

Characteristics of the ionospheric total electron content of the equatorial ionization anomaly in the three sector longitude

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Abstract : We analyze the vertical Ionospheric total electron content (VTEC) of the equatorial ionization anomaly (EIA) using IGS network around the magnetic equator region during 2013-2017. The study includes a morphological analysis of regular variations in the ionization during sun activities: diurnal variation, seasonal variation and variation based on the solar cycle 24th, obtained by processing of GPS stations in three different sector America, Europe-Africa and Asia. The results reveal that diurnal and seasonal variations control the morphology of the EIA structure in accordance with previous studies. Our results also show that the highest VTEC values are displayed during the two months of the spring equinox, after sunrise and before sunset. The lowest values are found during the summer and winter seasons. A double ionization peak is observed due to the proximity of the equatorial fountain stations. Seasonal variations in VTEC make it possible to identify and characterize the effects of solar cycle phases on VTEC at low latitude. We notice a strong asymmetry in the two equinoctial peaks. Peak formations occurred in March/April and October/November corresponding to the maximum of the sunspot cycle.

Keywords : Ionosphere equatorial, GPS, VTEC.

1. Introduction

In low-latitude, the most important ionospheric phenomenon is equatorial ionization anomaly (EIA). At the equator, the Earth's magnetic field is horizontal and the ExB drift, related to the Laplace force, is vertical. During the daytime, when the zonal electric field is eastward the plasma moves up, and reaches higher altitudes, where the pressure gradient and gravity forces become important. At these higher altitudes, the plasma is driven by the ambipolar diffusion along the magnetic field lines, this process is called the equatorial fountain effect. This fountain effect creates the EIA composed by a trough of density at the equator and two ionization peaks at magnetic latitudes (15°N and 15°S) [1]. The EIA is controlled by the electric field, neutral wind and magnetic declination between the magnetic and geographical equator. On the other hand, the effect of EIA on TEC variation is dependent on seasons, local time, and the most important parameter is the magnetic latitude. In this work, we analyze the VTEC of the EIA using IGS network around the magnetic equator region in the three longitude sectors during 2013-2017. The project consists of a morphological-analysis of regular variations in ionization during solar activities : diurnal, semi-annual, seasonal and 24th solar cycle variations. We show that diurnal and seasonal variations control the morphology of the EIA structure in accordance with ionospheric studies

[7], [9]. The problem of asymmetry [3], [2] and [4] between equinoxes and solstice and between northern hemisphere and southern hemisphere is also examined. Finally, we compare the amplitude of VTEC variations in the 03 sectors of longitude in order to show the response of the ionosphere in local time (LT).

II. Methodology

GPS satellites in orbit around the Earth, 20200 km above the Earth's surface, provide TEC. The total number of electrons is integrated along the receiver path to each GPS satellite, expressed by :

$$TEC = \int_R^S N_e(s) ds$$

Where N_e is the electron density, R is the receiver altitude and S is the satellite altitude. The TEC is measured in TEC units (TECU), 1 TECU=10¹⁶ electrons / m². TEC obtained using two frequencies concerns GPS stations in different sectors. There are two cases to calculate the relative phase delay between the two carrier frequencies : (1) the pseudo-distance method gives an absolute scale of TEC with less accuracy. (2) The differential phase method increases the accuracy of the measurement but does not allow knowing the number of phase cycles. According to [5], it is impossible to obtain an absolute value of the TEC, but only an estimated value called STEC (Slant TEC). The TEC varies in time and space and depends on solar activity, the location of the user and the elevation angle of the satellite.

This measurement is called vertical TEC (VTEC). When converting STEC to vertical TEC (VTEC), it is common to assume that the ionosphere is a thin-film model with a fixed height (h) in the range of 350 to 400 km [5]. To convert STEC to VTEC, we used the following equation [10] :

$$\text{STEC} = \text{VTEC} \sqrt{1 - \left(\frac{R_T}{R_T + h} \cos \theta \right)^2}$$

With :

$R_T = 6371$ km is the average radius of the earth ; θ the elevation angle of the satellite.

The methodology is well described in our paper [11].

III. Data analysis

Using the IGS station network (<https://cddis.gsfc.nasa.gov>), data were collected from 6 stations in America, Asia, Europe and Africa for a 5-year period from 2013 to 2017. The station coordinates are given in (table. 1).

Tab 1. Geographic coordinates of GPS stations

Station code	Geographic coordinates		Dip	Station location	UT LT
	Latitude	Longitude			
America sector					
BRAZ	-15,95	-47,88	-10.35	Brazil	-3
RIOP	-1,65	-78,65	10.38	Equateur	-5
Europe-Africa sector					
ADIS	9,04	38,77	0.70	Ethiopia	2
NKLG	0,35	9,67	-13.40	Gabon	0
Asian sector					
COCO	-12,19	96,83	-25.51	Australia	6
PIMO	14,64	121,08	7.72	Philippines	8

IV. The annual variation of the VTEC

(Figure 1) shows the annual variations of the VTEC, at low latitude, recorded by the BRAZ and RIOP (America), NKLG and ADIS (Africa) and COCO and PIMO (Asia) stations during the study period. In the 3D maps generated, the x-axis represents the days of the year, the y-axis displays 24 hours in local time (LT). The color scale represents the VTEC values in TECU. All maps show that the daily VTEC values during the study period are significantly higher during the day than at night. The maximum VTEC values are recorded during the spring equinox periods, followed by those recorded during the autumn equinoxes. Rishbeth [8], [7] obtained the same results. In contrast, VTEC values are lower in winter and even lower in summer, in accordance with [9]. An asymmetry between equinoxes and solstices is observed for all stations during the period 2013-2017 (figure 1). Variations in the VETC in 2013 are greater at the autumn equinox than at the spring equinox, which corresponds to the increase in solar flux

in that year. The year 2014 shows the largest variations in the VTEC, reaching maximums exceeding 110 TECU during the spring and autumn equinoxes. For the years 2015, 2016 and 2017, the VTEC values recorded during the spring equinox periods show a gradual decrease compared to those of 2014. Note that 2017 is the quietest year, with VTEC values not exceeding 50 TECU during the spring equinox. (Figure 1) (top) shows that the VTEC values in the Northern Hemisphere (NH) at the RIOP station are higher than those recorded at the BRAZ station symmetrically located with respect to the magnetic equator in the Southern Hemisphere (SH). The same behavior is observed at ADIS (NH) stations compared to NKLG (SH) and finally at PIMO (NH) and COCO (SH) stations which are conjugated magnetically. During the spring equinox in the HN, stations in the America sector near the magnetic equator have VTEC values slightly higher than those observed in the Asia and Europe-Africa sectors. In NH, during the summer period, VTEC values in the Asia segment are slightly higher than those in the Americas and Europe-Africa segments. For the SH, stations near the magnetic equator show that VTEC values in the Asian sector are significantly higher than those in the American and Europe-Africa sectors, especially during the spring equinox. In contrast, night VTEC values are slightly higher in the Americas sector than in Asia and Europe-Africa. The effect of the equatorial anomaly is visible on the peaks (time interval from 12:00 to 16:00 in LT). During this period, the contribution of electron density induced by particle precipitation under the effect of the equatorial fountain is visible by the increase in the slope of VTEC variations, i.e. the increase in its values.

V. VTEC variation with solar activity

(Figure 1) (last panel) shows that the variation in VTEC follows the diurnal variation in solar activity indicated by the F10.7cm sfu index. It decreases slowly during the night, goes through a minimum before sunrise, and then grows fast enough to reach a maximum around 15.00 h LT. The curves show that the afternoon decline of the VTEC is faster than the morning growth. At sunrise, the term production, i.e. the creation of free electrons under the action of EUV, UV and X-ray radiation, is fast. The time of the daytime maximum is shifted by about 2 hours from the maximum position of the sun, causing a slight sunset effect during the VTEC decay period. After sunset, the term of production disappears but ionization is maintained by the movement of electrons, with time constants governing the disappearance of ionization by recombination or fixation for a long period of time [6].

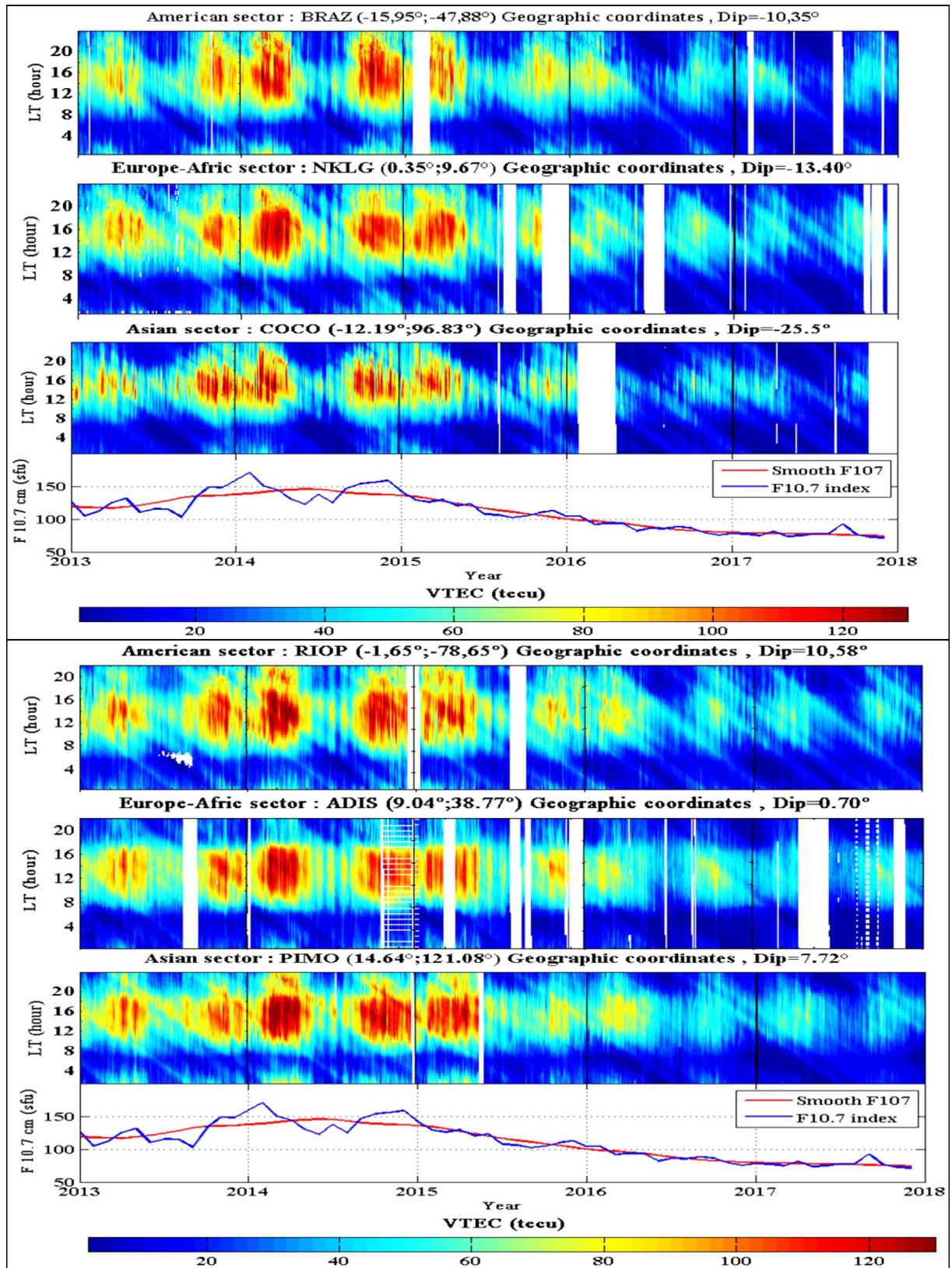


Fig. 1 VTEC variations in NS (Top) and SH (down) at the magnetic equator.
The last panel shows F10.7 solar activity variation (blue curve) and the smoothed version (red curve)

VI. Conclusion

The study includes a morphological analysis of regular variations in ionization during solar activities : daytime variations, seasonal variations and variations based on the 24th solar cycle, obtained by processing GPS stations in America, Europe-Africa and Asia. - We show that the highest VTEC values are displayed during the two months of the spring equinox, located after sunrise and before sunset. The lowest values are found during the summer and winter seasons.

Similarly, there is also a double ionization peak in the morning and evening, due to the proximity of the equatorial fountain stations. The amplitude of the diurnal variation of the VTEC depends on the phase of the solar cycle. This is well known and is explained by the fact that total ionization depends on the solar radiation related to the phases of the solar cycle. -We show the variability of the VTEC during this period, which corresponds to the increasing phase of the solar cycle 24 observed around 2013-2014 as well as the decreasing phase around 2015-2017. There is a strong asymmetry in both equinoxial peaks and the localization of the peaks occurred in March/April and October/November at most in the sunspot cycle and in the decreasing phase. The correlation coefficient between VTEC and sunspots is high and varies according to the phases of the solar cycle In the NH, during the spring equinox, stations in the America sector near the magnetic equator have VTEC values slightly higher than those observed in the Asia and Europe-Africa sectors. On the other hand, during the summer period, VTEC values in the Asia sector are slightly higher than those in the Americas and Europe-Africa sectors. In the SH, stations near the magnetic equator show that VTEC values in the Asian sector are significantly higher than those in the American and Europe-Africa sectors, particularly during the spring equinox.

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