Combination of a radio wave scattering algorithm with coherent radar data for equatorial scintillation predictions

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1. Summary

Ionospheric scintillation exhibits extreme variability in space and time, significantly degrading both the performance and the availability of space-based communication and navigation systems. For their support at equatorial latitudes, short-term scintillation forecast systems based on real-time measurements may explore the facts that the irregularities are field-aligned, their motion is ordered, and their lifetime is relatively long. One such system, the Communication/Navigation Outage Forecasting System (C/NOFS) will be based on a non-geostationary equatorial satellite to be launched in an elliptical orbit with 350-km perigee, 700-km apogee and orbital inclination of 13^{o} [1-2] in June, 2008. Data from sensors on board the satellite, that include electric field, neutral wind and ion density, will drive an equatorial ionospheric model, which will be able to forecast the onset of plasma instabilities and their evolution (plasma bubbles). A radio wave scattering model will be used to determine the magnitude of phase and intensity scintillation of satellite signals propagating through the turbulent medium and received on the ground. This will be validated by scintillation measurements performed using tri-frequency (150 MHz, 400 MHz and 1067 MHz) beacon transmissions. Due to its orbital period, the satellite will be able to track the evolution and motion of plasma bubbles at 90-min intervals. The space-based C/NOFS, alone or together with the ground-based SCINDA [3], will be able to specify, forecast and validate scintillation products for the users.

Strictly speaking, the appropriate geometry for scintillation predictions is three-dimensional. That is, irregularities are assumed to be field-aligned and the field line through a given point maps to different heights at different magnetic latitudes and longitudes. An adequate description of the irregularity medium would have to include the set of values of the electron density along a large and well-distributed number of field lines within the volume of interest for different and closely-spaced instants of time. Temporal changes in the volume occur due to a complex interplay of geophysical conditions, seeding of a hierarchy of plasma instability processes, possible nonlinear evolution into upwelling bubbles, drifts across the field lines, and decaying processes.

Sensors on board any spacecraft transiting through the volume of irregularities along almost any trajectory would detect electron density fluctuations. However, they would only provide a partial description of the medium. For the present application, it is possible to build a surface of field lines sampled by C/NOFS satellite and to assign the measured electron density to each of them. It is also reasonable to assume that the irregularities are frozen to the medium and drift across the field lines in the magnetic east-west direction, particularly for those field lines sampled appropriately after the local sunset. However, information on the electron density fluctuations at points located above or below this surface but within the volume of interest would be missing. It is necessary to investigate whether, in addition to the above data, consideration of the vertical structure of the irregularities could lead to improved predictions of scintillation.

For the present work, information on the vertical structure of irregularities will be created with basis on coherent radar data from the São Luiz Observatory (2.33^{o}S, 44^{o}W, 1.3^{o} dip latitude) operating at 30 MHz. Unfortunately, the radar probe 5-m irregularities. That is, a scale size much smaller than the ones causing scintillation. Its spatial resolution is also significantly coarser than those from *in situ* measurements. In principle, this may seem inappropriate for the present application. However, the results from previous experimental campaigns [4-

5] 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. Therefore, each of these cells will be populated with wideband artificial electron-density fluctuations generated with an appropriate spectral model in such a way as to relate the power density of the 5-m irregularities to the backscatter power measured by the radar. These fluctuations will then be mapped along the field lines to create an irregularity layer. It should be observed that the irregularity layer model, characterized by the radar measurements and by the field-line geometry, is flexible enough to represent from relatively simple bottomside layers to those indicated by complex radar plumes.

An extended radio wave scattering model based on a numerical solution of a three-dimensional parabolic equation using the Fourier split-step algorithm [6] will be applied to the irregularity layer to predict the effects of the medium on the propagation of transionospheric signals with frequencies from the VHF to the upper UHF bands. In particular, values of the scintillation index S_4 will be calculated and compared with the ones resulting from VHF and L-band transmissions by selected geostationary and GPS satellites, respectively, and recorded by corresponding receivers located at the same site. This effort may be facilitated by the recent demonstration [7] that the scintillation index S_4 can be estimated with acceptable errors using sparsely sampled data. On the other hand, the sensitivity of the S_4 predictions to the spectral index of the power-law model adopted for the power spectral density the irregularities is a critical aspect of the above theory that will be investigated.

In the future, the above algorithms and irregularity models will be refined by incorporation of data from the C/NOFS *in situ* instruments in combination with those from the São Luiz and other Observatories. Further adjustments will be based on the comparison between predictions and the scintillation measurements at the co-located ground stations for the C/NOFS and COSMIC [8] tri-band transmissions. The results from this work, in addition to their scientific value, may be incorporated into the C/NOFS procedures to forecast the evolution of ionospheric irregularities and scintillation in near real-time or may act as independent validation and calibration tools for the algorithms actually implemented with the same purpose.

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3. References

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