Investigation On GPS Heighting Accuracy With Use Of Tropospheric Models In Commercial GPS Softwares For Different Heights

İsmail ŞANLIOĞLU And Mustafa ZEYBEK, Turkey

Key words: GNSS/GPS, Positioning, tropospheric models, gps processing softwares, gps heighting

SUMMARY

GPS pseudorange and carrier-phase measurements are affected by several random and systematic errors. These errors are originated from satellites, receivers and signal propagation through the atmosphere. Neutral atmosphere is consisting of the troposphere, tropopause and stratosphere. The combined effect of the electronically neutral atmosphere is called tropospheric refraction.

Tropospheric delay depends on the temperature, humidity and pressure. The tropospheric delay may be divided into dry and wet components. Several mathematical models such as Saastamoinen, Hopfield, Goad and Goodman, Black etc, are used to predict quantity of wet component using surface meteorological measurements or default meteorological data.

In this study different tropospheric models which are used in Trimble Geomatics Office and Leica Geo-Office commercial GPS processing softwares were compared. For this purpose GPS observations had been done at eight stations at different heights for three hours running in Konya city on May 2009. The baselines were computed by the above mentioned softwares. The most suitable tropospheric models were investigated on GPS heighting accuracy.

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1. INTRODUCTION

GPS pseudorange and carrier-phase measurements are affected by several random and systematic errors. These errors are originated from satellites, receivers and signal propagation through the atmosphere (Fig.1). Neutral atmosphere is consisting of the troposphere, tropopause and stratosphere. The combined effect of the electronically neutral atmosphere is called tropospheric refraction .The effective height of atmosphere in terms of tropospheric refraction is about 40 km

The troposphere is a nondispersive medium for radio waves below 15 GHZ [1,2]. It delays the GPS pseudorange and carrier-phase measurements exactly the same. The refraction is independent of frequency of signals transmitted through troposphere. It cannot be eliminated with a dual frequency observation as L1, L2, unlike ionospheric delay [3].

Tropospheric delay depends on the temperature, humidity and pressure. It varies with the height of receiver setup point and the type of terrains below signal path. Signals from satellites at low elevation angles travel a longer path through the troposphere than those at higher elevation angles. Therefore, the tropospheric delay is minimized at the user's zenith and maximized near the horizon. The effect is a delay (same sign as the ionosphere has on the codes) that reaches 2.0-2.5m in the zenith direction (satellite directly overhead) and increases approximately with the co-secant of the elevation angle, yielding about a 20-28 m delay at a 5° angle, about 9.3m for a 15° elevation angle. [4,5]
The tropospheric delay may be divided into dry and wet components [6]. The dry component contributes about 90 % of the total delay and wet component is %10.[7] It can be modeled to about 2-5 % using surface pressure and temperature, predicted to high degree of accuracy using mathematical models. The wet component depends on the water vapor. It is more difficult to quantity, because water vapor cannot be accurately predicted and modeled. Several mathematical models such as Saastamoinen, Hopfield, Goad and Goodman, Black etc, are used to predict quantity of wet component using surface meteorological measurements or default meteorological data. The combined models for dry and wet layer together predict the time delay caused by the neutral atmosphere.

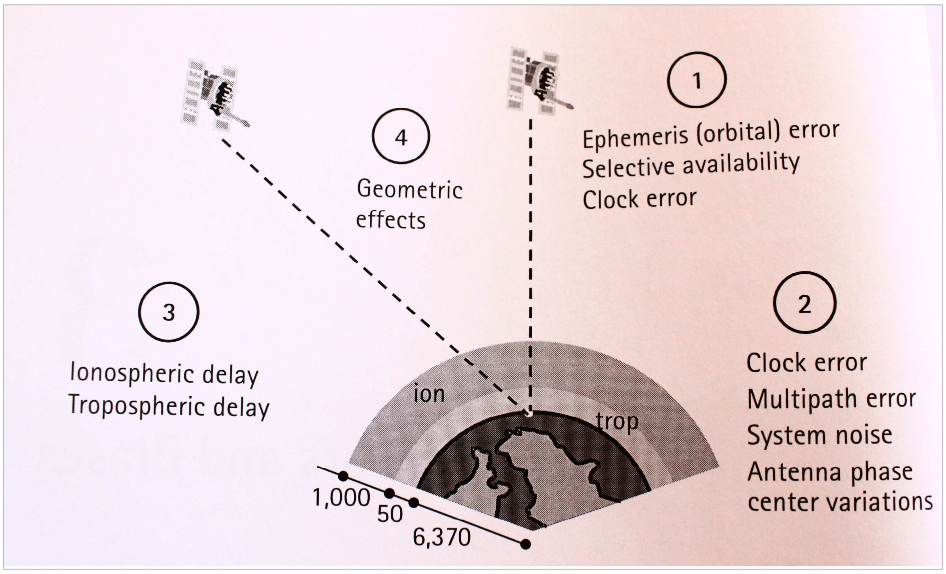

Fig.1: GPS errors and biases [3]

2. TROPOSPHERIC MODELS

2.1 Hopfield Model

Hopfield used real data covering the whole Earth. He has empirically found a representation of the dry refractivity as a function of the height h above the surface by,

$$N_d^{Trop}(h) = N_{d,0}^{Trop}\left[\frac{h_d - h}{h_d}\right]^4$$

$$h_d = 40136 + 148.72(T - 273.16) \quad [m] \qquad (1)$$

Here T is the temperature in Kelvin (K).
This model assumes the same functional model for both the wet and dry components. Thus,

$$N_w^{Trop}(h) = N_{w,0}^{Trop}\left[\frac{h_w - h}{h_w}\right]^4 \qquad (2)$$

Where the mean value

$$h_w = 11000\,m \qquad (3)$$

is used.
The result equations for wet and dry components are;

$$\Delta_w^{Trop}(E) = \frac{10^{-6}}{5}\frac{-12.96T + 3.718\,10^5}{\sin\sqrt{E^2 + 2.25}}\frac{e}{T}11000$$

$$\Delta_d^{Trop}(E) = \frac{10^{-6}}{5} \frac{77.64\frac{p}{T}}{\sin\sqrt{E^2+6.25}}[40136+148.72(T-273.16)] \quad (5)$$

$$\Delta^{Trop}(E) = \Delta_d^{Trop}(E) + \Delta_w^{Trop}(E) \quad (6)$$

Measuring *p*, *T*, *e* at the observation location and calculating the elevation angle *E*, the total tropospheric path delay is obtained in meters by (6) after evaluating (5).

2.2 Saastamoinen Model

The refractivity can alternatively be deduced from gas laws. The interrelationship is demonstrated, e.g., Janes et al. (1989)[8]. The Saastamoinen model is based on this approach where again some approximations have been employed. Here, any theoretical derivation is omitted. Saastamoinen (1973) models the tropospheric delay, expressed in meters,

$$\Delta^{Trop} = \frac{0.002277}{\cos z}\left[p + \left(\frac{1255}{T} + 0.05\right)e - \tan^2 z\right] \quad (7)$$

as a function of *z*, *p*, *T* and *e*. As before *z* denotes the zenith angle of the satellite, p is the atmospheric pressure in millibar, *T* is the temperature in Kelvin, and e is the partial pressure of water vapor in millibar.

Saastamoinen has refined this model by adding two correction terms, one being dependent on the height of the observing site and the other on the height and on the zenith angle. Bauersima (1983) gives the refined formula

$$\Delta^{Trop} = \frac{0.002277}{\cos z}\left[p + \left(\frac{1255}{T} + 0.05\right)e - B\tan^2 z\right] + \delta R \quad (8)$$

The correction terms B, can seen in tables [9].

2.3 Essen-Froome Differential Model

$$n_i = (77.64\frac{P}{TD} - 12.96\frac{e}{TD} + 371780\frac{e}{TD^2})10^{-6} \quad (9)$$

i=station name (A and B)
than correction between A and B point,

$$\Delta S^{A_0} = \frac{n_A+n_B}{2} l \qquad (10)$$

can be account as up.

$$l = \frac{h_B-h_A}{\sin z_A} \qquad (11)$$

- Orthometric elevation of stations
- : Satellite zenith angle on lowest height station

Total tropospheric delay correction is

$$\Delta S^{z}_{trop} = \Delta S_A^{A_0} + \Delta S^{z}_{A_0} \qquad (12)$$

2.4 Goad and Goodman

Goad and Goodman (1974) modified the Hopfield model by assuming that the temperature decreases linearly with increasing height in the troposphere, but that it remains constant in the stratosphere (two-layer atmosphere), the same assumptions used by Saastamoinen (1973) in deriving his mapping function. The Goad and Goodman mapping functions are sometimes referred to in the literature as Modified Hopfield. This designation should be avoided, as it may be confused with the Moffett mapping functions [10]
More details can be found in Goad and Goodman (1974) [11].The resulting formulas can be found , e.g., in Remondi (1984) [12].

$$r_i = \sqrt{(R_E+h_i)^2-(R_E\cos E)^2} - R_E\sin E \qquad (13)$$

$$\Delta_i^{Trop}(E) = 10^{-12} N_{i,0}^{Trop}\left[\sum_{k=1}^{9}\frac{\alpha_{k,i}}{k} r_i^k\right] \qquad (14)$$

2.5 The Neil Model

The Neil Model is a combination of the Saastamoinen zenith path delay together with Neil mapping functions [13]. The parameters (a, b, c) used in the dry and wet components of the models as expressed in equations (15) and (16) are calculated based on the interpolation of the average and seasonal variation (amplitude) values as functions of latitude and time. For the dry component:

Height correction terms

$$NMF_h(\varepsilon) = \frac{1+\frac{a}{1+\frac{b}{1+c}}}{\sin\varepsilon+\frac{a}{\sin\varepsilon+\frac{b}{\sin\varepsilon+c}}} + \left[\frac{1}{\sin\varepsilon} - \left(\frac{1+\frac{a_{ht}}{1+\frac{b_{ht}}{1+c_{ht}}}}{\sin\varepsilon+\frac{a_{ht}}{\sin\varepsilon+\frac{b_{ht}}{\sin\varepsilon+c_{ht}}}}\right)\right] \qquad (15)$$

And wet component:

$$NMF_w(\varepsilon) = \frac{1+\frac{a_{wet}}{1+\frac{b_{wet}}{1+c_{wet}}}}{\sin\varepsilon+\frac{a_{wet}}{\sin\varepsilon+\frac{b_{wet}}{\sin\varepsilon+c_{wet}}}} \qquad (16)$$

Where: *md* and *mw* = mapping functions for dry and wet components respectively
ε = satellite elevation angle,
H = orthometric height,
a, *b*, *c* = coefficients in the dry component ,
aw, *bw*, *cw* = coefficients in the wet component ,
aht, *bht*, *cht* = coefficients in the height component.

2.6 Black Model

Black developed a tropospheric model based on Hopfield's work [14]. Seeber gives the formulas for the hydrostatic component,

$$\delta S_{[HYD]} = \frac{1.553 \times 10^{-5}\left[\frac{K}{hPa}\right] \times \frac{p_0}{T_0} H_d}{\sqrt{1 - \left(\frac{\cos\varepsilon}{1+l_c\frac{H_d}{r}}\right)^2}} - \frac{1.92\left[\frac{m}{o}\right]}{\varepsilon^2+0.6^{o}} \qquad (17)$$

p_0 : pressure at site in [hPa]
T_0 : temperature at site in [K]
H_d: upper boundary height for the hydrostatic delay
r : radial distance from earth center to GPS antenna
e : elevation angle in [degrees] [15]

The wet mapping function derived by Black is described by Seeber.The slant wet delay is

$$\delta S_{[wet]} = \frac{0.07465\left[\frac{K^2}{hPa}\right]\cdot\frac{e_0}{T_0^2}\cdot H_T}{\sqrt{1-\left(\frac{\cos\varepsilon}{1+l_c\cdot\frac{H_T}{r}}\right)^2}} - \frac{1.92\left[\frac{m}{o}\right]}{\varepsilon^2+0.6^0} \qquad (18)$$

e_0 : partial water vapor pressure at site in [hPa]
T_0 : temperature at site in [K]
H_T : upper boundary height for the wet delay/height of the tropopause
r : radial distance from earth center to site
e : elevation angle in [degrees]

3. STUDY AREA

In this study six pillar and three concrite block have been established on various topography and the direction south-west on Konya-Adana freeway during Konya-Afyon highway for the purpose of our research. Ellipsoidal heights which relating to our points have obtained by GPS observation (Fig.2). GPS surveys have accomplished by static survey method on nine stations simultaneously three and seven hours

Ashtech, Leica, Topcon and Trimble receivers have been used on surveying (Table 1). In this table antenna heights are rinex value, so these heights are different from original land surveying. The session plan has been shown in Fig. 3. N.06 station which belongs to TNGN (Turkey National GNSS Network) project in Selcuk University Campus and the other station are points of Konya Local network (Fig. 4).

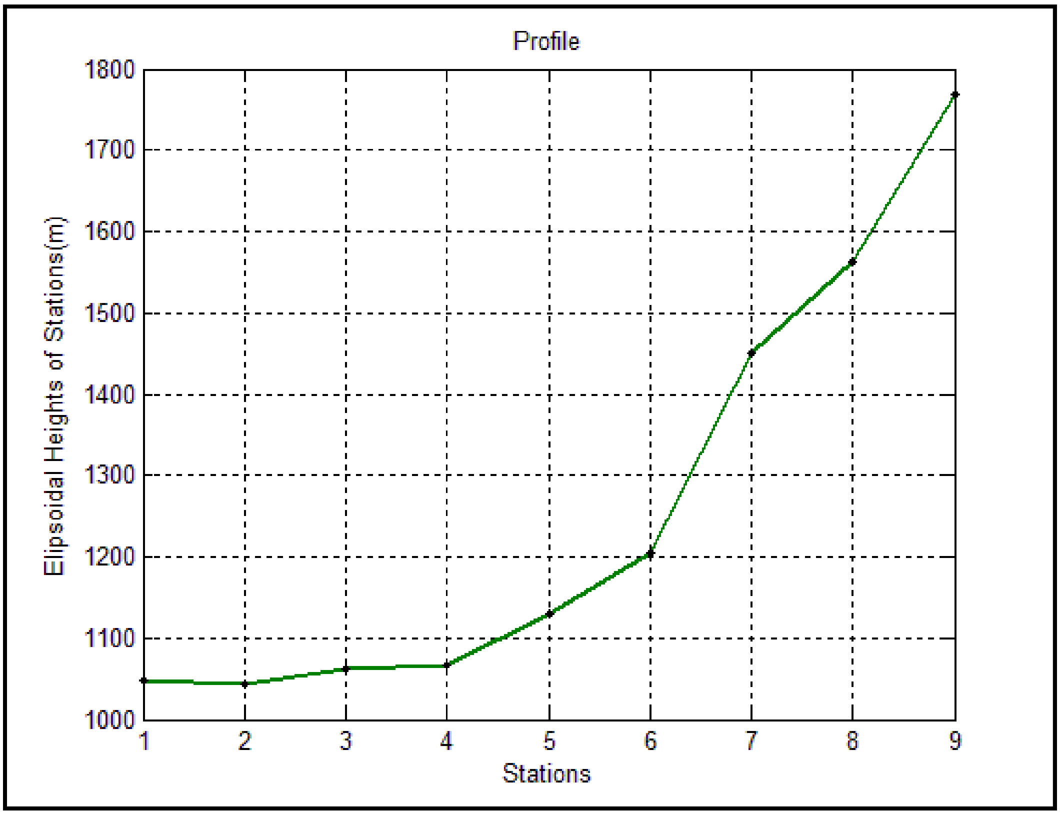

Fig.2: Ellipsoidal heights of stations

Table 1: Antenna and receiver information

List of Occupations									
#	Point or *Occup.	Start	End	Num. of Epochs	Receiver		Antenna		
					Type	Ser.N	Type	Height	Vert/Slant
1	N.01	1.May.09 05:48:00	1.May.09 13:24:40	5481	1	TRM0220360764	1	0.093	vert
2	N.02	1.May.09 06:13:00	1.May.09 14:02:55	5640	1	TRM0220359316	2	1.523	vert
3	N.03	1.May.09 06:28:25	1.May.09 13:34:25	5113	1	TRM0220358796	2	1.518	vert
4	N.05	1.May.09 06:59:25	1.May.09 14:12:50	5202	1	TRM0220351880	2	0.068	vert
5	N.06	1.May.09 07:12:15	1.May.09 12:11:00	3586	2	LEI10102	3	0.176	vert
6	N.09	1.May.09 08:30:20	1.May.09 13:51:45	3858	1	TRM0220351859	4	0.067	vert
7	N.04	1.May.09 09:31:35	1.May.09 15:01:00	3954	3	ASH928000270	2	0.060	vert
8	N.10	1.May.09 10:22:00	1.May.09 13:18:15	2116	1	TRM0220352756	2	1.169	vert

List of Occupations									
#	Point or *Occup.	Start	End	Num. of Epochs	Receiver		Antenna		
					Type	Ser.N	Type	Height	Vert/Slant
9	N.12	1.May.09 10:27:05	1.May.09 13:32:45	2229	3	ASH928000273	5	1.158	vert

Receivers:
1 - TRIMBLE5700
2 - LEICA SR9500
3 - ASHTECHUZ-12

Antennas:
1 - TRM41249.00
2 - TRM39105.00
3 - LEIAT302-GP
4 - TPSHIPER_PLUS
5 - ASH701975.01BGP

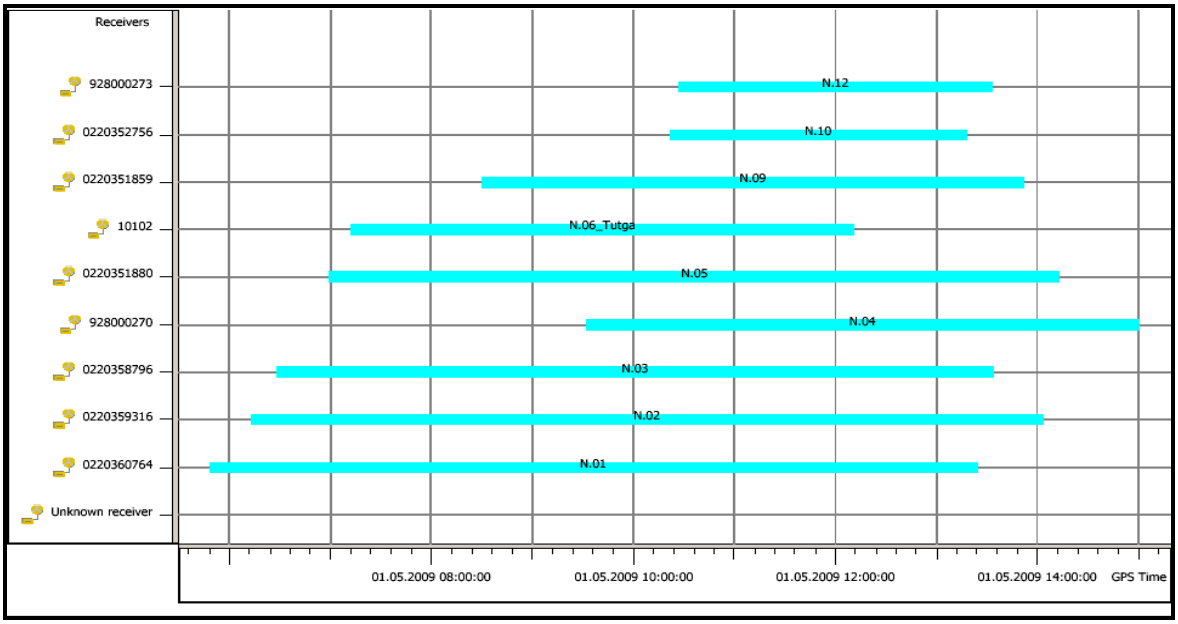

Fig.3: Session Plan

4. PROCESSING

Observations have been processed in Trimble Geomatics Office 1.6 (TGO) and Leica Geo Office 5.0 (LGO) softwares. TNGN point "N.06" has used as fixed point in inner constraint. The point coordinates are in ITRF 96 reference coordinate system and 2005.00 reference epoch on GRS-80 ellipsoid. Grid sheet and baselines are seen at Fig.5. For the purpose of tropospheric models investigation, reference model is Hopfield and reference elevation mask is 15^{o} in LGO software. Other models as Saastamoinen, Essen-Frome in LGO, Hopfield, Black, Goad and Goodman, Neill in TGO were used with different elevation mask 0^{o}, 5^{o}, 10^{o} and 15^{o}. All the same steps have been done with TGO, too.

Fig. 6, Fig. 7 and Fig. 8 show the RMS errors of station heights with different tropospheric models. Elevation mask angles are respectively 0 to 15 degree except Saastamoinen model in TGO. In Fig 7 at second graphic the processing does not have solution for 0^{0} in Saastemoinen model.

Fig. 4: Stations used in study area in Konya City

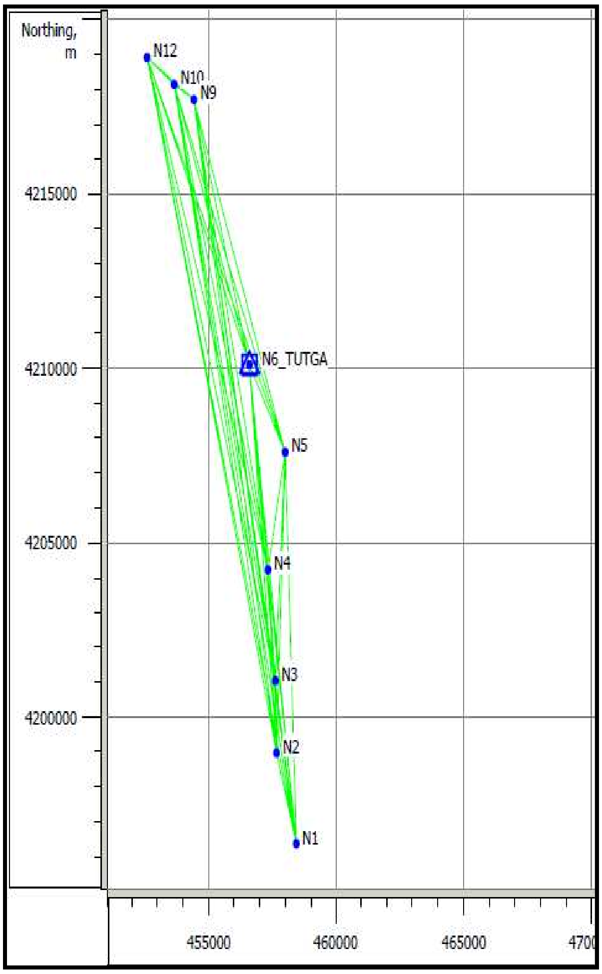

Fig.5: Observation baselines between points

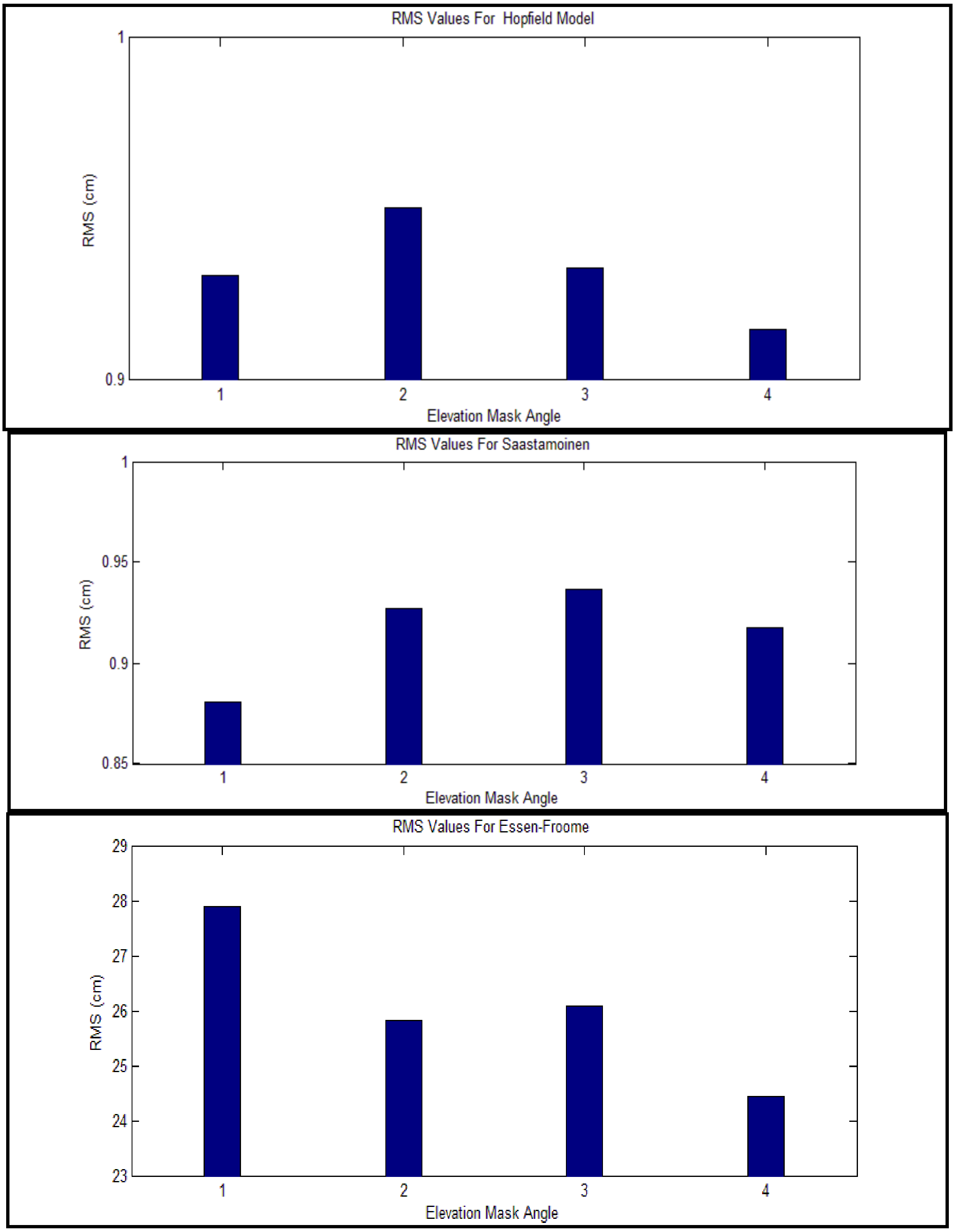

Fig.6: the RMS errors of station heights in Leica Geo Office software

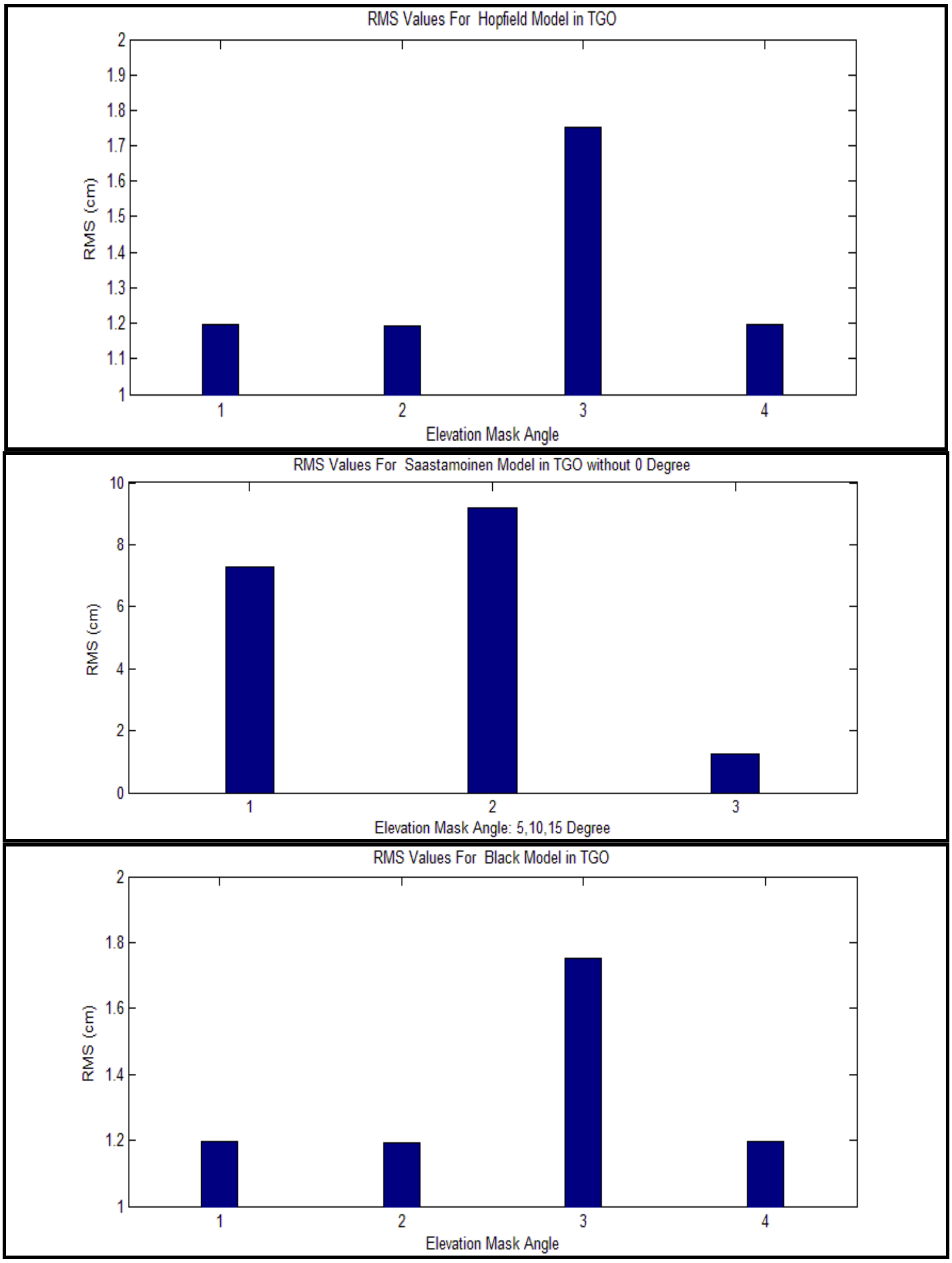

Fig.7: RMS Errors in Trimble Geomatics Office software

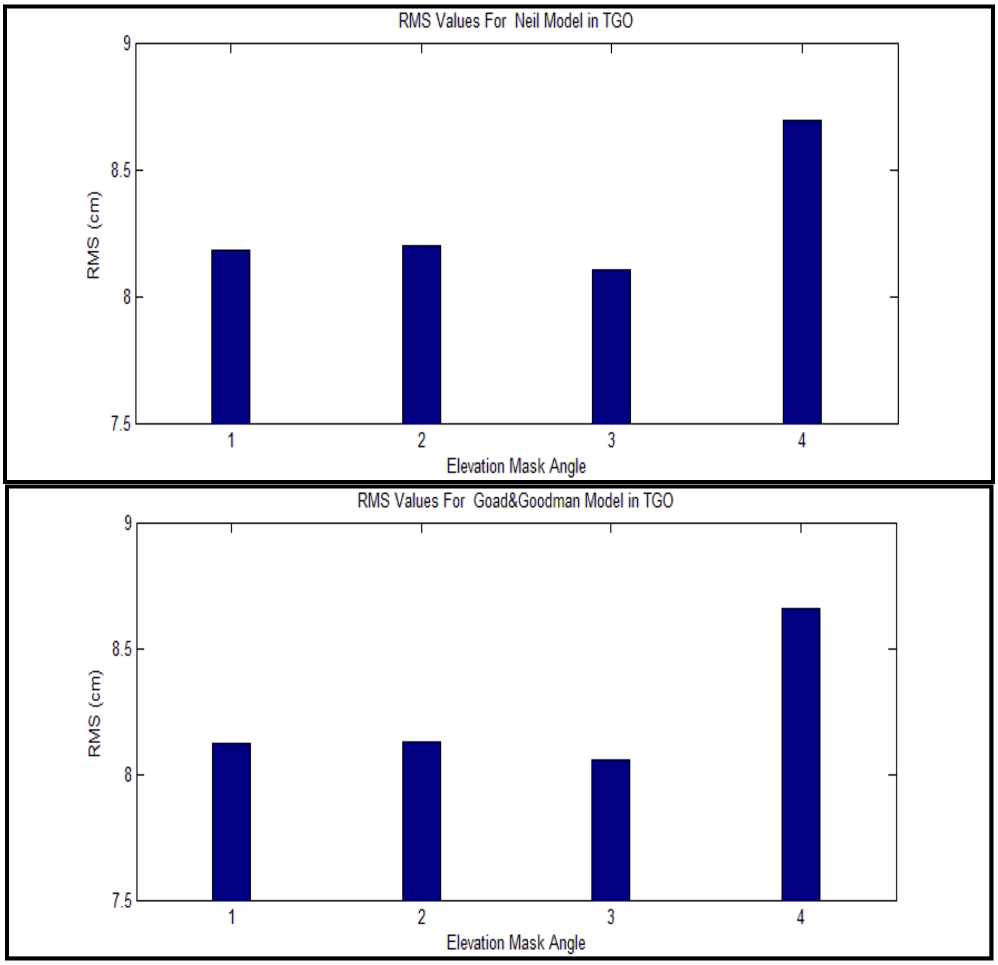

Fig.8: RMS Errors in Trimble Geomatics Office software

5. CONCLUSIONS

Fig. 7 shows RMS (Root Mean Square) errors in different Tropospheric models. As if different tropospheric models are used at the same stations, they have different RMS errors which is shows difference from real height. With different elevation mask angles as 0, 5, 10, 15 degree One of Tropospheric models has a great value of RMS and we can say that Trimble Geomatics Offices software is not running in 0^0 by Saastamoinen tropospheric model.

The tracking of low elevation angle satellites is therefore to be avoided because the uncertainties in modeling both the wet and dry tropospheric delay are amplified at low elevation angles. For surveys of less than a few tens of kilometers in extent, the tropospheric delay will tend to be the same at both ends of a baseline.

Any uncertainty in modelling the differential tropospheric refraction bias results mostly in a degradation of the height component in the solution. Beutler et al (1989) have suggested the "rule-of-thumb": 1mm differential tropospheric bias causes a height error of about 3mm.There is only a minimal effect on latitude and longitude.

Leica Geo office works faster than Trimble Geomatics Offices in our work. And it is important if the project has many station for processing in height. Processing of baselines can take many hours for calculation.

Future work will be used and investigated Ashtech GNSS Solutions and Pinnacle GNSS software packages. Academic softwares , as GAMIT, BERNESSE and GPSY will use for developing the research.

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BIOGRAPHICAL NOTES

CONTACTS

İsmail ŞANLIOĞLU
Seljuk University
Engineering and Architecture Faculty
Geomatics Engineering
Konya
Turkey
Tel. +903322231940
Email:sanlioglu@selcuk.edu.tr

Mustafa ZEYBEK
Seljuk University
Engineering and Architecture Faculty
Geomatics Engineering
Konya
Turkey
Tel. +903322231897
Email:mzeybek@selcuk.edu.tr