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COMPARISON OF A LOW AND A MIDDLE LATITUDE GPS-TEC IN AFRICA DURING DIFFERENT SOLAR ACTIVITY LEVELS

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ABSTRACT

In this work, we compared TEC values at Libreville (a low latitude station) with Sutherland (a middle latitude station) over Africa using Global Positioning System (GPS) receivers during high solar activity (HSA), moderate solar activity (MSA) and low solar activity (LSA). Apart from our confirmation that high, moderate and low values of TEC responded well to HSA, MSA and LSA, respectively at the low and middle latitude, equatorial ionization anomaly (EIA) played significant roles as regard higher values of TEC at Libreville compared to Sutherland. Interestingly, the TEC difference between a low and middle latitude revealed how EIA is majorly responsible for the occurrence of pre-reversal enhancement (PRE) in equinoctial months at Libreville. In addition, TEC difference majorly due to EIA is inactive around pre-sunrise and sunrise hours on some days during HSA and MSA. However, it is always active on all hours in all of the days during LSA. The obliterated semi-annual signature seen during HSA of seasonal difference in TEC magnitude is significantly associated with inactive EIA around 0400 LT – 0900 LT during March equinox, September equinox and December solstice.

Keywords: Low latitude; total electron content (TEC); solar activity; equatorial ionization anomaly (EIA).

INTRODUCTION

One of the major challenges that hinders maximizing the ionosphere for radio wave propagation purposes is its high variability. The ionosphere, especially its F2-layer height and its topside, is influenced by several factors, which include but not limited to time of the day, seasons, geographical locations, and the Sun's activity (Adeniyi, 2007). In characterizing the ionosphere, several parameters such as the critical frequency (foF2), maximum electron density of the F2-layer (NmF2) and the height-integrated total electron content (TEC), which factored-in the total column of electron per unit surface area of the ionosphere have been investigated (Bolaji et al., 2013; Ikubanni and Adeniyi, 2014; Adebiyi et al., 2014). These three ionospheric parameters have been reported to share similar features (Gupta and Singh, 2001; Chen et al., 2009; Adewale et al., 2012) due to the couplings of the topside with the bottom side electron density. In addition, earlier investigations on TEC from various satellites of radio-beacon-experiments in the early 1960s have yielded significant characterization of the low latitude ionosphere as regard its role on radio-propagation, communication and navigation. For example, Skinner (1966) observed two daytime peaks in TEC variations over Zaria (11.21°N, 7.71°E). A maximum TEC value about two to three hours after local noon at Ibadan (7.51°N, 7.71°E) and Thumba (8.51°N, 77.1°E) was reported by Olatunji (1967) and Rastogi et al. (1973), respectively.

At present, most TEC measurements are retrieved from Global Positioning System (GPS) receivers (Bolaji et al., 2012, 2013; Adebiyi et al., 2014). Evidences have shown that similar features observed from these aforementioned older works at low latitudes are as well revealed by GPS observations in Africa. For example, investigations carried out over Nigeria in 2009 (a year of low solar activity, LSA) revealed maximum daily and monthly mean TEC associated with afternoon slight depressions indicating two peaks in TEC variability during daytime (Bolaji et al., 2013). The formation of the two peaks and greater magnitude of TEC in the daytime are attributed to extreme ultra-violet (EUV) photo-ionization coupled with upward vertical *ECB* drift that initiated fountain effect or equatorial ionization anomaly (EIA). Over Kenya, Adewale et al. (2012)

reported that maximum TEC values in the daytime are generally higher during high solar activity (HSA) compared to LSA period irrespective of their daily and seasonal dependent. Their efforts are in support of Stubbe (1964) and Rishbeth (1964) investigations that revealed increasing thermospheric temperature profile as the solar activity increases. Similar works on solar activity dependence irrespective of the season reported by Moeketsi et al. (2016) in the middle latitude of Africa are few. They are more focused on GPS TEC modelling ranging from Neural Network (Mckinnell and Poole, 2004), International Reference Ionosphere (Okoh et al., 2010) to South Africa TEC prediction, SAPTECP (Habarulema et al., 2011).

These aforementioned literatures indicate that the theme of most works done in Africa utilizing GPS TEC either at a low or middle latitude were mainly devoted to diurnal, seasonal, solar activity variations and modelling studies. Oversight on simultaneous comparison of GPS TEC between the low and middle latitude of Africa during LSA, moderate solar activity (MSA) and HSA despite the availability of a long-term data has left a huge gap on furthering our understanding as regards the dynamics of ionospheric electron density distributions over Africa. The reason is that the effect of photo-ionization from EUV on the low latitude ionosphere has been majorly associated with EIA (Appleton, 1946; Bramley and Peart, 1965; Moffet and Hanson, 1965; Bramley and Young, 1968; Rush et al., 1969; Bolaji et al., 2013). No attempt has been made in Africa to address the difference between the magnitude of TEC significantly influenced by EIA at low latitude and that of TEC, which is not majorly influenced by EIA at middle latitude. The quantification from this difference that will unveils nearly additional TEC value in the low latitude initiated by the EIA is herein referred to as TEC difference. It is TEC difference because, meridional neutral winds (Batista et al., 2011; de Paula et al., 2015), compositional effects of O/N_2 ratio (Hedin et al., 1991; Chen et al., 2008) to mention a few are as well modulating the TEC values across latitudes. To further our understanding, we will investigate the morphology of these additional TEC values in the low latitude due to EIA during LSA, MSA and HSA in Africa.

In summary, this paper presents the difference in TEC magnitudes using simultaneous comparative study of TEC magnitudes between a low and middle latitude station in Africa during different solar activity levels. Apart from comparing differences in their TEC magnitudes on monthly and seasonal basis at different solar activity levels, we will inquire for possible mechanisms responsible for their variability.

DATA AND METHOD OF ANALYSIS

Records of uncorrected slant TEC of two GPS stations in Africa for year 2000, 2004 and 2008 are retrieved from the archives of International GNSS service (IGS) at www.igs.org. One of the stations is located at Libreville (NKLG) in Gabon, a low latitude station and the other one is located at Sutherland (SUTH) in South Africa, a middle latitude station. Both stations geomagnetic coordinates are located in the southern hemisphere (Table 1.0) with latitudinal difference of ~ 33°. There are no data available between January and March, 2000 at Libreville. Table 1.0 shows the station names, their geographic and geomagnetic coordinates. Table 2.0 depicts the mean annual solar activity conditions for the years under investigation categorized as low, moderate and high solar activity phases.

Table 1.0: Station name, geographic and geomagnetic coordinates

Station Name	Station Code	Geographical Coordinates		Geomagnetic Coordinates	
Libreville, Gabon	RCMN	0.42°N	9.46°E	7.96°S	80.85°E
Sutherland, South Africa	SUTH	32.41°S	20.67°E	41.10°S	84.60°E

The daily values of all available uncorrected slant TEC are corrected and converted to vertical TEC using the GPS-TEC analysis described by Bolaji et al. (2012).The deduced vertical TEC (herein referred to as TEC) measured in TECU (1 TECU = 10^{16} electron/m^2) are further grouped into monthly mean values using the most five quiet days in a month from the archives of Geoscience Australia at www.ga.gov.au/oracle/geomag/iqd-form.jsp.We used five most quiet days in each month to avoid the effects of magnetospheric disturbances(geomagnetic storm, solar flares, burstse.t.c.) from polluting our estimates of equivalent EIA. For seasonal estimates, the months were classified into four seasons: March equinox (February, March, April), June solstice (May, June, July), September equinox (August, September, October) and December solstice (November, December, January). On the deduction of equivalent EIA superimposed on low latitude, it is the difference in hourly TEC between the low and middle latitude. It is our interest to calculate the equivalent EIA using the simultaneous most five quite days at both stations. However, as a result of data gap regarding the most five quiet days between Libreville and Sutherland, where for example in April, the most five quiet days is available in Libreville and the most four quiet days is available at Sutherland, we further deduced their monthly mean. Hence, the monthly mean TEC values at Sutherland is subtracted from that at Libreville. This is repeated for all the months in year 2000, 2004 and 2008.

RESULTS

Quiet days, monthly mean and seasonal variations at Libreville and Sutherland

The quiet days TEC values (black lines) and their monthly mean values (red lines with asterisks) are shown with Fig. 1 to Fig. 6 panel a – l. The y-axis shows the daily/monthly mean of TEC in TEC unit (TECU) and the x-axis depicts the time of variations in local time (LT). There are no data between January and March 2000 and also, we could notretrievedata up-to five most quiet days in some months, for example at Sutherland in April (Fig. 2). Also, Fig. 7 and Fig. 8 are 2-dimensional plots showing monthly variations of TEC at Libreville and Sutherland in year 2000, 2004 and 2008. The y-axis shows the months and the x-axis shows the LT in hours. The colour bar beside the contour plots represent the monthly mean TEC magnitude. The seasonal variations of TEC at Libreville and Sutherland in year 2000, 2004 and 2008 are depicted with Fig. 9 panel a-f showing black lines with asterisks (March equinox), green lines with asterisks (September equinox), red lines with asterisks (June solstice) and blue lines with asterisks (December solstice). The y-axis shows the seasonal values of TEC (TECU) and the x-axis is in LT. The monthly mean equivalent EIA in year 2000, 2004 and 2008 are shown with 2-dimensional plots in Fig. 10 similar to Fig. 7 and Fig. 8 in descriptions. Also, the seasonal equivalent EIA in Fig. 11 have plots lines and axes similar to Fig. 9.

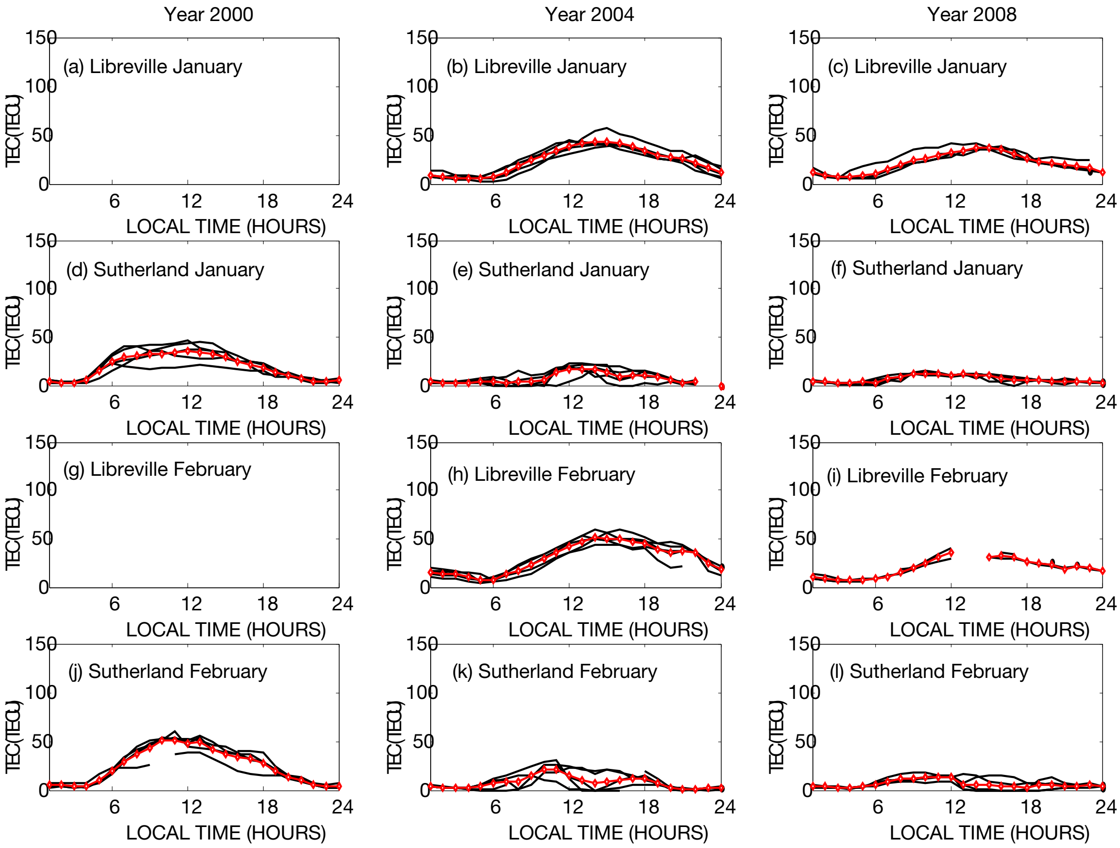

Fig.1: Five most quiet days and monthly mean of TEC at Libreville and Sutherland in January and February during low, moderate and high solar activity.

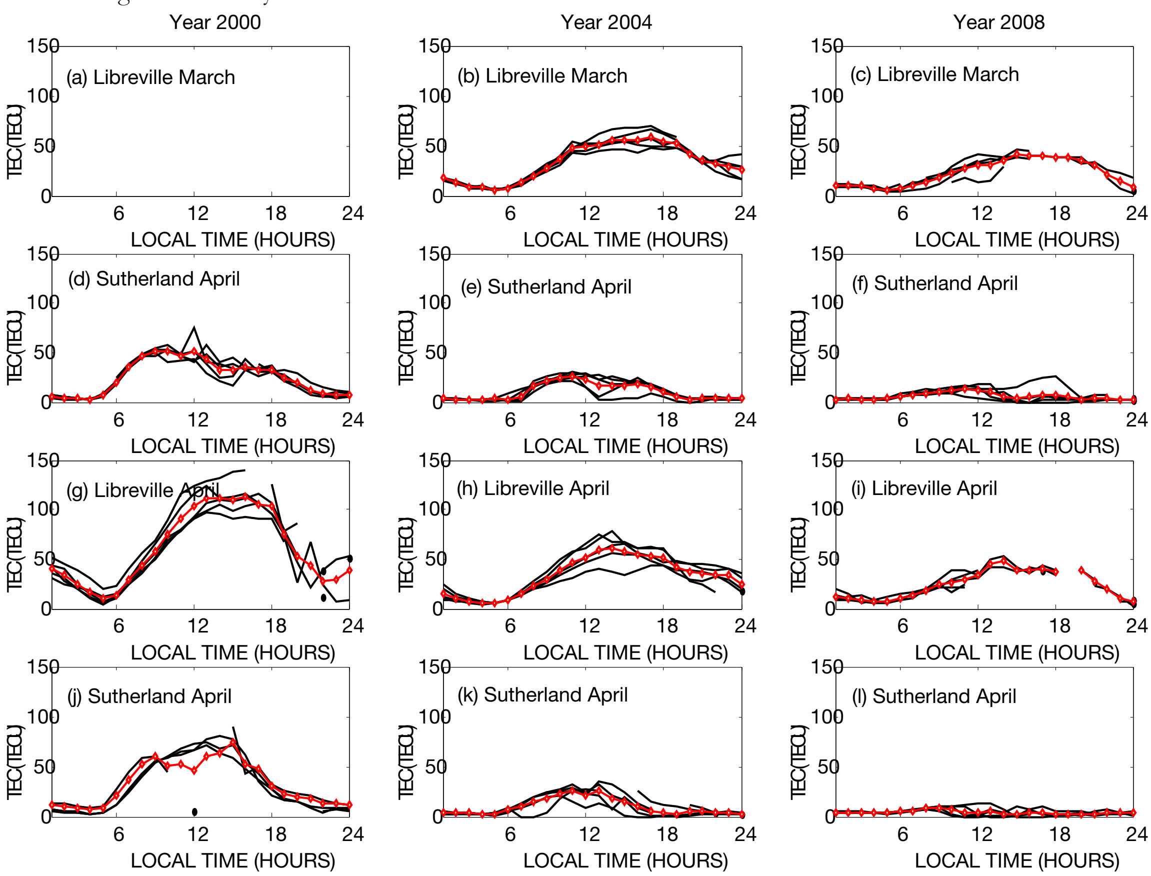

Fig. 2: Five most quiet days and monthly mean of TEC at Libreville and Sutherland in March and April during low, moderate and high solar activity.

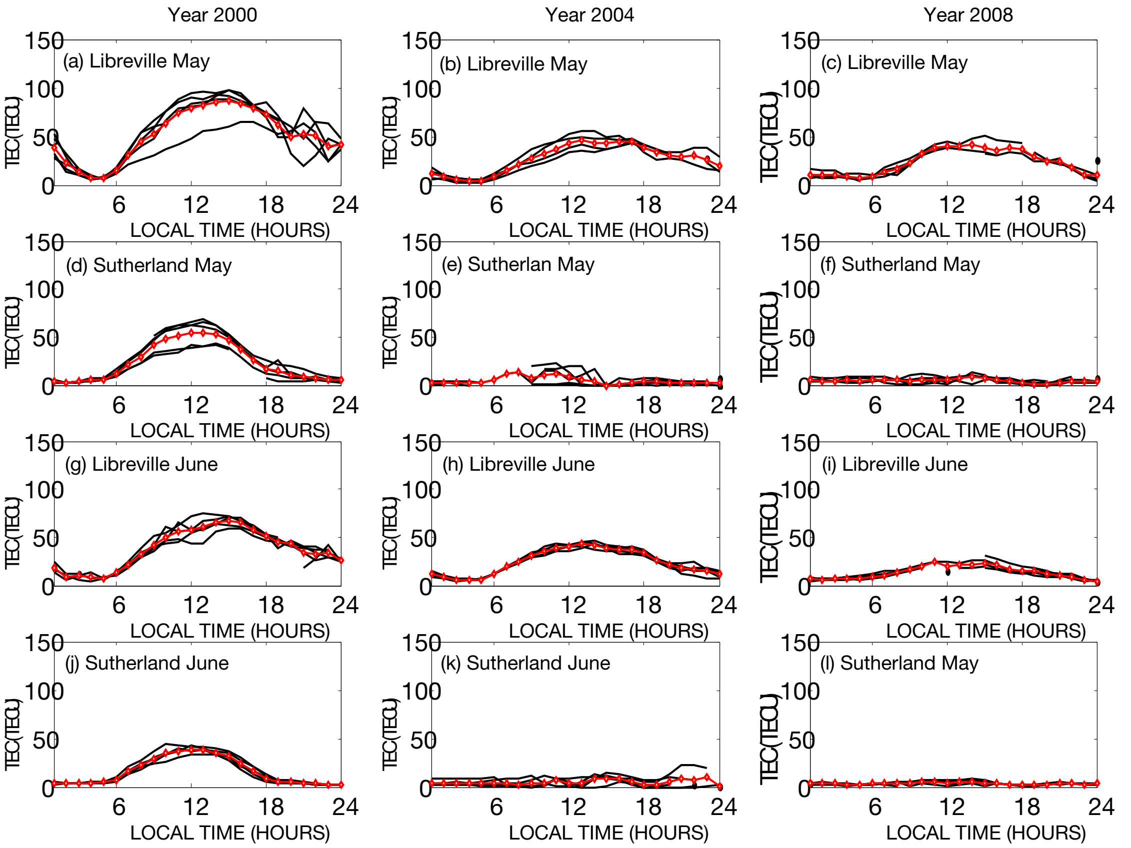

Fig. 3: Five most quiet days and monthly mean of TEC at Libreville and Sutherland in May and June during low, moderate and high solar activity.

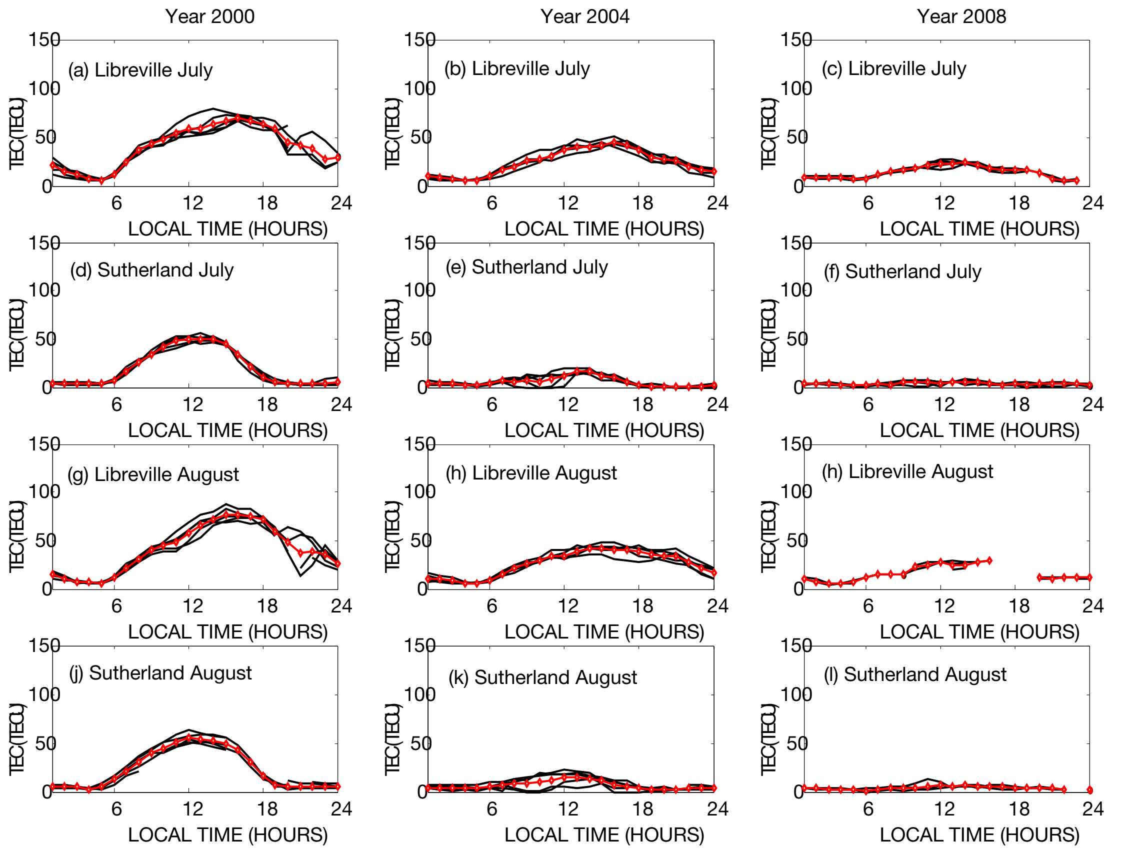

Fig. 4: Five most quiet days and monthly mean of TEC at Libreville and Sutherland in July and August during low, moderate and high solar activity.

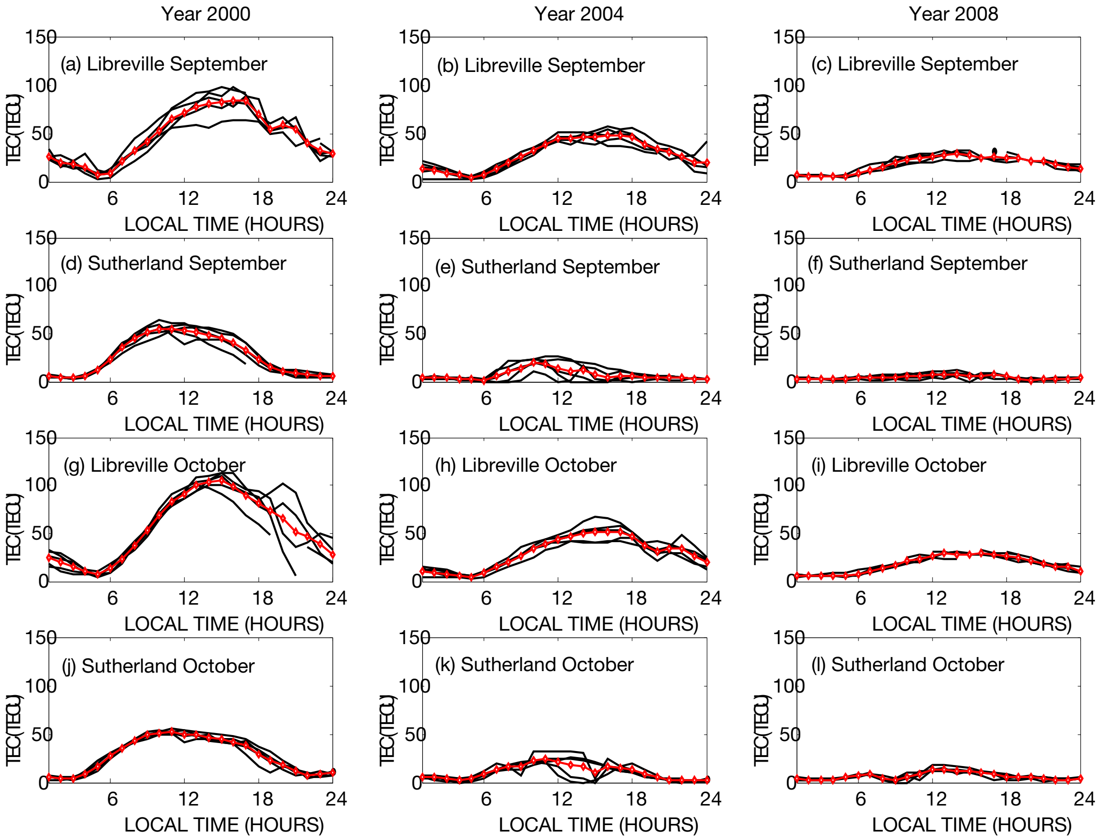

Fig. 5: Five most quiet days and monthly mean of TEC at Libreville and Sutherland in September and October during low, moderate and high solar activity.

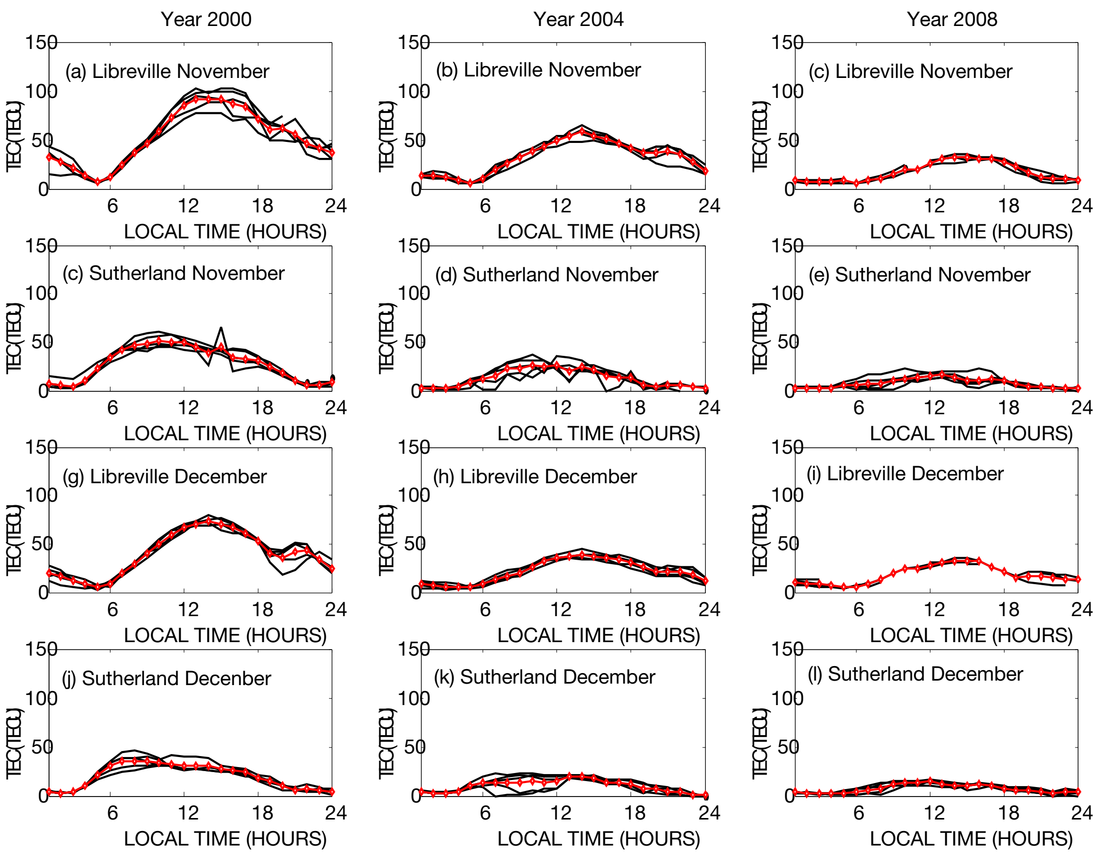

Fig. 6: Five most quiet days and monthly mean variations of TEC at Libreville and Sutherland in November and December during low, moderate and high solar activity.

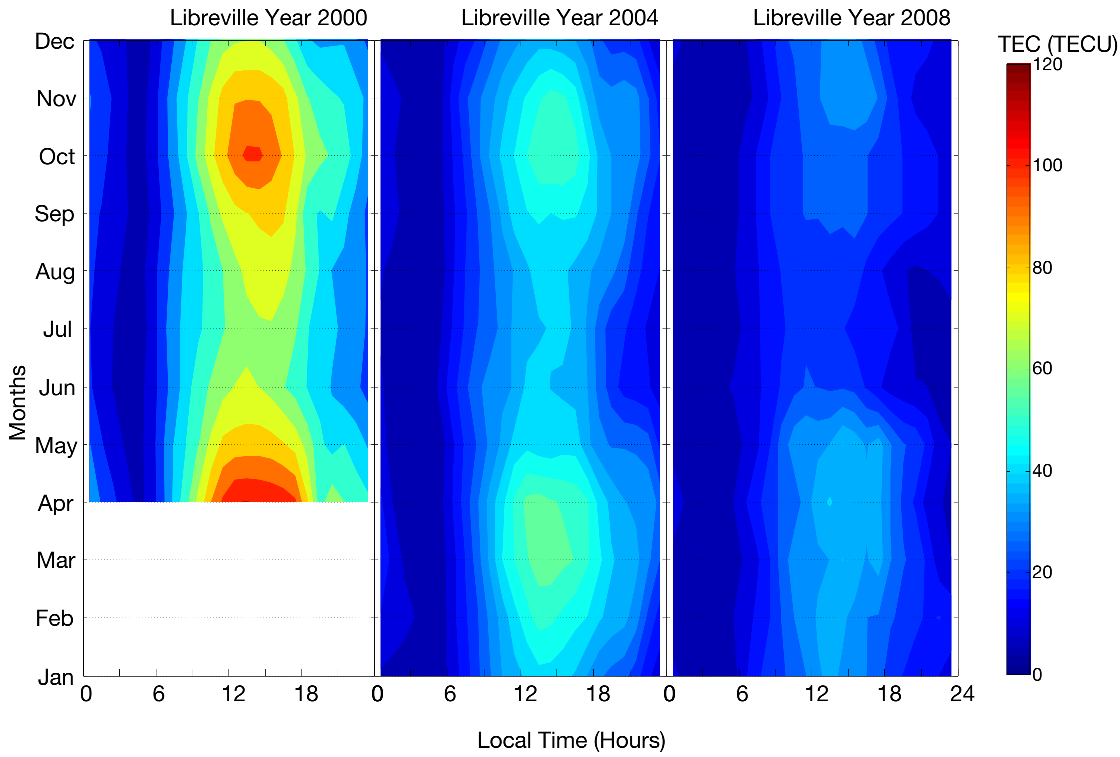

Fig.7: Monthly mean variation of TEC at Libreville.

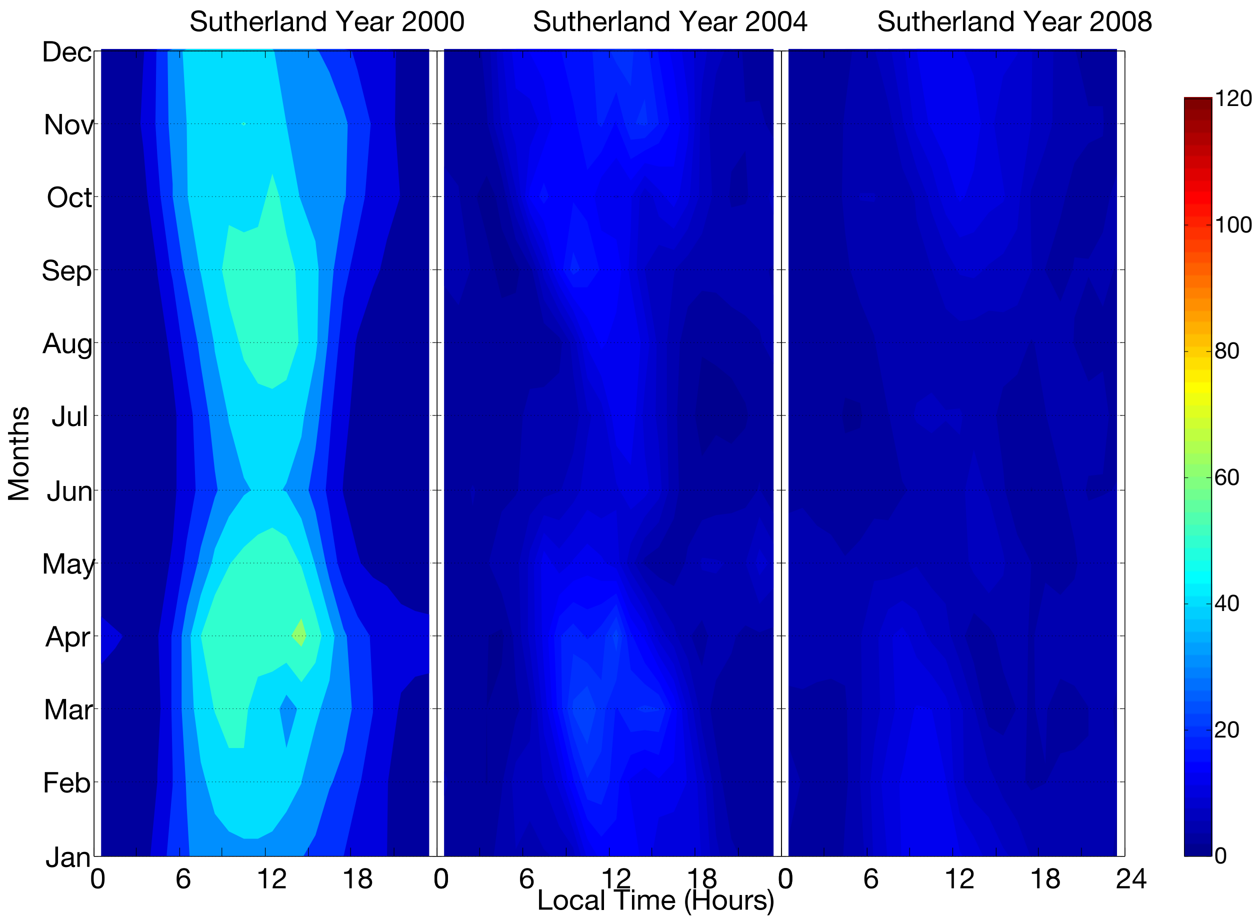

Fig. 8: Monthly mean variation of TEC at Sutherland.

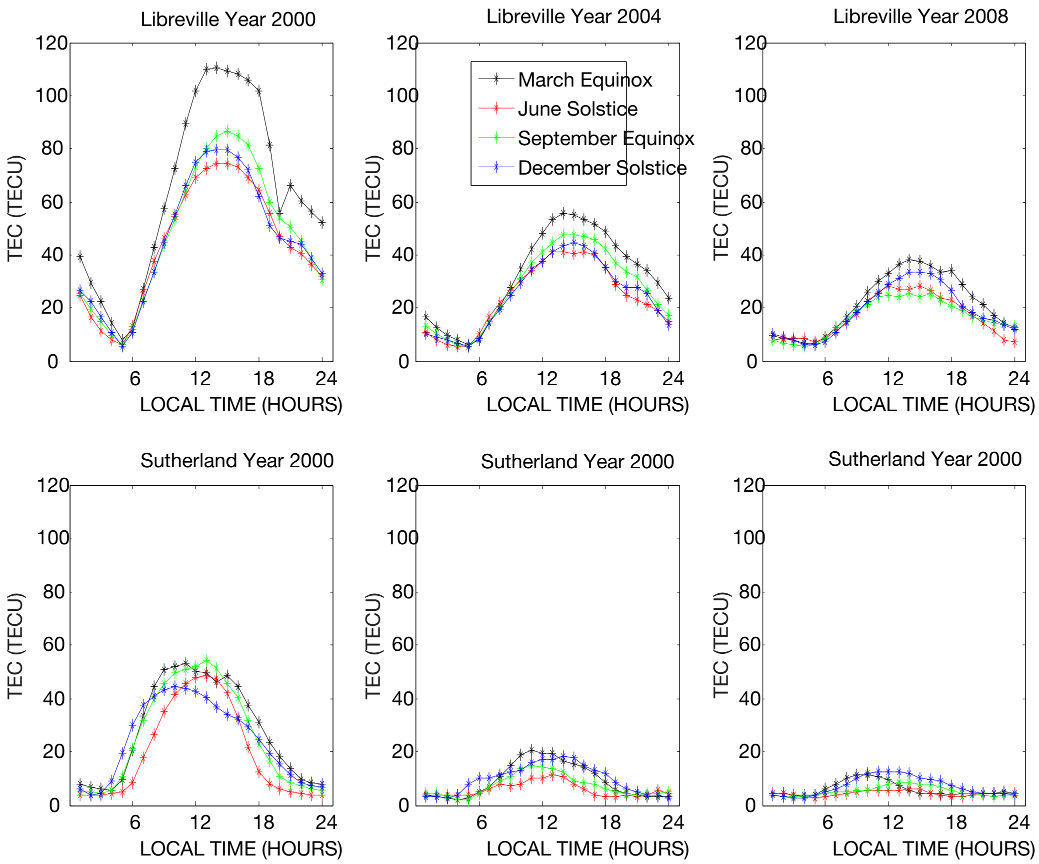

Fig. 9: Seasonal variations of TEC at Libreville and Sutherland during low, moderate and high solar activity.

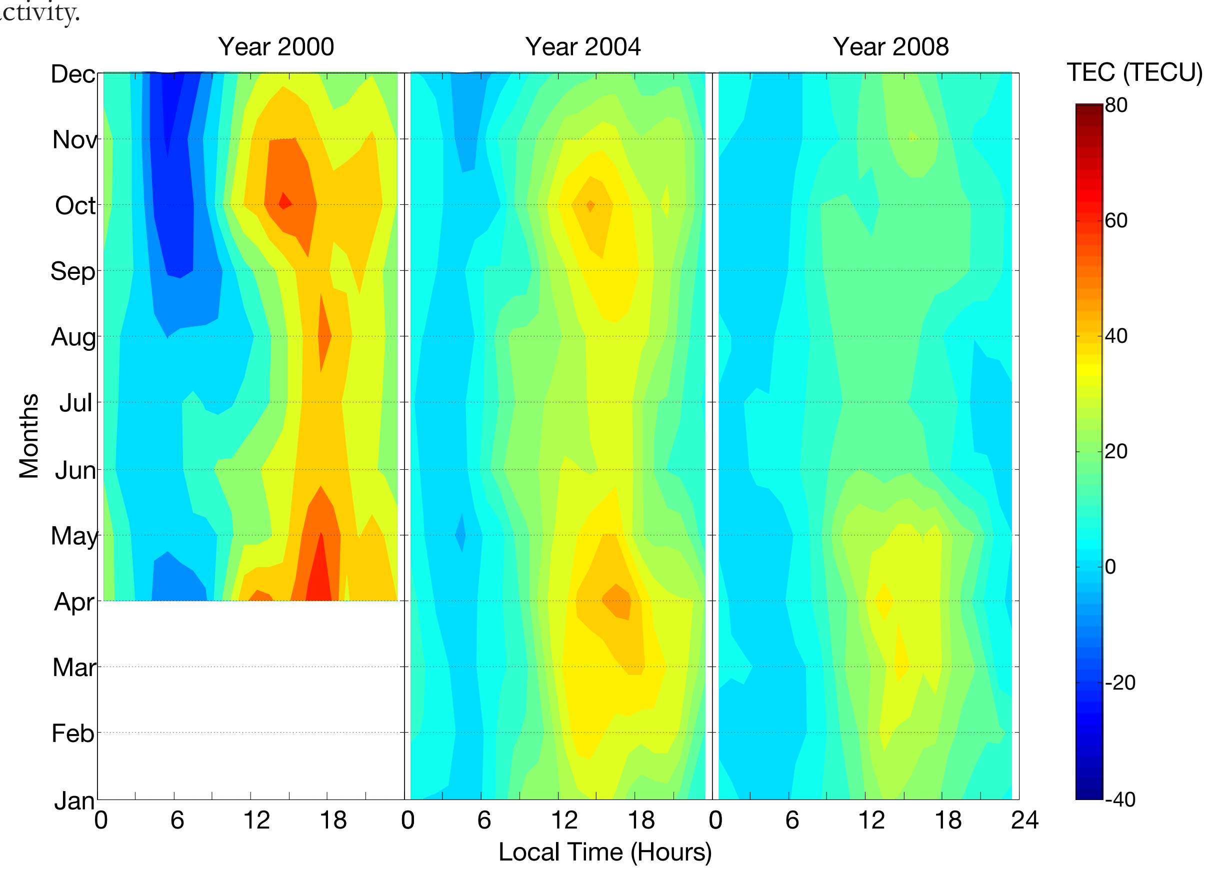

Fig. 10: Monthly mean variations of equivalent EIA at during low, moderate and high solar activity.

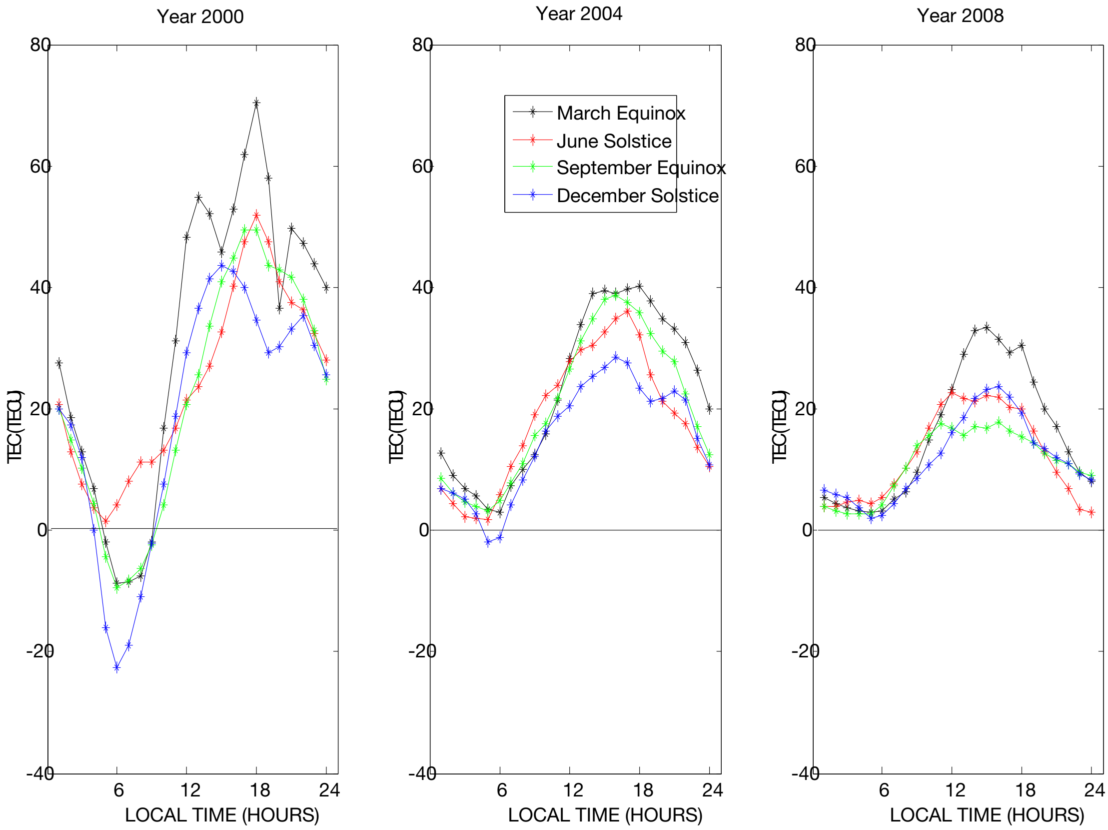

Fig. 11: Seasonal variations of equivalent EIA during low, moderate and high solar activity.

Generally, minimum daily and monthly mean variability of TEC in all of the months are found around 0500 LT and 0600 LT (pre-sunrise). Their maximum values are seen between 1300 LT and 1500 LT (daytime) and thereafter reduce gradually until nighttime (1900 LT - 0200 LT). Irrespective of years in Libreville, maximum quiet daytime magnitude of TEC in the range of ~ 141 TECU - ~ 53 TECU are found in April. Also, minimum quiet daytime magnitude of ~ 93 TECU - ~ 46 TECU are found in December in all of the years with an exception in year 2008. The minimum quiet daytime TEC value (~ 7 - ~ 11 TECU) in year 2008 was observed in July. In Sutherland, maximum quiet daytime TEC value found in April is ~ 80 TECU and ~ 38 TECU in 2000 and 2004, respectively. In November 2008, the maximum quiet daytime value of TEC is ~ 1 - ~ 5 TECU and its corresponding minimum TEC value seen in August is ~ 1 - ~ 2 TECU. The minimum quite TEC value seen in June is ~ 41 TECU and ~ 11 TECU for year 2000 and 2008, in that order.

The monthly mean variability in Libreville and Sutherland (Fig. 1 to Fig. 6 panel a – l) generally show variability similar to that of quiet day signatures. However, TEC monthly mean are generally reduced compared to quiet day magnitudes. For example, these reductions in TEC values are obvious at Libreville in April in all of the years. Compared to highest quiet day magnitudes (~ 141 TECU ~ 53 TECU), the highest monthly mean values in the daytime at Libreville that was observed in April of each year range between ~ 120 TECU and ~ 40 TECU. Also, in Sutherland, the quiet day maximum TEC value observed in April 2000 is ~ 101 TECU and in 2004, it is ~ 50 TECU. For comparison with monthly mean, maximum TEC value in April 2000 is ~ 64 TECU and in April 2004, it is ~ 24 TECU. In addition, the monthly mean TEC variations at Libreville and Sutherland (Fig. 7 and 8) are characterized by reduction in TEC around July in all of the years. The associated two peaks in TEC at Libreville are found in April and October, March and October, and April and November in 2000, 2004 and 2008, respectively. At Sutherland, the weakened two peaks in TEC variability are seen in April and September, 2000. The nearly obliterated two peaks in TEC straddled January-April and September-December in 2004 and straddled January-February and November-

December in 2008.

The TEC seasonal variations at Libreville (Fig. 9 panel a-c) show highest magnitude in March equinox and the lowest in June solstice in all of the years with an exception in 2008. The exception seen in 2008 shows lowest seasonal value in TEC (~ 23 - ~ 24 TECU) in September equinox at the peak period (1100 - 1600 LT). The March equinox in 2000, 2004 and 2008 has the highest TEC seasonal value of ~ 110 TECU, ~ 56 TECU and ~ 39 TECU, respectively. The lowest in June solstice around the peak period is ~ 74 TECU and ~ 41 TECU in 2000 and 2004, in that order.

In Sutherland, seasonal variability shown with Fig. 9 panel d-f in year 2000 reveals that highest magnitude of TEC fluctuates between March and September equinox at peak period. Prior to noon time, March equinox was highest with TEC value of ~ 53 TECU. At noon, September equinox takes over and reach highest magnitude of ~ 53 TECU in the afternoon. The lowest seasonal magnitude was as well observed fluctuating between June and December solstice. Prior to the noon during the sunrise period, June solstice was lowest and December solstice becomes lower around noon compared to June solstice with a value of ~ 39 TECU around 1400 LT. In year 2004, March equinox was highest (~ 20 TECU) until 1300 LT and by 1400 LT, December solstice becomes higher compared to March equinox with a reduced TEC magnitude of ~ 18 TECU. In year 2008, the highest seasonal value was observed in December solstice and has a value of ~ 10 TECU. For the lowest seasonal values, they are found in 2004 (~ 8 TECU) and 2008 (~ 2 TECU) in June solstice.

Monthly mean and seasonal variations of equivalent EIA
The equivalent EIA variation shown with Fig. 10 in year 2000 and 2004 is weaker (~ -17 to ~ -0.1 TECU) around 0400 – 0900 LT and weak (~ -4 to ~ -0.1 TECU) around 0500 - 0700 LT, respectively. In year 2000, 2004 and 2008, it is highest around 1200 – 2300 LT, higher around 1200 – 2000 LT and high around 1200 – 1800 LT, respectively. As can be observed, a semi-annual equivalent EIA was seen in year 2004 and 2008 with an exception in year 2000. The highest equivalent EIA observed in year 2000 is ~ 70 TECU in April at 1800 LT. As regard the two peaks associated with equivalent EIA in 2004, one was observed in April (~ 47 TECU) around 1700 LT and the other in October (~ 46 TECU) around 1500 LT. In year 2008, the first one (~ 37 TECU) straddled March and April around 1400 – 1500 LT, and the second one (~ 22 TECU) straddled November and December around 1500 – 1600 LT. In year 2000, the highest and high equivalent EIA has a value of ~ 70 TECU and ~ 52 TECU in April and August, respectively around 1800 LT. The higher one found in October is ~ 60 TECU at 1500 LT.

The seasonal variation of equivalent EIA (Fig. 11) in year 2000 shows significant negative excursions between 0400 LT and 0900 LT (~ -22 - ~ -9 TECU) with an exception in June solstice. Between 1000 LT and 1400 LT, the seasonal equivalent EIA are observeto be increasing and maximize at 1500 LT in December solstice (~ 44 TECU) and at 1700 LT in September equinox (~ 50 TECU). At 1800 LT, the highest and higher seasonal equivalent EIA value seen in March equinox and June solstice is ~ 70 TECU and ~ 52 TECU, respectively. In year 2004, maximum ~ -2 TECU was found at 0500 in December solstice. Despite the negative excursions around 0500 LT – 0600 LT, December solstice seasonal equivalent EIA variation recovered faster, increases simultaneously in similar manner with other seasons from 0700 LT and maximizes at 1600 LT (~ 28 TECU). The highest seasonal equivalent EIA found during March equinox at 1800 LT is ~ 40 TECU and the higher one found in September equinox at 1600 LT is ~ 39 TECU. In June solstice, maximum seasonal equivalent EIA is ~ 36 TECU at 1500 LT. In year 2008, highest value of seasonal equivalent EIA seen in March equinox at 1500 LT is ~ 33 TECU and the lowest seen in September equinox around 1600 LT is ~ 18 TECU. Apart from the slight daytime depressions common to March equinox in the daytime in all of the years, all the seasonal equivalent EIA in year 2000 and 2004 are characterized by higher values between 1900 LT and 0100 LT. Their range in magnitudes are ~ 25 TECU to ~ 40 TECU and ~ 11 TECU to ~ 20 TECU in year 2000 and 2004, respectively.

DISCUSSION

We have investigated the solar activity influence on the TEC in the ionosphere and table 2 shows that the ratio between year 2000 and 2008 with mean annual sunspot number of ~ 120 and ~ 3, respectively is ~ 40:1. The implication of these values on our results as regard the TEC of quiet days and monthly mean TEC is the availability of higher extreme ultra-violet (EUV) photo-ionization during high solar activity (HSA, year 2000) compared to low solar activity (LSA, year 2008). An example (Fig. 2 panel g and i) is the highest TEC value of ~ 141 TECU on a quiet day seen in April at Libreville during HSA compared to the high value (~ 44 TECU) seen in the same April at Libreville during LSA. Another example (Fig. 2 panel j and l) at Sutherland in April is the highest magnitude of TEC (~ 80 TECU) during HSA compared with high magnitude of ~ 3 TECU during LSA. These indicate that the higher the intensity of a solar activity, the higher the EUV photo-ionization and the magnitude of TEC. Otherwise, low magnitude of TEC is due to low EUV photo-ionization from low intensity of solar activity. These results, which are in agreement with the works of Stubbe (1964); Risbeth, (1964); Liu and Chen (2009); Adewale et al. (2012); Liu et al. (2013) that investigated solar activity dependence of ionospheric electron content is well-known for decades. They attributed higher electron content value in the ionosphere during HSA to increasing temperature variations in the thermosphere responding to simultaneous increase in solar activity and radiation intensity.

It is clearer from our investigations that all of the quite days and monthly mean TEC comparison are always higher at Libreville than at Sutherland. These evidences shown in Fig. 1 to Fig. 6 panel a – l that are as well not new as far as ionospheric perturbations are concerned are in agreement with the works of Appleton (1946); Bramley and Peart (1965); Moffet and Hanson (1965); Bramley and Young (1968); Rush et al (1969); Bolaji et al., 2013. These signifythat the low latitudes are significantly prone to EIA. Therefore, the morphology and statistical evidence ofthe combine effect of EUV photo-ionization and EIA that could significantly increase the TEC within the low latitude as the plasma is transported to higher altitudes will be discussed later. Also, the middle latitude, which is not significantly prone to the EIA could be one of the reasons for having reduced TEC values compared to the low latitude. It is worthy of note that the same annual sunspot number in a year is used to quantify the solar activity influence at both latitudes. This is because the time series of EUV spectrum and Lyman-α (121.6 nm), which could have appropriately quantified the solar activity value at each location and further unveiled directly the ionized primary atmospheric constituents O, O_2, N_2, NO_2, H_e, and H at each location are not readily available for longer periods. Basically and from our results, the annual sunspot number is able to clarify the solar activity levels between the years (Fig. 1-6 panel a-l). The low latitude, as a naturally designated subsolar point is also one of the major factors that contributed to increase in the TEC at the low latitude compared to the middle latitude. As the overhead Sun at solar noon in the low latitude releases more radiation for more EUV photo-ionization, the overall effect on the ionosphere is higher TEC values (Fig. 9) in the low latitude compared to the middle latitude.

Another important factor that is responsible for additional TEC in the low latitude apart from being a naturally designated subsolar point is the EIA as earlier mentioned. Our results in Fig. 10 indicate that the equivalent EIA in the low latitude, which is the additional TEC contributed by EIA in all of the months is high, moderate and low during HSA, MSA and LSA, respectively. With these results, it is obvious that the EIA formation has a strong relationship with the solar activity levels, which could be a future topic. As can be observed from our results, there is no contributions from EIA to increase TEC magnitudes in the low latitude during HSA for ~ 6-hour (0400 – 0900 LT) in April, October, November and December. There is no contribution as well during MSA for ~ 2-hour (0500 – 0600 LT) in December. These are due to the negative values in the variations of equivalent EIA, which is an indication that EIA is not active. We therefore suggest that in these periods over these months, EUV photo-ionization is the major physical mechanism, which is active around 0400 LT – 0900 LT and between 0500 LT and 0600 LT during HSA and MSA, respectively. It is worthy to report here that the additional role played by the EUV photo-ionization, which included sustaining the TEC magnitudes when EIA is inactive is responsible for higher TEC magnitudes in the daytime.

To substantiate this role, we clarify the effect of high equivalent EIA on TEC magnitudes during HSA and make detailed comparison between monthly mean TEC (Fig. 7) and equivalent EIA (Fig. 10) in April at Libreville (low latitude). We found that the TEC due to EUV photo-ionization superimposes equivalent EIA from 0400 LT to 1600 LT and between 1700 LT and 0300 LT, equivalent EIA dominates. For most cases during MSA, EUV photo-ionization TEC dominate the sunrise periods (0500 LT – 1100 LT) and the moderate equivalent EIA is observed as the major contributor near noon hours until night-times. Interestingly, the low equivalent EIA superimposed the TEC induced by EUV photo-ionization mid-way of sunrise and dominated until near midnight in most of the cases during LSA. We therefore suggest that EIA is always available on all hours in all of the days.The superimposition of TEC due to EUV photo-ionization on EIA TEC in the daytime will depends on how well the intensity of available EUV spectrum could initiate similar highest photo-ionization seen in this work during HSA.

The continuous triggering of additional TEC by EIA that supports the TEC produced by EUV photo-ionization is also responsible for the semi-annual signatures exhibited by the equivalent EIA. These were simultaneously visible in equinoctial months (March, April and October) and July in the low latitude on quite days and monthly mean variations during HSA and MSA. The consequences on quite days (Fig. 1 – 6 panel a-l) and monthly mean (Fig. 7 and 8) in the low latitude are higher TEC values in March-April and October associated with reduced TEC values in July in the daytime.

Apart from supporting increment in TEC magnitudes at low latitude as discussed, the equivalent EIA variability provided further clarifications and understanding about how EIA triggers pre-reversal enhancement (PRE) in the TEC variations at sunset in some months (equinoctial months) during HSA, MSA and LSA at the low latitude. We have established from our results (Fig. 10) that equivalent EIA became strongest after noon hours and extended into evening hours. Hence, PRE as one of the implications of equivalent EIA while sustaining highest magnitudes in April 2000 till evening hours at Libreville is seen over day-to-day and monthly mean TEC (Fig. 2 panel g and Fig 7) around 2100 LT and 2200 LT. Generally, we suggest that PRE responds well to equivalent EIA influence during equinoctial months and is high, moderate and low during HSA, MSA and LSA, respectively. Investigating TEC variations at the low latitudes, Gupta et al. (2002), Whalen (2003, 2004), and Bolaji et al. (2012) reported similar PRE around evening periods in equinoctial months. The renewal of EIA or fountain effect was suggested as the physical mechanism responsible for the occurrence. They further suggested that during sunset, PRE is crucial to initiating scintillation, plasma bubble, Spread-F and ionospheric irregularities in equinoctial months. By implication, our results give further credence to the suggestions made by Basu et al. (1988); Whalen (2003, 2004); Gupta et al. (2002); Retterer and Gentile (2009); Bolaji et al. (2012) that EIA plays significant role as regard initiating PRE in the evening hours during equinoctial months.

Semiannual patterns, higher TEC values in equinoctial months associated with reduced TEC values in solstice months found in seasonal variations during HSA and MSA at Libreville and at Sutherland during HAS (Fig. 9) is similar to the works of Bolaji et al. (2012). However, semiannual pattern is obliterated at Libreville during LSA and at Sutherland during MSA and LSA.

Also, semiannual pattern is visible during seasonal variation of equivalent EIA with exceptions during HSA and LSA (Fig. 11). Interestingly, EIA is not active and could not support EUV photo-ionization to increase seasonal variation of equivalent EIA between 0400 LT and 0900 LT in March equinox, September equinox and December solstice during HSA. This is one of the major reasons for obliteration of semiannual signature during HSA. Also, in year 2004, the EIA is not active in December solstice between 0500 LT and 0600 LT.

CONCLUSIONS

We have employed Global Positioning System (GPS) data from Libreville (a low latitude station) and Sutherland (a middle latitude station) in Africa (both in the southern hemisphere) to study TEC variations in the low and mid-latitude during different solar epochs. We observed that contributions of equatorial ionization anomaly (EIA) to extreme ultra violet (EUV) photo-ionization is the reason for higher TEC values at Libreville compared to Sutherland irrespective of all seasons and solar flux levels. Equivalent EIA representing the EIA in the low latitude is deduced by subtracting monthly mean TEC at Sutherland from monthly mean TEC at Libreville revealed its significance to semiannual signature and pre-reversal enhancement (PRE), respectively. The shortcoming of seasonal equivalent EIA when it is inactive during HSA and its failure to support EUV photo-ionization was obvious during pre-sunrise and midway into the sunrise period in March equinox, September equinox and December solstice. This study reveals the role of EIA as regard the morphology of the low-latitude ionosphere in the southern hemisphere of Africa. Also, more investigations are required to fully understand the characteristics of the African ionosphere regarding EIA in the northern hemisphere.

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