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Estimating the daytime vertical E×B drift velocities in the F-region of the equatorial ionosphere using the IEEY and AMBER magnetic data in West Africa

A A. Kassamba* (1), V. Doumbia (1), O. Olivier (1), F. Grodji, Z. Tuo (1), N. Kouassi (1) and E. Yizengaw(2)
(1) Laboratoire de Physique de l'Atmosphère, UFR-SSMT, Université Felix Houphouët Boigny, Abidjan, Côte d'Ivoire
(2) Space Science Application Laboratory, The Aerospace Corporation, El Segundo, CA, USA

Abstract

In this paper the daytime vertical $\vec{E} \times \vec{B}$ drift velocity in the F-region of the equatorial ionosphere was estimated from the magnetic effect of the equatorial electrojet (EEJ) in West African sector for September equinoxes in 1993 during solar cycle 22 and in 2013 during solar cycle 24. Geomagnetic data recorded during the International Equatorial Electrojet Year (IEEY) from 1993 to 1994 and the ongoing AMBER (African Meridian B-field Education and Research) program since 2008 were used. The vertical drift velocity was inferred from the EEJ contribution (ΔH) in the geomagnetic field horizontal component. The IEEY data were used to examine the seasonal variations of the daytime vertical drift velocity. The noontime seasonal averages are V_d=10.95m/s and V_d=9.46 m/s respectively for March and September equinoxes, and V_d= 8.75 m/s and V_d=8.27 m/s for December and June solstices. The daytime vertical drift velocity was found to be larger in equinoxes than in solstices. The dependence of the daytime vertical drift velocity on solar cycle was also shown by comparing the results of September equinox in 1993 and 2013. The drift velocity of 9.5m/s in 1993 is significantly weaker than that of 24.5m/s in 2013. This strong difference in V_d reflects the level of solar cycle between 1993 when the mean $F_{10.7}$=109.86 sfu and 2013 when the mean $F_{10.7}$=122.55 sfu.

1 Introduction

Plasma vertical $\vec{E} \times \vec{B}$ drift is an important process of the equatorial ionosphere electrodynamics. Therefore, the plasma vertical drift velocity has become an important parameter for different processes that dominate the equatorial ionosphere such as the equatorial electrojet (EEJ) current flow, the EIA, diverse plasma instabilities, etc.[1]. Various methods have been used to estimate the low latitude plasma vertical drift velocity in different longitude sectors. Based on Jicamarca and AE-E (Atmosphere-Explorer 2) satellite measurements, [2] developed a quiet time empirical F-region vertical drift model for different seasons and solar activity conditions. [3] used the drift measurements of ROCSAT-1 (Republic of China Satellite) to develop a global empirical model for moderate and high solar activity conditions for four seasons. It was shown that the longitudinal dependence of the daytime and nighttime vertical drift velocities was stronger than that reported in previous studies. Based on a comparative study, [4] have shown that the ROCSAT-1 measured vertical drifts velocities were highly correlated with the ground-based measured Equatorial Electrojet (EEJ) strength during the solar maximum (2001-2003) in the Asian longitude sectors. Various alternate methods have also been applied to estimate the equatorial vertical drifts and the zonal electric field, with particular emphasis on the daytime observations. Indeed, [5] used the IPS-42 ionosonde data in semi-empirical approach to estimate the daytime F-region vertical drift velocity in West Africa. [6] demonstrated that the daytime vertical drift velocity can be estimated from the magnetic effect of the EEJ. This approach consisted of estimating the amplitude difference (ΔH) between the horizontal component (H) of the geomagnetic field measured in a pair of ground-based magnetometer stations, with one located at the magnetic equator and the other at a certain distance off the magnetic equator. By comparing ΔH with the vertical $\vec{E} \times \vec{B}$ drifts velocities observed by the Jicamarca Incoherent Scatter radar, [6] established a linear relationship between the two parameters. In the present work the relationship established by [7] is used to estimate the equatorial F-region vertical drift velocity from the geomagnetic field recorded in the West African longitude sector. In that purpose the geomagnetic field data from International Equatorial Electrojet Year (IEEY) and the African Meridian B field Education and Research (AMBER) [8] magnetometer network will be considered.

2 Data sets

In this study, magnetic data recorded in West Africa, during the "International Equatorial Electrojet Year (IEEY)" from 1993 to 1994, and the ongoing AMBER program that started in 2012. The three IEEY stations that are used in this study are: Sikasso (0.12° dip-lat.) the station near the magnetic dip-equator, Tombouctou (6.76° dip-lat.) the station located north from Sikasso and Lamto (-6.27° dip-lat.), the station located to the south. Tombouctou and Lamto represent the off dip-equator stations beyond the EEJ influence band. Hourly mean values of the horizontal component (H) of the geomagnetic field recorded during geomagnetic quiet periods are considered to estimate the EEJ strength in 1993 (F10.7=109.86sfu). The geomagnetic quiet time data were selected according to the daily mean geomagnetic activity index Am less than 20 nT. Data from 30 quiet days including 20 days for the station pair Sikasso-Tombouctou and 10 days for the pair Sikasso-Lamto were selected. For this study, geomagnetic field data recorded at Conakry (CNKY) and Abidjan (ABAN) are used. It should be noted that the two stations did not operate continuously throughout the year 2013. So, for both stations data used are those of the September equinox data to determine the EEJ strength.

2.1 Data processing

For the two sets of data, the night time value is considered as the baseline of the daily variations, which corresponds to the average midnight values (H_0) of the H component. For each station H_0 is obtained by averaging the hourly values of H from 2300 to 0100 LT during the two nights that frame the day of concern. At each station, the hourly departure $H_i(t)$ (where i stand for the relevant station) of the diurnal variation of the H component at a given local time (t) is estimated by subtracting the resulting H_0 from the total hourly values H(t) of H.

$$H_i(t) = H(t) - H_0 \quad (1)$$

For the IEEY dataset, the diurnal variations H_i at Sikasso, Tombouctou and Lamto are denoted respectively as H_{Sik}, H_{Tom} and H_{Lam}. For the AMBER dataset, H at Conakry and Abidjan are respectively H_{Cnky} and H_{Aban}.
Thus, for this dataset, the EEJ strength was calculated by considering the two situations as follow:

$$\Delta H_{S\text{-}T} = H_{Sik} - H_{Tom} \quad (3)$$

$$\Delta H_{S\text{-}L} = H_{Sik} - H_{Lam} \quad (4)$$

Where $\Delta H_{S\text{-}T}$ represents the EEJ strength when the pair Sikasso–Tombouctou is considered, and $\Delta H_{S\text{-}L}$ represents the EEJ strength when the pair Sikasso–Lamto is considered. Figure 1.a. presents the daily variation of H_{Sik}, H_{Tom}, H_{Lam}, $\Delta H_{S\text{-}T}$ and $\Delta H_{S\text{-}L}$.
For the AMBER dataset, H_{Cnky} is considered as the diurnal variation of the geomagnetic field at the dip-equator and H_{Aban} as the diurnal variation out of the EEJ influence area. The EEJ magnetic effect $\Delta H_{C\text{-}A}$ is computed as:

$$\Delta H_{C\text{-}A} = H_{Cnky} - H_{Aban} \quad (5)$$

The daily variation of H_{Cnky} (red curve), H_{Aban} (blue curve) and $\Delta H_{C\text{-}A}$ (black curve) are shown in Figure 1.b. In the next section, the EEJ magnetic effect will be used to estimate the daytime plasma vertical $\vec{E} \times \vec{B}$ drift velocities on the basis of the IEEY and AMBER datasets.

2.3 Estimating the plasma vertical drift velocity from the EEJ magnetic effect

Using ground-based magnetic data and the F-region plasma vertical drift velocity measurements in the Peruvian longitude sector, [7] established a quantitative relationship.
Thus, an estimate of the F-region daytime plasma vertical $\vec{E} \times \vec{B}$ drift velocity, whose intensity V_d can be expressed by Eq. (6) as:

$$V_d = -1989.51 + 1.002 \times Year - 0.00022 \times DOY - 0.0222 \times F_{10.7} - 0.0282 \times F_{10.7A} - 0.0229 \times A_p + 0.0589 \times K_p - 0.3661 \times LT + 0.1865 \times \Delta H + 0.00028 \times \Delta H^2 - 0.0000023 \times \Delta H^3 \quad (6)$$

Where Year is the year of measurements, DOY is the day of year, $F_{10.7}$ (in s.f.u) is the daily solar flux index, $F_{10.7A}$ (in s.f.u) is the daily solar flux adjusted index, A_p (nT) is the daily planetary amplitude index, K_p (nT) is the planetary index, LT (hours) is the Local Time, ΔH (nT) is the EEJ magnetic effect.

On the basis of this method, the F-region daytime plasma vertical drift velocity is estimated from the EEJ magnetic effect recorded in West Africa in 1993 ($F_{10.7}$=109.86sfu) and 2013 ($F_{10.7}$ = 122.55sfu).

3 Results

3.1 The daily variation of the EEJ magnetic effect

The EEJ strength $\Delta H_{S\text{-}L}$ and $\Delta H_{S\text{-}T}$ (black lines) estimated from station-pairs SIK-LAM and SIK-TOM respectively, are shown in Figure 1. a. The amplitudes of the EEJ magnetic effect $\Delta H_{S\text{-}T}$ are greater than $\Delta H_{S\text{-}L}$. Indeed, the values of the peak amplitudes around noon are $\Delta H_{S\text{-}T}$=73.35 nT and $\Delta H_{S\text{-}L}$=65.8 nT on 19/02/1993; $\Delta H_{S\text{-}T}$= 65.25 nT and $\Delta H_{S\text{-}L}$=52.75 nT on 25/07/1993. Another remarkable difference is a morning depression in the daily variation H_{Lam}, which is not observed in H_{Tom}.

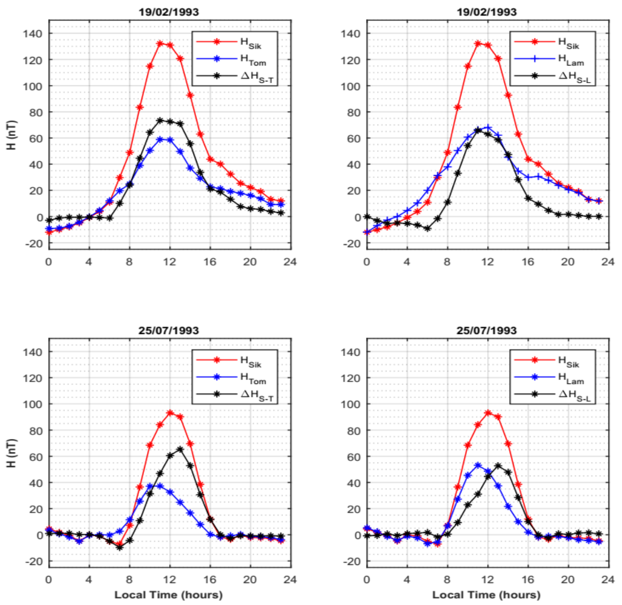

Figure 1. a. Daily variations of H component of the magnetic fluctuations recorded at the geomagnetic equator (H_{Sik}, red curves) and off the magnetic equator (H_{Lam}, blue curves) on two days. The black curves (ΔH) are the difference between red and blue curves, representing the equatorial electrojet (EEJ) strength.

It is as if LAM is still under the EEJ magnetic influence, although located at -6.27° dip-latitude, while TOM (6.76° dip-latitude) seems to be mostly out of that influence area. In Figure 1.b. the daily variations of the H component of the geomagnetic field, at Conakry H_{Cnky} (red line) and at Abidjan H_{Aban} (blue line) are shown, along with the daily variation of the EEJ strength $\Delta H_{C\text{-}A}$ (black curve). $\Delta H_{C\text{-}A}$ exhibits an important depression in the early morning before it increases toward the noontime maximum. This depression corresponds to a morning Counter EEJ (CEJ) that occurs on 05/09/2013 and 20/10/2013, with a minimum of ΔH=-19.32 nT and ΔH=-21.94 nT respectively.

3.2 The daily variation of the F-region plasma vertical drift velocity

The main purpose of the present work is to estimate the F-region daytime vertical $\vec{E} \times \vec{B}$ drift velocities V_d from

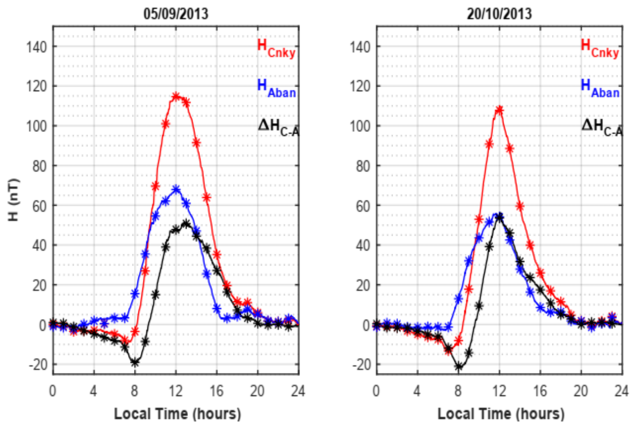

Figure 1. b. Same as Figure 1. a. but for the stations of Conakry and Abidjan for the year 2013.

the EEJ magnetic effects recorded in the West African longitude sector. Fig. 2.a. show the diurnal variation of the vertical drift velocity estimated respectively from $\Delta H_{S\text{-}T}$.

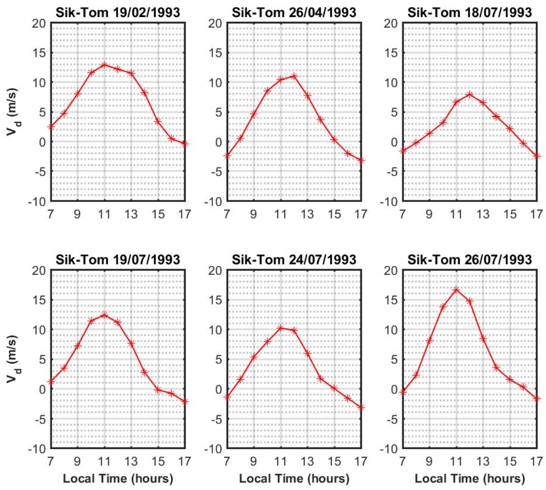

Figure 2. a. Diurnal variation of the quiet time equatorial vertical drift velocities estimated using $\Delta H_{S\text{-}T}=H_{Sik}\text{-}H_{Tom}$ on six days.

In these figures the daytime vertical drift velocity V_d exhibits the same trend as the corresponding EEJ magnetic signature. V_d increases from 0700 LT to attain its peak amplitude around local noon (1100-1300 LT), and then it decreases in the afternoon before vanishing at sunset. The noontime peak values of the drift velocities related the EEJ strength $\Delta H_{S\text{-}T}$ range between 8.12 m/s and 16.62 m/s. For the drift velocities related to $\Delta H_{S\text{-}L}$, the noontime peak values range between 8 m/s and 12.85 m/s. In Fig. 2.b., the diurnal variations of the vertical drift velocity estimated from $\Delta H_{C\text{-}A}$ of six quiet days in 2013 are shown. In response to the morning CEJ observed in $\Delta H_{C\text{-}A}$, the drift velocities drop down between 0700 LT to 0800 LT to minimums of 14 m/s to 16 m/s. After this morning depression, the drift velocity increases and attains its maximum 21.57 m/s to 27.66 m/s around local

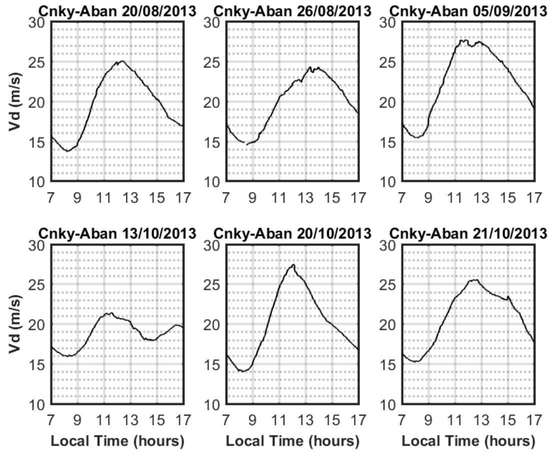

Figure 2. b. Diurnal variation of the quiet time equatorial vertical drift velocities estimated using $\Delta H_{A\text{-}C}=H_{Cnky}\text{-}H_{Aban}$ on six days.

noon, then decreases during the afternoon. These results show that the values of the vertical drift velocity in 2013 are significantly stronger than those obtained in 1993.

4 Dependence of the vertical drift velocity on seasons and solar cycle

The average daily variations in the March equinox, June solstice, September equinox and December solstice are shown in Figure 3. The patterns of the drift velocity are roughly similar for the March equinox, June solstice, September equinox, with noontime maxima at 1200LT. In December solstice the maximum drift velocity is attained around 1100LT and the decreasing phase in the afternoon starts earlier and faster than the other seasons. The highest noontime amplitudes of the vertical drift velocity are observed in equinoxes, being higher in March equinox than in September equinox [9]. Similarly, the amplitude of the vertical drift velocity is weaker in the June Solstice than in December solstice. The noontime average values of the vertical drift velocity are 10.95 m/s for March equinox, 9.46 m/s for September equinox, 8.75 m/s for December solstice and 8.27 m/s for June solstice.

5 Discussion and conclusions

As the IEEY network included 10 stations along a meridian chain across the magnetic equator, we have taken advantage to consider two pairs of stations on either side of the EEJ. Thus, the pairs “SIK-TOM” to the north and “SIK-LAM” to the south, were considered to determine $\Delta H_{S\text{-}T}$, $\Delta H_{S\text{-}L}$ and the respective values of V_d. In the two cases the shape of the diurnal variations of V_d were found similar to that of ΔH. This pattern can be associated with the diurnal variation of the ionospheric conductivity. The values of $\Delta H_{S\text{-}T}$ and its corresponding V_d are slightly higher than those of $\Delta H_{S\text{-}L}$ and its related V_d Although asymmetry in the EEJ latitudinal structure could be one of the possible reasons of this difference, the most plausible cause may be the

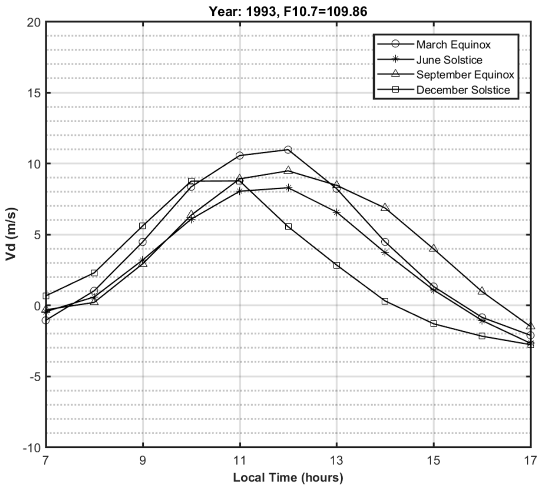

Figure 3. The quiet time vertical drift velocity inferred from magnetic data in West Africa in March equinox (curve with circles), June solstice (curve with asterisks), September equinox (curve with triangles) and December solstice (curve with squares) in 1993.

larger distance of TOM from the magnetic equator than that of LAM. [10] made the same observation when examining the longitudinal variability of the EEJ and the occurrence of the CEJ in the South American, African and Philippines sectors. Their results indicated that the pair with the largest latitudinal separation exhibits the strongest EEJ. Examining the seasonal variability of the drift velocity, we found that the patterns of the average diurnal variations of the vertical drift velocity are approximately same for the June solstice, and March and September equinoxes, with the maxima at about 1200LT. Different pattern was noticed in December solstice, for which the maximum appears earlier, at about 1100LT. The amplitudes are higher in equinoxes, with strongest values during the March equinox. The maximum in the December solstice is stronger than in June solstice. The noontime seasonal averages of the drift velocities are 10.95m/s, 9.46 m/s, 8.75 m/s and 8.27 m/s for March equinox, September equinox, December solstice and June solstice respectively. The noontime seasonal averages obtained by [5] in the same area and during the same period, were 15.61 m/s in March equinox, 15.01 m/s in June solstice, 15.30 m/s in September equinox and 13.81 m/s for in December solstice. These values are higher than ours. The difference between the two results is possibly due to the use of different approaches. Indeed, [5] made a semi-empirical approach based on IPS-42 ionosonde data to the F-region vertical drift velocity.

6 Acknowledgements

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