

# THE DETERMINATION OF TROPOSPHERIC REFRACTION CORRECTIONS FOR GPS MEASUREMENTS, PERFORMED ON THE AREA OF IAȘI COUNTY

## DETERMINAREA CORECȚIILOR DATORATE REFRAȚIEI TROPOSFERICE LA MĂSURĂTORILE GPS EFECTUATE PE TERITORIUL JUDEȚULUI IAȘI

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**Abstract.** *This paper analyses the tropospheric effects on GPS signals and how tropospheric refraction varies depending on the atmospheric parameters, season and elevation angle. There will be presented the main mathematical formulas for the tropospheric refraction and will be determined how the elevation angle of the observations influences the measurements. There were determined also, as a case study, the corrections to be applied to GPS measurements, performed on the area of Iasi County, for different cadastral works.*

**Key words:** GPS, satellite, Geodesy, troposphere, ionosphere, refraction

**Rezumat.** *Lucrarea de față analizează efectul troposferei asupra semnalului GPS, modul de variație a refracției troposferice în funcție de regiunea geografică, de sezon, precum și în funcție de unghiul de oblicitate. Sunt prezentate expresiile pentru corecțiile ce trebuie aplicate observațiilor GPS, astfel încât să fie eliminate erorile datorate fenomenului de refracție troposferică la măsurarea pseudodistanțelor. În ultima parte sunt determinate, pe un caz concret, corecțiile ce trebuie aplicate măsurărilor GPS, efectuate pe teritoriul județului Iași, în cadrul lucrărilor de cadastru general.*

**Cuvinte cheie:** GPS, sateliți, geodezie, troposferă, ionosferă, refracție.

## INTRODUCTION

The propagation of radio waves through the troposphere, is subject to the laws of physics. The signal path bends from the straight geometrical connection between the observer and the satellite, and as a result of tropospheric refraction, the optical distance measured is longer than the direct geometrical range.

The troposphere represents the lowest, gaseous part of the atmosphere situated between the surface of the Earth to about 40-50km. The propagation delay of the GPS signals through the troposphere depends on the water vapor content and on temperature. Hence, tropospheric refraction varies with geographic location and season.

## MATERIAL AND METHOD

The troposphere can be defined as the gaseous part of the lower atmosphere where the weather takes place. Given the fact that charged particles are virtually

absent and the uncharged atoms and molecules are well mixed, the troposphere can practically be considered a neutral gas. Within the troposphere the temperature decreases with height by 6.5 °C/km and varies horizontally with only a few *degrees/km*. Furthermore, because nearly 90% of the atmospheric mass is below 16 km altitude and nearly 99% below 30km (Lutgens, Tarbuck 1998), the index of refraction, which is slightly greater than 1 to begin with, decreases with increasing height and becomes nearly 1 at the upper limit of the troposphere, corresponding to the continuously decreasing density of the medium.

The index of refraction does not depend on the frequency of the signal; it depends on air pressure, temperature and water vapor pressure of the atmosphere. Because these three parameters vary so much and are so dynamic within the troposphere, it is very difficult to predict and/or model the index of refraction.

A direct measurement of the refractivity along the signal propagation path is then not feasible. Therefore various models for a description of the height-dependent behavior of the refractivity have been developed. Best results were obtained by Hopfield (1969), who has done the basic research in the field. Input parameters are mostly the meteorological surface data near the observation site.

According with the Helen Hopfield, the impact of the state of the troposphere on the propagation of waves  $[\partial d_t]$ , can be characterized by the following algorithm:

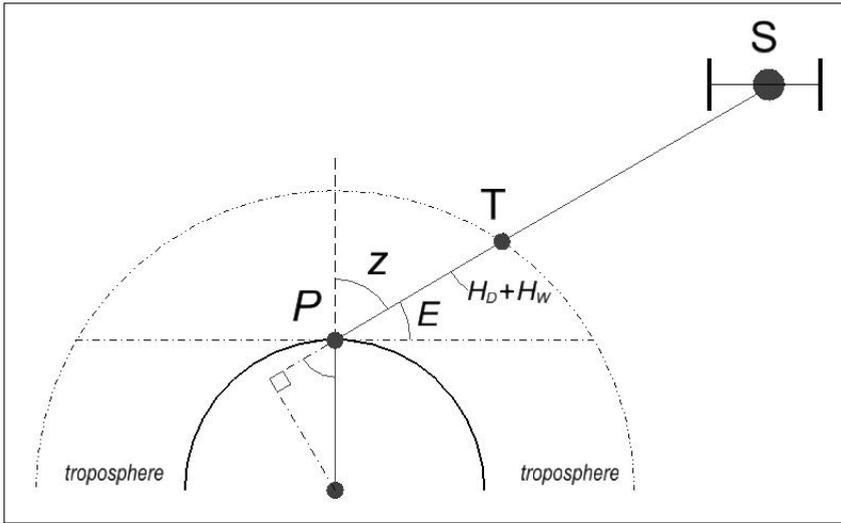
$$\partial dt = \partial d_d + \partial d_w = \frac{k_d}{\sin \sqrt{(E^2 + 6.25)}} + \frac{k_w}{\sin \sqrt{(E^2 + 6.25)}},$$

where  $[k_d]$  and  $[k_w]$  describe the total effect of the tropospheric refraction in the direction to the zenith, corresponding to the dry term and to the wet term, respectively, and  $[E]$  represents the elevation angle of the satellite the way it is seen by the observer, as illustrated in Fig.1.

The dry and the wet items,  $[\partial d_d]$  and  $[\partial d_w]$ , are determined separately because their parameters are formulated as distinct functions of height:

$$k_d = 155.2 \cdot 10^{-7} \frac{P}{T} H_d; k_w = 155.2 \cdot 10^{-7} \frac{4810e}{T} H_w,$$

with  $[P]$ , the air pressure in Hectopascal [HPa],  $[e]$ , the partial pressure of the water vapor [HPa], and  $[T]$  representing the temperature in Kelvin.  $[H_d]$  and  $[H_w]$  are the effective altitudes of the dry and the wet terms respectively.



**Fig.1.** The tropospheric model

Generally, for  $[H_w]$  a mean value is accepted  $[H_w = 11000m]$ , but the parameter  $[H_d]$  was determined by Helen Hopfield empirically from globally distributed balloon data:

$$H_d = 40136 + 148.72(T - 273.16).$$

For elevations  $[E > 30^\circ]$ , Harold Black (1978) proposes the simple correction formulas:

$$\partial d_{trop} = (2.31 \cdot P + Q_w) \cos ecE,$$

where  $[P]$  is the air pressure in atmospheres  $[1atm = 1013.25HPa]$ , and  $[Q_w]$  is a regional empirical constant with values ranging for Romania from 0.06 during the winter to 0.28 for summer, as showed in Table 1.

The two expressions depending of  $[P]$  and  $[Q_w]$ , to which equation (4) could expand, correspond to the two layers of the troposphere, dry and wet, respectively:

$$\partial d_{trop} = 2.31 \cdot P \cos ecE + Q_w \cos ecE.$$

The global variation by region and season of the regional empiric constant that integrates the atmospheric conditions  $[Q_w]$ , determined according with the simplified Harold Black model, is presented in Table 1.

*Table 1*

**The global variation of the regional empiric constant for  
Harold Black model**

Region and Season	$[Q_w]$
Summer in tropical areas or mean latitudes	0.28
Spring or autumn in mean latitudes	0.20
Winter in maritime latitudes	0.12
Winter in continental mean latitudes	0.06
Polar regions	0.05

## RESULTS AND DISCUSSIONS

Based on the models presented above, there were determined the values of the errors due to the tropospheric refraction, associated with a set of GPS observations made in the summer of 2008 and in the winter of 2009 for a series of cadastre works carried out in Iasi County area.

The atmospheric conditions corresponding to the two sessions of observations were recorded in table 2.

*Table 2*

**The atmospheric parameters associated with the two observation sessions**

Atmospheric parameters	Summer	Winter
Temperature [T]	25°C	-12°C
Atmospheric pressure [P]	1002.25 HPa	1023.38 HPa
Partial water vapor pressure [e]	33.25 HPa	5.22 HPa

In table 3 there were also presented the actual dry altitudes, along with the dry and the wet parameters  $[k_d]$  and  $[k_w]$  that characterize the total effect of the tropospheric refraction in the direction to the zenith, determined with the equations (2) and (3), for both sessions of the GPS measurements.

*Table 3*

**The dry altitude of the troposphere and the total tropospheric refraction influence to the zenith calculated based on the Hopfield model**

Determined parameters		Summer	Winter
Dry altitude ( $H_d$ )		43854.0 m	38351.4 m
The total tropospheric refraction effect to the zenith	Dry term ( $k_d$ )	2.2891 m	2.3338 m
	Wet term ( $k_w$ )	0.3075 m	0.0629 m

The errors due to the tropospheric refraction, associated with the GPS observations made in the summer of 2008 and in the winter of 2009 in Iasi County

area, for the given atmospheric conditions, determined with the Hopfield algorithm were tabulated in Table 4.

*Table 4*

**The errors due to the tropospheric refraction at GPS measurements in Iași County area [Hopfield model]**

[E]		90°	60°	45°	30°	15°	10°	5°
[ $\partial d_d$ ] [m]	Summer	2.29	2.64	3.23	4.56	8.73	12.79	23.50
	Winter	2.33	2.69	3.30	4.65	8.90	13.04	23.96
[ $\partial d_w$ ] [m]	Summer	0.31	0.35	0.43	0.61	1.18	1.75	3.38
	Winter	0.06	0.07	0.09	0.13	0.24	0.36	0.69
[ $\partial d_t$ ] [m]	Summer	2.60	3.00	3.67	5.18	9.91	14.54	26.88
	Winter	2.40	2.77	3.39	4.78	9.14	13.40	24.65

The errors due to the tropospheric refraction, associated with the GPS observations made in the summer of 2008 and in the winter of 2009 in Iasi County area, determined with the simplified Black algorithm were tabulated in table 5.

*Table 5*

**The errors due to the tropospheric refraction at GPS measurements in Iași County area [Black model]**

[E]		90°	60°	45°	30°	15°	10°	5°
[ $\partial d_d$ ] [m]	Summer	2.29	2.64	3.24	4.58	8.84	13.18	26.26
	Winter	2.33	2.69	3.30	4.67	9.02	13.44	26.78
[ $\partial d_w$ ] [m]	Summer	0.28	0.32	0.40	0.56	1.08	1.61	3.21
	Winter	0.06	0.07	0.08	0.12	0.23	0.35	0.69
[ $\partial d_t$ ] [m]	Summer	2.57	2.97	3.63	5.14	9.93	14.79	29.48
	Winter	2.39	2.76	3.39	4.79	9.25	13.79	27.47

From the analysis of the values from tables 4 and 5, one can observe that the effect of tropospheric refraction increases with increasing zenith angle [Z] or, in other words, with decreasing the elevation angle [E]. For elevations [E < 5°] the errors at GPS observations due to the tropospheric refraction and hence the corrections that need to be applied to the measured ranges, easily exceed 20 m.

On the other hand, the portion of the wet term, which depends on the distribution of water vapor in the atmosphere and is therefore harder to model, reaches only around 10% of the total influence.

Moreover, the values in tables 4 and 5, show that the differences from summer to winter conditions between the total errors due to the tropospheric refraction in determining the pseudo-range at GPS signal propagation are also within 8-10% from one another. Same thing, when station distances are smaller

[<50km] and when the height differences are small (in non mountainous regions, as those in the Iași county area), the atmospheric conditions are sufficiently correlated with one another which means that the water vapor content of the air is almost identical horizontally.

## CONCLUSIONS

The resulting range error, for GPS signals, because of the tropospheric refraction can vary from less than 3 m to more than 26 m.

The effect of tropospheric refraction increases severely for GPS observations at low elevation angles. It is hence advisable not to make observations for the satellites that are seen by the observer under 10-15° above the horizon. The differences from summer to winter conditions between the total errors due to the tropospheric refraction in determining the pseudo-range at GPS signal propagation are limited in size.

For a small network it is not advisable to introduce the observed meteorological data into the adjustment of the determinations separately for each station. If the stations are close together, the tropospheric residual error disappears almost completely by differencing in the relative observation mode.

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