Observation of Ionosphere Scintillation and Total Electron Content (TEC) Characteristic at Equatorial Region

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Abstract. Ionosphere scintillation and total electron content (TEC) measurement were investigated in terms of value at Equatorial based on GPS/GNSS measurement. This paper presents the analysis month-to-month variation of Scintillation (S4) and Total Electron Content (TEC) based on during night time and day time activity. This paper also presents the analysis of scintillation (S4) and Total Electron Content (TEC) during equinox and solstice. The analysis presented from January to December 2016. The measurement and recorded data of scintillation (S4) and Total Electron Content (TEC) was done by GPS Ionosphere Scintillation and TEC Monitoring (GISTM), installed at UKM, Malaysia (2.92°N 101.78°E). Strong Scintillation (S4) was obtained from PRN 135 with S4 ≥ 0.4 (0.430368) on 11:33 UTC (19:33 UT). The maximum Total Electron Content (TEC) was found on midday, generally the daily peak is around 5:00 to 10:00 UTC (13:00 to 18:00LT). April shows that the highest Total Electron Content (TEC) about 152 TECU. For seasonal variation, Scintillation (S4) highest on equinox and lowest on solstice, meanwhile Total Electron Content (TEC) highest on equinox and lowest on solstice. The disturbance will cause error in distance measurement for positioning and navigation.

Keywords— Scintillation, Total Electron Content, Ionosphere, GPS / GNSS

1. Introduction

Ionosphere is an upper layer of the earth’s atmosphere that contains a high concentration of ions and free electrons, which can exert an effect on GPS signals. An ionosphere condition in Malaysia is located in the south geomagnetic latitude (lower latitudes) has a high electron density, thus causing potential disruption of electromagnetic waves through the ionosphere in the area. Interference caused by the activity of the ionosphere on the GPS / GNSS passing through the ionosphere could be a delay for code measurements, as well as fluctuations in amplitude and phase to phase measurement. One of the phenomena in the ionosphere irregularities that interfere with the satellite signal propagation are
Ionosphere scintillation. Ionosphere scintillation is the rapid fluctuations of the amplitude and phase of the satellite signal as shown in Figure 1. Satellite communication systems disrupted by ionosphere scintillation is a system that uses multiple GHz frequency or frequency band L (L-Band). GPS signals, which uses L-band frequencies, used as ionosphere scintillation monitoring and interruption of satellite communications to satellite communication systems in the L-band frequency. To determine the effects of ionosphere scintillation on satellite communications then do a comparison between the index data S4 with CNO ratio of GPS data. The results show that the greater the S4 index, the ratio CNO increasingly fluctuating. Fluctuations such signals are satellite signals are disrupt by ionosphere scintillation.

Furthermore, the TEC’s study at Equatorial region is significant for unpredictable and highly variable of phenomena like fountain effect and Equatorial anomaly. TEC is refer of the total number of electrons be present along a path in between a radio transmitter to receiver. Where is the presence of electrons will be affected the radio waves. This means that the more radio signal will affect when there are many electrons along the path of the radio waves. The unit is TEC - Unit (TECU) which is equivalent to 10,000 billion electrons per square meter or 1 TEC Unit = 1016 el / m2. TEC good value will vary daily, seasonal, annual (following cycles of solar activity) even the location (latitude). In one day, TEC will be undervaluing in the morning, getting higher during the day, to reach the peak, and then decreases back toward evening. This is because the electron production is highly dependent on the level of solar radiation. In the daytime, the intensity of solar radiation received ionosphere is very high and decreases in the afternoon.

High solar activity will cause any disruption in the ionosphere higher. The effects are decreasing in number of electrons, the velocity of the iron will increase and the temperature and the plasma cut-off frequency will decrease [1]. Disturbances in the ionosphere can cause problems in the application of radio waves such as radio communications, satellite navigation systems and space weather so the study ionosphere disturbances become an important subject in the research contributions of space weather. The radio signal from the satellite as it passes through the disturbed ionosphere will cause interference with the faraday rotation signal and the signal is also fluctuated rapidly in amplitude and phase are received in the receiver due to the irregularity of the ionosphere electron density medium. These fluctuations are known as ionosphere scintillation [3], [11].

The parameters of spatial and temporal variations ionosphere at mid-latitudes are quite small comparing to the low-latitude and equatorial regions. The specific knowledge is important to determine the value of TEC for different location in different geophysical conditions. A few researches have been conducted to investigate the characteristics of short-term temporal and spatial for the condition of local ionosphere. This is to be ensuring these characteristics are well understood in Malaysia [4]. However, the coupling effect of sun earth on the equatorial ionosphere is lacking due to the barely distributed GPS stations at the equatorial region in comparison to the high latitude and mid-latitude regions [3].

The objective of this research is to investigate Ionosphere Scintillation and Total Electron Content (TEC) Characteristic at Equatorial region. This research also will evaluate the value of Ionosphere Scintillation and Total Electron Content (TEC) at Equatorial region. From this evaluation, it will verify and validate the characteristic of Ionosphere Scintillation and Total Electron Content at Equatorial region.
2. Data and Methodology

This research was done by data collection of dual-frequency GSV4004B GPS Ionosphere Scintillation and TEC Monitoring (GISTM) installed at UKM, Malaysia. There were 11 GPS satellites able to track simultaneously by GPS receiver at L1 and L2; and the satellite data were converts to slant TEC (STEC). All available satellites TEC data were sampled into 60s interval. The slant TEC (TEC along the line of sight) is obtained through an excel file as shown in Figure 2.

\[ \text{STEC} = \text{TEC0} \]  
(Eq. 1)

The sampling rate of amplitude scintillation is recorded more than 60 second intervals in 50Hz. The two parameters of S4, which are the correction of S4 (S4cor) and total S4 (S4t) are compute by the receiver. Where is the total of S4 (S4t) is includes of ambient noise effect [14]. The corrected S4 index analysis was conducted without the influence of ambient noise and it is determined by using:

\[
S4 = \sqrt{S4t^2 - S4cor^2}
\]

| Scintillation Type | Range        |
|-------------------|--------------|
| Negligible        | $S4 < 0.2$   |
| Weak              | $0.2 \leq S4 \leq 0.3$ |
| Moderate          | $0.3 \leq S4 \leq 0.4$ |
| Strong            | $S4 \geq 0.4$ |
The 12-months data analysis was collected from January to December 2016. The data was analyzed based on Equinox (20 March 2016 and 22 September 2016) and Solstice (20 June 2016 and 21 December 2016) occurring. The result is present the scintillation (S4) and Total Electron Content (TEC) for January to December 2016.

3. Result and Discussion

This section presents the result of measurement of Scintillation (S4) and Total Electron Content (TEC) month – to – month variation based on night time and day time activity, also seasonal variation from January to December 2016.

3.1. Month – to – month variation of Scintillation (S4) and Total Electron Content (TEC)

Refer to Figure 3 and Figure 4 show that variation month – to – month of Scintillation and Total Electron Content (TEC) for all PRNs was monitored at UKM station from January to December 2016. Coordinate Universal Time (UTC) is equal to Local Time (LT) when plus eight (LT=UTC+8).

![Figure 3](image1.png)

**Figure 3.** Month – to – month variation of Scintillation (S4)

As shown as in Figure 3, the strong Scintillation (S4 ≥ 4) is occurred on March, May, July, August and September during the nighttime. This strong Scintillation (S4 ≥ 4) occurred from 10:00 to 22:00 UTC (18:00 to 6:00 LT). Meanwhile on January, February, April, June, October, November and December shows that moderate Scintillation (0.3 ≤ S4 ≤ 0.4) was occurred during night time from 10:00 to 22:00 UTC (18:00 to 6:00 LT). Moderate Scintillation (0.3 ≤ S4 ≤ 0.4) was occurred during daytime from 00:00 to 10:00 UTC (8:00 to 18:00 LT) during the year of 2016. Generally, the occurrence of the ionosphere scintillation events that occurs in equatorial region is happen after local sunset and before local sunrise due to irregularities of equatorial density [14].
As per result in Figure 4, the graph shows the low of TEC in the early morning and will be increase with time. The post noon is recorded as the maximum TEC value and slowly decreases after sunset. We identify the pattern of gradual morning rise starting on 00:00 UTC (8:00 LT) and evening decrease of TEC is around 10:00 UTC (18:00 LT) in all month. While, around 5:00 to 10:00 UTC (13:00 to 18:00 LT) is recorded as a daily peak of TEC values. April shows that the highest Total Electron Content (TEC) about 152 TECU and the lowest Total Electron Content (TEC) is on December about 77 TECU.

3.2. Scintillation (S4) and Total Electron Content (TEC) activity during night time

As per result on Figure 3, it showed that Scintillation (S4) was occurred during night time and has a strong Scintillation (S4). For example, on 30 May 2016, measurement of Scintillation (S4) was obtained from PRN 135 with S4 ≥ 0.4 (0.430368) on 11:33 UTC (19:33 UT). This night time ionosphere disturbance is happening may be due to large and small-scale irregularities that exist together during nighttime at UKM station, Malaysia [14].

Figure 4 shows that TEC is low during night time. The recombination between electrons and ions during night time will cause of TEC decays.

3.3. Scintillation (S4) and Total Electron Content (TEC) activity during day time

Refer to Figure 3, we can see that Scintillation (S4) was occurred in day time in moderate Scintillation (S4) type. For example, on 31 October 2016, measurement of Scintillation (S4) was obtained from PRN 9 with 0.3 ≤ S4 ≤ 0.4 (0.301076) on 2:46 UTC (10:46 UT). Mostly the Daytime Scintillation (S4) is occurs without the phase scintillation occurrence. However, significant TEC variations are rarely took place throughout daytime scintillation activity. As Figure 4, the maximum TEC was found on midday, generally the daily peak is around 5:00 to 10:00 UTC (13:00 to 18:00 LT). For example, TEC show the highest value on February, March and April. The TEC of daytime variation shows large variability comparing to nighttime variation. This is due of decays of TEC values because of
recombination between electrons and ions during nighttime. While, the electrons density is increasing during daytime due to particle emission by sun in the ionosphere. This daily variation happens because of daily earth rotation on its own axis and following the movement of the Sun.

3.4. Equinox and Solstice phenomena of Scintillation (S4) and Total Electron Content (TEC) activity

The data that are collected from January to December 2016 (12 months data) was analyzed based on Equinox (20 March 2016 and 22 September 2016) and Solstice (20 June 2016 and 21 December 2016) occurring. The result is presented scintillation (S4) and Total Electron Content (TEC) based on Equinox and Solstice.

| Phenomena | Month   | S4          | TEC |
|-----------|---------|-------------|-----|
| Equinox   | March   | 0.401251    | 145 |
|           | September | 0.407598   | 127 |
| Solstice  | June    | 0.386964    | 82  |
|           | December | 0.382412    | 77  |

Based on Table 2, seasonal variation of Scintillation (S4) and TEC are presented. From the table it show that both Scintillation (S4) and TEC highest on equinox and lowest on solstice. The increase in the emergence of the scintillation associated with the terminator summer sun's magnetic field and meridians that form on these months. Formation of the magnetic field and the solar terminator causes the dynamo EXB drift current in the equatorial F layer strip thereby increasing plasma irregularity. This disorder is also associated with increased plasma bubbles in the coming months until the scintillation intense in these months. The neutral composition and O/N2 ratio at low latitude and equatorial will increase when there is changes in the flow of meridional winds during daytime from pole to equator region. The decrease will be maximum during the equinox. Hence, the result will be higher TEC in equinox due to higher of electron density. The ionosphere is varying with geographic location, time, certain solar and geomagnetic activities. The quantity of emission and solar activity from the Sun are very correlate with the sunspots number on its surface. In addition, the sudden sun eruption may cause the increasing activity in ionosphere and this correlated with number of sunspot.

Conclusion

Ionosphere Scintillation (S4) and Total Electron Content (TEC) were observed in terms of value at equatorial region based on GPS/GNSS measurement. Strong Scintillation (S4) was obtained from PRN 135 with S4 ≥ 0.4 (0.430368) on 11:33 UTC (19:33 UT). The maximum TEC was found on midday, generally the daily peak is around 5:00 to 10:00 UTC (13:00 to 18:00 LT). April shows that the highest TEC about 152 TECU. For seasonal variation, Scintillation (S4) highest on summer and lowest on winter, meanwhile Total Electron Content (TEC) highest on equinox and lowest on summer. In order to observe the effects and characteristic of Ionosphere Scintillation (S4) and Total Electron Content (TEC) on GPS/GNSS receivers at equatorial region, the investigation of Ionosphere Scintillation (S4) and TEC activity should be made based on long-term data series.

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