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Climatology of ionospheric scintillation over the Vietnam low-latitude region for the period 2006–2014

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Abstract

This paper presents the characteristics of the occurrence of ionospheric scintillations at low-latitude, over Vietnam, by using continuous data of three GSV4004 receivers located at PHUT/Hanoï (105.9°E, 21.0°N; magnetic latitude 14.4°N), HUES/Hue (107.6°E, 16.5°N; magnetic latitude 9.5°N) and HOCM/Ho Chi Minh city (106.6°E, 10.8°N; magnetic latitude 3.3°N) for the period 2006–2014. The results show that the scintillation activity is maximum during equinox months for all the years and depends on solar activity as expected. The correlations between the monthly percentage scintillation occurrence and the F10.7 flux are of 0.40, 0.52 and 0.67 for PHUT, HUES and HOCM respectively. The distribution of scintillation occurrences is dominant in the pre-midnight sector and around the northern crest of the equatorial ionization anomaly (EIA), from the 15°N to 20°N geographic latitude with a maximum at 16°N. The results obtained from the directional analysis show higher distributions of scintillations in the southern sky of PHUT and in the northern sky of HUES and HOCM, and in the elevation angles smaller than 40°. The correlation between ROTI and S_4 is low and rather good at PHUT (under EIA) than HOCM (near equator). We found better correlation in the post-midnight hours and less correlation in the pre-midnight hours for all stations. When all satellites are considered during the period of 2009–2011, the range of variation of the ration between ROTI and S_4 is from 1 to 7 for PHUT, from 0.3 to 6 for HUES and from 0.7 to 6 for HOCM.

Keywords: Equatorial ionosphere; Scintillation; Ionospheric irregularities

1. Introduction

The existence of equatorial plasma bubbles (EPB) is attributed to the instability of the Rayleigh-Taylor (R-T) plasma (Kelley, 2009 and references therein). The instability of the Rayleigh-Taylor plasma is triggered by the intensification of the eastward equatorial electric field just before its reversal, this intensification is called the Pre Reversal Enhancement (PRE). At the time of the PRE, the electric field oriented towards the east rapidly raises the ionospheric layers and creates large gradients of electronic density which is a condition for the development of R-T instability. The R-T instability mechanism is considered the primary mechanism responsible for the generation of ionospheric plasma density irregularities or plasma bubble in equatorial and low-latitude region (Maruyama, 2002; Rama Rao et al., 2006; Fejer et al., 1999). The plasma bubbles have typical east-west dimensions of several hundred kilometers, these contain irregularities with scale-lengths ranging from tens of kilometers to tens of centimeters (Tsunoda, 1980), extending along the geomagnetic field lines to the latitudes of the anomaly crest regions. These irregularities affect the propagation of electromagnetic

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waves and cause scintillations on the Global Positioning System (GPS) signal (Basu and Basu, 1981). The amplitude and phase of a radio signal crossing a region of irregularities in electronic ionospheric density are modified. The irregularities with size comparable or smaller than the first Fresnel zone ($D = \sqrt{2\lambda z}$, where D is the scale size of the irregularity, λ is the radio wavelength, and z is the altitude of the irregularity layer) can cause scintillation in the GPS signal (Yeh and Liu, 1982). So far, the ionospheric scintillations associated with ionospheric irregularities remains a major subject regarding the space weather effects on trans-ionospheric signal propagation systems, such as the global positioning system (GPS), particularly at equatorial and low-latitude regions.

There are number of studies which reported climatology of GPS ionospheric scintillation and ionospheric irregularities activity from the GPS phase fluctuations in the different latitude regions (Pi et al., 1997; Basu et al., 1999; Valladares et al., 2004; Rama Rao et al., 2006; Spogli et al., 2009; Beniguel et al., 2009; Alfonsi et al., 2013; etc.). Pi et al. (1997) have defined a ROTI index, based on the standard deviation of the rate of change of total electron content (TEC) over a 5-min period to monitor the ionospheric irregularities from the GPS phase fluctuations. Rama Rao et al. (2006) showed the spatial and temporal characteristics of L-band over Indian with the scintillation activity is stronger around the equatorial ionization anomaly (EIA) region and these scintillations are often accompanied by the TEC depletions scintillations over the Indian. Valladares et al. (2004) found out the anomaly crests are the regions where the most intense GPS scintillations and the deepest TEC depletions are encountered in South America. Recently, Abadi et al. (2014) investigated ionospheric scintillations for Indonesia low-latitude region and showed the characteristics of GPS scintillation associated with low-latitude ionospheric disturbances. Huang et al. (2014) reported GPS ionospheric scintillation during the phase of rising solar activity from 2010 to 2014 for the low latitude station of Shenzhen (China). In addition, several researchers have used TEC fluctuations (ROTI) to compare with amplitude scintillation (S_4 index) in low-latitude region. By comparing amplitude scintillations (S_4) with TEC fluctuations, Beach and Kintner (1999) concluded that the S_4 index is roughly proportional to ROTI for weak scintillations and that the ratio ROTI/S_4 varies between 2 and 5 at Ancón, Peru. Using their own data set, Basu et al. (1999) similarly found that ROTI/S_4 varies between 2 and 10 at Ascension Island. Li et al. (2007) reported the ratio of ROTI/S_4 varies between 0.3 and 6 in the Chinese low latitude region.

This study is the first which gives the characteristics of ionospheric scintillations observed on GPS at low latitudes over Vietnam. We used three receivers installed at PHUT (Hanoi), HUES (Hue) and HOCM (Ho Chi Minh City) during the period 2006–2014. Our study presents the climatology of scintillation and their directional occurrences. We considered the ratio between the ROTI and S_4 indices during the increasing phase of solar activity (2009–2011) in order to provide additional informations on the relationship between scintillation and ROTI at low-latitudes.

2. Data and method of analysis

We used scintillation data recorded by three GISTM receivers (GPS ionospheric scintillation and TEC monitors), installed in Vietnam in the framework of the scientific co-operation between the Institute of Geophysics (Vietnam) and University of Rennes 1 and National School of Telecommunication of Brest (France). Fig. 1 shows the location of the stations and the GPS satellites paths at the level of the piercing points at the altitude of 400 km, on January 07, 2010. On this figure the magnetic equator calculated by the IGRF 2010 model is plotted by a line quasi parallel to the geographic equator at a latitude 7.5–8°N.

The GSV4004 receiver measures the amplitude and the phase of the scintillation from the L1 frequency signal at a sampling rate of 50 Hz, and the ionospheric TEC from the L1 and L2 signals. In this paper, we use the S_4 index to study the characteristics of occurrence of ionospheric scintillations. The S_4 index is computed from the normalized standard deviation of raw signal intensity (S_{4T}) and for each 1-min period. The corrected S_4 index is computed by removing the effects of ambient noise (S_{4No}), as follow (Rama Rao et al., 2006; Abadi et al., 2014):

$$S_4 = \sqrt{S_{4T}^2 - S_{4No}^2} \quad (1)$$

However, S_4 calculated with this formula may still contain multipath effects, particularly at low elevation angles. In previous studies, to avoid multipath effects, there are two methods: (1) to remove the data at elevation angle lower than 40° (Rama Rao et al., 2006; Li et al., 2007) and (2) to use a filter limit for separating multipath and ionospheric scintillation signal (Van Dierendonck and Hua, 2001; GSV GPS Silicon Valley, 2005; Beniguel and Adam, 2007; Romano et al., 2013; Abadi et al., 2014). In this study, we used the method of Van Dierendonck and Hua (2001) and Abadi et al. (2014). Details on methodology can be found in Abadi et al., 2014. Following this technique, we defined the filter limit for the scintillation data of PHUT, HUES and HOCM stations as shown in Fig. 2. All scintillation data above the line are likely multipath effects, are excluded from the data analysis.

Fig. 3 illustrates the difference between the unfiltered and filtered data. The maximum S_4 values of all visible satellites each minute are plotted according to the same color scale for PHUT, HUES and HOCM during March 2010. Fig. 3a–c shows the maximum S_4 values without filter for PHUT, HUES and HOCM, respectively. The dark region indicates that no there are data. The plots are very noisy because the same S_4 variation is repeated every

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