosphere is an ionized part of the atmosphere consisting of electrons and ions



- It is ionized due to the solar radiation and depends on (Locations: latitude, longitude, Local time and seasons, and Solar activities (sunspot number, solar storm, etc.)

Total Electron Content (TEC) on the Slant path (STEC)

$$STEC = \int_s N_e ds$$

TEC Unit (TECU) (10^{16} electrons/m^2)

N_e : Electron density (electrons/m^3)
S : Distance along the propagation path

GPS-Derived TEC

➢**Slant TEC (STEC)** is derived by differencing the pseudo ranges (P_1 and P_2) or the phases (*L1* and *L2*) of the two frequencies.

$$STEC = \frac{2(f_1 f_2)^2}{k(f_1^2 - f_2^2)}(L_1\lambda_1 - L_2\lambda_2)$$

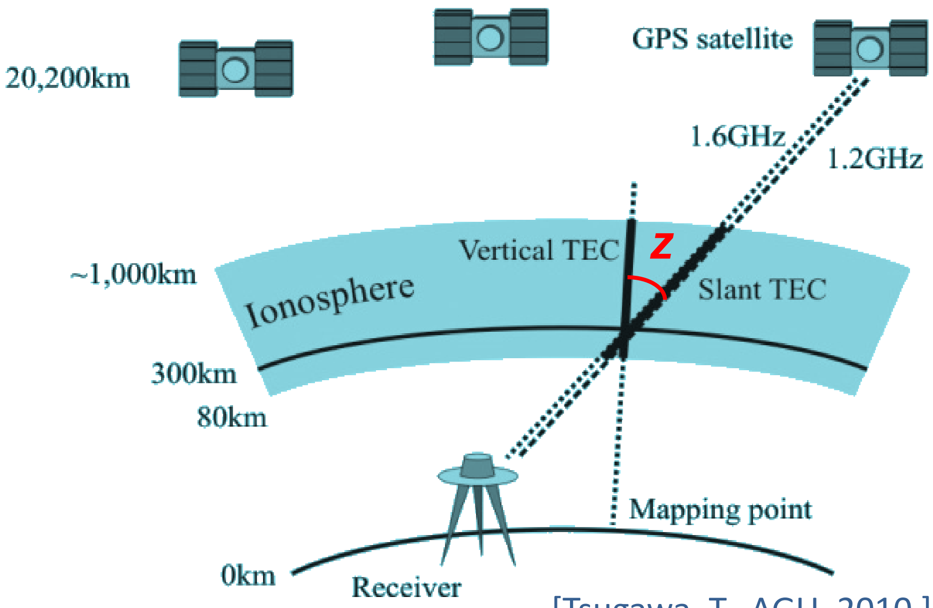
$$STEC = \frac{2(f_1 f_2)^2}{k(f_1^2 - f_2^2)}(P_2 - P_1)$$

[Blewitt, 1990]

f_1 = 1575.42 MHz,
f_2 = 1227.60 MHz
λ_1 = 0.1904 m
λ_2 = 0.2444 m
k = 80.62 (m^3/s^2)

➢**Vertical TEC (VTEC)** can be computed from the STEC value and the zenith angle.

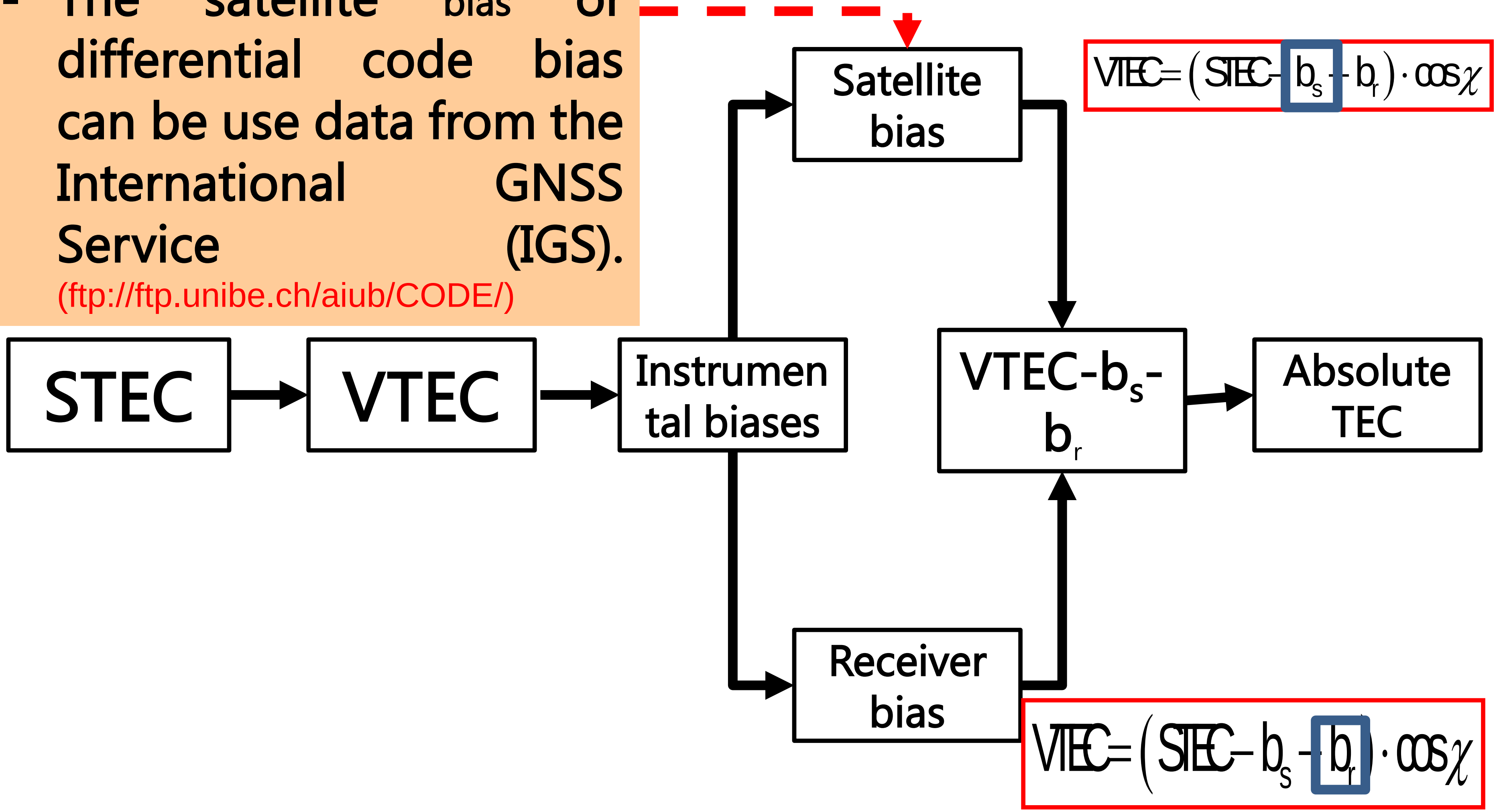
$$VTEC = STEC.\cos(z)$$



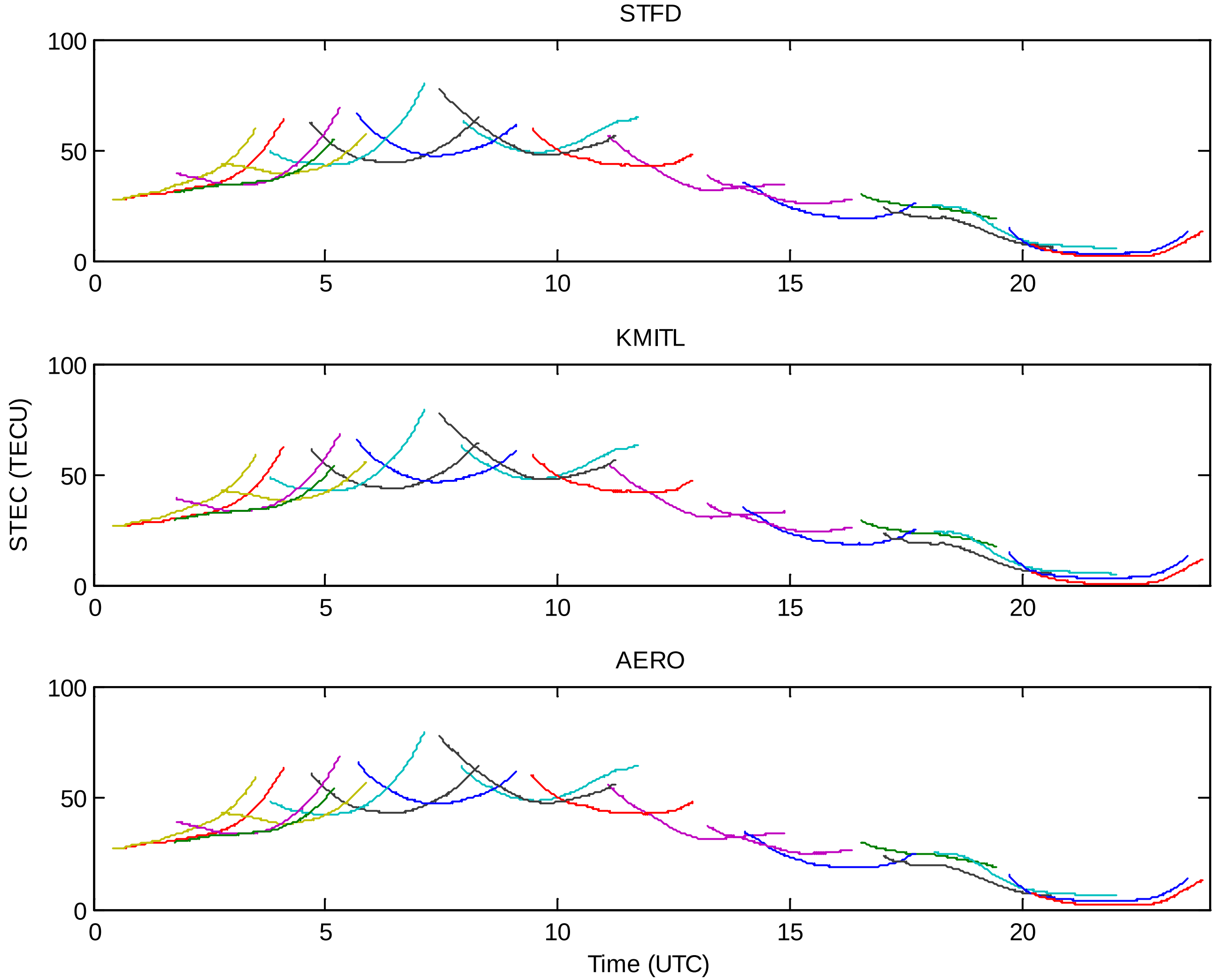
[Tsugawa, T., AGU, 2010]

Instrumental bias estimation

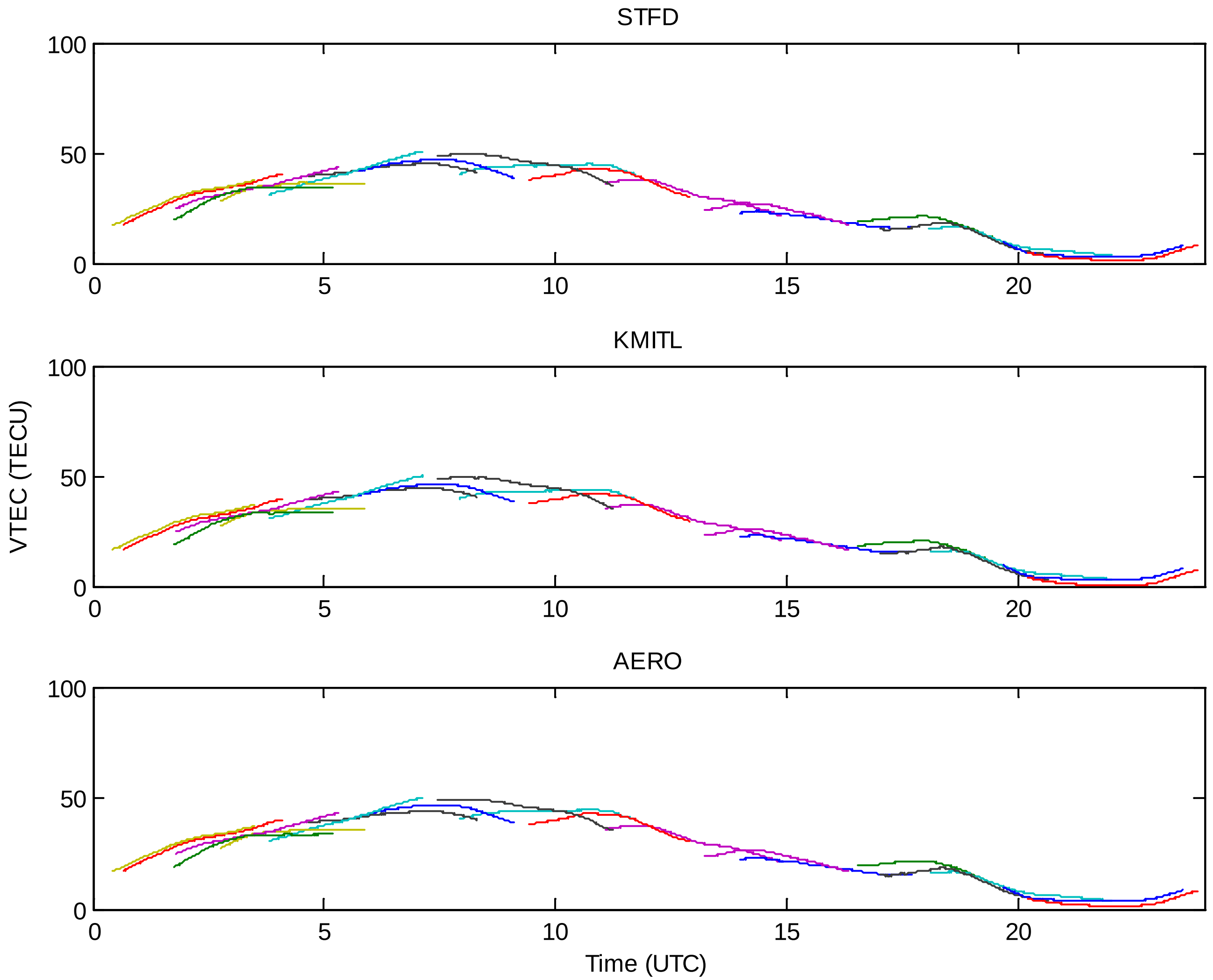
- The satellite bias or differential code bias can be use data from the International GNSS Service (IGS). (ftp://ftp.unibe.ch/aiub/CODE/)



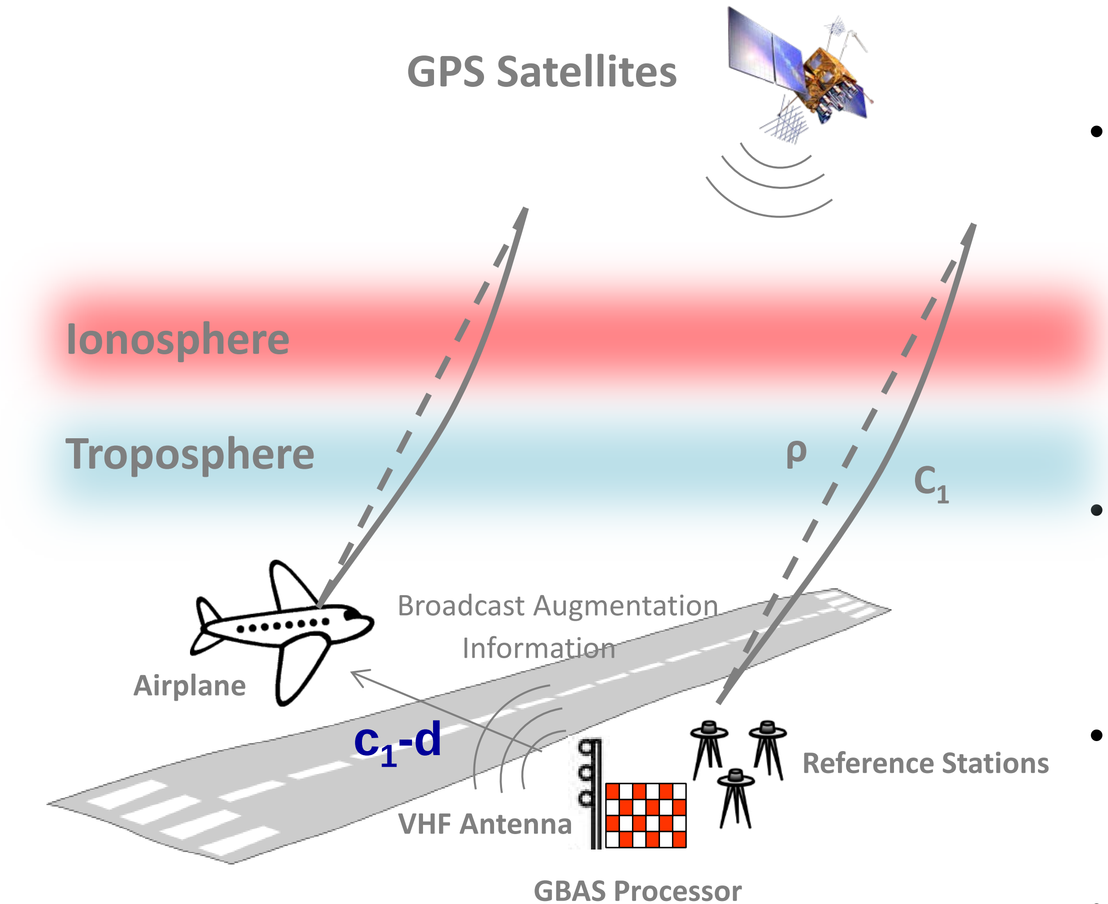
STEC (removed biases)



VTEC (removed biases)



Ground-Based Augmentation System (GBAS)



- **The GBAS processor calculates the pseudorange error (e) of each GPS satellite.**

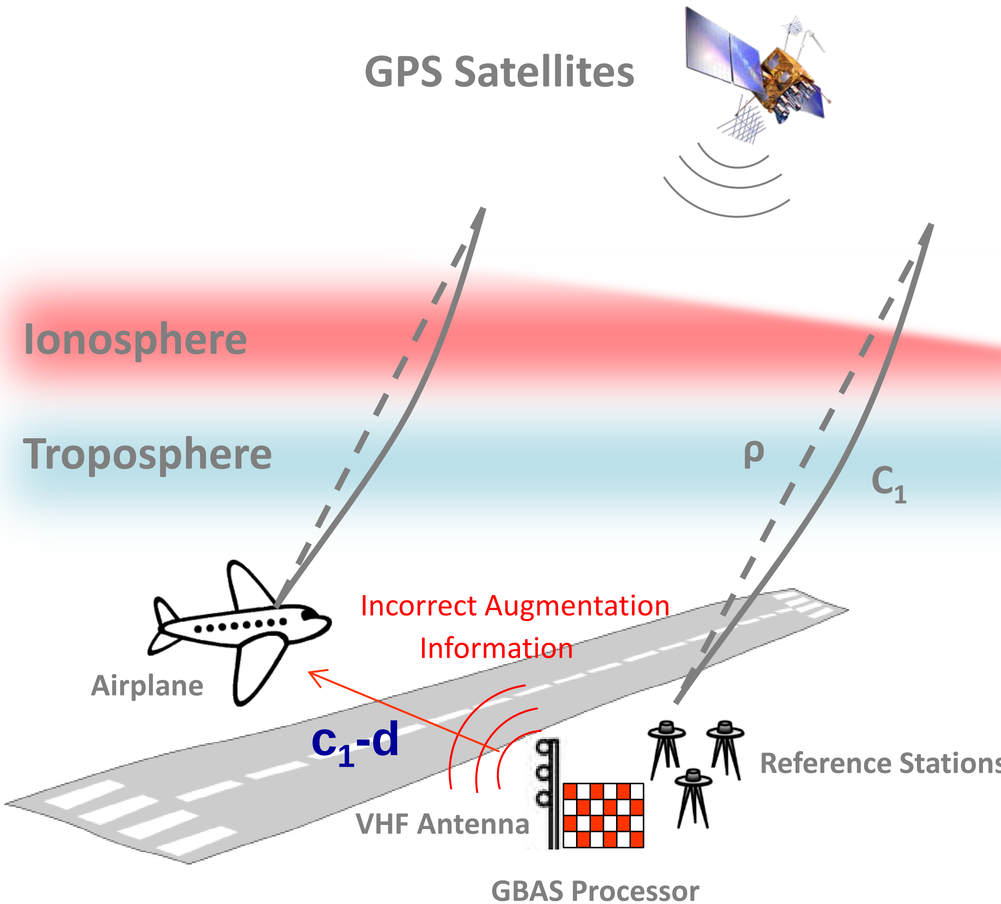
$$e = c_1 - d$$

True distance (d)

Observe distance (c_1)

- **The augmentation information (error e) is then broadcast to the approaching airplanes**
- **The pseudorange errors are assumed to be the same in the nearby area.**
- **The coverage area is about 40-60 km around the airport.**

Ionospheric Delay Gradients with GBAS



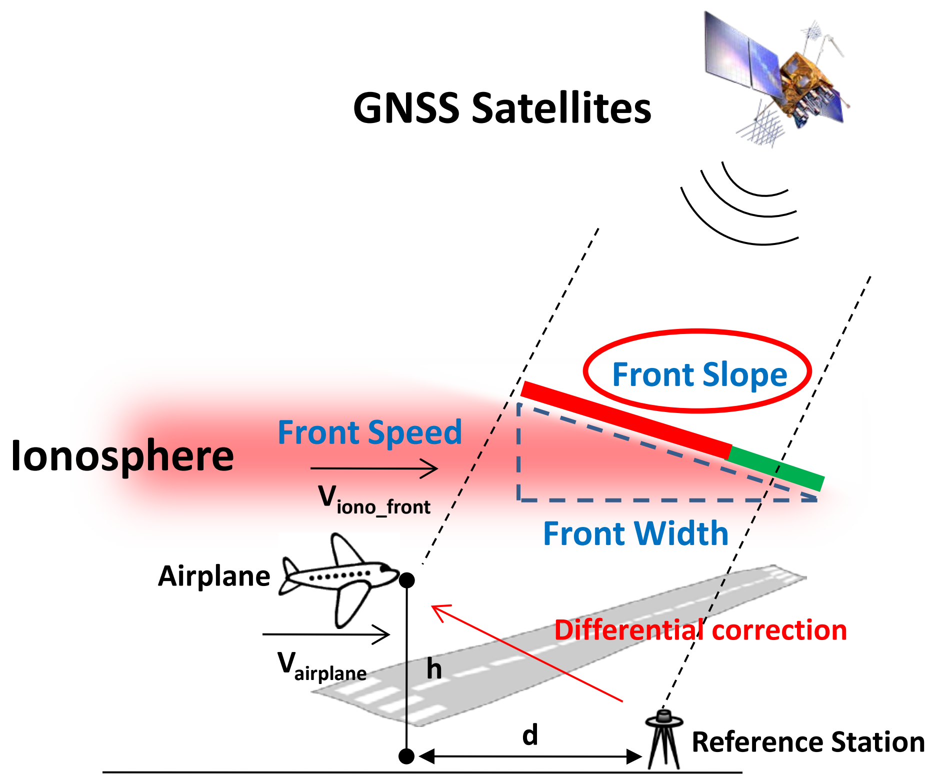
- The reference stations provide the differential corrections and integrity information to the receiver that are equipped in the aircraft in the nearby area.

- However, the ionospheric irregularities can cause the error of the differential correction information that is 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

Simplified ionosphere wave front model

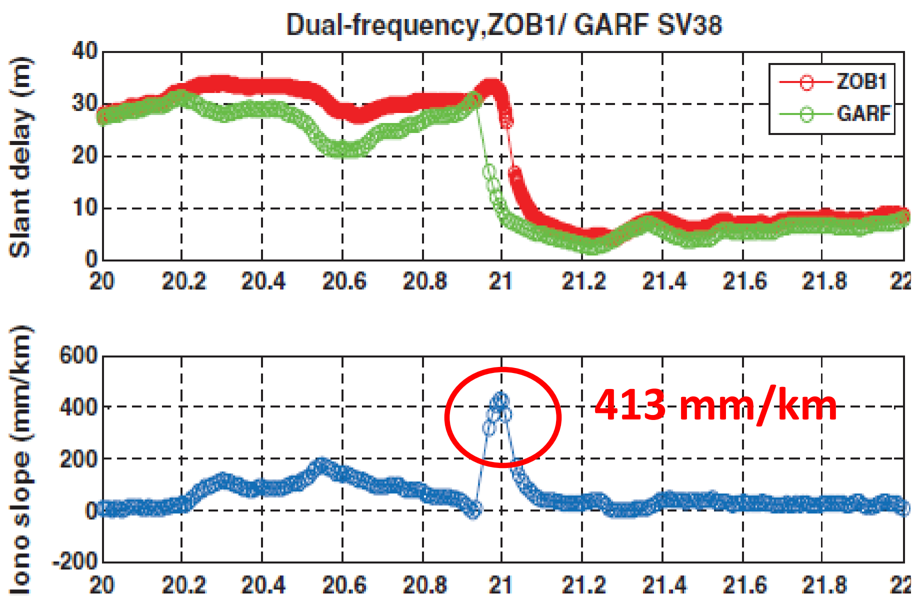


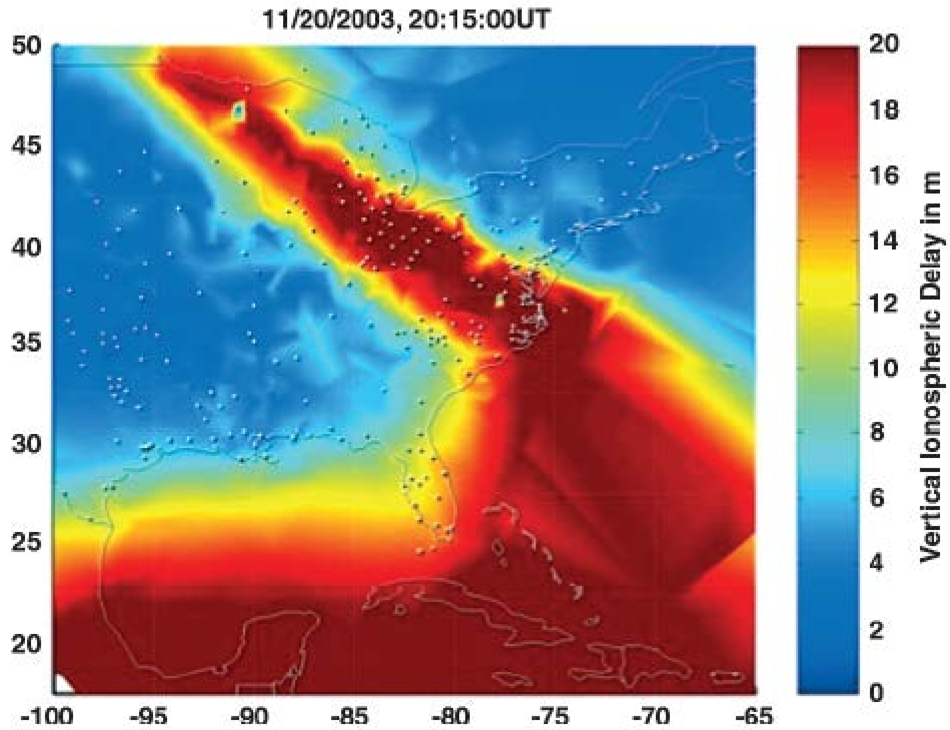
- **Front Slope** or **"Ionospheric delay gradient"**
- **Causes of Ionospheric delay gradient,**
  1. **Due to the physical ionospheric separation between aircraft and reference station.**
  2. **Due to the ionospheric irregularities (plasma bubbles, SED).**
- **Q : How large of the ionospheric delay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

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

Ionospheric effects to GBAS

20 November 2003

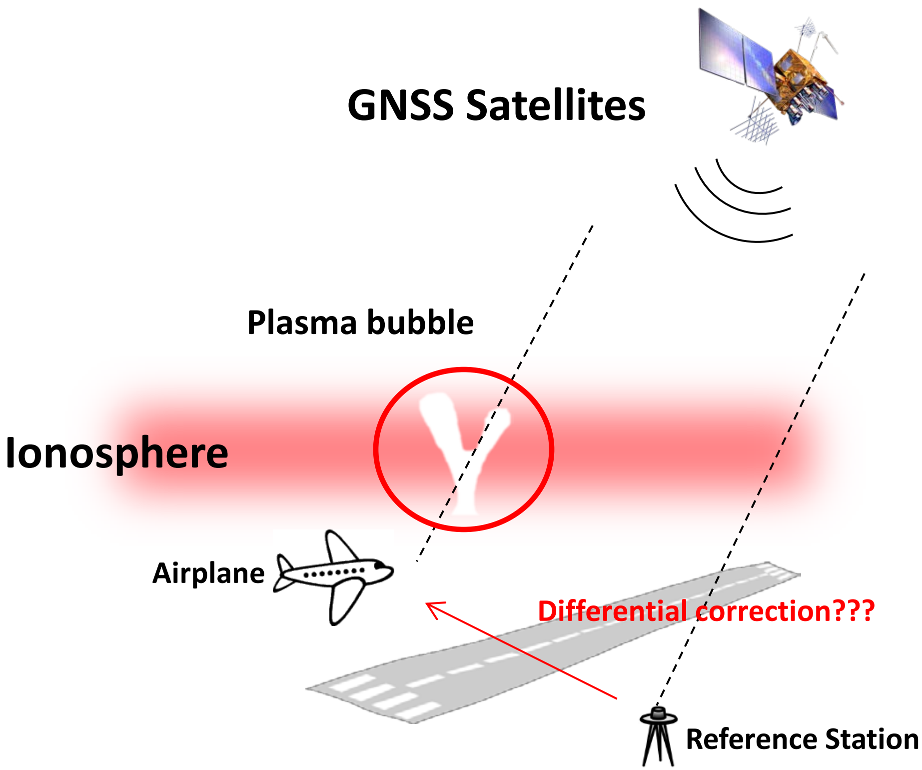


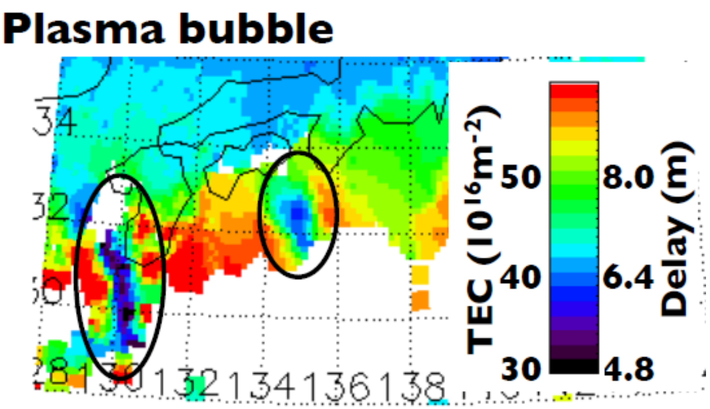


S. Datta-Barua, et al., 2010.

This extreme event stimulate the ionospheric delay gradient research in various regions.

Ionospheric effects to GBAS



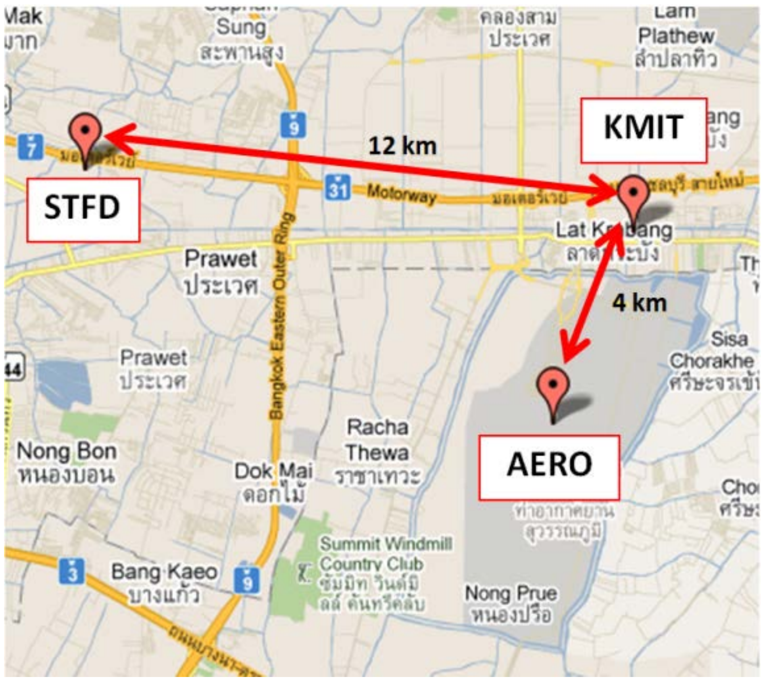


S. Saito 2011.

- Plasma bubble frequently occurs in low-latitude region after sunset , and more occurrence during high solar activity period..
- This phenomena can cause ionospheric delay gradient and also scintillation, which degrades the GBAS performance.

The ICAO has recently realized the impact of this issue and recommended each country to investigate ionospheric delay gradient in that region.

Short baseline experiments



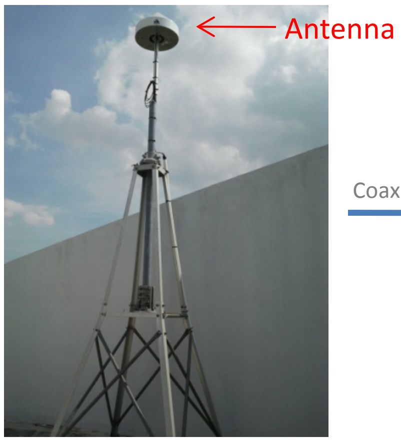
- Short baseline experiment needs to be carried out to monitor the ionospheric delay gradients near Suvarnabhumi international airport.

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

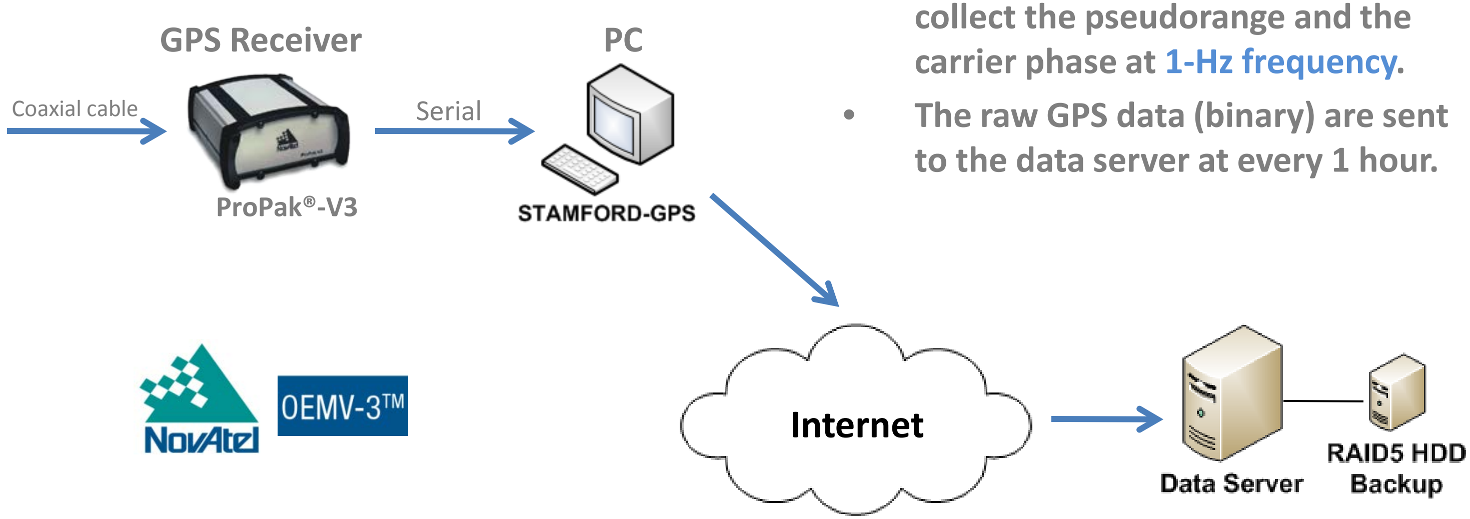
  1. King Mongkut's Institute of Technology Ladkrabang (KMITL)
  2. Electronic Navigation Research Institute (ENRI), Japan
  3. Aeronautical Radio of Thailand Ltd. (AEROTHAI)
  4. Stamford International University

- This project started July 2011.

Experimental Setup

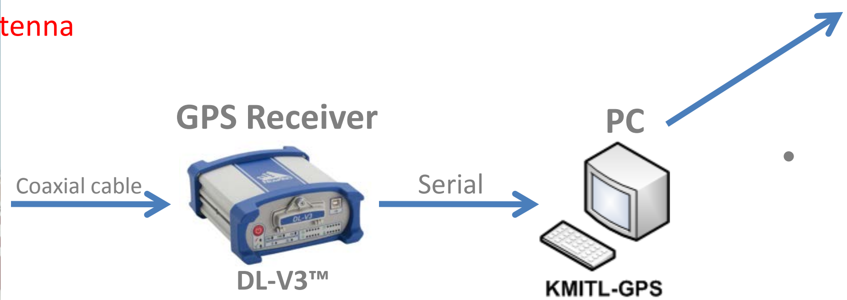


STFD



- The dual-frequency GPS receivers collect the pseudorange and the carrier phase at 1-Hz frequency.
- The raw GPS data (binary) are sent to the data server at every 1 hour.

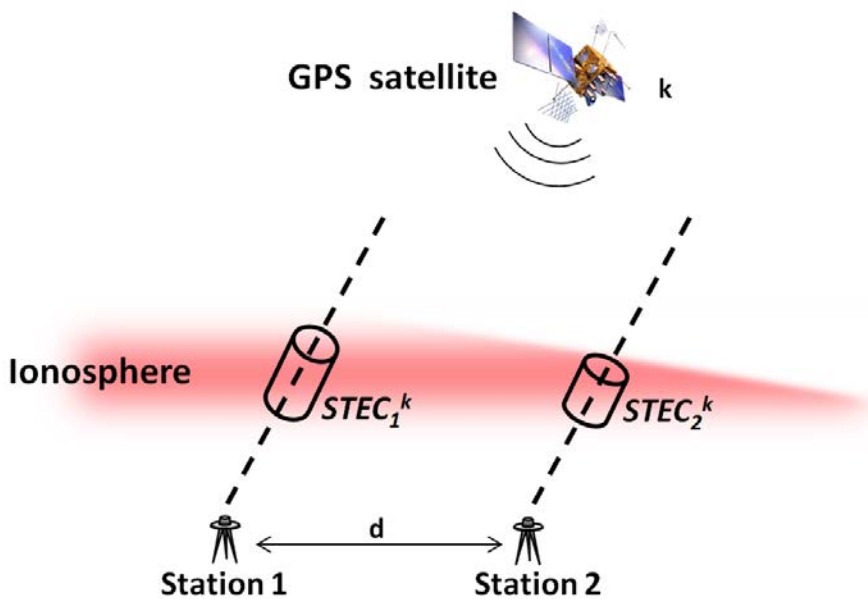
KMITL



- The raw GPS data are converted into RINEX (Receiver Independent Exchange) format (ASCII).

Ionospheric delay gradient calculation

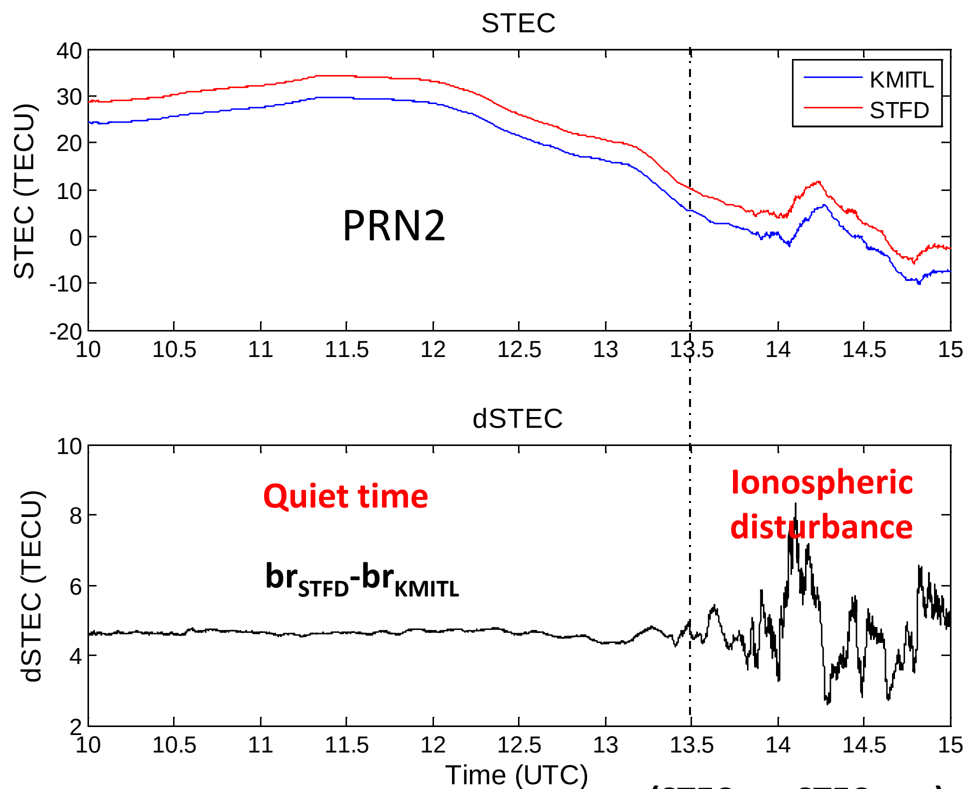
Single difference method



$$STEC_{adj\_1}^{k} = STEC_{1}^{k} + B_{S}^{K} + B_{R\_1}$$

$$STEC_{adj\_2}^{k} = STEC_{2}^{k} + B_{S}^{K} + B_{R\_2}$$

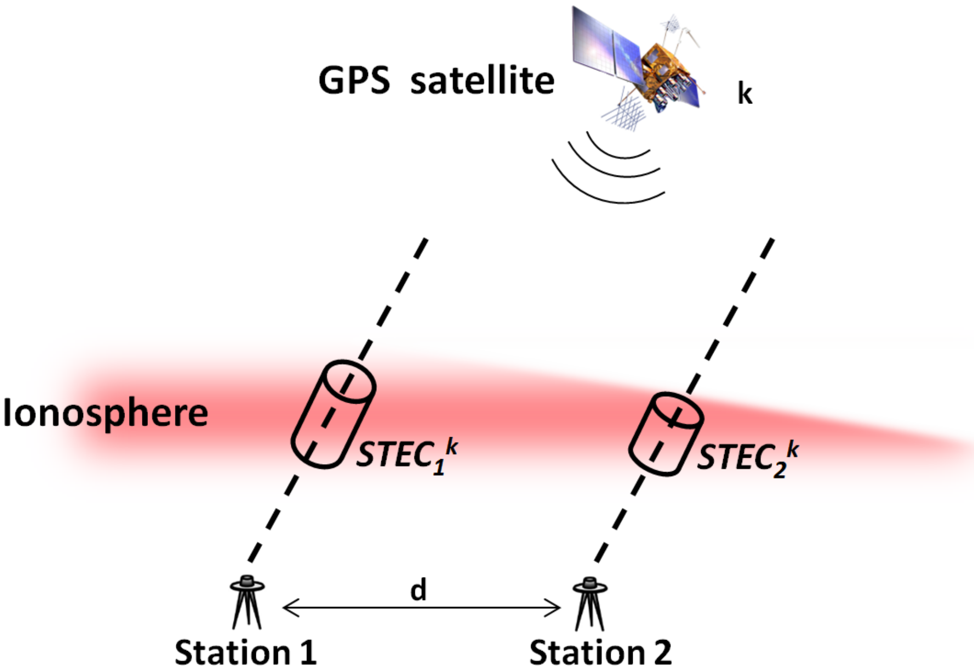
1 September 2011

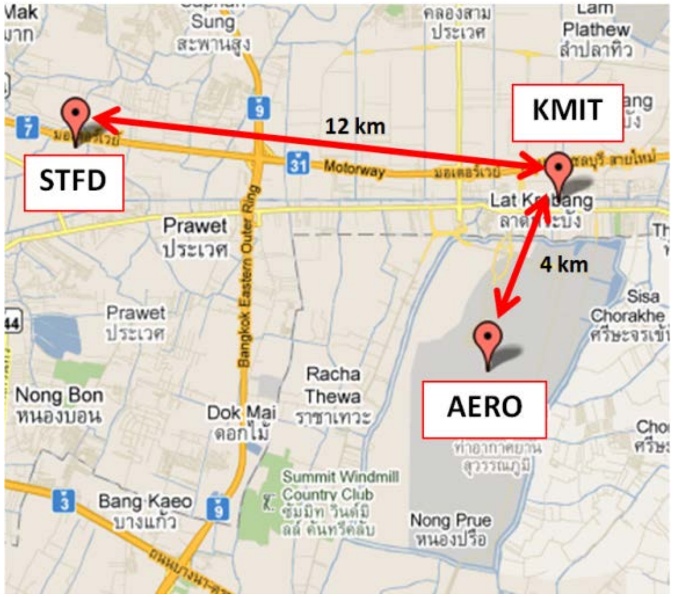


$(STEC_{STFD}$-$STEC_{KMITL})$ + $(Br_{KMITL}$-$Br_{STFD})$

$$dSTEC^{k} = STEC_{adj\_1}^{k} - STEC_{adj\_2}^{k}$$
$$= (STEC_{1}^{k} - STEC_{2}^{k}) + (b_{R1} - b_{R2})$$

Ionospheric delay gradient calculation



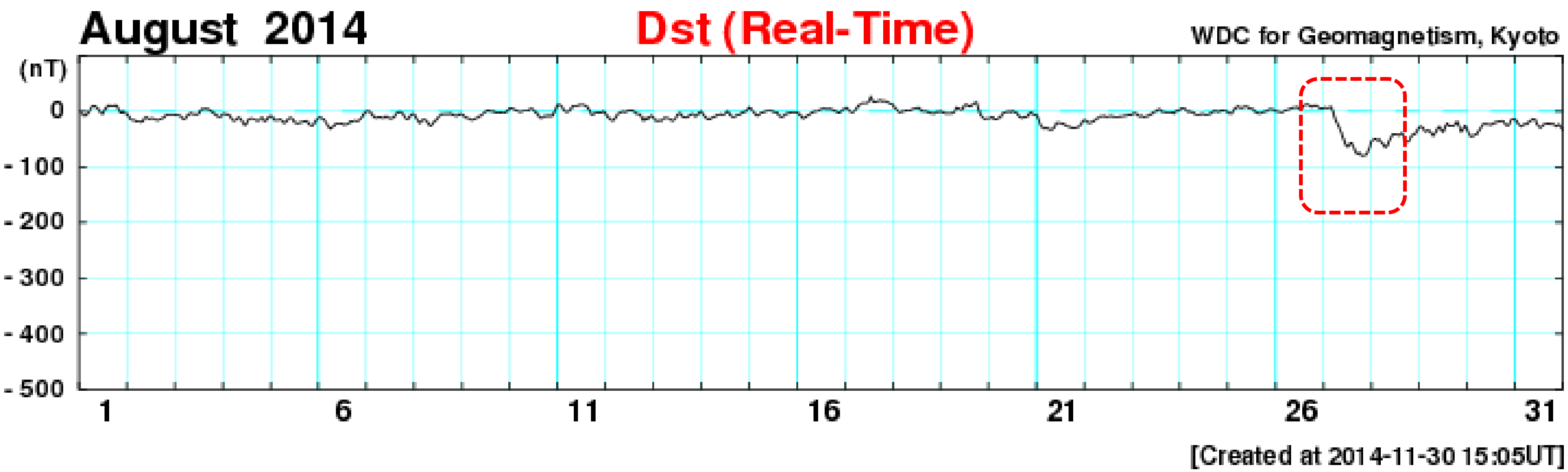


$$dSTEC^k = (STEC_1^k - STEC_2^k) + (b_{R1} - b_{R2})$$

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

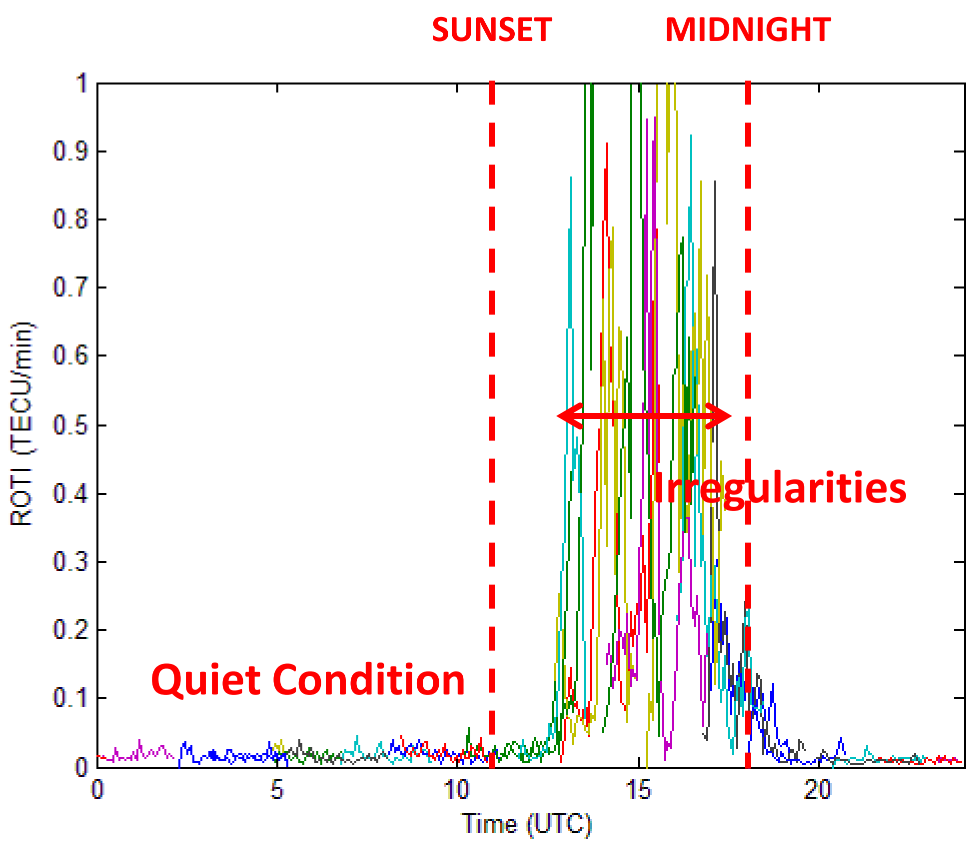
Ionospheric delay gradient (mm/km)

Dst Index



August 2014
Dst (Real-Time)
WDC for Geomagnetism, Kyoto
(nT)
0
-100
-200
-300
-400
-500
1
6
11
16
21
26
31
[Created at 2014-11-30 15:05UT]

ROTI (Rate of TEC change index)



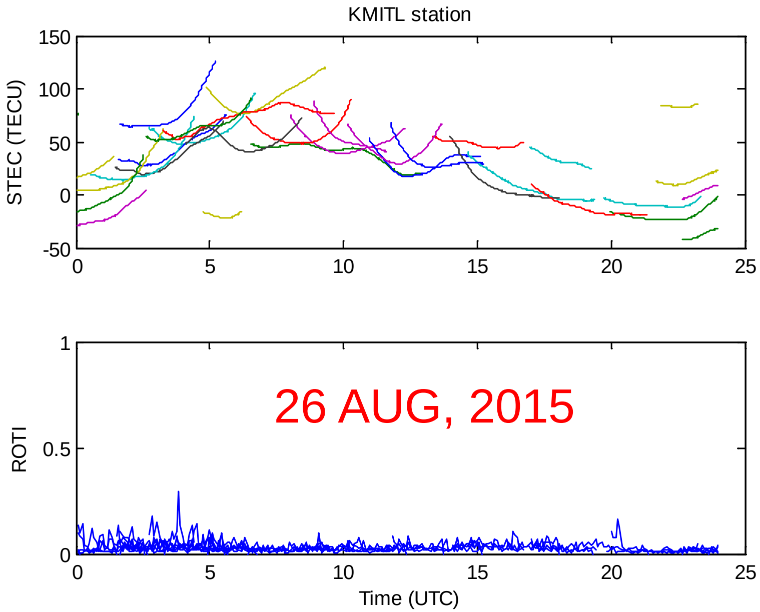
Example ROTI

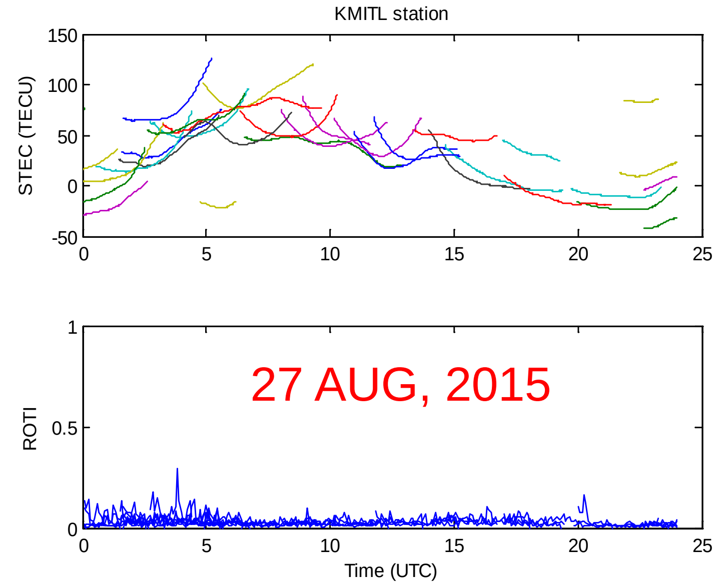
- **In order to detect the ionospheric irregularities, we use the rate of TEC change index or ROTI.**

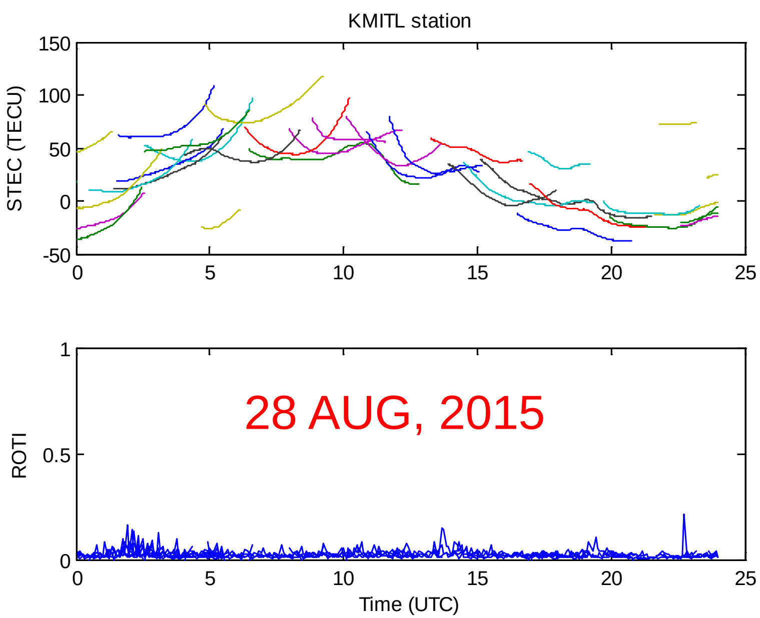
$$ROT(i) = STEC(i+1) - STEC(i)$$

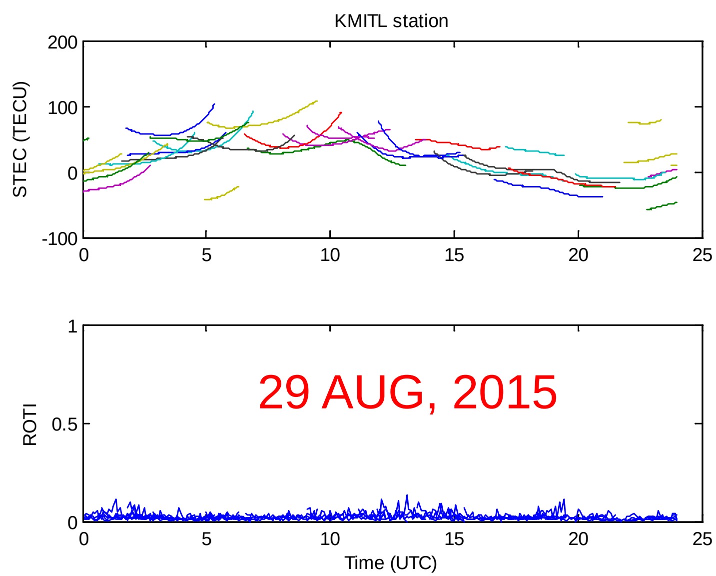
$$ROTI = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(ROT(i) - \overline{ROT})^2}$$

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

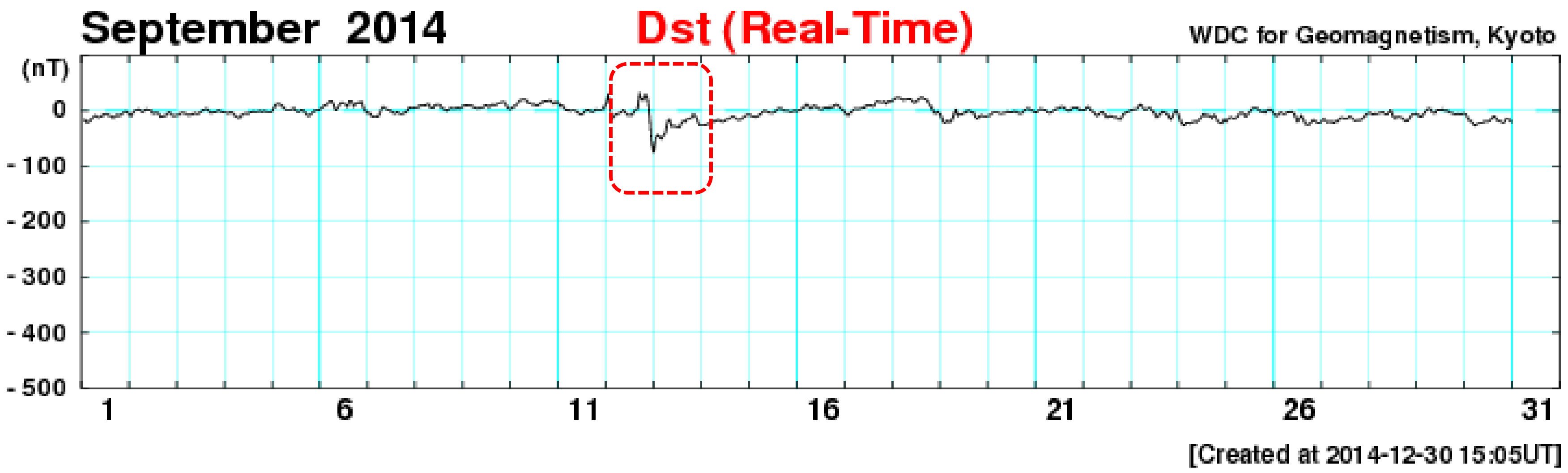

KMITL station
STEC (TECU)
ROTI
Time (UTC)
26 AUG, 2015


KMITL station
STEC (TECU)
ROTI
Time (UTC)
27 AUG, 2015


KMITL station
STEC (TECU)
ROTI
Time (UTC)
28 AUG, 2015

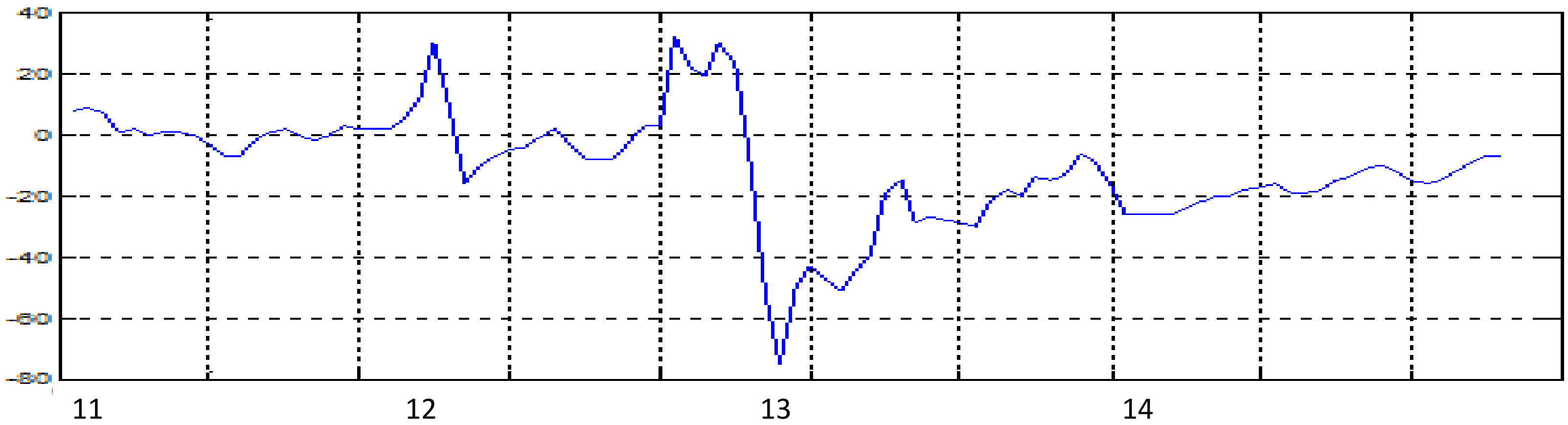

KMITL station
STEC (TECU)
ROTI
Time (UTC)
29 AUG, 2015

Dst Index

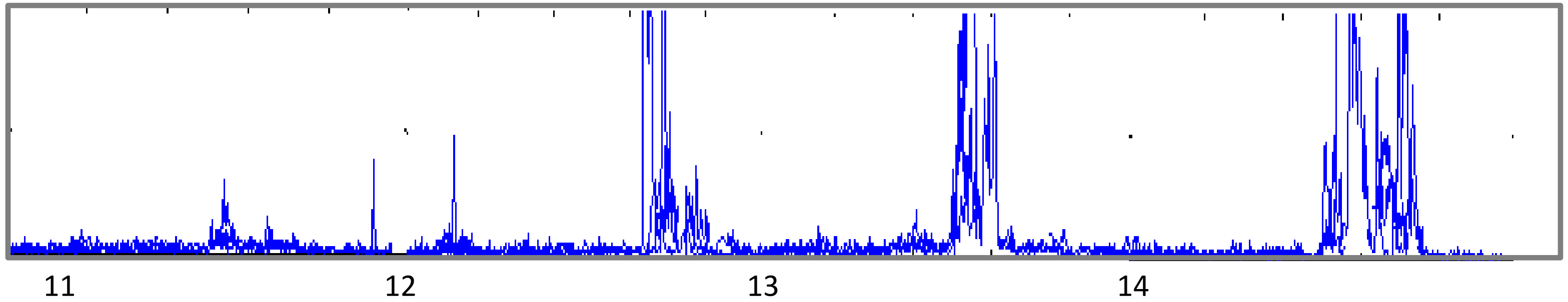


September 2014
Dst (Real-Time)
WDC for Geomagnetism, Kyoto
(nT)
0
-100
-200
-300
-400
-500
1
6
11
16
21
26
31
[Created at 2014-12-30 15:05UT]

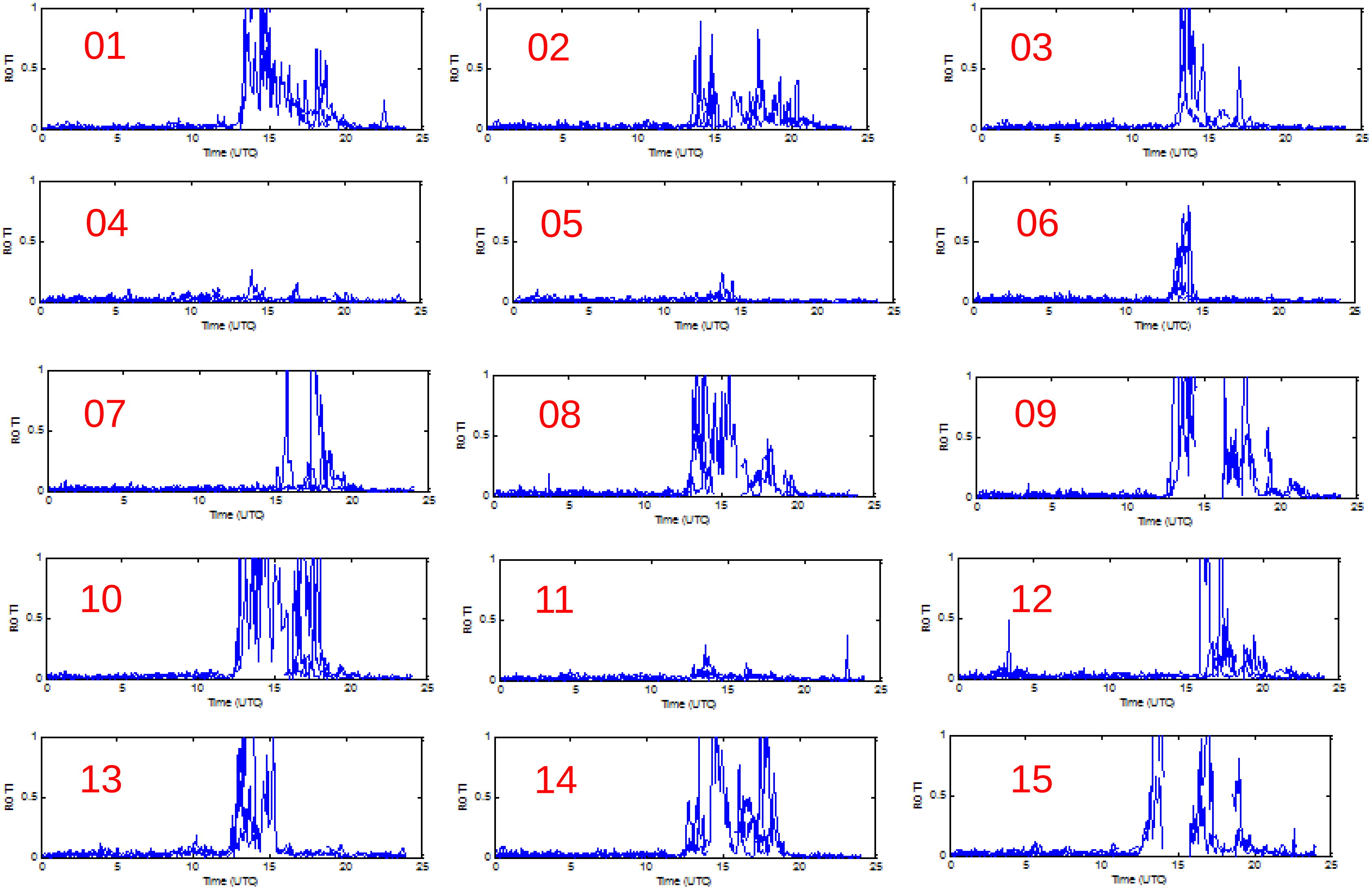
D_{st}



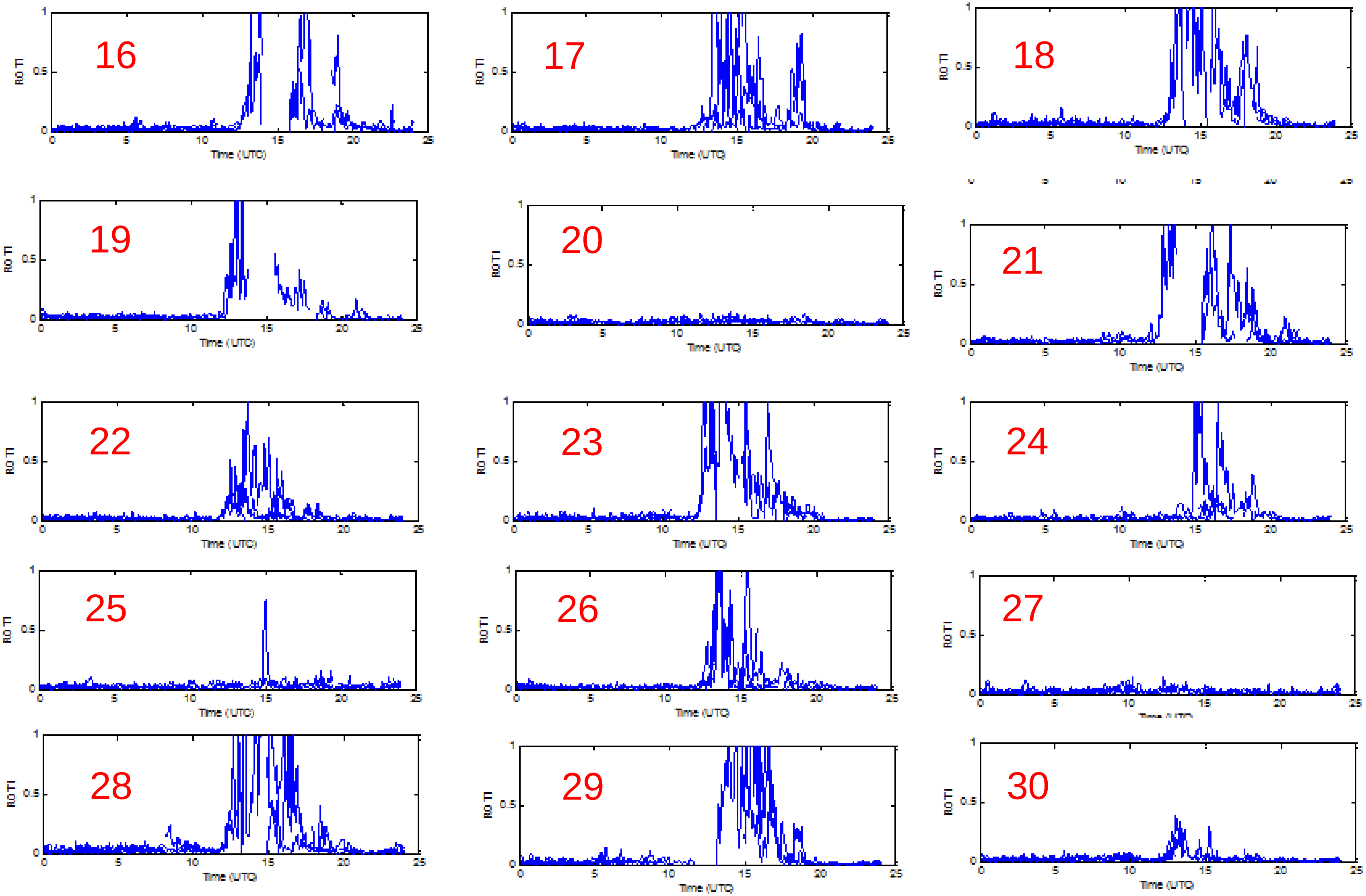
ROTI



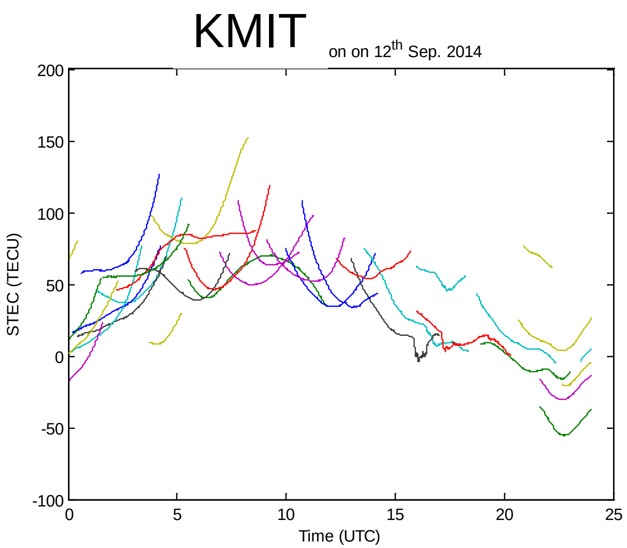
ROTI – Sept. 2014

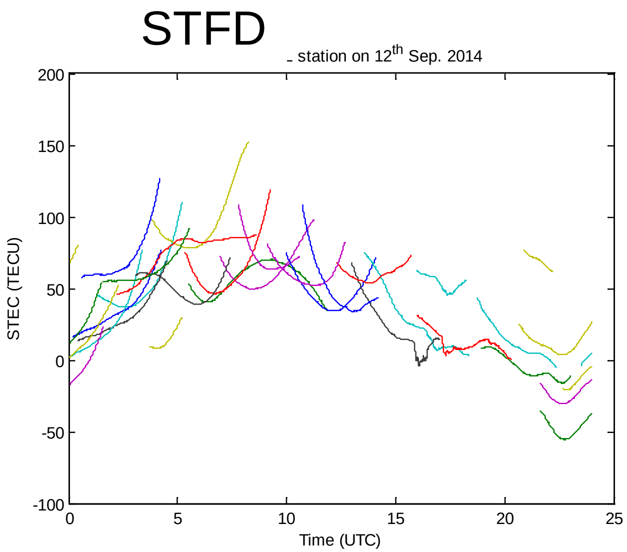


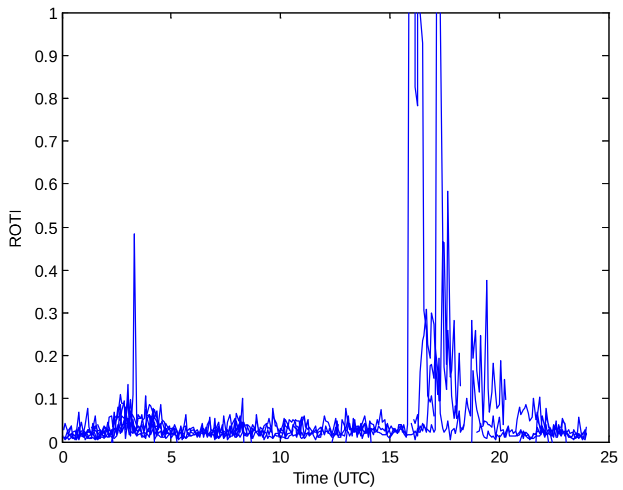
ROTI – Sept. 2014

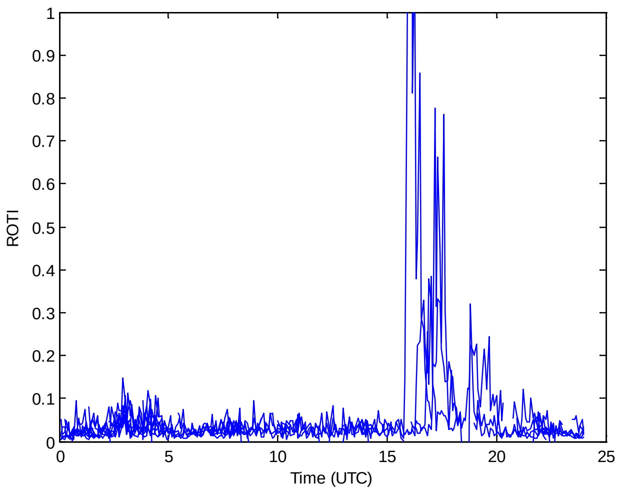


PRN21, 12 Sept, 2014

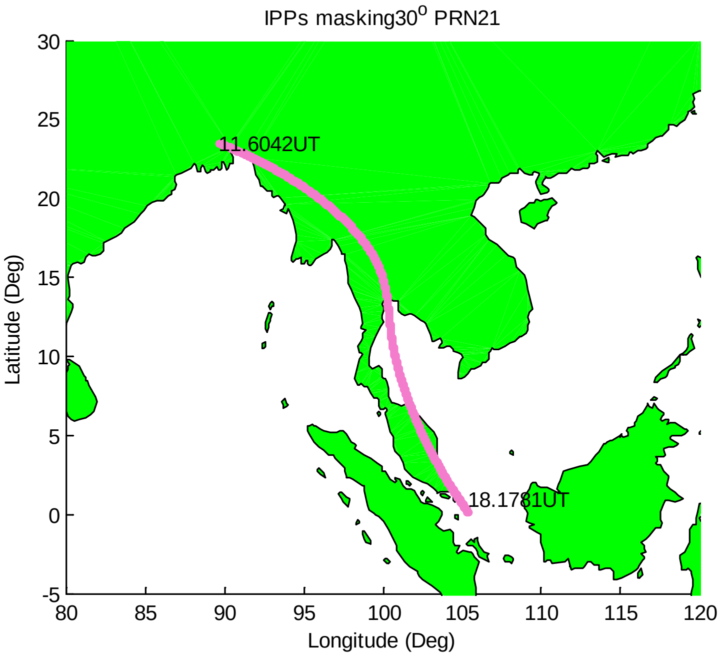






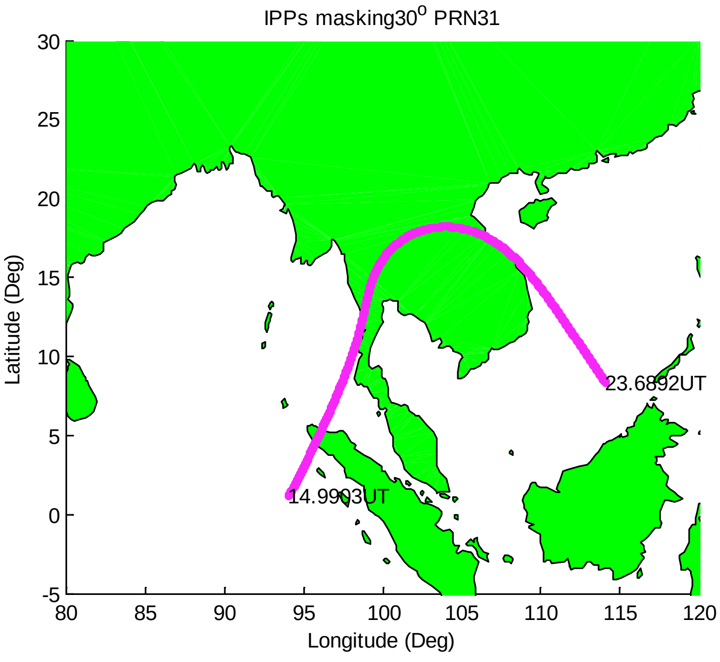


PRN 21



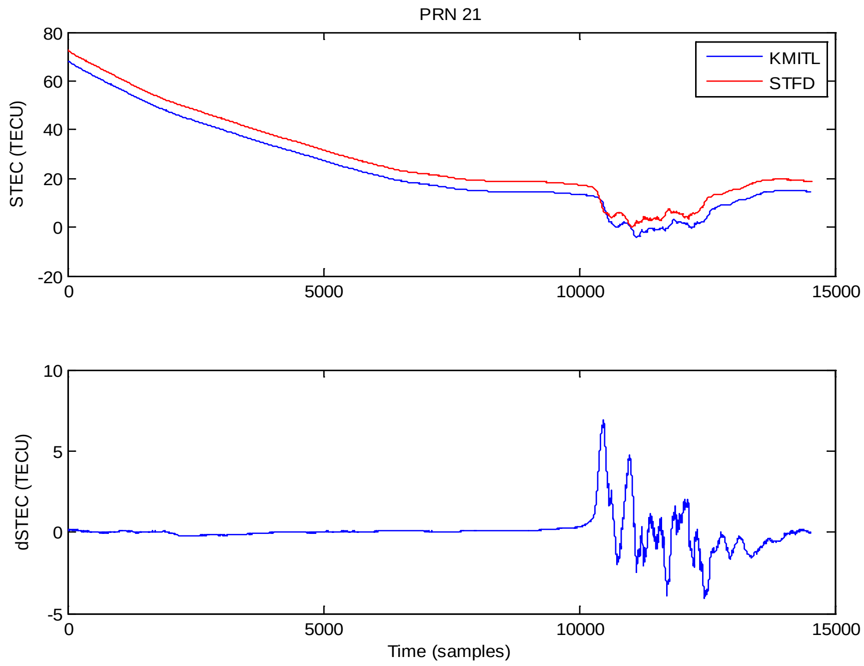
IPPs masking30^{o} PRN21
11.6042UT
18.1781UT
Latitude (Deg)
Longitude (Deg)
30
25
20
15
10
5
0
-5
80
85
90
95
100
105
110
115
120

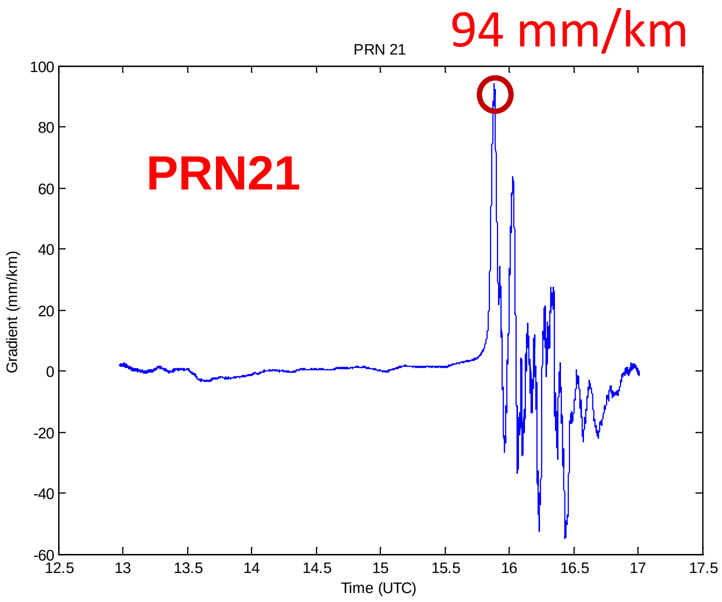
PRN 31



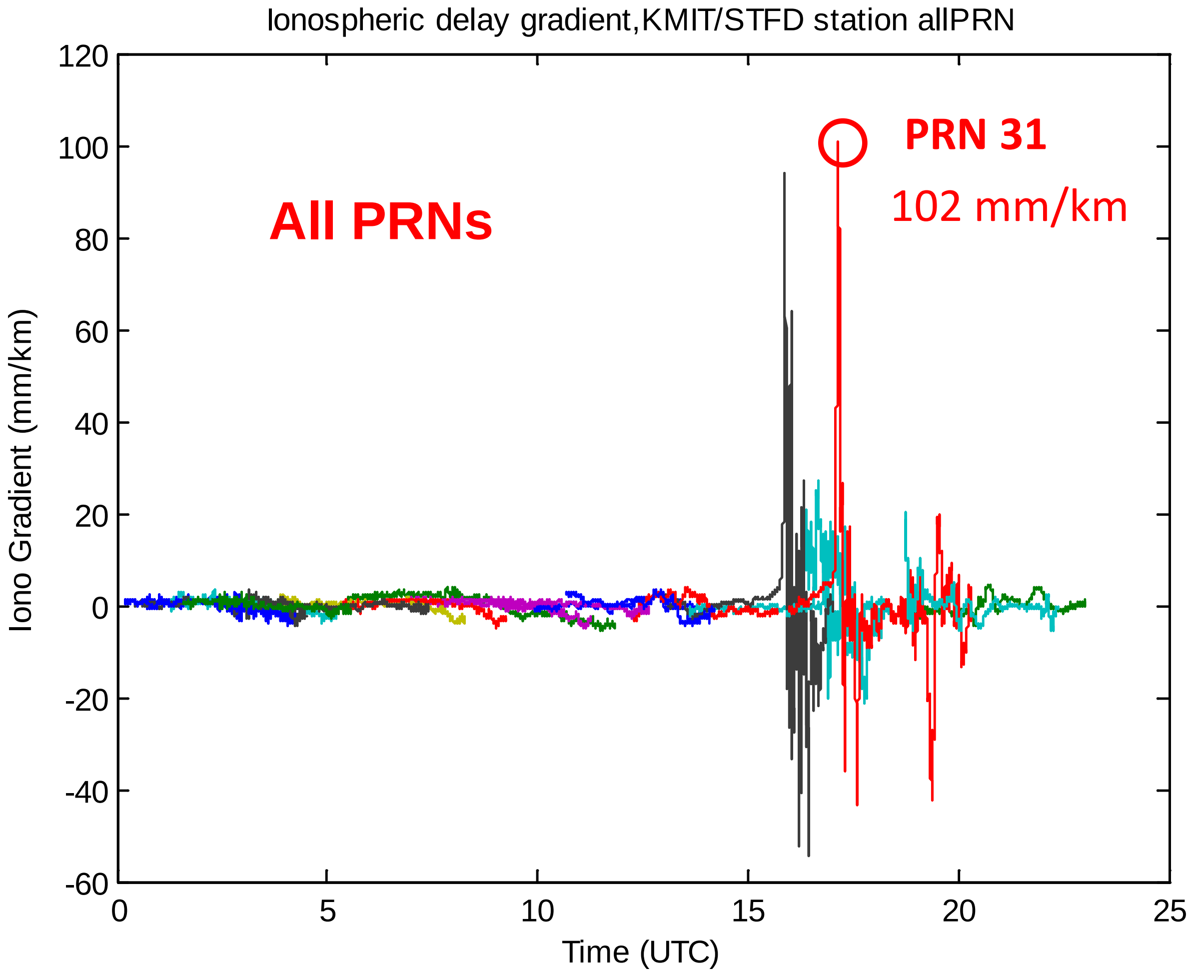
IPPs masking30^{o} PRN31
23.6892UT
14.9903UT
Latitude (Deg)
Longitude (Deg)
30
25
20
15
10
5
0
-5
80
85
90
95
100
105
110
115
120

12 Sept, 2014


PRN 21
KMITL
STFD
STEC (TECU)
dSTEC (TECU)
Time (samples)
80
60
40
20
0
-20
10
5
0
-5
0
5000
10000
15000

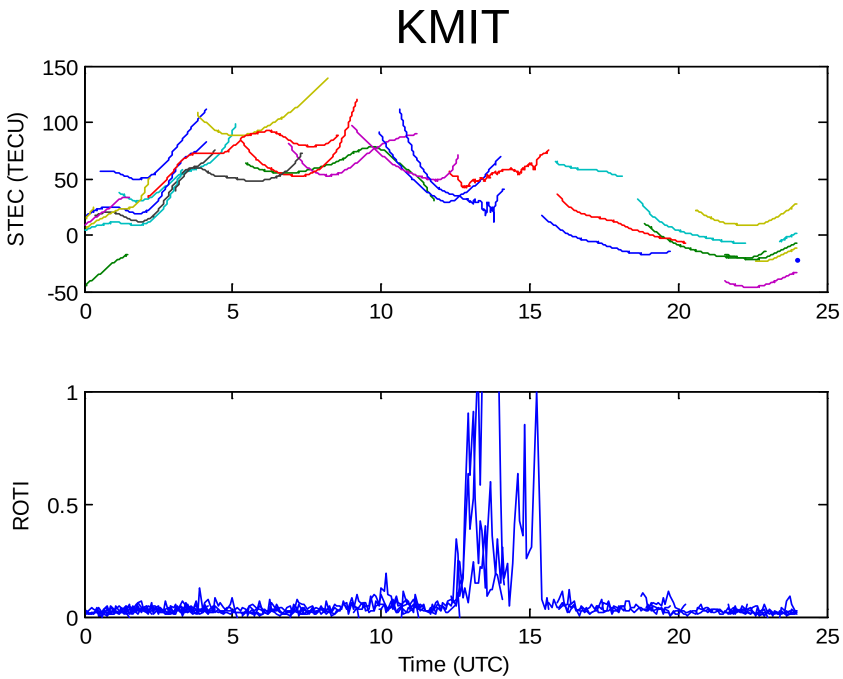

94 mm/km
PRN 21
PRN21
Gradient (mm/km)
Time (UTC)
100
80
60
40
20
0
-20
-40
-60
12.5
13
13.5
14
14.5
15
15.5
16
16.5
17
17.5

12 Sept, 2014

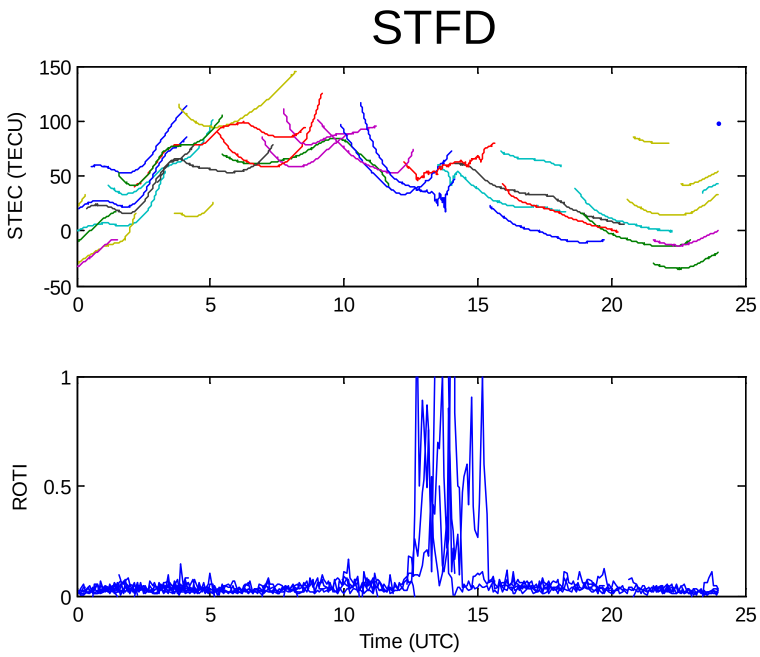


PRN	Speed (m/s)
21	124
25	90
31	91

13 Sept, 2014

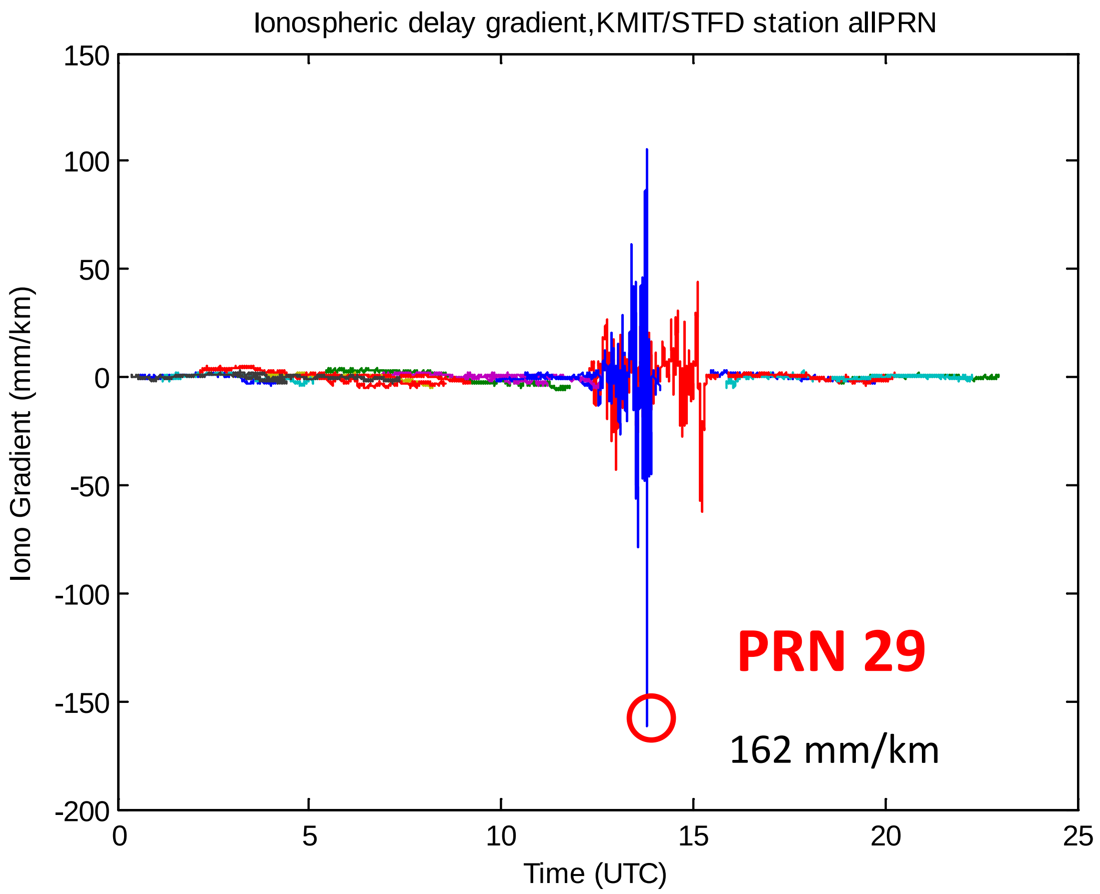


KMIT
STEC (TECU)
150
100
50
0
-50
0
5
10
15
20
25
ROTI
1
0.5
0
Time (UTC)



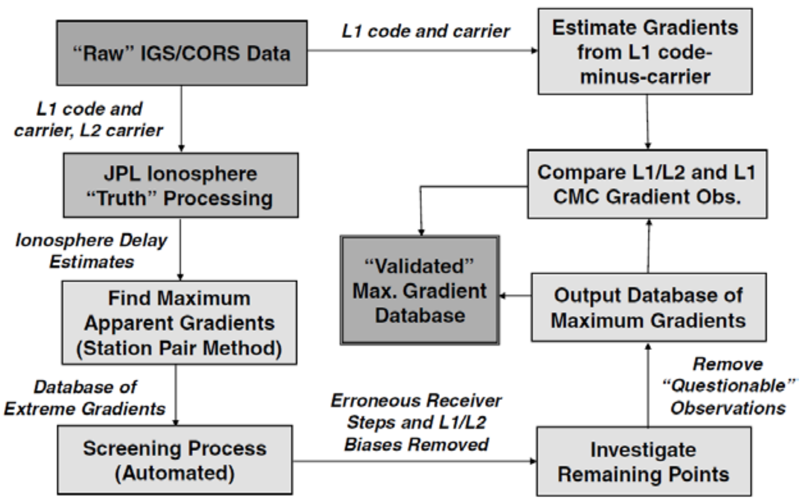
STFD
STEC (TECU)
150
100
50
0
-50
0
5
10
15
20
25
ROTI
1
0.5
0
Time (UTC)

13 Sept, 2014

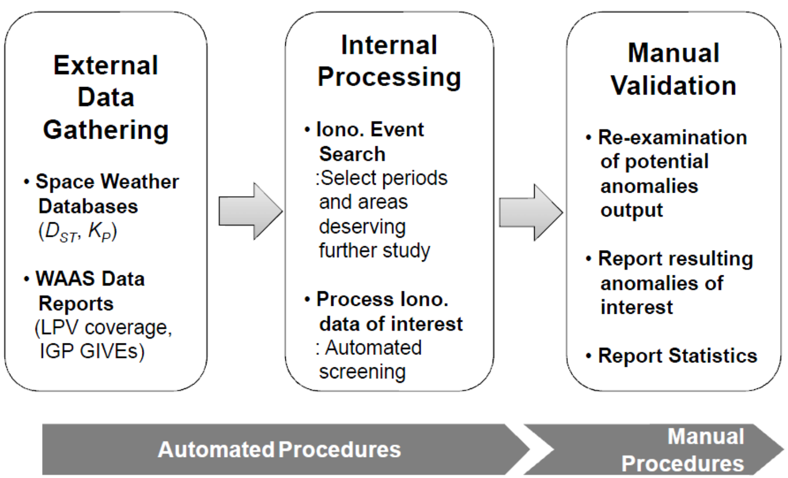


PRN	Speed (m/s)
24	160
29	187.5

Previous processing-step proposed



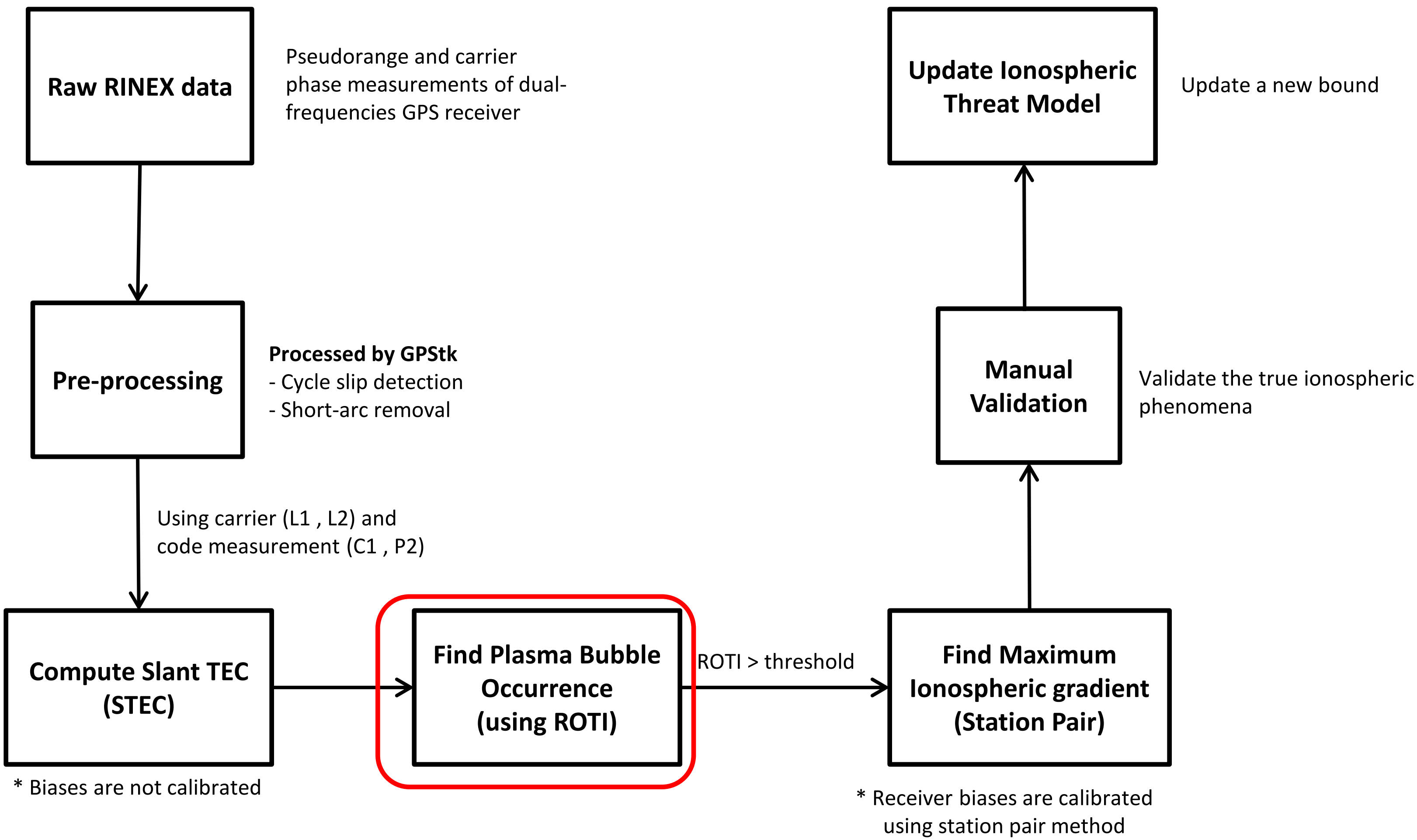
S. Datta-Barua, et al., 2010.



J. Lee, et al., 2011.

- **In order to process a lot of GPS data for ionospheric delay gradient monitoring, the previous studies proposed the data processing-step, focus on the SED event on 20 November 2003.**
- **However, they did not consider the plasma bubble occurrence in equatorial and low-latitude regions.**

Ionospheric delay gradient for equatorial an d low-latitude regions



Conclusions

- **The geomagnetic storm during 26-27 Aug, 2014 nor 12-13 Sept, 2014 did not cause the ionospheric disturbance as seen from the ROTI plot around low-latitude KMITL station, but ROTI plots show disturbance around sunset time during the whole of September**

12-13 Sept, 2014

- **We see the disturbance around the sunset time during 12-13 Sept, 2014, likely caused by the plasma bubbles (common during the equinoctial months).**
- **The maximum slant TEC gradient on the East-West direction is measured to be 162 mm/km (PRN29)**

Thank you for your attention!

Question?

International Reference Ionosphere (IRI) 2015 Workshop

Improved Accuracy in the Equatorial Region and Progress Towards a Real-time IRI Model

A COSPAR Capacity-Building Workshop

November 2-13, 2015

King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok, Thailand

Website: http://www.iri2015.kmitl.ac.th (available in 2015)





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- Chalermchon Satirapod, Chulalongkorn University (Thailand)
- Pornchai Supnithi, KMITL (Thailand)

International Technical Committee

IRI 2015 workshop aims to provide a venue to bring together a wide audience of academics and researchers from around the world to meet and discuss the latest ideas and present research results related to Space, ionospheric modeling, and IRI improvements and extensions. Special emphasis will be on improvements of IRI in the equatorial region and on the progress towards a Real-Time IRI. It is also our intention to enhance the research collaboration worldwide.

Topics include:

- Ionospheric observation
- Ionosphere-Troposphere Coupling
- Topside and bottomside profiles
- Global representation of peak parameters
- Representation of plasma temperatures
- IRI and GNSS
- Real-time IRI
- IRI Applications
- New Inputs for IRI
- Space Weather Education
- Effects of Ionosphere on GNSS (aeronautical, satellite, etc.)
- Space Weather applications (disasters, satellite, communications)