ANALYSIS OF PROBLEMS THAT COULD ARISE WITH GPS IONOSPHERIC SCINTILLATION MEASUREMENTS

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ABSTRACT

A possible explanation of high phase scintillation against low amplitude scintillation measured at high latitudes from GPS signals is presented on the basis of "frozen" data filtering conditions. Possible enhancements in scintillation activity, due to purely geometrical factors, are discussed in the case of scintillation measurements by means of GPS signals.

INTRODUCTION

One limitation of experimental methods lies on data detrending. The data detrending, when the separation of deterministic and stochastic components is done by using a fixed cut-off frequency that do not take into account the geophysical conditions of the measurements (0.1 Hz is the most used value [1, 2]), can lead in some cases to modifications of amplitude and phase scintillation data not related to ionospheric irregularities. The modifications include the possibility of obtaining "phase without amplitude scintillation" cases when data are treated in that way.

DATA DETRENDING

At high latitudes usually is $\nu_F > \nu_c$ (where ν_F is the Fresnel frequency and ν_c is the cut-off frequency of the detrending algorithm used). ν_F could also be one order of magnitude greater than ν_F at low latitudes. At high latitudes the major contribution to amplitude scintillation spectrum is pushed toward higher frequencies with respect to the frequency range found at low latitudes. If the cut-off frequency ν_c used at high latitudes is the same of that used at low latitudes, the fluctuations spectra observed at high latitudes are both pushed toward higher frequencies, with respect to the fluctuations spectra observed at low latitudes.

The resulting effect is an increase in σ_ϕ and S_4 (i.e., the area under these curves). The increase in σ_ϕ is, however, more evident than the increase in S_4 because the phase spectral density function behaviour at low temporal frequencies is $\Phi_\phi \propto \nu^{1-p}$, where p is the spectral index, while the amplitude spectral density function at low temporal frequencies is $\Phi_\chi \propto constant$ [3]. Under these circumstances, both amplitude and phase scintillation information is distorted: particularly, the phase scintillation is overestimated more than the amplitude scintillation, because fluctuations at frequencies not pertaining properly to "scintillations" have been taken into account in the phase spectrum.

The problem is the choice of a particular cut-off frequency that is fixed in order to attempt automated processing operations. In the case indicated in [1], a cut-off frequency $\nu_c = 0.1\,Hz$ was chosen for the particular system used in the Wideband experiment. The problem appears when for GPS scintillation monitors the same cut-off frequency value as in [1] is used. In the case of GPS scintillation monitors the relative velocity values are very different from those of the Wideband experiment. For low latitudes the problem can not be so critical (as showed before), but for high latitudes the choice of an appropriate cut-off frequency can be crucial.

Such a mechanism becomes critical in evaluating phase scintillation activity at high latitudes during geomagnetic storms. In Fig. 1 an illustrative situation that could provide a possible explanation of high phase scintillations against low amplitude scintillations is shown. The theoretical behaviour for amplitude and phase spectra is sketched in double logarithmic scales, taking into account asymptotical slopes only (a 3-D spatial power law irregularity spectrum is assumed) [3], for quiet and disturbed geomagnetic conditions at high latitudes. The amplitude spectrum at high latitudes would not be substantially modified in presence of geomagnetic storm because the measured amplitude scintillation is low [4]. The geomagnetic storm effect should be more evident in the phase spectrum. The phase spectrum slope at low frequencies (i.e., $\nu < \nu_F$) should be increased, as experimental rates of change of TEC indicate [4]. The high frequency phase spectrum slope would be nearly equal to the amplitude spectrum, according to the two-slope mechanism for the phase spectrum observed in [5]. If the phase spectrum slope increase that occurs during geomagnetic storms is not eliminated by proper data detrending, high phase scintillations for low amplitude scintilations could be observed. This case would appears when the cut-off frequency value used in data detrending is not appropriate to the actual value of the Fresnel frequency.

Data detrending not appropriate to the geophysical conditions could give rise to cases of high phase scintillation against low amplitude scintillation. If not eliminated by data processing, TEC fluctuations during geomagnetics storms would play a dominant role in the computation of phase standard deviations , because of the low frequency phase spectrum increase. In such situations the data interpretation is confusing and erroneous: faster TEC fluctuations are not recognized and phase scintillation is overestimated.

GEOMETRICAL ENHANCEMENT

The average nighttime auroral zone scintillation activity can be also characterized by a localized enhancement at the point at which the propagation vector lies within an L shell. Because of the unique location of this feature the hypothesis that the purely geometrical enhancement is due to sheetlike irregularities has been suggested [6, 7]. This localized enhancement disappears when the magnetic activity is weak [6]. It has been also noted that the ratio of phase to amplitude scintillation was too large to be satisfactorily explained purely by the geometrical enhancement and the associated effects in the amplitude scintillation [6]. Such a feature in auroral scintillation activity was discovered by means of Wideband data, referring to a satellite beacon from a near polar orbit (an altitude of $1000\,km$) transmitting at several frequencies (ten spectral lines between VHF and S band) [1].

The geometrical enhancement factor G is defined by [8]: for axially symmetric irregularities, it achieves a maximum only at the magnetic zenith, while for sheetlike structures G maximizes whenever the propagation vector lies within the plane of the sheets. In the case of Wideband satellite, the enhancement for L shell aligned sheets occurs at a fixed magnetic latitude, irrespective of elevation of the pass. The propagation angle relative to the local magnetic field direction varies with altitude. The actual geomagnetic latitude assigned to the enhancement varies slightly with the altitude assigned to the structured region [7].

Such a geometrical enhancement has been observed in Wideband TEC data as well. Such a TEC structure can be explained by vertical F region slabs about $100\,km$ thick with steep gradients on their equatorwards edge [7].

To check the possible geometry influence for GPS observations, the geometrical factor G behaviour has been also analyzed here for two auroral locations as Anchorage and Poker Flat (Alaska). As in the case of Wideband satellite, an F region reference height of $350\,km$ has been used. Such an analysis has been done for two kind of irregularities: sheetlike (axial ratio 8:8:1) and rodlike (8:1:1).

As it can be seen in Fig. 2, the geometrical enhancement for a GPS satellite could not last tens of minutes but can extend up to several hours. In addition, the geometrical factor G has a different behaviour if the same satellite is observed from a different location (Fig.2), because the propagation vectors will have a different position with respect to the geomagnetic field. In Fig. 3 the geometrical factor G for a different GPS satellite is shown for consecutive passes. In such case, the G factor shows a dependence probably on the elevation angle. Since the enhancement both in scintillation activity and in TEC depends on the propagation geometry (i.e., satellite and receiver positions) with respect to geomagnetic field, data from different GPS satellites should be analyzed with care., in order to understand the irregularities structure and their effect on navigation systems.

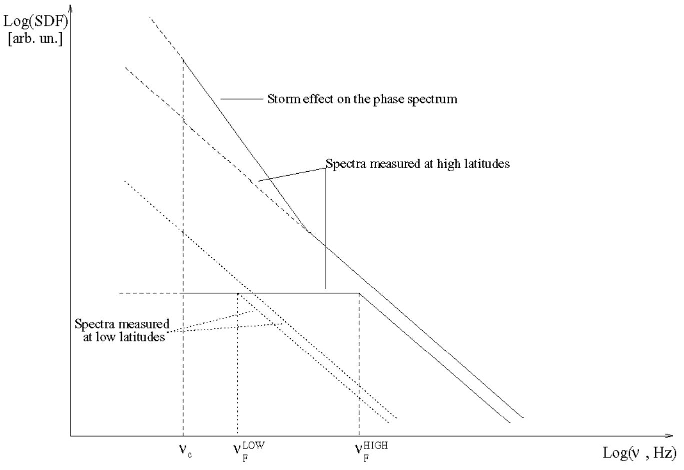

Fig. 1. Power spectral density functions as observed at high latitudes with a fixed cut-off frequency.

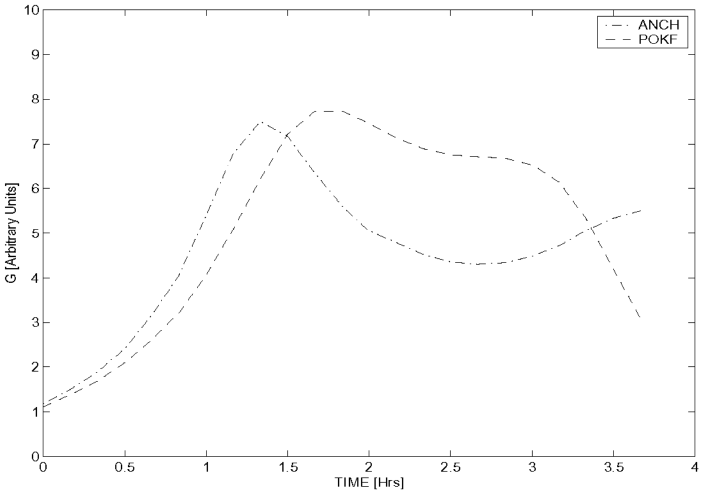

Fig. 2. G factor for PRN 07 from Anchorage and Poker Flat (Alaska), for sheetlike structures (8:8:1)

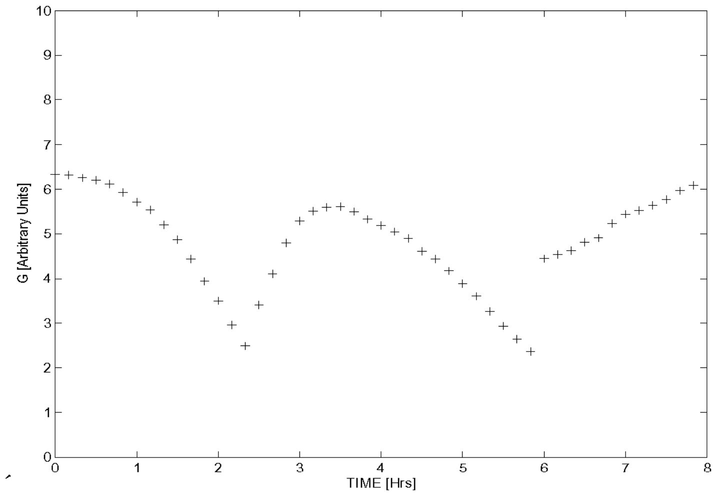

Fig. 3. G factor for PRN 22 from Anchorage (Alaska), for sheetlike structures (8:8:1)

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