Journal of Geosciences and Geomatics, 2015, Vol. 3, No. 4, 88-95
Available online at http://pubs.sciepub.com/jgg/3/4/1

DOI:10.12691/jgg-3-4-1

Determination of the best-fit Tropospheric Delay Model on the Nigerian Permanent GNSS Network

Dodo Joseph Danasabe[1,*], Ojigi Lazarus Mustapha[2], Tsebeje Samuel Yabayanze[1]

[1]Space Geodesy and Systems Division, Centre for Geodesy and Geodynamics, Toro, Nigeria
[2]Mission Planning, IT and Data Management, National Space Research and Development Agency, Abuja, Nigeria
*Corresponding author: jd.dodo@gmail.com

Received July 14, 2015; Revised August 05, 2015; Accepted August 09, 2015

Abstract The Federal Government of Nigeria through the Office of the Surveyor General of the Federation (OSGoF) set up surveying infrastructure throughout the country known as the NIGerian Reference GNSS NETwork (NIGNET). The NIGNET is a network of Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) set up at different locations in Nigeria for surveying and mapping. They are satellite tracking stations operating 24 hours a day providing positional solutions. As signals from the satellite pass through the different layers of the atmosphere (ionosphere and troposphere), they are refracted thus, causing delay on the arrival of the signal, which in-turns affect positioning in the horizontal and height component. The most dominant spatially correlated bias is the tropospheric effect on the GNSS satellite signals. Several global tropospheric delay models are in use by different countries to mitigate the biases cause by the troposphere. This study therefore aim to determine the best-fit tropospheric delay model for the NIGerian GNSS Reference NET work (NIGNET) using data collected from the NIGNET stations across Nigeria. Three different global tropospheric models, namely; the Saastamoinen model, Hopfield model and Niell models were used, and results compared. Four processing strategies were adopted. The first strategy was without the application of any of the models, while in the second, third and fourth strategies, the GNSS data were processed with the application of each of the models. The results indicate that, the Niell model has the lowest mean zenith tropospheric delay (ZTD) of 2.330m with root mean square error (rmse) of 0.45m, while the Hopfield and Saastamoinen models have ZTD of 2.386m and 2.398m with rmse value of 0.60m and 0.71m respectively. On the overall, the Niell model has better performance in the network. This suggests that, the application of Niell model in the processing of all GNSS data will give a more reliable result in the position domain as well as the height component. The results are very useful to surveyors and geodesist engaged in surveying and mapping, and spatial positioning of infrastructures. It will enhance the effectiveness and reliability of the tropospheric delay resolution process for regional Global Positioning System (GPS) network users.

Keywords: *tropospheric delay, Hopfield model, Saastamoinen model, Niell model, NIGNET*

Cite This Article: Dodo Joseph Danasabe, Ojigi Lazarus Mustapha, and Tsebeje Samuel Yabayanze, "Determination of the best-fit Tropospheric Delay Model on the Nigerian Permanent GNSS Network." *Journal of Geosciences and Geomatics*, vol. 3, no. 4 (2015): 88-95. doi: 10.12691/jgg-3-4-1.

1. Introduction

One of the fundamental issues in Network GPS is the ability to mitigate all potential errors and biases in the system. The term bias here refers to a physical phenomenon whereas the term error refers to the quantity remaining after the bias has been mitigated [2]. 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 [12]. 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 double-frequency ionospheric free linear combination [6,9].

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 the 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 employed today. With the establishment of the Nigerian Permanent GNSS Network 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.

2. Tropospheric Delay

The troposphere is the lower part of the atmosphere close to the earth surface. Troposphere is where the inhabitants of our planet live, it starts on the surface of the Earth and goes up to height of 9 to 18 km. The depth of it varies with the latitude; it is greatest at the equatorialregions (approximately 18 km) and minimal near the poles (about 9 km). Approximately 75-80 % of the mass of the whole atmosphere is in the troposphere including nearly all water vapour (about 99%) and dust particles [22]. The refractive index showing the ratio of the vacuum speed of light and the real speed of the signal is always bigger than 1. It means that the signals emitted by the satellites reach the receiver later, therefore a greater satellite-to-receiver range is measured. Troposphere is a non-dispersive medium for radio frequencies below 15 GHz, hence its effect is independent of GNSS frequencies. It causes delay in both GNSS carrier and code observations.

Due to the highly variable tropospheric water vapour content, it is difficult to achieve desired accuracy in this region [1]. The tropospheric delay in equation (1) is directly proportional to the refractive index, which is expressed as a function of atmospheric temperature and pressure. It is therefore expressed as [6]:

$$D^{trop} = \int (n-1) ds \tag{1}$$

where D^{trop} is the tropospheric delay, n is the refractive index and ds is the path length.

The refractivity can be divided into dry and water vapour due to the troposphere containing dry and water vapour content, hence;

$$N = N_d + N_w \tag{2}$$

where, N_d : refractivity of dry air N_w : refractivity of water vapour. Expressing in terms of refractivity N; from equation (1); we obtain;

$$N^{trop} = 10^{-6}(n-1) \tag{3}$$

where; N^{trop} : tropospheric refractivity, hence ;

$$D^{trop} = 10^{-6} \int N^{trop} ds \tag{4}$$

The tropospheric delay can be separated into the hydrostatic (dr) N_d^{trop} and non-hydrostatic (wet) N_w^{trop} component as shown in Figure 1.

$$N^{trop} = N_d^{trop} + N_w^{trop} \tag{5}$$

where; N_d^{trop} : dry tropospheric refractivity

N_w^{trop} : wet tropospheric refractivity resulting from water vapour.

The hydrostatic and wet components are caused by the dry gases (primary nitrogen and oxygen) and water vapour respectively. About 90% of the tropospheric delay is caused by the dry component, while the remaining 10% is from the wet component. The tropospheric delay is then expressed as a linear combination of the hydrostatic and wet components [5];

$$D^{trop} = 10^{-6} \int_{path} N_d^{trop} ds + 10^{-6} \int_{path} N_w^{trop} ds \tag{6}$$

or

$$D^{trop} = D_d^{trop} + D_w^{trop} \tag{7}$$

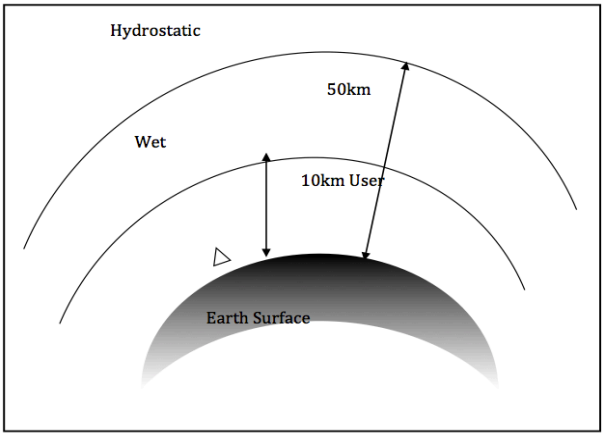

Figure 1. Schematic diagram of the Hydrostatic and Wet components of the troposphere [9]

Tropospheric delay is calculated in the zenith direction over the GPS station, hence the term zenith tropospheric delay, a combination of the zenith hydrostatic delay and zenith wet delay. 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 is the case with the ionosphere and cannot be eliminated through linear combination of L1 and L2 observations [15].

3. Tropospheric Delay Models

Several global tropospheric models such as the Saastamoinen model, Hopfield model, Niell 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 conditions, used as constants in these models, provide a broad approximation of the tropospheric conditions, but ignore the actual atmospheric conditions on a given location, i.e., do not take into account the latitudinal and seasonal variations in the atmosphere [11]. Besides, daily variation in temperature, pressure and relative humidity can lead to error in tropospheric delays obtained using the global tropospheric models especially in the height components [3]. The location of Nigeria in the equatorial and tropical region makes it susceptible to high tropospheric effect thereby having an adverse effect on the GPS signals, which, in turn, affects positioning. In order to determine the best-fit tropospheric model for processing of data collected from the Nigerian Permanent GNSS Network, the need to investigate the impact of the different global tropospheric models on the network becomes imperative. The research investigates the performance of three global tropospheric delay models, namely Refined Saastamoinen model [14], Modified Hopfield model [7] and Niell model [10].

3.1. The Refined Saastamoinen Model

The Saastamoinen model as in [12] is expressed as a function of height of the observation station and the zenith angle. This was later modified and functionally expressed as [5]:

$$D_Z^{trop} = \frac{0.002277}{\cos z}\left[P + \left(\frac{1255}{T} + 0.05\right)P_w - B\tan^2 z\right] + \delta R \quad (8)$$

Where z = zenith angle of satellite
P = pressure (mbar)
T = temperature (K)
P_w = partial pressure of water vapour (mbar)

D_z^{trop} = tropospheric path delay in metres
B and δR are the corrections that depends on height (h) of the station and z.

3.2. The Modified Hopfield Model

[6] used data from different parts of the world to develop an empirical tropospheric delay model. The Hopfield model shows dry and wet refractivity components as a function of tracking station height h above the Earth's surface and is given in the following forms:

$$N_d^{Trop} = N_{d,0}^{Trop}\left[\frac{H_d - h}{H_d}\right]^{\mu} \quad (9)$$

$$N_w^{Trop} = N_{w,0}^{Trop}\left[\frac{H_w - h}{H_w}\right]^{\mu} \quad (10)$$

where $\mu = 4$ is empirically determined power of the height ratio, $H_d = 40136 + 148.72(T - 2734.16)$ is the polytropic thickness for the dry part (m), $H_w = 11000$ is the polytropic thickness for the wet part (m), $N_{d,0}^{Trop} = K_1\frac{P_0}{T_0}$ is the dry tropospheric refractivity for the stations at the Earth's surface as a function of pressure (millibars) and temperature (Kelvin), $N_{d,0}^{Trop} = K_2\frac{e_0}{T_0} + K_3\frac{e_0}{T_0^2}$ is the wet tropospheric refractivity for the station at theEarth's surface as a function of water vapor, pressure, and temperature.

Inserting equations 9 and 10 into equation 6, and integrating each element with the respective integration ranges along the vertical direction (i.e. from h = 0 to h = H_d and from h = 0 to h = H_w for the dry and wet components), we then obtain tropospheric zenith delay in units of meters [6]:

$$T\frac{Z}{K} = \frac{10^{-6}}{5}\left[N_{d,0}^{Trop}H_d + N_{w,0}^{Trop}H_w\right] \quad (11)$$

3.3. The Niell Model

The Niell Model is a combination of the Saastamoinen zenith path delay with Neil mapping functions [10]. The parameters (a, b, c) used in the dry and wet components of the models as expressed in equations (10) and (11) are calculated based on the interpolation of the average and seasonal variation (amplitude) values as functions of latitude and time. For the dry component:

$$m_d(\varepsilon) = \frac{1 + \dfrac{a_d}{1 + \dfrac{b_d}{1 + c_d}}}{\sin\varepsilon + \dfrac{a_d}{\sin\varepsilon + \dfrac{b_d}{\sin\varepsilon + c_d}}} + \left[\frac{1}{\sin\varepsilon} - \frac{1 + \dfrac{a_{ht}}{1 + \dfrac{b_{ht}}{1 + c_{ht}}}}{\sin\varepsilon + \dfrac{a_{ht}}{\sin\varepsilon + \dfrac{b_{ht}}{\sin\varepsilon + c_{ht}}}}\right]\cdot\frac{H}{100} \quad (10)$$

For the wet component:

$$m_w(\varepsilon) = \frac{1 + \dfrac{a_w}{1 + \dfrac{b_w}{1 + c_w}}}{\sin\varepsilon + \dfrac{a_w}{\sin\varepsilon + \dfrac{b_w}{\sin\varepsilon + c_w}}} \quad (11)$$

where; m_d and m_w is the mapping functions for dry and wet components respectively; $\mathcal{E}$ is the satellite elevation angle and H = orthometric height a_d, b_d, c_d are the coefficients in the dry component; a_w, b_w, c_w are the coefficients in the wet component and a_{ht}, b_{ht}, c_{ht} are the coefficients in the height component.

4. The Nigerian Permanent GNSS Reference Network

Theoffice of the Surveyor General of the Federation (OSGoF) established the NIGerian Permanent GNSS NETwork (NIGNET).The goal is to implement a new reference frame for Nigeria in line with the recommendation of the United Nation Economic Commission of Africa (UNECA) through Committee on Development, Information Science and Technology (CODIST) [8]. It is expected that, the Nigerian Permanent GNSS Reference Network as presented in Figure 2, will directly contribute to the Africa Reference Frame (AFREF).

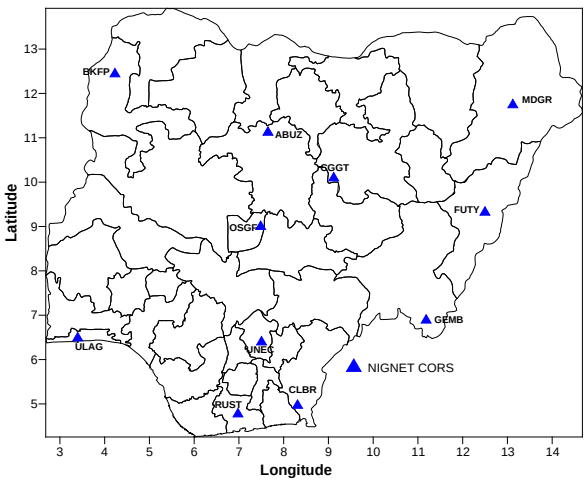

Figure 2. NIGNET CORS [Authors]

About Eleven (11) NIGNET CORS stations were established at the time of conducting this research as shown in Figure 1. With the growing capabilities of GPS as a high precision positioning system for surveying and mapping, monitoring geophysical hazards, sea level change and as well as coordinating geodetic activities; there is a necessity for the NIGNET stations to be defined on the precise reference system such as International Terrestrial Reference System (ITRS) that managed the International Terrestrial Reference frame (ITRF).

5. Materials and Methods

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 [17]. This allows modelling of the atmospheric errors such as the tropospheric propagation delays that complicate 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.

5.1. Study Area

Six (6) stations of the Nigerian Permanent Network of Continuously Operating Reference Stations (CORS) were used. The choice of these stations is due to data availability from these stations for the period of study compared to other stations of the network. Table 1 shows description of the six (6) NIGNET stations used in this research.

5.2. Data Acquisition

Twenty-four hours (24hrs) raw GPS data at 30-second data rate in RINEX format for the stations shown in Figure 2 and precise satellite ephemeris data for GPS week 1409 were downloaded from the International GNSS Service (IGS) for the day of the year (DoY) 01/2011 to 07/2011. The ocean tide loading data for each station was obtained from [18]. Similarly, the Earth Orientation Parameters and the Ionosphere models were downloaded from the Bernese website [19]. Summary of the parameters used are given in Table 2.

Table 1. Description of the NIGNET Site

Station ID	Station locations	Receiver	Antenna	Antenna height(m)	Approximate Lat.(N)	Approximate. Long.(E)	Ellipsoidal height (m)
ULAG	University of Lagos, Lagos	Trimble	Choke Ring	0.1710	06^0 31'2.375''	03^0 23'51.444''	44.5752
RUST	River State University of Science and Technology Port Harcourt	Trimble	Choke Ring	0.1710	04^0 48'6.609''	06^0 58' 42.677''	45.5892
UNEC	University of Nigeria Enugu campus	Trimble	Choke Ring	0.1710	06^0 25' 29.301''	07^0 30' 17.968''	254.4055
BKFP	Birnin Kebbi Federal Polytechnic	Trimble	Choke Ring	0.1710	12^0 28'6.876''	04^0 13' 45.271''	250.0118
CGGT	Centre for Geodesy & Geodynamics, Toro	Trimble	Choke Ring	0.1710	10^0 07' 23.141''	09^0 07' 5.922''	916.4462
FUTY	Federal University of Technology, Yola	Trimble	Choke Ring	0.1710	09^0 20'59.073''	12^0 29' 52.072''	247.4052

Table 2. Summary of General Processing Parameters

Parameter	Description
RINEX data	30 second sampling rate
Orbital Data	IGS final/Pricise orbit
Processing window	24 hours sliding window
Ocean tide loading	FES2004
Reference Frame	ITRF 2008
Satellite Elevation Angle	10^0 Cut-off
Double Difference Ionosphere	Quasi-Ionosphere free (L_3) ambiguity free
Mapping Function	Troposphere delay mapping function of $^1/_{cosz}$
Adjustment	All Stations coordinate minimally constrained to their apriori

5.3. Processing Strategy

Four processing strategies using the Bernese GPS Scientific Software V.5.0 were employed. They include:

Strategy I: In this strategy, the processing is done without the application of the tropospheric model. The ionosphere-free double difference (IF DD) residuals and final coordinates are extracted for analysis.

Strategy II: Processing with the application of the Niell model and standard atmosphere, the IF DD residuals, final coordinates and the zenith tropospheric delay are extracted for analysis.

Strategy III: Processing with the application of the Modified Hopfield model and standard atmosphere; the IF DD residuals, final coordinates and the zenith tropospheric delay are extracted for analysis.

Strategy IV: Processing with the application of the Refined Saastaminen model and standard atmosphere; the IF DD residuals and final coordinates are extracted for analysis purpose.

The coordinates of all stations were estimated. This retains the flexibility for later changes in the realization of the reference frame. However, to check the consistency of the data used in the processing with the coordinates of the IGS core sites, a minimal constraint solution was generated for the network.

6. Results and Discussions

The analysis of the results was done based on the Ionospheric Free Double Difference (IF DD) residuals, the final station coordinates and the zenith tropospheric delay obtained from each of the global tropospheric delay model, in order to ascertain the best fit tropospheric delay model for the network.

6.1. Assessment of the Tropospheric Delay Models on the basis of the Baseline Ionospheric-free Double Difference (IF DD) Residual

One of the tools used in the assessment of tropospheric model in a GPS network is the comparison of the baseline IF DD residuals over which the tropospheric models are being assessed [4]. The Root Mean Square Error (RMSE) characterizes the performance of the models. Fifteen baselines were formed from where the RMSE were computed for all satellites.

Table 3 summarises the numerical results for all the baselines in terms of the RMS IF DD residuals. The IF DD residuals of strategy I (No model) has largeresiduals compare to strategies II, III and IV respectively. This is expected because no model is applied. The result indicates that, the three models are able to reduce the size of the residuals. However, no significant residual difference in the three models is noticed. The UNEC-RUSThaving the shortest baseline of 188.8km hasrmse value of 11.9cm when no model is applied, while the longest baseline ULAG-FUTY has RMS value of 17.0cm. This presupposes that, the tropospheric delay is distance-dependent error. This result is in agreement with [21]. The longer the baseline, the more the effects of the troposphere. The Niell model gave a better result.

Table 3. Summary statistics of baseline RMS DD IF residual

Baseline	Baseline Length (km)	Total RMS error (cm) of IF DD			
		No Model	Niell Model	Modified Hopfield	Saastamoinen Model
BKFP-CGGT	595.1	11.3	8.1	8.2	8.5
BKFP-FUTY	974.8	10.4	8.9	9.1	9.3
BKFP-RUST	906.2	13.6	9.8	10.0	10.5
RUST-CGGT	636.2	15.8	9.7	9.8	10.2
RUST-FUTY	794.3	16.0	10.0	10.6	10.6
BKFP-ULAG	667.1	11.9	8.5	8.6	8.7
ULAG-CGGT	749.1	16.3	8.6	8.5	8.6
ULAG-FUTY	1060.5	17.0	9.0	9.4	9.2
ULAG-RUST	440.4	14.9	9.2	9.6	14.0
BKFP-UNEC	762.6	13.2	8.6	8.8	9.1
UNEC-CGGT	446.7	12.3	8.7	8.3	10.6
UNEC-FUTY	940.1	13.5	9.0	9.1	9.1
UNEC-RUST	188.8	11.9	11.3	11.2	13.0
UNEC-ULAG	455.2	12.3	8.8	8.4	9.7

Table 4. Percentage improvement in the RMS DD IF residuals after applying tropospheric delay models

Baseline	Niell Model (%)	Modified Hopfield Model (%)	Refined Saastamoinen Model (%)
BKFP-CGGT	39.51	37.805	32.9
BKFP-FUTY	16.85	14.286	11.8
BKFP-RUST	38.78	36.000	29.5
RUST-CGGT	62.89	61.224	54.9
RUST-FUTY	60.00	50.943	50.9
BKFP-ULAG	40.00	38.372	36.8
ULAG-CGGT	89.53	91.765	89.5
ULAG-FUTY	44.44	38.298	41.3
ULAG-RUST	61.96	55.208	6.4
BKFP-UNEC	53.49	50.000	45.1
UNEC-CGGT	41.38	48.193	16.0
UNEC-FUTY	50.00	48.352	48.4
UNEC-RUST	5.31	6.250	8.5
UNEC-ULAG	39.77	46.429	26.8
Average	46.0	41.3	35.6

Table 4 provides the percentile improvement in the RMS DD IF residuals for strategies II, III and IV respectively. From the table, the result reveals that baseline percentage improvement varies from 8% to 91%. The Niell model had the most percentage improvement in the network with an average of 46%. The modified Hopfield and Saastaminen models had 41.3% and 35.6% respectively. All stations connect to station RUST have large rmse, this could be attributed to data gabs at station RUST.

6.2. Assessment of the Tropospheric Models in the Position Domain

To study the tropospheric delay models in the position domain, the coordinate differences of the station in the North, East and Height (horizontal and height) components were computed and analysed. Figures 3.0, 4.0, and 5.0 shows the standard deviation of the coordinates in North, East and Height components.

The result reveals that, the Niell and Hopfield models show no significant deviations in the North and East components respectively.

However, the differences in the application of the tropospheric delay models reveals that, the Niell model shows considerable improvement with network standard deviation of 5.02m, 3.72m in the north and east component respectively, while the Hopfield Model followed closely with network standard deviation of 5.22m and 3.8m in the north and east components respectively.

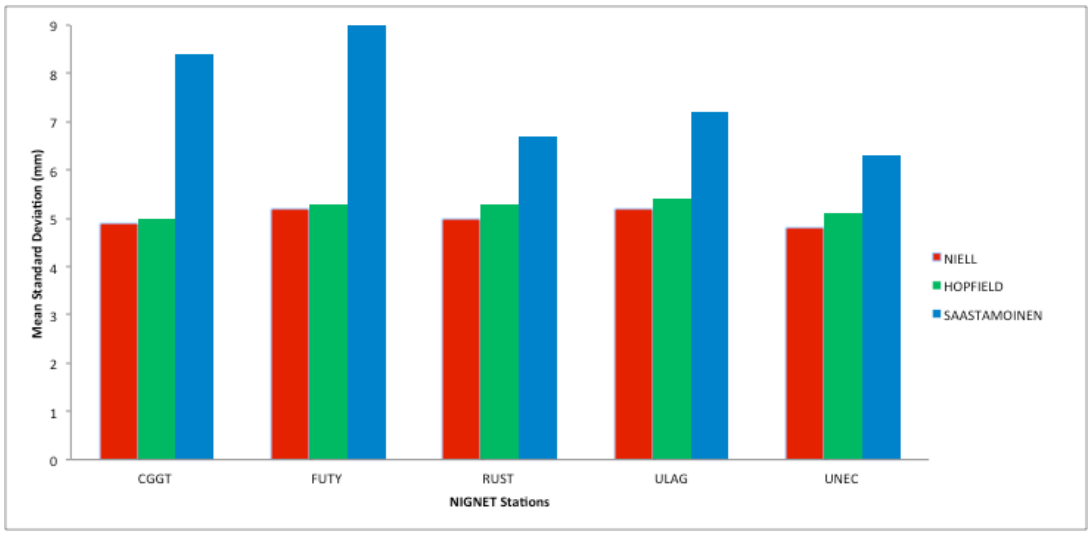

Figure 3. Standard deviation in the North component

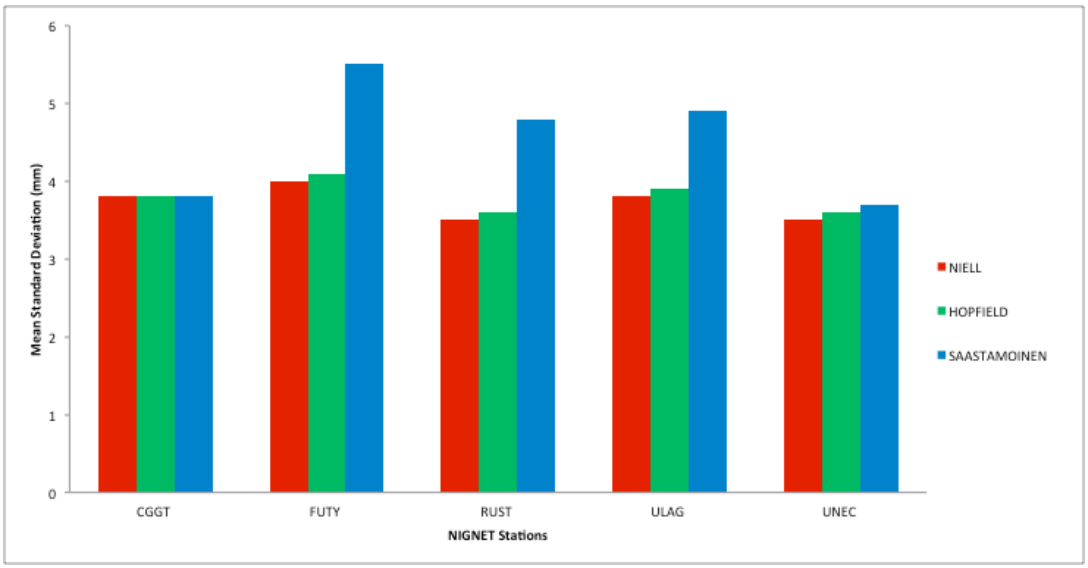

Figure 4. Standard deviation in the East component

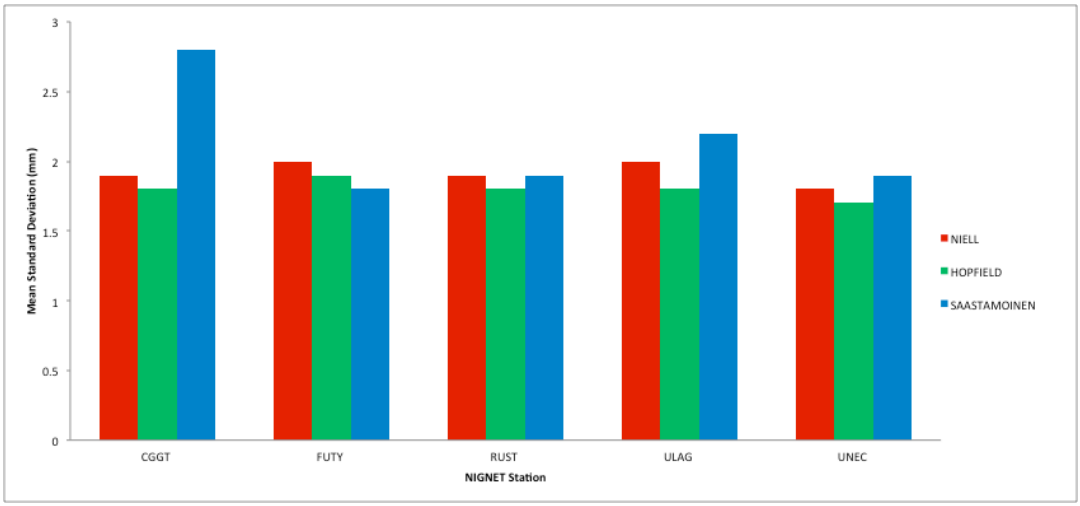

Figure 5. Standard deviation in the Height component

6.3. Mean Zenith Tropospheric Delay (ZTD) at each Station

The tropospheric delay is calculated in the zenith direction over the GNSS station. The Zenith Tropospheric Delay (ZTD) gives insight into the tropospheric conditions above the GPS site. Table 5 show the statistics of the zenith tropospheric delay for each of the GNSS station based on the application of each tropospheric delay model.

The mean ZTD computed at each station reveals that, station RUST has the highest ZTD value of 2.503m,

2.562m and 2.592m for Niell, Hopfield and Saastamoinenmodels respectively. This is followed closely by station ULAG having 2.57m, 2.51 and 2.57m for Niell, Hopfield and Saastamoinen models respectively. This result presupposes that stations at low latitude are highly susceptible to tropospheric delay [21]

Table 5. Statistics of the ZTD estimate at each GNSS statio

Station	Niell Model				Modified Hopfield Model				Refined Saastamoinen Model			
	Mean (m)	RMS (m)	Max (m)	Min (m)	Mean (m)	RMS (m)	Max (m)	Min (m)	Mean (m)	RMS (m)	Max (m)	Min (m)
BKFP	2.323	0.41	2.337	2.303	2.341	0.63	2.352	2.332	2.326	0.72	2.333	2.319
CGGT	2.172	0.33	2.181	2.162	2.187	0.76	2.195	2.169	2.182	0.78	2.192	2.170
FUTY	2.363	0.41	2.376	2.352	2.364	0.64	2.371	2.358	2.369	0.56	2.375	2.362
RUST	2.485	0.55	2.503	2.471	2.535	0.54	2.562	2.521	2.566	0.76	2.592	2.529
ULAG	2.435	0.57	2.573	2.405	2.479	0.58	2.511	2.422	2.539	0.67	2.570	2.474
UNEC	2.382	0.47	2.413	2.332	2.407	0.53	2.429	2.385	2.405	0.78	2.440	2.380
Average	2.36	0.45	2.391	2.336	2.386	0.61	2.403	2.365	2.398	0.71	2.417	2.372

The mean Network ZTD produced by the three tropospheric delay shows that the Niell model has the lowest network ZTD of 2.36m with mean RMS value of 0.45m, follow by the Hopfield model with network ZTD of 2.386m and mean RMS value of 0.61m. The Saastamoinen model has the highest mean network ZTD of 2.398m with mean RMS value of 0.71m.

7. Conclusion

This research has demonstrated the influence of different tropospheric delay models on the Nigerian Permanent GNSS Network. The result indicates that the residual tropospheric delay affects the position precision.

Increase in baseline length results in higher tropospheric effect, this is noticed on baseline ULAG-FUTY with the highest baseline length of 1060.5km. Tropospheric delay increases during the morning hours and decreases at sunset. The three models investigated i.e. the Saastamoinen, Hopfield and Niell models show no significance difference in their performance; better improvements in the position domain were achieved by the application of the Niell model compared to Hopfield and Saastamoinen models. The Niell model produced a better mitigation of the tropospheric delay, with an average percentage improvement of 46.0% while; Hopfield and Saastamoinen models have 41.3% and 35.6% percentage improvement respectively. The result also indicates that, the Niell has the lowest mean average zenith tropospheric delay (ZTD) of 2.33m with RMS of 0.45m. On the overall, the Niell model has better performance in the network in this research. This result is in agreement with [20].

Acknowledgement

The authors acknowledge the Office of the Surveyor General of Nigeria for providing the data used in this research.

References

[1] Ahn, Y. W., Lachapelle, G., Skone, S. and Sahm, S. "Analysis of GPS RTK Performance using External NOAA Tropospheric Corrections Integrated with a Multiple Reference Station Approach", *GPS Solution*, 10, 171-186. 2006.

[2] Bingley, R, *GNSS Principles and Observables*, Nottingham, IESSG, University of Nottingham UK, M.Sc. Lecture Monograph. 2004.

[3] Dodo, J. D., and Kamarudin, M. N. "Investigation on the Impact of Tropospheric Models on baseline precision in a local GPS network: Case of the Malaysian RTKnet",*Journal of Geomatics* 2 (1) 137-142. 2008.

[4] Don, K., Sunil, B., Langley, R. B., Dare, P. "Performance of Long-Baseline real-Time Kinematic Applications by Improving Tropospheric Delay Modelling", *ION GNSS International Technical Meeting of the satellite Division.* Long Beach, California, USA. 2004.

[5] Guochang, X,*GPS Theory, Algorithms and Application*, Springer-Verlag Berlin Heidelberg, New York. 2003.

[6] Hofmann-Wellenhof, B., Lichtenegger, H. and Collins, J,*GPS, Theory and Practice*, Springer-Verlag Wien, New York. 2001.

[7] Hopfield, H. S, "Two Quartic Tropospheric Refractivity Profile for Correcting Satellite Data". *Journal of Geophysical Research* 74(18), 4487-4499.1969.

[8] Jatau, B., Fernandes, R.M.S., Adebomehin, A., and Goncalves, N "NIGNET-The New Permanent GNSS Network of Nigeria", *FIG Congress 2010 Facing the Challenges – Building the Capacity Sydney*, Australia, 11-16 April 2010.

[9] Leick, A, *GPS Satellite Surveying*, USA: John Willey & Sons, Inc, 2004.

[10] Niell, A.E, "Global Mapping for the Atmospheric Delay at Radio Wavelenghts",*Journal of Geophysical Research* 111 (B2), 3227-3246.1996.

[11] Roberts, C., and Rizos, C, "Mitigating Differential Troposphere for GPS-based Valcano Monitoring", *5th International Symposium on Satellite Navigation Technology and Applications.* Canberra, Australia. 2001.

[12] Rizos, C, "Network RTK Research and Implementation - A Geodetic Perspective". *Journal of Global Positioning System*, 1(2), 144-150.2002.

[13] Saastamoinen, J, "Atmospheric Correction for Troposphere and Stratosphere in Radio Ranging of Satellites",*Geophysical Monograph*, American Geophysical Union, Washington D.C. 247-252. 1972.

[14] Saastamoinen, J, "Contribution to the theory of Atmosphere Refraction",*Bulletin of Geodesique* (105,106,107): 279-298, 383-397, 13-34. 1973.

[15] Satirapod, C., and Chalermwattanachai, P, "Impact of Different Tropospheric Models on GPS Baseline Accuracy: Case Study in Thailand", *Journal of Global Positioning Systems*, 4(1-2), 36-40.2005.

[16] Sickel, V., J, *GPS for Land Surveyors*, Taylor and Francis 3rd, Edition Florida, United State of America, 2008.

[17] Vollath, U., Buecherl, A., Landau, H., Pagels, C. and Wagner, B, "Multi-Base RTK Positioning Using Virtual Reference Stations",*Institute of Navigation, ION GPS-2000*, Salt Lake City, 22-19 September, 123-131.2000.

[18] "Ocean Tide Loading" Available: http://www.oso.cha. [AccessedSept. 20, 2009].

[19] "The Earth Orientation Parameters and the Ionosphere models" Available: http://www.bernese.unnibe.ch/ [Accessed: Sept. 21, 2009].

[20] Péter, B. "The evaluation of troposphere models applied in the Hungarian Active GNSS Network" *The Council of European Geodetic Surveyors* 2012.

[21] Tajul, A. M., Lim, S., Yan, T. and Rizos, C. "Mitigation of Distance-Dependent Errors for GPS Network Positioning". *International Global Navigation Satellite Systems Society IGNSS Symposium*, Surfers Paradise, Australia.

[22] Randy Russel, "The Toposphere, Window to the Universe". [http://www.windows2universe.org/earth/Atmosphere/troposphere .html] , 2010. Last accessed 23/10/2012.