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TEC and Scintillation Study of Equatorial Ionosphere: A Month Campaign over Sipitang and Parit Raja Stations, Malaysia

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Abstract: Problem Statement: Ionospheric scintillations, which cause significant effects on satellite signals for communication and navigation, often takes place in equatorial region such as Malaysia. However, this disturbance are not fully understand due to few studies performed. This research reports the study and monitoring activity on Total Electron Content (TEC) and ionospheric scintillation in Malaysia using GPS measurements. **Approach:** One dual-frequency GPS receiver was positioned at the main station in Parit Raja, West Malaysia (1.86° N, 103.8° E) and Sipitang, East Malaysia (5.10° N, 115.56° E) respectively. Dual-frequency GPS data collected during the one-month ionospheric experimental campaign was used for TEC and scintillation computation and analysis. The TEC with 15 sec interval were computed from combined L1 and L2 code-pseudorange and carrier phase measurements. Whereas, the scintillation parameter S4 index was computed as a standard deviation of the received signal power normalized to average signal power every 60 sec on L1. A corrected S4 (without noise effects) was also computed and used in the analysis. **Results:** It was found that the daily maxima vTEC for Parit Raja (PR) ranged from 38-100 TECU, which is generally higher than those of Sipitang, which ranged from 30-42 TECU. However, a general consistency for both stations can be seen during the 1 month campaign period. **Conclusions/Recommendations:** In conclusion, these results show good agreement in the existence of the equatorial anomaly observed during moderate solar flux conditions and undisturbed geomagnetic condition. This will contributes to the knowledge of equatorial ionosphere and help in space weather condition. However, to better understand and characterize the ionosphere over Malaysia, more campaigns should be encouraged.

Key words: TEC, scintillation, equatorial ionosphere, GPS

INTRODUCTION

The ionospheric disturbances cause significant effects on satellite signals for communication and navigation, which are dependent on the signal frequency and the ionospheric electron content. Ionospheric scintillations, the most significant manifestation of such disturbances, often takes place in equatorial region such as Malaysia. The ionosphere morphology is mainly due to the temporal and diurnal variability of the electron density. This is dependent on the solar and geomagnetic activity of the earth. Determination of the total electron content will aid in reliable and secure radio communications.

Significant research on ionospheric study has been done and several ionospheric models have been introduced for mid-latitude regions[3,7,8,11,19]. Comparatively, few corresponding research has been done on the low latitude (equatorial) ionosphere. There are however, significant differences in the structure and effect on radio propagation of the ionosphere at these latitudes including the equatorial electrojet and accompanying equatorial anomaly, greater absorption and the geomagnetic field orientation being nearly horizontal. Unfortunately not all these phenomena are completely understood because there are fewer observations here than at higher latitudes.

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The observations of oblique total electron content can be obtained from the delay or advance of GPS signals on channels L1 (1575.42 MHz) and L2 (1227.6 MHz). The Total Electron Content (TEC) is the number of electrons in a column of 1 m^2 cross section along the ray path[4,9]. Measurements of TEC are useful for the study of ionospheric dynamics, structure and characteristics.

The ionosphere in Malaysia is unique because of her location near the equator, where a lot of phenomena such as the equatorial anomaly and fountain effect makes it good for studies[10,16,20]. Zain and Abdullah[21] reported on the analysis of TEC using the GPS station at Arau, Perlis, in the northern part of Malaysia. Short term TEC analysis was also made using GPS station at Miri, Sarawak[22]. Furthermore, D region analysis from GOES-7 soft solar x-ray data at Universiti Kebangsaan Malaysia has also been carried out[1,2]. Ho *et al*. reported on typical hourly variations for quiet ionosphere over Malaysia during 24 h on July 14, 2000 and continued with the variation during the geomagnetic storm on July 15-17, 2000[23].

In order to be close to the magnetic equator, an ionospheric monitoring was held from Nov 30-Dec 23, 2005 at Sipitang, Malaysia, which lies about 5.5° North. Sipitang is located at latitude 5.10° N and longitude 115.56° E at an altitude of 5.5 m. During the observation, TEC and scintillation parameters were extracted from dual-frequency GPS monitoring data. The ionospheric parameters were further compared to the main observatory at Wireless and Radio Science Centre (WARAS), Parit Raja, Batu Pahat, which is located at latitude 1.86° N and longitude 103.8° E at an altitude of 7.3 m.

MATERIALS AND METHODS

Total Electron Content (TEC) from GPS: The ionosphere is the region between 70-1000 km above the earth containing ionized gas and electrons. A wave traveling through it will experience a time delay. The radio signals from GPS on channels L1 (1575.42 MHz) and L2 (1227.6 MHz) will experience difference delays[13,14]. TEC is a measure of the number of electrons along the path from the GPS satellite and is reported in TEC units (TECU = electrons$\times10^{16}$ m^{-2}). As mention before, TEC can be obtained from the ionospheric delay between L1 and L2 signals as Eq. 1:

$$\text{TEC} = \left[9.483\times\left(\text{PR}_{\text{L2}} - \text{PR}_{\text{L1}} - \Delta\right)\right] + \text{CAL} \qquad (1)$$

where:

PR_{L2} = L2 pseudo-range in meters

PR_{L1} = L1 pseudo-range in meters

Δ = Input bias between the C/A and P code chip transitions in meters

CAL = TEC result due to internal receiver L1/L2 delay and the offset

In other words, the TEC introduced in Eq. 1 (slant TEC) is defined as the total number of electrons integrated along the path from the receiver to each GPS satellite in a column having a cross sectional area of one m^2 and is measured at different elevation angles. The vertical TEC (at elevation angle of 90°) or simply vTEC, as seen in Fig. 1, is modelled using a mapping function[15,18] as below:

$$\text{vTEC} = \text{TEC}\left(\cos\chi'\right) \qquad (2)$$

with

$$\cos\chi' = \sqrt{1-\sin^2\chi'}$$

$$\sin\chi' = \frac{R_E}{R_E + h_m}\sin\chi$$

where:

χ and χ' = Zenith angles at the receiver site and at the ionospheric pierce point, IPP

R_E = Mean earth radius

h_m = Height of maximum electron density (450 km)

Amplitude scintillation from C/A code GPS receiver: Amplitude scintillation monitoring is traditionally accomplished by monitoring index S4. The S4 index is derived from signal intensity of signals received from satellites. Signal intensity is actually received signal power, which is measured in a way that its value doesn't fluctuate with noise power. When the S4 index is normalized, the receiver's absolute gain is not important, as long as it is relatively constant during the period. It is also important that the intensity measurements be linear with respect to the signal power over its entire range including deep scintillation fades.

S4 measured at L band (L1 and L2 frequencies) needs to have the effects due to removal of ambient noise. It is because the ambient noise at the L1 frequency translates to a relatively high S4 at lower frequency VHF and UHF frequencies band.

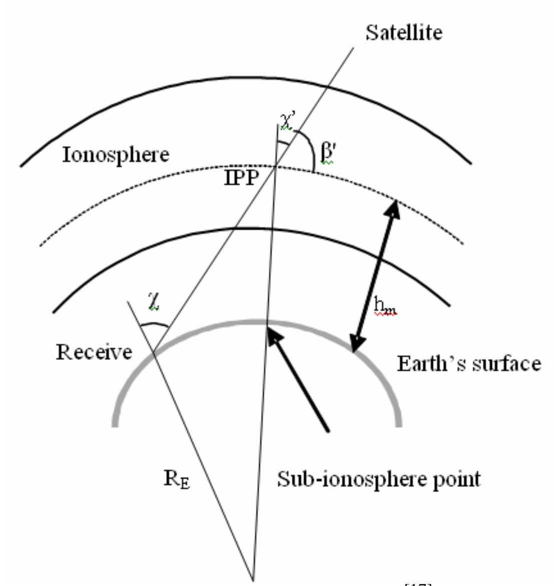

Fig. 1: Ionosphere single layer model[17]

The total amplitude scintillation index, $S4_T$, including the effects of ambient noise, is defined as follows:

$$S4_T = \sqrt{\frac{\langle SI^2\rangle - \langle SI\rangle^2}{\langle SI\rangle^2}} \quad (3)$$

$S4_T$ = Total amplitude scintillation index
SI = Satellites signal intensity

where $S4_T$ represents the expected (or average) value over the interval of interest (i.e., 60 sec)[5,12].

Unfortunately, the total S4 defined in Eq. 3 can have significant values simply due to ambient noise. Thus, it is desirable to remove. The ambient noise of Eq. 3 can be removed by estimating the average signal-to-noise density over the entire evaluation interval (60 sec) and using that estimate to determine the expected S4 due to ambient noise. This is legitimate since the amplitude scintillation fades do significantly alter the average signal-to-noise density over a 60 sec time interval.

If the signal-to-noise density (S/N) is known, the predicted S4 due to ambient noise is:

$$S4_N = \sqrt{\frac{100}{S/N}\left(1+\frac{500}{19S/N}\right)} \quad (4)$$

Thus, by replacing the S/N with the 60 sec estimate $\hat{S}/\hat{N}$, an estimate of signal-to-noise density, we obtain an estimate of the S4 due to noise $S4_{\hat{N}}$.

$$S4_{\hat{N}} = \sqrt{\frac{100}{\hat{S}/\hat{N}}\left(1+\frac{500}{19\hat{S}/\hat{N}}\right)} \quad (5)$$

Subtracting the Eq. 5 from Eq. 3 yields the corrected value of S4 as following:

$$S4 = \sqrt{\frac{\langle SI^2\rangle - \langle SI\rangle^2}{\langle SI\rangle^2} - \frac{100}{\hat{S}/\hat{N}}\left(1+\frac{500}{19\hat{S}/\hat{N}}\right)} \quad (6)$$

RESULTS

The results of the observed vTEC and S4 parameters are presented in this section. In both cases, comparisons are made between the campaign location (Sipitang) and the main observatory (Parit Raja). The daily maxima vTEC and S4 parameter are shown and discussed.

vTEC: The one-month results obtained during the campaign have been summarized as below. Figure 2 shows the daily maxima vTEC for GPS week 1351 to 1354 (Nov. 30th-Dec 23rd).

Maxima vTEC was chosen from the maximum value of vTEC during the 24 h period. It is noted that the daily maxima vTEC for Parit Raja (PR) with values ranging from 38-100 TECU during the campaign period. However, vTEC values for Sipitang are generally lower as compared to Parit Raja, ranging from 30-42 TECU. It is also of interest to note that a general consistency for both stations at Parit Raja and Sipitang Hill can be seen during the 1 month campaign period.

Scintillation parameter, S4: The scintillation parameter, S4 index, was computed as a standard deviation of the received signal power normalized to average signal power every 60 sec, based on 50 Hz sampling data rate (3,000 data samples) on L1.

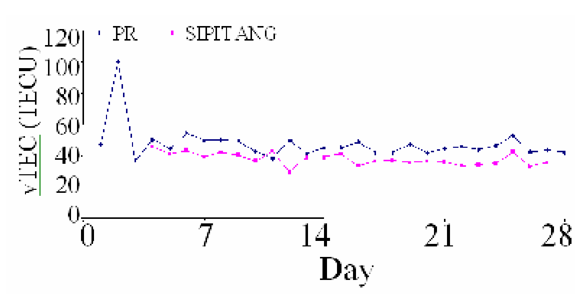

Fig. 2: The maxima vTEC for GPS week from 1351-1354 at Parit Raja and Sipitang

Base on GISM Chart (Global Ionosphere Scintillation Model), scintillation activity indicated by S4 has four categories i.e. S4≤0.25 is quiet, S4>0.25 and S4≤0.5 is moderate, S4>0.5 and S4≤1 is disturbed, then S4>1 is severe[6]. Figure 3-6 show the scintillation parameter, S4 for both stations during the campaign period. Results indicate the overall S4 values for both stations are quite consistent.

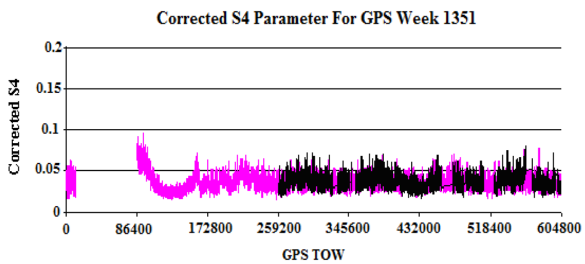

Fig. 3: Corrected scintillation parameter, S4 for GPS week 1351 at Parit Raja and Sipitang (Parit Raja=Pink Line, Sipitang=Black Line)

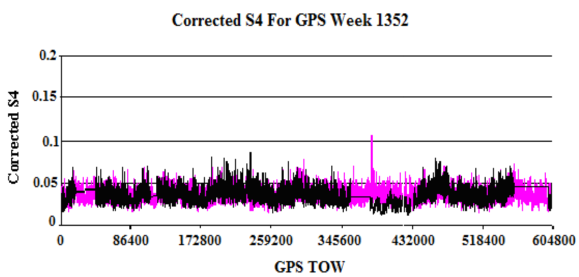

Fig. 4: Corrected scintillation parameter, S4 for GPS week 1352 at Parit Raja and Sipitang (Parit Raja=Pink Line, Sipitang=Black Line)

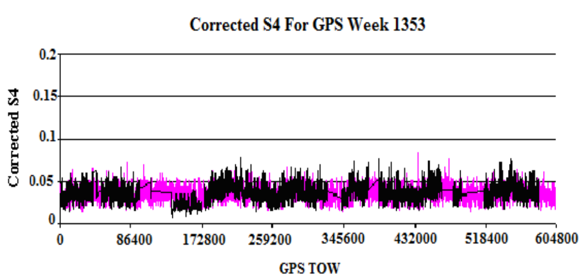

Fig. 5: Corrected scintillation parameter, S4 for GPS week 1353 at Parit Raja and Sipitang (Parit Raja=Pink Line, Sipitang=Black Line)

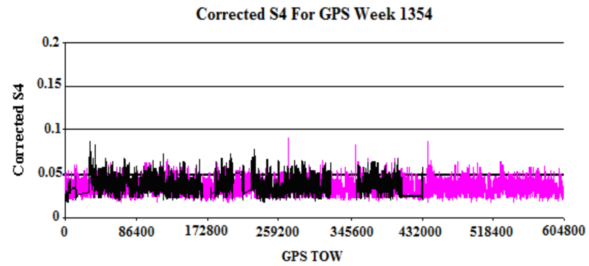

Fig. 6: Corrected scintillation parameter, S4 for GPS week 1354 at Parit Raja and Sipitang (Parit Raja=Pink Line, Sipitang=Black Line)

DISCUSSION

The TEC parameters maxima vTEC observed at Sipitang are lower as compared to the station at Parit Raja. It is because of the location of Sipitang is closer to the magnetic equator as compared to Parit Raja. The equatorial fountain effect makes the lower electron density for such location near to magnetic equator. This can also be seen in the Fig. 1, that the Sipitang vTEC is much lower than the Parit Raja vTEC shows the presence of equatorial anomaly[1].

However, both observation stations are showing a general consistency for their TEC parameters. It is because the TEC parameters are mainly due to solar and geomagnetic activities of the earth. The geomagnetic index that is the Kp index is undisturbed condition during the observation which is less than 5 (The index runs from 0-9, where 9 is the most disturbed).

CONCLUSION

From the results, quiet scintillation event was observed at most of the week. Observations are taken on December 2005 (GPS week 1351-1354) where the geomagnetic is undisturbed condition during observations.

Although the duration of this observation was only for almost a month, results confirm the presence of the equatorial anomaly. More campaigns should be carried out to properly understand and characterize the ionosphere over Malaysia and the equator.

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