IONOSPHERIC SCINTILLATION INCIDENCE PROBABILITY FOR DIFFERENT LEVELS OF SOLAR AND MAGNETIC ACTIVITIES OVER BRAZILIAN TERRITORY

Felipe Pellegrini Hernandez[1], Alison de Oliveira Moraes[2,4], Eurico R. de Paula[3], Waldecir Perrella[4], João F. Galera Monico[5]

1- EMBRAER, Brazilian Aeronautics Company, São José dos Campos, SP
2- IAE, Institute of Aeronautics and Space, São José dos Campos, SP
3- INPE, National Institute for Space Research, São José dos Campos, SP
4- ITA, Institute Technological of Aeronautics , São José dos Campos, SP
5- UNESP, São Paulo State University, Presidente Prudente, SP

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Abstract (Font: Arial Bold, 9)

The navigation and Positioning using satellite became essential in many areas, for instance in the terrestrial navigation, precise agriculture, aircraft landing, no manned aircraft control, petroleum prospection, between many other applications. Many factors can affect the performance of these navigation systems, like inclement weather, multipath, the troposphere, the ionosphere and even jammings. These interferences, depending of their severity intensity can degrade the positioning systems and even to interrupt the navigation, what can eventually affect one substantial number of users.

Between the sources of positioning errors using GPS, the ionosphere in the Brazilian territory is probably the most important factor that has influence over the positioning. The ionosphere causes delays and advances in the carrier and code signal, that result in pseudorange errors. Besides those effects, the GPS signal, when crossing the ionospheric bubbles with depleted densitites, suffers variations in the amplitude and phase, what is named ionospheric scintillation. The scintillation affects the receiver performance through signal distortions that produce positioning errors or in extreme events can interrupt the system operation. In this work it is presented one ionospheric scintillation analysis of the GPS signal based on the scintillation occurrence intensity during the spring and summer solstice for the 2013 to 2016 years. The analyzed data were obtained from two stations located at Presidente Prudente and São José dos Campos, both in the São Paulo state. These stations are located in a region suitable for this kind of study since they are located in low latitude and under the crest of the equatorial ionization anomaly. The aim of this work is to propose a set of equations to represent the scintillation occurrence probability in these stations during two seasons of the year.

The input parameters for the proposed approximations are the Kp index representing the magnetic intensity and the F10.7 cm representing the solar flux level. The proposed equations representing the scintillation estimative are validated with Presidente Prudente and São José dos Campos data. So this model will allow users to estimate the expected scintillation night-by-night based on the Kp and F10.7 values and they will be able to predict its incidence and consequently to reduce its impact mainly during more severe scintillation events.

Introduction and methodology

The ionospheric scintillation data used in this work are the amplitude S4 indices from Septentrio PolaRxS-PRO scintillation monitors (GNSS receivers). These receivers belong to the ionosphere monitoring UNESP network called CIGALA / CALIBRA. The period of data acquisition to be analyzed in this work is from January 2013 to June 2016 recorded in local time between 17:00 and 02:59, during the summer solstice for the monitoring stations of Presidente Prudente and São José dos Campos.

The results presented are based on complementary cumulative distribution (CCD) curves. Such curves are the complement of the probability distribution and, thus, the value of the Y axis will represent the probability of occurrence of scintillation above the respective value referring to the X axis. The CCD curves in this work will represent the probability of scintillation occurrence above a certain threshold from S4 to the chosen window of 10 hours per day.

After determining the CCD curves for the data the next step was to obtain the fitted quadratic (in Kp) polinomials (function) to represent the real data for each season, Kp value and for 3 solar flux levels (F10.7≤130, 130<F10.7≤180, and F10.7>180) for each site. The Kp values were considered for the time interval of 15 to 18 LT. In order to obtain these equations, the mean data were approximated by a polynomial equation of the second order parameterized by Kp, so as to guarantee that the average data would be well represented by these equations.

The equations that represent the proposed approximation for the estimated CCD are given respectively for the following 3 levels of solar fluxes F10.7 ≤ 130, 130 < F10.7 ≤ 180 and F10.7 >180, by:

$$\begin{aligned} CCD_{\mathrm{F10.7} \leq 130}(K_P, S4) &= (0.2907K_P^2 - 1.149K_P - 0.457)S4^2 \\ &+ (-0.4063K_P^2 + 1.655K_P - 2.224)S4 + (0.1673K_P^2 \\ &- 0.7077K_P + 0.0186) \end{aligned}$$

$$\begin{aligned} CCD_{130 < \mathrm{F10.7} \leq 180}(K_P, S4) &= (0.1842K_P^2 - 0.3479K_P - 1.389)S4^2 \\ &+ (-0.1218K_P^2 + 0.06333K_P - 0.684)S4 \\ &+ (-0.0222K_P^2 + 0.03507K_P - 0.2547) \end{aligned}$$

$$\begin{aligned} CCD_{\mathrm{F10.7} > 180}(K_P, S4) &= (4.828K_P^2 - 15.18K_P + 7.239)S4^2 \\ &+ (-4.303K_P^2 + 12.96K_P - 8.339)S4 + (-0.0704K_P^2 \\ &+ 0.3292K_P - 0.496) \end{aligned}$$

Results

Figures 1a and 1b show respectively the CCD curves for the Presidente Prudente (a) and São José dos Campos (b) stations in the summer solstice for the occurrences of S4. Analyzing these figures, for the condition of the solar flux index F10.7≤130 (low solar flux), it can be observed in the CCD curves, for different Kp levels lower than 4.5, even considering conditions that could suggest a disturbed scenario with 3 <Kp≤4.5, that these values of Kp would not affect the occurrences of scintillation in amplitude (S4). In this figure it can be seen that for the perturbed condition of 4.5<Kp≤6 (pink curves), amplitude scintillation inhibition occurs. Similar behavior was observed for 130<F10.7≤180. For F10.7>180 conditions the data statistics is very poor and no clear conclusions could be driven.

Figures (2a) and (2b) shows the comparison between CCD values inferred from data and estimated from the function (quadratic polynomial) in Presidente Prudente during the summer solstice of 2013 (a) and 2014 (b) respectively, representing 2 solar flux levels. It is possible to notice a very close approximation between the red curve (estimated) and the real curve in blue..

The first finding of the analysis performed in this work is the clear statistical evidence of the influence of the Kp index on the occurrence of scintillation. The results showed that nights with low Kp values have a greater number of occurrences of scintillation, or at least a greater chance of scintillation occurrence. Statistically, it was also verified that the increase in Kp index implies a reduction of scintillation activity in amplitude. Despite the significant influence of Kp, it is notable that the factor of greater preponderance in the scintillation activity is the solar flux. The results of Figures 1 and 2 not only showed the influence of Kp on the probability of occurrence of scintillation, but also verified the condition in which the scintillation inhibition occurs, in scenarios with 4.5 <Kp≤6. Unfortunately, it was not possible to confirm this behavior for high solar flow conditions, f10.7> 180, however for the other solar flux intervals, it was possible to verify this condition of inhibition.

Conclusion

GPS is very important in today's world, being used from civil to military. Its operation is strongly influenced by the space climate, mainly by effects in the ionosphere, therefore the study of this effect is necessary to prevent or to correct possible errors introduced in the system.

In this analysis it was observed the inhibition of scintillation with the increase of Kp, with values between 4.5 and 6. The inhibition of scintillation could only be verified for low values of solar flow, since the measurements with high values were scarce during the solar cycle 24.

In this work curves (functions) parameterized by Kp and by the solar flux F10.7 that can, with certain limitations, represent the complementary probability (CCD) of occurrence of scintillation for a determined Kp were determined. The statistical prediction of the occurrence of scintillation is of paramount importance to the GPS user, since in this way it may be possible to elaborate methods of compensating the positioning errors introduced by the GPS. Through this work it was possible to demonstrate that it is possible, within certain parameters, to elaborate equations that can predict the probability of occurrence of scintillation for a given value of Kp and a given solar flux (F10.7) and thus predict the occurrence of flicker and elaborate methods of correcting the errors imposed by it in GPS.

Acknowledegements

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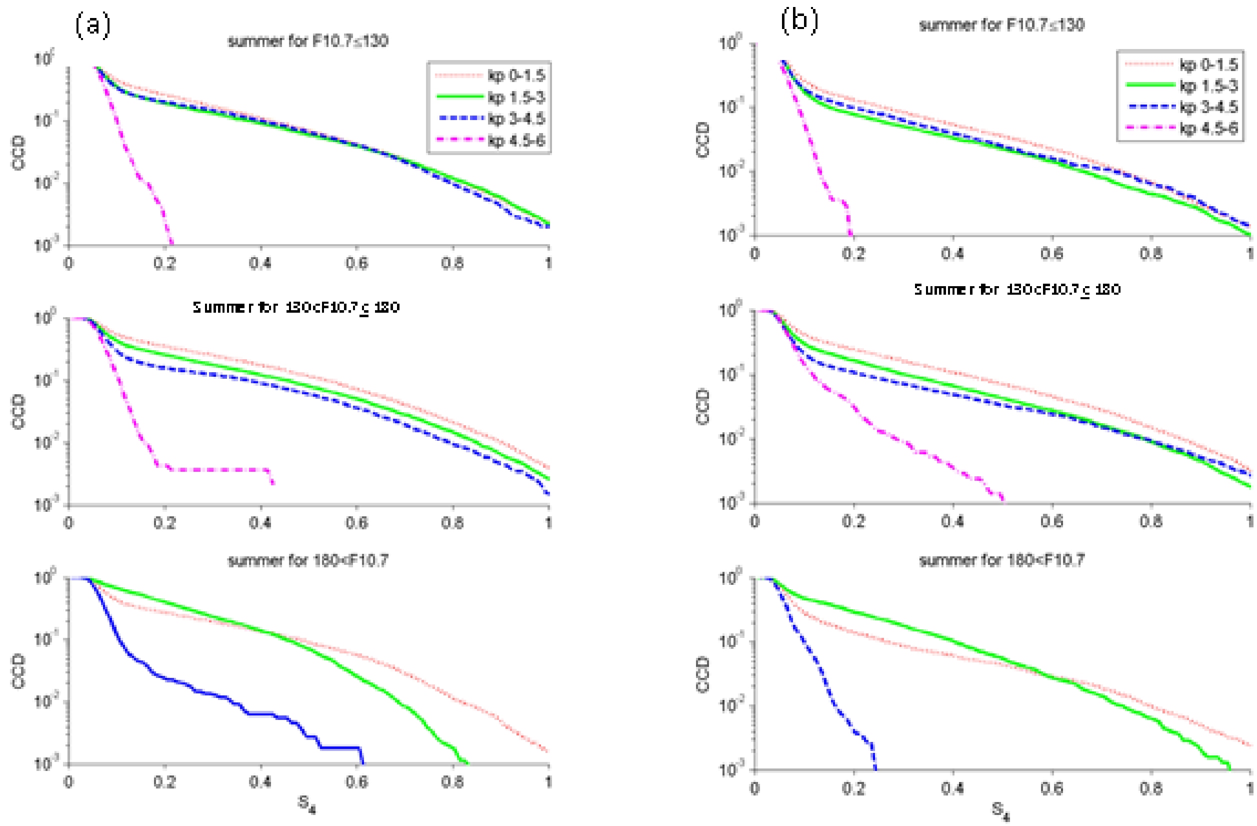

Figures 1a and 1b. CCD values for summer solstice in Presidente Prudente (a) and São José dos Campos (b) in function of S4, for 4 Kp levels and for 3 solar flux levels.

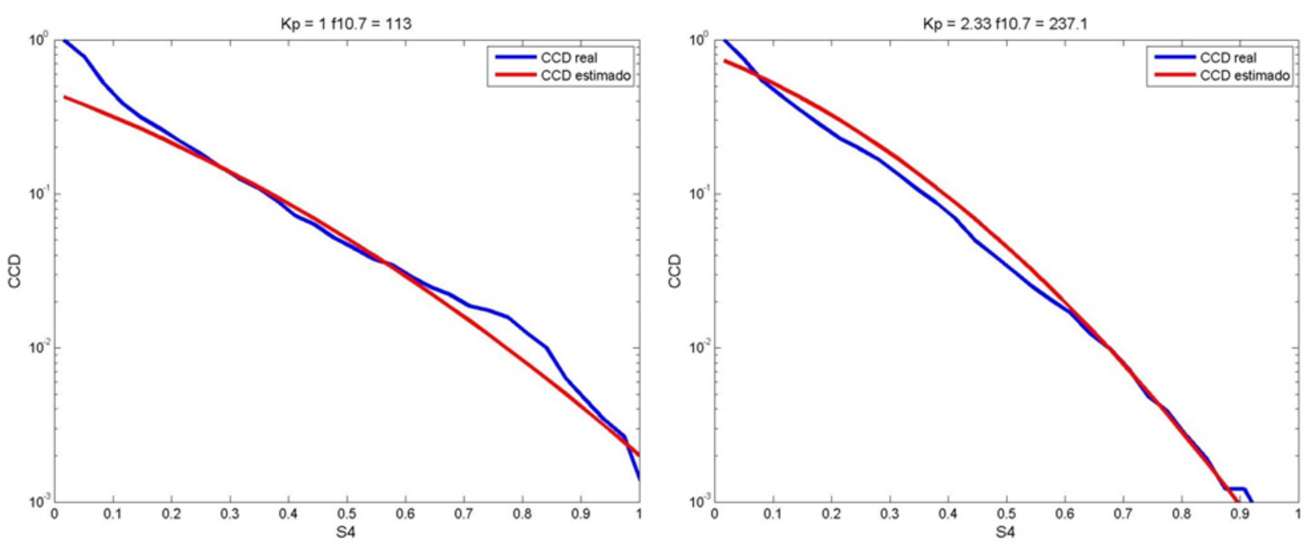

Figure 2. Comparison between the CCD values inferred from data above a certain threshold from S4 with CCD estimated function values at Presidente Prudente for summer solstice of 2013 (a) and 2014 (b) representing 2 levels of solar flux