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

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- Aeronautical Radio of Thailand
- City Planning Department, 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
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)**.

Total electron content (TEC) is an important ionospheric parameter which directly affects the radio waves propagating through the ionosphere.
Some interesting locations near the equator
Introduction

• The availability of TEC measurement data are required for the development of ionospheric models such as the International Reference Ionosphere (IRI).

• 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)

<table>
<thead>
<tr>
<th>Station</th>
<th>GPS Receiver</th>
<th>Type of observation</th>
<th>Interval (s)</th>
<th>RINEX Version</th>
</tr>
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<tbody>
<tr>
<td>Chiangmai (CMU)</td>
<td>Javad TPS</td>
<td>C1 P1 P2 L1</td>
<td>30</td>
<td>2.1</td>
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<td>Bangkok (KMI)</td>
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<td>Javad TPS</td>
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<tr>
<td>Phuket (PTC)</td>
<td>Javad TPS</td>
<td>C1 P1 P2 L1</td>
<td>30</td>
<td>2.1</td>
</tr>
</tbody>
</table>

**4 STATIONS**

- **Chiangmai (CMU)**: Javad TPS, Legacy, C1 P1 P2 L1, Interval 30 s, RINEX Version 2.1
- **Bangkok (KMI)**: Javad TPS, Legacy, C1 P1 P2 L1, Interval 30 s, RINEX Version 2.1
- **Chumpon (CPN)**: Javad TPS, Legacy, C1 P1 P2 L1, Interval 30 s, RINEX Version 2.1
- **Phuket (PTC)**: Javad TPS, Legacy, C1 P1 P2 L1, Interval 30 s, RINEX Version 2.1
Department of Public Works and Town & Country Planning (DPT), Thailand

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

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<tr>
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<td>2.11</td>
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*** Total = 11 stations ***
In collaboration with Kyoto University

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<tr>
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<td>Manual</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* CU = Chulalongkorn University
Stations

Phuket

Sukhothai

Nongkhai

Phimai
TEC Basics

1 TECU = $1 \times 10^{16}$ el/m$^2$

Depending on place & time.

GPS Satellite

Receiver

Ionosphere

TEC
TEC Basics

Time dependent

Location dependent

Ionospheric TEC Map

Chumphon station

Total Electron Content (TEC) on 24 December 2007 at Chumphon Station

GPS TEC, NN TEC, and IRI TEC for year 2007 over Chumphon at 00h30LT
Solar Cycle

Monthly averages

11-year cycle

Current cycle: 24

Source: http://solarscience.mfc.nasa.gov/SunspotCycle.shtml
Slant TEC can be computed from the pseudorange $P_1$, $P_2$ or the carrier phase $L_1$, $L_2$ (Blewitt, 1990)

\[
\text{STEC} = \frac{2 \left( \frac{f_1 f_2}{f_1^2 - f_2^2} \right)^2}{k \left( f_1^2 - f_2^2 \right)} \left( P_2 - P_1 \right)
\]

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

Need cycle slip correction for the ambiguity of the cycle number
**Vertical TEC (VTEC)**

\[ \text{VTEC} = \text{STEC} \times \cos \chi \]

where \[ \chi = \arcsin \left( \frac{R_E \cos \alpha}{R_E + h} \right) \]

where \( \chi \) = the zenith angle
\( R_E \) = the mean radian of the Earth
\( \alpha \) = the elevation angle of GPS
\( h \) = the height of the ionosphere
Bias computation

I
Satellite and receiver bias is lumped into one
The biases are computed by The MMSE method

II
Satellite bias and receiver bias are determined from MMSE method

III
Satellite bias is determined
Receiver bias is determined from minimum variance method

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

$b_r = 0.5$ ns
The measured distance (in meters) can be expressed as

\[ d = d_0 + \delta_{\text{ion}} + \delta_{\text{tropos}} + c \cdot \delta_t + w \]

- \( d_0 \) - an actual distance
- \( \delta_{\text{ion}} \) - ionospheric errors
- \( \delta_{\text{tropos}} \) - tropospheric errors
- \( \delta_t \) - hardware clock error
- \( w \) - the noise.

The ionospheric delay

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

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

Chumphon (10.72 °N, 99.37 °E)
Bangkok (13.73 °N, 100.78 °E)

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

Amplifier -> GPS Receiver -> Computer Unit

Rinex files every 30 seconds
TEC Computation

- **RINEX OBS**
  - **RNX2TEC**
    - Slant TEC Include Bias
      - TEC2BIAS
        - Bias (Satellite + Receiver)
          - T-B2ATEC
            - Absolute Slant TEC

  - Orbit File

- **TEC2GRD**
  - GRID Data (Vertical TEC)
    - plot

- **TEC MAP**

- **Orbit File**
  - TEC, ROTI plot

- **TEC**, **VTEC**

- **Time**
  - Satellite Bias
  - Receiver Bias
  - Orbit
Diurnal variation of VTEC at Chumphon station

![Graph showing diurnal variation of VTEC with time (UTC) on the x-axis and VTEC (TECU) on the y-axis. The graph includes lines for Vernal Equinox, Summer Solstice, Autumnal Equinox, and Winter Solstice.]
Diurnal variation of VTEC at Bangkok station

![Graph showing diurnal variation of VTEC at Bangkok station with curves for Vernal Equinox, Summer Solstice, Autumnal Equinox, and Winter Solstice.](image-url)
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

(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
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

Dual-frequency GPS Data Collection

KMITL

AIRPORT

HIGH SCHOOL

3-4 km

7 km
Thank You
BACKUP
\[ f_1 P_1 = f_1 \rho + \frac{I}{f_1} + f_1 c (\tau_1' + \tau_1^i) + f_1 \varepsilon_{P1} \]

For Pseudo range

\[ f_2 P_2 = f_2 \rho + \frac{I}{f_2} + f_2 c (\tau_2' + \tau_2^i) + f_2 \varepsilon_{P2} \]

\[ f_1 P_1 - f_2 P_2 = (f_1 - f_2) \rho + \left( \frac{1}{f_1} - \frac{1}{f_2} \right) I + c [f_1 (\tau_1' + \tau_1^i) - f_2 (\tau_2' + \tau_2^i)] + (f_1 \varepsilon_{P1} - f_2 \varepsilon_{P2}) \]

\[ \frac{1}{(f_1 - f_2)} (f_1 P_1 - f_2 P_2) = \rho + \frac{1}{(f_1 - f_2)} \left( \frac{1}{f_1} - \frac{1}{f_2} \right) I + \frac{c}{(f_1 - f_2)} [f_1 (\tau_1' + \tau_1^i) - f_2 (\tau_2' + \tau_2^i)] \]

\[ + \frac{1}{(f_1 - f_2)} (f_1 \varepsilon_{P1} - f_2 \varepsilon_{P2}) \]
\[ P_3 = \frac{1}{(f_1 - f_2)}(f_1 P_1 - f_2 P_2) \]

\[ P_3 = \rho + \frac{1}{(f_1 - f_2)} \left( \frac{1}{f_1} - \frac{1}{f_2} \right) I + \frac{c}{(f_1 - f_2)} \left[ f_1(\tau'_1 + \tau'_2) + f_2(\tau'_1 + \tau'_2) \right] + \frac{1}{(f_1 - f_2)} (f_1 e_{p_1} - f_2 e_{p_2}) \]

\[ P_3 = \rho + \frac{1}{(f_1 - f_2)} \left( \frac{f_2 - f_1}{f_1 f_2} \right) I + \frac{c}{(f_1 - f_2)} \left[ (f_1 \tau'_1 - f_2 \tau'_2) + (f_1 \tau'_1 - f_2 \tau'_2) \right] + \frac{1}{(f_1 - f_2)} (f_1 e_{p_1} - f_2 e_{p_2}) \]

\[ P_3 = \rho - \frac{1}{f_1 f_2} I + \frac{c}{(f_1 - f_2)} \left[ (f_1 \tau'_1 - f_2 \tau'_2) + (f_1 \tau'_1 - f_2 \tau'_2) \right] + \frac{1}{(f_1 - f_2)} (f_1 e_{p_1} - f_2 e_{p_2}) \]

**Hardware delay term**

**Noise term**
\[ P_3 = \frac{1}{(f_1 - f_2)}(f_1 P_1 - f_2 P_2) \]

\[ P_3 = \rho + \frac{1}{(f_1 - f_2)} \left( \frac{1}{f_1} - \frac{1}{f_2} \right) I + \frac{c}{(f_1 - f_2)} \left[ f_1 (\tau_1^d + \tau_1^r) - f_2 (\tau_2^d + \tau_2^r) \right] + \frac{1}{(f_1 - f_2)} (f_1 e_{P_1} - f_2 e_{P_2}) \]

\[ P_3 = \rho + \frac{1}{(f_1 - f_2)} \left( \frac{f_2 - f_1}{f_1 f_2} \right) I + \frac{c}{(f_1 - f_2)} \left[ (f_1 \tau_1^d - f_2 \tau_2^d) + (f_1 \tau_1^r - f_2 \tau_2^r) \right] + \frac{1}{(f_1 - f_2)} (f_1 e_{P_1} - f_2 e_{P_2}) \]

\[ P_3 = \rho - \frac{1}{f_1 f_2} I + \frac{c}{(f_1 - f_2)} \left[ (f_1 \tau_1^d - f_2 \tau_2^d) + (f_1 \tau_1^r - f_2 \tau_2^r) \right] + \frac{1}{(f_1 - f_2)} (f_1 e_{P_1} - f_2 e_{P_2}) \]

- **Hardware delay term**
- **Noise term**
Melbourne-Wubbena Linear Combination

\[ MWLC = \lambda_3 n_3 + \frac{c}{(f_1 + f_2)} [(f_1 \tau_1' + f_2 \tau_2') + (f_1 \tau_1' + f_2 \tau_2')] + \frac{1}{(f_1 + f_2)} (f_1 \varepsilon_{p1} + f_2 \varepsilon_{p2}) + \frac{1}{(f_1 - f_2)} (f_1 \varepsilon_{L1} - f_2 \varepsilon_{L2}) \]

Hardware delay term

\[ \frac{f_1}{f_1 - f_2} \approx 4.529 \quad \frac{f_2}{f_1 - f_2} \approx 3.529 \]
\[ \frac{f_1}{f_1 + f_2} \approx 0.562 \quad \frac{f_2}{f_1 + f_2} \approx 0.438 \]

Code observable noise

\[ \sigma(\varepsilon_{p, \text{code}}) = \sqrt{(0.562)^2 + (0.438)^2} \sigma(\varepsilon_{p1}) \approx 0.7 \sigma(\varepsilon_{p1}) \]

Phase observable noise

\[ \sigma(\varepsilon_{L3}) \approx 5.75 \sigma(\varepsilon_{L1}) \]
Melbourne-Wubbena Linear Combination

\[ MWLC = \lambda_5 n_5 + \frac{c}{(f_1 + f_2)} [(f_1 \tau_1' + f_2 \tau_2') + (f_1 \tau_1 + f_2 \tau_2)] + \frac{1}{(f_1 + f_2)} (f_1 \varepsilon_p + f_2 \varepsilon_p) + \frac{1}{(f_1 - f_2)} (f_1 \varepsilon_{21} - f_2 \varepsilon_{22}) \]

**Hardware delay term**

**Code observable noise**

**Phase observable noise**

**Noise term**

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

This term is constant if no cycle slip occur.

This term is constant in a day.

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