Applying Meteorological Data in GPS Measurements

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SUMMARY

Space geodesy is leading the fields of mapping and surveying. Nowadays geodetic networks are solely measured by using GPS (Global Positioning System). The method is considered to be very accurate even though GPS measurements contain a variety of errors. Those errors are minimized by mathematical models and adjustment methods. One of those errors is the tropospheric path delay. This delay affects mainly the height ordinate and is felt mostly in measurements of mountainous areas.

The tropospheric path delay values are calculated by existing models using standard atmosphere parameters. These parameters are generic and standard and therefore are not suitable for most days of the year, stressing the need for the measuring of true atmospheric data along with GPS surveying in order to obtain troposphere delay values which best express the path delay of the measurements.

In GPS surveying project carried out in collaboration with researchers from the Jade University of Applied Sciences, Germany in August 2010, 22 points of the Carmel ridge were measured during six days in eight hours sessions while collecting meteorological information (temperature, atmospheric pressure and humidity). The network was solved using standard atmospheric parameters on the one hand and meteorological data collected on the other.

This paper presents the differences in troposphere path delay values using several tropospheric models with standard atmospheric parameters compared to using real meteorological data collected in intervals of 30 seconds during the measurement. Additionally, this study shows the influence of meteorological data on the location of points in geodetic network and theirs accuracy compared with the location and accuracies obtained by using standard meteorological parameters.

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1. INTRODUCTION

The recent advancements in technology over the last few years has brought a great increase in the usage of GPS technology in many fields, form car navigation systems to extensive geodesic research. A wide variety of GPS uses stems from the availability of the system, and the simplicity of decoding the data and converting it to geographic information. Many studies are utilizing GPS technology in establishing a geographical database and geo-reference the research area to a sought coordinate system. The main difference between the different uses is in the attained level of accuracy. As a rule of thumb, the easier the system is to use, the lower is the degree of accuracy attained. Geodesy requires the highest levels of accuracy, requiring a long and quality measurement process and a solution process which considers all influencing factors.

GPS measurement's accuracy decreases due to many interfering factors: ionosphere, troposphere, multipath, satellite and receiver clock errors etc. The management of each of these factors is paramount in Geodesy in order to ensure the most accurate results. This article will focus only on the influence of tropospheric delay on GPS measurements. Many data sources were used in order to examine the effects, such as standard atmospheric parameters used extensively throughout the solution process of tropospheric delay parameters, and meteorological data gathered along with the measurements.

The troposphere is the lowest layer of the atmosphere. This layer begins at the surface of the earth and extends to the height of 12km. Some studies have marked the top of the troposphere at 16km, but most consider the layer of the atmosphere between 12km and 16km above the surface as the tropopause layer at which the temperature remains constant between -60 and -80 degrees Celsius. The tropopause layer is a sub-layer of the troposphere. The troposphere is considered as the neutral atmospheric layer, since all elements and molecules in it are at their neutral state. Charged particles are located at the ionosphere layer between 70km and 1000km above the surface. Reduction of ionosphere's delay effect over the GPS measurements is done using L_1 and L_2 frequencies. Between the troposphere and the ionosphere exists an atmospheric layer known as the stratosphere (16km to 70km above the surface) in which the temperature rises along with the rise in altitude.

The tropospheric delay can be separated into the wet component and the dry component. The dry component is the main error factor, accounting for 90% of the entire tropospheric delay (Janes et al., 1989). Despite its great influence, the dry component is easily modeled since the behavior of gases composing the atmosphere is uniform. Using the laws of physics the behavior of atmospheric gases can be defined into an equation and that is then utilized in calculating the delay caused by the dry component. The wet component, although accounting for only 10% of the entire delay, is the problematic one. The wet component, the humidity percentage, cannot be modeled and its atmospheric spread is not uniform as the many factors influence it such as vicinity to water, temperature, air pressure, altitude and so on. The multiplicity of factors influencing the wet atmospheric component prevents the construction of an accurate model depicting the behavior of vapor air in the atmosphere. The effect are of this factor is centered in the troposphere layer in between the surface and 4km altitude, and above 12km (the tropopause). The rest of the troposphere contains little to no water vapor (Spilker, 1996).

The tropospheric delay is influenced by three atmospheric factors: air pressure, temperature, and humidity percentage. Air pressure is caused by the weight of the air of the atmosphere onto the surface. The earth's gravity "pulls" the atmosphere towards the surface resulting in the atmosphere applying pressure onto the surface, called air pressure. At sea level the atmospheric pressure is on average 1013 hPa. This is the default air pressure value in most atmospheric models. Atmospheric pressure drops exponentially with the rise in altitude above sea level from 1013 hPa to 300 hPa over the poles and 70 hPa over the equator.

The temperature discharged by the ground is caused by rays of light reaching from the sun. Upon hitting the ground they are discharged as heat energy. The behavior of temperature is considered to be linear as temperature drops with the rise in altitude above sea level, until the tropopause at which it remains steady and then begins to rise in the next atmospheric layers. Temperature drops at a rate of between -5 and -7 Celsius degrees per km. However, at altitudes between 0m and 500m, temperature does not behave in a linear fashion due to environmental effects and objects on the ground. This paper examines the field of research focusing on altitudes between 0m and 500m.

The percentage of humidity is determined by the relative portion of water vapor out of the entire air in the atmosphere. Relative humidity spreads heterogeneously both vertically and horizontally. There is no regularity in the distribution of humidity and so there is no way to model its behavior as an atmospheric component, although the humidity is dependent upon temperature (which behaves in a linear manner) and on air pressure (which behaves in an exponential manner). The change in humidity's state between gas and liquid and vice versa is dependent on temperature, air pressure, location and altitude (Mockler, 1995). Despite the variance in the behavior of the humidity, certain patterns emerge that can be used in the tropospheric delay solution. Humidity decreases drastically with altitude as temperature drops (as the law of gases concentrations dictates). Approximately 50% of the humidity is concentrated at the layer between the surface and an altitude of 1.5km above sea level. Less than 5%-6% of the humidity is above an altitude of 5km above sea level (Schuler, 2001).

Standard atmospheric parameters used in all models are a barometric pressure of 1013 hPa, a temperature of 18º Celsius, and 50% humidity.

2. TROPOSPHERIC MODELS

Finding the tropospheric delay parameters for GPS measurements is performed by solving different models. Each model is divided into two components, one to solve the dry component, and the second to solve the wet component. The received tropospheric delay is positive, and by its very name indicates that the signal emitted by the satellite is slowed down by atmospheric factors and takes longer to reach the receiver antenna than it would have arrived through a vacuum. The calculated range will be longer than the actual range, as we can see using the pseudo range equations (Leick, 2003).

$$P_A^i(t) = \rho_A^i + c\left(dt_A - dt^i\right) + Iono_A^i + Tropo_A^i + \delta m_A^i + \varepsilon_P \quad (1)$$

$\mathrm{\rho}_{\mathrm{iA}}^{\mathrm{i}}$ – The true range between satellite *i* and receiver A.

dt_{A} – Receiver clock error.

dt^i - Satellite clock error.
δm_A^i – Multipath
ε_P – Measurements noises.

This study utilizes three common models: Saastamoinen (1973), Hopfield (1971) and Goad and Goodman (1974). These models were chosen for this research since they are used as default models for most GPS data processing software.

2.1 Saastamoinen Model

This model is popular because of its high accuracy (Elgered et al., 1991). The initial work assumption in developing this model is that the water vapors behave as ideal gases and are concentrated in the troposphere layer. Another assumption is that the temperature changes linearly as altitude increases. This model neglects the height dispersal of the measuring point, in order to simplify the integral of the refraction. As a result, the refraction's derivative is simpler (first order differential), and can be calculated in a simple numerical fashion, increasing the calculation's accuracy (without neglecting the derivative is a second order differential with no easy numerical solution). The altitude is directly dependent upon the air pressure in a dry atmosphere. The main difference between this model and other models is the definition of gravity. Other models treat gravity as a fixed parameter, while Saastamoinen model calculates gravity's acceleration as a function of height.

2.2 Hopfield Model

This model's development is based on many meteorological measurements, spread over several years and geographical location. This model was built based on the same assumption of the Saastamoinen model, with the only difference being the attitude towards gravity. This model factors gravity as a constant ($g = 9.805\ m/s^2$). In Hopfield's model, air pressure on the surface dependence of altitude, and the change of temperature dependence of altitude are calculated as fixed parameters (the change dependence of altitude is fixed).

2.3 Goad and Goodman Model

This model is base on Hopfield model. This model is one of many in a model family called Simplified Hopfield Models. Members of this model family are all based on Hopfield's idea that the atmosphere is a polytropic[1] layer. In addition to the Goad and Goodman (1974) model, the family contains the Yionoulis (1970), Black (1978), Black and Eisner (1984) models.
Also, in order to simplify the integral describing the tropospheric delay, mathematical manipulations are performed by geometrical assumption of Snell's law in a homogenously dispersed spherical atmosphere for a simpler integral. Most of the manipulations are performed on the geocentric radius bending coefficient in Snell's law's equation. This model also calculates the wet delay and the dry delay separately (Janes et al., 1991).

[1] Polytropic Atmosphere – A model to represent the atmosphere reflects the temperature behavior in a clearer and more credible way. In this model the temperature does not change in a linearly, but rather exponentially as a dependence of a polytropic coefficient (Goad and Goodman, 1974).

The mentioned above models were developed empirically and fit Europe mostly (Saastamoinen Model) and north America (Hopfield model, Goad and Goodman model), due to their development in those areas. The atmospheric data in the model is determined by an average in the area of the model's development. The global constants in these models do not take atmospheric changes into account as a dependence of the latitude or seasonal changes. Great altitude differences between points assembling the baseline can cause a 2-5mm error for each 100m of altitude difference (Satirapod and Chalermwattanachai, 2005).

3. Aims and Methodology

This study was aimed at examining the differences between the different tropospheric models. At the first stage experiments were performed in order to examine and learn the difference between the solutions obtained through the different models (Saastamoinen Model, Hopfield Model, Goad & Goodman Model). These experiments were motivated by desire to learn if there are differences between the different models and if so, in what size the differences are. An additional purpose was to learn the influence of meteorological data on the solution of the tropospheric delay parameters. The main motivation of this purpose is to examine whether meteorological data improve accuracy. During the experiments, performed to examine the influence of meteorological data, a motivation was formed to examine the influence of meteorological data density on the solution of the tropospheric delay parameters.

3.1 Field Work

The field work was collaboration with a group of students and researches from the Jade University of Applied Sciences in Germany. Without the collaboration between the German group, headed by Prof. Dr.-Ing. Joerg Reinking and the Israeli group of the Technion headed by Dr. Gilad Even-Tzur, the measuring project would not have been successful. Without this collaboration, the research described in this paper could not have been put into practice.

During the field work between the last two weeks of august 2010, 22 points spread across the Carmel ridge and the Lower Galil were measured for 6 days. 6 to 8 points were measured each day at eight hour sessions. Measuring points included G1 national network stations, and CR Carmel network station (see figure 1).

During the measurements meteorological data of barometric pressure, temperature and humidity was measured using an Almemo 2290-4 device at three stations during each measuring day. The meteorological unite measured data automatically at given intervals. Data was measured at 30 seconds intervals during this study. Meteorological data were measured at stations between which there was a maximal altitude difference at the day of the measuring. The use of meteorological data was performed at 60 seconds interval, although data was collected at 30 seconds intervals. Since there are no differences in atmospheric behavior of air pressure, temperature and humidity parameters at a 30 seconds interval, a 60 seconds interval was used in order to reduce data amount and the solution's duration. This filtering significantly lessened the data processed and significantly shortened the process' run time, without damaging the accuracy (Dach et al., 2007).

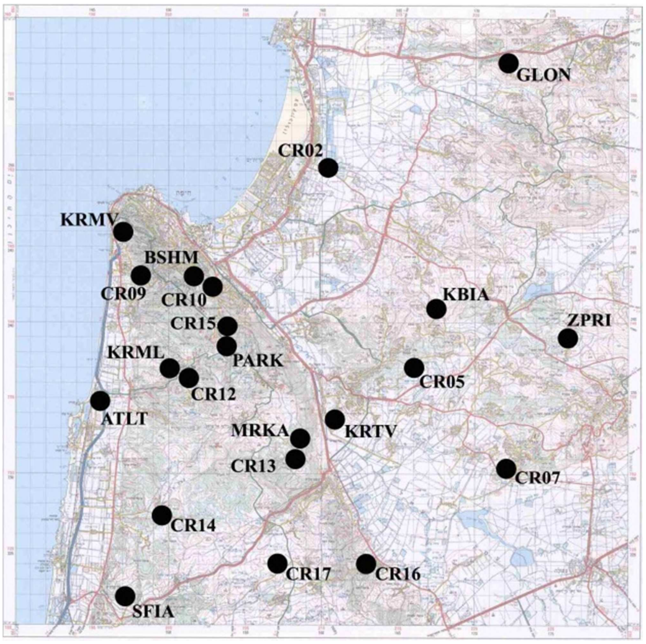

Figure. 1 – The Carmel network point distribution measured during the measuring camp of 2010.

3.2 Data Processing

Solving the location of the points was done using a scientific program to process GPS measurements named Bernese and codes written in Matlab.
During the research work several runs of the network solution were performed on Bernese. Every measuring day was solved using three tropospheric models presented in chapter 2 with the standard atmospheric parameter (1013 hPa barometric pressure, 18º Celsius temperature and 50% humidity). Afterwards, that measuring day was solved using the true field measured meteorology data. As aforementioned in chapter 3.1, meteorological data were only gathered in some of the stations, and so the solution of the meteorological data was only calculated for stations in which meteorological data exists. During the first stage the results obtained are the location of the points in a geocentric system (X,Y,Z), in WGS84. This data is then transferred to a local level system (N,E,U) in order to view the influence of the tropospheric delay over the height component. The tropospheric delay is most expressed in the height ordinate. At the conclusion of this stage, six independent processed systems were obtained.
Calculating the location of the point contains many errors from many elements such as satellite orbit corrections, ionosphere, multipath and more. This research focuses on the tropospheric influences and so those need to be isolated from all other effects in order to examine the differences between the different models as dependant of standard atmospheric parameters and as dependant of true meteorological data. Matlab codes were used in order to calculate the tropospheric delay parameters on the one hand, and the tropospheric delay parameters were solved using Bernese. For the purpose of the discussion the Bernese results will be referred to as “real”, and the Matlab results will be referred to as simulated.
After finding the tropospheric delay parameters based on an eight hour measuring session while using meteorological data, an experiment was conducted to test the meteorological data

density. The source data contains eight hours worth of data of 30 seconds intervals (a total of 960 readings throughout the session). However, meteorological equipment gathering data in such a frequent rate cannot always be acquired, and so arose the need to examine the influence of the meteorological data density on the obtained tropospheric delay parameters. Tests were conducted using the following intervals: 30 minutes, 60 minutes, 120 minutes, and 240 minutes.

4. RESULTS

Although only the results of the experiments conducted during one day of measuring will be presented in this chapter, these represent all six days worth of results. The chosen day is 25.08.2010, in which meteorological data was gathered in three stations KRTV, PARK and CR02.

4.1 The testing of models with standard atmospheric parameters and meteorological data

In the following tables, the values appearing in the Tropo or Meteo column are the tropospheric delay values of the height component in the local level system (N,E,U) built around the KRTV point. The KRTV point is located in the center of the network (Fig. 1) and so it was chosen as the point around which the transition into a local level frame network was done for network points. For all solutions 60 seconds interval was used for standard atmosphere parameters or meteorological data respectively.

The names of the models are denoted in results tables as followed: Saastamoinen – SAS; Hopfield – HOP; Goad & Goodman – G&G.

The standard atmospheric parameters used were: Pressure = 1013 hPa, Temperature = 18º C, Humidity = 50%.

Table 1 and Table 2 present the tropospheric delay values solved using standard atmosphere parameters (Tropo) and meteorological data (Meteo) respectively with three tropospheric delay models: SAS, HOP and G&G. The differences in tropospheric delay solved using meteorological data (Meteo) and using standard atmospheric parameters (Tropo) for each model are presented in Table 3. Table 4 presents the average differences of all six days of measurements between the different models when standard atmospheric parameters were used on the one hand (Tropo), and meteorological data was used on the other hand (Meteo).

Station	SAS		HOP		G&G		Δ_1 (m)	Δ_2(m)	Δ_3(m)
	Tropo (m)	σ (m)	Tropo (m)	σ (m)	Tropo (m)	σ (m)	SAS - HOP	SAS – G&G	HOP – G&G
CR02	2.48187	0.00329	2.47105	0.00211	2.46901	0.00208	0.01082	0.01286	0.00204
PARK	2.29867	0.00243	2.30930	0.00205	2.28603	0.00198	0.01063	0.01264	0.02327
KRTV	2.44748	0.00239	2.43269	0.00208	2.42972	0.00200	0.01479	0.01776	0.00297

Table 1 – Solving the three stations with the three standard atmospheric models.
σ - Tropospheric delay values accuracy calculated using least squares adjustment.
Δ_1 – the tropospheric delay values according to the SAS model minus the delay values according to the HOP model. Δ_2 – the tropospheric delay values according to the SAS model minus the delay values according to the G&G model. Δ_3 – the tropospheric delay values according to the HOP model minus the delay values according to the G&G model.

Station	SAS		HOP		G&G		Δ_1 (m)	Δ_2(m)	Δ_3(m)
	Tropo (m)	σ (m)	Tropo (m)	σ (m)	Tropo (m)	σ (m)	SAS - HOP	SAS – G&G	HOP – G&G
CR02	2.45784	0.00224	2.45439	0.00218	2.45216	0.00204	0.00450	0.00568	0.00223
PARK	2.26100	0.00205	2.26424	0.00219	2.26759	0.00222	-0.00324	-0.00659	-0.00335
KRTV	2.40729	0.00221	2.40250	0.00219	2.40208	0.00204	0.00479	0.00521	0.00042

Table 2 – Solving the three stations with meteorological data.
σ - Tropospheric delay values accuracy calculated using the Least squares adjustment. Δ_1 – the tropospheric delay values according to the SAS model minus the delay values according to the HOP model. Δ_2 – the tropospheric delay values according to the SAS model minus the delay values according to the G&G model. Δ_3 – the tropospheric delay values according to the HOP model minus the delay values according to the G&G model.

Station	SAS		HOP		G&G		Δ_1 (m)	Δ_2(m)	Δ_3(m)
	Meteo (m)	Tropo (m)	Meteo (m)	Tropo (m)	Meteo (m)	Tropo (m)	SAS	HOP	G&G
CR02	2.45784	2.48187	2.45439	2.47105	2.45216	2.46901	-0.02403	-0.01666	-0.01685
PARK	2.26100	2.29867	2.26424	2.30930	2.26759	2.28603	-0.03767	-0.04506	-0.01844
KRTV	2.40729	2.44748	2.40250	2.43269	2.40208	2.42972	-0.03958	-0.03019	-0.02764

Table 3 – tropospheric delay differences between using meteorological data and using standard atmospheric parameters.
Meteo – Tropospheric delay values calculated according to meteorological data. Tropo - Tropospheric delay values calculated according to standard atmospheric parameters. Δ_1 – the tropospheric delay values according to the SAS model with meteorological data minus the delay values with standard atmospheric parameters. Δ_2 – the tropospheric delay values according to the HOP model with meteorological data minus the delay values with standard atmospheric parameters. Δ_3 – the tropospheric delay values according to the G&G model with meteorological data minus the delay values with standard atmospheric parameters.

Atmospheric Parameters	Δ_1 (m)	Δ_2(m)	Δ_3(m)
Tropo	0.01104	0.01023	0.00254
Meteo	0.00322	0.00725	0.00212

Table 4 – The average differences in the tropospheric delay using meteorological data and using standard atmospheric parameters for all six days of measurements.
Meteo – Tropospheric delay values calculated according to meteorological data. Tropo - Tropospheric delay values calculated according to standard atmospheric parameters. Δ_1 – the tropospheric delay values according to the SAS model with meteorological data minus the delay values with standard atmospheric parameters. Δ_2 – the tropospheric delay values according to the HOP model with meteorological data minus the delay values with standard atmospheric parameters. Δ_3 – the tropospheric delay values according to the G&G model with meteorological data minus the delay values with standard atmospheric parameters.

4.2 Differences in tropospheric delay as dependant of meteorological data density

This study tested the influence of the meteorological measurements interval on the calculated tropospheric delay. The tropospheric delay was calculated along with the filtering of the original measured data into the different time intervals. Tests were conducted using the following intervals: 30 minutes, 60 minutes, 120 minutes and 240 minutes. Table 5 presents the differences in the tropospheric delay as dependant on the meteorological data density.

		30 Minutes Interval		**60 Minutes Interval**		**120 Minutes Interval**		**240 Minutes Interval**	
Model	**Station**	**Tropo (m)**	**σ (m)**	**Tropo (m)**	**σ (m)**	**Tropo (m)**	**σ (m)**	**Tropo (m)**	**σ (m)**
SAS	CR02	2.45785	0.00224	2.45787	0.00224	2.45801	0.00232	2.45813	0.00253
	PARK	2.26101	0.00205	2.26120	0.00205	2.26429	0.00257	2.26532	0.00237
	KRTV	2.40732	0.00221	2.40732	0.00221	2.40978	0.00278	2.40801	0.00252
HOP	CR02	2.45444	0.00218	2.45445	0.00218	2.45811	0.00231	2.45942	0.00265
	PARK	2.26428	0.00219	2.26431	0.00219	2.26561	0.00233	2.26603	0.00254
	KRTV	2.40257	0.00219	2.40263	0.00219	2.40398	0.00225	2.40605	0.00266
G&G	CR02	2.45226	0.00204	2.45223	0.00204	2.45268	0.00242	2.45567	0.00232
	PARK	2.26763	0.00222	2.26775	0.00222	2.26993	0.00239	2.27192	0.00278
	KRTV	2.40216	0.00204	2.40215	0.00204	2.40461	0.00234	2.40807	0.00252

Table 5 – Differences in the tropospheric delay as dependant on the meteorological data density.
σ – Tropospheric delay values calculated using the least square adjustment.

4.3 Differences in tropospheric delay with missing data

This experiment tested the influence of the meteorological data continuum on the tropospheric delay solution. This experiment simulates a situation in which the meteorological data collector malfunctions during the measuring, due to a shortage in internal memory or battery depletion. During each day of measurements an 8 hour session was performed during which GPS data was gathered in 5 seconds intervals. Meteorological data were gathered since the beginning of the session and until the meteorological unit was shut down. During this experiment the data was processed in 60 seconds intervals. Table 6 presents the results of the tropospheric delay values using meteorological data in different data continuum. Table 7 presents the differences between 8 hours solution, and a 6/4/2 hours solution using meteorological data.

		8 hours of data gathering		6 hours of data gathering		4 hours of data gathering		2 hours of data gathering	
Model	**Station**	**Meteo (m)**	**σ (m)**	**Meteo (m)**	**σ (m)**	**Meteo (m)**	**σ (m)**	**Meteo (m)**	**σ (m)**
SAS	**CR02**	2.45784	0.00224	2.45912	0.00324	2.47201	0.01006	2.48671	0.01052
	PARK	2.26100	0.00205	2.26345	0.00342	2.29829	0.01089	2.29989	0.01087
	KRTV	2.40729	0.00221	2.40871	0.00341	2.47778	0.01087	2.47788	0.01045
HOP	**CR02**	2.45439	0.00218	2.45667	0.00343	2.48911	0.01101	2.48932	0.01097
	PARK	2.26424	0.00219	2.26563	0.00343	2.29761	0.01100	2.29781	0.01097
	KRTV	2.40250	0.00219	2.40541	0.00351	2.47898	0.01078	2.47908	0.01067
G&G	**CR02**	2.45216	0.00204	2.45442	0.00360	2.51068	0.01234	2.51111	0.01252
	PARK	2.26759	0.00222	2.26897	0.00347	2.27893	0.01034	2.27932	0.01001
	KRTV	2.40208	0.00204	2.40346	0.00349	2.45561	0.01008	2.45654	0.01015

Table 6 - Differences in tropospheric delay as dependant of data gathering duration.
σ – Tropospheric delay values calculated using the least square adjustment.

Differences	Station	6 hours of data gathering	4 hours of data gathering	2 hours of data gathering
SAS	**CR02**	-0.00128	-0.01417	-0.02887
	PARK	-0.00245	-0.03729	-0.03889
	KRTV	-0.00142	-0.07049	-0.07059
HOP	**CR02**	-0.00228	-0.03472	-0.03493
	PARK	-0.00139	-0.03337	-0.03357
	KRTV	-0.00291	-0.07648	-0.07658
G&G	**CR02**	-0.00226	-0.05852	-0.05895
	PARK	-0.00138	-0.01134	-0.01173
	KRTV	-0.00138	-0.05353	-0.05446

Table 7 - The differences between an 8 hours solution, and a 6/4/2 hours based solution using meteorological data.

5. CONCLUSION

- Table 1 describes the difference between the models in an attempt to examine the distinctions obtained through solving the network as dependant of the initial choice of the tropospheric model. No fixed trend can be identified in the distinctions between the different models according to the results. Also, the obtained distinctions are up to 1.5cm on average, it can be assumed that all models are equally suitable. There is no way of determining the best model for the solution. All models have proven their quality and efficiency for this data set.
- Tables 1 and 2 indicate similar differences between the Hopfield and the Goad & Goodman models whether meteorological data is used or standard atmospheric parameters. Since both models belong to the Simplified Hopfield Models family, small differences between the solutions are expected (with standard atmospheric parameters and meteorological data).

- According to table 1 the difference between the Saastamoinen model and the other two is relatively large (up to 10mm) when using standard atmospheric parameters. However, table 2 indicates that these differences lessen when using meteorological data.
- According to tables 1 and 2 the distinctions between the different models lessen when using meteorological data.
- This article has presented the differences in the tropospheric delays when using standard atmospheric parameters on the one hand, and when using true meteorological data on the other hand. According to the experiments results (table 3) differences of up to 4.5cm can be noticed between the results of each method. The differences are constantly characterized by the same positive trend. These results can indicate the distinctions between the different methods. The same distinctions can be viewed during the other days of the measurements (table 4).
- The density of the meteorological differences influences the quality of the solution. However, table 5 indicates that the density itself is nearly meaningless. The valuable and important factor to the solution's accuracy is a homogenous data spread across the entire measurement time. We can see that 120 minutes density (for 8 hours of measurements) produces similar result within 5mm disparity of the 60 seconds density solution (for 8 hours of measurements).
- If we have a high data density but are missing data, for example, 4 out of 8 hours of measurements, the results start deviating away for the solution, resulting in up to 7cm disparities (table 6 and table 7). This level of accuracy is not acceptable in most geodesic projects. The reason for the occurrence of such disparities can stem from the deficient interpolation process of the missing 4 hours.
- According to table 6 and table 7, a good solution can be obtained using missing data, when the shortage of data doesn't surpass 25% of the entire session. We can see that the results of a full 8 session and a partial 6 hours session differ by 3mm at the most. However, partial 4 or 2 hours session's results differ by several centimeters to as much as 8cm from an accurate solution.
- In conclusion, this study indicates that at most geodesic research, even that requiring very high level of accuracy, the results obtained using standard atmospheric parameters are just as good as the results obtained using meteorological data. This is because models with standard parameters are better at describing the atmosphere and the change in the calculated atmospheric parameters using mapping functions as dependant of point altitude; time and location are good enough and produce quality results. The tropospheric delay models were developed around standard atmospheric parameters, and so solving using these parameters produces good results.

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