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EQUATORIAL SCINTILLATION CALCULATIONS BASED ON COHERENT RADAR AND C/NOFS IN SITU DATA COMPARISON WITH GPS MEASUREMENTS

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Abstract.

1 INTRODUCTION

Sensors on board the Communication/Navigation Outage Forecasting System (C/NOFS) provide a one-dimensional description of ionospheric irregularities, which can be extended to two dimensions if the structures were assumed to be elongated in the direction of the magnetic eld lines. It is also necessary to investigate if consideration of the vertical structure of the irregularities could lead to improved predictions of scintillation. This information can only be routinely provided by radars, which probe irregularities with scale sizes much smaller than the ones causing scintillation, with spatial resolutions signicantly worse than that from *insitu* measurements. In principle, this may seem inappropriate for the present application. However, the results from previous experimental campaigns showed a good correlation between the occurrence of depletions and structures with sharp gradients in rocket data and the strength of backscatter power from the corresponding cells simultaneously sampled by the radar.

Motivated by the needs and diering arguments listed in the previous paragraph, the present work will investigate to which extent scintillation can be predicted with main basis on rangetime- intensity (RTI) measurements performed by the São Lu coherent scatter radar ($2.57^o S, 44.21^o W, dip angle 1.73^o$), in combination with C/NOFS *in situ* data and additional information. The results from the scintillation model will be compared with corresponding measurements by the co-located GPS receiver.

2 SLANT PROPAGATION THROUGH AN IRREGULARITY LAYER

The eld $U(x, z) = u(x, z) exp[ik(sin\ x + cos\ z)]$ resulting from the slant propagation of a plane wave through a bidimensional irregularity layer, rigorously modeled by the wave equation, can be represented by the product of a complex amplitude $u(x, z)$ and a phase term, where k is the free space wavenumber and is the zenith angle of the wave vector. For suciently high frequencies and small zenith angles, the phase-screen approximation can be adopted, leading to[1]

$$u_m(0) = \sum_{q= Q}^{+Q} C_q e^{i \quad m \quad q(h)} = \sum_{q= Q}^{+Q} C_q e^{\quad i \frac{r_e z}{cos} \quad N \ m \quad q(h)} \tag{1}$$

In the above equation, $\varphi\ (h)$ represents random phase located at the bottom h of the irregularity layer, $r_e = 2.817910\ \ ^{15} m$ is the classical electron radius, is the wavelength of the transmitted signal, and the propagation coecients C_q are specied by Costa and Basu[1]. The irregularity layer is initially subdivided into a large number of thin slabs of constant thickness z . The zero-mean electron density uctuation $N\ _i(h)$ within each slab is characterized by its mean square value $< N\ ^2 >_i$, which is related to the corresponding signal-to-noise (power) ratio $(s/n)_i$ measured by coherent scatter radar by the approximate expression

$$(s/n)_i \quad [\frac{r_e^2}{32\ \ ^3}(\frac{G^2\overline{g^2}\ \ _{3\perp} h\ \ _r\ \ _r^3 P_t}{k_B T_{sky} B_N L_{tot}})](\frac{\ \ _r^{q+1}}{2^q S_1 L_o^p\ \ ^q L_b^q\ \ ^p})\frac{< \quad N^2 >_i}{r^2} \quad C_r C_m \frac{< \quad N^2 >_i}{r^2} \tag{2}$$

where

$$S_1 = \frac{1}{(\frac{p\ \ 1}{2})}[1 \quad \frac{1}{(1 + (\frac{L_o^2}{L_b^2})^{\frac{p\ \ 1}{2}}}] + \frac{1}{(\frac{q\ \ 1}{2})}\frac{(\frac{L_o^2}{L_b^2})}{(1 + \frac{L_o^2}{L_b^2})^{\frac{p+1}{2}}} \tag{3}$$

The above expressions have been obtained from the radar equation for monostatic scattering, under the assumption of a three-dimensional power spectral density for the electron density uctuation characterized by an outer scale size L_o, a break-point scale size L_b, as well as by spectral indices p for scale sizes in the interval (L_b, L_o) and q for scale sizes less than L_b. Additionally, G is the antenna gain; g^2 is the average value of the radiation pattern (spatial power ux distribution normalized to maximum unit value); $\ _{3\perp}$ the half-power beamwidth in the geomagnetic EW plane; P_t is the transmitted power; L_{tot} aggregates system and propagation losses; $_r$ are the radar wave number and wavelength, respectively; r is the vertical range; $h\ _r$ is the pulse length; $k_B = 1.3810\ ^{23} J/K$ is the Boltzmanns constant; T_{sky} is the sky noise temperature; and B_N is the receiver eective noise bandwidth. Next, the rms electron density uctuation value $\langle\ N^2\rangle^{1/2}$ is dened by collecting the contributions from all the slabs

$$\langle\ N^2\rangle^{1/2} = \sqrt{\ _i\langle\ N^2\rangle_i} \tag{4}$$

Finally, this value is combined with xed values for the parameters L_o, L_b, p, and q to dene the power spectrum density of the irregularities in the layer, which is subsequently used to generate the random vector $N\ _m\ _q(h)$ that is used in expression (1). The scintillation index S_4 is estimated from the complex amplitude $u_m(0)$ of the eld received on the ground.

The xed values for the parameters *Lo = 12.5 km, Lb = 0.08 km, p = 2.6*, and *q= 4.6* have been selected by matching the one-dimensional power spectral density model to results from *in situ* C/NOFS Plasma Langmuir Probe (PLP) measurements of electron density uctuations. These values are consistent with other satellite-based measurements, but it is interesting to note that rocket data provide higher values for p and q.

3 RESULTS AND COMPARISON WITH GPS SCINTILLATION DATA

The scintillation calculation model described in the previous section has been applied to data from the 30 MHz coherent scatter ionospheric radar located at INPE São Lu Observatory. For the present study, RTI data were also available from November 16, 2001; December 28, 2001; October 06, 2002; October 16, 2002; December 01, 2002; and December 05, 2002. It should be observed that geomagnetically-quiet days have been selected, with three-hourly Kp-index values below 4o, but with 10.7 cm (2800 MHz) solar radio ux density approximately equal to 145 s.f.u. (1 solar ux unit equal to 10 $^{22} W/m^2/Hz$).

Simultaneous measurements of amplitude scintillation of Global Positioning System (GPS) L1 signals (*fL1 = 1575.42 MHz*) were also performed. Scintillation index S_4 values were determined every minute (from 3000 amplitude samples) for all tracked satellites.

It has been assumed in the calculations that the structures in the RTI map are eld-aligned and undergo frozen drift through the radar with a simple climatological pattern, independent of height, which is consistent with airglow measurements: $v_{Dwe} = 150$ m/s for $UT < 23h$, with a linear decrease such that $v_{Dwe} = 80$ m/s at UT = 29 h. For each Universal Time, the procedure updates the position of the RTI map with respect to the radar, as well as the positions of the GPS satellites, using the azimuths and elevations of their ray paths. Next, a vector of $(s/n)_i$ values is determined along each ray path. The procedures described in the previous section are then applied to specify the phase screen, determine the received signal and calculate the S_4 value for the corresponding GPS satellite at the Universal Time.

Two examples of successful agreement between S_4 calculations and measurements as functions of Universal Time are shown in Figure 1. This Figure also displays the elevation of the corresponding GPS satellite. The scatter plot in Figure 2 displays the ratio S_{4meas}/S_{4calc} between measured and calculated S_4 values as a function of elevation for the complete data set. Note that, as the elevation decreases, the corresponding ray paths would intercept structures that are farther away from the radar beam. For an altitude of 500 km and an elevation of 55^o, these structures would be 350 km from the vertical axis of the radar beam and would have drifted for approximately 40 minutes, probably experiencing internal changes due to decay and more complex drift patterns, which would tend to degrade the agreement between S_4 calculations and measurements. The upper red line indicates, for 5-degree bins in elevation, values that are exceeded for 10 % of the cases. The lower red line indicates, for 5-degree bins in elevation, values that are exceeded for 90 % of the cases. The scatter plot seems to indicate that, for high elevations, the ratio S_{4meas}/S_{4calc} falls in the interval (0.5, 2.0) for a substantial number of cases. However, this interval widens as the elevation decreases.

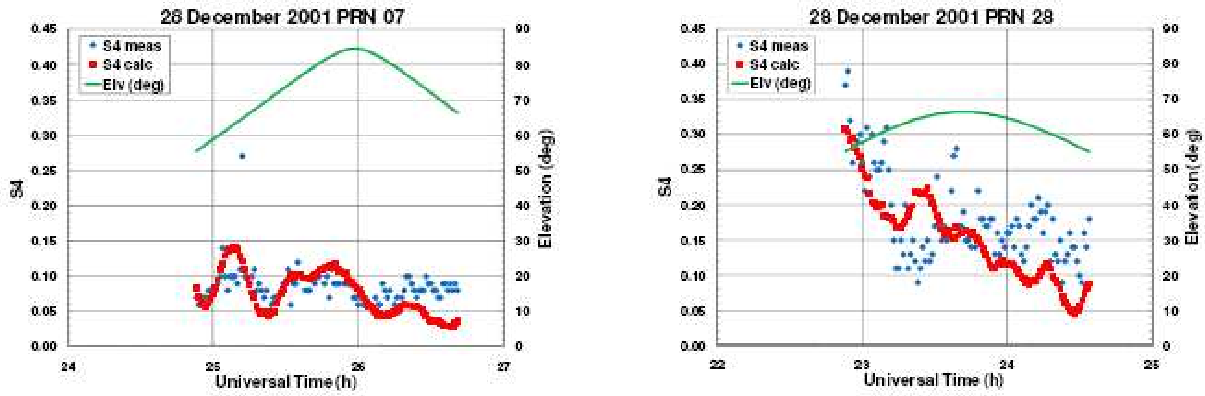

Figure 1: Examples of successful agreement between S_4 calculation and measurements as functions of Universal Time. The elevations of the corresponding GPS satellites are also shown.

4 CONCLUSION

The present work has assessed the extent to which scintillation can be predicted with main basis on range-time-intensity (RTI) measurements performed by São Lʀ coherent scatter radar, in combination with limited use of C/NOFS in situ data and additional information, by comparison of calculation results with corresponding GPS measurements. The results seem to indicate that, for high elevations, the ratio S_{4meas}/S_{4calc} can be found

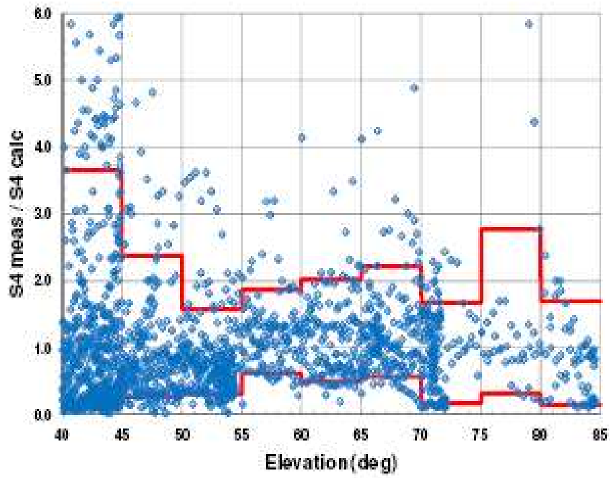

Figure 2: Ratio S_{4meas}/S_{4calc} as a function of elevation for the complete data set. The upper (lower) red line indicates, for 5-degree bins in elevation, values that are exceeded for 10 % (90 %) of the cases.

in the interval (0.5, 2.0) for a substantial number of cases. However, this interval widens as the elevation decreases.

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