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Assessment of Various Ocean Tide Models on GNSS Data over Nigerian Continuously Operating Reference Stations

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Abstract

Nigeria has a long coast line with some of its GNSS Continuously Operating Reference Stations (CORS), otherwise known as NIGNET located in this coastal environment. It is therefore essential to identify an appropriate model that could perform optimally over Nigeria. Hence, this paper examines the effects of various ocean loading models on the accuracy of data processing over the NIGNET CORS. The study was conducted using selected five Ocean Tide Models (OTMs) which include FES2004, FES2012, FES2014b, GOT00.2 and HAMTIDEOTMs. The five ocean loading models were downloaded from Onsala Space Observatory and separately utilised for GNSS data processing, one month (October, 2011) of the NIGNET data was used. The result was subjected to statistical analysis using their corresponding RMSE to recommend the most appropriate model for processing CORS data over Nigeria. HAMTIDE OTM performed best with a RMSE range of 0.6mm to 1.43mm followed closely by GOT00.2 OTM with RMSE range of 0.6mm to 1.46mm. FES2014b had a RMSE range of 0.74 mm to 1.52 mm. FES2004 had a RMSE range of 0.76 mm to 1.69 mm. FES2012 OTM showed the least performance with a RMSE range of 3.96mm to 7.09mm. It was concluded that HAMTIDE OTM and GOT00.2 OTM are the most preferable for GNSS data processing over Nigeria.

Keywords: Ocean Tide loading, Ocean Tide Models, CORS, GNSS, NIGNET

1.0 Introduction

A Global Navigation Satellite System (GNSS) consists of a constellation of satellites revolving (orbiting) around the Earth, constantly transmitting signals that provide the users with their three-dimensional (3D) positions globally. For several years, US Global Positioning System (GPS) was the only fully operational GNSS system [1]. In December 2011, the Russian GLObal NAvigation Satellite System (GLONASS) was reinstated to full operation. The Chinese BEIDOU and European GALILEO systems are currently under development, notwithstanding BEIDOU commenced preliminary operating service (Phase II) in December 2011. The principle of GNSS positioning is based on solving a fundamental geometric problem, consisting of the distances (pseudo-ranges) of points on Earth to a group of at least four (4) GNSS satellites with well-known coordinates. The ranges and coordinates of satellites are computed by the user's receiver using navigation data and signals transmitted by the satellites; the determined coordinates can be computed to an accuracy of several meters. Nonetheless, centimetre-level positioning is feasible and realizable using more advanced techniques [2].

Ocean tides imply mass movements on a global scale and whence the relative locations of the mass centre of the solid earth and that of the ocean are subject to temporal variations. Assuming that only the solid earth (and unless expressly noted otherwise: jointly the core) counterbalance the oceanic mass dislocation in order to maintain a uniformly moving centre of gravity of the entire planet, the offset of the solid earth mass centre from the Joint mass centre due to ocean tides can be readily computed [3].McCarthy [4] gave the formula for the ocean loading displacement as:

$$\Delta c = \sum_j f_j A_{cj} \cos(\omega_j t + \chi_j + u_j - \Phi_{cj}) \qquad (1)$$

The summation over j represents eleven tidal waves traditionally designated as semi diurnal (M_2, S_2, N_2, K_2) diurnal (K_1,O_1,P_1) and long periodic (M_f, M_m, S_{sa}). The symbols w_j and x_j reflect the position of the sun and the moon. F_j and u_j depend on the longitude of the lunar node. The station specific amplitudes (A_{cj}) and phases (ϕ_{cj}) can be computed using ocean tide models and coastal outline data. The International Earth Rotation Service (IERS) makes these values available for most International Terrestrial Reference Frame (ITRF) stations. Typically the M_2 loading deformations are largest, but they do not exceed 5cm in the vertical and 2cm in the horizontal [5]

Ocean tide models are the various algorithms built and established to minimize the displacements due to ocean tide loading, these are classified as global and local ocean tide models. One of reactions for change of the Earth's gravity potential field due to orbital motions of celestial bodies is ocean tide. The most significant influence is generated by the Moon and the Sun. The tides are strongly influenced by local factors and thus tide models are based on grids covering the ocean surface [6].Ocean Tide Loading (OTL) is generated by tidal ocean mass distribution variations. It can be calculated as a convolution of the ocean tides model with point surface load, which in turn can be described by Green function [7]. Integration over global ocean results in final displacement of a particular point due to the ocean tides.

The analysis of precise altimetric measurements from TOPEX/POSEIDON as well as parallel developments in numerical tidal modelling and data assimilation has led to the development of several global ocean tide models since1994 [8]. However, time variable deformation of the Earth caused by ocean tides could reach up to 100 mm at some special coast regions hence, with the increasing demands for high precision geodetic observations, ocean tidal loading (OTL) correction is essential in precise GNSS data processing with baseline lengths of up to several thousand kilometres [9]. Hitherto, the ocean loading service provides many ocean tide models (OTMs) and geodetic users could easily implement OTL corrections by introducing global grid or station list files for different OTMs. The accuracy of the OTL values depend on the errors in the OTM, Green's function, coastline representation as well as the numerical scheme of the loading computation itself [6, 9]. The most popular GNSS scientific processing softwares are the BERNESE, GIPSY/OASIS and GAMIT. Interestingly, each of these softwares has a number of the OTMs incorporated for GNSS data analysis. However, various models perform differently in different regions of the world; hence, there is the need to investigate the regional performance of these models. Nigeria has a long coast line of about 853 km; some stations of NIGNET are located in this coastal environment. It is then imperative to identify an appropriate model that could be used for processing CORS data over Nigeria [10]. A detail discussion on the distribution and spread of the Nigerian CORS can be found in Naibbi and Ibrahim [11].This paper therefore, examines the effects of various OTM on the accuracy of data processing over the NIGNET CORS with a view to identifying an appropriate ocean tide model (OTM) for processing CORS data over Nigeria.

2.0 Materials and Methods

The CORS data over Nigeria are usually accessible from the NIGNET website via www.nignet.net. However, during the course of this study, the website was not available for data download. Consequently, archived NIGNET GPS data of October 2011 was utilised for this study. Figure 1 depicts the map of Nigeria and the location of NIGNET CORS.

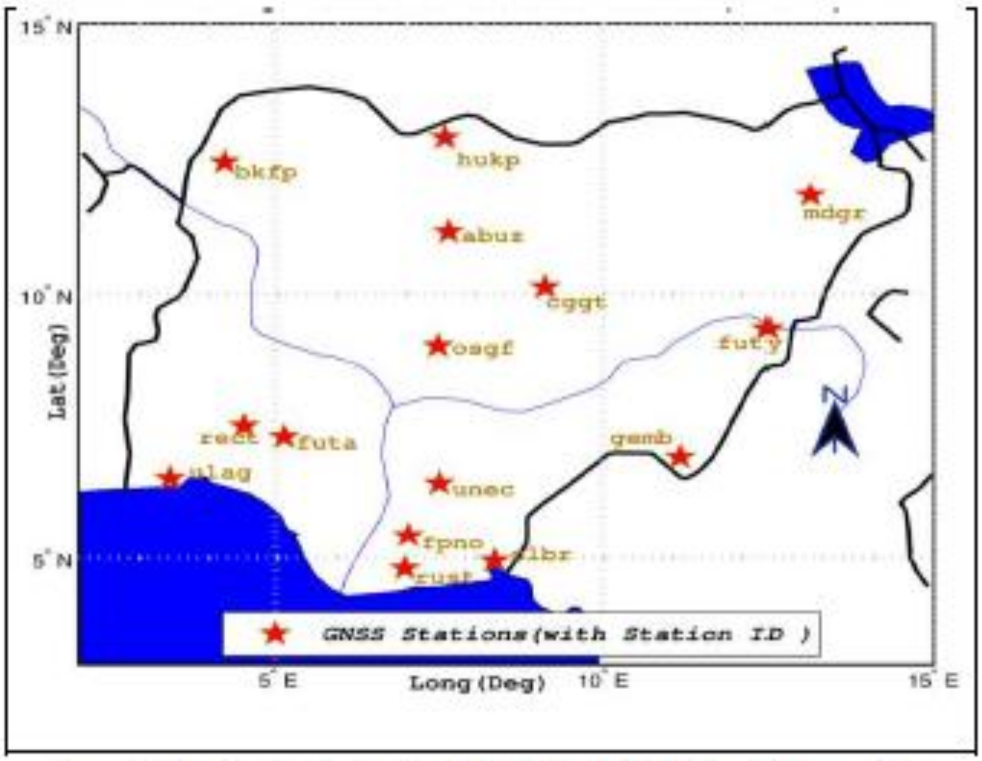

Figure 1: Map depicting the location of NIGNET CORS in Nigeria (Source: [12])

The Cartesian and geodetic coordinates of these NIGNET CORS have been provided in Adebomehin [13]. However, due to data incompleteness, stations CLBR and GEMB were not included in this study. Besides the acquisition of the NIGNET data, the need for IGS CORS data of the corresponding period of the year 2011 is highly imperative for the network adjustment and baseline formation during the data processing. The IGS CORS data was downloaded from the IGS website using *RTKLIB 2.4.2* software, the selected IGS CORS are described in Table 1.

Table 1: The list of the Three (3) selected IGS CORS

S/No.	IGS CORS ID	Geographical Locations
1	DAKR	Senegal
2	NKLG	Gabon
3	BJCO	Benin

(Source: http://www.igs.org/)

Figure 2 shows the distribution of IGS stations with the selected IGS stations highlighted in black colour.

Figure 2: The IGS CORS distribution in Africa showing the three selected IGS CORS in black colour (Source: http://www.igs.org/)

The ocean loading parameters were acquired from the Onsala Space Observatory website (http://holt.oso.chalmers.se/~loading). As discussed earlier, five ocean tide models were selected for this study based on their popularity and recency, they are GOT00.2, FES2004, FES2012 FES2014b and HAMTIDE.

The NIGNET GPS CORS data was processed using the Bernese GPS processing software version 5.0.Thus, the RINEX observation files were renamed in accordance with Bernese format, while necessary satellite orbit files and models were downloaded from Bernese website. The parameter settings and models for the processing strategy are detailed in Table 2.

Table 2: Parameter settings and models for the data processing strategy

Parameters	**Processing Strategy**
Network design	OBS-MAX.
Elevation cut-off angle	15°.
Weighting of GPS observations	Cos^2 (z); z = zenith angle.
Sampling rate	30-180s.
Orbits/EOP	IGS final Orbit and Earth Orientation parameters (EOP).
Station coordinates	Tightly constrained to the ITRF2008 reference frame.
Absolute antenna phase centre corrections	PHAS COD.I08, SATELLIT.I08.
Ocean loading model	Varying: GOT00.2, FES2004, FES2012, FES2014 band HAMTIDE.
Ionosphere	Double-difference ionospheric-free (IF) linear combination.
Ambiguity resolution	Fixed solution, resolved using QIF strategy.
Ionosphere model for ambiguity fixing	Global ionosphere model from CODE.
Gradient estimation	Horizontal gradient parameters: tilting at 24hrs interval.
A-priori model	A-priori Saastamoinen hydrostatic model with dry Neill mapping function.
Mapping function	Wet-Neill mapping function (1hr interval).
Relative troposphere constraints	Loose.
ZPD estimates	Hourly (1hr).

The OTMs were used in the processing of the CORS data by varying them while other factors and inputs remained constant. Thus, using the constant values for the a-priori coordinates, the station coordinate were estimated hourly yielding 24 estimates per day; the data was reprocessed five times using the five models examined in this study. The effects of varying the ocean tide models on the station coordinates was assessed using the root mean square errors (RMSE).

3.0 Results

In order to assess the effect of each model on the estimated station coordinates, the root mean square errors and the mean difference in coordinates using the a-priori coordinates as reference were derived as summarised in Table 3 to 7.The mean errors and the RMS errors derived fromGOT0 0.2 OTM are shown in Table 3.

Table 3: Mean errors and RMSE from GOT0 0.2 Ocean Tide Model

Station name	Type	Diff in Coord: Estimated Coord -A priori Coord (m)	RMS error (m)
ABUZ	X	-0.00024	0.001336667
	Y	0.000296667	0.00106
	Z	-0.000566667	0.000696667
BKFP	X	-0.000216667	0.001376667
	Y	0.00028	0.00108
	Z	-0.00055	0.000706667
CGGT	X	-0.000192857	0.001407143
	Y	0.000246429	0.001178571
	Z	-0.000525	0.000796429
FUTY	X	-0.00028	0.00135
	Y	0.0003	0.001076667
	Z	-0.000586667	0.000693333
MDGR	X	-0.000214815	0.00142963
	Y	0.000292593	0.001137037
	Z	-0.000551852	0.000737037
OSGF	X	-0.000253333	0.001293333
	Y	0.00029	0.00105

	Z	-0.0006	0.000683333
ULAG	X	-0.000336667	0.00135
	Y	0.000303333	0.00105
	Z	-0.000613333	0.000683333
UNEC	X	-0.000336667	0.0013
	Y	0.000303333	0.001053333
	Z	-0.000616667	0.000683333

From Table 3, the minimum and maximum RMS errors are 0.000683333m and 0.001463333mrespectively. Hence, the model error is within 0.68mm and 1.46mm limit of accuracy. As regardsFES2004 OTM, the mean errors and the RMS errors are depicted in Table 4.

Table 4: Mean errors and RMSE from FES2004 OTM

Station name	Type	Diff in Coord: Estimated Coord - A priori Coord (m)	RMS error (m)
ABUZ	X	-0.00060333	0.00151
	Y	0.00018667	0.00125
	Z	-0.0009	0.000816667
BKFP	X	-0.00057333	0.001553333
	Y	0.00016333	0.001276667
	Z	-0.00087667	0.000833333
CGGT	X	-0.00056429	0.0016
	Y	0.00013214	0.001392857
	Z	-0.000875	0.000928571
FUTY	X	-0.00071111	0.001688889
	Y	0.00021852	0.001407407
	Z	-0.00102593	0.000903704
MDGR	X	-0.00073704	0.001633333
	Y	0.00022222	0.001366667

	Z	-0.00094074	0.00087037
OSGF	X	-0.00062	0.00147
	Y	0.00018	0.00124
	Z	-0.00093667	0.0008
ULAG	X	-0.00072	0.001516667
	Y	0.00018	0.001243333
	Z	-0.00096333	0.000803333
UNEC	X		0.001386667
	Y	0.01683667	0.00118
	Z		0.00076

From Table 4, the minimum and maximum RMS errors from FES2004 OTM are 0.00076m and 0.001688889mrespectively which suggests that the model is within the accuracy limit of 0.76mm and 1.69mm. Meanwhile, the mean errors and the RMSE from Finite Element Solution (FES) 2012 Ocean Tide Model are presented in Table 5.

Table 5: Mean errors and RMSE from FES2012

Station name	Type	Diff in Coord: Estimated Coord - A priori Coord (m)	RMS error (m)
ABUZ	X	-0.00972414	0.006089655
	Y	-0.00263793	0.006493103
	Z	-0.00976897	0.004110345
BKFP	X	-0.00965172	0.006234483
BKFP	Y	-0.00281379	0.006593103
BKFP	Z	-0.00966897	0.004155172
CGGT	X	-0.0088	0.00662963
	Y	-0.00245185	0.007085185
	Z	-0.00931852	0.004551852
FUTY	X	-0.00935667	0.005913333

	Y	-0.00232	0.006333333
	Z	-0.00955333	0.00396
MDGR	X	-0.00946538	0.0065
	Y	-0.00240769	0.006930769
	Z	-0.00964615	0.004380769
OSGF	X	-0.00981379	0.006041379
	Y	-0.00263103	0.00647931
	Z	-0.00997586	0.004089655
ULAG	X	-0.01028621	0.0061
	Y	-0.0028	0.006482759
	Z	-0.01027241	0.004082759
UNEC	X	-0.00995862	0.006062069
	Y	-0.00257586	0.006486207
	Z	-0.01017931	0.00407931

The minimum and maximum RMS errors from FES2012 OTM are 0.00396m and 0.007085m respectively (Table 6) which suggests that the model is within the accuracy limit of 3.96mm and 7.09mm.In the case of Finite Element Solution (FES) 2014b Ocean Tide Model, the mean errors and the RMSE are displayed in Table 6.

Table 6: Mean errors and RMSE from FES2014b

Station name	Type	Diff in Coord: Estimated Coord - A priori Coord (m)	RMS error (m)
ABUZ	X	0.0284633	0.00139
	Y	0.03864	0.00111
	Z	0.0187167	0.00075
BKFP	X	-0.0251633	0.00144
	Y	0.0290433	0.001136667
	Z	0.0264933	0.000766667
CGGT	X	0.0121857	0.001478571
	Y	0.0170786	0.001239286
	Z	-0.0432714	0.000853571
FUTY	X	-0.0745033	0.00141
	Y	-0.04195	0.00113
	Z	-0.0084867	0.00075
MDGR	X	0.011075	0.001485714
	Y	-0.0589679	0.001192857
	Z	-0.0041143	0.000789286
OSGF	X	0.08684	0.00136
	Y	0.0002367	0.001103333
	Z	0.0019167	0.000743333
ULAG	X	0.0235767	0.001403333
	Y	-0.0098367	0.001113333
	Z	0.0025767	0.00074
UNEC	X	-0.0953867	0.001366667
	Y	-0.00075	0.00111
	Z	-0.0208833	0.00074

The minimum and maximum RMS errors from FES2014b OTM are 0.00074m and 0.00152m respectively (Table 6) which suggests that the model is within the accuracy limit of 0.74mm and 1.52mm.The summary of errors from the HAMTIDE Ocean Tide Model is depicted in Table 7.

Table 7: Mean errors and RMSE from HAMTIDE OTM

Station name	Type	Diff in Coord: Estimated Coord - A priori Coord (m)	RMS error (m)
ABUZ	X	-0.00023	0.001336667
	Y	0.000293	0.001056667
	Z	-0.00057	0.000696667
BKFP	X	-0.00021	0.00138
	Y	0.00029	0.00108
	Z	-0.00055	0.000706667
CGGT	X	-0.0002	0.001410714
	Y	0.000239	0.001175
	Z	-0.00052	0.000796429
FUTY	X	-0.00027	0.00135
	Y	0.00031	0.00108
	Z	-0.00058	0.000696667
MDGR			
	Y	0.000296	0.001137037
	Z	-0.00056	0.000737037
OSGF	X	-0.00026	0.001296667
	Y	0.000293	0.00105
	Z	-0.0006	0.000686667
ULAG	X	-0.00033	0.001346667
	Y	0.0003	0.00105
	Z	-0.00062	0.000683333
UNEC	X	-0.00034	0.001306667
	Y	0.000307	0.001053333
	Z	-0.00062	0.000686667

The minimum and maximum RMS errors from HAMTIDE OTM are 0.000683333m and 0.001410714m respectively (Table 6) which suggests that the model is within the accuracy limit of 0.68mm and 1.41mm.

4.0 Discussion of Results

For the purpose of analysis, the OTMs are classified into old and recent models as depicted in Table 8 which presents the summary of the range of RMSE from the five OTMs.

Table 8: The summary of RMSE range from the five OTMs

TYPE	OCEAN TIDE MODEL	RMSE Range
OLD OTMs	GOT00.2	0.68 mm to 1.46 mm
	FES2004	0.76 mm to 1.69 mm
RECENT OTMs	FES2012	3.96 mm to 7.09 mm
	FES2014b	0.74 mm to 1.52 mm
	HAMTIDE	0.68 mm to 1.41 mm

From the results, it was found that the HAMTIDE OTM performed better than the rest ocean tide models. It is evident in Table 8 that among the three most recent ocean tide models, HAMTIDE OTM performs better followed by FES2014b while GOT00.2 OTM showed better performance amongst the old OTMs. The FES2012 has the worst performance having minimum and maximum errors of 3.96mm and 7.09mm respectively in the estimated coordinate. Such error is considered significant in precise geodetic positioning because conventionally, the acceptable limit of a-posteriori RMS error in GNSS data processing is about 1.0 mm to 1.5 mm. In order to better appreciate the magnitude of errors from each OTM, the RMSE from the five ocean tide models were plotted as depicted in Figure 3.

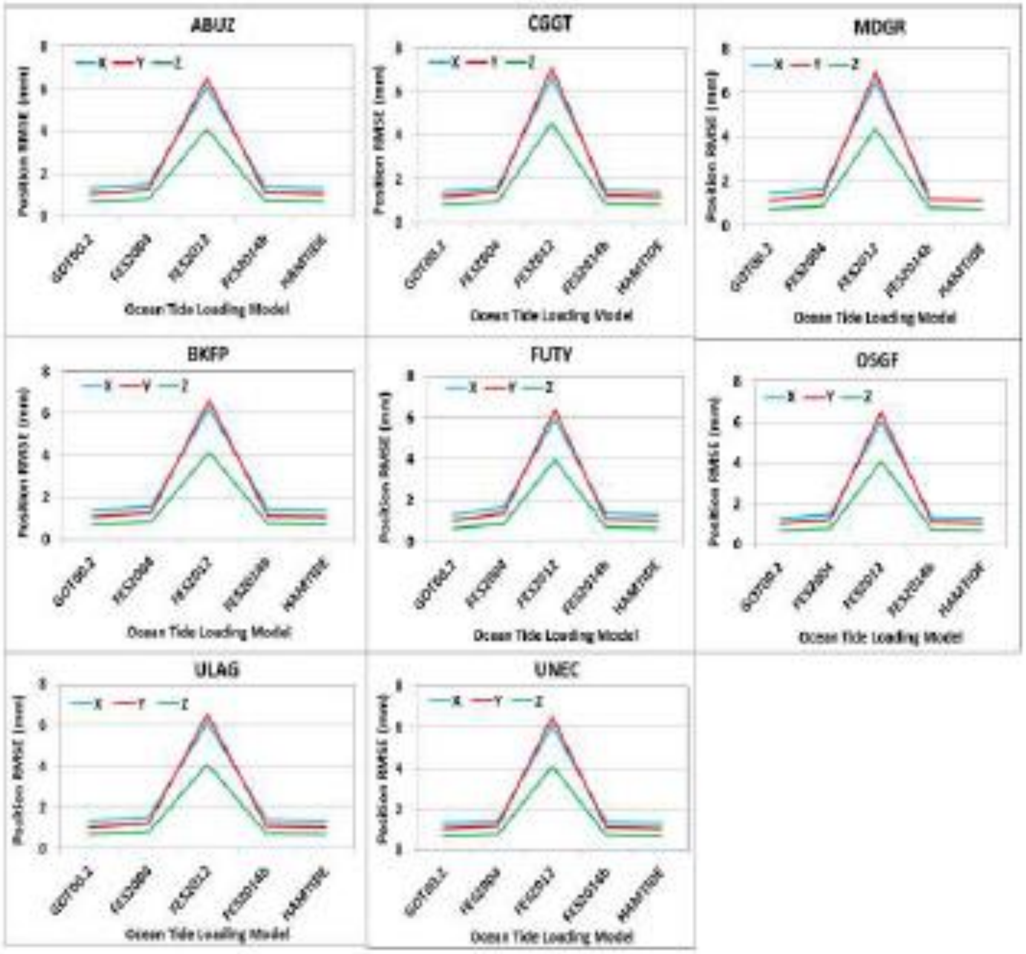

Figure 3: The magnitude of the position RMSE from the five OTMs.

It can also be seen from Figure 3 that FES2012 OTM has the highest positional errors at all the stations. Nevertheless, it is expected that errors arising from OTL should propagate more in the coastal/near coastal stations like ULAG in University of Lagos and UNEC in University of Nigeria Enugu Campus than the northerly lying stations. Conversely, the greatest errors were observed at stations CGGT in Toro, Bauchi State and MDGR in Maiduguri, Borno State which are among the stations in the northern region, this required further investigation to draw a reliable conclusion. The trend of the models RMSE in XYZ coordinate over the NIGNET CORS is shown in Figure 4.

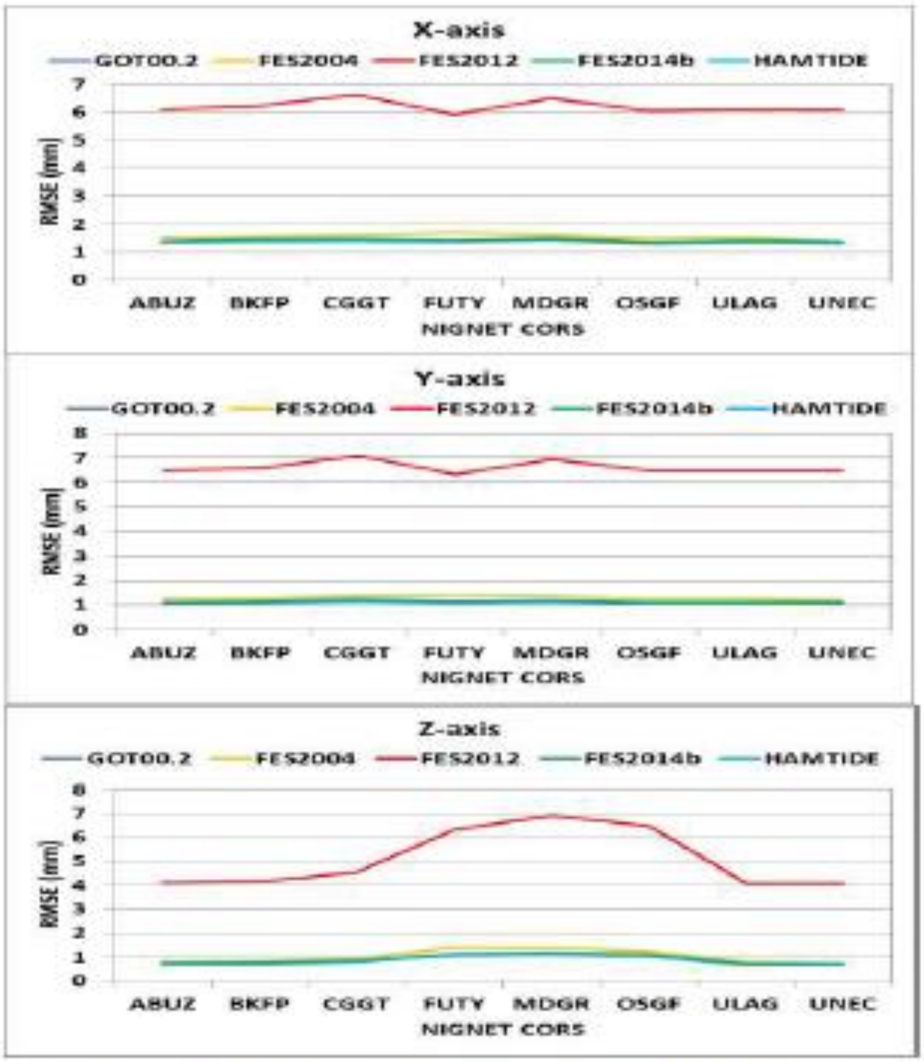

Figure 4: The trend of the five OTMs in XYZ-axes at the NIGNET CORS

Figure 4 is the trend of error from each of the five ocean tide models in station coordinate. The weakness of FES2012 OTM is also glaringly discernible from the figure; the poor performance may be due to the incompatibility of the Nigerian coastline representation with the model. The results suggests that HAMTIDE and GOT00.2 OTMs with the RMSE range of 0.68 mm to 1.43 mm and 0.68mm to 1.46mm respectively are the most preferred OTL models for processing GNSS data over Nigeria followed closely by FES2014b and FES2004 models respectively.

5.0 Conclusion

The Continuous Operating Reference Stations of Nigeria are subject to movements due to the loading of the lithosphere by ocean tides. Using a month (October, 2011) of continuous GPS data, this research examined the effects of various ocean loading models on the accuracy of data processing over the CORS across the Federation. Theoretical ocean loading displacements were based on the five selected OTM available for download in Onsala Space Observatory (http://holt.oso.chalmers.se/loading/).

The ocean tide models were then subsequently used for processing the campaign data in the Bernese GPS software 5.0. While changing the ocean tide model employed for the processing, other factors such as tropospheric model and other input options remained constant. This was done so as to see the variation that exists between the a priori coordinates and the estimated coordinates.

The results of different OTM were subjected to statistical analyses using the RMSE. It was found that the HAMTIDE and GOT00.2 OTM are the most preferable ocean tide model for GNSS data processing over Nigeria CORS with the RMSE range of 0.68mm to 1.41mm and 0.68mm to 1.46mm respectively. Since this study utilised one month data, long term data analysis could lead to a robust judgement on the performance of various ocean tide models over Nigeria CORS; this should consider recent GPS data.

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