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<th>Journal:</th>
<th>Canadian Journal of Physics</th>
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<td>Manuscript ID:</td>
<td>cjp-2017-0985.R2</td>
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<tr>
<td>Manuscript Type:</td>
<td>Article</td>
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<td>Date Submitted by the Author:</td>
<td>19-Apr-2018</td>
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</table>
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| Keyword: | Equatorial Ionization Anomaly, low latitude ionosphere, Total Electron Content, Position of the crest, Magnitude of the crest |
| Is the invited manuscript for consideration in a Special Issue?: | Not applicable (regular submission) |

https://mc06.manuscriptcentral.com/cjp-pubs
Variability of the African Equatorial Ionization Anomaly (EIA) crests during year 2013

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Abstract
This paper discusses the variability of the position and magnitude of the crests of African Equatorial Ionization Anomaly (EIA) during noon and post sunset periods. Total Electron Content (TEC) data covered year 2013, and were obtained from a chain of Global Positioning System (GPS) receivers in both hemispheres around 37\degree E longitude. Local magnetometer data were used to infer the direction and magnitude of the ExB drift, while the solar EUV proxy index (PI) was used as a measure of solar activity. It was found that the time of formation of both crests varied from 1400-1700 LT. Additionally, the position of the crests was found to be asymmetric with respect to the magnetic equator. During noon period, the position of the northern and southern crests varied from 4.91\degree to 7.36\degree and -9.17\degree to -12.62\degree respectively. During post sunset period, it varied from 8\degree to 11.7\degree and -9\degree to -16\degree. Seasonally, with reference to the magnetic equator, both crests moved poleward during equinoxes and collapsed towards the equator during winter/summer. Equinoxes recorded the greatest crest magnitude followed by winter then summer over both hemispheres during noon period. However, this trend persisted over the northern crest only during post sunset period. Overall, during noon period, we recorded correlation coefficient of 0.67 and 0.68 between crests magnitude and ∆H, a proxy for equatorial electrojet current, and 0.88 and 0.81 between crests position and ∆H, for the northern and southern crests respectively. During the Halloween day storm of 30\textsuperscript{th} October 2013, a westward electric field inhibited the development of the post sunset crests.

Key words: Equatorial ionization anomaly, low latitude ionosphere, total electron content., position of the crest, magnitude of the crest.

1. Introduction

The equatorial/low latitude ionosphere is a vast portion that defines the Equatorial Ionization Anomol (EIA) region [1]. During disturbed geophysical conditions, the electrodynamics of the
ionosphere over this region can vary drastically, with significant implications on the operational 
capability of Global Navigation Satellite System (GNSS) which now have extensive applications 
in our day-to-day activities.

During the day, eastward electric field resulting from tidal and zonal winds interact with the 
north-south terrestrial magnetic field lifting ionization upward. Under the effect of gravity and 
pressure gradient, the lifted ionization diffuses downward along the geomagnetic field lines 
forming two peaks of enhanced ionization on both sides of the magnetic equator at about ±15° dip latitude, with a trough in ionization at the magnetic equator. This is the Equatorial Ionization 
Anomaly (EIA) [2] and the two regions of enhanced ionization are known as the crests of the 
EIA [3].

The persistence of the EIA into the night is due to the pre-reversal enhancement (PRE) in 
eastward electric field. The PRE is generated through the interaction of zonal neutral wind in the 
F-region and conductivity gradient caused by the solar terminator at sunset [4]. It plays a 
significant role in destabilizing the post-sunset ionosphere, hence, in the generation of 
ionospheric irregularities through the Rayleigh-Taylor Instability (RTI) mechanism and the 
associated gravity wave seed perturbation [5, 6]. Irregularities are responsible for scintillations of 
trans-ionospheric Global Positioning System (GPS) signals which in turn affect adversely the 
operational capability of critical space based technologies widely used in various endeavours 
nowadays. As such, the development and decay of the EIA is associated with two significant 
effects on trans-ionospheric GPS signals over the equatorial/low latitude region: (i) high total 
electron content (TEC) which are source of additional range errors [7] and (ii) enhanced 
scintillations effects on GPS signals [8].

For this reason, variations of the EIA have been extensively studied over various sectors [9-17]. 
The previous studies have revealed that the EIA main parameters such as the magnitude, 
ocurrence time, locations of the crest as well as crest to trough ratio exhibit significant 
variations with local time, season, solar and geomagnetic activities. This extreme variability is 
driven to a large extent by change in composition [18], thermospheric wind and wave, and tidal 
forces of lower atmospheric origin [19], changes in the equatorial electrojet (EEJ) [20] together 
with the associated variations in \( \mathbf{E} \times \mathbf{B} \) drift velocity [21]; as well as changes in noon solar zenith 
angle in relation with the geometry of magnetic field lines [22, 23].
However, most of such studies have been done over the Asian and American sectors with few studies over the African sector. The paucity of such studies is due to the sparse distribution of GPS receivers over Africa. Furthermore, the few studies from Africa on EIA were done with sparsely spaced GPS receivers, in fact, some of these previous studies used data from two GPS stations, one located at the trough while the other located away from the magnetic equator, and mostly in the African southern hemisphere. Zhao et al. [13] argued that because the longitudinal and latitudinal variation of the EIA is large, its temporal and spatial behaviour trends cannot be adequately monitored with just a pair of GPS receivers. Consequently, a better understanding of EIA variability can only be achieved using a chain of receivers well clustered around a specific longitude and reasonably spaced in latitude.

Traditionally, the crests of the EIA have been located within about ±15 to ±20 degrees dip latitude [1]. But parameters controlling the variability of the EIA vary significantly from one longitudinal sector to another. For example the drift have been found to be weaker over Africa, where winds are thought to dictate the dynamics of ionospheric processes to a large extent [24]. The implication is that the crests will vary significantly both in magnitude and position. As such, using a fixed crest position is liable to errors. It thus, becomes imperative to characterize the variation of the magnitude and position of the crests of the EIA.

This is all the more significant given the fact that there is a dearth of studies on the variation of the magnitude and position of the crests of the EIA over Africa using chain of GPS receivers in both hemispheres simultaneously. This, to a large extent constitutes an impediment to global understanding of ionospheric electrodynamics and a challenge to the specification and forecast of ionospheric effects on the emerging new critical technologies. The aim of this work is to characterize monthly and seasonal variations of the position and magnitude of the crests of the African EIA during noon and post-noon periods.

2. Data and method of analysis

The following parameters were used to study variations of the EIA over east Africa: Daily solar flux (F10.7) provided by the Dominion Radio Astrophysical Observatory (DRAO), Penticton and obtained at the website http://www.spaceweather.gc.ca/solarflux/sx-5-en.php. This was used to derive the improved weighted EUV-proxy index (PI) [25]. The Total Electron Content (TEC)
data were obtained from the University NAVSTAR Consortium (UNAVCO) website http://www.unavco.org/data/data.html. The GPS and magnetometer stations are shown in Fig. 1. The magnetometer at the Adigrat station is owned by the African Meridian B-Field Education and Research (AMBER), while the one at Addis Ababa is managed by the Institut de Physique du Globe de Paris (IPGP), France and data are distributed via Intermagnet. We computed the horizontal component of the Earth magnetic field and estimated ∆H as a measure of the strength of the equatorial electrojet (EEJ). Other parameters such as the disturbance storm time index (Dst), the symmetric disturbance index (SYM-H), the x component of the solar wind speed (Vx) and the x-component of interplanetary magnetic field (IMF Bz) were used to monitor interplanetary and magnetic conditions during the Halloween storm of 30 October 2013. Dst and SYM-H are made available by the World Data Centre for geomagnetism (WDC), Kyoto at the website http://wdc.kugi.kyoto-u.ac.jp while Vx and IMF Bz were obtained at the website http://www.srl.caltech.edu/ACE.

The improved weighted EUV-proxy (PI) defined by Chen et al. [25] was used as a proxy for solar activity.

\[
PI = 0.4F_{10.7} + 0.6F_{10.7A} \tag{1}
\]

where \(F_{10.7A}\) is the 81 day mean of daily \(F_{10.7}\)

The horizontal component of the Earth’s magnetic field (H) was derived from the north component (X) and east component (Y) of the geomagnetic field measured by magnetometers at Addis Ababa and Adigrat stations.

\[
H = \sqrt{X^2 + Y^2} \tag{2}
\]

Baseline values were computed and removed from the hourly values of H which were further corrected for non-cyclic variation following the method of Rabiu et al [26]. However, in the analysis of magnetic data, care was taken to consider only quietest days. As such, five quietest internationally days (IQDs) in each month of year 2013 were selected from the GFZ German Research Centre for Geosciences website ftp://ftp.gfz-potsdam.de. During these very quiet days, the magnitude and direction of \(\mathbf{E} \times \mathbf{B}\) drift was estimated using \(\Delta H\), a proxy for EEJ current [27, 28]. \(\Delta H\) was computed as the difference between H-components of the field recorded at two
magnetometer stations one located at the equator (Addis Ababa, dip 0.16°) and the other off the equator (Adigrat, dip 6.01°N). However, for analysis pertaining to the Halloween storm of 30 October 2013, there was no data for the magnetometer in Adigrat thus, ∆H was computed using equation 3 [29].

\[ \Delta H = [H_{\text{obs}} - H_{2-3 \text{ am}}] + C \times [\text{SYM-H} - \text{SYM-H}_{2-3 \text{ am}}] \quad (3) \]

where \( H_{\text{obs}} \) and SYM-H are the observed magnetic field and the corresponding SYM-H value at a given time, \( C \) is a constant determined from least square method [30]. As such positive (negative) \( \Delta H \) is thus, proportional to eastward (westward) electric field.

We processed GPS TEC data following the approach of Seemala and Delay [31]. This entailed leveling the carrier phase with the pseudorange measurements [32], detecting and correcting cycle slips in phase data [33], calibrating slant TEC (STEC) by removing satellite and receiver biases [34] and converting STEC to vertical TEC (VTEC) using the thin shell ionospheric model whose height is assumed at 350 km [35]. Data quality check was done using the Translating Editing and Quality Checking (TEQC) software [36]. We used an elevation cut-off of 30° [37-38]. Higher elevation as suggested by Rama Rao et al. [39] over the Indian sector will obviously restrict the range of observations, and thus, obfuscate the full extent of the EIA. Aggarwal et al. [14] used a cut-off elevation of 20° and showed that errors due to low cut off elevation are covered by statistical variations in TEC.

In reconstructing the EIA we defined a mean longitude (L) as in equation 4 and estimated time difference, \( \Delta t \) (hours) between each receiver and that of the mean longitude as in equation 5 [15].

\[ L = \sum_{i=1}^{N} \frac{\theta_i}{N} \quad (4) \]

where \( \theta_i \) is the longitude of station \( i \) and \( N \) are the number of stations.

\[ \Delta t = \frac{L-L_{RX}}{c} \quad (5) \]

where \( L_{RX} \) is the longitude of each receiver and \( c = 15 \) deg/hour, is the hour to longitude conversion factor.

Then, time correction was performed by adding \( \Delta t \) to the time data of each receiver so that the measurement time was corrected to the time of the mean longitude. The African EIA was
reconstructed using monthly mean diurnal values of VTEC with a time resolution of 1 hour and latitudinal resolution of $5^\circ$.

3. Results

Fig. 2 shows contour maps of the monthly mean diurnal variation of TEC for the year 2013 over the African EIA. The time of occurrence of maximum TEC as well as the latitudinal position of occurrence of such peak were used to define the time duration and position of the EIA crests respectively. From this figure, the time of occurrence of the crests was found to vary from 1400 LT to 1700 LT. In March and August, both crests however, formed at the same time (1700 LT) as well as in April and October (1600 LT) and December (1500 LT). In January, February and November the northern crest formed earlier than the southern crest while the reverse is the case in May, June and September. Data from November to December was unavailable likely as a result of power failure. The position of the southern crest varied from $-12.62^\circ$ to $-9.17^\circ$ dip latitude while that of the northern crest varied from $4.91^\circ$ to $7.36^\circ$ dip latitude. The magnitude of both crests is shown in Fig. 3 for the noon period only. A maximum in both crests value occurred in March and October-November while a minimum occurred in July. For the northern crest, the October peak is higher than the March peak whereas for the southern crest the November peak is higher. The evolution of the EIA with drift data will be presented in Figure 9.

Fig. 4 shows the TEC profile during post sunset period at about 2100 LT from January to December, 2013. Clear variations of the position and magnitude of both crests are observed in this figure. The position of the northern crest is seen at about $8^\circ$ dip latitude in January, March, August and October while it shifted to $11.7^\circ$ dip latitude in April, September, November and December (see broken horizontal line in Fig. 4). In February, May June and July however, it is at about $7^\circ$ dip latitude. Generally the southern crest is located at about $-11.5^\circ$ dip latitude during most months of the year. It however, shifted to $-9^\circ$ dip latitude in October and $-16^\circ$ dip latitude in December. As for the magnitude of the post sunset crests, highest (smallest) magnitudes were recorded in November (June) for the northern crest and April (January) for the southern crest. On the other hand, the Northern crest was higher in magnitude than the southern crest in January, February, November and December while the reverse was the case in March, April, May, June, July, August, September and October.
Fig. 5 shows the seasonal variations of the EIA for the year 2013. The main seasons considered were represented by winter (November, December, January, February); summer (May, June, July, August) and equinoxes (March, April and September, October). During winter, the southern crest formed at \(-10.22^\circ\) at about 1700 LT with a magnitude of 55.115 TECu (1 TECu = \(10^{16}\) electrons per m\(^2\)) while the northern crest formed at \(4.91^\circ\) at about 1500 LT with a magnitude of 55.84 TECu. During equinoxes, the southern crest expanded to \(-12.42^\circ\) at about 1600 LT with a magnitude of 58.61 TECu while the northern crest expanded to \(7.36^\circ\) at about 1600 LT corresponding magnitude of 60.00 TECu. Finally during summer, the crests collapsed at \(-10.22^\circ\) at about 16:00 LT with magnitude of 43.39 TECu for the southern crest and at \(4.91^\circ\) at about 16:00 LT with magnitude of 43.94 TECu for the northern crest.

Fig. 6 shows the seasonal variations of the position and magnitude of the EIA during the post sunset period. From this figure, the southern crest formed at \(-11^\circ\) with a magnitude of 27.43 TECu during winter while the northern crest formed at \(8^\circ\) with corresponding magnitude of 31.94 TECu. During equinoxes, both crests remained at \(-11^\circ\) and \(8^\circ\) with corresponding magnitude of 41.76 TECu and 35.30 TECu for the southern and northern respectively. The southern crest still formed at \(-11^\circ\) with a magnitude of 32.64 TECu while the northern crest collapsed slightly to \(7^\circ\) with corresponding magnitude of 23.79 TECu during summer.

In Fig. 7, the monthly mean diurnal variations of \(\Delta H\) from January to September 2013 are presented. There is no available data from October to December 2013. Generally, the profile for \(\Delta H\) is characterized by a negative excursion in the morning below \(-5\) nT followed by a rise to a peak value close to noon, then a decrease in the afternoon. This is known as the counter electrojet (CEJ). The peaks in \(\Delta H\) were reached at about 1200 LT in the months of January, April, May, August and September. The corresponding values were 43.79 nT, 43.63 nT, 22.95 nT, 41.46 nT and 42.15 nT respectively. For the other months the time of occurrence and peak values were: February (11:00LT, 26.32 nT), March (14:00 LT, 45.40 nT); June (14:00 LT, 11.95 nT) and July (14:00 LT, 17.84 nT). Overall, March had the highest noon peak while June had the lowest. The seasonal variations of \(\Delta H\) are presented in Fig. 8. Because of the unavailability of magnetic data from October to December, we took mean values of \(\Delta H\) for January and February only to represent winter while the mean values of delta H from March, April and September was used for the equinoxes. For summer all for months were represented. From this figure, the
minimum in ΔH occurred at about 0800 LT while a peak value is reached at about 1200 LT during all seasons under consideration. Equinoxes recorded the highest noon peak (43.37 nT) followed by winter (31.32 nT) and summer (19.17 nT).

Fig. 9 presents a comparison of the evolution of the EIA and ΔH from 0800 to 1400 LT on a seasonal basis. The EEJ started developing from a negative value of ΔH at about 0800 LT to a peak value at about 1200 LT. The strength of the EEJ is shown in the bottom of the figure. During the three seasons under consideration, right from the time of negative ΔH till when a maximum in ΔH is reached and after about 3 hours, there is only one peak in the EIA profile. The double peak in ionization however, made its appearance at about 1100 LT (3 hours after current reversal).

In Fig. 10, variations of monthly PI index are presented from January to December 2013. The months of May, October, November and December recorded the highest PI values of 124.4, 133.8, 147.4 and 147.1 sfu respectively. February and September had the lowest PI value of 111.1, 195.0 and 106.7 sfu respectively. Correlations between (a) crests magnitude and ΔH, and (b) crests position and ΔH during the noon period are presented in Fig. 11. Correlation coefficients of 0.67 and 0.68 were obtained for crest magnitude versus ΔH as well as 0.88 and 0.81 for crest position versus ΔH for the northern and southern crests respectively.

Fig. 12 shows variations of interplanetary and magnetic parameters during the Halloween storm of 30 October 2013. Unlike the Halloween storm of 2003, this event is a minor geomagnetic storm with gradual storm commencement and a long duration main phase characterized by a two step response in Dst with minima of 35 nT at 12:00 UT and 56 nT at 2400 UT (panel 3). There is no significant change in the magnitude and direction of ΔH (panel 4) in the local noon period except for the slight reduction in magnitude on the 31st of October. In response to the disturbance, ΔH was negative from about 1200 UT on the 30th October till about 0500 UT the following day. During this time interval, IMF $B_z$ (panel 1) went on several southward journeys. It nevertheless, remained south from about 1900 to 2200 UT with the associated $IEF_y$ (panel 2) westward. The response of the EIA is presented from 1700 to 2000 UT (2000 to 2300 LT) in Fig. 13. On 29 and 31 October, both peaks of the EIA are observed from 1700 to 2000 UT. On 30 October, they can still be seen at 1700 UT while from 1800 to 2000 UT only a single peak can be seen.
4. Discussion

The formation of the crests of the EIA is due to the fountain effect which itself depends on a combination of processes mainly, solar ionization and the $\mathbf{E x B}$ drift among other. The time of occurrence of maximum $\Delta H$, a good proxy for $\mathbf{E x B}$, varied on a monthly and seasonal basis (Figs. 7 and 8) and was an important mechanism responsible for the observed variation in the time of occurrence of the noon crests (Figs. 2 and 5). The estimated difference in the time of maximum EEJ as inferred from $\Delta H$ and the time of occurrence of the crests of the EIA was found to be about 4 hours during equinoxes and 2-3 hours during solstices. This time delay represents the response time of the EIA to changes in zonal electric field. Aggarwal [14] found that such time varies between 3-4.5 hours over India. The response time is thus, a function of mechanisms such as vertical drift velocity, height of the populated flux tube as well as intensity of meridional winds [14]. Fejer et al [40] showed that the magnitude and time of occurrence of peak drift velocity vary with local time, season and longitude. Zhang et al. [41] observed that the noon peak of the EIA around $120^\circ$E longitude formed at about 1300-1400 LT from 1998-2004.

The crests were well developed in magnitude and formed farther away from the magnetic equator during equinoxes than winter, then summer especially for the noon period (Figs. 5 and 6). Delta H similarly reached peak value during equinoxes, then winter and finally summer (Figure 8). This annual variation in crest magnitude was thus, modulated by similar variation in $\mathbf{E x B}$ drift. Sherliess and Fejer [42] similarly explained these seasonal variations in terms of larger daytime $\mathbf{E x B}$ drift velocities during equinoctial and winter months as oppose to weaker values during summer months. In addition, the fact that the crests formed farther from the magnetic equator (poleward) during equinoxes and closer (equatorward) during summer and winter is an indication of the contribution of thermospheric neutral winds. According to Dickinson et al [43] and Roble et al [44], solar heating drives a circulation from the equatorial region toward both poles during equinoxes. The poleward winds in conjunction with the stronger equinoxes drift were hence, responsible for the movement of the crests. The significance of winds nonetheless still requires investigation especially over the African sector that has been void of ionospheric observational tool for a long period.

On the other hand, during winter the northern crest had higher magnitude than the southern crest while the reverse is the case during summer. This was due to change in composition resulting
from summer to winter winds driven by interhemispherical circulation at solstice. Dickinson et al. [45] had shown that during solstice, solar heating generates a circulation with rising motion over the summer pole and meridional wind in the direction of the winter hemisphere. It is well known that such winds exert a great control on the formation of the crests of the EIA. Since they flow from the summer hemisphere towards the winter hemisphere [44] they can drag ionization along the magnetic field lines thus, increasing or decreasing the rate of diffusion of ionization towards the winter crest or summer crest. As a result, the formation of the summer crest is retarded while the winter crest is enhanced. Huang and Cheng [10] studied cycle variations of the northern EIA crest using TEC from 1985–1994 at Lunping and found that the winter crest appears larger and earlier than the summer crest. Tsai et al. [11] found that both crests of the EIA fully develop around midday in winter, post noon during equinox and late in the afternoon during summer in the Asian sector.

The hour by hour analysis of the formation of the crests of the EIA and the EEJ strength revealed that it took 3 hours for both crests to develop after the reversal of current from westward to eastward (Fig. 9). This time delay which often corresponds to the response time of the EIA to transition from counter electrojet (CEJ) to EEJ is consistent with results of Stolle et al [46] obtained over the South America sector. The good correlation between crests magnitude and delta H (Fig. 11a) further highlights the contribution of electric field to the variability of the magnitude of the crests of the African EIA. Stolle et al [45] obtained good correlation between vertical drift velocities, equatorial electrojet strength and EIA parameters over Jicamarca, Peru. In the same vein, Rastogi and Klobuchar [47] found a linear dependence between TEC crest and trough ratio at 14:00 LT and EEJ strength at 11:00 LT from 1975 to 1976 over India.

The position of the northern and southern crests is asymmetric with respect to the magnetic equator (Fig. 5). The equatorial fountain effect is not symmetry with respect to the magnetic equator due to trans-equatorial wind blowing from the northern to southern hemisphere and also an asymmetry in \( \mathbf{E} \times \mathbf{B} \) drift. As mentioned earlier, this wind can bring more ionization to the southern hemisphere but also push the crest farther from the magnetic equator. Another contributing factor could be the location of the magnetic equator in the northern hemisphere over Africa. Kassa et al. [15] had previously reported the asymmetry in the position of the crests of
the EIA over East Africa during 2012. Le Huy et al. [16] found an asymmetry between the
amplitude and the position of the two crests of the EIA over the Asian sector.

The post sunset peaks in ionization (Figs. 4 and 6) are brought about by the pre-reversal
enhancement (PRE) in eastward electric field. It is important to recall that equatorial electric
field during quiet time period is eastward (upward drift) before reversing to westward at about
2100 LT. Before the reversal at sunset an increase in electric field occurs. This is the so-called
PRE [48]. The increased electric field redistributes ionization near the crests. This additional
ionization in conjunction with neutral wind counters the normal decay of ionization thus,
producing a second peak or ledge in ionization [49]. The position of the post sunset crests did not
vary significantly on a seasonal basis (Fig. 6). However, it was found to be asymmetric with
respect to the magnetic equator. This variability is controlled by the variability of the PRE as
well as transequatorial wind.

During the Halloween storm day, westward electric field associated with the southward turning
of IMF $B_z$ as well as increase in convection electric field [50] in the local post sunset to midnight
period manifested as negative perturbation in $\Delta H$. Such westward prompt penetration electric
field (PPEF) acted to suppress the regular PRE, thereby preventing ionization to be lifted up. As
such, both peaks of the EIA could not form in the post sunset period. Generally, during similar
electrodynamic conditions (westward electric field), the formation of ionospheric irregularities is
usually inhibited during a geomagnetic storm [29].

5. Conclusions

In this paper, the variations of the position and magnitude of the crests of the Equatorial
Ionization Anomaly over East Africa in the noon and post sunset sector have been investigated
using GPS TEC data obtained from a chain of 12 GPS receivers extending from the southern to
northern hemisphere during year 2013.

(i) The drift as estimated by delta H was found to be a crucial parameter driving the dynamics of
the position and magnitude of the crests of the EIA on a monthly and seasonal basis. As such, the
northern and southern crests formed within 4.91° to 7.36° and -9.17° to -12.6° dip latitude during
noon period; 8° to 11.7° and -9° to -16° dip latitude during post noon period respectively.
Particularly, variations of the magnitude of the EIA crests were more obvious during post sunset period with the southern crest developing more than the northern crest.

(ii) The time response of the formation of the noon crests of the EIA was about 3 hours after the time of occurrence of minimum $\Delta H$. Additionally, the development of the post sunset crests was inhibited during the Halloween day storm of 30th October 2013 as a result of storm time westward electric field.

(iii) The significance of the contribution of plasma drift velocities during noon period was further highlighted with the existence of good correlation between crests position and the EEJ strength. Nevertheless, moderate correlation between crests magnitude and EEJ implied the existence of additional mechanisms mainly transport as well as rate of recombination over both hemispheres.

(iv) The poleward and equatorward movement of the crests during equinoxes and winter/summer respectively has not been reported before and as such, underscores the significance of thermospheric meridional wind in modulating the morphology of the African EIA. However, wind pattern as well as transport processes are mechanisms that still require investigation over Africa.

Acknowledgements
The authors wish to express their gratitude to the following organizations: UNAVCO for the GPS TEC data, the World Data Center for Geomagnetism (WDC) for Dst and SYM-H data, and INTERMAGNET for the magnetometer data. We also acknowledge the Dominion Radio Astrophysical Observatory (DRAO), Penticton for the solar flux data, the ACE SWEPAM team for the ACE data and the GFZ German Research Centre for Geosciences for the international quietest days. The authors thank E. Yizengaw, E. Zesta, M. B. Moldwin and the rest of the AMBER and SAMBA team for their magnetometer data. AMBER is operated by Boston College and funded by NASA and AFOSR. SAMBA is also operated by UCLA and funded by NSF.


**Figure caption**

Fig.1. Location of the stations: the brown solid curve indicates the magnetic equator (dip = 0) while broken curves represents ± 15 degree dip latitudes.

Fig.2. Monthly variations of the position and magnitude of the African EIA crests for the year 2013.

Fig.3. Monthly variations of the magnitude of the north crest (panel 1) and south crest (panel 2) during noon period.

Fig.4. Variations of the position of the African EIA crests for 2013 during the post sunset period (≈ 21:00 LT). The double arrow shows the latitudinal extent of variation during this year.

Fig.5. Seasonal variations of the EIA for the year 2013.

Fig.6. Seasonal variations during the post sunset period (≈ 21:00 LT). The error bars represents the standard deviation used to demarcate the limit of day-to-day variability.
Fig. 7. Monthly variations of ∆H from January to September 2013 (No data from October to December). The error bars represent the standard deviation used to represent the day-to-day variability.

Fig. 8. Seasonal variations of ∆H for year 2013. The error bars represent the standard deviation used to demarcate the limit of day-to-day variability.

Fig. 9. Comparison of EIA and delta H during winter, equinoxes and summer.

Fig. 10. Monthly PI index for the year 2013.

Fig. 11. Correlation between (a) crests magnitude and Delta H, and (b) crests position and Delta H during noon period.

Fig. 12. Variations of interplanetary and magnetic parameters during from 29 to 31 October 2013.

Fig. 13. Response of the EIA to the Halloween storm of 30 October 2013.
Fig. 1. Location of the stations: the brown solid curve indicates the magnetic equator (dip = 0) while broken curves represents ± 15 degree dip latitudes.
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Fig. 3. Monthly variations of the magnitude of the north crest (panel 1) and south crest (panel 2) during noon period.
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Fig. 9. Comparison of EIA and delta H during winter, equinoxes and summer.

Fig. 10. Monthly PI index for the year 2013.
Fig. 11. Correlation between (a) crests magnitude and Delta $H$, and (b) crests position and Delta $H$ during noon period.
Fig. 12. Variations of interplanetary and magnetic parameters during from 29 to 31 October 2013.

Fig. 13. Response of the EIA to the Halloween storm of 30 October 2013.