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THE IONOSPHERIC IMPACT ON GPS MEASUREMENTS

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Abstract. This paper analyses the ionospheric effects on GPS signals, how ionospheric refraction varies depending on geographic area and season, and also the influence of the time when observations are made. There will be presented the single layer ionospheric model and the corresponding mapping functions in order to determine the effect of the ionospheric propagation delay on range measurements.

Key words: GPS, ionospheric model, ionospheric propagation.

1. Introduction

The ionosphere represents the part of the atmosphere situated between about 50 km and 1000 km above the Earth's surface. The propagation delay of the GPS signals through the ionosphere depends on the electron content along the signal path and on the frequency used. The influencing parameters for the electron content are mainly the geomagnetic field and the solar activity. Hence, ionospheric refraction varies with geographic location and time. The resulting range error, for GPS signals, can vary from less than 1 m to more than 100 m.

2. The Single Layer Model

The ionosphere can be defined as the part of the high atmosphere where sufficient electrons and ions are present to affect the propagation of radio waves (Davies, 1990; Langley, 1998). The generation of ions and electrons is proportional with the radiation intensity of the sun and to the gas density.

The state of the ionosphere is described by the electron density n_e, [el/m^3]. The electron density varies with height as shown in Table 1.

Table 1

The Electron Density Variation with Height

Layer		I	II	III	IV
Height domain	[km]	50…100	100…140	140…200	200…1000
Electron density	at day	10^8	10^{11}	5×10^{11}	10^{12}
n_e, [el/m^3]	at night	–	2×10^{11}	5×10^{11}	3×10^{11}

The impact of the state of the ionosphere on the propagation of waves can be characterized by the total number of the electrons ($\check{\xi}$), that are included in a column with a cross-sectional area of 1 m^2, counted along the signal path (s), between the satellite (S) and the receiver (P), and can be written as:

$$\xi = \int_S^P n_e(s)\mathrm{d}s \,. \tag{1}$$

In order to simplify the problem, for satellite geodesy one has proposed the single layer model. In this, the total electron content is represented by a spherical layer at the mean ionospheric height, which is at about 400 km, as illustrated in Fig.1.

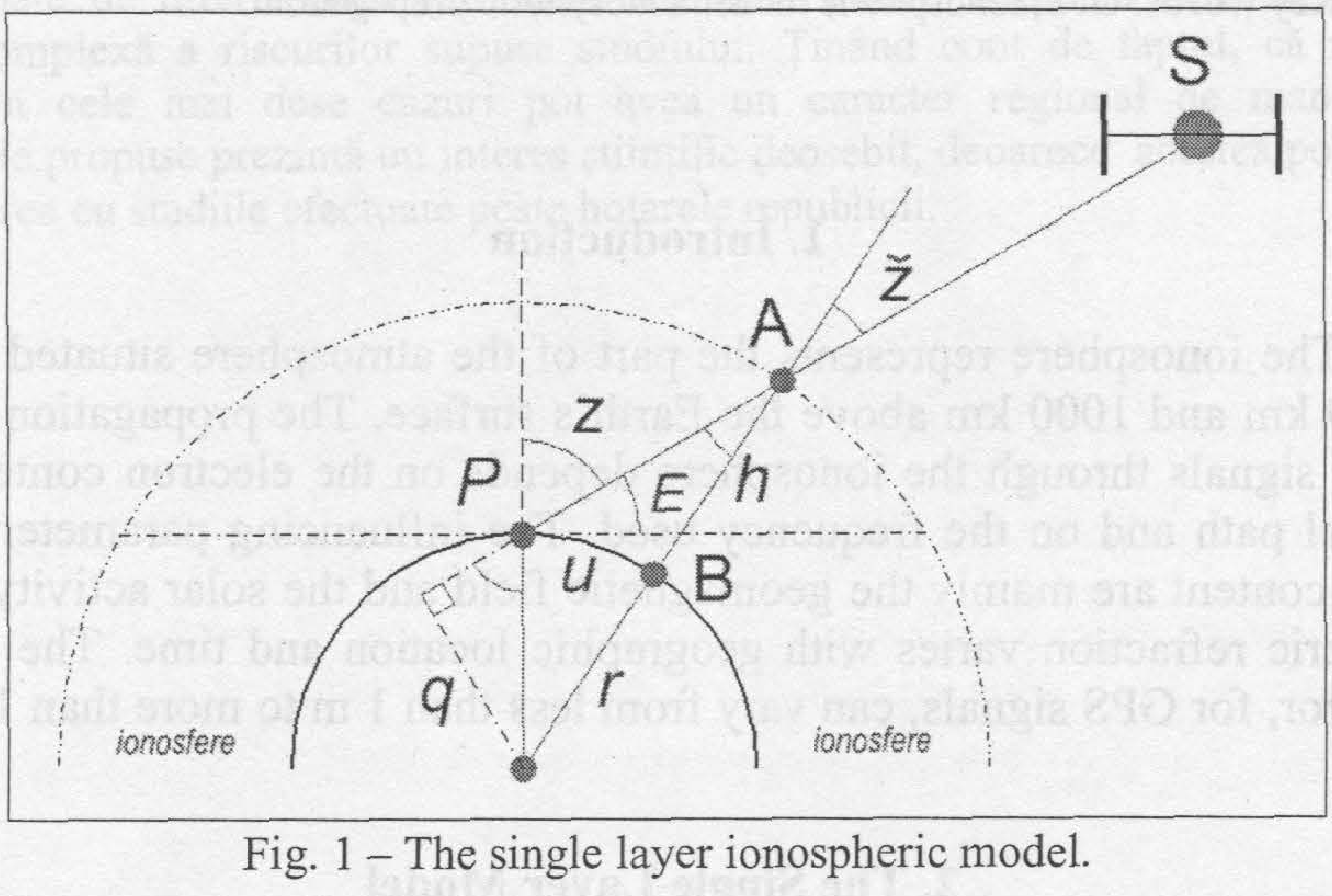

Fig. 1 – The single layer ionospheric model.

According to (Fig. 1), the zenith angle ($\check{z}$), of the ionospheric piercing point (A) by which the signal penetrates the ionosphere layer, is depending on the zenith angle (z) of the point (P) from the Earth's surface and on the height of the ionosphere layer (h) and can be written as follows:

$$\sin \check{z} = \frac{r}{r+h} \sin z. \tag{2}$$

The obliquity factor or the mapping function (F), can be defined by the following relation:

$$F = \frac{1}{\cos z}. \tag{3}$$

In In (Table 2) there were determined some values for the main geometric elements that characterize the phenomenon of ionospheric refraction and from the analysis of those values one can observe that the effect of ionospheric refraction increases with increasing zenith angle (z).

Table 2

Obliquity Factor, Zenith Angle and the Distance Between the Observer and the Subionospheric Point

E, [degree]	z, [degree]	$\check{z}$, [degree]	F	u, [km]
90	0	0	1.00	0
60	30	28	1.13	215
30	60	55	1.73	603
20	70	62	2.14	873
10	80	68	2.66	1,344
5	85	70	2.87	1,712

Table 2 shows that for small elevation angles the total number of the electrons (ξ), counted along the signal path, can reach at most three times the value of the total number of the electrons corresponding to the vertical (ξ_V), as deducted also from the following relations:

$$\xi_V = \xi \cos z \frac{1}{F} \xi. \tag{4}$$

Very important to satellite observations, is the ultraviolet flux emitted by the sun. Regions with highest ionospheric refraction are located up to 15 to 20 degrees on each side of the equator. The electron density is on average 10 to 100 times higher during the day than during the night, as shown in Table 1.

Of particular importance to satellite observations is the change in UV flux emitted by the sun, which occurs after a cycle with a period of approximately 11 years (the last maximum of solar activity occurred in 2000 and the following up will take place in 2011). During maximum solar activity, the signals sent by satellite GPS system can be corrupted very seriously and accordingly, GPS observations errors will have, in turn, maximum values.

3. The Determination of Ionospheric Refraction Corrections

The propagation of radio waves in a dispersive medium such as the ionosphere, is subject to the laws of physics. Namely, the refractive index (n_g), for a group of waves (generated from the overlapping of several different frequency waves), as with the method of measuring the phase codes, can be written, starting from a power series [1], [5] as follows:

$$n_g = 1 + Q\frac{n_e}{f^2}, \tag{5}$$

while the refractive index (n_1), for a single wave (wavelength uniform), such as with the method of measuring the carrier phase is

$$n_1 = 1 - Q\frac{n_e}{f^2}, \tag{6}$$

where (Q) is a constant that includes the many parameters and has a value of ($Q = 40.3$) and (f) is the frequency.

Moreover, the total error in determining the pseudorange with the method of measuring the phase codes, due to ionospheric refraction phenomenon has the expression:

$$\delta d_{\text{ion, g}} = \int_S^P \left(n_g - 1\right)\mathrm{d}s, \tag{7}$$

and correspondingly, the total error due to the ionospheric refraction in determining the pseudorange with the method of measuring the carrier phase is

$$\delta d_{\text{ion, 1}} = \int_S^P (n_1 - 1)\,\mathrm{d}s. \tag{8}$$

Substituting (5) and (6) into (7) and (8) respectively, and simplifying, yields

$$\delta d_{\text{ion, g}} = \frac{Q}{f^2}\int_S^P n_e \mathrm{d}s, \tag{9}$$

(10) $$\delta d_{\text{ion},1} = -\frac{Q}{f^2}\int_S^P n_e \, ds.$$

Hence the range from a code phase observation is measured as too long, and the range from a carrier phase observation is measured as too short.

The unknown integral can be determined by a set of two measurements for the range (ρ), namely the ranges (ρ_1) and (ρ_2), on both frequencies (L_1) and (L_2), respectively, with:

(11) $$\rho = \rho_1 - \delta d^1_{ion,g}\, ; \;\; \rho = \rho_2 - \delta d^2_{ion,g}.$$

By substitution of (9) into (11), it follows that the expression of range correction for code phase measurements on (L_1), derived from dual frequency observation is

(12) $$\delta d^1_{ion,g} = \frac{f_2^2}{f_1^2 - f_2^2}\left(\rho_2 - \rho_1\right).$$

Therefore the ionospheric effect on GPS signals, can be very successfully modeled by dual frequency observations.

4. Conclusions

If only single-frequency receivers are available, the correction due to ionospheric refraction phenomenon is very difficult to determine because it implies an elaborated ionospheric correction model that has to include approximations for the above integral which deals with the total number of the electrons along the path of the GPS signal.

It is hence advisable that for high precision applications to be used only dual frequency equipment. The maximum range errors that can be expected for dual frequency corrected signal is less than 2 cm.

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IMPACTUL IONOSFEREI ASUPRA MĂSURĂTORILOR GPS

(Rezumat)

Se analizeaza efectul ionosferei asupra semnalului GPS, modul de variație a refracției ionosferice în funcție de regiunea geografică şi de sezon, precum şi de ora la care se fac observațiile. Se prezintă modelul stratului unic şi parametrii care influențează refracția ionosferică şi sunt determinate variațiile refracției ionosferice în funcție de unghiul de oblicitate.

În a doua parte sunt determinate expresiile pentru corecțiile ce trebuie aplicate observațiilor GPS, astfel încât sa fie eliminate erorile datorate fenomenului de refracție ionosferică la măsurarea pseudodistanțelor.