Measurement of Ionospheric Plasma Distribution Over Myanmar Using Single Frequency GPS Receiver

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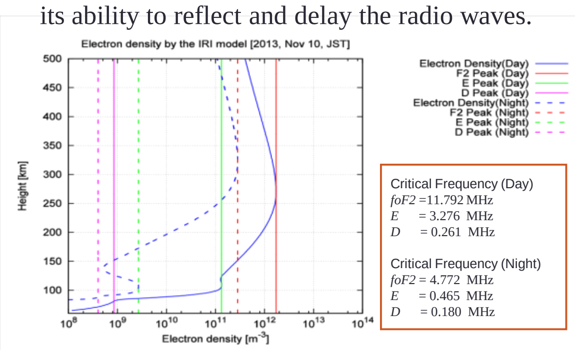
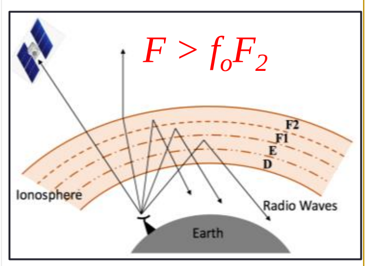
Abstract— The Earth ionosphere is located at the altitude of about 70 km to several 100 km from the ground and it is composed of ions and electrons called plasma. In the ionosphere, these plasma makes delay in GPS (Global Positioning System) signals and reflect in radio waves. The delay along the signal path from the satellite to the receiver is directly proportional to the total electron content (TEC) of plasma, and this delay is the largest error factor in satellite positioning and navigation. Recently, continuous monitoring of the TEC using networks of GNSS (Global Navigation Satellite System) observation stations, which are basically built for land survey, has been conducted in several countries. However, in these stations, multi-frequency support receivers are installed to estimate the effect of plasma delay using their frequency dependence and the cost of multi-frequency support receivers are much higher than single frequency support GPS receiver. In this research, single frequency GPS receiver was used instead of expensive multi-frequency GNSS receivers to measure the ionospheric plasma variation such as vertical TEC distribution.

Relation Ionosphere and Radio Waves

- The Earth's ionosphere is composed of ions and electrons which are generated by ionization of neutral particles from ultraviolet radiation.
- Altitude of the ionosphere: from a few tens kilometers ~ several hundred kilometers.
- An important feature of the ionospheric plasma in terms of radio communications is its ability to reflect and delay the radio waves.





Ionospheric TEC observation by GPS signals

TEC along propagation path of the signal is proportional to propagation delay called slant TEC. The propagation delay can be accurately estimated by pseudoranges measured by dual frequency signals because of its frequency dependence. It can be measured as follows-

$$I_{\mathrm{slant}} = \frac{8\pi^2 m\varepsilon_0 c f^2}{e^2}\delta^i_{\mathrm{ion}}$$

$$\delta^i_{\mathrm{ion}} = \frac{P_1 - P_2}{1/{f_1}^2 - 1/{f_2}^2}\ [/\mathrm{m}^2]$$

where:
e : elementary charge, m : mass of electron, f : signal frequency

f_1, f_2 : signal frequency [Hz]
P_1, P_2 : pseudorange [m]

Research Methodology

Step 1. TEC variation can be derived from difference between code pseudorange and carrier phase

Code pseudorange : $$R^i = \rho^i + c(\delta t_r - \delta t_s^i) + \delta^i_{\mathrm{ion}} + \delta^i_{\mathrm{tro}} + \varepsilon \quad \text{… ①}$$

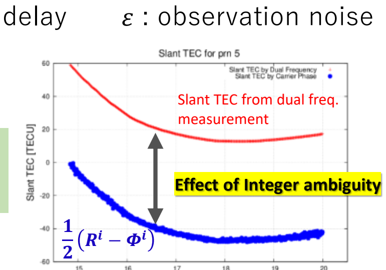
Carrier phase : $$\Phi^i = \rho^i + c(\delta t_r - \delta t_s^i) - \delta^i_{\mathrm{ion}} + \delta^i_{\mathrm{tro}} + \lambda N^i + \varepsilon' \quad \text{… ②}$$

ρ : real distance　δt_r : receiver clock error　δt_s : satellite clock error
δ_{ion} : ionospheric delay　δ_{tro} : tropospheric delay　ε : observation noise
N : integer ambiguity　λ : wave length

$\frac{①-②}{2}$:

$$\delta^i_{\mathrm{ion}} = \frac{1}{2}(R^i - \Phi^i) - \frac{\lambda N^i}{2} + \varepsilon \propto I_{\mathrm{slant}}$$

The problem is how to estimate ***integer ambiguity for each satellite*** (**N^i**)



Step 2. Integer ambiguities are estimated from sequential observations.

$\frac{①+②}{2}$:

$$\frac{1}{2}(R^i + \Phi^i) = \rho^i + c(t_{\mathrm{rec}} - t^i_{\mathrm{sat}}) + \delta^i_{\mathrm{tro}} + \frac{\lambda N^i}{2} + \varepsilon + \varepsilon'$$

$$ct_{\mathrm{rec}} + \frac{\lambda N^i}{2} = \frac{1}{2}(R^i + \Phi^i) - \rho^i + ct^i_{\mathrm{sat}} - \delta^i_{\mathrm{tro}} + \varepsilon + \varepsilon'$$

To find unknown parameters $ct_{\mathrm{rec}} + \frac{\lambda N^i}{2}$, by averaging of the recording those parameter for all satellite,

	Satellite #1	Satellite #2	…	Satellite m
Record 1	$ct^1_{\mathrm{rec}} + \frac{\lambda}{2}N^1$	$ct^1_{\mathrm{rec}} + \frac{\lambda}{2}N^2$	…	$ct^1_{\mathrm{rec}} + \frac{\lambda}{2}N^m$
…			…	
Record n	$ct^n_{\mathrm{rec}} + \frac{\lambda}{2}N^1$	$ct^n_{\mathrm{rec}} + \frac{\lambda}{2}N^2$	…	$ct^n_{\mathrm{rec}} + \frac{\lambda}{2}N^m$

When satellites are different, it can be considered a the same receiver clock error,

	Satellite #1	Satellite #2	…	Satellite m
Record 1	—	$\frac{\lambda}{2}(N^2 - N^1)$	…	$\frac{\lambda}{2}(N^m - N^1)$
…			…	
Record n	—	$\frac{\lambda}{2}(N^2 - N^1)$	…	$\frac{\lambda}{2}(N^m - N^1)$

From this average record, ,

$$\frac{\lambda N^i}{2} = \frac{\lambda N^1}{2} + \frac{\lambda \Delta N^i}{2}$$

Then,

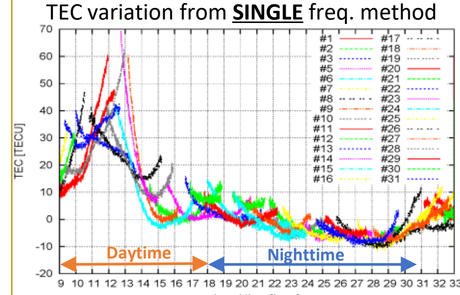
$$\delta^i_{\mathrm{ion}} = \frac{1}{2}(R^i - \Phi^i + \lambda\Delta N^i) + \frac{\lambda N^1}{2} \propto I_{\mathrm{slant}}$$

In this case, only the integer ambiguity of satellite #1 at record 1 is unknown. This unknown term can be estimated from an approximate TEC map which is derived by a least-squares method for multiple data observed at known locations under an assumption that latitudinal and longitudinal TEC distribution is represented by 1st order polynomial functions [Zaw et al., 2016].

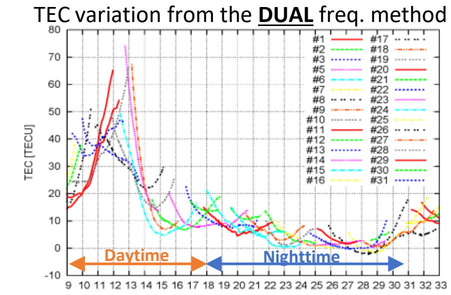
Examination and Comparison of the developed method

In this measurement, single-frequency support ublox GPS receiver was used to probe ionospheric TEC. The validity of the method was evaluated by measurements obtained by the Japanese GNSS observation network called GEONET. The performance of measurement results using single-frequency of GPS receiver were compared with the results by dual-frequency measurement as shown in figures.

TEC variation from **SINGLE** freq. method



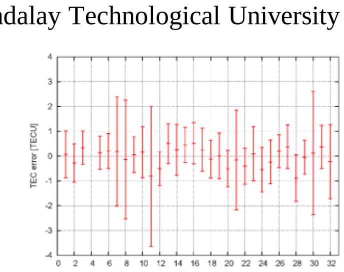
TEC variation from the **DUAL** freq. method

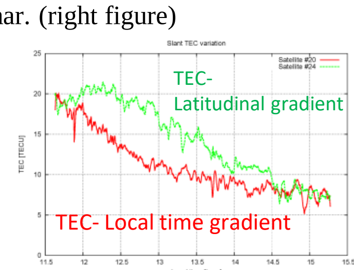


TEC estimation error of single method for each satellite

The measurement error of TEC variation from single frequency method was evaluated by dual frequency method as following (left figure).

This developed method was applied to measure TEC variation in the campus of Mandalay Technological University in Myanmar. (right figure)





- Ionospheric TEC is obtained with an accuracy of less than a few TECU.
- The bias errors are less than one TECU.
- The random errors can be reduced by Kalman filter.

Conclusions

- An estimation method of TEC distribution at lower latitude region from single frequency GPS data was proposed.
- The method was evaluated by using GEONET data that includes multi-frequency observations.
- Bias errors of the estimated TEC was less than ±3 TECU, and therefore, it was possible to observe plasma bubbles with the method at lower latitude regions.