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Ionospheric Effects on Signal in Space and on Ground Based Augmentation System

Teddy M. Surco Espejo(1), Emanoel Costa(1), Alison de O. Moraes(2), Eurico R. de Paula(3), João Francisco Galera Monico(4)
(1)Centro de Estudos de Telecomunicações, Pontifícia Universidade Católica do Rio de Janeiro (CETUC PUC-Rio); Rua Marquês de São Vicente 225; Rio de Janeiro, Brazil; teddy@cetuc.puc-rio.br, epoc@cetuc.puc-rio.br
(2)Instituto de Aeronáutica e Espaço/Instituto Tecnológico de Aeronáutica, Praça Marechal Eduardo Gomes 50; São José dos Campos, Brazil; aom@ita.br
(3)Instituto Nacional de Pesquisas Espaciais (INPE), Av. dos Astronautas, 1.758 - Jardim da Granja, São José dos Campos, Brazil, eurico.paula@inpe.br
(4)Universidade Estadual Paulista Júlio de Mesquita Filho - UNESP, R. Roberto Símonsen, 305, Presidente Prudente, Brazil, galera.monico@unesp.br

Abstract

The ionosphere affects the propagation of GPS signals in the equatorial and low-latitude regions. Even auxiliary systems based on GPS such as the Ground Based Augmentation System (GBAS), are affected by ionospheric effects. This contribution will present analysis of position errors resulting from the simulation of GPS observables and GBAS using differential corrections during aircraft approach and landing operations.

1 Introduction

The Global Positioning System (GPS) has an increasing role in Air Traffic Control. However, ionospheric delays and scintillation cause positioning error that degrades the accuracy, performance and availability of associated operations, particularly in the equatorial and low-latitude regions [1], [2].

Even auxiliary systems such as the Ground Based Augmentation System (GBAS) based on GPS signal in space have been developed to meet the safety requirements of air navigation, using differential corrections to provide higher accuracy during aircraft approach and landing operations. However, GBAS operations may also be severely affected by the equatorial and low-latitude ionosphere [3].

2 Methodology

For all active channels between GPS satellites and receivers, the following expressions apply for the pseudorange, carrier phase, and received power of the GPS L1 signal:

$$PR_{(i,j)} = \rho_{(i,j)} + c\left[\Delta t_{r(j)} - \Delta t_{s(i)}\right] + I_{(i,j)} + T_{(i,j)} + \\ + m_{\mathrm{PR}(i,j)} + v_{\mathrm{PR}(i,j)} \quad (1)$$

$$\phi_{(i,j)} = \rho_{(i,j)} + c\left[\Delta t_{r(j)} - \Delta t_{s(i)}\right] - I_{(i,j)} + T_{(i,j)} + \\ + m_{\phi(i,j)} + \lambda_{L1} N_{(i,j)} + \phi_{Iscint(i,j)} + v_{\phi(i,j)} \quad (2)$$

$$C_{(i,j)} = EIRP_{(i)} + \mathrm{G}_{(i)} + L_{(i,j)} + G_{(j)} + m_{\mathrm{C}(i,j)} \\ + 20\log\left[a_{Iscint(i,j)}\right] \quad (3)$$

where $\rho_{(i,j)}$ is the geometric range; $\Delta t_{r(j)}$ and $\Delta t_{s(i)}$ are the receiver and satellite clock errors, respectively; $I_{(i,j)}$ and $T_{(i,j)}$ represent the ionospheric and tropospheric delays, respectively; $m_{PR,\phi,C(i,j)}$ are associated with multipath effects on the pseudorange, carrier phase, and power, respectively; $v_{PR,\phi(i,j)}$ represents random errors in the pseudorange and carrier phase, respectively; $\lambda_{L1} = c/f_{L1}$ is the L1 wavelength, c is the velocity of light in free space, and f_{L1} is the L1 frequency; $N_{(i,j)}$ is an integer number representing the cycle ambiguity, which considers effects from cycle-slips; $\phi_{Iscint(i,j)}$ and $a_{Iscint(i,j)}$ represent phase and amplitude ionospheric scintillation effects; $EIRP_{(i)}$ is the effective isotropic radiated power of each satellite transmitter; $G_{(i)}$ and $G_{(j)}$ are the gains of the satellite and receiver antennas in the pertinent directions, respectively; and $L_{(i,j)}$ is the free-space path loss.

To simulate ionospheric delays, the vertical Total Electron Content is characterized through a statistical analysis of dual-frequency GPS data from the Rede Brasileira de Monitoramento Contínuo (RBMC) [4] and their residuals relative to those provided by the International Reference Ionosphere (IRI 2016). This study considers different combinations of five geophysical parameters. The α-μ probability distribution model is used to represent amplitude scintillation. To define the parameters of this distribution, a random value for the S_4 index (the standard deviation of the received power, normalized by its average value) and the associated value for α and μ are selected, according to data from the CIGALA/CALIBRA network.

Successive samples for the phase scintillation term are generated similarly, according to empirical relationships between S_4 and σ_ϕ (the standard deviation of phase fluctuations) values, combined with zero-mean Gaussian probability distributions [5], [6] and [7].

Next, the signal in space is tested and analyzed by the functions of a GBAS (Signal-in-Space Receive and Decode; Signal Quality Receiver; Signal, Measurement, and Data Quality Monitoring; Multiple Reference Consistency Check) showed in Figure 1. The functional blocks are integrated by the Executive Monitor to test, smooth, correct, and average signals, as well as to estimate protection levels and to generate correction messages that will be transmitted to aircraft via a Very High Frequency Data Broadcast link [8].

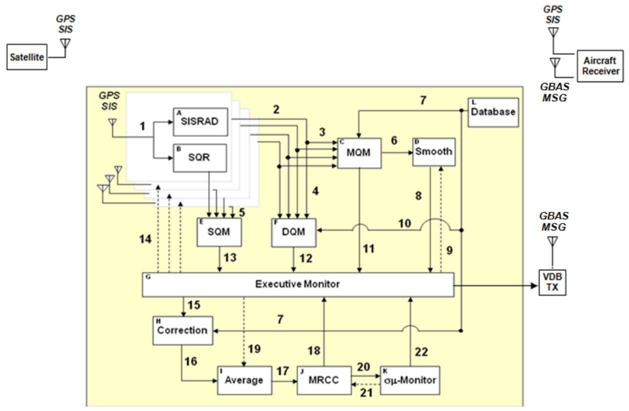

Figure 1. GBAS Ground System functional flow diagram

3 Data

Data from the RBMC Brazilian network were obtained to study the variation of the vertical TEC as a function of position, local time, season and solar activity over the Brazilian region. The data were stored in the Receiver Independent Exchange format (RINEX) format with 15-second sampling rate. The measurements were extracted from data collected using an elevation cut-off angle of 20°, to avoid multipath. RBMC RINEX files were used from January to December corresponding to the years 2002, 2008 and 2013. The deployed stations over the Brazilian territory used to estimate the vTEC are shown by dots in Figure 2.

4 Results

The results will be presented for a specific case, these observables will be simulated using Galeão Airport Rio de Janeiro receiver station on 11 November 2013 between 22:00 UTC and 22:10 UTC corresponding to the landing of the domestic flight between Recife and Rio de Janeiro. The results of the aircraft position errors without GBAS corrections and using GBAS corrections described as ECEF coordinates are showed in Figure 3.

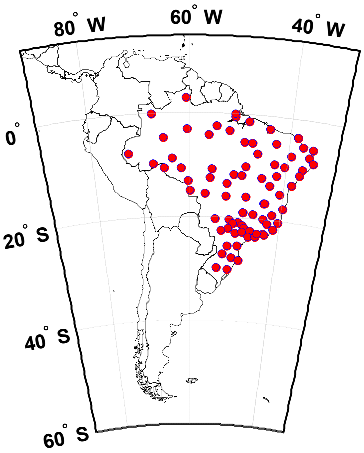

Figure 2. Positions of the ground-based RBMC stations

For this analysis we consider four receiver and the GBAS system installed at Galeão International Airport that send the corrections of pseudorange observable using only the L1 signal.

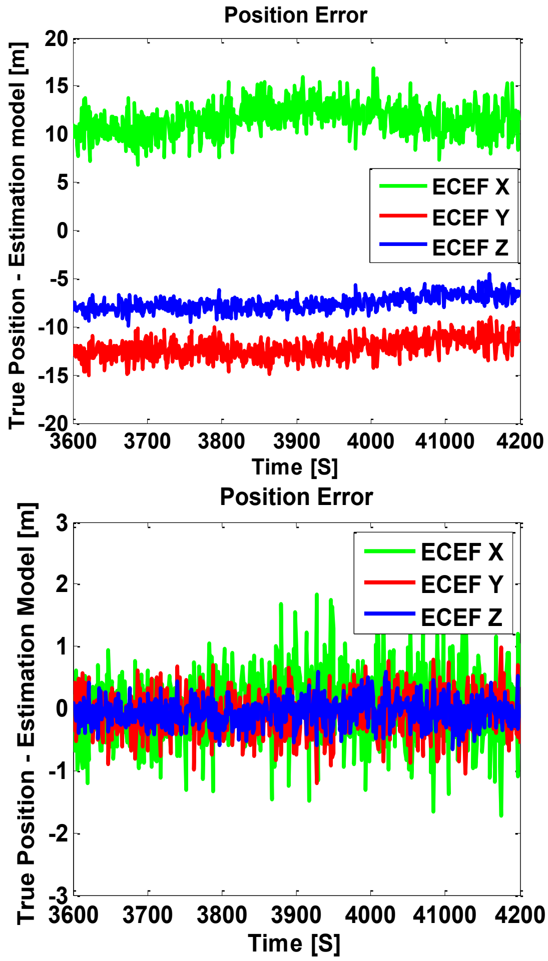

Figure 3. Aircraft position error without GBAS corrections (top) and with GBAS corrections (bottom) for Galeao Airport on 11 November 2013

The top panel in Figure 3 shows estimated results of the aircraft position errors using GPS measurements only and the true position of the aircraft. The estimated value of F10.7 index was 160.4 sfu. The maximum error is 16.1 meters and it is presented in the X coordinate. Also, the estimated three ECEF coordinates presenta large errors that exced 5 meters..

The bottom panel in Figure 3 depicts estimated results of the aircraft position errors using GPS measurements, GBAS corrections and the true position of the aircraft. The maximum error is 1.8 meters and is presented in the X cordinate. In this case, when corrections are applied to the estimation of the position, the errors are small, in comparison to the case without GBAS system. Consequently, the minimum requirements of a GBAS system are limited for the use of GNSS satellites ranging sources.

5 Conclusions

Pseudorange, phase and received power represented by models for ionospheric delay (IRI combined with residuals based on RBMC data); tropospheric delay; two-ray assumption for multipath effects; as well as amplitude and phase scintillation.

Simulated signals in space were processed by a GBAS computer model to study the effects of equatorial and low-latitude ionosphere. GBAS has not been certified to operate in the Galeão Airport, due to the ionospheric effects.

6 Acknowledgements

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7 References

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