Published by
NIGERIAN SOCIETY OF PHYSICAL SCIENCES
Available online @ https://journal.nsps.org.ng/index.php/jnsps

J. Nig. Soc. Phys. Sci. 2 (2020) 77–90

Journal of the Nigerian Society of Physical Sciences

Original Research

Inter-Hemispheric Comparison of Ionospheric TEC Variation at Each Latitudinal Band During Quiet Geomagnetic Condition

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Abstract

This paper compares the quiet time variation of the Total Electron Content (TEC) over four stations located at high and mid latitudes in the northern and southern hemispheres of the African-European longitudes. Five years Global Positioning System (GPS) data, from 2002 to 2006, representing the periods of high to low solar activities were used for the study. Generally, the maximum diurnal values of TEC are observed between 10:00 – 14:00 LT in all the stations during the periods investigated. The minimum values of TEC are observed during the pre-sunrise hours for the two mid latitude stations and around the pre-midnight/post-midnight for the high latitude stations. The maximum values of TEC, however vary with season, latitude and solar activity in all the stations. The values decrease with increase in latitudes and decrease in solar activity. The values range between 10 – 32 and 11 – 50 TECU respectively, for high and mid latitudes for all the years considered. Seasonally, the highest values of TEC are generally observed during the equinoxes in all the stations except at the southern mid latitude station where it can as well be observed in summer, particularly during the Moderate Solar Activity (MSA) and Low Solar Activity (LSA) periods. The lowest values of TEC are observed in winter in all the stations in the southern hemisphere and can be observed in both winter and summer for stations in the northern hemisphere depending on the latitude and solar activity period. TEC variation also exhibits (1) asymmetry in the equinoctial values in all the stations and the magnitude is most pronounced during the period of High Solar Activity (HSA); (2) winter ionosphere anomaly feature, observed only in the northern hemisphere stations; and (3) daytime minimum and nighttime maximum in the diurnal structures of TEC at high latitude in the northern hemisphere during the winter. The nighttime maximum value was observed around 21:00 LT with magnitude that decreases with decrease in solar activity. The annual maximum value of TEC decreases with solar activity at all the stations, with the highest/lowest peak observed in HSA/LSA periods.

Keywords: TEC, Solar activity, Winter anomaly, Equinoctial asymmetry

Article History :
Received: *01 December 2019*
Received in revised form: *07 April 2020*
Accepted for publication: *11 April 2020*
Published: *14 May 2020*

Communicated by: O. J. Abimbola

1. Introduction

For a reliable ionosphere forecast, the ionosphere morphology during different space weather conditions must be well understood. The Global Positioning System (GPS) technology has made the estimation of the total electron content (TEC) possible and has offered a convenient means to monitor the ionosphere and its dynamics. Scientific investigations of the ionosphere dynamics at different locations during quiet geomagnetic conditions have been extensive e.g., [1-14]. Result from these studies have shown that TEC variation depends on many factors such as the time of the day, the seasons of the year, solar activity, latitude and so on. In terms of the geomagnetic coor-

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dinate, the ionosphere can be classified into three latitudinal bands, namely: the equatorial and low (0° ± 30°), the middle (±30° − 60°) and the high (±60° − 90°) latitudes. Apart from the equatorial and low latitude region, which play host to several ionosphere anomalies, the high latitude ionosphere also play host to several features such that the different current systems which influence the magnetic activity of the region that make the region quite complicated. Thus, simultaneous investigation of the ionospheric variation of these latitudinal bands in both hemispheres under the same external conditions may reveal the uniqueness of the plasma dynamics of each region. Although, a number of quiet time investigation of ionosphere variation has been carried out, particularly over the individual receiving stations, however, comparative studies of quiet time ionosphere variation can provide relevant information that serve as a baseline to the understanding of the thermosphere-ionosphere-plasmasphere coupling at individual stations or region during disturbed conditions.

This study aimed at comparing the quiet time variation of TEC at four stations in the African-European longitude. Two located in at the high and mid latitudes in the northern and southern hemispheres. The station used are located at mid and high latitudes in each hemisphere. Five years' data, spanning from 2002 to 2006, representing the periods of high to and low solar activities were used to study the diurnal monthly, seasonal and year-to-year variations of TEC at the two latitudinal bands in both hemispheres.

2. Data and method of analysis

The diurnal monthly averaged values of vertical TEC (TEC_v) used for the study are derived from the GPS measurements of five quietest days (based on the classification of the Helmholtz Centre Potsdam, GFZ German Research Centre for Geoscience, available at http://www.gfz-potsdam.de/en/section/earths-magnetic-field/data-products-services/kp-index/qd-days/) of each month of the years under investigation. The GPS data were obtained from the International GNSS Service (IGS) database available at ftp://garner.ucsd.edu. The GPS data are those from four receivers that are located at mid and high latitudes of the two hemispheres in the Afro-European sector as shown in Fig. 1. The geographic and geomagnetic coordinates of the locations of the GPS receivers are listed in Table 1. Five years GPS data, representing the periods of HSA (2002), MSA (2003, 2004) and LSA (2005, 2006), are used for the study. During these periods, the annual average value of the solar flux at 10.7 *cm* (F10.7 index) decreases from 179 *sfu* in 20002 to 80 *sfu* in 2006, while the Sunspot Number (Rz) also decreases from 104 to 15 as shown in Table 2. The values of TEC_v over each station were estimated from the GPS data based on equation 1 using the GPS software code developed by G. K. Seemala of the India Institute of Geomagnetism. The software automatically estimates the relative slant TEC (TEC_s) from the GPS Receiver INdependent EXchange (RINEX) files (i.e. raw GPS observable files), removes the instrumental biases from the relative STEC (known as calibrated TEC_s) and converts the calibrated TEC_s to TEC_v. The relative slant TEC is the integral of the electron density in a column of 1 m^2 along the receiver-satellite path. In practice, the relative STEC is determined from the combination of both the carrier phase and pseudo range measurements of the GPS observations. In this study, only the GPS measurements from satellite passes with elevation angle greater than 50° were considered to minimize the multipath effects. In order to calibrate the relative TEC_s, the satellite bias was removed using the code files published by the Center for Orbit Determination in Europe (CODE) which are available at ftp://ftp.unibe.ch/aiub/CODE/, while the receiver bias was determined from the diurnal value of TEC (value between 03:00 - 06:00 LT) that minimizes the effects of ionosphere variation. The 03:00 - 06:00 LT window used in the calibration of TEC has been shown by [15] over the equatorial region as the time when the spatial gradients are minimal and also the period when the receiver bias estimate is insensitive to the assumed centroid height used in the single-layer approximation of the ionosphere.

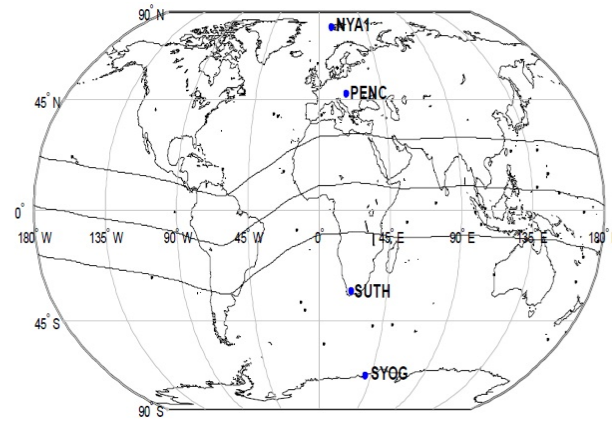

Figure 1. World map showing the locations of the GPS receivers.

$$TEC_v = [TEC_r - A(b_r + b_s)] / S(\epsilon) \tag{1}$$

where TEC_r is the Leveled carrier phase measurement of TEC, b_r and b_s are respectively receiver and satellite biases, A has a value of 2.854 $TECU/ns$ and $S(\epsilon)$ is defined by the mapping function given in equation 2

$$S(\epsilon) = \left[1 - \left(\frac{R\cos\epsilon}{R+h}\right)^2\right]^{-1/2} \tag{2}$$

where R is the radius of the earth, ϵ is the elevation angle and h is the Ionospheric Piercing Point (IPP) height. In this study, an IPP height of 350 *km* and elevation cut-off angle of 50° were assumed. The choice of using an IPP of 350 *km* in the conversion algorithm was based on the investigation by [16]. They reported that an IPP of 350 *km* is valid over the Indian equatorial and low latitude stations provided that the elevation mask angle of the satellite passes is ≥ 50°. The diurnal values of TEC_v over the station were obtained by subjecting the data to a two-sigma (2σ) iteration in order to remove the outliers. The software writes the estimated TEC in ASCII format where the hourly values of TEC_v are computed. The seasonal values of TEC are determined from the averaged of the monthly value

Table 1. IGS stations used in the study with their geophysical details.

Location	Country	Station ID	Geographic Lat.	Geographic Long.	Geomagnetic Lat.	Geomagnetic Long.
Ny Alesund	Norway	nya1	78.93	11.87	75.6	11.87
Penc	Hungary	penc	47.79	19.28	46.4	102.17
East Ongle Island	Antarctica	syog	-69.01	39.58	-70.27	83.76
Sutherland	South Africa	suth	-32.38	20.81	-32.19	86.72

Table 2. The periods investigated together with the annual average values of F10.7 index and sunspot number (SSN).

Year	F10.7 (sfu)	SSN	Solar Activity period
2002	179	104	High
2003	128	64	Moderate
2004	109	40	Moderate
2005	92	30	Low
2006	80	15	Low

of TEC by dividing the year into four seasons. The seasons are: February, March and April to represent the March equinox (MEQU) value, May, June and July as June solstice (JSOL), August, September and October as September equinox (SEQU) and November, December and January as December Solstice (DSOL).

3. Results

3.1. Diurnal variation of TEC over the entire stations

Figs. 2 and 3 show the respective monthly diurnal variation of TEC over the high and mid latitude stations in both hemispheres for all the years considered. The result obtained shows that TEC increases from nighttime minimum values to daytime maximum values and then decrease after the sunset over the entire stations in all the years considered. The magnitude of the daytime maximum value of TEC, however, varies with latitude and solar activity.

At NYA1 (northern high latitude station), no regular pattern in TEC variation is observed i. e. a number of peaks and troughs were observed as shown in Fig. 2 (a) – (e). Also, the differences between the daytime and nighttime values of TEC are less significant at NYA1 compared to the values at SYOG (southern high latitude station) where significant differences were observed. The maximum values of TEC are observed around the pre-noon (between 1000 LT and 1100 LT) period at NYA1, while at SYOG, it observed at noon period. The annual average value of the diurnal monthly value ranges between (10 – 17) TECU at NYA1 and (13 – 32) TECU at SYOG for all the years considered. Also, the minimum values are observed around the post-midnight hours (between 0000 LT and 0300 LT) at NYA1 while it is observed around the pre-midnight hour (between 2200 LT and 0000 LT) regardless of the months and years considered. Also from Fig. 2, the rate of production and decay of TEC are observed to be steeper at SYOG than at NYA1 for all the years considered. This indicates that the rate of production and loss of ionization is faster at SYOG than at NYA1.

At the mid stations, the trend of diurnal TEC variation is identical in all the years considered as shown in Fig. 3. However, the magnitude of the diurnal maximum values of TEC and its periods of occurrence differs. At PENC (northern hemisphere station), the maximum values of TEC are observed around the pre-noon period (between 10:00 LT and 12:00 LT) with values between 11 and 40 TECU, while at SUTH (southern hemisphere station) it is observed round noon with values between 16 and 50 TECU in all the years investigated.

3.2. Seasonal variation of TEC over the two high latitude stations

Fig. 4 shows the seasonal variation of TEC over the two high latitude stations. The result obtained shows that the diurnal maximum values of TEC vary with season. At NYA1, the highest diurnal values of TEC are generally observed during the equinoxes while the lowest is observed in winter (DSOL) regardless of the solar activity period. The bar chart in Fig. 5 shows the frequency of occurrence of the diurnal maximum values of TEC (in percentage) in all the stations at different seasons. The classifications according to the period of the day are: the pre-noon period (06:00 – 11:00) LT; the noon period (12:00) LT; the post-noon period (13:00 – 17:00) LT; the pre-midnight period (18:00 – 23:00) LT and the post-midnight (01:00 – 05:00) LT periods. From the plots, the diurnal maximum values of TEC are majorly observed at the pre-noon hours in equinoxes and summer (JSOL), while in winter, it is majorly observed at pre-midnight hours as shown in Fig. **??**(a). Also, TEC value in MEQU is generally higher than the values in SEQU, indicating asymmetry in TEC variation during the equinoxes in most of the years at NYA1. The magnitude of this equinoctial asymmetry is observed to be most significant during the period of HSA. In addition, at NYA1, TEC value in winter is higher than the summer value around the pre-midnight hours during the periods of HSA and MSA and it most pronounced during the period of HSA. Also, TEC value during the nighttime is higher than the daytime value in winter at NYA1. During these periods, the values of TEC are observed to increase immediately after the sunset (around 17:00 LT), peaked around 21:00 LT and then decrease thereafter. This nighttime enhancement in the value of TEC is observed to decrease with decreasing solar activity and is less significant in 2006.

At SYOG, the highest diurnal values of TEC are observed in equinoxes and lowest in winter for all the years as shown in Figs. 4(f) – (j). Also, the daytime maximum values are majorly observed at noon period during the equinoxes, at the pre-noon hour in summer (against the pre-midnight period in NYA1) and can either be observed at the pre-noon or the noon hours in winter for all the years. TEC variation also exhibits equinoctial asymmetry for all the years considered, however, TEC in summer was higher than in winter indicating the absence of winter ionosphere anomaly at SYOG.

3.3. *Seasonal variation of TEC over the two mid latitude stations*

Fig. 6 shows the seasonal variation of TEC variation over the two mid latitude stations. There are no GPS observations at PENC for the year 2005; therefore, its seasonal variation cannot be determined. At PENC, the highest diurnal value of TEC is observed in March equinox in most of the years except in the year 2006 when it was observed in summer (JSOL) as shown in Figs. 6(e). The lowest values of TEC are observed in summer during the periods of HSA and in winter (DSOL) during the periods of MSA and LSA. Also, the value of TEC in winter is considerably higher than the summer value during the period of HSA, indicating the winter anomaly feature. The strength of the anomaly in the year 2003 appears to be less significant compared to that of 2002. Also, the diurnal maximum values of TEC were majorly observed at the pre-noon hours irrespective of the season and solar activity period.

At SUTH, the highest values of TEC were observed in March equinox (in 2002, 2004 and 2005) and in summer (DSOL) (in 2003 and 2006), while the lowest daytime values are observed in winter (JSOL) in all the years as shown in Figs. 6(f) – (j). The values of TEC in summer are generally higher than the winter values, indicating the absence of winter anomaly feature over the station. The values of TEC during the March equinox are also higher than the September equinox values in all the years. In equinoxes and winter, the diurnal maximum values of TEC are majorly observed at noon, while in summer it can either be observed in the pre-noon hours, especially during the period of HSA, or at noon hour as shown in Fig. 5(d).

3.4. *General observations and comparison with previous studies*

Generally, the diurnal value of TEC in all the stations vary significantly with season, latitude, and solar activity. The seasonal change in the values of TEC is more pronounced during the daytime than at nighttime in all the stations except at NYA1, where TEC vary significantly at nighttime during the winter. The seasonal variation of TEC variation shows notable similarities as well as asymmetries in the northern and southern hemispheres. TEC values during the equinoxes shows a notable asymmetry over the entire stations for all the years investigated. The TEC values during the MEQU are generally higher than the value during the SEQU. The magnitude of the equinoctial asymmetry is most pronounced during the period of HSA. [17] had earlier reported this feature (equinoctial asymmetry) over some mid latitude stations in both hemispheres and reported a higher value of TEC in spring than that in autumn during period of HSA. Also, [18] reported an increase in equinoctial asymmetry in all latitudes with an increase in solar activity. Our result agrees with the results of these previous investigations.

Also, the diurnal seasonal variation of TEC shows that the value of TEC in winter is higher than the values in summer at the northern hemisphere stations only, thus showing winter ionosphere anomaly. The appearance of this winter anomaly feature at the northern hemisphere depends on the solar activity and latitude. It is observed over the high latitude station during the period of HSA and MSA and over the mid latitude station during the HSA. The winter anomaly is most pronounced during the period of HSA. This result is consistent with the results by [19, 20, 21]. On the other hand, the TEC variation over the southern hemisphere stations did not show the winter anomaly effect at any latitude in all the years of study. This shows a notable asymmetry in the seasonal variation of TEC between the northern and southern hemispheres. This result also agrees with the result shown by [19] and also recent studies by [21, 22, 23]. [19] had earlier reported that winter anomaly is more pronounced during the high solar activity and in the northern hemisphere, than in low solar activity and the southern hemisphere. [22] have observed winter anomaly over a mid-latitude station in the northern hemisphere while it was completely absent in the mid latitude of the southern hemisphere. [23] using data from China, South-East Asian and Australian network stations reported that the winter anomaly effect is not seen in the southern crest-to-trough TEC ratio but appeared in the north.

3.5. *Yearly variation of TEC over the entire stations*

Fig. 7 shows the diurnal annual average plot of TEC over the entire stations during the years under investigation. The level of solar activities for each of the years investigated are indicated with the annual average values of F10.7 and SSN indices in the upper panels. From the plots, the annual peak in TEC value decreases as the solar indices decrease, thus, indicating a linear relationship between TEC and solar activity. This is true for all the stations investigated. Also, it is observed that the annual peak in TEC value decreases with increase in latitude. Table 3 shows the annual averaged values of the solar indices and the corresponding annual maximum values of TEC for each year investigated. The maximum value of TEC is observed in 2002 (when the mean F10.7 = 179 sfu and SSN = 104) and the minimum in 2006 (when the mean F10.7 = 80 sfu and SSN = 15) in in all the stations.

Table 3. Annual peak values of TEC (in TECU) in all the stations during the years investigated.

	2002	2003	2004	2005	2006
nya1	17	12	10	9	8
penc	40	22	16		11
syog	32	22	17	16	14
suth	50	32	24	21	16

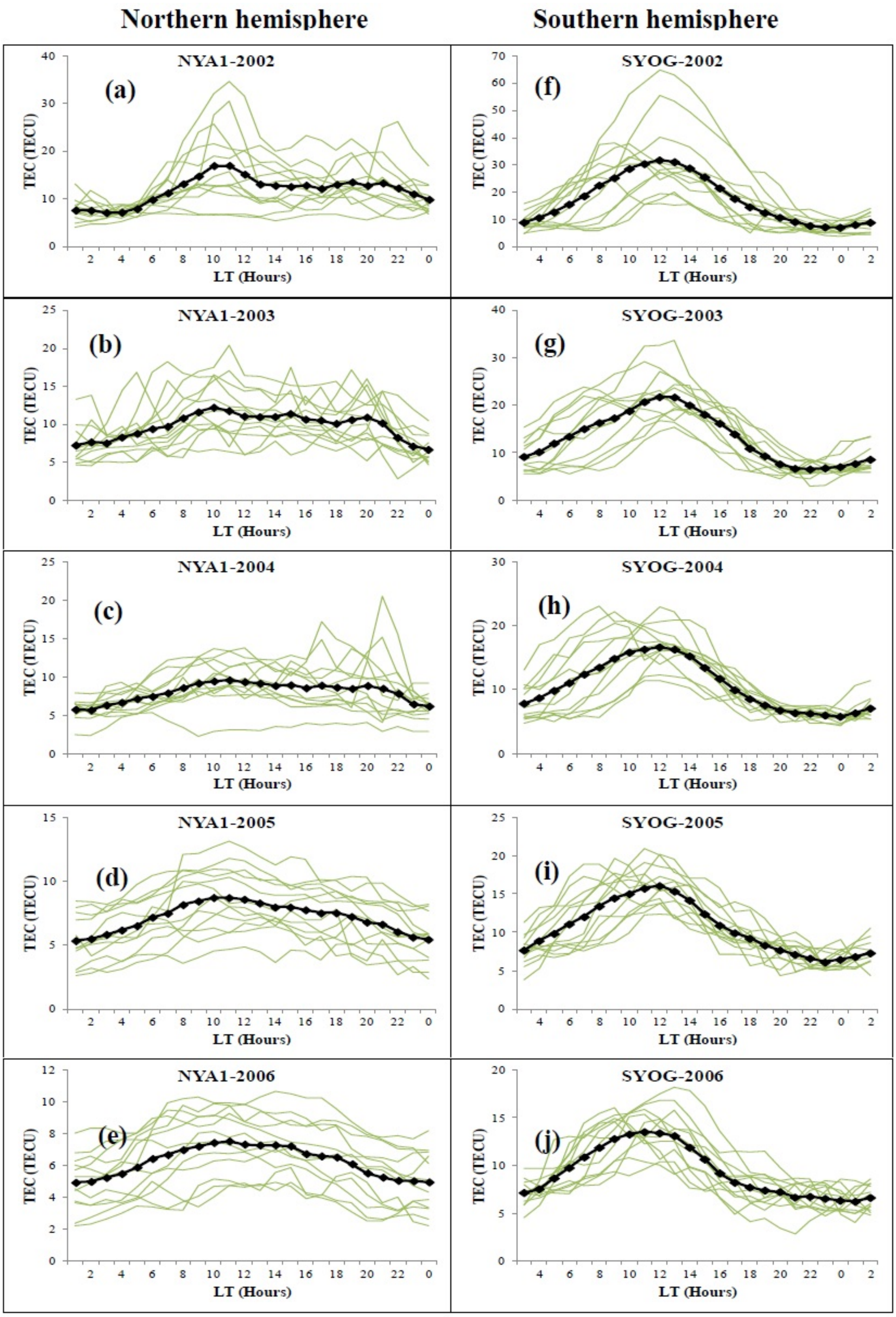

Figure 2. The monthly variation of TEC for the entire years considered at two high latitude stations in the northern [(a) – (e)] and southern [(f) – (j)] hemispheres. The solid line with line marker indicates the average monthly variation in each year.

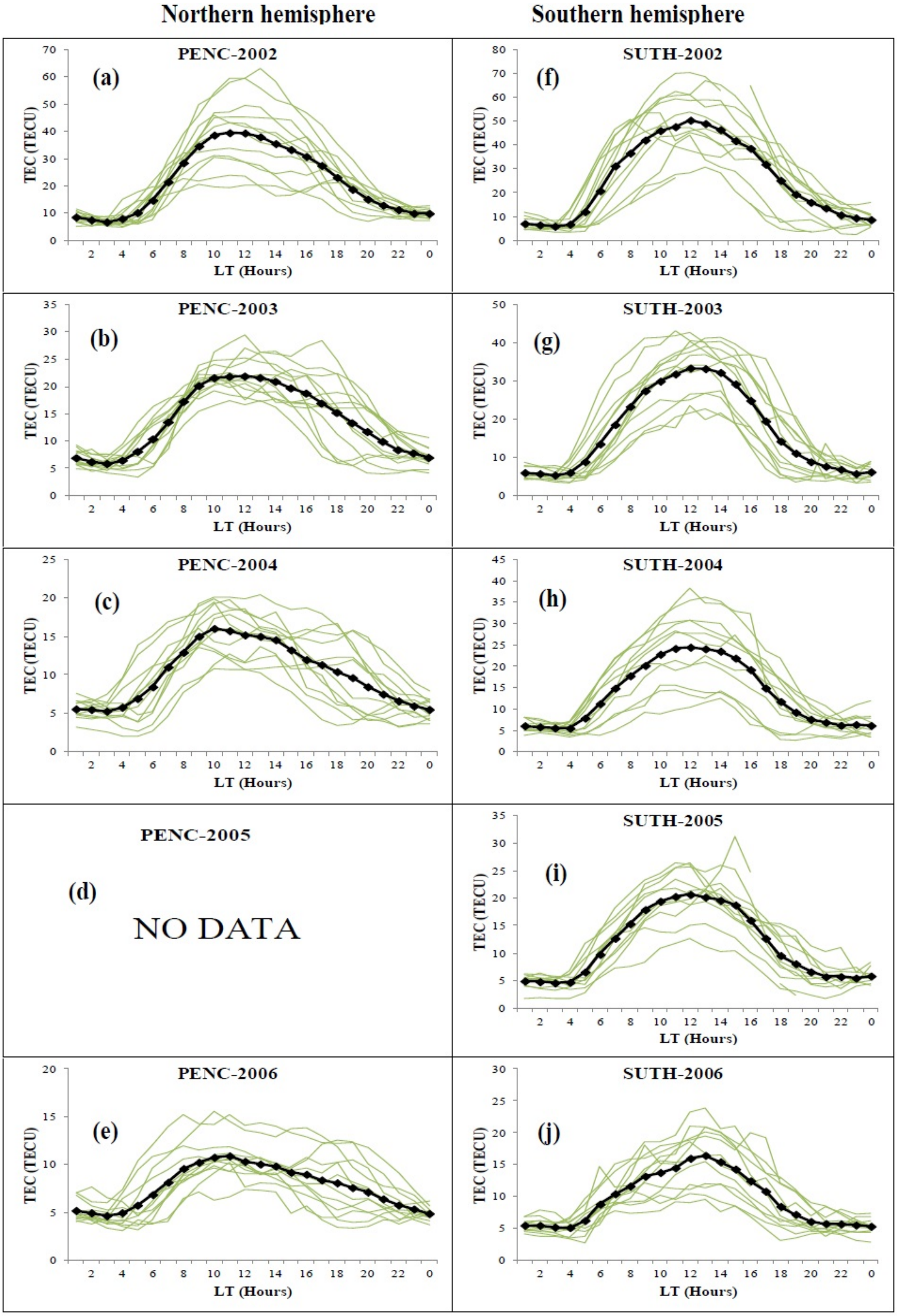

Figure 3. Same as in Fig. 2 but for the two mid latitude stations.

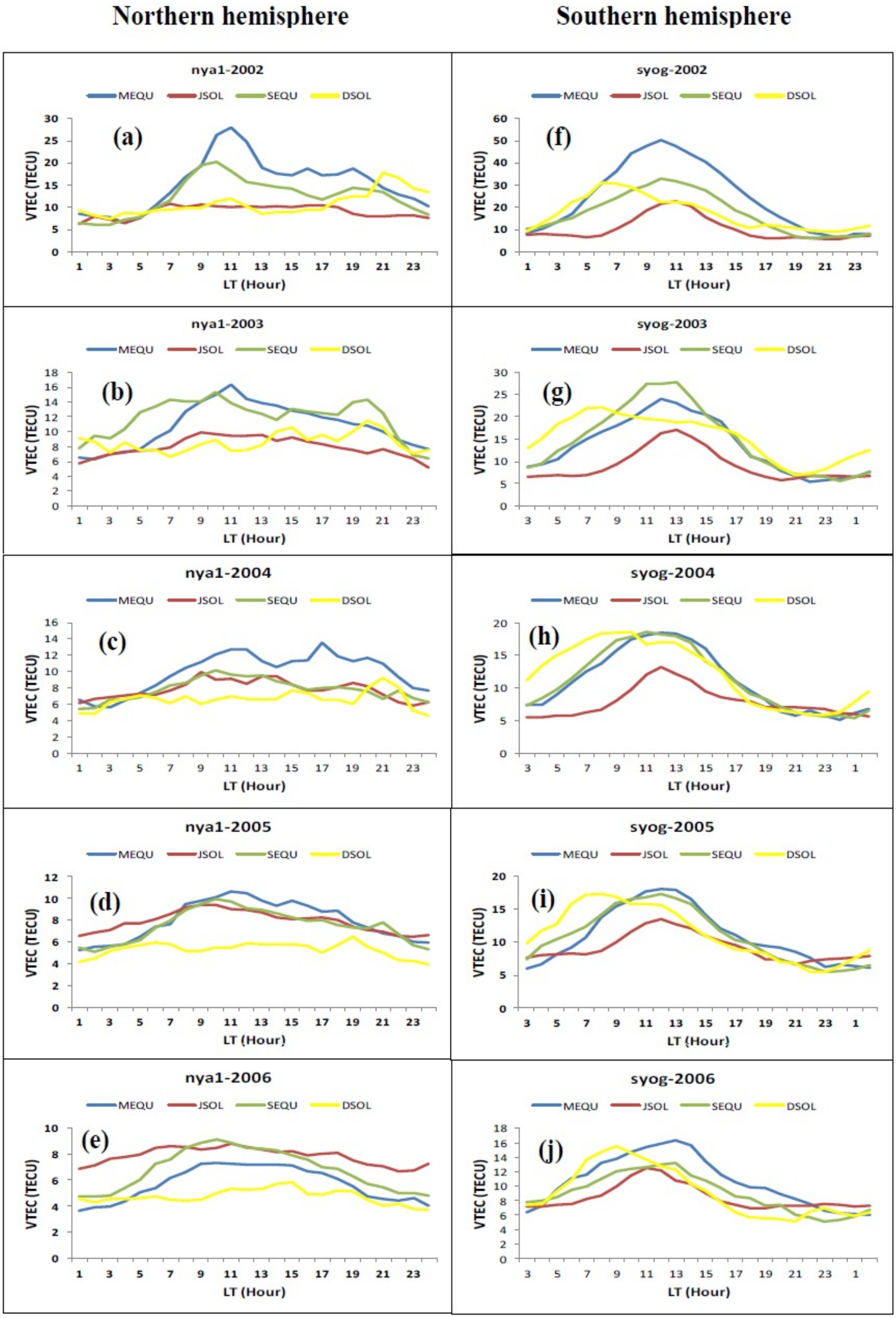

Figure 4. Seasonal variation of TEC at two high latitude stations in the northern [(a) – (e)] and southern [(f) – (j)] hemispheres for the all the years considered.

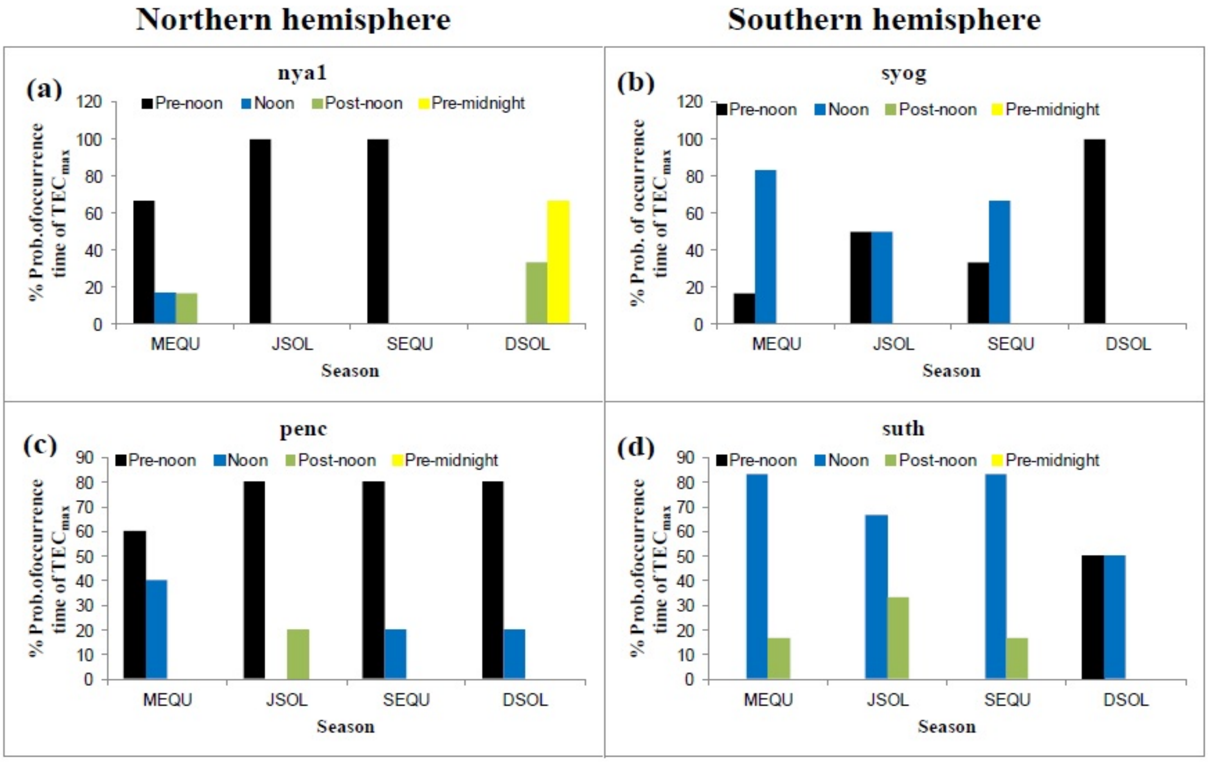

Figure 5. The bar chart showing the frequency of occurrence of the daytime maximum value of TEC (expressed in percentage) in all the stations at different seasons.

4. Discussion

Results obtained from this study have shown that the quiet time values of TEC vary significantly with latitude, season and solar activity. Factors such as solar EUV flux, electric fields and changes in thermospheric conditions have been shown by many authors as the controlling mechanisms responsible for the quiet time variation of TEC [1, 2, 4, 13, 24]. The diurnal variation of TEC can be attributed to the effect of the rotation of the Earth about its axis causing variation in the solar zenith angle and hence variation in the intensity of solar radiation over a location. It is well known that the level of ionization in the ionosphere depends on solar radiation. Solar radiation increases from sunrise up to maximum around the noon period and then decrease thereafter. Thus, the diurnal values of TEC are higher during the daytime compared to the nighttime values since the ionization source is absent at nighttime. We observed a number of peaks and troughs in the diurnal structure of TEC at the northern high latitude stations. This may be attributed to the effect of magnetospheric activity or other high latitude current systems on the high latitude ionosphere as reported by [25]. Magnetospheric activity has reported to vary continuously and may affect the electron variation at the lower latitudes in the near-magnetic pole [21, 26]. In addition, collisional ionization caused by soft electron precipitation has been reported by [27] and [28] as a possible source of ionosphere variation at high latitudes.

Further, the latitudinal and solar activity dependence of TEC variation can be explained in terms of the differences in the amount of solar insolation. It is well known that solar insolation is high at lower latitudes (due to the position of the subsolar point) and low at the high latitudes (due to the obliquity of the solar ray). Consequently, region located around the lower latitudes, where solar insolation is higher compared to the polar region, may experience high level of ionization [29]. Thus, this may account for the high TEC values observed at the two mid-latitudes. Since the magnitude of solar flux is high/low during the period of HSA/LSA, this may also account for high/low values of TEC observed during the period of HSA/LSA in all the stations.

The seasonal characteristics of TEC observed in this study can be explained in term of seasonal changes in the location of the subsolar point, thermospheric wind and neutral composition [18, 21, 30]. Seasonal oscillation of the sub-solar point between the Tropic of cancer and the Tropic of Capricorn, due to the revolution of the earth round the sun, brings about seasonal differences in the amount of solar radiation received at different locations. Hence, this results to a seasonal pattern that are opposite in both hemispheres. Consequently, this may produce a substantial variation in TEC variation at different locations depending on the prevailing season. The amount of solar radiation received in summer is higher than one receiver in winter. As expected, this may explain the high values of TEC observed in summer, particularly in the southern hemisphere where the diurnal seasonal values of TEC observed in summer is generally higher than the winter values in all the solar activity periods; and also in the northern hemisphere during

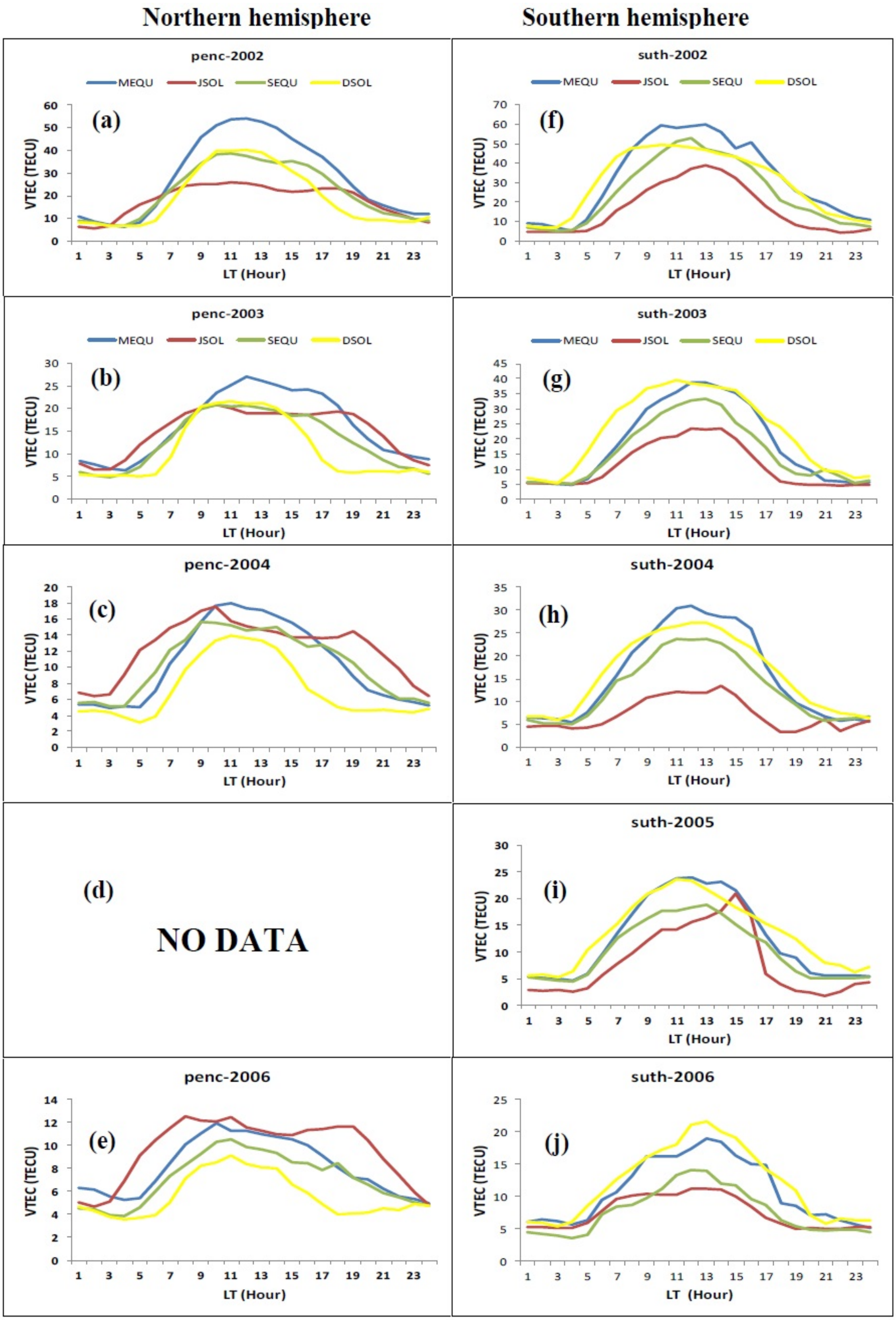

Figure 6. Same as in Fig. 4 but for Mid latitude stations.

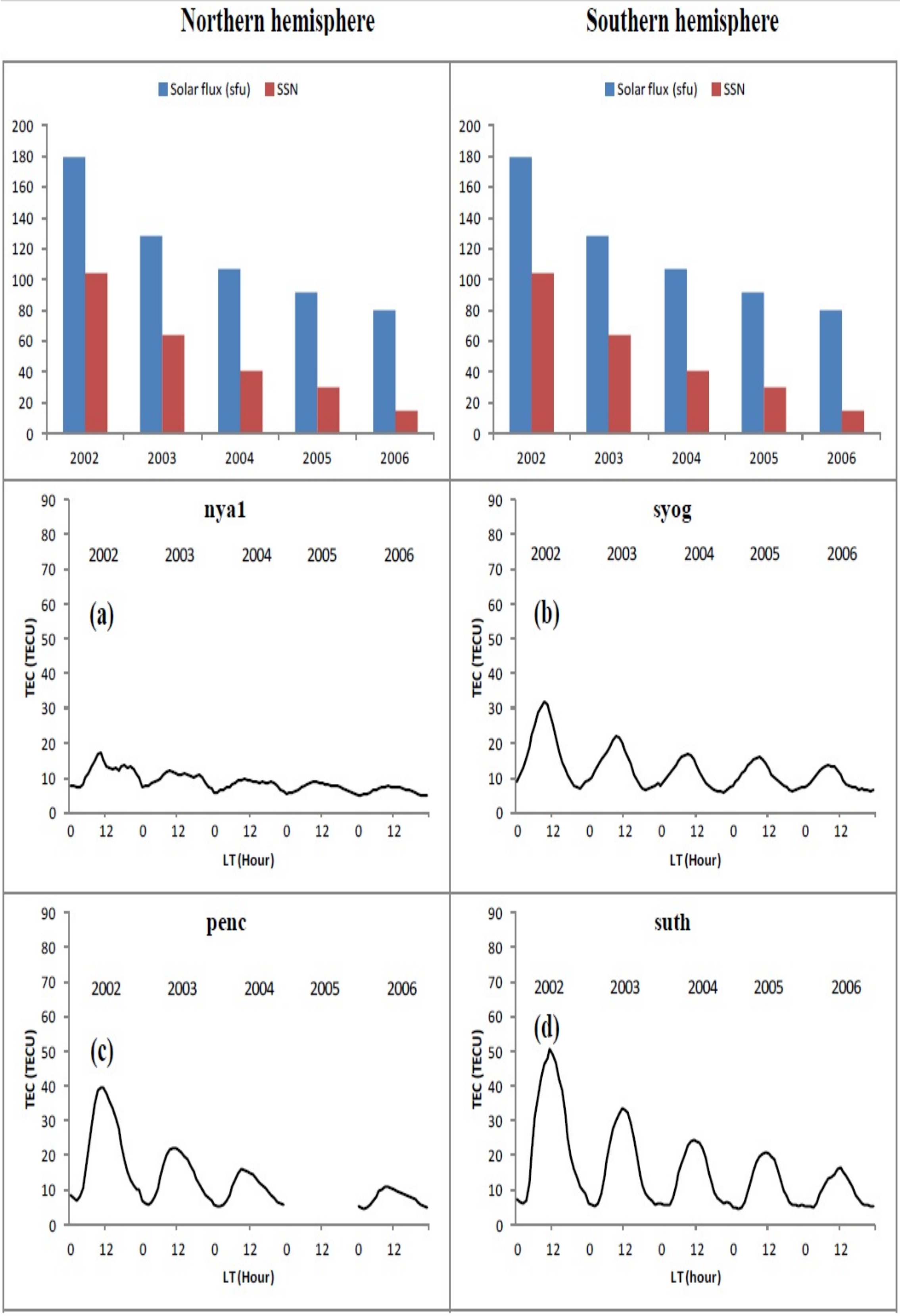

Figure 7. Diurnal annual average of TEC at (a) nya1 (b) syog (c) penc (d) suth from the year 2002 to 2006. The plots in the upper panel show the corresponding annual average variation of two solar indices (i.e. F10.7 index and SSN) during the same period.

the years of MSA and LSA. On the hand, we also observed that the values of TEC in winter are higher than the summer values over the northern hemisphere stations. This TEC winter anomaly feature observed in the northern hemisphere can be attributed to changes in thermospheric O/N_2 density ratio [21, 25, 31]. It is well known that the major atmospheric neutral gas components at the heights of the ionosphere F layer are the atomic Oxygen (O) and molecular Nitrogen (N_2). According to [32], the atomic oxygen is the main source of electron production while molecular Nitrogen is the primary source of recombination. Therefore, the amount of electrons present in the ionosphere may depend on the thermospheric $[O/N_2]$ density ratio. Seasonal variation of the density ratio may affect the ionosphere electron content at different seasons of the year. This had been validated by many researchers using either the modeled or experimental data e.g., [21, 25, 31]. [21] using data obtained from NRLMSISE-00 atmospheric model reported that the TEC winter anomaly in the European-African region is well correlated with $[O/N_2]$ ratio. [31] used the O/N_2 density ratio obtained by the TIMED/GUVI satellite to examine the possible driving mechanism responsible for winter anomaly. They observed a higher O/N_2 density ratio in winter than in summer during the period of high solar activity. [25] also suggested that the O/N_2 density ratio is enhanced by thermospheric circulation in the winter hemisphere. On the hand, higher rate of electron recombination in northern summer (due to solar heating) than winter has also been reported by [21] as a possible mechanism responsible for the generation of the winter anomaly feature at low latitudes. However, the absence of the winter anomaly feature in the southern hemisphere may suggest either a lower O/N_2 ratio in winter than in summer or lower recombination rate in summer compared to winter. Further studies are needed in this direction to establish the exact cause. Also, the noon minimum and the pre-midnight maximum values of TEC observed at NYA1 in winter during the years of HSA and MSA may be due to the vertical plasma drift caused by the thermospheric wind system. [29] have reported this abnormal feature in TEC and foF2 and attributed it to the action of a wind system which causes a downward/upward motion of plasma during the daytime/evening hours resulting into difference in the loss rate. During the equinoxes, the location of the sub-solar point is around the equator, thus, the solar zenith angle in March and September equinoxes is equal. However, the ionosphere structure reported in this study during the equinoxes still show clear differences under equivalent solar activity conditions. The observed equinoctial asymmetry in TEC values may be attributed to the equinoctial differences in the thermospheric composition changes, thermospheric wind, solar activity and ionosphere dynamic [18, 21, 30, 31, 33, 34, 35]. [31] has attributed the equinoctial asymmetry observed over Dibrugarh, a station located near the Northern EIA crest, to equinoctial differences in the thermospheric O/N_2 density ratio. Higher (lower) values of TEC during the equinoxes may imply higher (lower) density ratio. In order to substantiate this assertion, the thermospheric density ratio images captured by the Global UltraViolet Imager (GUVI) on board the Thermosphere, Ionosphere, Mesosphere Energetic and Dynamics (TIMED) spacecraft of the National Aeronautics and Space Administration (NASA) solar connection program are used. Fig. 8 shows the images of the thermospheric density ratio $[O/N_2]$ obtained from the TIMED/GUVI satellite on some representative quiet days in March and September equinoxes in all the years under consideration. The figures also include the corresponding global TEC images during the same periods. From the images, it can be observed generally that the density ratio is higher in March equinox than the corresponding observations in September equinox. Also, the values of TEC from the global TEC images in March equinox are generally higher than the corresponding values in September equinox. This agrees well with our result. In addition, the thermospheric $[O/N_2]$ density ratio is observed to decrease with decrease in solar activity. This may explain why the magnitude of the equinoctial asymmetry is most pronounced during the period of HSA. Equinoctial difference in the thermospheric winds may also play a significant role in TEC equinoctial asymmetry. [36] used the neutral wind observation from MU Radar to explain the equinoctial asymmetry of the electron density. They found out that there is a clear equinoctial difference in the daytime polewards wind between the two equinoxes. [33] reported that the equinoctial differences in thermospheric wind and ion are the main source of asymmetry forcing of the high-latitude thermosphere-ionosphere. The equinoctial difference in the daytime polewards wind during the equinoxes may produce a significant difference in the movement of plasma through the action of thermospheric wind along the lines of the geomagnetic field to regions of different loss rate. Equinoctial differences in solar activity may also contribute significantly to TEC differences during the two equinoxes. Since the level of ionization in the ionosphere is also a function of solar activity, equinoctial difference in solar activity may cause a significant difference in the level of ionization in the ionosphere between the two equinoxes. Table 4 shows the averaged values of F10.7 index during the two equinoxes for all the years considered. It can be observed that the differences in F10.7 value is highest in 2002 and this may also explain the large equinoctial differences in the values of TEC over the entire stations during the HSA. On the other hand, the higher values of F10.7 index in 2003 and 2004 during the SEQU do not translate to high values of TEC in SEQU than MEQU. This may suggest that the asymmetry observed during these periods may not be as a result of asymmetry in solar activity but may be due to other factors discussed above.

Table 4. The average values of F10.7 index (in sfu) during the equinoxes in all the years investigated.

	2002	2003	2004	2005	2006
MEQU	189	127	106	90	80
SEQU	177	130	107	87	78

Also, since the stations used are not conjugates, this may also contribute to the observed north-south asymmetry in TEC variation. For example, the fact that SUTH is a low mid-latitude station while PENC is a high mid-latitude station may add significantly to the differences observed in their ionosphere mor-

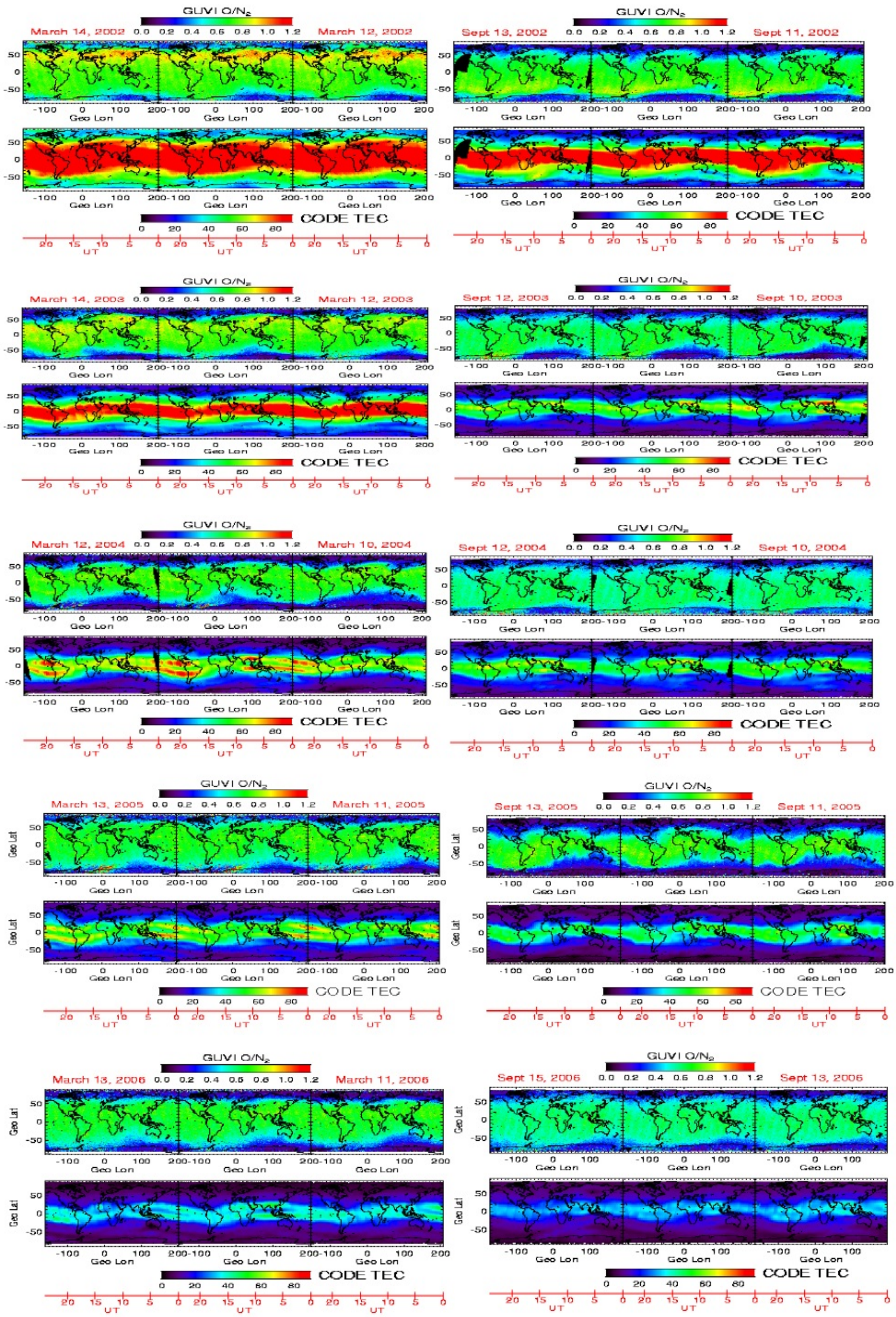

Figure 8. TIMED/GUVI images showing the global thermospheric neutral composition with the corresponding TEC variations for some selected representative quiet days in March and September for the years 2002 to 2006.

phology. We hope to further investigate this in future when ground-based instrument coverage improves in African region to ascertain the extent it contributes to the north-south asymmetry.

5. Conclusion

In this paper, a comparative investigation of the quiet time variation of TEC at mid and high latitudinal bands of both hemispheres in the Afro-European sector has been conducted to provide an insight into the ionosphere behavior of TEC between the two hemispheres. We have shown that diurnal, seasonal and annual variation of TEC depends strongly on latitude and solar activity. The highest diurnal values of TEC are observed at the mid latitude and the lowest at the high latitude regardless of the solar activity. Also, the comparative analysis revealed prominent similarity as well as asymmetry in TEC variation between the two hemispheres. We have shown that there is asymmetry in TEC variation during the equinoxes in all the stations in both hemispheres. The strength of the asymmetry is most pronounced during the high solar activity period. The equinoctial asymmetry in TEC variation has been attributed to several factors, such as the thermospheric composition change, thermospheric wind and asymmetry of solar activity. It will be interesting to further investigate the behavior of this phenomenon in relation to these driving mechanisms. This will give a possible insight as to which of the drivers (or combination of mechanisms) may be responsible for the generation of this phenomenon at different latitudes and solar activity conditions. Notable asymmetry in TEC variation between the northern and southern hemispheres that has been reported in this paper includes the winter ionosphere anomaly, which is observed only in the northern hemisphere stations. Besides the winter anomaly, the diurnal values of TEC show an abnormal variation at high latitude in the northern hemisphere in winter, with a peak that was found to depend on solar activity. This abnormal variation has been attributed to the mechanical action of thermospheric wind on electron distribution. Lastly, this paper has also shown that the mean annual variation of TEC depends on solar activity, with peak values that decrease with decrease in solar activity and increase in latitude.

Acknowledgments

The Authors are grateful to the management team of National Space Science Data Center (http://nssdcgsfc.nasa.gov/omniweb) for the solar data, as well as the Scripps Orbit and Permanent Array Center (SOPAC) (ftp://garner.ucsd.edu) and IGS for making GPS data available for research use. The Global Ultraviolet Imager (GUVI) images used for this study are provided through the support from the NASA MO & DA program. The GUVI instrument was designed and built by the Aerospace Corporation and The Johns Hopkins University. The principal investigator (PI) is Dr. Andrew B. Christensen and the Chief Scientist and co-PI is Dr. Larry J. Paxton. We also wish to thank the referees for the positive enlightening comments and suggestions, which have greatly helped us in making improvements to this paper.

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