THE INFLUENCE OF DIFFERENT GLOBAL TROPOSPHERIC MODELS ON BASELINE PRECISION IN A LOCAL GPS NETWORK: Case of the Malaysian Johor RTKnet

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Abstract:

GPS network is restricted by the effects of de-correlate atmospheric refraction on the GPS signal. The two main components of the atmospheric refractions are the ionospheric and tropospheric refraction, showing distinct spatial correlation characteristic in the vertical direction. Although the ionospheric bias can be mitigated using dual frequency receivers, tropospheric bias is currently one of the major error sources in GPS Network, which limits the full functionality of GPS Positioning. The delay of the radio signals caused by the troposphere can range from 2m at zenith to 20m at lower elevation angles (below 10 degrees). In order to reduce the tropospheric effects, global tropospheric models derived experimentally using radiosonde data are been employed today. These models are derived using data obtained from Europe and America. Considering the location of Malaysia in the equatorial and tropical region, it is susceptible to high tropospheric effect thereby having an adverse effect on the GPS signals which in- turns affect positioning. With the establishment of the Malaysian RTK GPS Network (MyRTKnet) as one of the latest innovation of a real-time precision positioning in meeting up with the nation's development, security and defence; the need to investigate the impact of the different global tropospheric models became imperative. This paper provides details on the network test carried out by comparing GPS baseline results obtained from three different global tropospheric models which include Saastamoinen model, Hopfield model and the Neil model by applying standard and assumed local surface meteorological data. The results show that, there are no statistically significant differences in the performance of the three tropospheric models. Similarly, the result indicates a statistically significant correlation in the application of the standard and local surface meteorological data. On the overall, the Saastamoinen model produced a more precise baseline result with 89% in the horizontal component and 92% in the height component than the Hopfield and Neil models.

Keywords: Hopfield model, Neil model, Baseline precision, Tropospheric effect, Saastamoinen model.

1.0 Introduction

One of the fundamental issues in Network GPS is the ability to mitigate all the potential errors and biases in the system. The term *bias* here refers to a physical phenomena whereas the term *error* refers to the quantity remaining after the bias has been mitigated (Bingley, 2004). The error sources are the satellite related errors, (satellite coordinate errors, satellite clock offsets and satellite ephemeris errors), the atmospheric related errors (tropospheric and ionospheric errors) and the station related errors (receiver clock offsets, antenna phase centre variations, multipath, solid earth tides and ocean tide loading). The carrier phase measurements are compromised by these errors; as such most of the errors except for troposphere, receiver clock and ionospheric delay can be mitigated to some extent through modelling (Rizos, 2002). The ionospheric delay which is a function of the total electron content along the signal path, and the frequency of the propagated signal can be eliminated because of its frequency dependency by using the double-frequency ionospheric free linear combination (Leick, 2004; Hofmann-Wellenhof et al, 2001).

The troposphere is the lower part of the atmosphere close to the earth surface; it is 9km over the poles and 16km over the equator (Sickel, 2001) which extends from the sea to about 50km (Hofmann-Wellenhof et al, 2001). It is considered as a neutral atmosphere. This region has an index of refraction that varies with altitude. The index of refraction is slightly greater than unity, causing an excess group delay in the signal waveform beyond that of free space; hence it is regarded as a non-dispersive region affecting the L1 and L2 signals by the same amount. Due to the highly variable tropospheric water vapour content, it is difficult to achieve the desire accuracy in this region (Ahn, et al, 2006). The tropospheric delay is a function of elevation and altitude of the receiver which depends on factors such as atmospheric temperature, pressure and relative humidity. It is not frequency-dependent as the case with the ionosphere and cannot be eliminated through linear combination of L1 and L2 observation (Satirapod and Chalermwattanachai, 2005).

Several global tropospheric models such as the Saastamoinen model, Hopfield model, Neil model etc. have been empirically developed and employed in GPS timing receivers to correct for the tropospheric delay. These models are derived using data from available radiosonde obtained from Europe and North America continents. The global atmosphere condition used as constants in this models provides a broad approximation of the tropospheric conditions, but ignores the actual atmospheric conditions on a given location i.e. do not take into account the latitudinal and seasonal variations in the atmosphere (Roberts and Rizos, 2001). Besides, daily variation in temperature, pressure and relative humidity can result to error in tropospheric delays obtained using the global tropospheric models especially in the height components. The location of Malaysia in the equatorial and tropical region, make her susceptible to high tropospheric effect thereby having an adverse effect on the GPS signals which in- turns affects positioning.

A study conducted by Tajul et al (2005) in the South-East Asia, investigating the tropospheric delay at the regional level revealed that, there is a wide variation of the tropospheric delay which in effect has impact on the precision of the GPS positioning activities in the region. The variation becomes high between the months of November to early March and early May to August which are regarded as periods of high rainfall. The result also shows that, the a priori models could not effectively remove the residual troposphere delay except with the application of a scale factor in the least square estimation process.

In order to determine the best-fit tropospheric model for processing of data collected from the Malaysian RTK network, the need to investigate the impact of the different global tropospheric models on the GPS baseline precision becomes imperative. This paper investigates the influence of the different tropospheric models on GPS baseline precision derived from the three tropospheric models namely; the Saastamoinen model (Saastamoinen, 1973), Hopfield model (Hopfield, 1969) and Neil model (Neil, 1996). The paper is arranged in five sections. The second section describes the Test Network (MyRTKnet) and data collected. The third section explains the data processing strategy employed. The fourth section presents the analysis of the results obtained and followed by conclusions as the final section.

2.0 Test Network

The use of network of reference stations instead of the single reference station has become widely acceptable within the GNSS community as solution for high precision satellite positioning applications (Vollath et al, 2002). This allows the modelling of the atmospheric errors such as the tropospheric propagation delays that complicates the process of ambiguity fixing, which is often considered necessary for high-precision positioning and thus, significantly reducing the errors for long baselines thereby enhancing positioning accuracy.

The Malaysian RTK Network is designed with the primary objective of ensuring real-time capability by way of providing centimetre positioning over the entire territory of Malaysia through a network correction broadcast from a centralized processing centre (Ali et al, 2006). The network consists of 27 base stations in the Peninsular Malaysia, and one base station each in Sabah and Sarawak. The Peninsular Malaysia has three dense network namely; Klang Valley, Penang and Johor Bahru. These areas are represented in Fig.1.

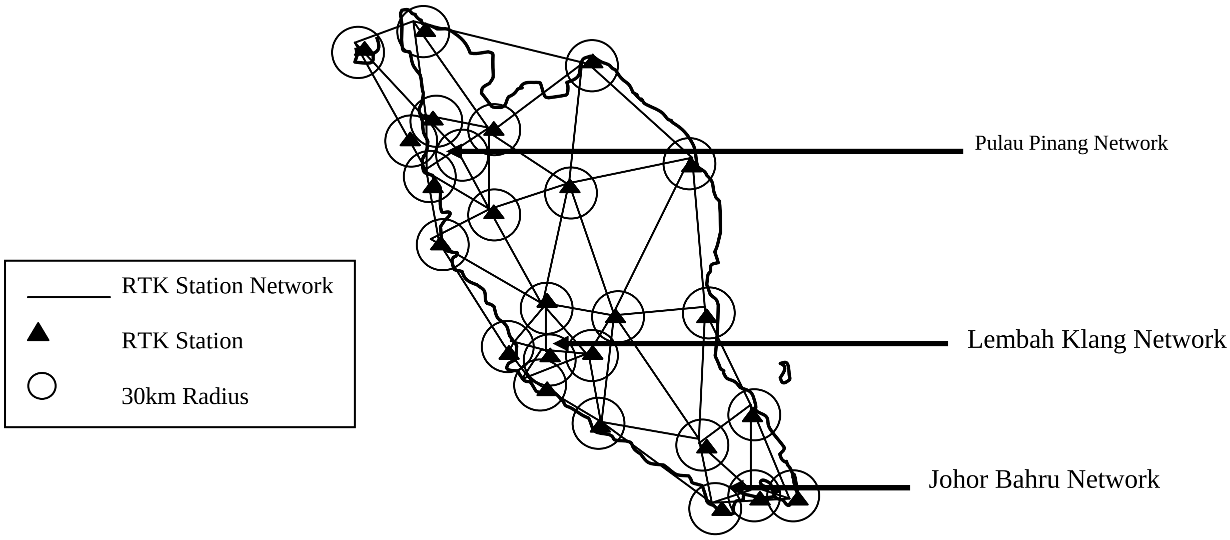

Fig. 1: The Peninsular Malaysia MyRTKnet

The Johor Dense Network consists of four GPS reference stations namely; JHJY, KLUG KUKP and TGPG. Each station is equipped with dual frequency GPS receiver (Trimble 5700). Fig.2 shows the Johor Dense Network and the Singapore IGS station (NTUS) used in this study.

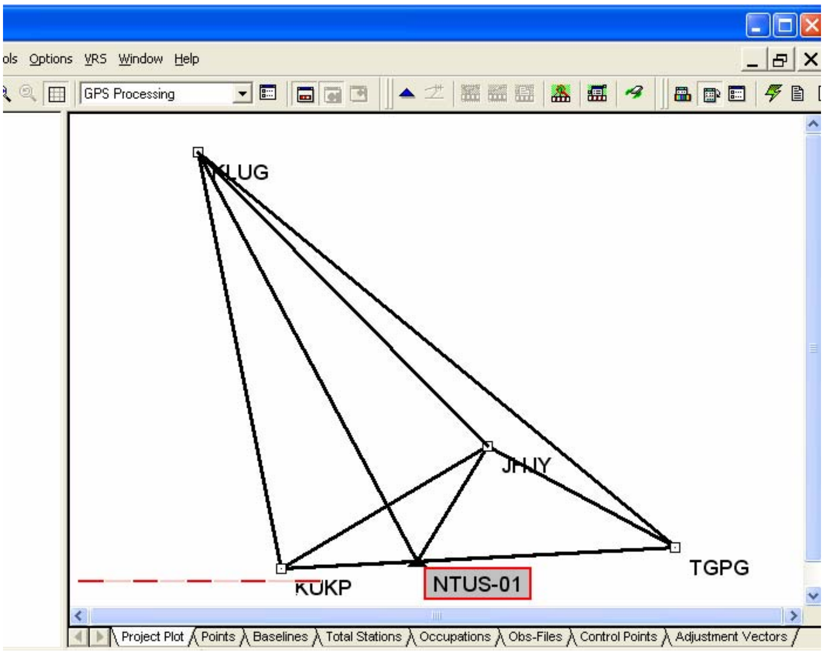

Fig. 2: Johor Dense Network with Singapore IGS Station (NTUS) as reference station.

Dataset were obtained from the Department of Surveying and Mapping Malaysia (JUPEM). Seven days long dataset each from seven different months in 2006 (months of January to August with the exception of the month of June) for the network at 15-second data rate in RINEX format were obtained from JUPEM. The International GNSS Service (IGS) station located in Singapore (NTUS) was used as the reference station, Daily RINEX observation data and computed station coordinates were obtained from the IGS website. Similarly, local surface meteorological data for each day within the network were obtained from US National Weather Service (NSW) via Weather Underground website. Table 1 shows the approximate baseline length from NTUS to each of MyRTKnet stations.

Table 1: Baseline length of MyRTKnet stations from NTUS

Station	Distance (km)	Ellipsoidal Heights (m)
JHJY	24.787	39.1959
KLUG	85.320	73.5879
KUKP	25.248	18.0874
TGPG	47.725	15.4282
NTUS	-	75.425

3.0 Data Processing

Two data processing strategies were employed. The first strategy involved the use of the standard atmosphere along side with the global tropospheric models while the second was the use of the local surface meteorological data (temperature, pressure and relative humidity) along side with the same global tropospheric models. In each case, the coordinates of the NTUS were held fixed in the baseline estimation for the network. The dataset were processed using the Trimble Total Control (TTC) GPS processing software version 2.73. Summary of the parameters used are presented in Table 2.

Table 2: Summary of Processing Parameters used

Cut-off angle	10^0
Orbit Type	IGS Precise
Solutions	Ionosphere-free double difference fixed
Tropospheric Models	Saastamoinen, Hopfield and Neil
Scale Factor	None
Atmosphere	Global and Local
Network Adjustment	Constrained

The dataset were divided into seven groups with each group representing one month. Each group was splited into seven batches representing seven days data in one month with each batch of 24hrs length, thus representing one day dataset. Each batch was treated as an individual session and processed using the Saastamoinen, Hopfield and Neil global tropospheric models respectively.

4.0 Analysis of Results

The analysis of the results was done on the basis of the baseline residuals obtained from each tropospheric model with the application of the standard atmosphere and the local surface meteorology in each individual session respectively. The performance of the global tropospheric model is characterized by the Root Mean Square Error (RMSE). The RMSE were calculated from the baseline residuals for the horizontal and height components for stations JHJH, KLUG, KUKP and TGPG and presented in Tables 3 and 4 respectively. It can be seen from the RMSE values that, the Saastamoinen model tend to produce a more reliable baseline result than the Hopfield and Neil models.

Table 3: Summary of RMSE values and results of F-Test statistics of the baseline from NTUS to stations JHJY, KLUG, KUKP and TGPG in the Horizontal component.

MONTH	TROPO. MODEL	RMSE (mm) IN THE HORIZONTAL COMPONENT				F-TEST STATISTICS at 5% SIGNIFICANCE LEVEL			
		STATIONS FROM NTUS				NULL HYPOTHESIS H_O			
		JHJY	KLUG	KUKP	TGPG	JHJY	KLUG	KUKP	TGPG
JAN	SAASTAMOINEN	0.498	1.079	0.735	1.160	REF.	ACCEPT	ACCEPT	ACCEPT
	HOPFIELD	0.770	1.852	0.826	1.041	ACCEPT	ACCEPT	ACCEPT	ACCEPT
	NEIL	1.142	1.671	1.061	2.814	ACCEPT	ACCEPT	ACCEPT	REJECT
FEB	SAASTAMOINEN	1.008	17.249	1.2251	1.184	ACCEPT	REJECT	ACCEPT	ACCEPT
	HOPFIELD	1.210	12.028	1.516	0.957	ACCEPT	REJECT	ACCEPT	REF.
	NEIL	1.013	6.676	1.325	1.216	ACCEPT	REJECT	ACCEPT	ACCEPT
MARCH	SAASTAMOINEN	0.607	0.831	0.763	1.035	ACCEPT	ACCEPT	ACCEPT	ACCEPT
	HOPFIELD	0.590	0.859	0.867	0.985	ACCEPT	ACCEPT	ACCEPT	ACCEPT
	NEIL	0.586	1.512	1.615	1.110	REF.	ACCEPT	ACCEPT	ACCEPT
APRIL	SAASTAMOINEN	1.417	1.432	1.957	4.967	ACCEPT	ACCEPT	ACCEPT	ACCEPT
	HOPFIELD	1.700	6.117	2.049	6.089	ACCEPT	REJECT	ACCEPT	REJECT
	NEIL	1.066	2.859	2.900	5.298	REF.	ACCEPT	ACCEPT	ACCEPT

MONTH	TROPO. MODEL	JHJY	KLUG	KUKP	TGPG	JHJY	KLUG	KUKP	TGPG
MAY	SAASTAMOINEN	1.115	6.104	1.446	10.700	REJECT	REJECT	REJECT	REJECT
	HOPFIELD	0.150	1.600	1.954	14.631	REF.	REJECT	REJECT	REJECT
	NEIL	0.237	1.885	2.036	17.867	ACCEPT	REJECT	REJECT	REJECT
JULY	SAASTAMOINEN	0.420	1.288	0.683	0.615	ACCEPT	ACCEPT	ACCEPT	ACCEPT
	HOPFIELD	0.712	1.582	1.342	0.714	ACCEPT	ACCEPT	ACCEPT	ACCEPT
	NEIL	0.419	1.153	0.545	0.955	REF.	ACCEPT	ACCEPT	ACCEPT
AUGUST	SAASTAMOINEN	0.829	4.543	0.896	1.228	ACCEPT	REJECT	ACCEPT	ACCEPT
	HOPFIELD	1.154	4.691	1.285	5.985	ACCEPT	REJECT	ACCEPT	REJECT
	NEIL	0.784	4.865	1.387	1.251	REF.	REJECT	ACCEPT	ACCEPT

The result also shows that, the height component gives higher RMSE values ranging from 0.76mm to 28.01mm as against the horizontal component with RMSE between 0.419mm to 17.2mm, suggesting that, the effects of the troposphere is more on the height component than the horizontal component. A closer look on the baseline RMSE reveals that, KLUG with the longest baseline length in the network from NTUS has higher values of RMSE. This presupposes that, as the distance between the reference and the rover increases, the tropospheric effects becomes severe.

Table 4: Summary of RMSE values and results of F-Test statistics of the baseline from NTUS to stations JHJY, KLUG, KUKP and TGPG in the Height component.

MONTH	TROPO. MODEL	RMSE (mm) IN THE HEIGHT COMPONENT				F-TEST STATISTICS at 5% SIGNIFICANCE LEVEL			
		STATIONS FROM NTUS				NULL HYPOTHESIS H_O			
		JHJY	KLUG	KUKP	TGPG	JHJY	KLUG	KUKP	TGPG
JAN	SAASTAMOINEN	1.750	5.000	2.733	3.767	ACCEPT	ACCEPT	ACCEPT	ACCEPT
	HOPFIELD	1.433	6.683	2.767	3.933	REF.	ACCEPT	ACCEPT	ACCEPT
	NEIL	2.067	10.33	2.733	4.183	ACCEPT	REJECT	ACCEPT	ACCEPT
FEB	SAASTAMOINEN	1.300	28.014	2.143	1.700	ACCEPT	REJECT	ACCEPT	ACCEPT
	HOPFIELD	1.457	27.414	1.914	1.629	ACCEPT	REJECT	ACCEPT	ACCEPT
	NEIL	1.229	6.071	2.114	2.114	REF.	ACCEPT	ACCEPT	ACCEPT
MARCH	SAASTAMOINEN	0.871	3.329	2.243	1.500	ACCEPT	ACCEPT	ACCEPT	ACCEPT
	HOPFIELD	0.814	4.200	2.287	2.643	REF.	REJECT	ACCEPT	ACCEPT
	NEIL	1.357	4.600	3.586	1.700	ACCEPT	REJECT	ACCEPT	ACCEPT
APRIL	SAASTAMOINEN	2.283	2.133	2.933	5.767	ACCEPT	REF.	ACCEPT	ACCEPT
	HOPFIELD	3.733	9.100	4.967	9.067	ACCEPT	ACCEPT	ACCEPT	ACCEPT
	NEIL	2.500	6.467	5.283	4.900	ACCEPT	ACCEPT	ACCEPT	ACCEPT
MAY	SAASTAMOINEN	1.100	3.900	5.750	11.650	REF.	ACCEPT	ACCEPT	REJECT
	HOPFIELD	2.050	4.850	1.100	37.55	ACCEPT	ACCEPT	REF.	REJECT
	NEIL	2.350	5.250	1.250	42.850	ACCEPT	ACCEPT	ACCEPT	REJECT
JULY	SAASTAMOINEN	0.860	3.140	0.760	2.140	ACCEPT	ACCEPT	REF.	ACCEPT
	HOPFIELD	1.780	3.300	4.200	2.600	ACCEPT	ACCEPT	REJECT	ACCEPT
	NEIL	0.767	2.488	1.758	3.003	ACCEPT	ACCEPT	ACCEPT	ACCEPT

AUGUST	SAASTAMOINEN	1.240	4.640	2.120	0.800	ACCEPT	REJECT	ACCEPT	REF.
	HOPFIELD	3.240	5.780	3.500	13.680	ACCEPT	REJECT	ACCEPT	REJECT
	NEIL	2.520	11.500	2.300	2.900	ACCEPT	REJECT	ACCEPT	ACCEPT

Further investigation was carried out using statistical hypothesis to test if the differences in baseline precision of each global tropospheric model are statistically significant. The horizontal and height component for individual station were tested. The smallest RMSE value in each component for each month in the network was chosen as the reference RMSE value. The smallest RMSE are indicated in large font size in Tables 3 and 4. A two-tailed F-test hypothesis at 5% significance level was employed to test if there is no difference in the values of the reference RMSE and the other RMSE values. The F-test hypothesis is given by (Snedecor and Coochram, 1989) as:

Null Hypothesis:

$$H_o : R_i = R_n$$

Alternative hypothesis

$$H_a : R_i \neq R_n$$

R_i represents the RMSE values obtained from the best tropospheric model in a given month in the network at a particular station, while the R_n represent other RMSE values of other tropospheric model. The result of the test shows that, there is no statistically significant difference in the baseline precision obtained from the three tropospheric models in both the horizontal and height components as presented in Tables 3 and 4.

Table 5: Summary Result of Two-Tailed Correlation Test at 0.05 Degree of freedom

MONTH	TROPO. MODEL	HORIZONTAL COMPONENT		HEIGHT COMPONENT	
		Null Hypothesis H_O		Null Hypothesis H_O	
		R^2 VALUES	DECISION	R^2 VALUES	DECISION
JAN	SAASTAMOINEN	0.412	REJECT	0.366	REJECT
	HOPFIELD	0.963	ACCEPT	0.972	ACCEPT
	NEIL	0.000	REJECT	0.986	ACCEPT
FEB	SAASTAMOINEN	0.988	ACCEPT	0.971	ACCEPT
	HOPFIELD	0.980	ACCEPT	0.673	REJECT
	NEIL	0.997	ACCEPT	0.962	ACCEPT
MARCH	SAASTAMOINEN	0.008	REJECT	0.515	REJECT
	HOPFIELD	0.019	REJECT	0.723	REJECT
	NEIL	0.053	REJECT	0.473	REJECT
APRIL	SAASTAMOINEN	0.033	REJECT	0.116	REJECT
	HOPFIELD	0.308	REJECT	0.169	REJECT
	NEIL	0.751	ACCEPT	0.509	REJECT
MAY	SAASTAMOINEN	0.999	ACCEPT	0.892	ACCEPT
	HOPFIELD	0.967	ACCEPT	0.672	REJECT
	NEIL	0.986	ACCEPT	0.938	ACCEPT
JULY	SAASTAMOINEN	0.870	ACCEPT	0.674	REJECT

	HOPFIELD	0.603	REJECT	0.028	REJECT
	NEIL	0.041	REJECT	0.307	REJECT
AUGUST	SAASTAMOINEN	0.856	ACCEPT	0.716	REJECT
	HOPFIELD	0.121	REJECT	0.019	REJECT
	NEIL	0.736	REJECT	0.971	ACCEPT

The relationship between the application of the standard atmosphere condition and the local surface meteorology in the three tropospheric models were further investigated. A two-tailed correlation test was performed at 0.05 degree of freedom. The analysis was to find out if the correlation between the baseline precisions obtained from the three tropospheric models using the standard atmosphere and that using the local surface meteorology are statistically significant. The result as presented in Table 5 reveals that there is statistically significant correlation in the baseline precision between the standard atmosphere and the local surface meteorology. This implies that, the weather condition has significant impact on the baseline result.

5.0 Conclusions

This paper has experimentally demonstrated the influence of different tropospheric models on MyRTKnet. The three models investigated i.e. the Saastamoinen, Hopfield and Neil models show no significance difference in their performance. Consequently, the height component is affected much more than the horizontal component. Increase in baseline length results to more tropospheric effect, hence the troposphere has shown to be a distant-dependent error (Tajul, 2006). The application of the standard atmosphere and the local surface meteorological data shows a statistically significant correlation. On the overall, the study shows that, the Saastamoinen model tends to produce the most reliable baseline results.

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