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Current GPS Monitoring Activities in Thailand and Total Electron Content (TEC) Study at Chumphon and Bangkok, Thailand

Sarawoot Rungraengwajiake[1]

Assoc.Prof. Dr. Pornchai Supnithi[2]

Dr. Takuya Tsugawa[3]

(1), (2) Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Thailand

(3) Space Environment Group, National Institute of Information and Communications Technology, Japan

Acknowledgements

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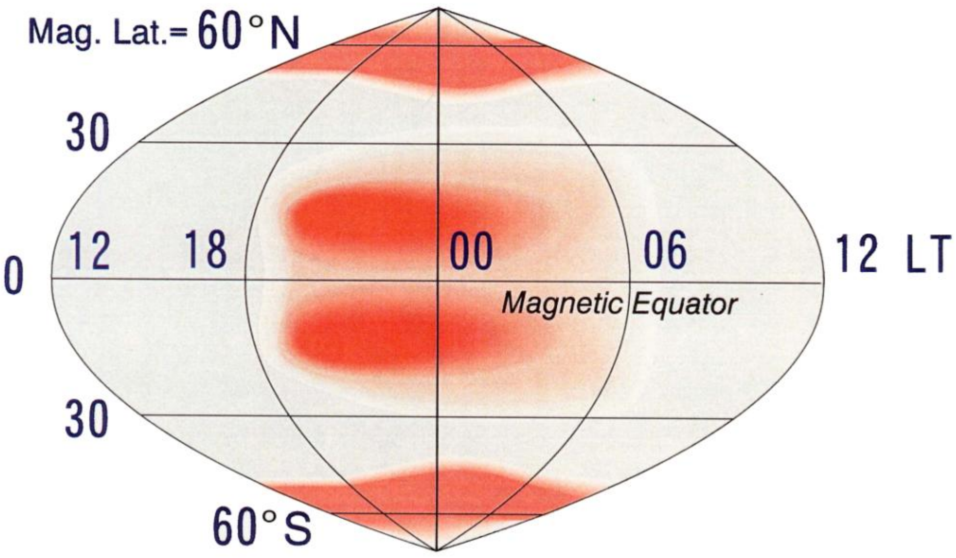
  - ENRI, Japan
  - NICT, Japan
  - Kyoto University
  - Meteorology Department, Thailand
  - Aeronautical Radio of Thailand
  - City Planning Dapartment, Thailand
  - Phuket Technical College, Thailand
  - Talang Technical College, Thailand

Outline

- Introduction
- Current GPS networks in Thailand
- TEC Basics
- Data and analysis method
- Results and discussions
- Conclusions

Introduction

Total electron content (TEC) is an important ionospheric parameter which directly affects the radio waves propagating through the ionosphere.



It is well-known that at the low latitude regions,
a characteristic of the ionosphere is symmetric peaks in electron density known as

Equatorial Ionospheric Anomaly (EIA)

Some interesting locations near the equator

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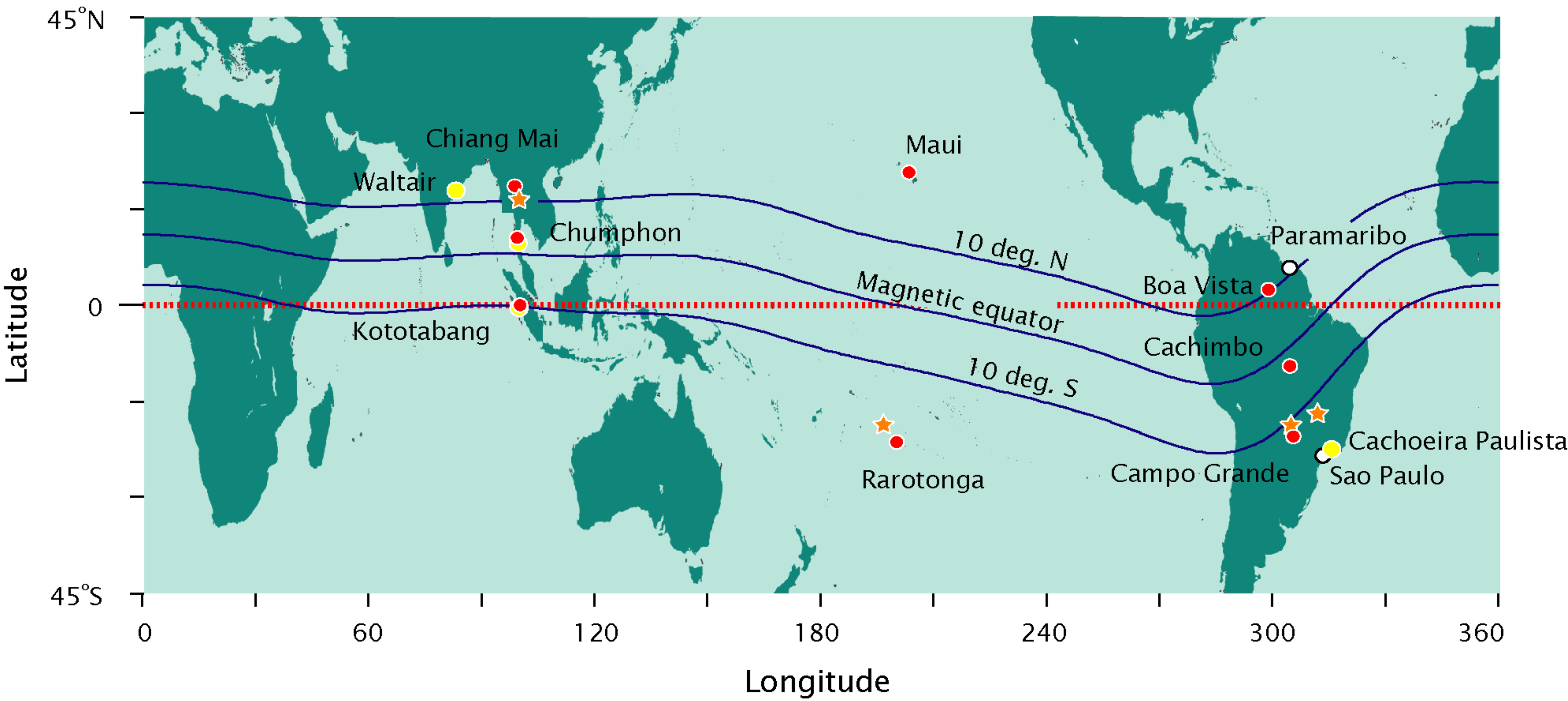


Introduction

- The availability of TEC measurement data are required for the development of ionospheric models such as the International Reference Ionosphere (IRI).
  - (IRI 2007 website - http://ccmc.gsfc.nasa.gov/modelweb/models/iri_vitmo.php)

- Recent increase in availability of TEC data has largely come from a rapid increase in the number of Global Position System TEC data (GPS TEC) over land.

- At the EIA regions, TEC is enhanced and peaks around from the magnetic equator. For the equatorial region, differential TEC contributes to the plasma bubble study.

Introduction

- Augmentations are necessary for the use of satellite-based navigation in aeronautical applications

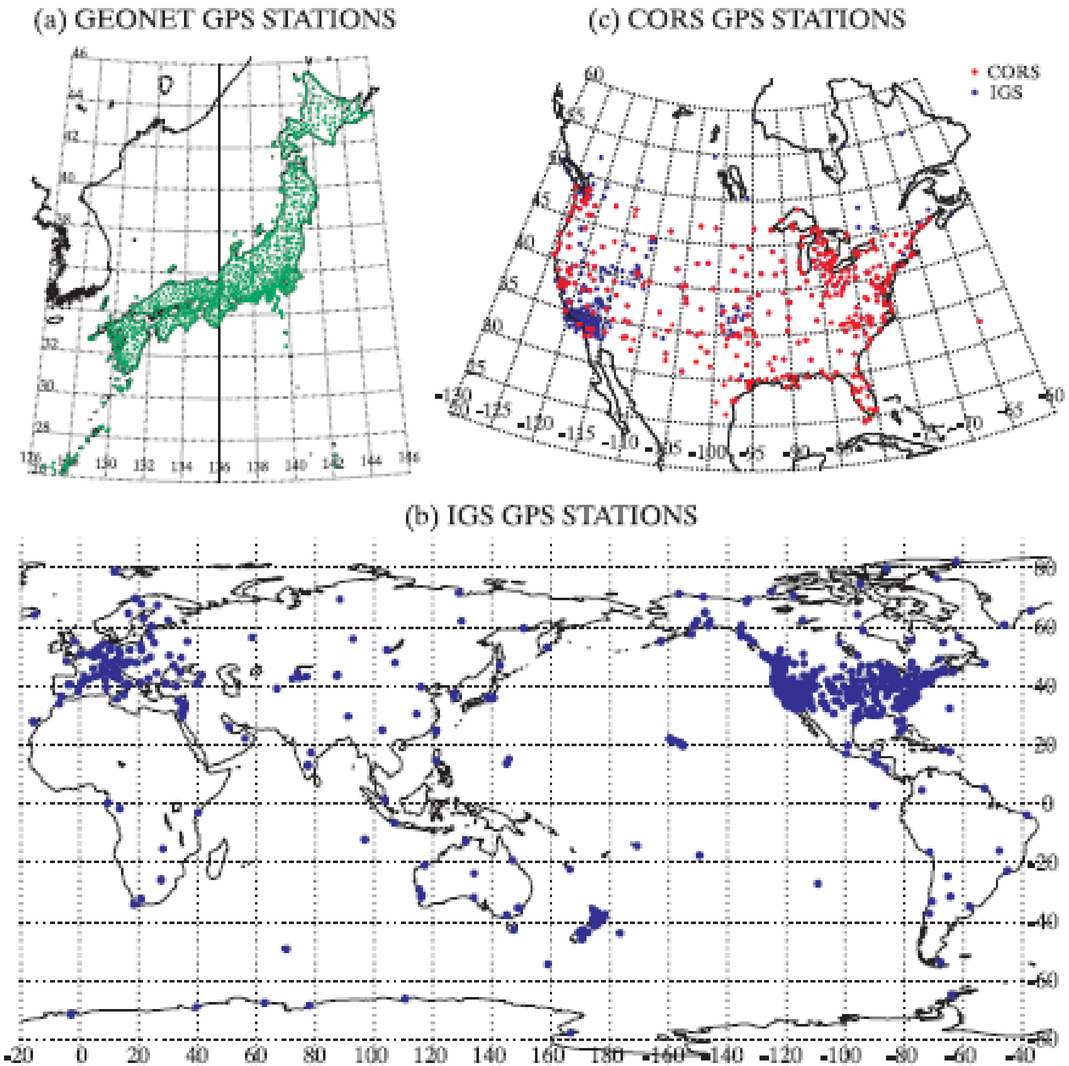
- One of the important sources of positional error is due to the ionospheric effects on the navigational signals. The ionospheric conditions vary depending on locations, time of year, solar activity and others, hence, they need to be well studied.

- The International Civil Aviation Organization (ICAO) has realized the importance of ionospheric effects on the global navigation satellite system (GNSS).

Objectives

- Overview available GPS networks in Thailand
- Study the diurnal and seasonal variations of total electron content (TEC) for different seasons at the equatorial magnetic latitude at Chumphon and Bangkok, Thailand during 2009.
- Both locations are near the magnetic equator.
- Analyze the slant TEC is converted into the delay in terms of distance relevant to aeronautical applications.

World GPS Networks



GPS Earth Observation Network (GEONET)

International GPS Service (IGS)

Continuously Operating Reference Stations (CORS)

SouthEast Asia Low-latitude

SouthEast Asia IOnospheric Network (SEALION)

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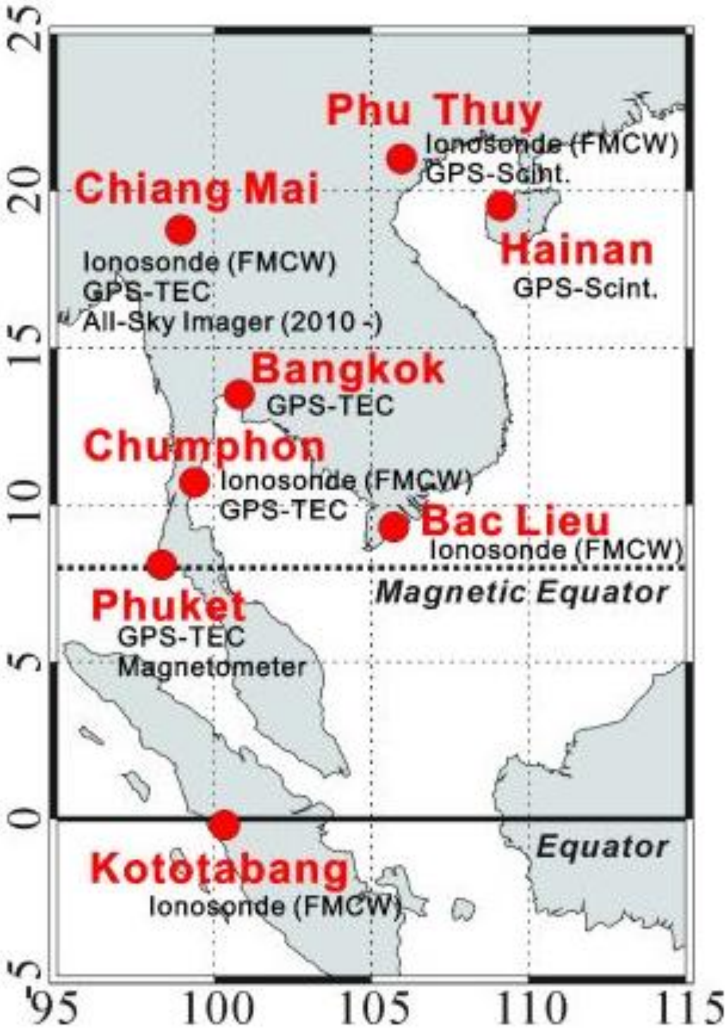


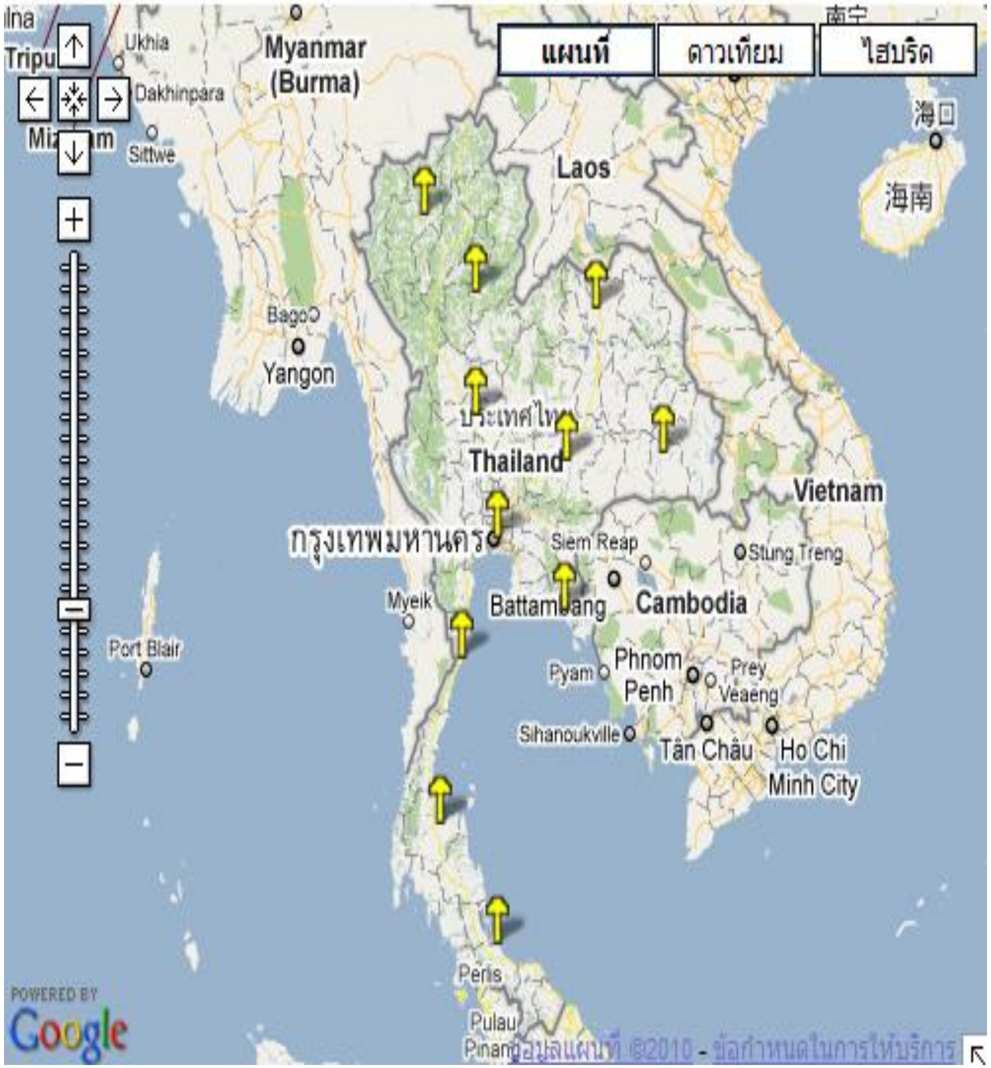
4 STATIONS

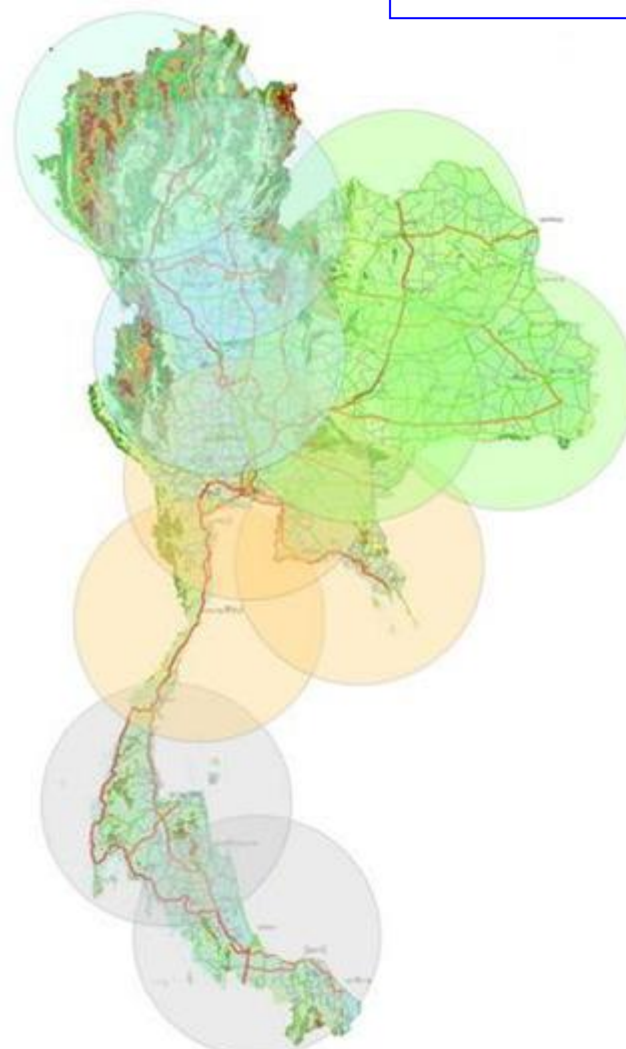
Station	GPS Receiver	Type of observation	Interval (s)	RINEX Version
Chiangmai (CMU)	Javad TPS Legacy	C1 P1 P2 L1 L2 D1 D2	30	2.1
Bangkok (KMI)	Javad TPS Legacy	C1 P1 P2 L1 L2 D1 D2	30	2.1
Chumpon (CPN)	Javad TPS Legacy	C1 P1 P2 L1 L2 D1 D2	30	2.1
Phuket (PTC)	Javad TPS Legacy	C1 P1 P2 L1 L2 D1 D2	30	2.1

Department of Public Works and Town & Country Planning (DPT), Thailand

KMITL

11 STATIONS





Department of Public Works and Town & Country Planning (DPT)

KMITL

Station	GPS Receiver	Type of observation	Interval (s)	RINEX Version
Chiangmai (CHMA)	Leica GRX1200 Pro	C1 L1 P2 L2	5	2.11
Uttaradit (UTTD)	Leica GRX1200 Pro	C1 L1 P2 L2	5	2.11
Udonthani (UDON)	Leica GRX1200 Pro	C1 L1 P2 L2	5	2.11
Nakhonsawan (NKSW)	Leica GRX1200 Pro	C1 L1 P2 L2	5	2.11
Sisaket (SISK)	Leica GRX1200 Pro	C1 L1 P2 L2	5	2.11
Nakhonratchasima (NKRM)	Leica GRX1200 Pro	C1 L1 P2 L2	5	2.11
Bangkok (DPT9)	Leica GRX1200 Pro	C1 L1 P2 L2	5	2.11
Chanthaburi (CHAN)	Leica GRX1200 Pro	C1 L1 P2 L2	5	2.11
Prachuapkhirikhan (PJRK)	Leica GRX1200 Pro	C1 L1 P2 L2	5	2.11
Suratthani (SRTN)	Leica GRX1200 Pro	C1 L1 P2 L2	5	2.11
Songkla (SOKA)	Leica GRX1200 Pro	C1 L1 P2 L2	5	2.11

*** **Total = 11 stations**

KMITL& CU Network

In collaboration with Kyoto University

6 STATIONS

Station	GPS Receiver	Type of observation	Interval (s)	RINEX Version
Nongkai	Trimble 5700	L1 L2 P2 C1	1	2.1
Srisamrong	Trimble 5700	L1 L2 P2 C1	1	2.1
Ubonratchathani	Trimble 5700	L1 L2 P2 C1	1	2.1
Pimai	Trimble 5700	L1 L2 P2 C1	1	2.1
Bangkok		Manual		
Phuket		Manual		

*** CU = Chulalongkorn University**

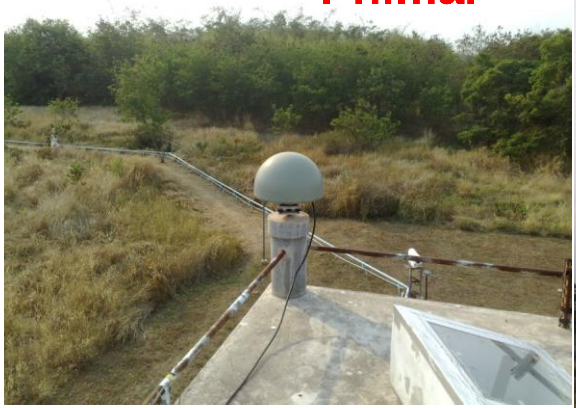
Stations

Phuket

Sukhothai

Nongkhai

Phimai

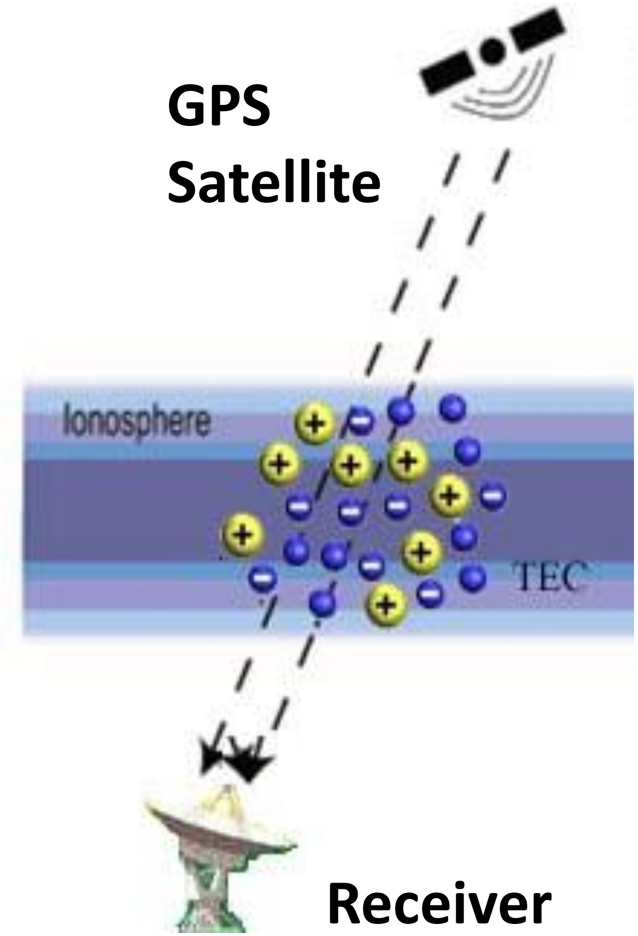


TEC Basics

TEC

1 TECU = 1×10^{16} el/m^2

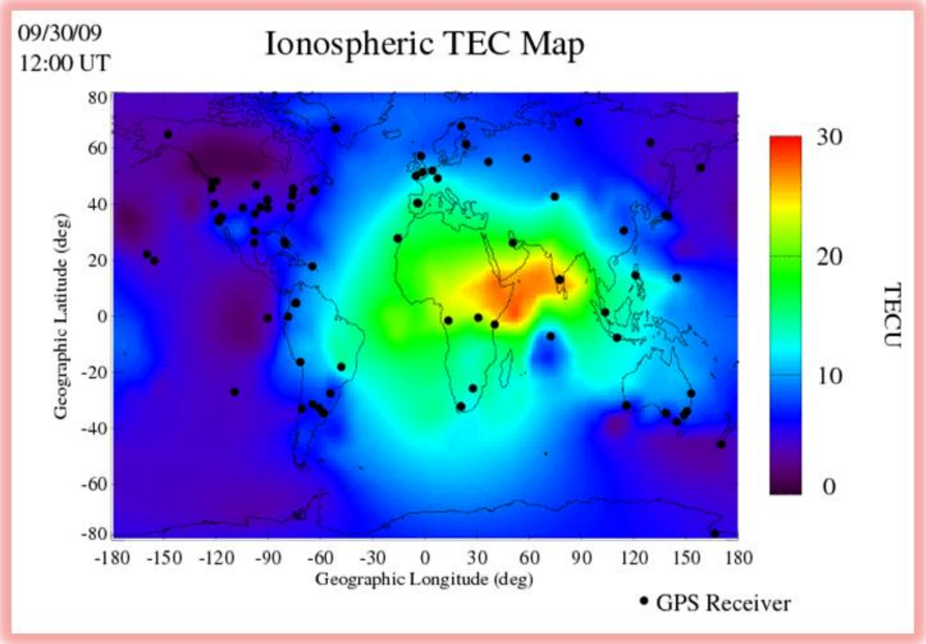
Depending on place & time.

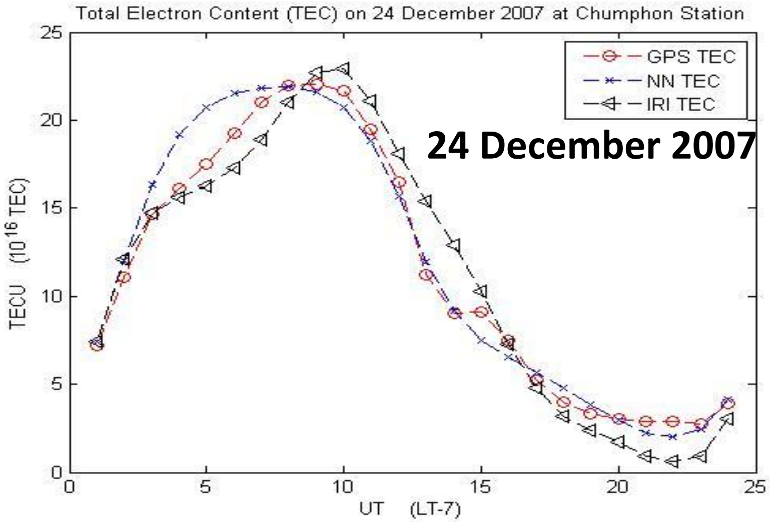


TEC Basics

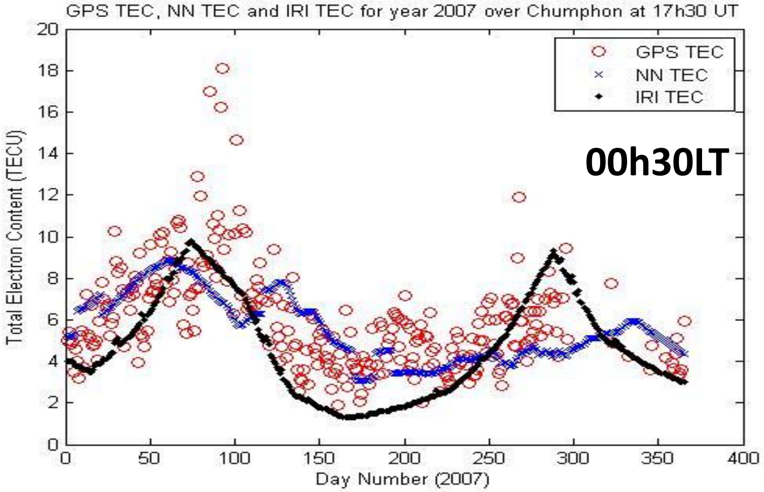
Time dependent

Location dependent

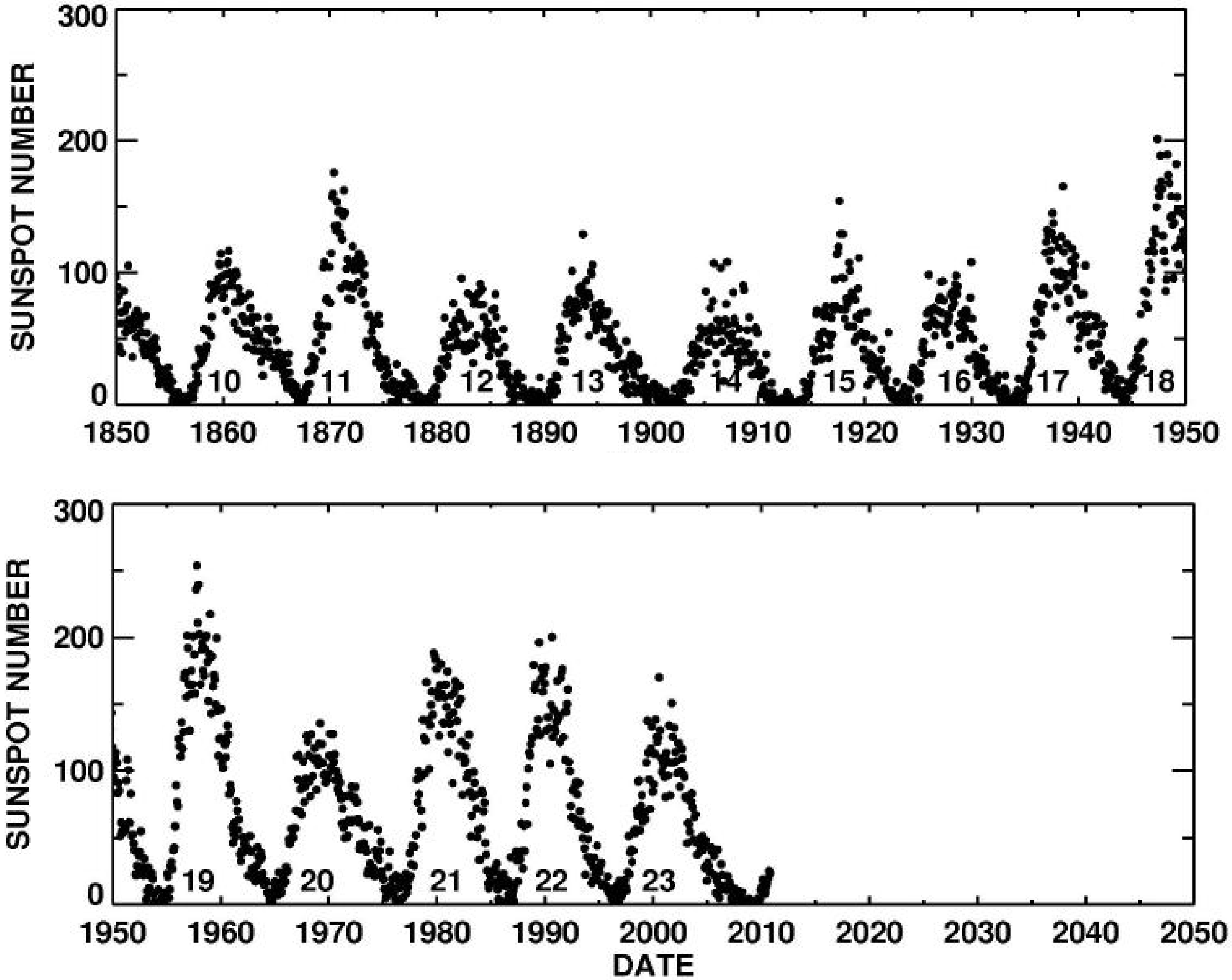




Chumphon station



Solar Cycle



Monthly averages

11-year cycle

Current cycle: 24

Source: http://solarscience.mfc.nasa.gov/SunspotCycle.shtml

Slant TEC

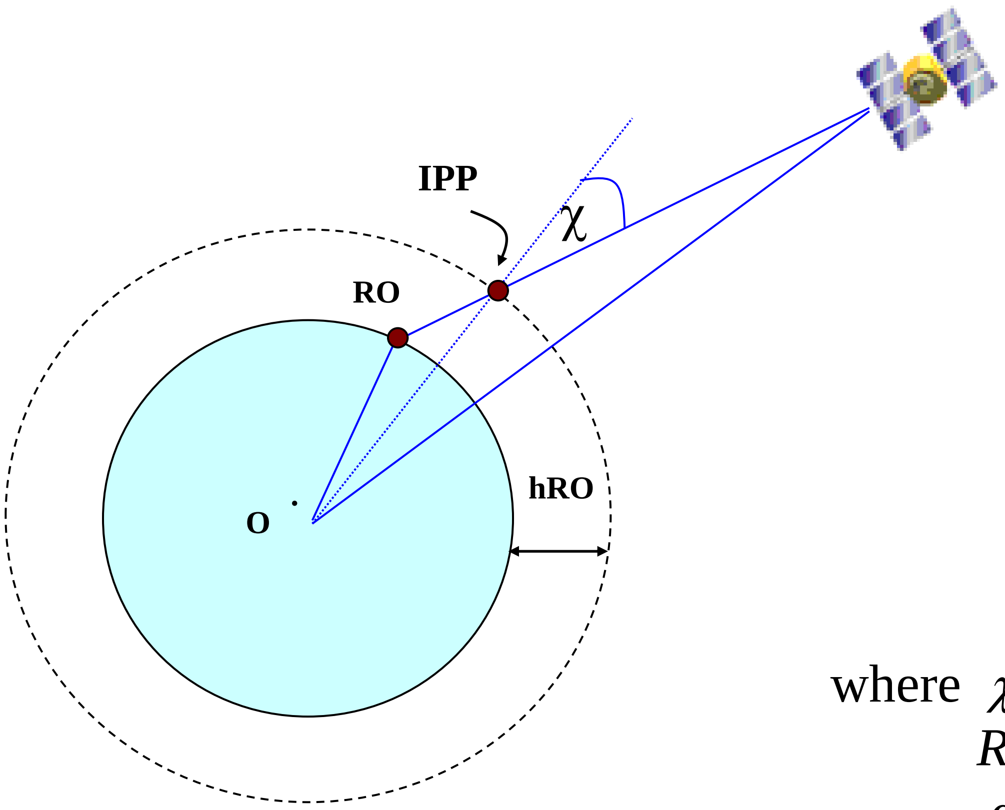
Slant TEC can be computed from the pseudorange P1, P2 or the carrier phase L1,L2 (Blewitt, 1990)

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

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

Need
cycle slip correction
for the ambiguity of
the cycle number

Vertical TEC (VTEC)



$$\mathrm{VTEC} = \mathrm{STEC} \times \cos\chi$$

where $\chi = \arcsin\left(\dfrac{R_E \cos\alpha}{R_E + h}\right)$

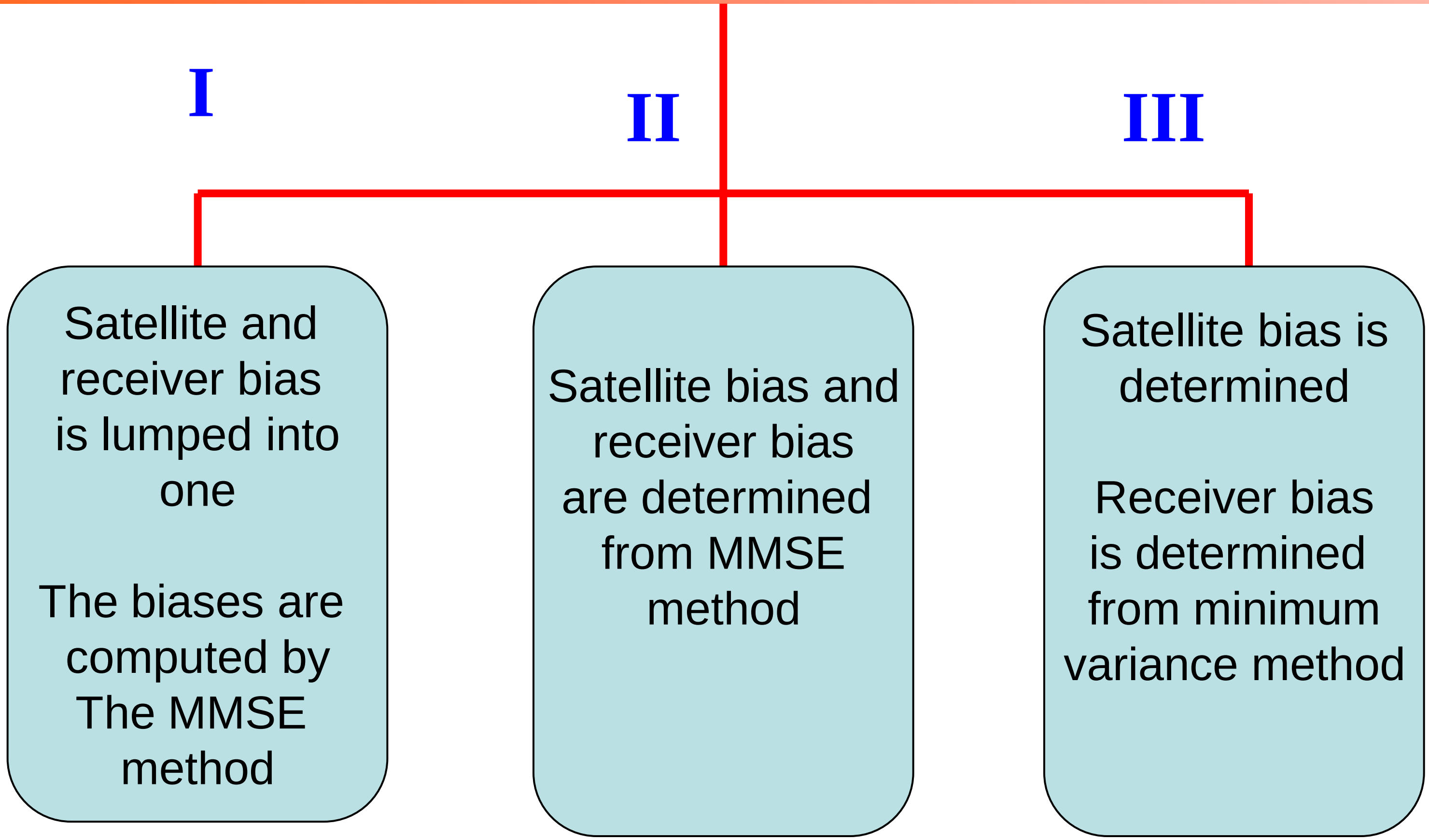
where χ = the zenith angle

R_E = the mean radian of the Earth

α = the elevation angle of GPS

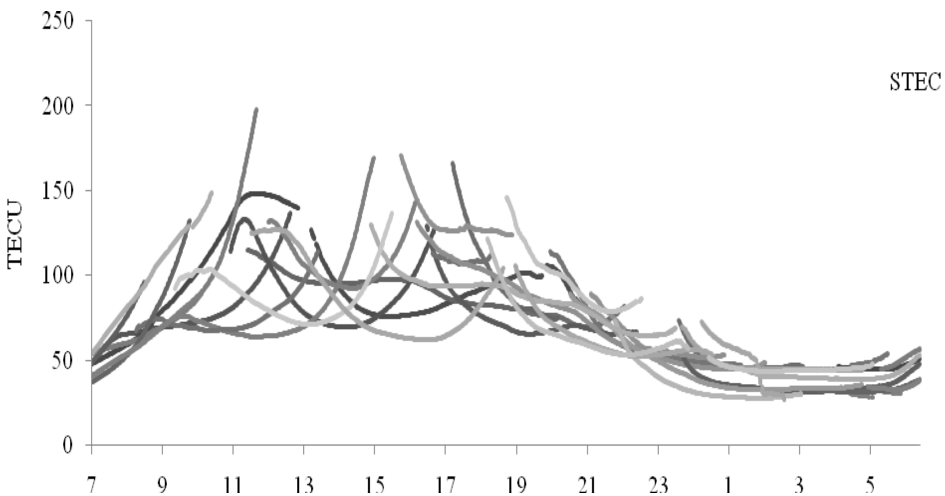
h = the height of the ionosphere

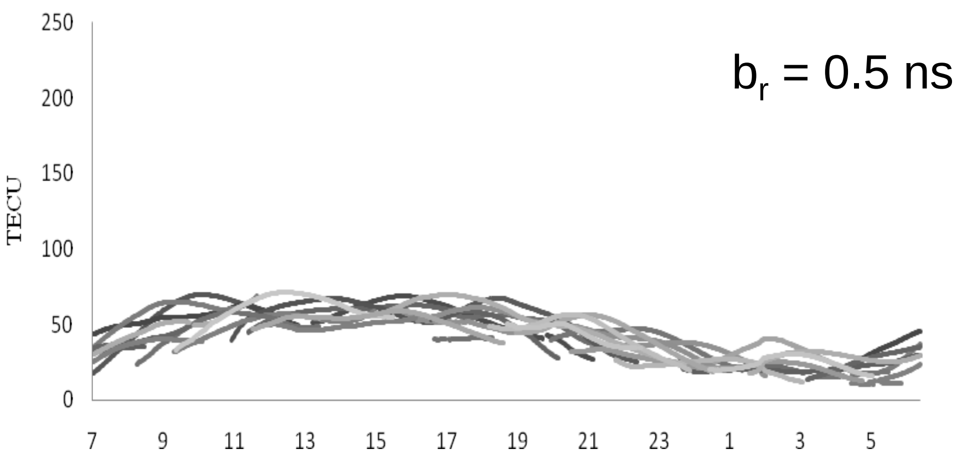
Bias computation



These techniques have been developed and verified for a network with many receiver stations

Receiver bias estimation





$$TEC = (STEC - b_s - b_r) \times \cos \chi$$

b_s - the satellite bias

b_r - the receiver bias

Minimum Variance Method

Select the receiver bias that gives

the minimum variance Slant TEC

Ionospheric Delay

The measured distance (in meters) can be expressed as

$$d = d_0 + \delta_{ion} + \delta_{tropos} + c * \delta_t + w$$

d_0 - an actual distance
δ_{ion} - ionospheric errors
δ_{tropos} – tropospheric errors
δ_t - hardware clock error
w - the noise.

The ionospheric delay

$$\delta_{ion} = \frac{40.3}{f^2} ATEC \quad \text{(m)}$$

For the L1 frequency at 1.57542 GHz, 1 TECU is about 16 cm delay.

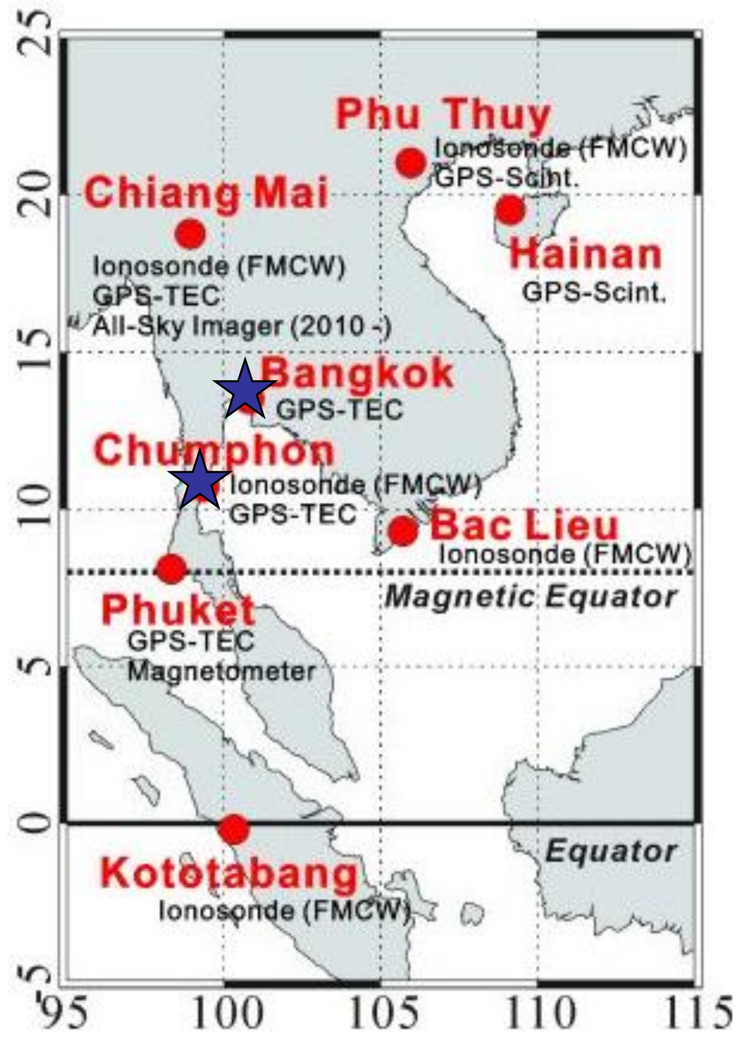
Data and Methodology

Chumphon (10.72 ºN, 99.37 ºE)

Bangkok (13.73 ºN, 100.78 ºE

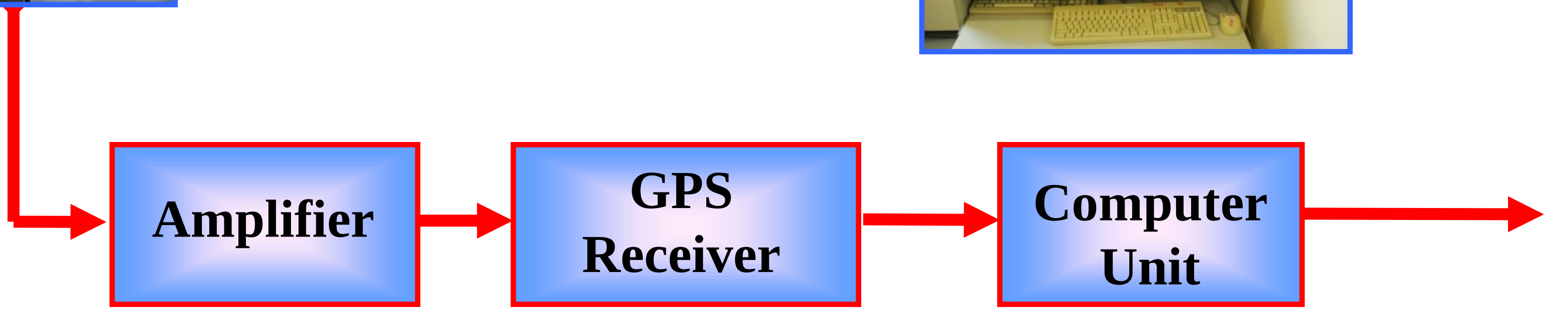
Seasons

- 20 March 2009 (March equinox)
- 21 June 2009 (Summer solstice)
- 8 October 2009 (Autumnal equinox)
- 21 December 2009 (Winter solstice),



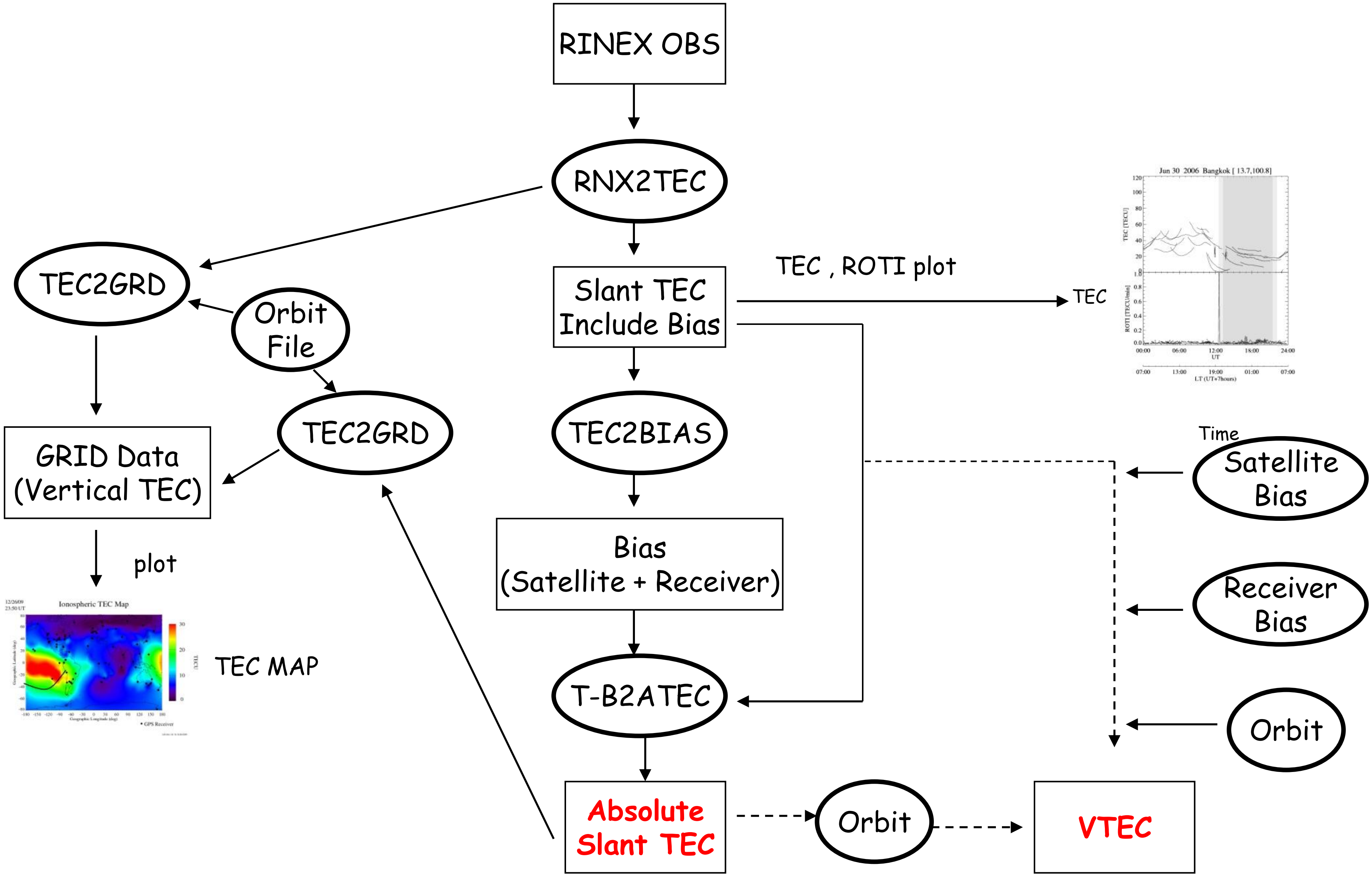
Observation Setup

Choke-ring antenna

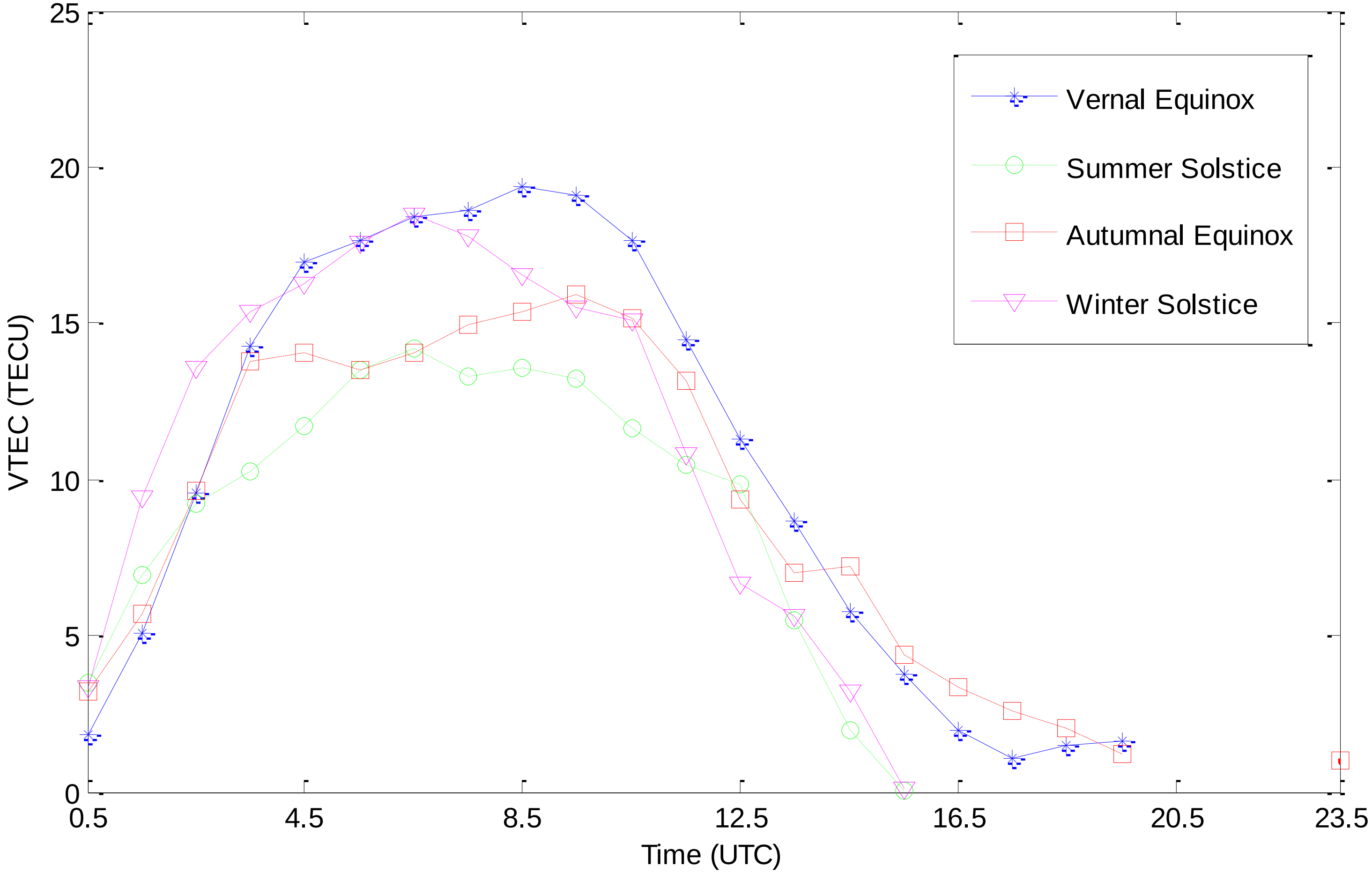


Rinex files every 30 seconds

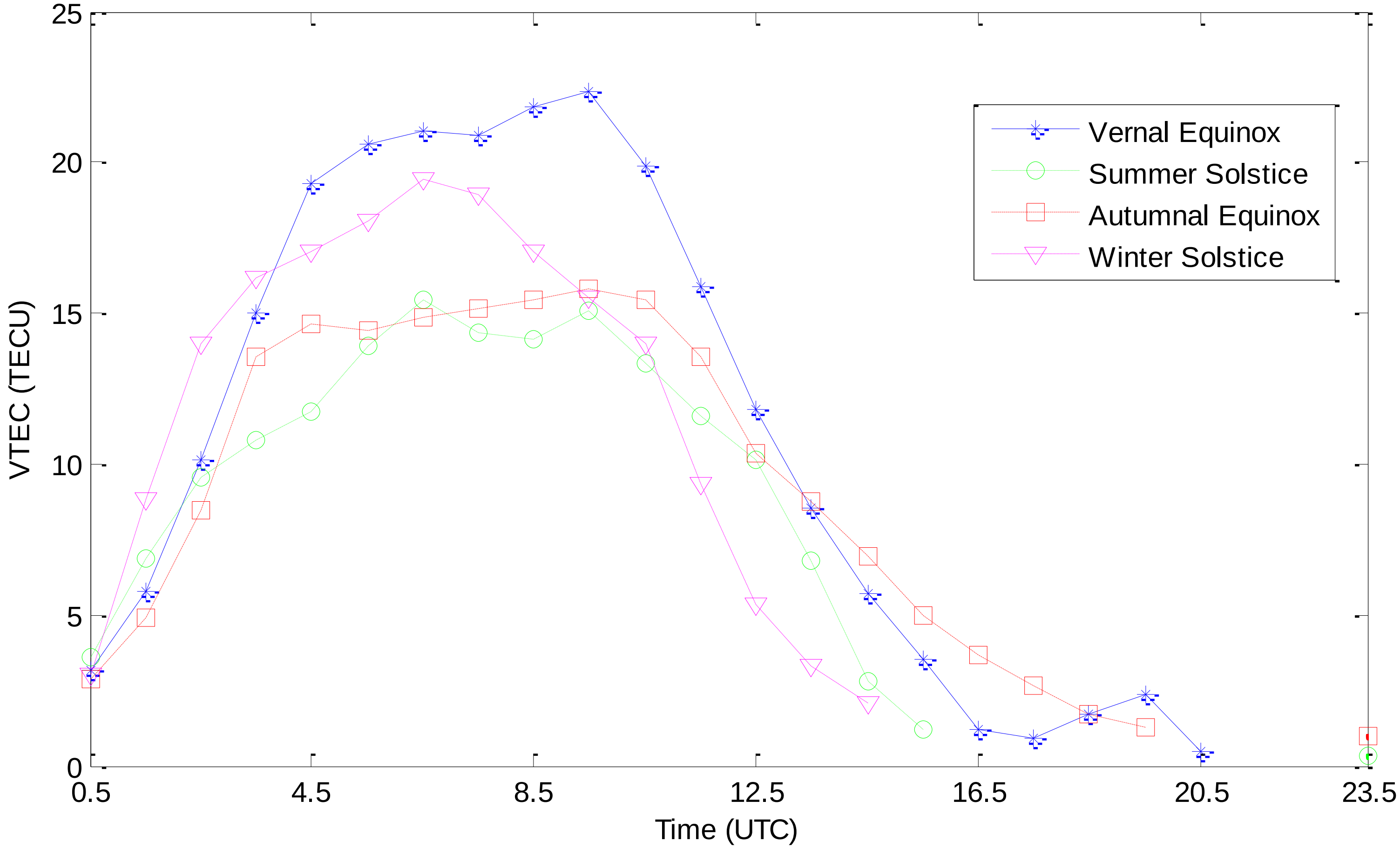
TEC Computation



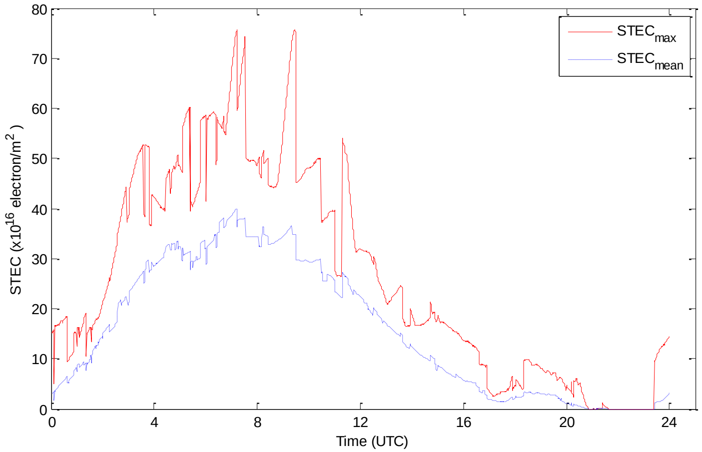
Diurnal variation of VTEC at Chumphon station



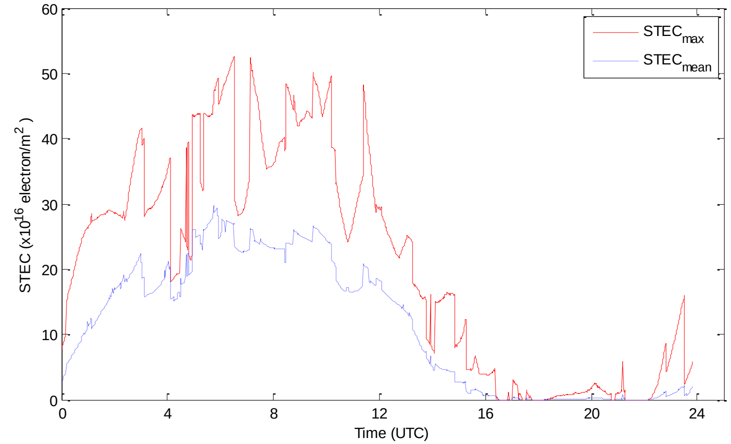
Diurnal variation of VTEC at Bangkok station



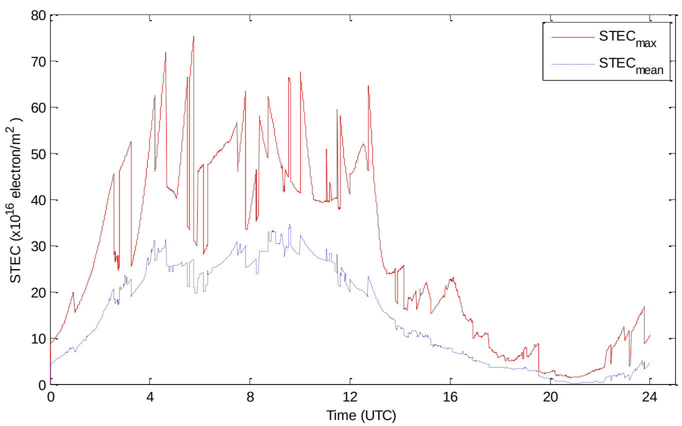
Slant TEC of Bangkok station in 2009



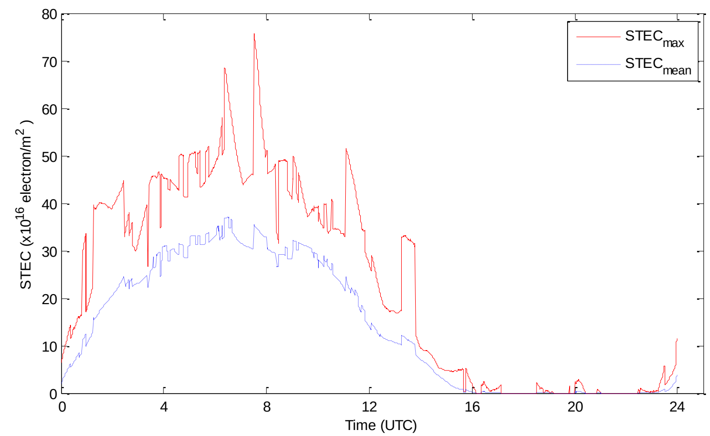
(a) Vernal equinox



(b) Summer Solstice

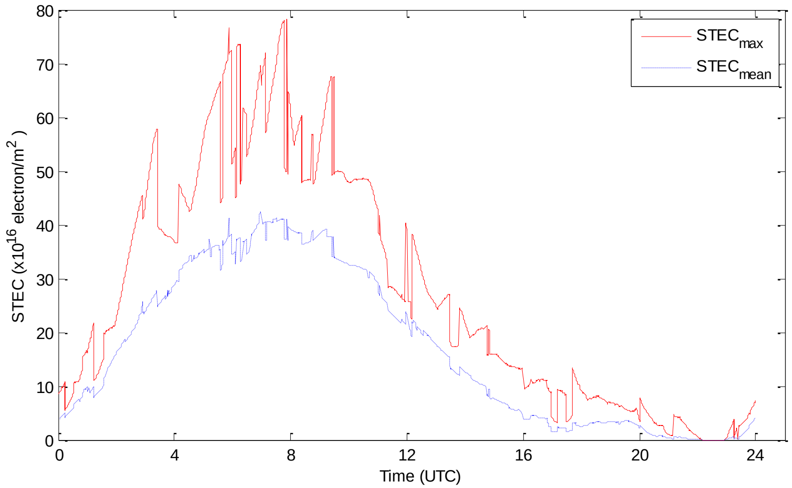


(c) Autumnal equinox



(d) Winter solstice

Slant TEC of Chumphon station in 2009



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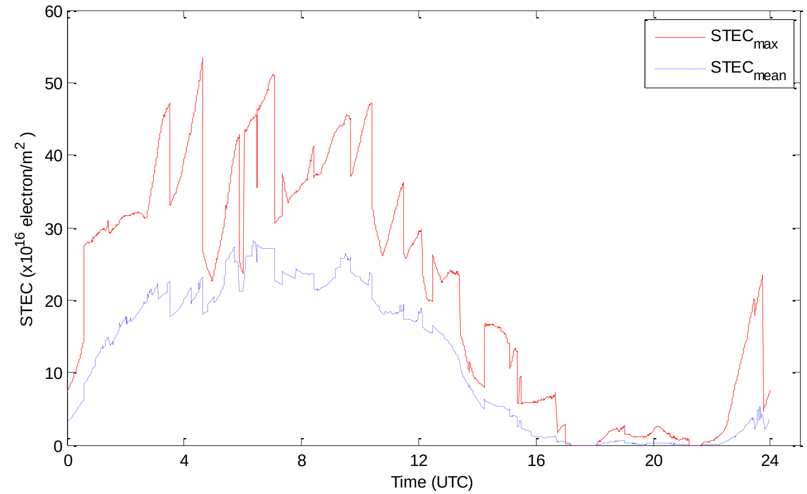
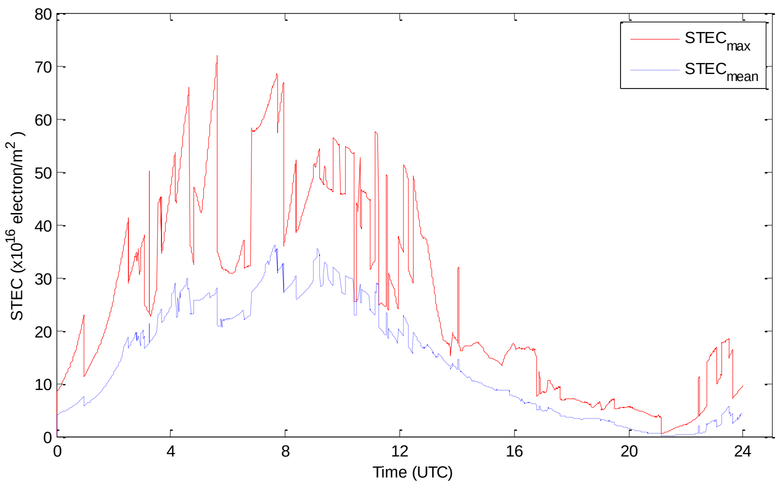
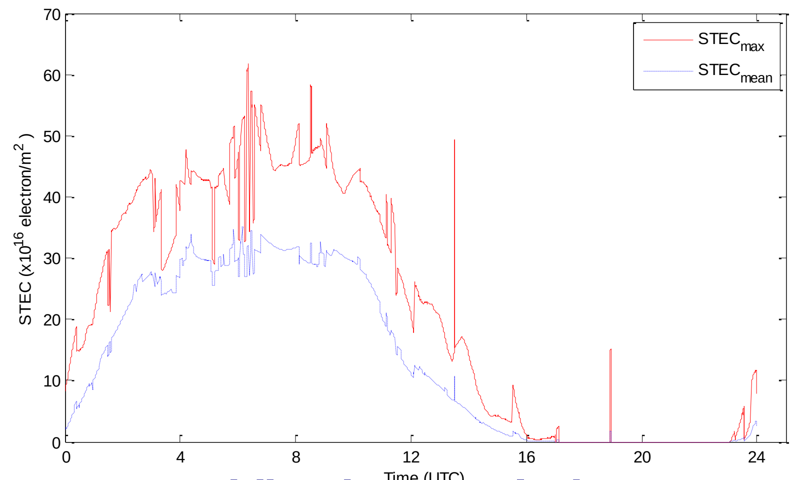


(b) Summer Solstice



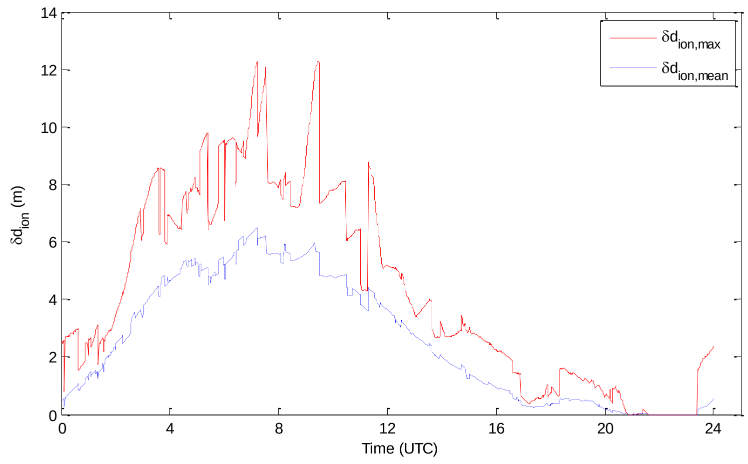
(c)

(c) Autumnal equinox

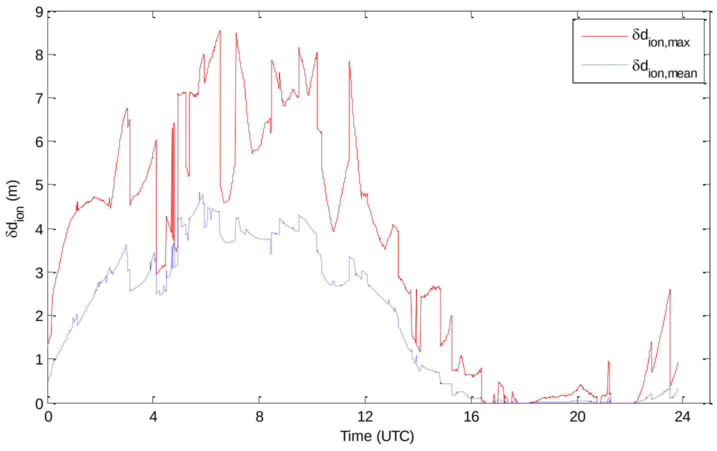


(d) Winter solstice

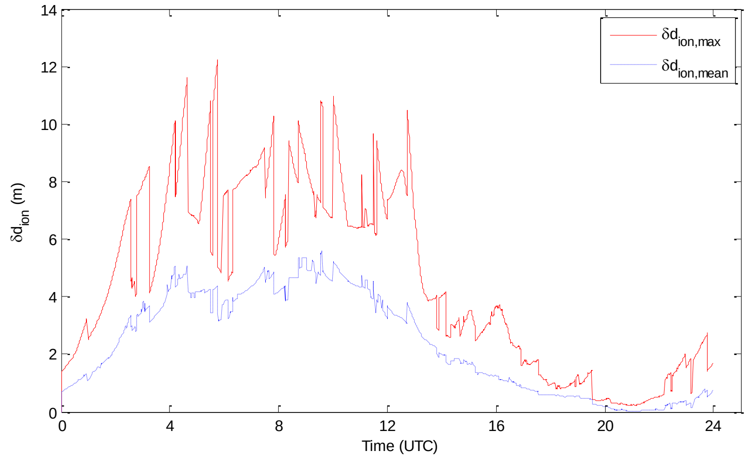
Ionospheric delay time of Bangkok station in 2009



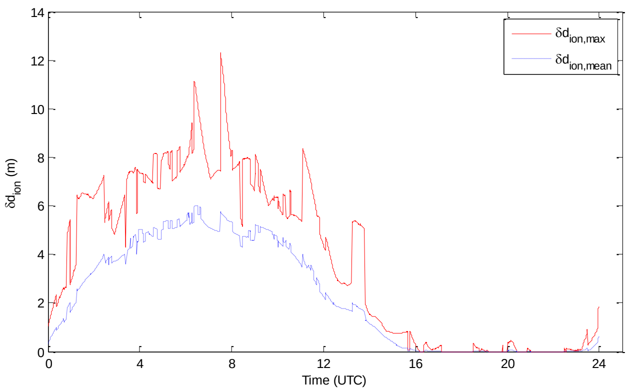
(a) Vernal equinox



(b) Summer Solstice

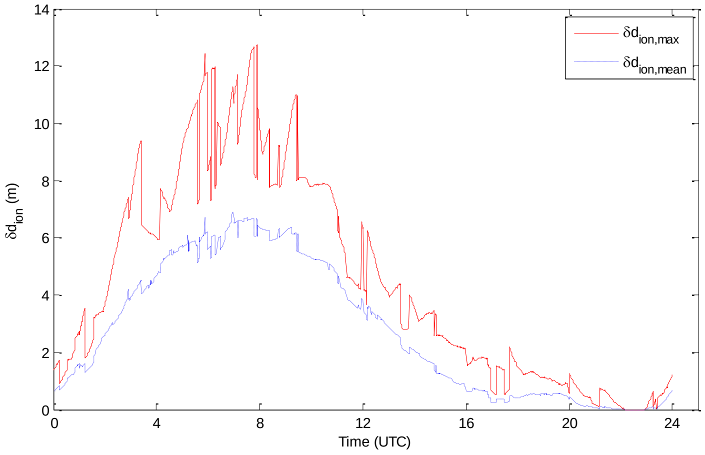


(c) Autumnal equinox

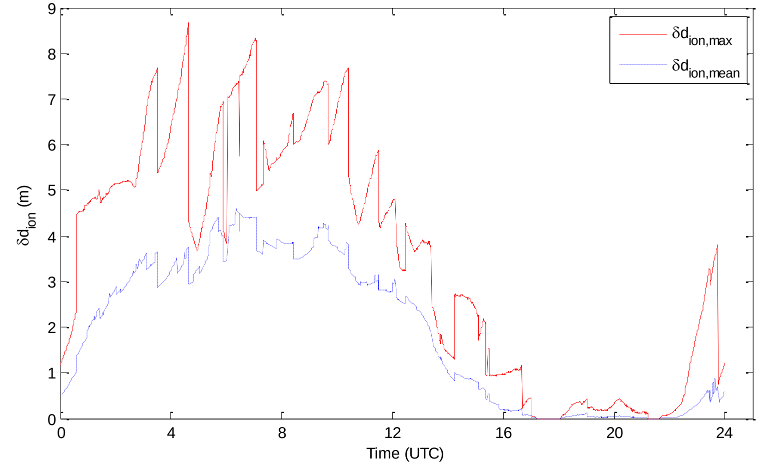


(d) Winter solstice

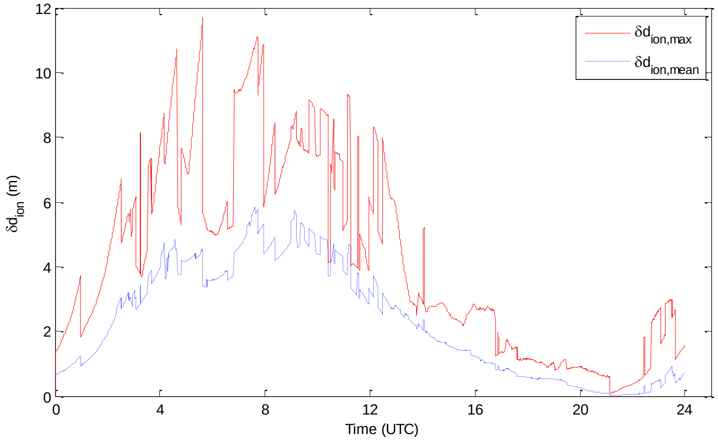
Ionospheric delay time of Bangkok station in 2009



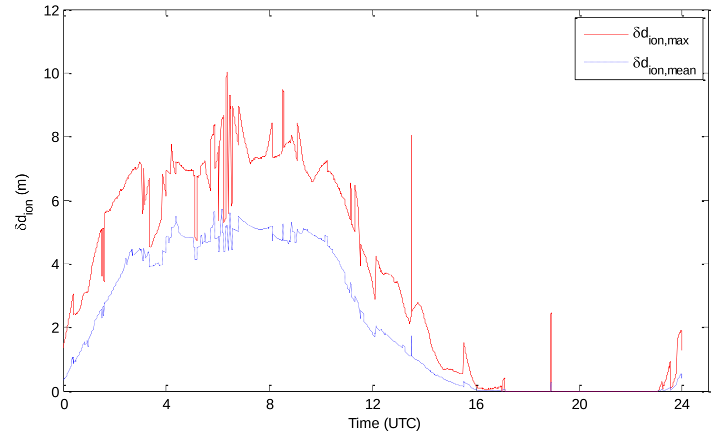
(a) Vernal equinox



(b) Summer Solstice



(c) Autumnal equinox

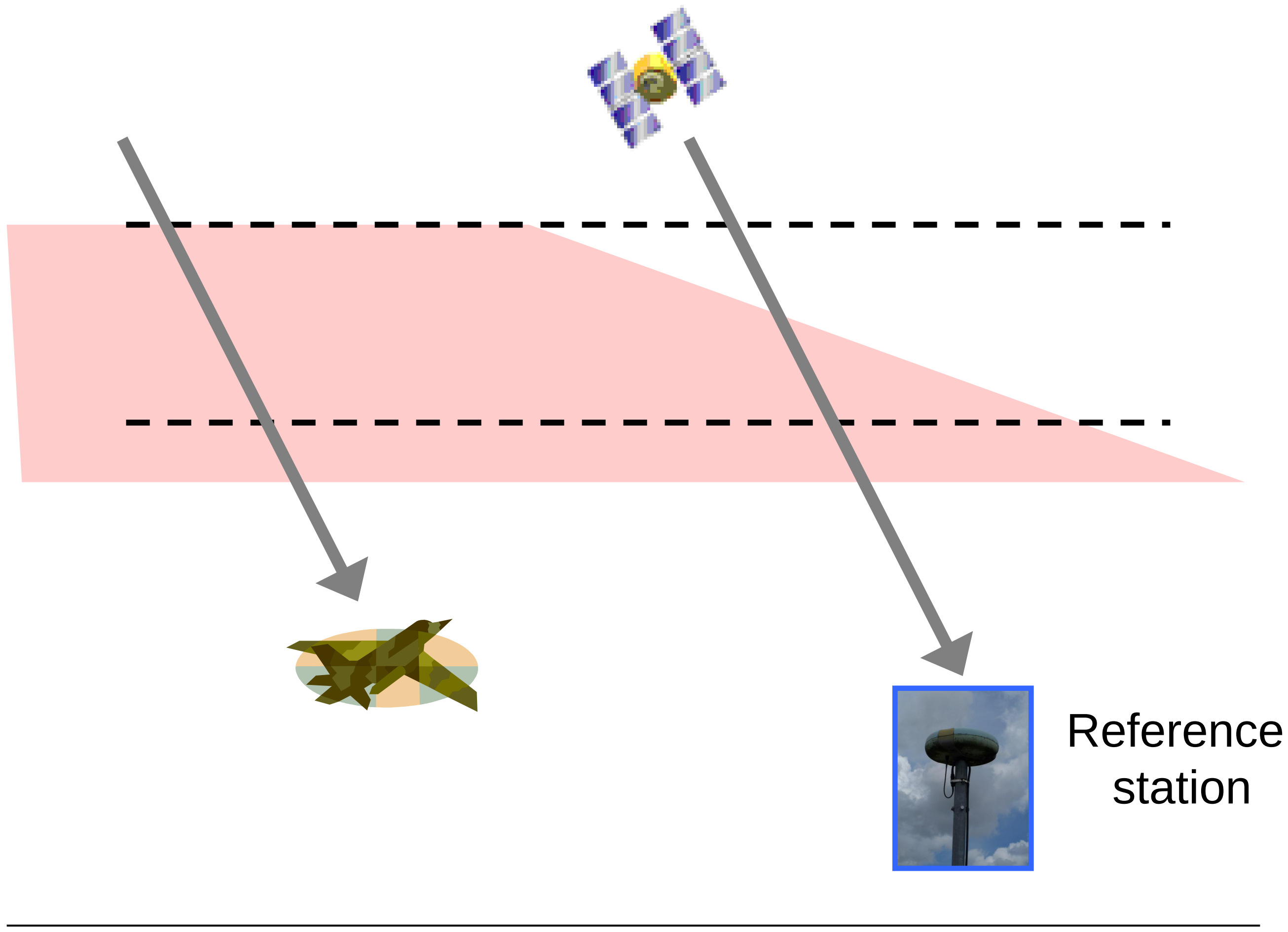


(d) Winter solstice

Future works

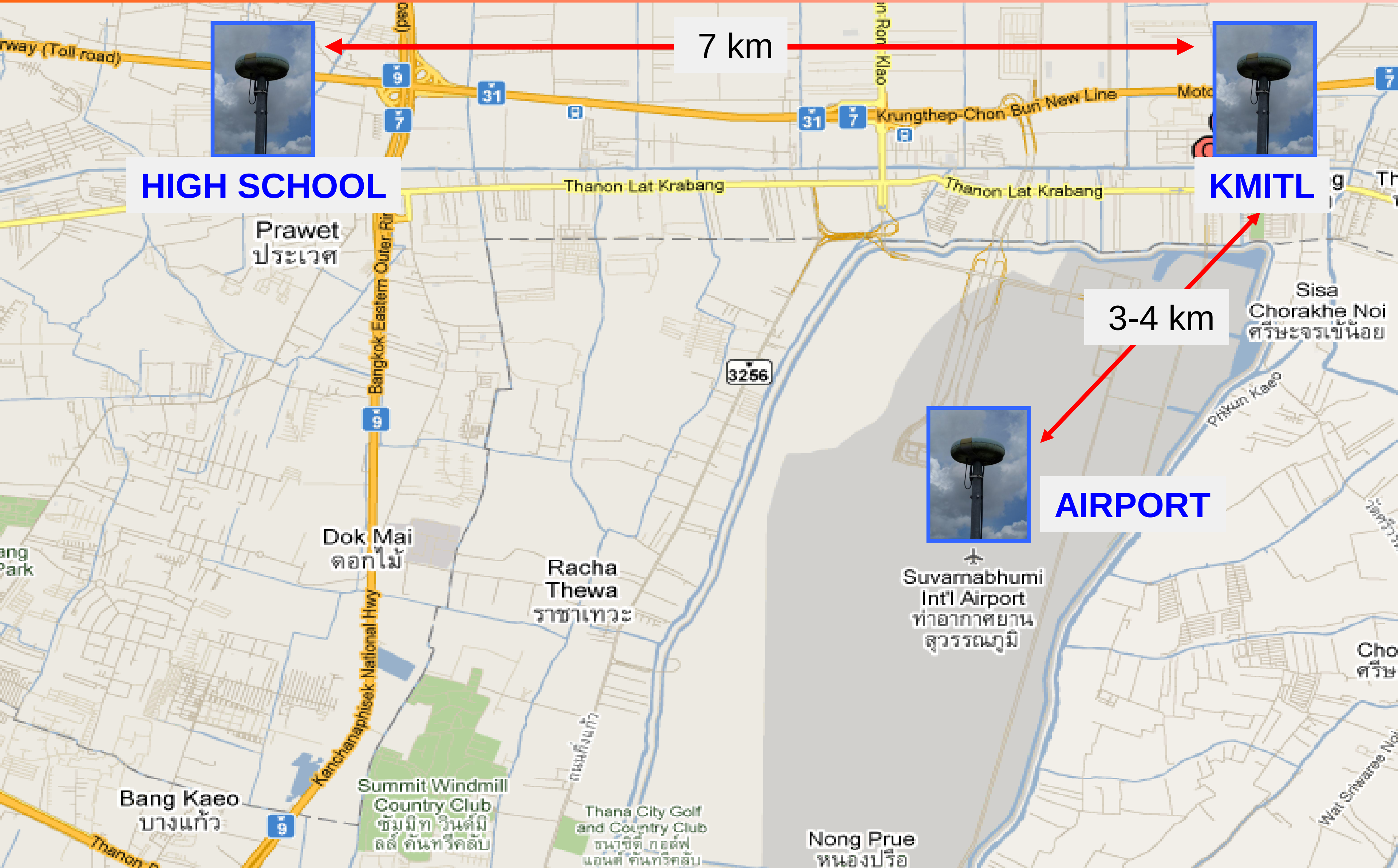
- TEC Gradient investigation around Suvarnabhumi airport
- Partners: KMITL, ENRI, Aeronautical Thailand Co.
- Cooperation on the data collection and analysis in the low-latitude and equatorial regions for the upcoming solar maximum period.

Non-uniform ionospheric delay distribution



* Working Paper: CNS/MET SG/14 WP/43, 19-22 July 2010, Jakarta, Indonesia

Dual-frequency GPS Data Collection



Thank You

BACKUP

$$f_1 P_1 = f_1 \rho + \frac{I}{f_1} + f_1 c(\tau_1^r + \tau_1^s) + f_1 \varepsilon_{P1}$$

For Pseudo range

$$f_2 P_2 = f_2 \rho + \frac{I}{f_2} + f_2 c(\tau_2^r + \tau_2^s) + f_2 \varepsilon_{P2}$$

$$f_1 P_1 - f_2 P_2 = (f_1 - f_2)\rho + (\frac{1}{f_1} - \frac{1}{f_2})I + c[f_1(\tau_1^r + \tau_1^s) - f_2(\tau_2^r + \tau_2^s)] + (f_1 \varepsilon_{P1} - f_2 \varepsilon_{P2})$$

$$\frac{1}{(f_1 - f_2)}(f_1 P_1 - f_2 P_2) = \rho + \frac{1}{(f_1 - f_2)}(\frac{1}{f_1} - \frac{1}{f_2})I + \frac{c}{(f_1 - f_2)}[f_1(\tau_1^r + \tau_1^s) - f_2(\tau_2^r + \tau_2^s)]$$
$$+ \frac{1}{(f_1 - f_2)}(f_1 \varepsilon_{P1} - f_2 \varepsilon_{P2})$$

$$P_3 = \frac{1}{(f_1 - f_2)}(f_1 P_1 - f_2 P_2)$$

$$P_3 = \rho + \frac{1}{(f_1 - f_2)}\left(\frac{1}{f_1} - \frac{1}{f_2}\right)I + \frac{c}{(f_1 - f_2)}[f_1(\tau_1^r + \tau_1^s) - f_2(\tau_2^r + \tau_2^s)] + \frac{1}{(f_1 - f_2)}(f_1 \varepsilon_{P1} - f_2 \varepsilon_{P2})$$

$$P_3 = \rho + \frac{1}{(f_1 - f_2)}\left(\frac{f_2 - f_1}{f_1 f_2}\right)I + \frac{c}{(f_1 - f_2)}[(f_1 \tau_1^r - f_2 \tau_2^r) + (f_1 \tau_1^s - f_2 \tau_2^s)] + \frac{1}{(f_1 - f_2)}(f_1 \varepsilon_{P1} - f_2 \varepsilon_{P2})$$

$$P_3 = \rho - \frac{1}{f_1 f_2} I + \underbrace{\frac{c}{(f_1 - f_2)}[(f_1 \tau_1^r - f_2 \tau_2^r) + (f_1 \tau_1^s - f_2 \tau_2^s)]}_{\text{Hardware delay term}} + \underbrace{\frac{1}{(f_1 - f_2)}(f_1 \varepsilon_{P1} - f_2 \varepsilon_{P2})}_{\text{Noise term}}$$

$$P_3 = \frac{1}{(f_1 - f_2)}(f_1 P_1 - f_2 P_2)$$

$$P_3 = \rho + \frac{1}{(f_1 - f_2)}\left(\frac{1}{f_1} - \frac{1}{f_2}\right)I + \frac{c}{(f_1 - f_2)}[f_1(\tau_1^r + \tau_1^s) - f_2(\tau_2^r + \tau_2^s)] + \frac{1}{(f_1 - f_2)}(f_1 \varepsilon_{P1} - f_2 \varepsilon_{P2})$$

$$P_3 = \rho + \frac{1}{(f_1 - f_2)}\left(\frac{f_2 - f_1}{f_1 f_2}\right)I + \frac{c}{(f_1 - f_2)}[(f_1\tau_1^r - f_2\tau_2^r) + (f_1\tau_1^s - f_2\tau_2^s)] + \frac{1}{(f_1 - f_2)}(f_1 \varepsilon_{P1} - f_2 \varepsilon_{P2})$$

$$P_3 = \rho - \frac{1}{f_1 f_2} I + \underbrace{\frac{c}{(f_1 - f_2)}[(f_1\tau_1^r - f_2\tau_2^r) + (f_1\tau_1^s - f_2\tau_2^s)]}_{\text{Hardware delay term}} + \underbrace{\frac{1}{(f_1 - f_2)}(f_1 \varepsilon_{P1} - f_2 \varepsilon_{P2})}_{\text{Noise term}}$$

Melbourne-Wubbena Linear Combination

$$MWLC = \lambda_5 n_5 + \frac{c}{(f_1+f_2)}[(f_1\tau_1^r + f_2\tau_2^r) + (f_1\tau_1^s + f_2\tau_2^s)] + \frac{1}{(f_1+f_2)}(f_1\varepsilon_{P1} + f_2\varepsilon_{P2}) + \frac{1}{(f_1-f_2)}(f_1\varepsilon_{L1} - f_2\varepsilon_{L2})$$

Hardware delay term — Code observable noise — Phase observable noise

Noise term

$$\frac{f_1}{f_1-f_2} \approx 4.529 \qquad \frac{f_2}{f_1-f_2} \approx 3.529$$

$$\frac{f_1}{f_1+f_2} \approx 0.562 \qquad \frac{f_2}{f_1+f_2} \approx 0.438$$

For assumption like L5 and P5, So

Code observable noise $\sigma(\varepsilon_{P_{MWLC}}) = \sqrt{(0.562)^2 + (0.438)^2}\,\sigma(\varepsilon_{P1}) \approx 0.7\sigma(\varepsilon_{P1})$

Phase observable noise $\sigma(\varepsilon_{L5}) \approx 5.75\sigma(\varepsilon_{L1})$

Melbourne-Wubbena Linear Combination

$$MWLC = \lambda_5 n_5 + \underbrace{\frac{c}{(f_1+f_2)}[(f_1\tau_1^r + f_2\tau_2^r)+(f_1\tau_1^s + f_2\tau_2^s)]}_{\text{Hardware delay term}} + \underbrace{\frac{1}{(f_1+f_2)}(f_1\varepsilon_{P1} + f_2\varepsilon_{P2})}_{\text{Code observable noise}} + \underbrace{\frac{1}{(f_1-f_2)}(f_1\varepsilon_{L1} - f_2\varepsilon_{L2})}_{\text{Phase observable noise}}$$

Noise term

$$MWLC = \lambda_5 n_5 + c(\tau_6^r + \tau_6^s) + \varepsilon_{MWLC}$$

This term is constant in a day.

This term is constant if no cycle slip occur.

***MWLC is useful to detect cycle slip of phase observable data.