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Quiet Time Correlation Between Geomagnetic Field Variations and the Dynamics of the East African Equatorial Ionosphere

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Abstract: The equatorial ionosphere is highly dynamic and consequently poses serious threats to communication and navigation systems. As a result, proper understanding of ionospheric dynamics is important. The present paper presents the results of an investigation of the correlation between quiet time vertical total electron content $(VTEC)$ and solar quiet variation in the horizontal component of geomagnetic field $(Sq(H))$ from low solar activity year (2009) to the high solar activity year (2014) within the equatorial East African sector using statistical analysis method. Values of $Sq(H)$ were observed to increase steadily from around 0700LT attaining maximum values around 1100-1200LT, then descending towards zero level and beyond. The magnitudes of $VTEC$ increase uniformly from around 0600-1000LT, then gradually, attaining maximum values around 1300-1500LT. The time instants of occurrence of these peaks are mainly controlled by $\vec{E}\times\vec{B}$ drifts and photo-ionization. The correlation coefficients (ccs) between $VTEC$ and $Sq(H)$ were found to be strongest during the ascending phase (0600-1200LT), ranging from 0.69 to 0.98 at Addis Ababa and 0.61 to 0.97 at Nairobi. During the descending phase (1300-1800LT), ccs range from -0.28 to 0.89 at Addis Ababa and-0.06 to 0.76 at Nairobi. A high level of significance (99.98%) of ccs was obtained. The good linear relationship is attributed to the independent increase of the eastward electric field and photo-ionization on $VTEC$ while poor relationship is possibly due to domination of photo-ionization over equatorial ionization anomaly (EIA) development. The annual ccs between $VTEC$ and $Sq(H)$ exhibit a general dependence on solar activity at Addis Ababa, closer to the dip equator, rather than at Nairobi during the ascending phase of the daytime. This observation suggests that the EEJ changes linearly with change in solar activity, thus streamlining the variations in TEC, through $\vec{E}\times\vec{B}$ drifts, and $Sq(H)$ by intensifying the eastward equatorial electric field.

Keywords: Equatorial Electrojet, Equatorial Ionization Anomaly, Solar Quiet, Total Electron Content, Correlation

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1. Introduction

The Earth's upper atmosphere absorbs photons at wavelengths shorter than 125nm, creating conducting layers of electrons and ions that are embedded in the neutral upper atmosphere from about 60 km to 1000 km: the layers of the ionosphere (Goodman, 2005). The process begins when an atom or a molecule intercepts an extreme ultraviolet (EUV) or X-ray photon of energy sufficient to detach an electron resulting in a positive ion and free electron. Ions and to a lesser degree, electrons in the E-region of the ionosphere are coupled to the neutral components of the atmosphere, hence follow their dynamics. Atmospheric winds and tidal oscillations of the atmosphere compel the E-region ion component to move across the magnetic field lines, while electrons move much slower at right angles to both the field and neutral wind (Baumjohann and Treumann, 1996). Such relative movement constitutes an electric current and the separation of charge produces an electric field which in turn influences the current. The relationship between conductivity σ, electric field, $\vec{E}$ and neutral wind velocity, $\vec{v}_n$ is obtained by adding an electric field term $\vec{v}_n \times \vec{B}$ to the Ohm's law equation to write

$$\vec{J} = \sigma.\left(\vec{E} + \vec{v}_n \times \vec{B}\right) \quad (1)$$

For mid and low latitude dynamo currents, the main driving force is the $\vec{v}_n \times \vec{B}$ electric field induced by movement of ions across the magnetic field. The current system created by the tidal motion is called solar quiet (Sq). The Sq currents can be estimated on the ground by magnetometers hence allowing the determination of the strength of the currents. In accordance with the contrast between day and night equatorial E-region electron densities, the Sq currents are concentrated in the day side region (Baumjohann and Treumann, 1996). The Sq field is known to vary slowly in amplitude and phase through the months of the year (Campbell, 2003).

The integrated electron density along the ionospheric ray path between the satellite and receiver, the total electron content (TEC) modifies the propagation of radiowaves. Consequently, TEC is a key parameter of the ionosphere in the description of the ionospheric propagation of radio signals.

The application of trans-ionospheric communication has increased enormously in the recent past, for example in Global Positioning System (GPS). However, the dispersive ionosphere introduces a time delay in the 1.57542 GHz (L1) and 1.22760 GHz (L2), simultaneous transmissions from GPS satellites orbiting at 20,200km. Such delays can cause effects such as range errors and scintillations. Fortunately, the relative ionospheric delay of the two signals is directly proportional to TEC (Sharma *et al*., 2012). It follows that the time delay measurements of L1 and L2 frequencies can be converted to TEC along the ray path from the receiver to the satellite (Lanyi and Roth, 1988). TEC measurements are made using the principle of the effect of the ionosphere on radio wave propagation. Ionospheric irregularities are capable of causing GPS signal delays, degradation and loss of lock in extreme cases, resulting in inefficient operations of ground and space based Global Navigation Satellite System (GNSS) and communication applications (Veenadhari and Alex, 2006, Oron *et al.,* 2013). Rapid fluctuations in the geomagnetic field can cause geomagnetically induced currents in ground based conductor systems such as electric power and telephone lines (Viljanen *et al*., 2006).

Extensive studies to characterize the dynamics of the ionosphere based on TEC (for example, Basu and Gupta, 1967, Olwendo *et al*., 2012, Sharma *et al*., 2012, Oron *et al*., 2013, Oryema *et al*., 2015) and Sq (for example, Rabiu, 2001, Rabiu *et al*., 2007, Rabiu *et al*., 2011, El Hawary *et al*., 2012, Abbas *et al*., 2013) have been done. The effect of $Sq(H)$ on TEC and other ionospheric parameters has been investigated. For example, Anderson *et al.,* (2002) used one minute averages of $Sq(H)$ from Peru, South America to give a quantitative report concerning the relationship between ΔH and $\vec{E} \times \vec{B}$ drifts. Their results based on 10 days of observations, reported a direct proportionality between ΔH and $\vec{E} \times \vec{B}$ drifts. Stolle *et al*., (2008) investigated the response of EIA derived from the proxy of equatorial electrojet (ΔH) over the equatorial crest and trough within South America by use of Challenging Minisatellite Payload (CHAMP). The study found that a weak Counter electrojet (CEJ) event (less than 1 hour duration with magnitude less than -5 nT) is associated with eastward electric field but EIA does not respond to it. However, if a strong CEJ occurs, the magnitude of EIA gradually decreases and reduces significantly with response time of approximately 1 to 2 hours after the occurrence of the CEJ. Mala *et al*., (2009) studied ionospheric variations based on TEC and equatorial electrojet (EEJ) near the EIA crest in India and discussed the possible mechanisms responsible for the variations. The study found that TEC variations exhibit a positive correlation with solar activity during geomagnetic quiet conditions. Bolaji *et al*., (2013) used TEC and H-field for 10 quiet days to study the relationship between TEC variations and $Sq(H)$ over the equatorial trough station, Ilorin in Nigeria. They found that a relationship exists between the two parameters.

The dynamics of the equatorial ionosphere within the East and West African regions are different (Rabiu *et al*., 2011). Due to this regard, the present paper focuses on the simultaneous variation of $Sq(H)$ and TEC at two equatorial stations within and outside the EEJ belt in East Africa.

In this paper, quiet time correlation between the variations of the horizontal (H) component of the geomagnetic field and ionospheric TEC values within the East African equatorial sector from the low solar activity year (2009) to the high solar activity year (2014) of the Solar Cycle 24 has been investigated using geomagnetic field data and corresponding co-located dual frequency GPS derived TEC data obtained from Addis Ababa (Ethiopia) and Nairobi (Kenya).

2. Data and Methods of Analysis

The data used in the present paper were obtained from magnetic observatories (International Real-time Magnetic Observatory Network (INTERMAGNET) and MAGnetic Data Acquisition System (MAGDAS)) together with corresponding co-located International GNSS Service (IGS) stations at Addis Ababa (geomagnetic latitude 0.18°N, geomagnetic longitude 110.47°E) and Nairobi (geomagnetic latitude 10.65°S, geomagnetic longitude 108.18°E). The geomagnetic observatories used were INTERMAGNET and MAGDAS at Addis Ababa and Nairobi respectively.

2.1. Determination of Geomagnetic Field Variations

All the days with maximum planetary K-index $K_p \le 2+$ were classified as quiet days. Such days were extracted from the list of K_p index posted by the World Data Centre for Geomagnetism, Kyoto on the website (http://wdc.kugi.kyoto-u.ac.jp/cgi-bin/kp-cgi).

A quiet level baseline for each day was defined as in the work of Yamazaki and Kosch (2015).

$$H_0 = \sum_{t=1}^{300} \frac{H_t}{300} \tag{2}$$

where H_t is the horizontal component of the geomagnetic field at time t.

The variation amplitude was defined by the relation:

$$\Delta H_t = H_t - H_0 \tag{3}$$

The resultant variation amplitude for any hour is associated with the ionospheric current at that hour (Rastogi *et al.*, 2004).

Non-cyclic variation, was performed on the data (Matsutisha and Maeda, 1965, Rastogi *et al.*, 2004) in the form

$$\Delta_c = \frac{(\Delta H_1) - (\Delta H)_{1440}}{1439} \tag{4}$$

where 1439 is the number of intervals in the dataset.

Setting $t = 1440 \Rightarrow 1439 = t - 1$ in equation (4) gives a general equation that represents the solar quiet variation as

$$Sq_t(H) = (\Delta H)_t + (t-1)\Delta_c : t = 1:1440 \tag{5}$$

2.2. Analysis of GPS Derived Data

The Receiver Independent Exchange (RINEX) observation files were processed using Gopi Seemala RINEX processing software version 2.9.3 (http://seemala.blogspot.com/), giving the desired (CMN) output files. The CMN files contain data for all visible satellites and elevation angles; hence some instants of time are repeated if more than one satellite passes simultaneously. Moreover, in order to obtain accurate ionospheric parameters above the station, it is important to set the elevation angle high (Sharma *et al.*, 2012, Kumar, 2016). The present study set a threshold elevation angle of 70°**.** This elevation limits the field of view of the GPS receiver hence reducing effects of low elevation angles such as those of troposphere, water vapour scattering and multipath. AMATLAB script was written to read each CMN file, select data corresponding to elevation angle greater or equal to 70° for all satellite pseudo random numbers (PRNs) and average repeated time instants, giving unique outputs.

2.3. Investigation of the Correlation Between $Sq(H)$ and VTEC

The geomagnetic field data has a resolution of 1 minute while the TEC data has a resolution of 30 seconds, a MATLAB interpolation process was applied to ensure that only data occurring at the same instants of time are investigated for possible correlation, after which correlation coefficients were computed. The statistical test for significance (t-test) of the observed correlation coefficients was performed.

3. Results and Discussion

3.1. Daytime Variations of VTEC and $Sq(H)$ at Addis Ababa

Simultaneous $VTEC$ and $Sq(H)$ variations on the quiet days from each month at Addis Ababa (AAB) for the year 2011, 2012 and 2013 are shown in Figures 1, 2 and 3 respectively.

The values of $VTEC$ are plotted on the left-hand side of the y-axis along with the corresponding $Sq(H)$ on the right-hand side of the y-axis in each month. The values of $VTEC$ are given in blue lines while $Sq(H)$ are given in red lines. The mean values of $VTEC(<VTEC>)$ and mean values of $Sq(H)(<Sq(H)>)$ are also shown in each graph. The black horizontal lines indicate the zero level of $Sq(H)$ at Addis Ababa.

A phase difference in the occurrence of peaks in TEC and Sq(H) is observed in Figure 1, Figure 2 and Figure 3. This is attributed to the difference in the strength of the driving mechanisms of the respective variables during these instants of time. That is, the decreasing solar zenith angle increases the intensity of solar flux thereby sustaining the increase of electron density through photo ionization. On the other hand, the eastward electric field that drives Sq(H) maximizes earlier then changes direction to westward.

Day-to-day variation of TEC and Sq(H) is also observed. The variations in TEC is attributed to changes in solar activity, intensity of incident solar radiation and solar zenith angle at which they impinge on the Earth's atmosphere as well as the contributions by EUV flux, EEJ strength and local atmospheric conditions in the thermosphere (Ayorinde *et al.,* 2016 and references there in). The day-to-day variation in Sq(H) is credited to solar activity, neutral thermospheric winds which provide the energy needed to maintain the zonal equatorial electric field (Alken and Maus, 2009) and EEJ.

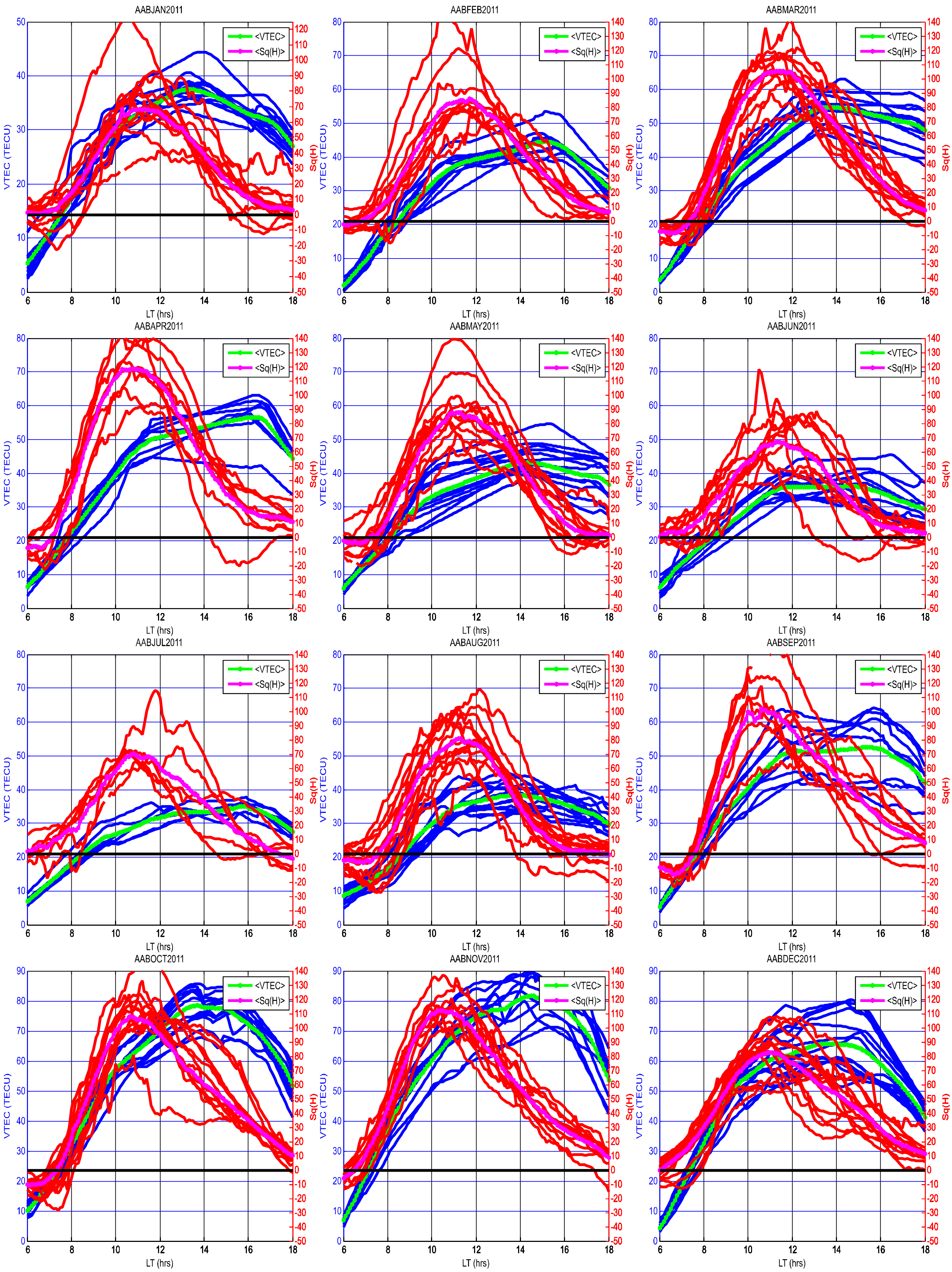

Figure 1. *Simultaneous day time variation of VTEC and Sq (H) at Addis Ababa in 2011.*

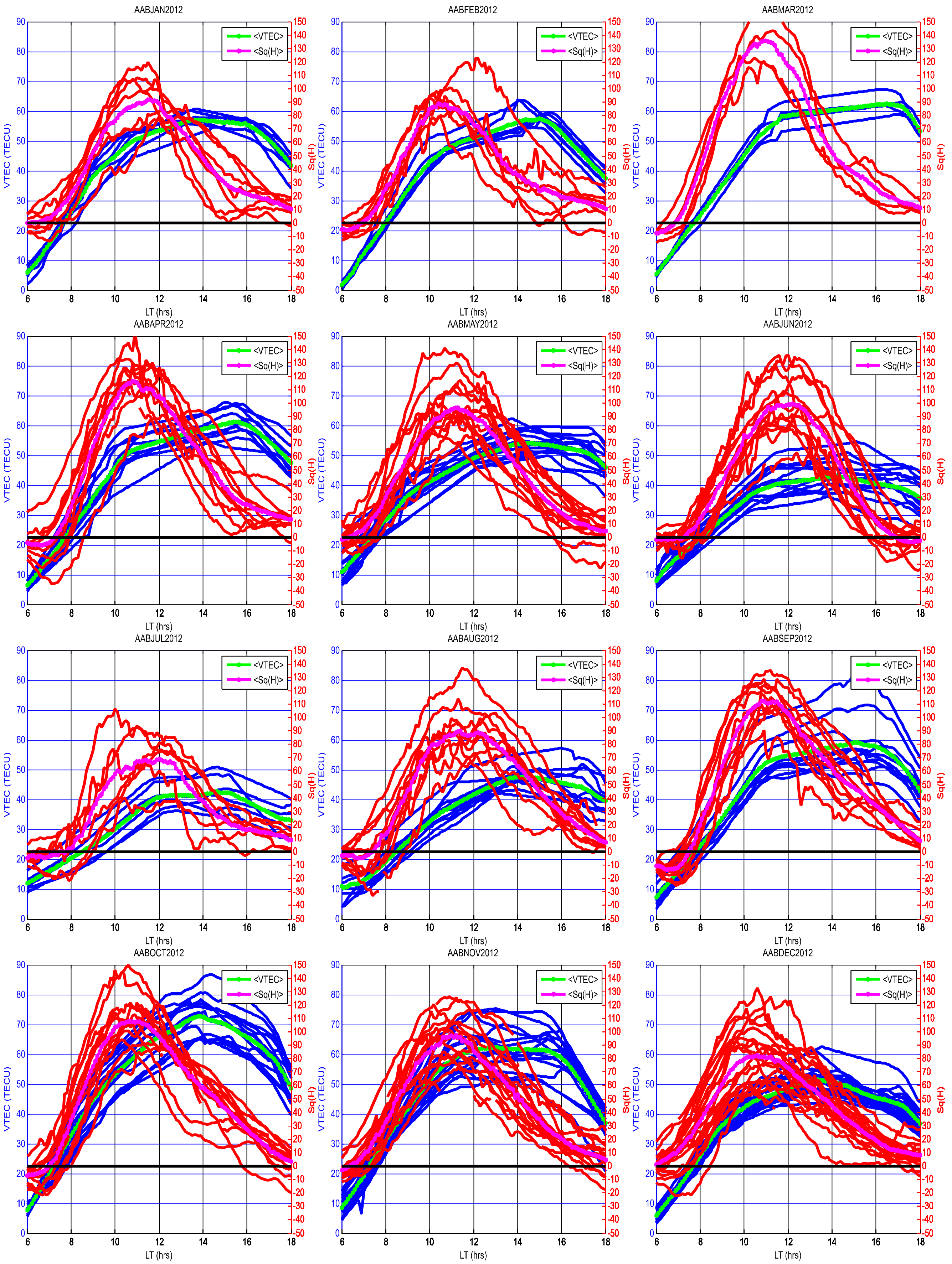

Figure 2. *Simultaneous daytime variation of VTEC and Sq(H) at Addis Ababa in 2012.*

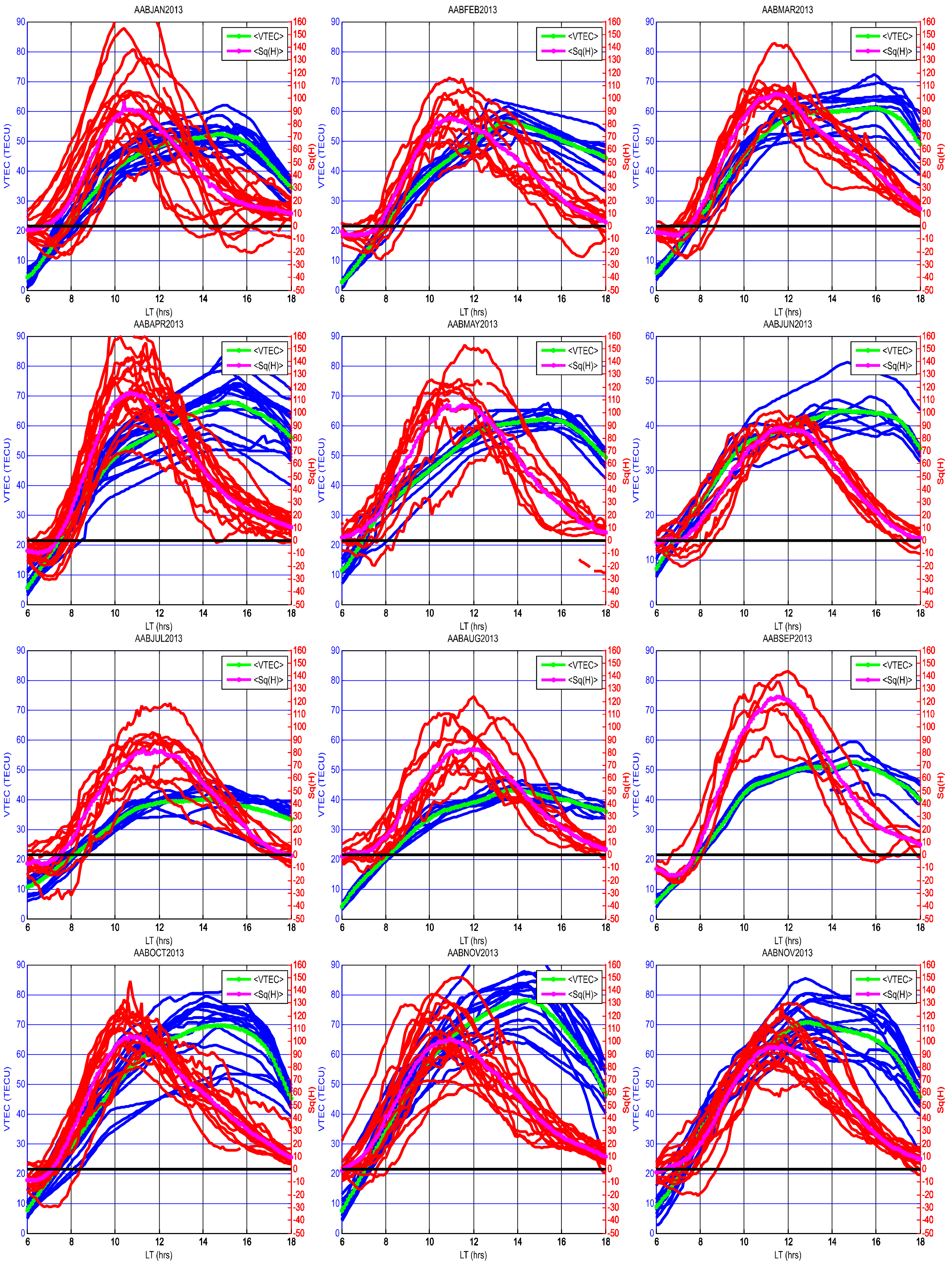

Figure 3. *Simultaneous daytime variation of VTEC and Sq(H) at Addis Ababa in 2013.*

3.1.1. Ascending Phase of Daytime (0600-1200LT) at Addis Ababa

The magnitudes of $VTEC$ have been found to increase steadily from 0600LT to around 0900LT during the entire period of study, consistent with the results of Chakraborty and Hajra (2008) as well as Bolaji *et al.*, (2013). Chakraborty and Hajra (2008) suggested that the contribution of solar flux to TEC maximizes around 0800-0900LT after which the rate remains approximately constant. Nevertheless, during this assumed constant period of rate of production, EIA can continue to dominate due to strong reversal of westward nighttime to the eastward daytime electric field around 0700LT. This can affect the steep increase on $VTEC$ around 1000LT resulting in its gradual increase and pre-noon peaks. The $Sq(H)$ averagely maximizes around 1100LT-1200LT. Maximized $Sq(H)$ implies full development of EIA caused by strongest vertical $\vec{E}\times\vec{B}$ drifts due to EEJ.

The $Sq(H)$ values attained their maxima earlier around 1100LT and 1200LT compared to that of $VTEC$ that occurred around 1300LT and 1500LT, except for some pre-noon peaks during the ascending phases. The pre-noon peaks are attributed to the absence of counter electrojet during sunrise hours, thereby creating great plasma intensity on $VTEC$ before and during noon. On the other hand, the absence of pre-noon and noon peaks result from the increase in the intensity of solar radiation which is inversely proportional to the solar zenith angle, making photo-ionization dominant over EIA forming mechanisms. The $Sq(H)$ at Addis Ababa generally attains its peak around 1100LT during low solar activity years 2009 and 2010 and near noon during high solar activity years 2013 and 2014 consistent with the results of Rastogi and Iyer (1976).

The annual correlation coefficients between $VTEC$ and $Sq(H)$ were computed for the ascending phase of the daytime variation as shown in Figure 4.

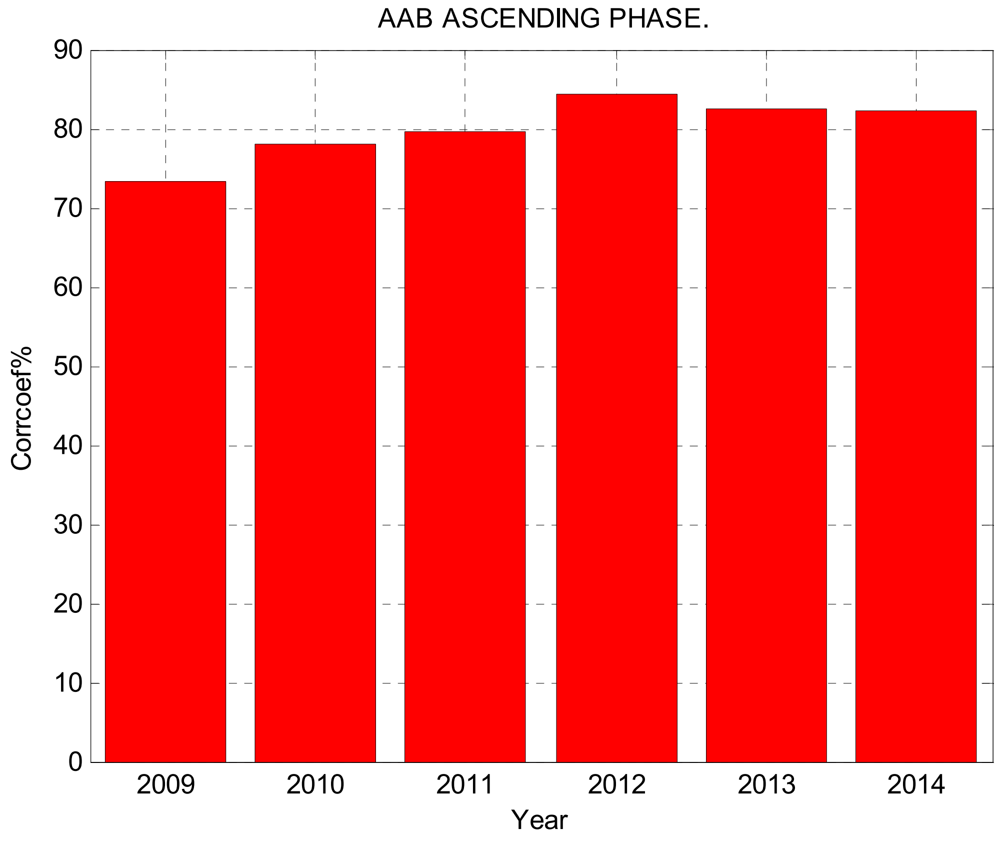

Figure 4. *Annual ascending phase correlation between VTEC and Sq(H) at Addis Ababa from 2009 to 2014.*

Figure 4 shows strong positive linear relationship between $VTEC$ and $Sq(H)$. The correlation coefficient during high solar activity year (2014) is greater than the corresponding correlation coefficient in the low solar activity year (2009). The annual correlation is highest in the year 2012, possibly due to the high F10.7cm solar radio flux emission during the year (http://www.swpc.noaa.gov/phenomena/f107-cm-radio-emissions).

3.1.2. Descending Phase of Daytime (1300-1800LT) at Addis Ababa

During the descending phase of the daytime, ccs computed range from -0.28 in March, 2014 to 0.89 in December, 2014.

Figure 5 shows the annual correlation coefficients between $VTEC$ and $Sq(H)$ at Addis Ababa during the descending phase of the daytime (1300-1800LT). The correlation is, generally, poor and attained the highest value of 0.39 in the year 2011.

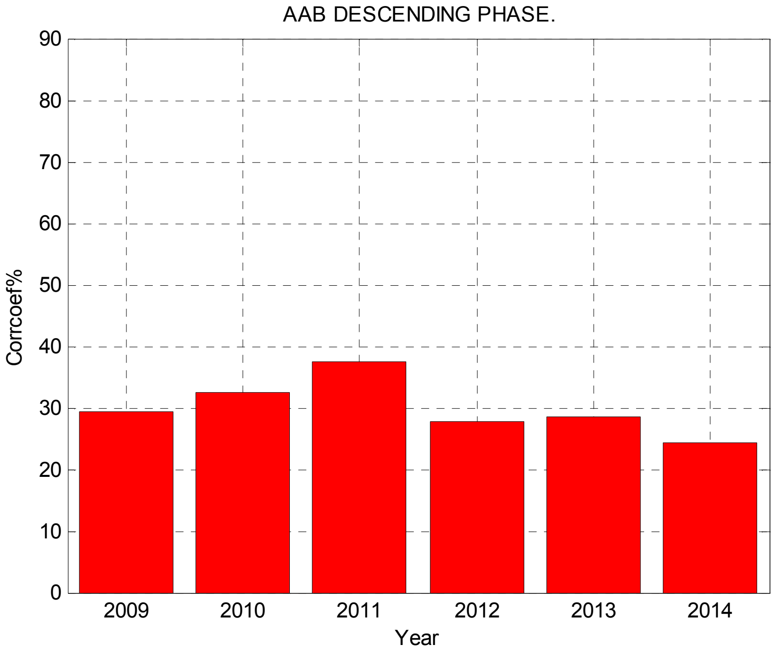

Figure 5. *Annual descending phase correlation between VTEC and Sq(H) at Addis Ababa from 2009 to 2014.*

The poor correlation is attributed to the discrepancy in the instants of turning points of $VTEC$ and $Sq(H)$ graphs. For example, after $Sq(H)$ has reached its peak and begun to descend, $VTEC$ is observed aiming to attain its peak resulting in phase shifts. The discrepancy in the instants of peak $VTEC$ and $Sq(H)$ is caused by two physical processes namely $\vec{E}\times\vec{B}$ drifts caused by the eastward electric field and photo-ionization caused by solar flux. The near perpendicular solar zenith angle to the ionosphere maintains photo-ionization, hence sustaining the increase in $VTEC$. However, $Sq(H)$ changes direction westward after reaching its peak and gets to the zero level and beyond due to the change in direction of $\vec{E}\times\vec{B}$ from upward to downward trend.

The correlation coefficients (ccs) between $VTEC$ and $Sq(H)$ values were computed on all the quiet days from each month based on the ascending and descending phases throughout the period of study. These ccs have been tabulated in Table 1.

Table 1. *Correlation coefficient values between VTEC and Sq(H) variations at Addis Ababa.*

Year	Hours (LT)/Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009	0600-1200	0.69	0.89	0.68									
	1300-1800	0.09	0.41	0.36									
2010	0600-1200	0.79	0.79	0.92	0.93	0.81	0.78	0.63		0.89	0.84	0.84	0.84
	1300-1800	0.61	0.42	0.14	0.54	-0.13	0.52	0.43		0.30	0.24	0.52	0.39
2011	0600-1200	0.88	0.90	0.94	0.90	0.88	0.81	0.88	0.93	0.91	0.92	0.91	0.93
	1300-1800	0.54	0.29	-0.06	0.22	0.25	0.43	0.28	0.31	0.63	0.61	0.59	0.50
2012	0600-1200	0.88	0.93	0.92	0.94	0.91	0.88	0.80	0.97	0.94	0.94	0.87	0.82
	1300-1800	0.36	0.16	0.55	0.19	0.17	0.04	0.37	0.13	0.39	0.66	0.49	0.44
2013	0600-1200	0.83	0.89	0.95	0.92	0.83	0.90	0.91	0.90	0.97	0.87	0.88	0.90
	1300-1800	0.18	0.47	0.15	0.18	0.27	0.13	0.26	0.42	0.15	0.49	0.40	0.53
2014	0600-1200	0.86	0.91	0.96	0.91	0.89	0.84	0.90	0.93	0.90	0.94	0.91	0.98
	1300-1800	0.66	0.46	-0.28	0.19	0.21	0.16	0.36	0.30	0.25	0.22	0.36	0.89

Correlation coefficients were computed in order to quantify the degree of the influence of $Sq(H)$ variability on TEC during different phases of the daytime within the East African region.

Table 1 shows that the ccs between $VTEC$ and $Sq(H)$ during the ascending phase (0600–1200LT) are greater than those obtained during the descending phase of the daytime hours and ranged from 0.69 in January, 2009 to 0.98 in December, 2014. This stronger ccs relationship was caused by the continuous independent increase of the magnitudes of $VTEC$ from photo-ionization and $Sq(H)$ magnitudes from the eastward electric field. This implies that photo-ionization on $VTEC$ variation increases linearly with the increase in $Sq(H)$.

3.2. Daytime Variations of $VTEC$ and $Sq(H)$ at Nairobi

Simultaneous $VTEC$ and $Sq(H)$ variations on the quiet days from each month at Nairobi (NAB) have been displayed in Figures 6 and 7, corresponding to the years 2010 and 2011 respectively.

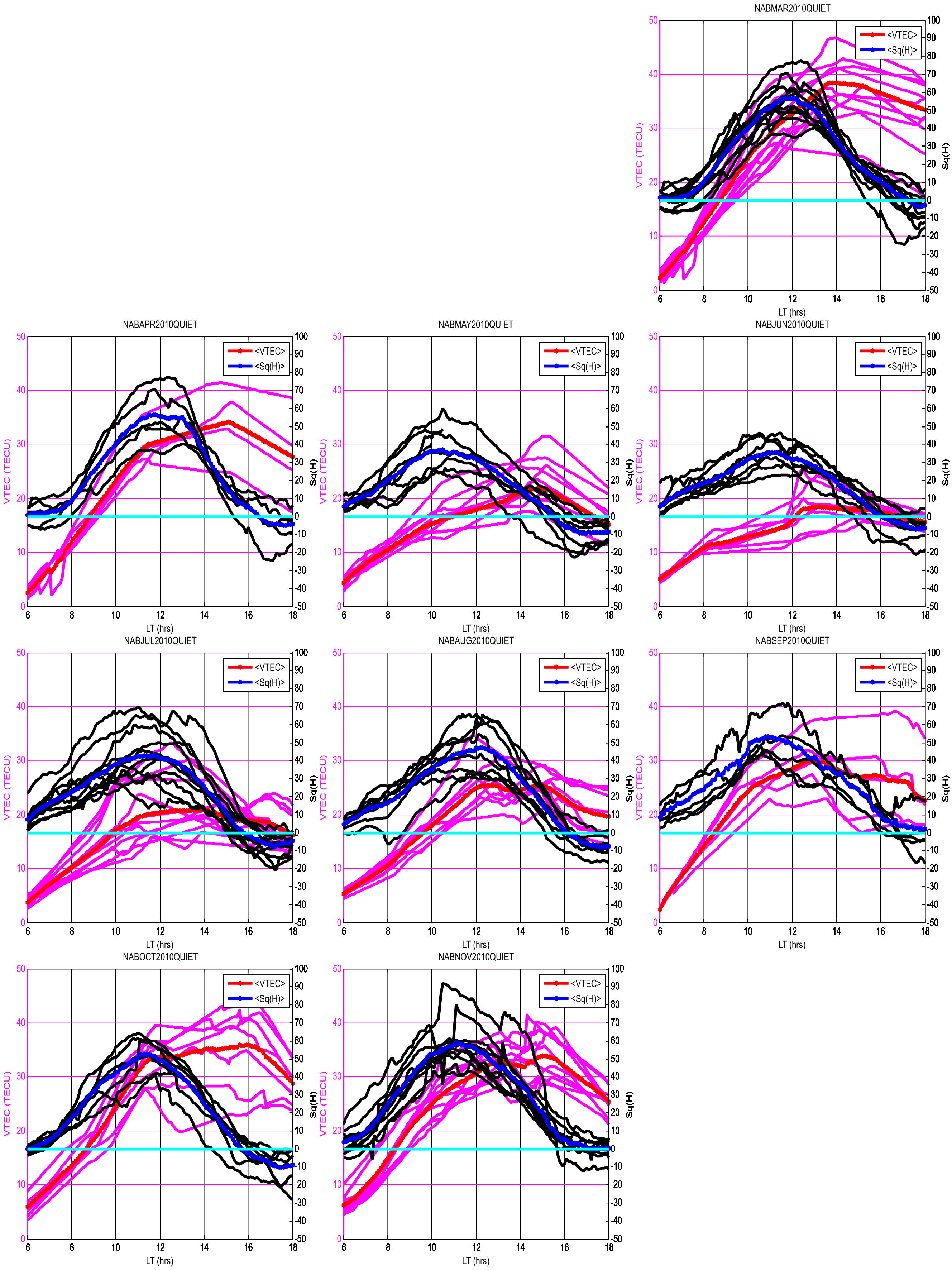

Figure 6. *Simultaneous daytime variation of VTEC and Sq(H) at Nairobi in 2010.*

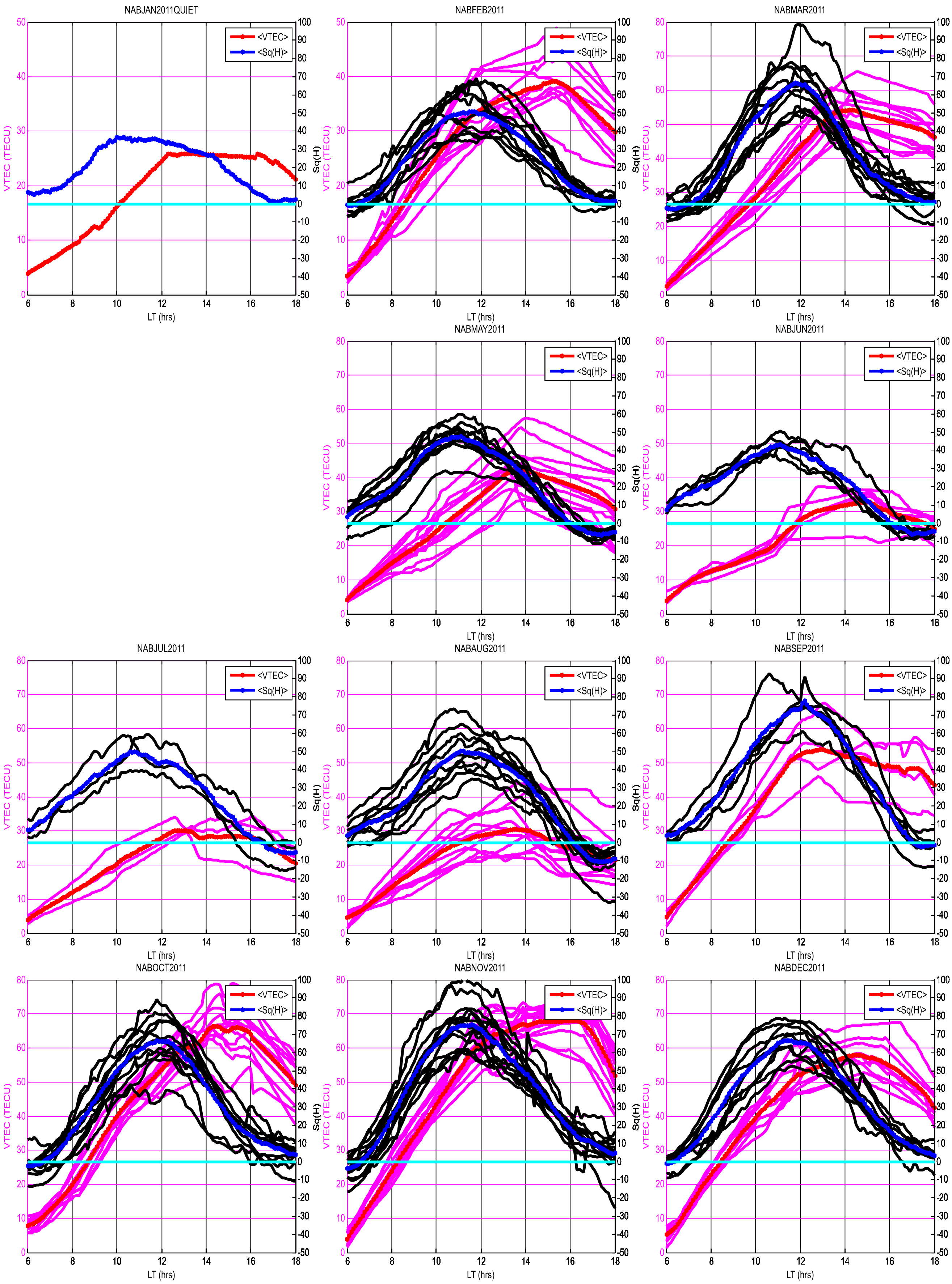

Figure 7. *Simultaneous daytime variation of VTEC and Sq(H) at Nairobi in 2011.*

The values of $VTEC$ are plotted on the left-hand side of the y-axis along with the corresponding $Sq(H)$ on the right-hand side of the y-axis in each month. The values of $VTEC$ are given in magenta coloured lines while $Sq(H)$ are given in black coloured lines. The mean values of $VTEC(<VTEC>)$ and mean values of $Sq(H)(<Sq(H)>)$ are also shown in each graph. The black horizontal lines mark the zero level of $Sq(H)$ at Nairobi.

TEC and $Sq(H)$, at Nairobi station exhibit day-to-day variation due to the day-to-day variation in solar flux and electric field.

3.2.1. Ascending Phase of Daytime (0600-1200LT) at Nairobi

The values of $VTEC$ increase steadily, from 0600LT to around 0900LT during the entire period of study, similar to observations at Addis Ababa. The increase then becomes gradual resulting in peak values in the range from 1300LT to 1500LT. The peak values of $VTEC$ at Nairobi are smaller than those at Addis Ababa, for example in the year 2011. These observations are attributed to the presence of EEJ at Addis Ababa which acts to deposit plasma on $VTEC$. $Sq(H)$, increases from 0800LT to around 1100-1200LT when they attain their peaks. Nevertheless, the magnitudes of $Sq(H)$ peaks are smaller at Nairobi than at Addis Ababa, for example in the year 2011, mainly due to the EEJ that is imposed onto the normal Sq current system at Addis Ababa. Moreover, the magnitudes of $VTEC$ and $Sq(H)$ at both stations are higher during high solar activity year (2014) than during low solar activity year (2009).

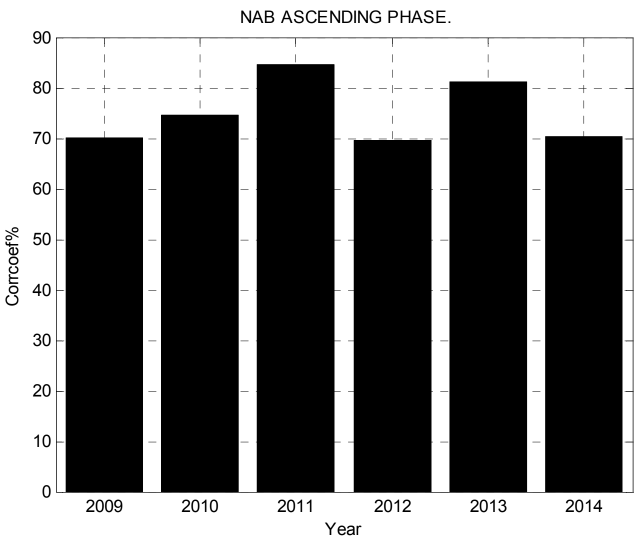

Figure 8. Annual ascending phase correlation between VTEC and Sq(H) at Nairobi from 2009 to 2014.

The annual correlation coefficients between $VTEC$ and $Sq(H)$ were also determined for the ascending phase of the daytime variation as displayed in Figure 8.

Figure 8 confirms the existence of fairly good (about 0.70) to strong (about 0.85) positive correlation between $VTEC$ and $Sq(H)$ annually at Nairobi during the ascending phase (0600-1200LT). Solar activity dependence of the annual ccs is not clearly exhibited at Nairobi as opposed to Addis Ababa where the annual ccs generally increase with increase in solar activity.

3.2.2. Descending Phase of Daytime (1300-1800LT) at Nairobi

During the descending phase of the daytime, ccs range from-0.06 in March, 2014 to 0.76 in December, 2013, depicting poor correlations in general. Incidentally, considering the annual ccs during the descending phase, the greatest positive correlation was observed in the year 2011, a year of moderate solar activity, just like at Addis Ababa.

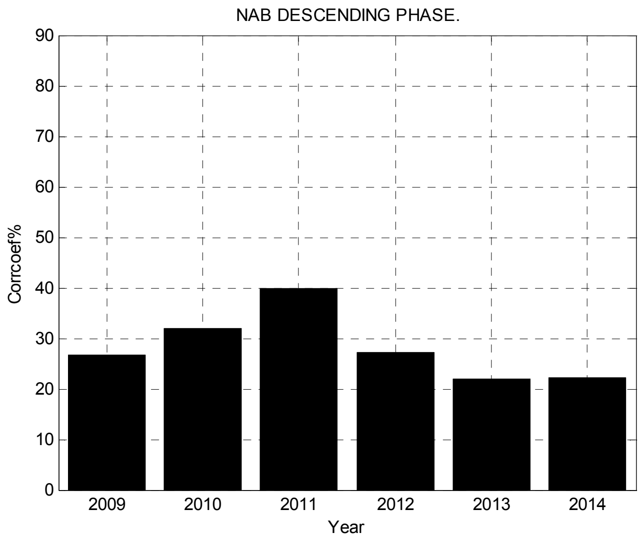

Figure 9. Annual descending phase correlation between VTEC and Sq(H) at Nairobi, from 2009 to 2014.

The ccs between $VTEC$ and $Sq(H)$ were calculated for each month based on ascending (0600-1200LT) and descending (1300-1800LT) phases in the entire period of study. The results are tabulated in Table 2. Table 2 indicates that during the ascending phase (0600-1200LT), ccs were stronger, ranging from 0.61 in June, 2010 to 0.97 in November, 2013. These observations of strong linear relationship between $VTEC$ and $Sq(H)$ are similar to those obtained at Addis Ababa for the same period. Further, the statistical test of significance (t-test) of the correlation coefficients at the two stations indicates a high level of significance at 99.98%, confirming the observed relationships are significant.

Table 2. *Correlation coefficient values between VTEC and Sq (H) variations at Nairobi.*

Year	Hours (LT)/Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009	0600-1200	0.75	0.84	0.94	0.84	0.78		0.84	0.87				
	1300-1800	0.68	0.59	0.04	0.31	0.27		0.40	0.27				
2010	0600-1200			0.91	0.88	0.69	0.61	0.62	0.82	0.83	0.94	0.90	
	1300-1800			0.24	0.16	0.11	0.37	0.27	0.29	0.24	0.26	0.29	
2011	0600-1200	0.92	0.88	0.96	0.90	0.76	0.82		0.91	0.94	0.92	0.93	0.93
	1300-1800	0.34	0.34	0.34	0.22	0.22	0.35		0.34	0.49	0.39	0.23	0.49
2012	0600-1200					0.94	0.81					0.95	0.82
	1300-1800					0.07	0.37					0.39	0.40
2013	0600-1200	0.96										0.97	0.91
	1300-1800	0.73										-0.04	0.76
2014	0600-1200	0.89	0.92	0.84	0.92	0.89	0.96						
	1300-1800	0.52	0.25	-0.06	0.32	0.39	0.50						

4. Conclusions

In the present paper, the variation of vertical total electron content $(VTEC)$ and solar quiet variation of the horizontal component of the geomagnetic field $(Sq(H))$ within (Addis Ababa) and outside (Nairobi) the EEJ belt using quiet days' data for the period 2009 to 2014 has been investigated. The observed variation in VTEC is attributed to changes in solar activity, intensity of incident solar radiation and solar zenith angle at which the radiations impinge on the Earth's atmosphere as well as the contributions by EUV flux, EEJ strength and local atmospheric conditions in the thermosphere as in the work of Ayorinde *et al.,* (2016) and references there in while the day-to-day variation in $Sq(H)$ is credited to solar activity, neutral thermospheric winds which provide the energy needed to maintain the zonal equatorial electric field as indicated in the work of Alken and Maus, (2009) and EEJ. The time instants of occurrence of peaks in $VTEC$ are controlled by the zonal electric field and solar zenith angle. These results are consistent with those of previous researches for example, Rastogi and Iyer, (1976), Chakraborty and Hajra, (2008), Rabiu *et al.*, (2011), Bolaji *et al.*, (2013) and Ayorinde *et al.* (2016). The trend of variation of VTEC and $Sq(H)$ in this paper are consistent with those of Bolaji *et al.*, (2013), the magnitudes of peaks larger in the East African equatorial region than West Africa due to the stronger equatorial electrojet in East African sector. The ccs between $VTEC$ and $Sq(H)$ calculated throughout the entire period of study show that during the ascending phase of the daytime (0600-1200LT) the linear relationship is stronger than during the descending phase (1300-1800LT). The statistical test of significance (t-test) of the correlation coefficients at the two stations indicates a high level of significance at 99.98%, confirming the significance of the correlation coefficients. The observed strong relationship during ascending phase of the daytime is attributed to the independent increase of the eastward electric field on $Sq(H)$ and photo-ionization on $VTEC$. Poor relationship during the descending phase is attributed to the discrepancy in the instants of turning points of $VTEC$ and $Sq(H)$ graphs. This discrepancy in the instants of peak $VTEC$ and $Sq(H)$ is controlled by two physical processes namely, $\vec{E}\times\vec{B}$ drifts caused by the eastward electric field and photo-ionization, caused by solar flux. The near perpendicular solar intensity to the ionosphere maintains photo-ionization, hence sustaining the increase in $VTEC$. The $Sq(H)$ changes direction westward after reaching its peak and gets to the zero level and beyond due to the change in direction of $\vec{E}\times\vec{B}$ from upward to downward trend. The magnitudes of peak $VTEC$ and $Sq(H)$ at Addis Ababa have been found to be greater than the corresponding peaks at Nairobi; mainly attributed to the strong EEJ at Addis Ababa. The annual ccs between $VTEC$ and $Sq(H)$ exhibit a general dependence on solar activity at Addis Ababa (closer to the dip equator) rather than at Nairobi during the ascending phase of the daytime. This observation suggests that the EEJ changes linearly with change in solar activity, thus streamlining the variations in TEC, through $\vec{E}\times\vec{B}$ drifts, and $Sq(H)$ by intensifying the eastward equatorial electric field.

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