Jurnal
Teknologi

Full Paper

VARIATIONS IN TOTAL ELECTRON CONTENT DURING THE PHASES OF LOW AND HIGH SOLAR ACTIVITIES

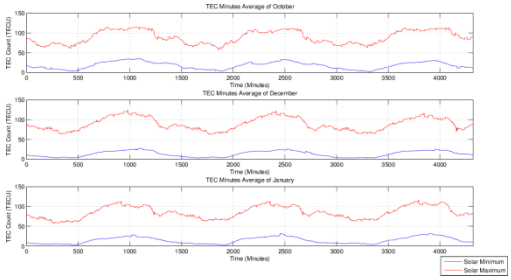
Mariyam Jamilah Homam*, Mohamad Aizat Ezri Ahmad Hapizudin

Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia

Article history
Received
2 July2015
Received in revised form
5 November 2015
Accepted
25 January 2016

*Corresponding author
mariyam@uthm.edu.my

Graphical abstract



Abstract

Variations in the Total Electron Content of the ionosphere were studied by utilizing data from the GISTM receiver installed at Universiti Tun Hussein Onn Malaysia. The study was conducted during periods of low solar activity (July 2007–July 2008) and high solar activity (July 2013–July 2014). Results show that the TEC are dependent on the solar activity.The values during high solar activity were significantly higher than that obtained during the solar minimum phase. The minimum TEC values for both phases varied between 89% and 97%, and the maximum TEC values varied between 70% and 81%. The pattern of daily TEC value changes was constant, and TEC peaked in the afternoon at ~14 LT. The highest TEC recorded during the solar maximum phase was 144.5 TEC Unit (TECU) in April 2014, whereas the highest TEC recorded during the solar minimum phase was 36.3 TECU in April 2008. TEC was maximized from March to May under both solar maximum and minimum phases.

Keywords: Total electron content; equatorial region; solar activity

1.0 INTRODUCTION

Two significant phases are observed in one complete solar cycle, namely, the solar minimum and solar maximum phases. A parameter that is strongly affected by these phases is the Total Electron Content (TEC) of the ionosphere. TEC is defined as the number of free electrons in a unit cross-sectional area (m^2) along the ray path; the unit of measure for this value is TEC Unit (TECU) where 1 TECU = 1×10^{16} electrons/m^2. To analyze the difference in TEC values between both phases, the TEC observed during the solar minimum phase is compared with that detected during the solar maximum phase. The values are obtained from the GPS Ionospheric Scintillation and TEC Monitor (GISTM) receiver installed at the Wireless and Radio Science (WARAS) Centre of Universiti Tun Hussein Onn Malaysia (UTHM), Johor (1°52' N, 103°06' E). This work focuses on the periods of July 2007–July 2008 [maximum daily sunspot number (SSN) of 36 and monthly SSN of 0.5–10], and of July 2013–July 2014 (maximum daily SSN of 154 and monthly SSN of 36.9–102.8). These periods represent times of low and high solar activity. The daily SSN values are obtained from CDAWeb.

Several studies were conducted previously on this particular subject. Changes in TEC was observed over four seasons during solar maximum (2000–2002) and solar minimum phases (2006–2008) at the low-latitude station Niamey (13°N, 2°E). The study results indicate that TEC is maximizedin the springtime and minimized during winter. Furthermore, the TEC in the solar maximum phase was higher than that in the solar minimum phase [1]. A study was also conducted by using data from another low-latitude station located at Kampala (0.3°N, 32.6°S) during the period of 2010–2011. This period exhibited increased solar activity. The results suggested that the maximum TEC for 2011 is almost 50% higher than that for

2010;thus, TEC is affected by changes in the solar cycle phase [2].

Another study focused on the TEC values obtained from several Ethiopian stations, with latitudes ranging from ~5°N to ~12°N during periods of solar minimum (2009) and solar maximum (2013) [3]. The study results showed that the diurnal peak vertical TEC (VTEC) is observed in equinoctial months, whereas the minimum peak is observed in June (the solstice month). In addition, the maximum and minimum mean hourly VTEC values measured per month are observed in October and July, respectively. Similarly, the maximum and minimum mean hourly VTEC values measured per season are observed during the March equinox and the June solstice, respectively.

1.1 IonosphericTotal Electron Content

The output of the GISTM receiver can provide the TEC values from L1 (1575.42 MHz) and L2 (1227.60 MHz) frequencies. The delay in the signal transmitted from a GPS satellite on L1 and L2 is applied to measure electron content along the propagation path given that such delays are proportionate to one another. Thus, the TEC can be determined as follows with the GISTM receiver [4]:

$$TEC = 9.483\left(PR_{L2} - PR_{L1} - \Delta_{C/A-P,PRN}\right) + TEC_{RX} + TEC_{CAL} \quad (1)$$

where PR_{L2} and PR_{L1} are the pseudoranges (in meters) for L1 and L2, respectively; $\Delta_{C/A-P,PRN}$ is the input bias between satellite C/A- and P-code chip transitions (meters); TEC_{RX} is the TECcaused by the internalreceiver L1/L2 delay (TECU); and TEC_{CAL} is the user defined TEC offset (TECU).

The GISTM receiver also provides the slant TEC (STEC) value, which can be converted to VTEC by assuming a thin-shell model and a horizontally uniform ionosphere as follows [5]:

$$VTEC = STEC\cos(\chi) \quad (2)$$

where $\cos(\chi)$ is the mapping function that is determined by:

$$\cos(\chi) = \sqrt{1 - \left(\frac{R_E}{R_E + h_{pp}}\cos(E)\right)^2} \quad (3)$$

where χ is the satellite zenith angle at the sub-ionospheric pierce point; R_E is the radius of the earth; E is the satellite elevation angle; and h_{pp} is the height of the sub-ionospheric point.

2.0 DATA AND METHODOLOGY

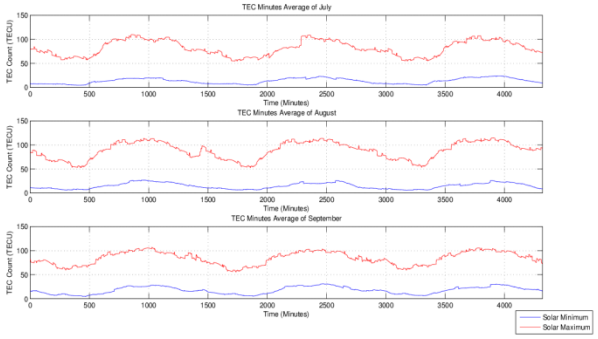
Datafrom the periods of July 2007–July 2008 and July 2013–July 2014 were obtained by the WARAS Centre, UTHM. The period of July 2007–July 2008 represents the solar minimum phase, with a maximum daily SSN of 36. The period of July 2013–July 2014 represents the solar maximum phase, with a maximum daily SSN of 154. The data from November 2007 and November 2013 were excluded due to insufficiency. Moreover, the raw data from the GISTM receiver were converted into text files with Parseismr.exe. Subsequently, the data were filtered by excluding invalid data that did not satisfy certain criteria.

Data were recorded every minute, and several GPS satellites were made available simultaneously. The TEC data from these satellites were then averaged per minute. In addition, the mean daily and monthly TEC values were calculated as well. Due to a lack of data, the daily and monthly mean data exhibited some discontinuity. Therefore, only presented data that were analyzed.

3.0 RESULTS AND DISCUSSION

3.1 Diurnal TEC

Figure 1 shows the diurnal TEC obtained for three days of each observed month. As mentioned in the previous section, data from November 2007 and November 2013 were excluded due to insufficiency. All of the studied data exhibit the same diurnal variations, in which TEC peaked at ~1430 LT for both solar minimum and solar maximum phases. The pattern in TEC value changes is as follows: TEC decreases during midnight and is at its minimum in the early morning. Thereafter, TEC keeps increasing until it is maximized in the afternoon. Then, this value decreases during the evening until midnight. As per the Ethiopian stations, TEC peaked between 13 and 16 LT in both solar minimum and solar maximum [3]. Similarly, according to the Kampala station, the TEC peak ranged from 13 LT to 18 LT [2].The TEC peak in a day is in accordance with the sun being most active during these hours. This increases the ionization, hence the TEC values.



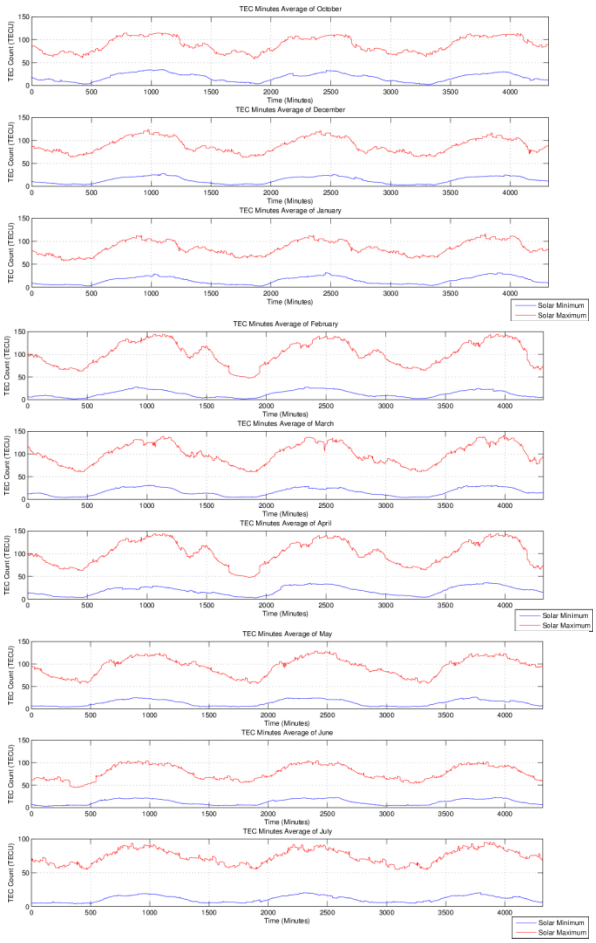


Figure 1 Diurnal TEC for the periods of July 2007–July 2008 and July 2013–July 2014. In each graph, the top plot (red) denotes the solar maximum and the bottom plot (blue) represents the solar minimum. All graphs show only data for three days of each month. The X-axis corresponds to UT in minutes. WARAS Centre is eight hours ahead of UT.

3.2 Daily and Monthly Mean TEC

The differences in TEC between the solar minimum and solar maximum phases are significant. Table 1 presents the minimum and maximum TEC values for each month. The highest TEC that was recorded during the solar maximum phase was 144.5 TECU in April 2014, whereas the highest TEC that was recorded during the solar minimum phase was only 36.3 TECU in April 2008. Overall, the differences between solar minimum and solar maximum phases werefrom 89% to 97% (for minimum TEC), and from 70% to 81% (for maximum TEC).Daily SSN was maximized at 36 in March 2008 in the solar minimum phase and at 154 in February 2014 in the solar maximum phase (Figure 2 and 3).

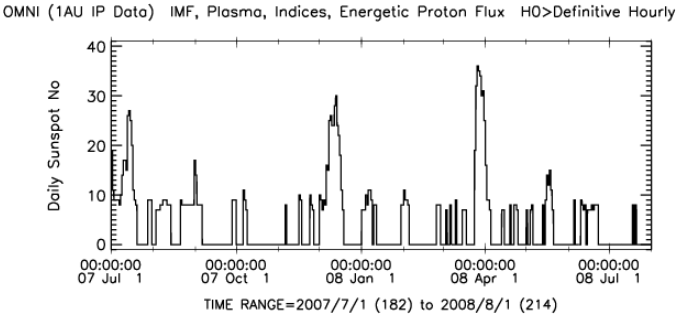


Figure 2 Daily SSN from July 2007 to July 2008 as per CDAWeb

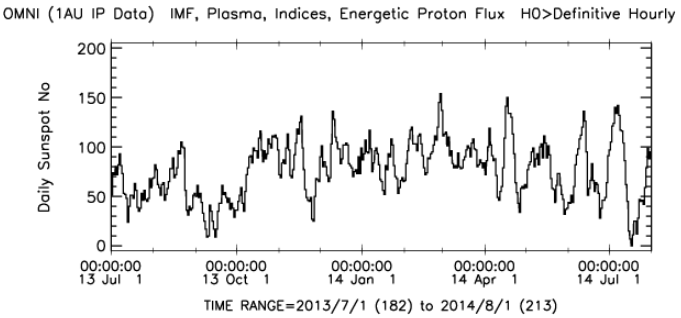


Figure 3 Daily SSN from July 2013 to July 2014 as per CDAWeb

Figure 4 depicts the daily mean TEC for both solar minimum and solar maximum phases. TEC increases with an increase in SSN during the same observation period. The lowest TEC in the solar minimum phase was 3.7 TECU (in January 2008), whereas the highest was 22.9 TECU (in March 2008). The values increased to 70.6 TECU (in October 2013) and 112.5 TECU (in May 2014) during the solar maximum phase. The maximum daily TEC recorded for 2010 was 24 TECU, whereas that for 2011 was 37 TECU. This increase in value is attributed to the fact that the SSN in 2011 is higher than that in 2010 [2].

Table 1 Minimum and maximum TEC recorded for each month under both solar minimum and maximum phases. Monthly SSN was also provided for all observed months in both phases.

Month	Solar Minimum			Solar Maximum		
	Monthly SSN	Min. TEC (TECU)	Max. TEC (TECU)	Monthly SSN	Min. TEC (TECU)	Max. TEC (TECU)
Jul	10.0	4.4	24.1	57.0	54.9	110.0
Aug	6.2	5.8	27.0	66.0	52.6	114.6
Sep	2.4	4.4	30.8	36.9	55.7	106.9
Oct	0.9	1.9	34.8	85.6	57.4	114.4
Nov	1.7	-	-	77.6	-	-
Dec	10.1	2.8	27.4	90.3	63.3	123.9
Jan	3.4	2.4	31.4	82.0	57.9	116.0
Feb	2.1	1.5	28.0	102.8	55.5	132.5
Mar	9.3	4.0	31.4	92.2	60.3	141.1
Apr	2.9	2.9	36.3	84.7	47.4	144.5
May	2.9	4.3	26.0	75.2	56.5	128.9
Jun	3.1	3.0	22.6	71.0	45.3	104.7
Jul	0.5	3.7	21.4	72.5	54.6	95.3

The maximum daily mean TEC values recorded in this study were 97 and 112.5 TECU for 2013 and 2014, respectively. SSN also increased from 2013 to early 2014; thereafter, this number decreased slightly (refer Table 1). However, in mid-2014, the SSN is starting to decrease, causing the TEC to decrease too. This shows that TEC is dependent on the solar activity. Moreover, the maximum TEC values for 2013 and 2014 were higher than those for 2010 and 2011 in [2] given that 2013–2014 represented a period of increased solar activity.

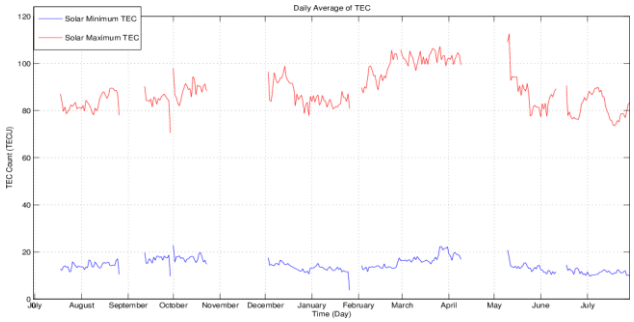


Figure 4 Daily mean TEC values for the solar minimum (blue line) and solar maximum (red line) phases. Only available data for both phases are considered

The monthly mean TEC values for both phases are shown in Figure 5. TEC peaks at around February 2014–May 2014 during the solar maximum phase. Furthermore, the monthly SSN for February 2014 is 102.8, which is the highest among those measured during the 13 months of observation under the solar maximum phase. The monthly SSNs for March 2014, April 2014, and May 2014, are 92.2, 84.7, and 75.2, respectively. A similar pattern is observed under the solar minimum phase but with significantly lower TEC values. Thus, the observed increase in TEC indicates its dependency on solar activity.

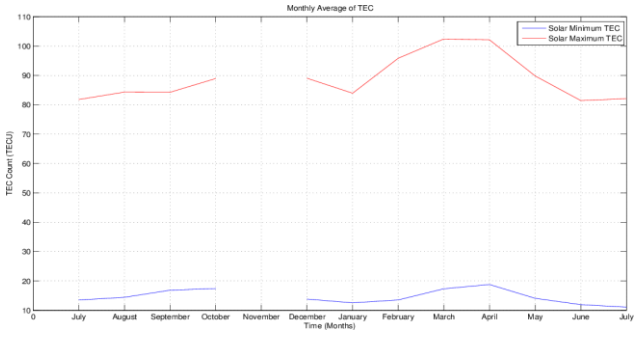


Figure 5 Monthly mean TEC values for the solar minimum (blue line) and solar maximum (red line) phases. Only available data for both phases are considered

Table 2 summarizes the daily and monthly mean TEC values. The results indicate that the TEC value during the solar maximum phase was approximately 84% higher than that during the solar minimum phase. Nonetheless, both daily and monthly TEC values do not differ significantly in both phases. The mean daily and monthly TEC values for the solar minimum and solar maximum phases were ~14 and ~88 TECU, respectively.

Table 2 Daily and monthly mean TEC values for both solar minimum and maximum phases

Mean TEC	Daily Mean	Monthly Mean
Solar Minimum Mean TEC (TECU)	14.4	14.6
Solar Maximum Mean TEC (TECU)	88.6	88.8
Difference in Mean TEC (%)	84%	84%

4.0 CONCLUSION

This study shows that the TEC recorded during the solar maximum phase was considerably higher than thatmeasured during the solar minimum phase. The minimum TEC values between both phases varied between 89% and 97%, and the maximum values varied between 70% and 81%. The pattern in daily TEC value changes was almost constant; TEC decreased during midnight and was minimized at 7 LT. The value then increased until it was maximized in theafternoon at approximately 14 LT. Subsequently, TEC value decreased until midnight. This is consistent with the activity of the sun in a day. The highest recorded TEC during the solar maximum phase was 144.5 TECU in April 2014, whereas the highest recorded TEC during the solar minimum phase was 36.3 TECU in April 2008. Finally, TEC was maximizedfrom March to May for both solar maximum and minimum phases. The TEC values are very much dependent on the solar activity. The values increase during the period of high solar activity, and decrease during low solar activity.

Acknowledgement

The authors acknowledge the WARAS Centre, UTHM for providing the GPS data. We are also grateful to the data providers J. H. King, N. Papatashvilli, at ADNET, NASA GSFC and CDAWeb for the SSN data. This work is funded by the Ministry of Higher Education Malaysia under FRGS Vot 1233.

References

[1] Christian, Z. et al. 2013. CODG TEC Variation During Solar Maximum and Solar Minimum Over Niamey. *European Scientific Journal.* 27(9): 74-80.

[2] Oron, S., D'ujanga, F. M. and Ssenyonga, T. J. 2013. Ionospheric TEC Variations During the Ascending Solar Activity Phase at an Equatorial Station, Uganda. *Indian Journal of Radio & Space Physics.* 42: 7–17.

[3] Asmare, Y., Kassa, T. and Nigussie, M. 2014. Validation of IRI-2012 TEC Model Over Ethiopia During Solar Minimum (2009) And Solar Maximum (2013) Phases. *Advances in Space Research.* 53(11): 1582–1594.

[4] GSV GPS Silicon Valley. 2007. *GSV4004B GPS Ionospheric Scintillation & TEC Monitor (GISTM) User's Manual*.

[5] Nava, B., Radicella, S. M., Leitinger, R. And Coisson, P. 2007. Use of Total Electron Content Data to Analyze Ionosphere Electron Density Gradients. *J. Adv. Space Res.* 39(8): 1292–1297.