Evidences of ionospheric scintillation effects over GPS loss of lock

L.F.C. de Rezende, E.R. de Paula, I.J. Kantor
INPE-CP 515 12.245-970 São José dos Campos SP

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Abstract

In collaboration with Cornell University, ionospheric scintillation monitors (SCINTMON) were installed at many sites over Brazil, to study the degradation of GPS signals due to ionospherics scintillations. These monitors are GEC-Plessey GPS development cards modified to sample the wide band power of the GPS signal at a high rate (50 samples/sec). To quantify the magnitude of the ionospheric scintillations, the S_4 index, that is the standard deviation of the GPS signal amplitude relative to its average for each minute, was used. This paper presents the correlations between the GPS signal scintillations, that occur during ionospheric irregularities, with signal loss of lock with consequent decrease of available satellites and degradation (increase) in the GDOP (Geometric Dilution of Precision). Data from Cachoeira Paulista (22.57° S, 45.01° W, dip latitude 18.12° S) and São José dos Campos (23.07° S, 45.86° W, dip latitude 18.01° S) during periods of average and high solar activity were used.

Introduction

The ionospheric irregularities, known as spread F, are generated at the equatorial region after sunset due to plasma instabilities (Fejer, 1996, Fejer et al, 1999, Hysell and Burcham, 1998, Sobral et al., 1980, Abdu, 2001, de Paula et al., 2003), affect substantially the telecommunication and global positioning systems. Both phase and amplitude of a radio signal fluctuate when it passes through ionospheric irregularities. The ionospheric irregularities have been studied by theoretical computational models and using VHF radars, ionosondes, payloads onboard satellites and rockets, airglow instrumentations, polarimeters and geostationary satellite signal receivers. The GPS system, recently established, provided a new technique to study the ionospheric small scale (400 m) irregularities. Since 1997 many GPS receivers (SCINTMON) were installed at the Brazilian territory in collaboration with Cornell University. This network of GPS receivers provides a large amount of data with latitudinal (from equator to the Equatorial Anomaly South Peak) and longitudinal coverage during the increasing phase of the solar activity. Many studies have shown that ionospheric scintillation causes degradation in the GPS navigational accuracy and limitations in GPS tracking performance (Skone et al., 2001). Kintner et al. (2001) using GPS data from Cachoeira Paulista showed examples of loss of lock during ionospheric irregularities and described potential consequences over aircraft navigation system during such losses of lock. GPS data from Cachoeira Paulista and São José dos Campos were analysed to study the ionospheric irregularities effects over GPS signal and examples of loss of lock are presented.

Methodology

The SCINTMON receivers (Beach, 1998, 2001) were developed at Cornell University, they use the GPS L1 band (1.575 GHz), and collect GPS data files with a rate of 50 samples/second. These data are processed to generate summary files at one minute rate. They are the Universal Time, number of tracked satellites, noise power, satellite identification (PRN), satellite and receiver coordinates, Doppler shifts, wide band power, loss of lock, S_4 scintillation index, and signal autocorrelation width. Following the GDOP (Geometric Dilution of Precision), satellite azimuth and elevation angles were calculated using the X, Y and Z components of the satellites and receivers. GPS data for several S_4 levels, elevation angles and for the local time interval of 19 to 26 were analysed and the results will be presented in the next section.

Results and conclusions

Figure 1 presents the scintillation index S_4, the wide band power (WBP), the number of loss of lock and the elevation angle of the satellite (PRN) 03 for October 4, 1998 at São José dos Campos from 19 to 26 LT. This figure shows a good correlation between the high level of the S_4 index, that is an indication of the presence of ionospheric irregularities, with the WBP scintillations and occurrence of a case of loss of lock when the satellite elevation was about 45° (LT interval of 21 and 22) and many cases of loss of lock when the satellite was at the elevation of 20-30° (LT interval of 22:30 and 23). The low elevation satellite angles increase the probability of loss of lock occurrence, so the large number of loss of lock observed at 22:30-23 LT interval has the contribution from both low elevation angles and ionospheric irregularities. Figure 2 presents the S_4 for all available satellites for the same date of Figure 1, the losses of lock, the number of satellites and the GDOP. Figure 2 shows many correlations between S_4 and the signal losses of lock, the decrease of the number of satellites and the degradation (increase) of the GDOP. Around 23:30 LT there is a critical situation when there were some GDOP increases above 11 and the number of satellites decreased to 4, that is the minimum number of satellites for the GPS system to provide the positioning and time information. At this time interval also there were losses of lock and high S_4.

This work presents some examples of deterioration of the GPS signal during events of ionospheric irregularities. When the number of available satellites is low and when it decreases more due to ionospheric irregularities, the GDOP can increase and the GPS system reliable operation becomes critical.

References

Abdu, M.A., Outstanding problems in the equatorial ionosphere-thermosphere electrodynamics relevant to spread F, Journal of Atmospheric and Solar-Terrestrial Physics, 63, p869-884, 2001.

Beach, T.L., Global positioning studies of equatorial scintillations, PhD Dissertation, Cornell University, Ithaca, NY, USA, 1998.

Beach, T.L., P.M. Kintner, Development and use of a GPS ionospheric scintillation monitor, IEEE Transactions on Geoscience and Remote Sensing, 39, p918-928, 2001.

de Paula, E. R., F.S. Rodrigues, K.N. Iyer, I.J. Kantor, M.A. Abdu, P.M. Kintner, B.M. Ledvina, H. Kil, Equatorial anomaly effects on GPS scintillations in Brazil, Adv. Space Research, 31(3),p749-754,2003.

Fejer, B.G., Natural ionospheric plasma wave, in Modern Ionospheric Science, Eds. H.Kohl, R. Ruster, K. Schlegel, 1996.

Fejer, B.G., L. Scherliess, E.R. de Paula, Effects of the vertical plasma drift velocity on the generation and evolution of equatorial spread F, Journal of Geophysical Research, 104(A9), p19859-19869, 1999.

Hysell, D.L., J.D. Burcham, JULIA radar studies of equatorial spread F, Journal of Geophysical Research, 103(A12), p29155-29167, 1998.

Kintner, P.M., H. Kil, T.L. Beach, E.R. de Paula, Fading timescales associated with GPS signal and potential consequences, Radio Science, 36 (4), p731-743, 2001.

Skone, S., K. Knudsen, M. de Jong, Limitations in GPS receiver tracking performance under ionospheric scintillation conditions, Phys. Chem. Earth (A), 26, p613-621, 2001.

Sobral, J.H.A., M.A. Abdu, I.S. Batista, Airglow studies on the ionospheric dynamics over low latitude in Brazil, Annales Geophysicae, 36(2), p199-204, 1980.

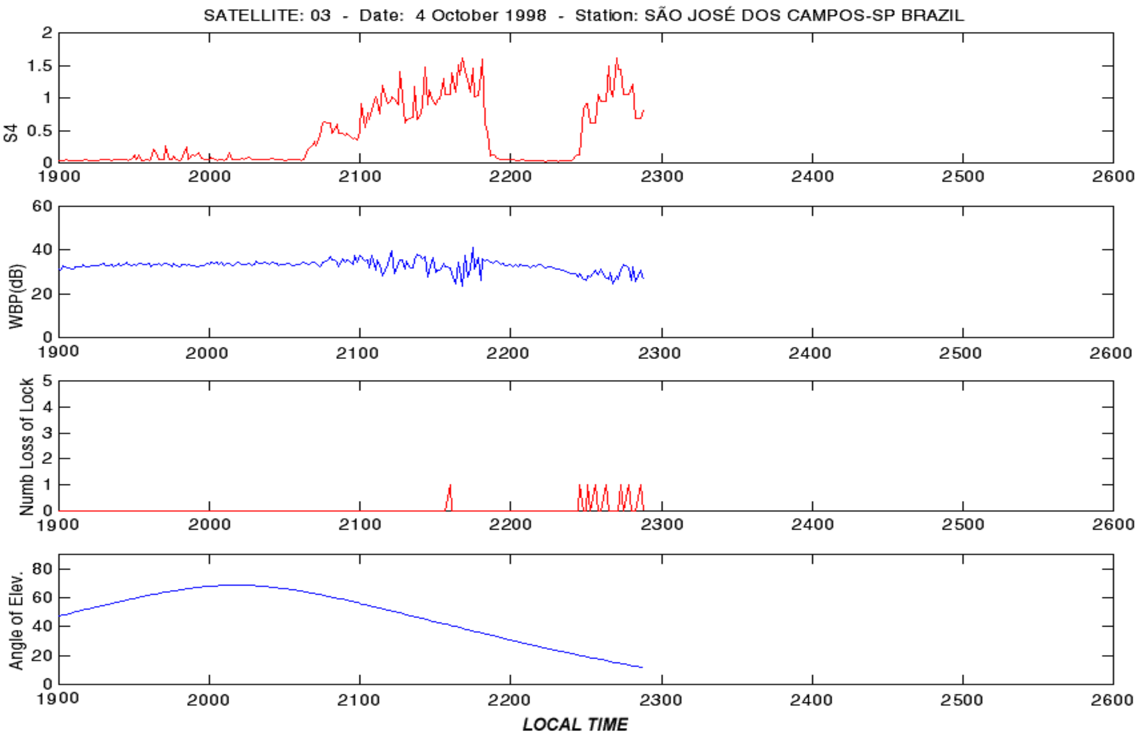

Figure 1 –Scintillation index S_4, the wide band power(WBP), the number of lock of loss and the angle of elevation of the satellite(PRN) 03 for October, 4,1998, at São José dos Campos.

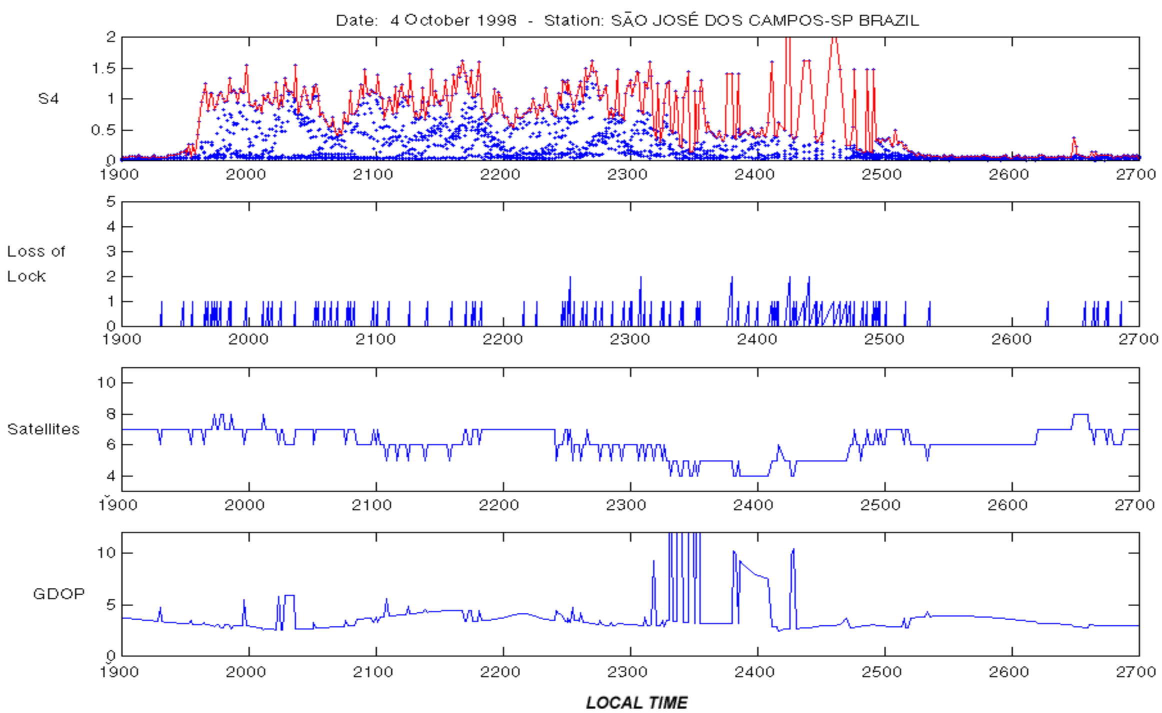

Figure 2 –Scintillation index S_4 for all available satellites, number of lock of loss, number of satellites available and GDOP for for October, 4, 1998, at São José dos Campos.