International Beacon Satellite Symposium BSS-2019
Olsztyn, Poland

Relation between signal frequency dependence of S_4 index and ESF irregularity spectrum: Modeling and observations at different latitudes

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ABSTRACT

Signal frequency dependence of the S_4 index for weak scintillations produced by two dimensional irregularities characterized by a single component power-law spectrum with slope $-m$, is of the form: $S_4 \propto f^{-n}$, where $n=(m+3)/4$ [1]. In the present paper, the frequency exponent n is computed using scintillations on a 251 MHz signal and a 1.575 GHz signal transmitted from geostationary satellites and recorded both at dip equatorial location and off-equatorial location (geomagnetic latitude of ionospheric penetration point (IPP) at 300 km altitude ~ 9.85°N) in the Indian region during March 2015. Scintillations recorded on the 251 MHz signal at both locations are often strong. At the equatorial location VHF (251 MHz) S_4 is also found to be greater than one during many scintillation events. Therefore it is necessary to compute n under strong scintillation conditions as well. In the past, variation of the frequency exponent estimated from S_4 indices computed for scintillations on L-band and C-band signals recorded at Ascension Island, near the crest of the equatorial ionization anomaly (EIA) region were explained using a phase screen model for the irregularities [2]. These authors had computed the wave field on the ground, after propagation through a phase screen characterized by a single or two component power-law spectrum for the irregularities. In the present paper, the S_4 index is calculated by solving the fourth moment equation for the complex amplitude of the wave using a two-dimensional model of the irregularities. Such a model is frequently used to describe the intermediate scale length (~ 100m – few km) irregularities in the equatorial ionosphere, which are aligned with the geomagnetic field and cause scintillations on VHF and higher frequency trans-ionospheric radio signals. These irregularities are produced due to the growth of the Rayleigh-Taylor instability on the bottom-side of the post-sunset equatorial F layer, which involves the interchange of magnetic flux tubes. During the non-linear phase of development of this instability, a plasma depleted region, referred to as the equatorial plasma bubble rises to the linearly stable topside of the dip equatorial F region and develops structures which map down to F region peak at off-equatorial locations [3]. In recent years it has been suggested that the intermediate scale irregularities encountered by a radio signal at off-equatorial latitudes in the EIA region may have a shallower

spectrum than those found near the equatorial F region peak in addition to the irregularities being stronger there on account of the higher background ionospheric density [4]. This explains the observed latitudinal pattern of L-band scintillations. In the present paper, theoretical results are obtained for irregularities characterized by a single component or a two-component power-law spectrum. For the two-component spectrum, different break scale lengths are considered. It is seen, that for weak L-band scintillations, the frequency exponent is sensitive to the break scale length, approaching the single component result for steeper slope for break scale lengths much longer than the VHF Fresnel scale; while for break scale lengths shorter than the L-band Fresnel scale, the frequency exponent approaches the single component result for shallower slope. The new result obtained in the present paper is that variation of the frequency exponent computed from VHF and L-band observations, as the S_4 index on L-band varies, is found to be significantly different for the equatorial and EIA region stations. Comparison of these with the theoretical results clearly indicates that in the equatorial case, the irregularities tend to be characterized either by a single component power-law spectrum with a steep slope (m between 4 and 5) or a two-component spectrum with a break scale longer than the VHF Fresnel scale. In the case of the EIA region station, , the irregularities may be characterized either by a single component power-law spectrum with a shallow slope (m between 1 and 2) or a two-component spectrum with a break scale much shorter than the L-band Fresnel scale. This corroborates the idea that the intermediate scale irregularities encountered by a radio signal at off-equatorial latitudes in the EIA region have a shallower spectrum than those found near the equatorial F region peak [4].

References:

[1] Yeh, K. C., Liu, C. H., (1982). Radio wave scintillations in the ionosphere, Proceedings of the IEEE, Volume 70, Issue 4, Pages 324-358.

[2] Franke, S. J., Liu, C. H., (1982). Observations and modeling of multi-frequency GHz and VHF scintillations in the equatorial region, Journal of Geophysical Research, Volume 88, Issue A9, Pages 7075 – 7085.

[3] Rino, C. L., Yokoyama, T., Carrano, C. (2018). Dynamic spectral characteristics of high-resolution simulated equatorial plasma bubbles, Progress in Earth and Planetary Science, 5:83 https://doi.org/10.1186/s40645-018-0243-0.

[4] Bhattacharyya, A., Kakad, B., Gurram, P., Sripathi, S., Sunda, S. (2017). Development of intermediate scale structure at different altitudes within an equatorial plasma bubble: Implications for L-band scintillations, Journal of Geophysical Research**:** Space Physics, Volume 121, Pages 1015–1030, doi:10.1002/2016JA023478.