United Nations Office for Outer Space Affairs

United Nations/Azerbaijan Workshop on the International Space Weather Initiative: The Sun, Space Weather and Geosphere

31 October – 4 November 2022
Baku, Azerbaijan

Comparison of the daytime variability of equatorial electrojet and vertical drift velocity inferred from ground-based magnetometers and C/NOFS observations in Africa

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Outline

- Aim
- Introduction
- Data Analysis and Method
- Results and discussion
- Conclusion

Aim

This study aims at discussing longitudinal effects on the variability of the vertical ExB drift velocity at low latitudes, specifically over African sector.

To this effect, observations from ground-based magnetometers and the Ion Velocity Meter experiment onboard C/NOFS satellite are analyzed in conjunction with equatorial electric field and neutral wind model estimates under geomagnetically quiet conditions in the years 2012-2013.

Introduction

A global knowledge of vertical drift is crucial for improving the accuracy of theoretical models as well as enhancing our understanding of ionospheric processes (electrodynamics) in the low-latitude. Unfortunately, the non-availability of radars over least covered regions such as Africa, the characteristics long-term absence of ionospheric observational tools and the sparse distribution of existing ones over this continent constitutes a major limitation (Akala et al., 2013; Amaechi et al., 2018). Even satellites observations which contribute to a better understanding of the variability of the vertical drift are limited in time for a given longitude.

Past studies have however, suggested that there are longitudinal differences in ionospheric parameters over the longitudinal sectors of Africa (Paznukhov et al.,2012; Mungufeni et al., 2016) This variability to a large extent has been attributed to changes in the vertical drift (Amaechi et al., 2021; Yizengaw, 2021) . The understanding of this variability is however, limited due to the lack of studies over the various longitudinal sectors of Africa.

Introduction

This work thus, examines the variability of vertical $\boldsymbol{E} \times \boldsymbol{B}$ drift velocity over the Atlantic, Western and Eastern African longitudes. We have utilised a combination of pairs of magnetometers to compute the EEJ, measurements of drift on board the Communications/Navigation Outage Forecasting System (C/NOFS) satellite as well as the equatorial electric field (EEF) derived from the EEF model and neutral wind data obtained from the Horizontal Wind Model 14 (HWM14) during quiet periods of years 2012 -2013.

Data Analysis and Method

Data sets

In this study, we have utilized the horizontal component of the Earth magnetic field (H) derived from ground-based magnetometers measurements in Africa. The geographic location of the 6 magnetometers along with their distribution into the Atlantic, Western and Eastern sectors is shown in **Figure 1**. The coordinates of the stations are given in **Table 1**.

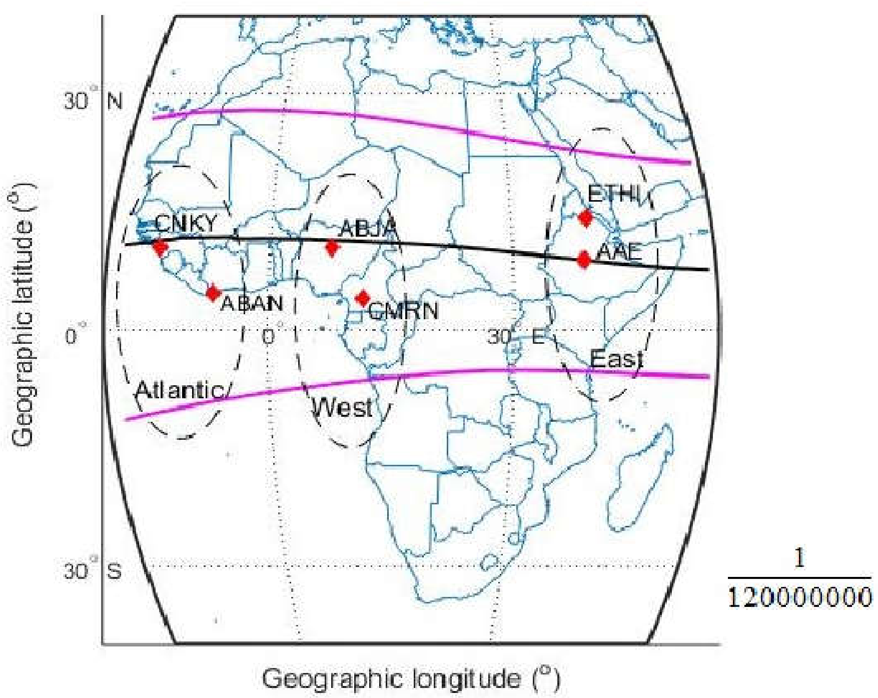


Figure 1. Geographic location of the ground-based magnetometers used. The black solid horizontal line depicts the geomagnetic equator while the two magenta lines indicate ± 15° dip.

Table 1. Geographic coordinates of the magnetometer stations used.

Station name	Station code	Geographic Latitude	Geographic Longitude	Magnetic Latitude	Magnetic Longitude
Addis Ababa	AAE	9.00°N	38.80°E	0.90°N	110.50°E
Adigrat	ETHI	14.30°N	39.50°E	6.00°N	111.10°E
Abuja	ABJA	10.50°N	7.55°E	0.60°S	79.60°E
Yaounde	CMRN	3.90°N	11.50°E	5.80°S	83.10°E
Conakry	CNKY	10.50°N	13.71°W	2.69°S	60.37°E
Abidjan	ABAN	4.60°N	6.64°W	8.54°S	65.82°E

Data Analysis and Method

Data sets

- We also utilized $E \times B$ drift (Vz) measurement from the Ion Velocity Meter (IVM), which is one of the Coupled Ion-Neutral Dynamics Investigation (CINDI) sensors on board the C/NOFS

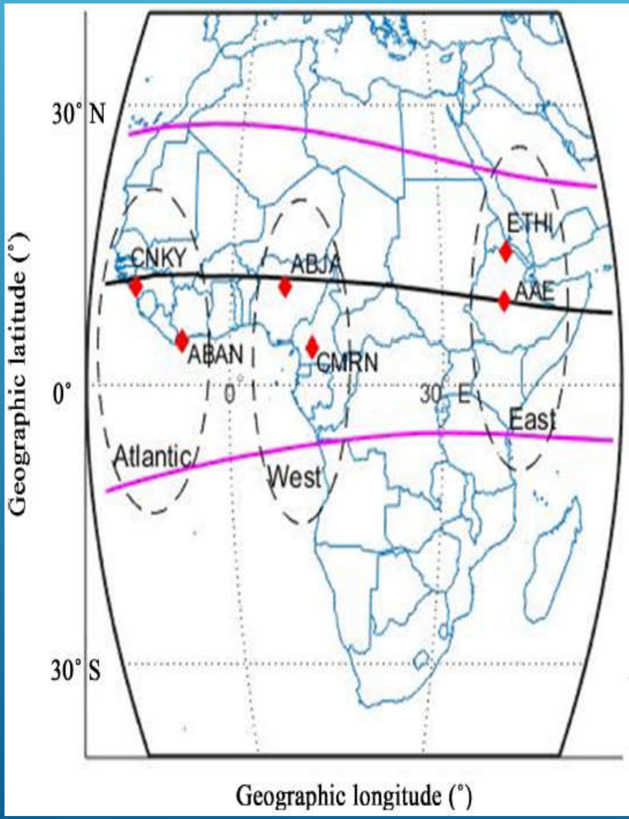
- Likewise, we utilized the neutral wind velocities computed from the Horizontal Wind Model 14 (HWM14) over the three longitudes.

- As the estimation of ExB technique, needs pairs of stations, the availability of the magnetic field data of the two ground-based magnetometers for the same quiet day is necessary. All available data sets for the three sectors were obtained during quiet days of years 2012 - 2013.

Data Analysis and Method

Method

How can we estimate EEJ ?



- Magnetometer at off the equator

$$B_{Obs} = B_{main} + B_{SQ} + B_{FAC} + B_{RC} + B_{MP}$$

- Magnetometer at the equator

$$B_{Obs} = B_{main} + B_{SQ} + B_{FAC} + B_{RC} + B_{EJ} + B_{MP}$$

EEJ estimation technique?

In this study, the pairs of magnetometers used are Abuja-Nigeria (ABJA) and Yaounde-Cameroon (CMRN); Conakry (CNKY) and Abidjan (ABAN); Addis Ababa (AAE) and Adigrat (ETHI). Abuja, Conakry, Addis Ababa are the ones at magnetic equator and Yaounde, Abidjan, Adigrat off equator.

For each sector, mainly Altantic, Western and Eastern longitude, the EEJ current contribution (ΔH) is given by the follow **Equations**

$$\Delta H_{Atlantic}\,(\Delta H_A) = H_{CNKY} - H_{ABAN} \quad (1)$$

$$\Delta H_{Western}\,(\Delta H_W) = H_{ABJA} - H_{CMRN} \quad (2)$$

$$\Delta H_{Eastern}(\Delta H_E) = H_{AAE} - H_{ETHI} \quad (3)$$

EEJ to $E \times B$ drift

The vertical E × B drift velocity has been estimated using the quantitative relationship of Anderson et al, as in Equation (4).

$$E \times B = K - TR1 - TR2 - TR3 + TR4 - TR5 + TR6 + TR7 - TR8 \quad (4)$$

where

K = -1989.51+1.002xYear - 0.00022 x DOY, Year is the year of measurements and DOY is the day of the year.

TR1 = 0.0222xF10.7, F10.7 is the daily solar flux observed index (in s.f.u) ;

TR2 = 0.0282xF10.7A, F10.7A is the daily solar flux adjusted index (in s.f.u);

TR3 = 0.0229xAp, Ap (nT) is the daily planetary amplitude index;

TR4 = 0.0589xKp, Kp (nT) is the planetary index;

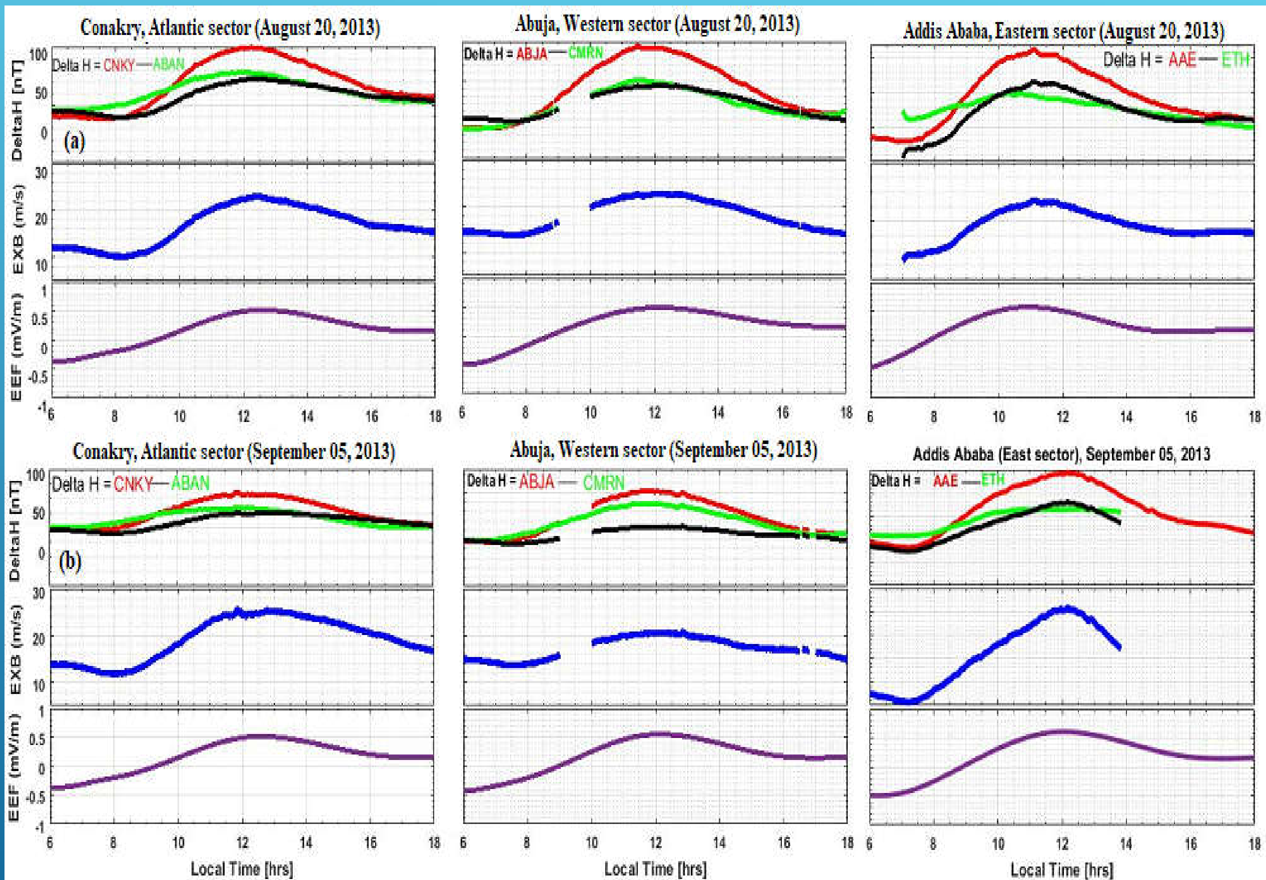
TR5 = 0.3661xLT, LT (hours) is the Local time;

TR6 = 0.1865xΔH, $\Delta H(nT)$ is the EEJ magnetic effect;

TR7 = 0.00028xΔH^2;

TR8 = 0.0000023xΔH^3.

Results and discussion



- **Existence of longitudinal difference in the EEJ between the Eastern, Western and Atlantic longitudinal sectors**
- Interestingly, these longitudinal differences were well captured by the EEFM (see magenta curves of **Figure 2**). As such, an upward drift of **22 m/s, 21 m/s, 28 m/s** corresponded to an eastward electric field of about **0.6 mV/m, 0.52mV/m and 0.70 mV/m** for the Atlantic, Western and Eastern longitude, respectively
- **Kelly (1989) had found that a zonal eastward drift of 100 m/s corresponded with a vertical downward electric field component of magnitude 2.5 mV/m.**

Fig. 2. Typical example of the estimated **EEJ** represented by **Delta H (nT)** (black curve), vertical $\boldsymbol{E \times B}$ **drift** velocity (m/s) (blue curve) and **EEF** (mV/m) (mangenta curve) on **(a) 20 August 2013** and **(b) 05 September 2013 over the Atlantic, Western and Eastern African sectors.**

Results and discussion

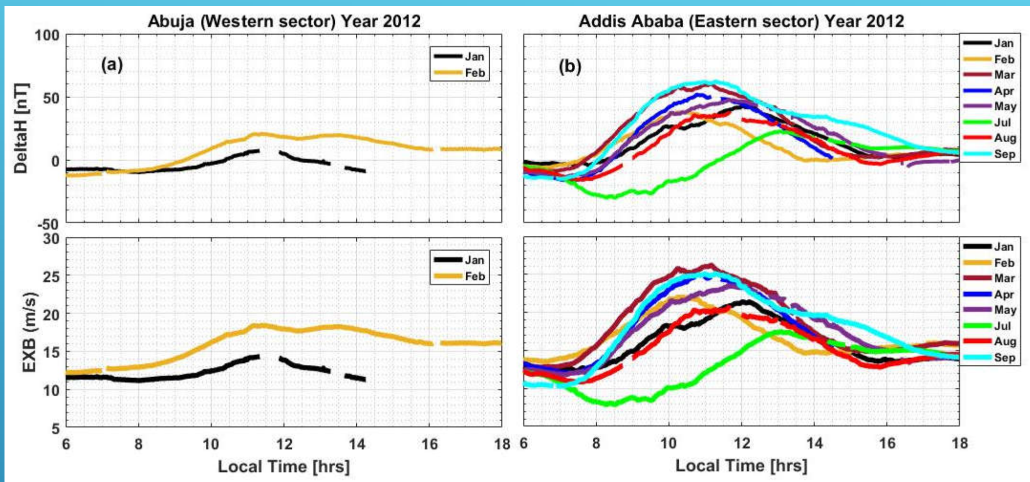


Fig. 3. Monthly variation of Delta H (top panel) and $E \times B$ drift (bottom panel) over (a) Abuja (Western sector) and (b) Addis Ababa (Eastern sector) in 2012. Data was only available in January-February in 2012

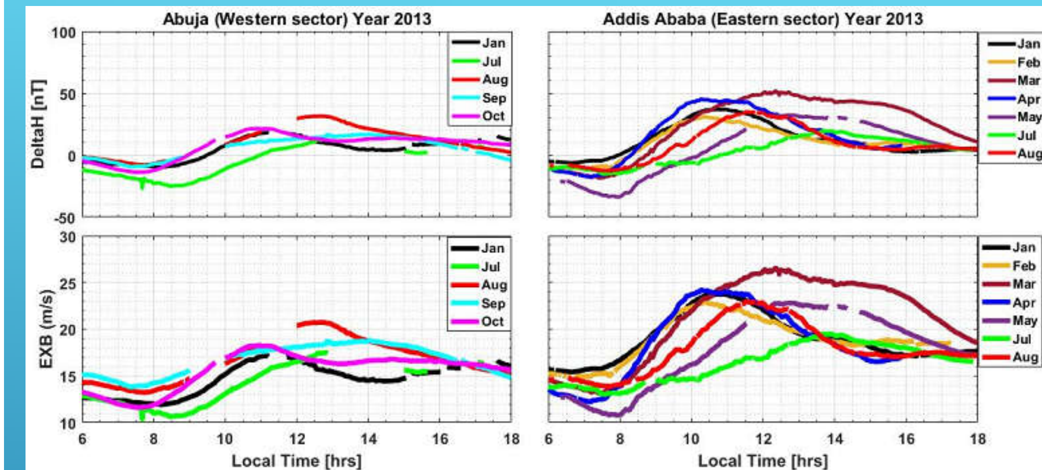


Fig. 4. Similar to Fig. 3 but for year 2013. During this year, Delta H data was available for 5/7 months in the Western/Eastern sector.

Notwithstanding the lack of data it could be seen that on monthly basis, Addis Ababa in the Eastern sector had the stronger EEJ and $E \times B$ drifts velocities at least in January and February of year 2012 (**Figure 3**) and in January, July and August 2013 (**Figures 4 and 6**). (**Rabiu et al., 2011**) for the first time clearly revealed that the western African EEJ appears weaker than eastern EEJ. This discrepancy suggests that there is a process of reinjection of energy in the jet as it flows eastward. This West-East Asymmetrical behavior in the EEJ strength in the African sector is further confirmed by **(Yizengaw et al., 2014)** using data set of arrays of magnetometers (AMBER).

Results and discussion

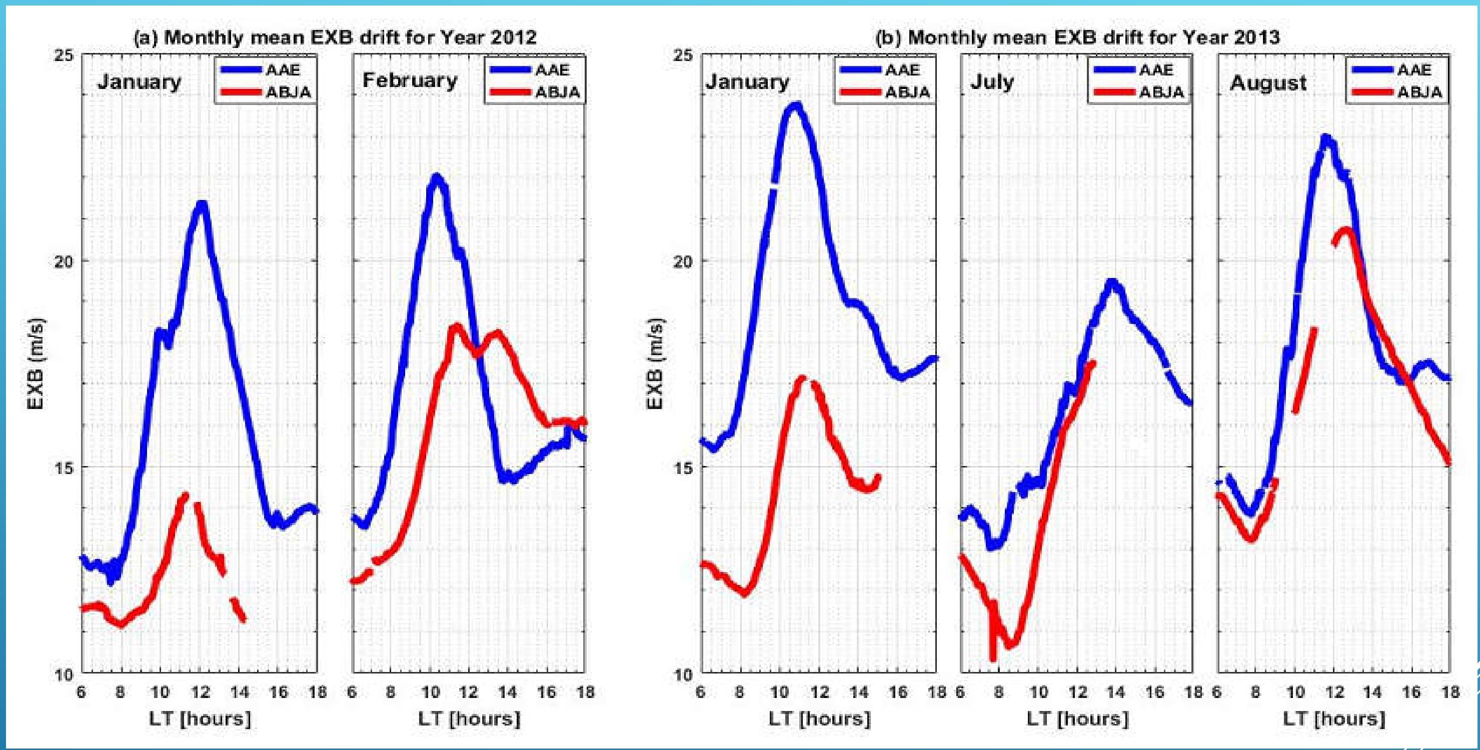


Fig. 6 Longitudinal variations of monthly mean $E \times B$ drift over the Eastern (blue line), Western (red line) during quiet period of year 2012 and 2013.

Results and discussion

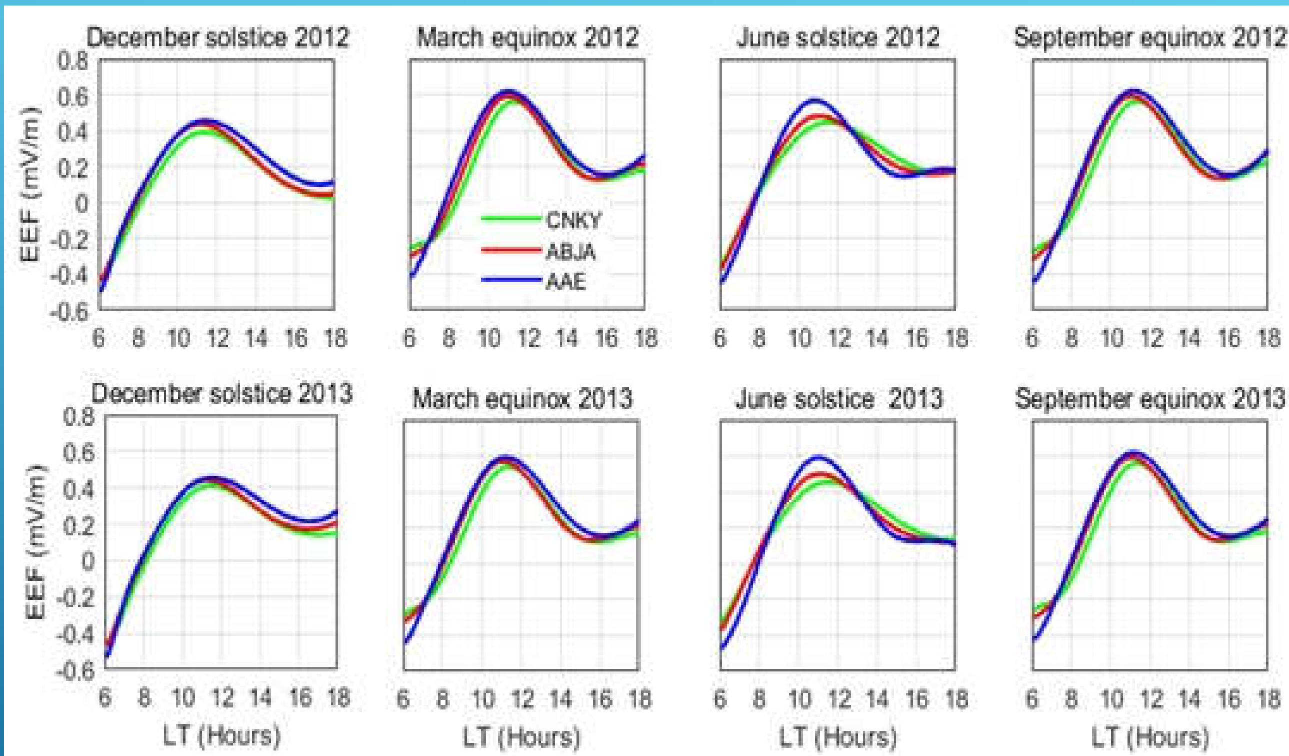


Fig. 7. Seasonal variations of equatorial electric field in Africa over Conakry (green line), Abuja (red line) and Addis Ababa (blue line) during quiet period of years 2012 and 2013.

Our results presented in **Figures 3** and **4,** show that $E \times B$ drift variation exhibit seasonal variation, where it maximizes in equinox and weaker during the June solstice. The similar trend was also observed in **figure 7** where September equinoxes recorded the highest **EEF** peaks. These results are in good agreement with results presented by **(Yizengaw et al, 2014)**. Their two independent observations show a consistent seasonal variation with peaks during equinox and weaker during June solstice.

We have thus, resolved to investigate the longitudinal differences on a seasonal basis using the EEFM. It was found that the peak EEF was generally increased from the Atlantic to the Eastern longitude (**Figure 7**).

Results and discussion

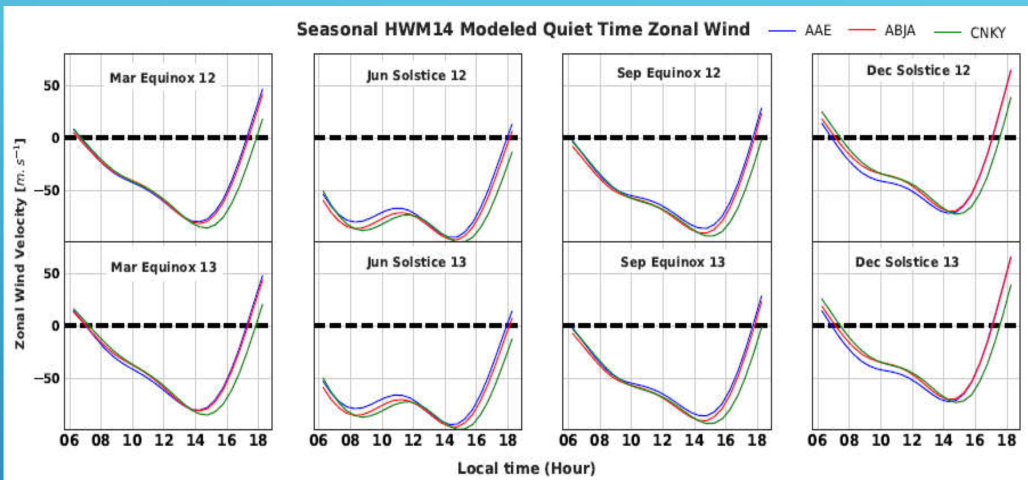


Fig. 8. **Seasonal variation of quiet time zonal wind derived from the HWM14 in 2012 (top panels) and 2013 (bottom panels) over Conakry (green line), Abuja (red line) and Addis Ababa (blue line).**

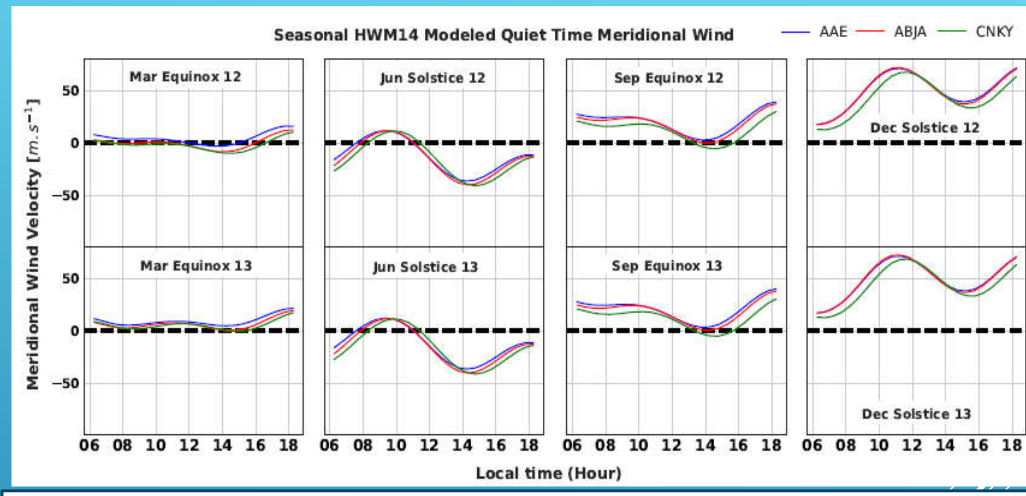


Fig. 9. Seasonal variation of quiet time meridional wind derived from the HWM14 in 2012 (top panels) and 2013 (bottom panels) over Conakry (green line), Abuja (red line) and Addis Ababa (blue line).

Our investigation of the seasonal variability of neutral wind at the three stations revealed that during all seasons, the zonal wind is westward with a peak velocity that increased from Addis Ababa to Abuja, and then Conakry at about 14:00 LT (**Figure 8**). Oppositely, the meridional wind is poleward with a velocity that decreased from Addis Ababa, then Abuja and Conakry. From 10:00 – 14:00 LT in June solstice however, the wind turned to equatorward with a weaker velocity in Conakry (**Figure 9**).

Results and discussion

We had earlier found that the peak EEF increased from Conakry to Addis Ababa. The meridional (zonal) wind was clearly the strongest (weakest) in Addis Ababa where the electric field was also the strongest of the three sectors. We thus, submit that the electric field was stronger at the longitudinal sector where the zonal wind was minimal and the meridional wind maximal

Hartman,and Heelis, (2007) had stressed on the role of the meridional wind on driving longitudinal difference in the eastward $E \times B$ drift at the equatorial region. They found that the longitudinal variation in the drift was related to the changes in the zonal currents driven by meridional winds at F region height of the equatorial ionosphere. It had been recently found that, changes in the thermospheric neutral winds are the reason for the longitudinal differences that have been reported in equatorial electric fields between the West and East Africa stations **(Yizengaw et al, 2014; Tesema et al, 2017; Rabiu et al., 2021)** They found that, in general, the neutral wind speed observed in eastern African sector is weaker and stronger in west African sector compared with speeds observed in other longitude sectors.

Conclusion

The following points can be taken as the main findings of this study :

(i) Satellite observations and ground-based data showed the existence of longitudinal differences in the magnitude of the ***E×B*** drift over the Atlantic, Western and Eastern sectors. These were well reproduced by the EEFM during the days when data were available at the three longitudinal sectors. We note that past works had only focussed on the Western and Eastern sectors.

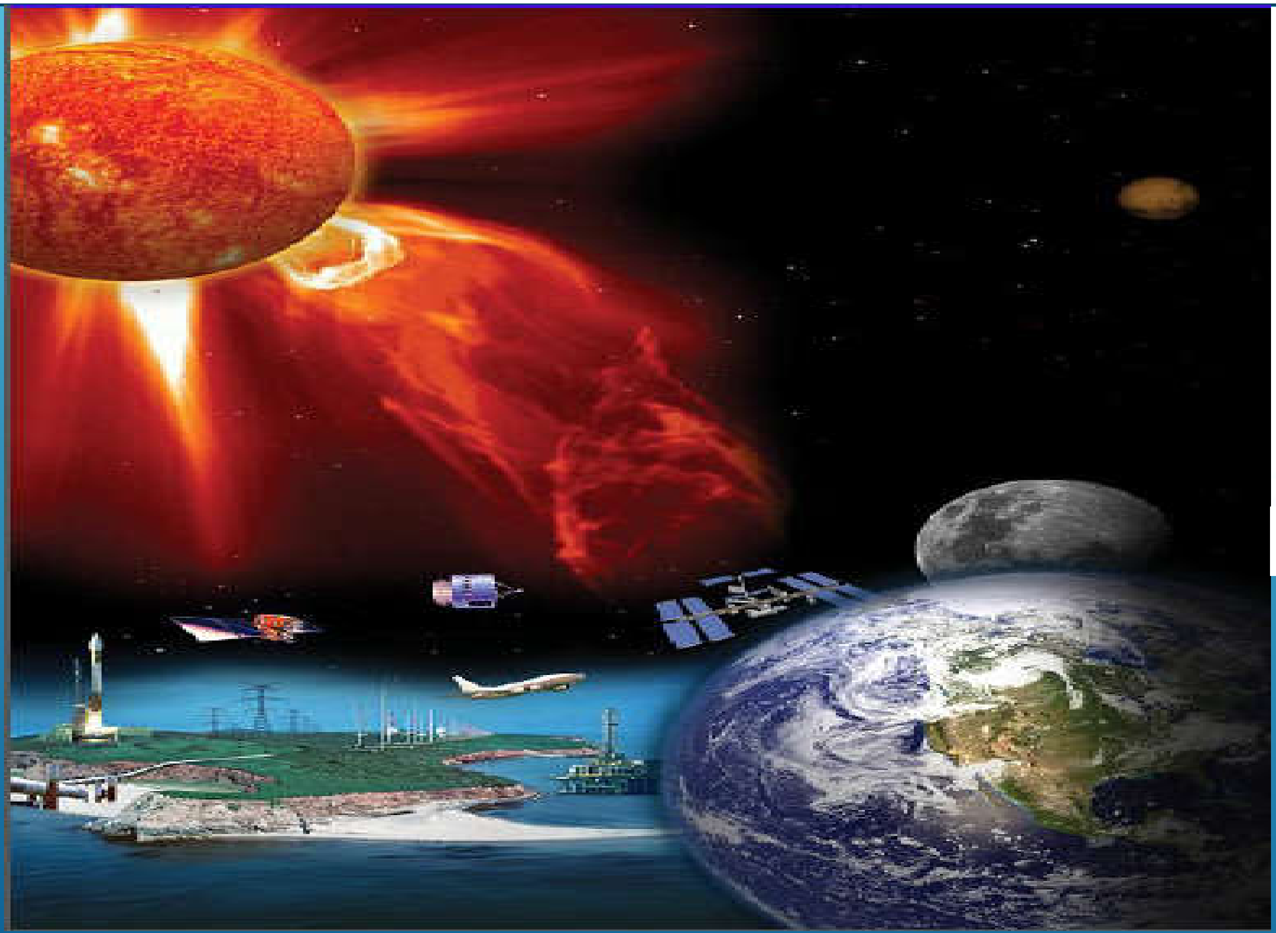
(ii) On a seasonal basis, strongest EEF peak was observed over the Eastern sector suggesting that the vertical drift is also the strongest over that sector. In addition, the trend of variation of EEF showed a reduction in peak from the Eastern sector to the Atlantic sector.

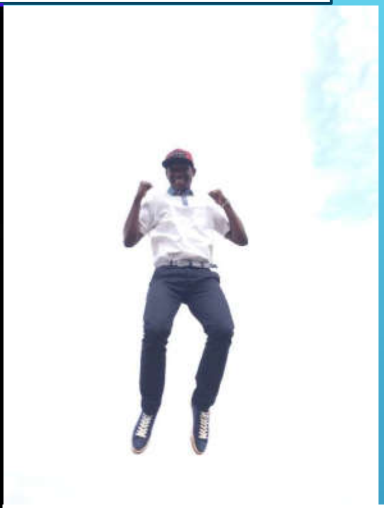
(iii) There was a longitudinal difference in the magnitude of the zonal wind which was essentially westward from 06:00 to 18:00 LT. Furthermore, the zonal wind velocity was higher at the station located in the Atlantic sector.

(iv) Overall, there was also a longitudinal difference in poleward meridional wind with its peak velocity being the highest in the Eastern sector. The trend in variation of the meridional wind showed a reduction from the Eastern to the Atlantic sector.

We could infer thus, that the neutral wind had played a crucial role in driving the longitudinal differences in the vertical drift velocity in Africa. The fact that the zonal wind is weaker while the meridional wind is stronger in the Eastern sector could account for the stronger vertical drift velocity measured at this longitude. Direct wind and drift measurements are therefore needed over this region for a better understanding of the equatorial ionospheric dynamics and its morphology and thus, the impact on critical navigation and communication technologies.

THANK YOU FOR YOUR KIND ATTENTION





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