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# Comparison of Transient Variation of Total Electron Content within and Outside Equatorial Ionization Anomaly Region

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Author ORO coordinated the study. Author AAA performed the statistical analysis and wrote the first draft of the manuscript. Author AOA proof-read the first draft manuscript and made necessary correction. Author RSF provided data used for the study. Author ABR designed the study and managed the analyses of the study. All authors read and approved the final manuscript.*

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## ABSTRACT

This research analyzed the Transient (Quiet and disturbed conditions) variation of Total Electron Content (TEC) within the Equatorial Ionization Anomaly (EIA) region and outside the anomaly region in the area of ground Global Positioning System (GPS) stations at Federal University of Technology Akure (FUTA) in Nigeria (a station in the EIA region) and Matera in Italy (a station in the middle latitude region) for period of 2008 to 2010. The work shows variation of TEC in function of the daily timing, geographical positioning of the studied area and seasons. The study correlates

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the TEC to the development of the investigated regions and to the variation of ultraviolet solar radiation and neutral winds. The data were collected using special equipment (Novatel GSV 4004B GPS SCINDA system installed at FUTA Nigeria by the US Air Force Research Laboratory (AFRL) USA (PI-keith Groves)) and the International GNSS Service (IGS) GPS system at Matera Italy. The diurnal variation shows TEC maximum on afternoon, for quiet days and almost similar variations, with small changes for the disturbed days. The difference observed between quiet and disturbed days are correlated with different space weather conditions. A predawn minimum (low in EIA region) and pre-midnight enhancement (higher at EIA region) were observed in each area investigated. Similarly the monthly and seasonal variations were analyzed. The study shows that TEC value is usually higher at the EIA region than the middle latitude region. But when storms occurs TEC Value at the middle latitude is higher. It observed from the study that TEC in the EIA region is mainly controlled by the EIA development, while the TEC variation in the middle latitude region is controlled by extreme ultraviolet solar radiation and neutral winds.

*Keywords: Transient variation; total electron content; equatorial ionization anomaly; Akure.*

## 1. INTRODUCTION

TEC is an important parameter in the mitigation of ionospheric effect on radio systems, with numerous applications involving radio links between satellites and ground, which play vital roles in the modern technology of communications, navigation and surveillance [1]. TEC is the integral of electron density along the line of sight from an observer to a satellite [2,3]. Several techniques have been adopted in probing the F-region ionosphere. Total electron content can be measured by the Global Position System (GPS) satellites using the derived propagation characteristics of the L-band signals transmitted by the GPS satellites, frequently used to investigate the F-region ionosphere [4].

The study of TEC and EIA structure can be traced back to the work of [5], based on the recording of the Faraday rotation of signals from the geostationary satellite at Hong Kong (22.2º N, 114.2ºE) and Singapore (1.4ºN, 103.8ºE) [6]. [7] Studied solar cycle variations of the equatorial ionospheric anomaly in TEC with radio signals transmitted from the US Navy Navigation Satellite System (NNSS) satellites and received by a single ground station at Lunping (25ºN, 121.17ºE). They found no significant solar cycle effect in the occurrence time and latitude of the most developed EIA crest. [8,9] also studied ionospheric TEC in the EIA region during 1994-2003 by analyzing dual-frequency signals from meridional chain of 9 observation sites around Taiwan (21.9º-26.2ºN, 118º4-121º6 E), they found that monthly values of the magnitude of TEC at the northern crest correlated well with the Dst geomagnetic activity index during low solar activity. [10] investigated the solar activity dependence of the electron density at the 400 km altitude in the whole equatorial anomaly regions through Challenging Mini-satellite Payload (CHAMP) observation. They found that the electron density in the crest regions of the EIA grows roughly linearly from solar minimum to solar maximum, with a higher growth rate than that in the EIA trough region. It was observed that the electron density growth rate with increasing solar activity around equinox seasons is greater than the growth rate around the solstice seasons [6].

Prompt penetration and over shielding effects of interplanetary electric field (IEF) or substorm-related electric field perturbations can alter the zonal electric field over dip equator resulting in the changes in the distribution of F-region ionization over low-latitude through fountain effect. Meridional winds are also known to cause hemispheric asymmetry in the crest to trough ionization density ratio as well as the location of the crest, lower atmospheric tidal processes are also believed to generate standing wave pattern in the F-region ionization around the EIA crest region. These compositional changes can alter the $O/N_2$ concentration ratio that can eventually change the TEC over the anomaly crest region [4]. Very few studies have been carried out in the African sector of the EIA region. From the few studies as well as other studies from the Asia and South America sector of the EIA region, it was observed that TEC in the region experience enhancement due to the ionization anomaly that occurs in the region. Thus this prompts a study of the behavior of TEC in the EIA region and Middle latitude region simultaneously, in order to study the effect of the equatorial ionization anomaly on TEC in the EIA region. TEC within the EIA region is compared to TEC outside the region. This helps to determine the effect of the equatorial ionization on TEC.

## 2. METHODOLOGY

The data used for this research was from the Novatel GSV 4004B GPS SCINDA system installed at the Federal University of Technology Akure (FUTA), Nigeria by the US Air Force Research Laboratory (AFRL) USA (PI-Keith Groves) and the IGS-GPS system at Matera Italy.

FUTA (geographic: lat. 7.3ºN, long. 5.2ºE; geomagnetic: lat. 2.65ºN, long. 77.21ºE) fall within the EIA region, while Mat1 (geographic: lat. 40.6ºN, long. 16.7ºE; geomagnetic: lat.34.03ºN, long. 90.9ºE) fall within the middle latitude region. GPS SCINDA (Scintillation Network and Decision Aid) is a network of ground receivers that monitors scintillations at ultra-high frequency (UHF) and lower (L) band frequencies. Scintillation is caused by the electron density irregularity in the equatorial ionosphere [11]. The GPS SCINDA system is a real time global GPS data acquisition and ionospheric analysis system developed by the US Air Force Research Laboratory (AFRL), to provide regional specification and short term forecast of scintillation to operational users in real time. The network includes 20 GPS receivers capable of measuring scintillation and 14 receivers capable of measuring TEC. The GPS SCINDA system consists of a GPS antenna, GPS receiver, GPS SCINDA data collection software and a computer running on a LINUX operating system with access to the internet. Matera GPS-TEC station is one of the International GNSS stations; the data obtained here was used to study TEC in the middle latitude.

The TEC derived from the GPS SCINDA system is a sixty seconds sequence data. This data is a Slant TEC (STEC) which is converted to it Vertical equivalent (VTEC: TEC along the Zenith path).

$$\mathrm{VTEC} = (\mathrm{STEC} - [b_R + b_S])\frac{1}{s(E)} \tag{1}$$

$$S(E) = 1 - \frac{R_E \cos\theta}{R_E + h_S} \tag{2}$$

$b_R$ and $b_S$ are the GPS receiver bias and GPS satellite bias respectively, where $R_E$ is the radius of the Earth, $h_s$ is the height of the satellite and $\theta$ is the angle of elevation of the satellite.

TEC in the two regions were studied based on the quietest and disturbed conditions of the geomagnetic field for year 2008 to 2010, thus each five quietest and most disturbed days for the 36 months during the period of the study were analyzed. The geomagnetic classification of quiet days and most disturbed days was obtained from the internet service of GFZ German Research Centre for Geosciences courtesy the Helmholtz Centre Potsdam. TEC data was analyzed using TEC application software developed by Gopi Seemala of Boston College. TEC in these regions were scaled into hourly data and studied based on the diurnal variation, monthly variation and seasonal variation. Following [12] and some other works such as [13,14] the months of the year were classified into four seasons: the December solstice (November, December, January and February), the March equinox (March and April), the June solstice (May, June, July and August) and the September equinox (September and October).

## 3. RESULTS AND DISCUSSION

It was observed that TEC values decrease to a mini value between 0400 LT and 0600 LT at the EIA region and middle latitude region from all the selected quiet days as shown in Fig. 1. The occurrence of pre-dawn minimum of TEC is due to the effect of equatorial ionization anomaly. TEC in the EIA region occurs in three phases as observed by [14]. They named the phases as the build-up phase, the plateau phase and the decay phase. The build-up phase consists of the predawn TEC minimum and the increase in TEC value due to sunrise. The plateau phase is the noon sector where TEC in the EIA region usually peaks, the decay phase occurs after sunset to mid night. While at the middle latitude region diurnal variation of TEC is not well defined as at EIA region. Sometimes depletion of TEC value occurs in the noon sector as observed in Fig. 1 (b and d). It was observed that during the quiet geomagnetic days in the EIA region TEC usually peaks in the noon sector, this period was also observed as period when the EIA crest fully develop during the day. However, in the middle latitude region depletion in TEC value occurs in the noon sector due to a pole-ward neutral wind which pushes plasma downward. Occurrence of daily minimum was observed in the middle latitude region this contradicts [15] that variation of TEC in the middle latitude is characterized by flat night variation, this could be due to the influence of the E X B drift of the anomaly ionization.

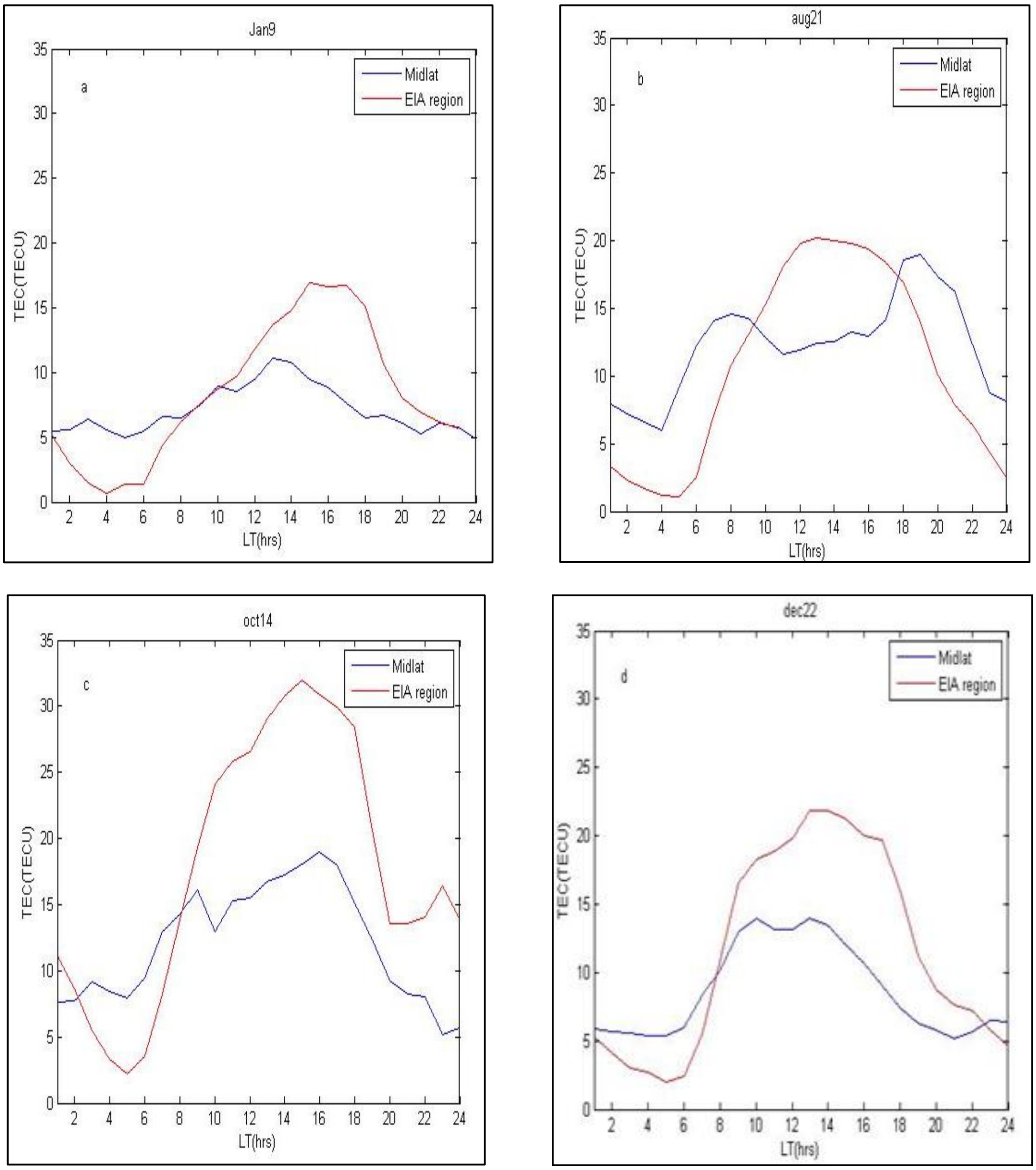


Fig. 1. Diurnal variation of TEC for some quiet days

Some dirunal variation of TEC for some disturbed days are shown in Fig. 2. As observed in Fig. 1 for the quiet days, occurrence of predawn TEC minium was also observed for the disturbed days in both regions. From Fig. 2 it was observed that TEC in the EIA region is usually higher than TEC in the middle latitude region except in Fig. 2, where TEC in middle latitude region was observed to be higher than TEC in the EIA region. Fig. 2a shows the dirunal TEC variation of July 23 2009, depletion in TEC value at the EIA region was due to the disturbance dynamo of the moderate storm of -79 nT that occur on July 22. [16,17] both observed that equatorial anomaly morphology is often disturbed by geomagnetic storm. [18] Observed that disturbance dynamo of geomagnetic storm causes a weaken equatorial fountain. This weaken equatorial fountain is attributed to the reduction in TEC level at the EIA region after occurrence of geomagnetic storm. Thus the moderate storm of July 22 2009 caused the disturbance of the equatorial anomaly morphology thereby weakening the equatorial fountain, resulting in the reduction of TEC level at the EIA region in Fig. 2a.

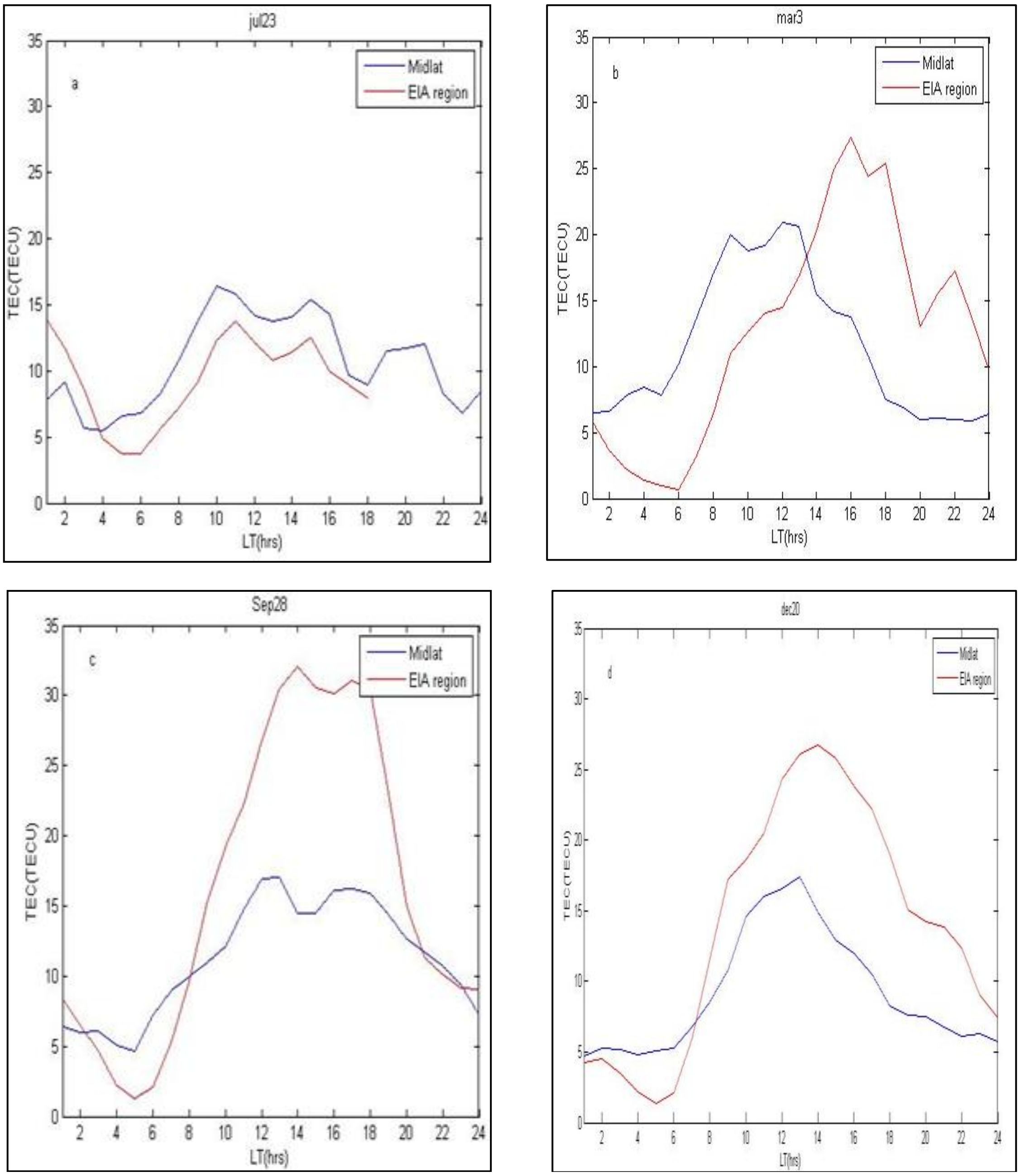


**Fig. 2. Diurnal variation of TEC for some disturbed days**

Pre-midnight TEC enhancement was observed for some days in both Figs. 1 and 2 at both the EIA region and middle latitude region. [19] observed pre-midnight enhancement in the EIA region as well as in the middle latitude region, especially during geomagnetic disturbance. [20] explained that pre-midnight enhancement in the EIA region is caused by scintillation in the region. Scintillation can occur at night time near the geomagnetic equator; this scintillation is associated with the spread-F occurrence in the region. At sunset the bottom side of the F region over magnetic equator is subject to gravitational Rayleigh-Taylor mechanisms, this results in generation of irregularities (known as plasma bubble) which raise the topside ionosphere due to non-linear evolution of the instability and produce scintillation in discrete patches [21,22]. [23] observed enhancement in the middle latitude region, they explained that this is due to vertical upward E X B drift velocity reversal in the equatorial latitude and the downward plasma flow from greater heights, triggered by the westward electric field. At night, equator ward winds move plasma up. At night time recombination of the plasma with neutral winds decreases, this increases the peak height of $F_2$ layer and the night peak electron density is maintained.

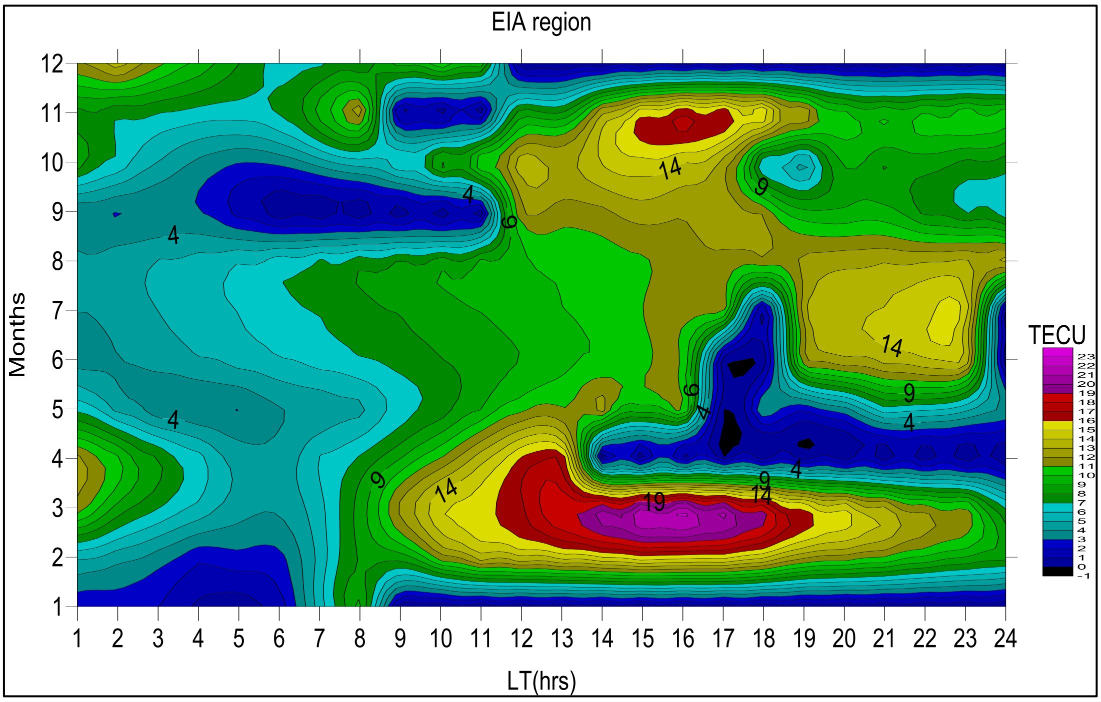
Fig. 3 shows the monthly diurnal variation of TEC in 2008. Fig. 3a shows the TEC variation at the EIA region; it was observed that, TEC usually peaks in the noon sector, but sometimes extend into the post sunset sector, as observed in February-March and June-July.

TEC was observed to maximize in March at about 23 TECU. While Fig. 3b shows the diurnal TEC variation at the middle latitude region; TEC were observed to be generally low between 0100 LT to 0700 LT and 1900 LT to 2400 LT, this shows that TEC is a function of solar radiation. As observed in the EIA region, TEC in the middle latitude peaks in the noon sector. TEC in this region was observed to maximize between March and May.

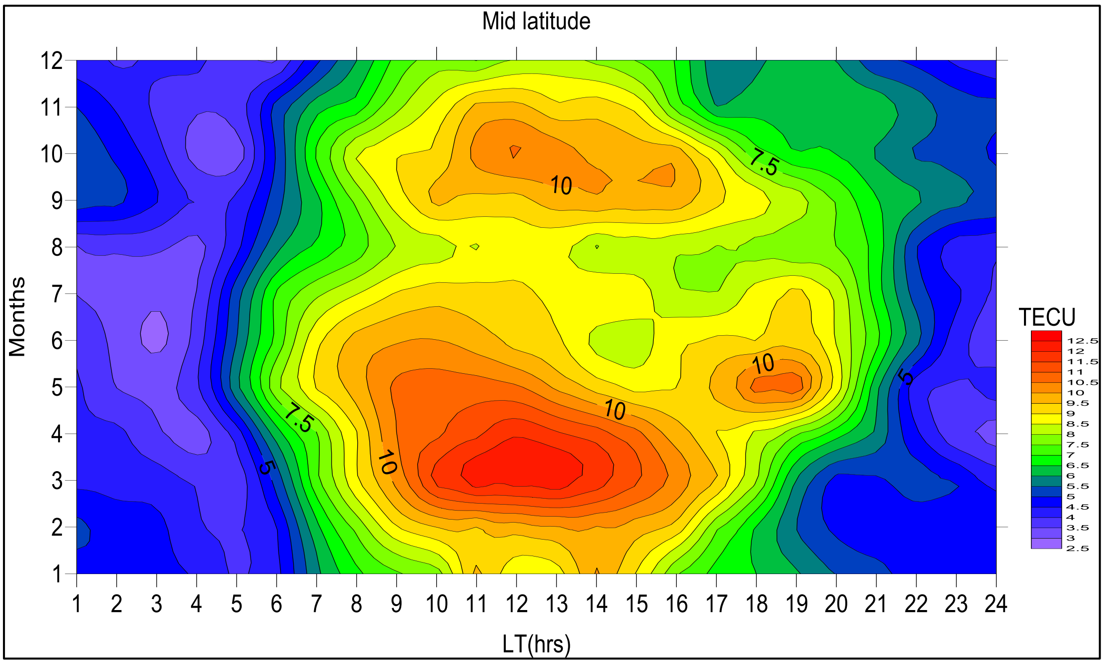
Fig. 4 shows the monthly diurnal variation of TEC in 2010. Fig. 4a shows the TEC variation in the EIA region; the dark spot shows a period when data was not obtained due to a mechanical fault developed by the GPS-SCINDA system, this occurs between April and June. TEC was observed to maximize in September-October at about 36 TECU. While Fig. 4b shows the TEC variation at the middle latitude region; TEC was observed to maximize in March-April and November-December. This result agrees with [24] observation that TEC maximizes in the Equinox months in the EIA region. Equinox months are March, April, September and October. [25] observed that TEC in the middle latitude region peaks when it is most enhanced.

From Figs. 3 and 4, it was observed that TEC in the EIA region is higher than TEC in the middle latitude region. This shows that equatorial fountain enhances TEC in the EIA region. It was also observed that the magnitude of TEC in Fig. 4 (2010) was higher than the magnitude in Fig. 3 (2008); these were observed to be the recovery phase of the solar cycle.

Figs. 5 and 6 show the seasonal variation of TEC for both the geomagnetic quiet days and disturbed days in 2008 and 2010. Fig. 5 shows the TEC seasonal variation for 2008; TEC at the EIA region were observed to maximize in March equinox and minimize in June solstice for both quiet and disturbed days. While in the middle latitude region, TEC was observed to maximize in the March equinox for both the quiet and disturbed days. Fig. 6 shows the TEC seasonal variation for 2010; TEC was observed to maximize in September equinox at the EIA



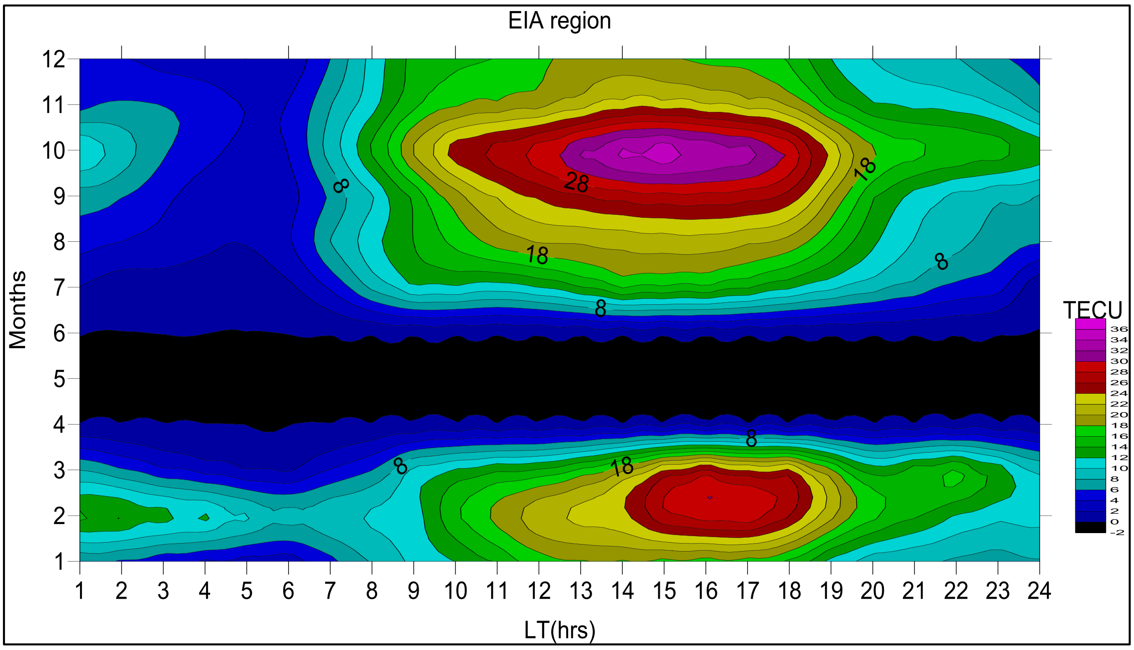
**(a)**



**(b)**

**Fig. 3. Monthly diurnal variation of TEC for 2008**

region for both quiet and disturbed days. However at the middle latitude, TEC maximize in the September equinox for the quiet days and June solstice for the disturbed days. From Figs. 5 and 6, it was observed that TEC in the EIA region maximizes in an equinox season (March equinox in 2008 and September equinox in 2010). [13] observed that ionospheric EIA crest manifest remarkable seasonal variation, maximizing in the equinox seasons. [14] observed that TEC shows a semi-annual variation in the EIA region; where TEC peaks in the March equinox, falls to minimum in June solstice. TEC then peaks again in September equinox with an intermediate value in the December solstice.



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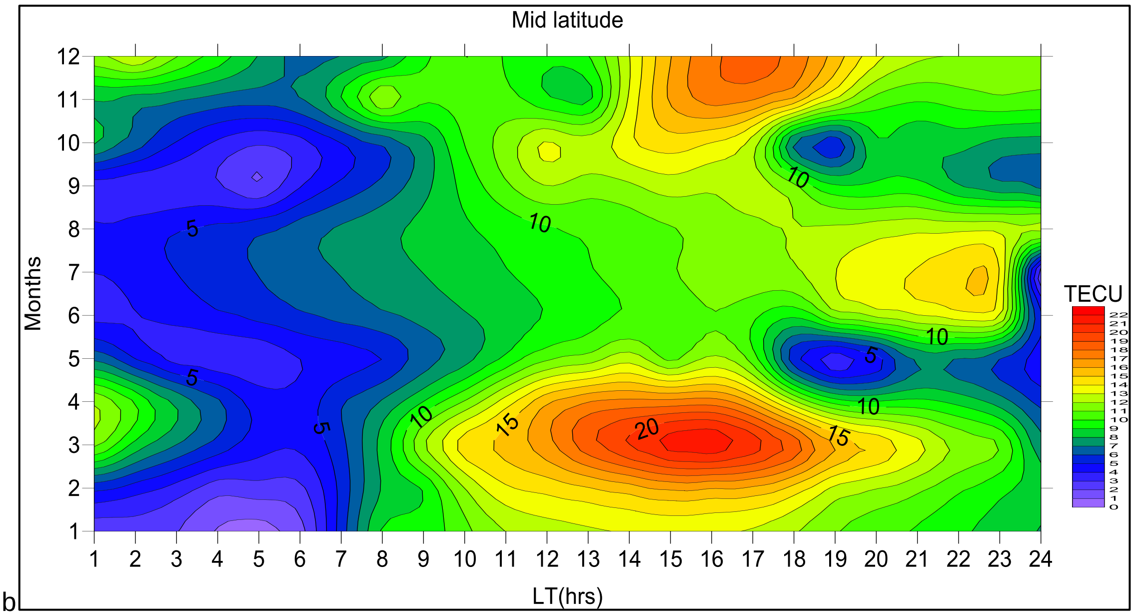

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**Fig. 4. Monthly diurnal variation of TEC for 2010**

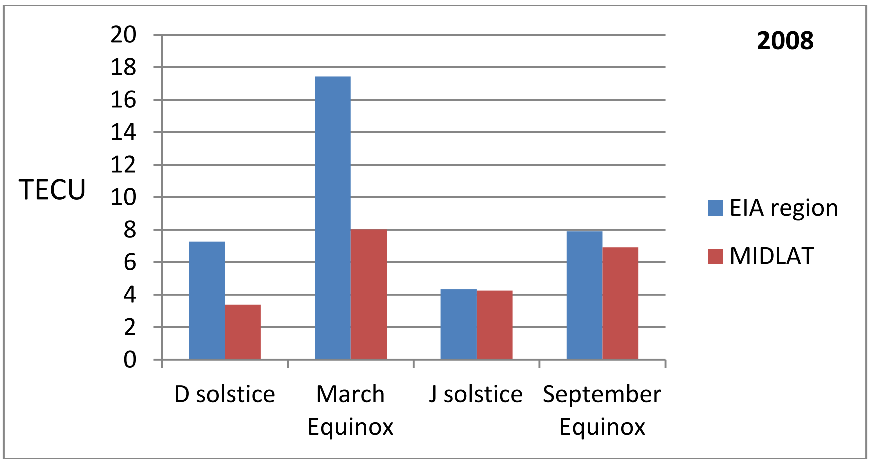

**Fig. 5a. Seasonal variation of TEC for geomagnetic quiet days in 2008**

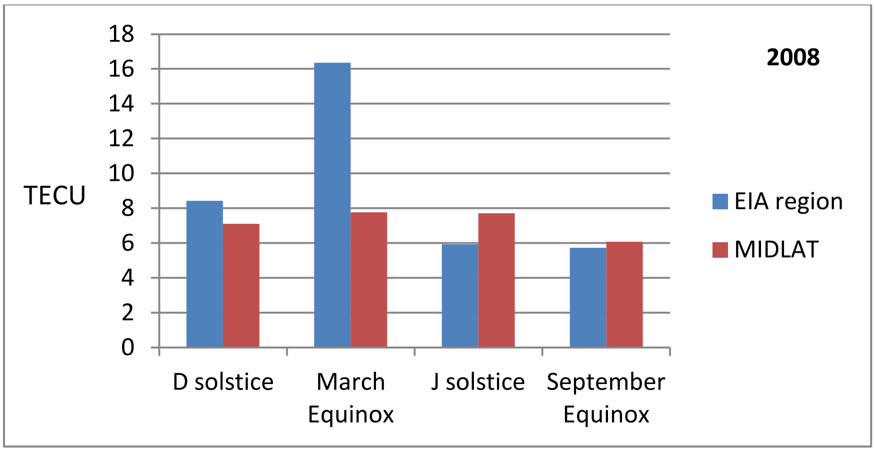

**Fig. 5b. Seasonal variation of TEC for geomagnetic disturbed days in 2008**

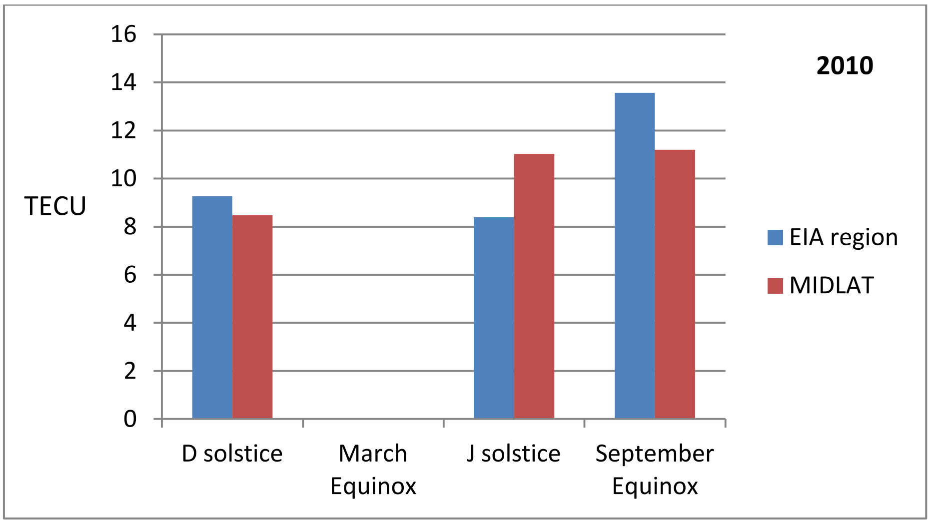

**Fig. 6a. Seasonal variation of TEC for geomagnetic quiet days 2010**

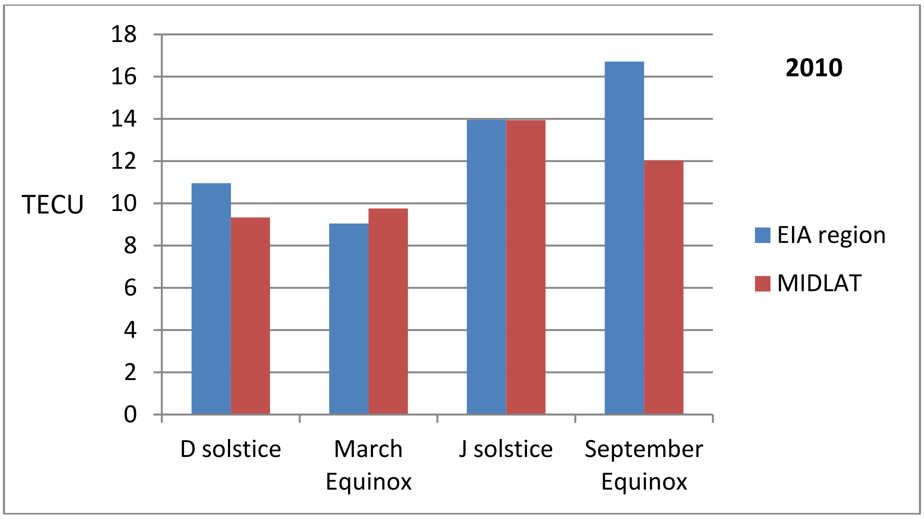

**Fig. 6b. Seasonal variation of TEC for geomagnetic disturbed days in 2010**

## 4. CONCLUSION

It was observed from this research that TEC in both the EIA region and middle latitude region exhibit a daily predawn minimum TEC value and sometimes exhibit pre-midnight enhancement due to action of the equatorial fountain effect; this shows that the equatorial ionization fountain effect extend into the low-middle latitude region. TEC in the EIA region is controlled by the equatorial anomaly morphology, while TEC in the middle latitude region is controlled by extreme ultraviolent solar radiation and neutral winds. It was observed that TEC in the EIA region is usually higher than TEC in the middle latitude region, thus equatorial anomaly enhances TEC in the EIA region.

## DISCLAIMER

Some part of this manuscript was previously presented in the following conference.

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Gopi Seemala developed the TEC application software used for the TEC analysis.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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