GPS scintillations, TEC and zonal plasma drifts observed during the COPEX 2002 campaign: Preliminary results

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Abstract

Radio signal amplitude scintillations at the Global Positioning System (GPS) L1 frequency (1.575 GHz) and the ionospheric irregularity zonal velocities were measured simultaneously at three sites during the Conjugate Point Equatorial Experiment (COPEX) campaign conducted in Brazil from October 1 to December 10, 2002. These observations used two GPS receivers at each site spaced geomagnetically in the east-west direction and the three observation sites were located along a same magnetic meridian, one at the magnetic equator, Cachimbo (9.5º S, 54.8º W, dip angle: -3.9º), one at the northern conjugate point, Boa Vista (2.8º N, 60.7º W, dip angle: 22.5º) and one at the southern conjugate point, Campo Grande (20.5º S, 54.7º W, dip angle: -22.5º). The data collected in the COPEX campaign occurred during high scintillation activity months which are associated to periods of high occurrence of ionospheric plasma depletions, also known as plasma bubbles. The average decimetric solar radio flux for this period of increased solar activity was about 156. Only magnetically quiet days with $\sum Kp \leq 24$ were selected for this study. Simultaneous dual-frequency GPS receivers measurements revealed total electron content (TEC) decreases, which are bubble signatures, during the observed strong amplitude scintillations. In this paper we will present some preliminary investigations of latitudinal variations and dynamics of scintillations, TEC and ionospheric zonal plasma drifts over magnetic conjugate points.

Introduction

The effects of the ionosphere on the radio communications, such as the satellite signals used for telecommunications downlinks and uplinks, geodesy and global navigation satellites systems have been extensively investigated in the last decade, and have also been exploited as a tool to Aeronomic studies. Ground-based GPS measurements have effectively been used for studies of equatorial ionospheric irregularities (see for example, Aarons *et al.*, 1997; Basu *et al.*, 1999; Beach and Kintner, 1999; de Paula *et al.*, 2003) and their zonal drift velocities (Kil *et al.*, 2000, 2002; de Paula *et al.*, 2002) by measuring the fluctuations or scintillations into the GPS radio wave signals strength during the evening and the night hours. The *F*-layer irregularities are known to be the main causes of GPS L-band scintillations, then degrading the performance and navigation accuracy. For the GPS L1 frequency and 350 km altitude irregularities, the scale-size plasma structures probed are about 400 m, what are comparable to the scale-size of the first Fresnel zone (Beach and Kintner, 1999). At equatorial and low latitude regions, the irregularities drift velocities are often in the order of 50 ~ 150 m/sec, yielding characteristics scintillations timescales of about 4 sec. (Pi *et al.*, 1997).

The present paper presents the preliminary results obtained from measurements of GPS receivers installed at three stations located along a field line with a 350-km apex over the equator. The geographic locations of the observatories are shown on the map of Figure 1. The principal aims of these analysis is to contribute to the understanding of the ionospheric irregularity behavior and dynamics at different magnetic points over the Brazilian sector and to associate the simultaneous measurements of L-band scintillations, TEC, and zonal plasma flows.

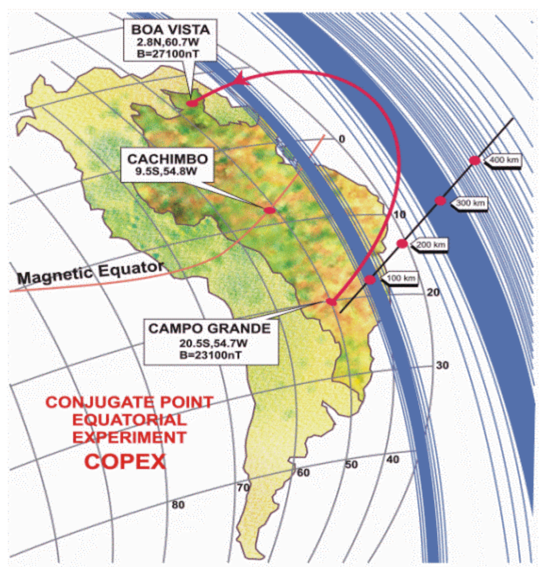

Figure 1 – The Brazilian COPEX stations. Cachimbo (CA), at the equator, and the conjugate stations at Boa Vista (BV) and Campo Grande (CG).

Experiment Description

The COPEX campaign was coordinated by the Aeronomy group from Brazilian National Institute for Space

Research (INPE), in a joint collaboration with others national and international groups, such as, a Brazilian Air Force group from CTA (Centro Técnico Aerospacial), a Japanese group from the Communication Research Laboratory (CRL), and two North American groups, one from the Air Force Research Laboratory Space Vehicles Directorate (AFRL/VSBX), USA, and one from the Center of Atmospheric Research, University of Massachusetts Lowell, USA (Batista *et al*., 2003). For this experiment, besides the GPS receivers for scintillation monitoring and TEC measurements, several equipments were operated along the three conjugate points, such as, HF receivers, digisondes, optical imagers, magnetometers and a 50 MHz radar.

The GPS receivers maintained at each observation site included two scintillation monitors (Scintmon) from Cornell University, spaced 100 m in the magnetic east-west direction and designed to detect the amplitude scintillations of the L1 frequency (1.575 MHz). In order to sample the local ionosphere over the observation site and to study the scintillations caused by nearly overhead small scale irregularity structures, only the satellites with elevation angle higher than 40 degrees were used to analyze the data. This consideration reduces the variations of the subionospheric distances at 350 km due to the satellite movement (Kil *et al.,* 2000; de Paula *et al*., 2002). The Cornell scintillation monitors are capable of logging the signal intensity at 50 samples per second for up to eleven visible satellites simultaneously, then the data collected are post-processed via software and, for each 60 seconds interval of data (3000 data points) the S4 scintillation index is computed (de Paula *et al*., 2003) for all satellites tracked during the observation nights (1800 LT to 0600 LT). The S4 index is the most used parameter to measure ionospheric amplitude scintillation activity and is defined as the normalized standard deviation of the received signal power intensity. It may be calculated by the following equation (Yeh and Liu, 1982):

$$S_4^2 = \frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2} \qquad (1)$$

where I is the field intensity.

The spaced GPS scintillation monitors configuration is adopted in order to infer the ionospheric irregularity drifts. This technique allows to determine an apparent velocity v_a of the irregularities from the time lag of the maximum cross-correlation of the scintillation patterns between the two receivers (Ledvina *et al*., 2004). Since the GPS satellites are not stationary, the relative apparent drift velocity v_r of the irregularities to the satellite movement should be determined firstly from the following relation (Kil *et al*., 2000):

$$v_r = \frac{d}{(n_{off}/f_s)} \qquad (2)$$

where d is the subionospheric distance (350 km), n_{off} is an offset number determined by the cross-correlation method and f_s is the sampling rate (50 samples/sec). Then, assuming that the scintillation pattern velocity is constant during the time lag, the satellite east-west movement v_{sat} gives the same effect as the irregularity structures moving in the opposite direction to the satellite (Ledvina *et al*., 2004). Therefore, with respect to the ground, the apparent irregularity zonal drift velocity v_a can be determined by the relation $v_a = v_r + v_{sat}$. A rigorous calculation of the true zonal velocity should take into account the random motions of the ionospheric irregularities. However, under the assumption of frozen-in irregularities and considering the low random velocity and quick decrease throughout the night, during a few seconds the apparent irregularity zonal velocity may be approximated to the true zonal velocity (Kil et al., 2000; 2002). The principal factor that differs the apparent drift velocity from the true velocity is the vertical drift in the early evening, during the growing phase of the ionospheric irregularities.

In order to obtain TEC measurements, an Ashtech GPS receiver from AFRL was installed at each observation site. The Ashtech is considered a robust dual-frequency receiver because of its capability to provide amplitude scintillation monitoring for both GPS L1 (1.575 MHz) and L2 (1.227 MHz) frequencies as well as Total Electron Content (TEC) informations (Groves *et al*., 2000). In the Ashtech receiver the amplitude and phase data are sampled at a 20 Hz rate, then the collected data are processed and the S4 scintillation parameter for all available satellites are recorded every 60 seconds. In this paper, we will present the Ashtech's S4 index obtained from the L1 frequency.

By processing the Ashtech data from both L1 and L2 frequencies it was possible to estimated how many electrons were encountered by the signal from the satellite to the receiver. This measure is the so called total electron content and is defined as the number of electrons found in a column with one square meter centered on the signal path, and is also proportional to the ionospheric delay between the GPS L1 and L2 frequencies. For convenience this is reported in TEC units (TECU), the quantity of 10^{16} electrons per square meter. It is found from previous studies that ionospheric irregularities can cause large depletions on the TEC values (Pi *et al.* 1997; Beach and Kintner, 1999; Basu *et al*., 1999) and their signatures can clearly be visible in the phase-derived TEC plots.

Examples of Results

Irregularities in the electron density at *F* region heights are mostly associated to the equatorial spread-*F* (ESF) phenomenon and with plasma depleted flux tubes. These irregularities are primarily responsible for the amplitude radio wave scintillations and for the TEC depletions relative to the background. Figure 2 illustrates measurements of signal power, scintillation and TEC recorded by the GPS receivers located at BV (left column) and CG (right column) and observed during the overpass of the GPS satellite 20 (PRN 20) on the night November 12-13, 2002. Notice that for the stations LT = UT – 3h. Figure 2a in the top left and right panels displays the signal power sampled every 1 min. for each station and recorded by the Scintmon receivers. At BV, during the half hour before 2300 UT, no amplitude scintillations were observed. At ~2300 UT the signal amplitude begins to fluctuate, due to ionospheric scintillations arising from equatorial spread-*F* (ESF).

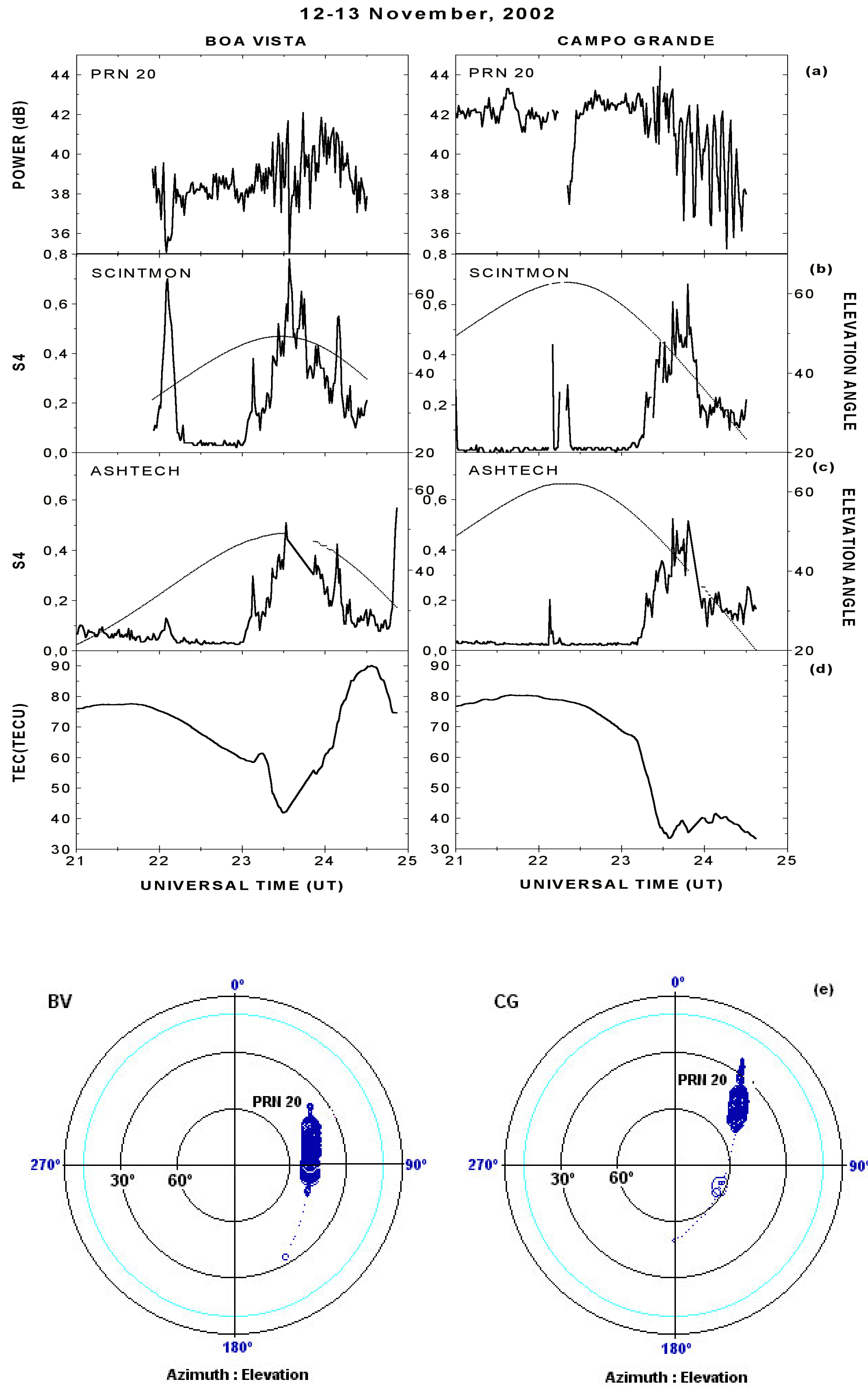

Figure 2 – Data collected for the conjugate stations Boa Vista (left column) and Campo Grande (right column), Brazil, on November 12-13, 2002. (a) Low-resolution Scintmon signal amplitude data (60 sec) from satellite 20 (PRN 20). (b) S4 index measured over 60 sec intervals from the Scintmon receiver and the satellite (PRN 20) elevation angle. (c) The same as Figure 2b but for the Ashtech receiver. (d) Equivalent vertical TEC given in TECU ($10^{16}/m^2$). (e) Azimuth-elevation diagram showing the satellite path from 2100 UT until 2430 UT as seen for each station. The path width is made proportional to the magnitude of S4 index.

About ten minutes later than BV, at ~2310 UT, the signal amplitude also begins to fluctuate at CG. Such differences in the time beginning of the observed fluctuations may be mainly due to the different ionospheric puncture points sampled at the two stations by the satellite PRN 20 signal, since at this time the elevation angle of the satellite at CG is higher than at BV. Figures 2b and 2c show that the satellite (PRN 20) at BV reaches 40º of elevation angle few minutes before 2230 UT, while at CG the elevation angle of the satellite is already higher than 40º at 2100 UT. For comparison, the amplitude of the power signal at CG is ~42 dB around 2230 UT, while at BV is ~38 dB. In this case the signal amplitude is higher at CG because the satellite elevation is also higher and the GPS signal traverses a smaller portion of the ionosphere. Are also shown in Figures 2b and 2c the S4 indices as measured by the Ashtech and Scintmon receivers, respectively. At BV, considering the elevation mask of 40º, the S4 index attains the maximum value around 2330 UT and remains high, but decreasing for the remainder of the overpass. At CG, it similarly increases and attains the peak value around 10 minutes later than BV, then it decreases rapidly to a value of ~0.2 and remains around this level until about 2430 UT when the satellite elevation angle descend to 20º. The relative TECs calculated from the ionospheric advance of the GPS L1 and L2 phases are presented on the bottom plots (Figure 2d). At BV the TEC started at a maximum value and began to decrease as the satellite elevation increased and the integration path through the *F* region decreased in length. At around 2330 UT a large TEC depletion occurred simultaneously with the increase in the S4 index, as expected, indicating that the overhead ionosphere was disturbed by ionospheric bubble. For the remainder of the evening, as the satellite elevation angle and the amplitude scintillation decreased, the TEC increased in value. At CG the TEC decreased slowly until around 2315 UT, when it began to decrease rapidly in despite of the decrease in the satellite elevation angle. A minimum in the TEC value occurred ~2330 UT, agreeing with the increase in the scintillation level, but in an opposite way that occurred at BV it passed trough short maxima and minima until around 2430 UT. These variations in TEC are typical of a disturbed spread-F ionosphere, and the lower TEC value observed at CG between 2330 UT and 2430 UT may be due to the action of transequatorial thermospheric neutral winds blowing southward. The sky maps in Figure 2e with azimuth-elevation coordinates show the GPS satellite PRN 20 path at 350 km as seen by the receivers at BV and CG. The widths of the paths are made proportional to the magnitude of the S4 index.

The averages and standard deviations of inferred zonal drift velocities of the ionospheric plasma irregularities during November, 2002, at CA, BV and CG are shown in Figure 3. In this calculation, we included data of elevation angle higher than 42º, S4 index higher than 0.15 and cross-correlation index higher or equal to 0.9. The averages were calculated for eight nights during November with coincidence in the scintillation data over the three stations. The standard deviations of the velocities for each observation site are presented as error bars. The observations show that the eastward zonal velocity decreases throughout the evening at the magnetic equator as well as at both conjugate locations. At the magnetic equator (CA) the zonal velocities are about 180 ms^{-1} at 2430 UT and 150 ms^{-1} around 0300 UT. At the southern conjugate point (CG) it was about 190 ms^{-1} at 2300 UT, 150 ms^{-1} around 2430 UT and about 130 ms^{-1} at 0300 UT. At the northern conjugate point (BV) the zonal velocity is about 160 ms^{-1} at 2430 UT, 110 ms^{-1} near 0300 UT, and like observed at CA and CG it decreases after 0300 UT (midnight in LST). On average, the zonal drift velocities at both conjugate stations are smaller than that at the magnetic equator, and at BV it is smaller than that at CG by about 25 ms^{-1} after 0100 UT. In a first approximation, the average zonal drift velocities calculated at the two conjugate stations BV and CG should be the same. However, the satellites signal sampled different ionospheric puncture points and in the calculation of the zonal drift velocities it probably bias the results (Kintner, 2005, personal communication). The differences were mostly within the error bars, but the eight days average velocities showed negative latitudinal gradient of the zonal velocity. These observations are consistent with previous one from Kil et al. (2002), in which latitudinal variations of the zonal velocities indicate a vertical shear of the zonal plasma flow.

Conclusions and summary

In this work, we have reported initial results for scintillation and TEC obtained at two conjugate stations during the COPEX campaign, and conducted in a period of spread-*F* season in the Brazilian region and during the maximum in the solar cycle activity (year 2002). The GPS measurements for the same satellite revealed that the scintillation occurrence was accompanied with TEC depletion in the sites aligned along the same magnetic meridian. Difference in the power signal amplitude and in the scintillation level measured among the stations may be associated to difference in the satellite elevation angle during its overpass at each observation site.

Simultaneous measurements of the irregularities zonal drift velocities using two spaced receivers technique and the cross-correlation method showed that the zonal velocities in the conjugate locations (Boa Vista and Campo Grande) are larger than the velocity at the magnetic equator (Cachimbo). Such latitudinal difference of the zonal plasma drift velocities is an indication of vertical shear of the plasma flow, since the velocities at different latitudes are projected to different heights in the equatorial plane. This feature is essentially due to the elongation of the irregularities along the magnetic field lines. Our observation agrees with previous zonal plasma velocities investigations at equatorial and low-latitudes stations achieved in the Brazilian sector.

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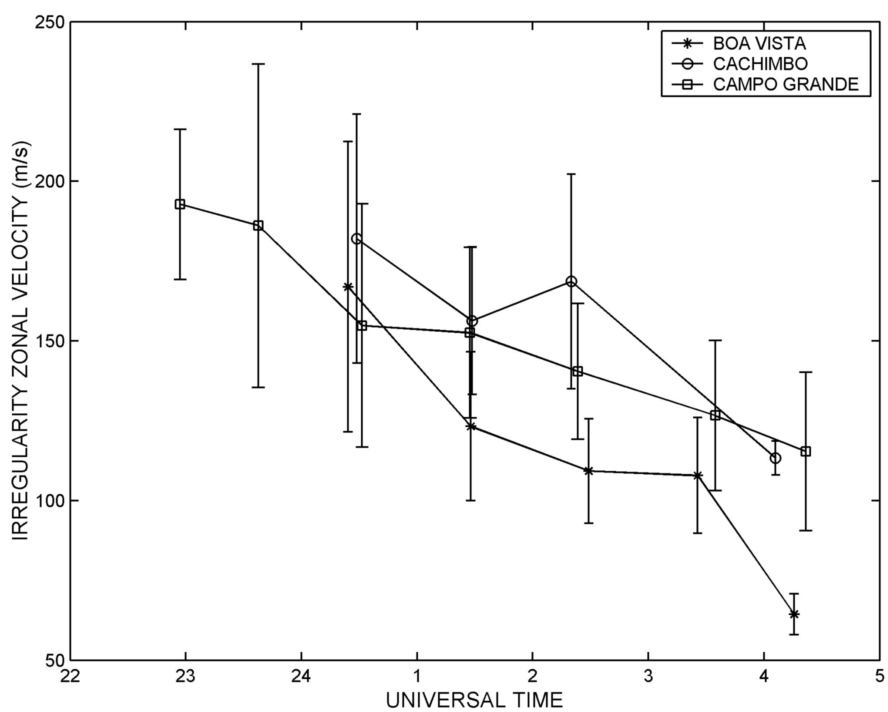

Figure 3 – Irregularity zonal average velocities and standard deviations inferred at the three COPEX stations.