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VALIDATION OF THE NIGERIAN CRUSTAL MOTIONS USING GNSS TECHNOLOGY

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Abstract

The Continental Drift Theory upholds that the land masses (tectonic plates) of the earth are in motion. These motions have been traced to the activities in the earth mantle. Nigeria is situated at the interior part of the Nubia Plate. Several research efforts have been made to depict the direction of the motions of Nigeria. Two of the recent efforts carried out in 2018: Bawa *et al* and Ayodele *et al*, appear to be contradicting each other. This paper investigates the rate of the Nigerian crustal motions as a way of validating which of the results is accurate. Data from the Nigerian NIGNET Stations were obtained and analyzed using the GAMIT/GlobK Software adopting ten IGS Stations as control stations while ensuring geometric balance. The mean horizontal velocity of the Nigerian Region of the Nubia Plate was found to be 22.5625±0.32583mm/yr East, 18.93±0.23417mm/yr North. This indicated a general North East motion which agrees with Bawa *et al*'s result and disagrees with Ayodele *et al*'s. It was observed that either the methodology and/or the data used by Ayodele *et al* was either faulty and/or erroneous.

Keywords: CORS, Crustal Motions, Velocity of Earth Motions, GAMIT/GlobK

Introduction

Crustal motions, which used to be a very contentious issue few years ago, have been seen to be as true as day and night. It has been closely connected to the Continental Drift Theory. Between late nineteenth and early twentieth century, this theory was largely argued against. One name that was found to reoccur each time the continental drift theory is mentioned is Alfred Wegener, a German Meteorologist, who was strongly opposed mostly by the German Geologists (Brown, 2016). Although Wegener was not the originator of the Continental Drift Theory, he re-proposed, championed the theory and even died in November, 1930, on the Greenland Inland Ice, in the process of defending the theory (Ingolfsson, 2008).

Further findings following activities before, during and after the Second World War, provided sound proofs to the validity of the cause of crustal motions (Ingolfsson, 2008). The concept of Sea-Floor Spreading, developed by Hess (1962), and the discovery of Mid-Ocean Ridges led the Canadian, J. Tuzo Wilson, in 1965 to offer a fundamental reinterpretation of Wegener's continental drift theory. Tuzo became the first person to use the term 'plates' to describe the division and pattern of relative movement between different regions of the Earth's surface. He also proposed a tectonic cycle (the Wilson cycle) to describe the lifespan of an ocean basin: from its initial opening, through its widening, shrinking and final closure through a continent-continent collision (McGregor (2018), Ingolfsson (2008), and Brown (2016)).

The African Tectonic Plate is the Nubian Plate. This plate, as shown in McGregor (2018)'s Map of the World with Tectonic Information

(Figure 1), has lots of tectonic hotspots and volcanic locations. The West African region of the map indicates volcanic locations in the Cameroon and tectonic hotspots in Nigeria and Cameroon. This begs for a geodetic investigation as a fundamental approach to understanding and possibly predicting tectonic activities (earthquakes and tremors) due to crustal motions. Nigeria, in West Africa, lies on the eastern flank of the Atlantic Ocean, and since Jurassic times, the Atlantic Ocean margins have been opening consistently. Unlike the Pacific Ocean margins, a typical example of a Convergent Plate Boundaries, which are characterized by subduction tectonics and occurrence of devastating earthquakes, the Atlantic Ocean margins, a Divergent Plate Boundary, are generally thought to be quiet (aseismic).

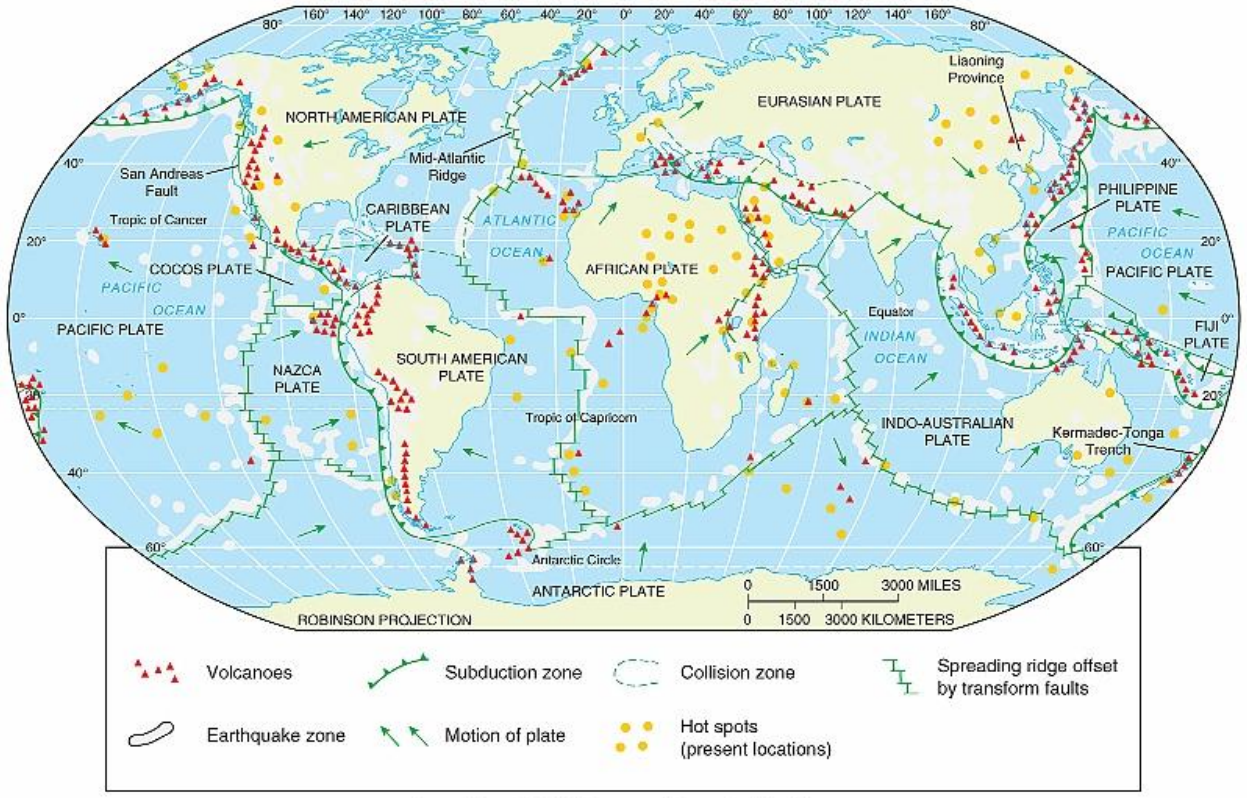


Figure 1: Map of the world, showing the Tectonic Plates and other Tectonic Information
Source: McGregor (2018)

However, earthquakes have been reported in some countries in the west coast of Africa that border the Atlantic Ocean (Akpan and Yakubu, 2010). The records from Earthquake Track (2018) indicate that the West African region is not "aseismic" as previously believed. Afegbua (cited in Orakpo, 2017) documented that the recent trend of earthquakes/tremors in Nigeria is an indication that seismic activities within the country are increasing and urgent measures need to be adopted to avert devastating consequences of big earthquakes in the country.

Researchers like Afegbua (cited in Orakpo, 2017); Eze *et al*. (2012); Tsalha *et al*. (2015); Afegbua *et al*. (2011) and Akpan and Yakubu (2010) have made several efforts to look at Earthquakes and Tremors that happened in Nigeria from 1933 to date, and have recorded over 35. The availability of few GPS CORS stations in the country affords the geodesist the capability of assessing the crustal motions of

the country. The NigNet CORS were used in the two experiments of 2018. Bawa, Ojigi and Dodo (2018) evaluated the Velocities of the NigNet CORS as a means of evaluating the Crustal Motion of the country and at the same time Ayodele *et al* (2018) investigated the same velocities. This paper seeks to investigate and validate which of the two experiment is correct. This is owing to the fact that while Bawa *et al* (2018) is indicating a general North East direction, Ayodele *et al* (2018) indicated a general North West direction of motion. This validation will clear the contradiction and strengthen the one that is found to be the true direction of Nigeria and by extension the Nubia Plate.

Materials and Methods.

Bawa, Ojigi and Dodo (2018), analyzed the velocities of the Nigerian CORS Network (NigNet) using the data from fourteen (14) NigNet stations (ABUZ, BKFP, CGGT, CLBR, FPNO, FUTA, FUTY, GEMB, HUKP, MDGR, OSGF, RUST, ULAG, & UNEC) from 2011 through 2015. They adopted nine (9) International GNSS SERVICE (IGS) Stations (HARB, NKLG, RABT, RBAY, SUTH, CAGZ, MAS1, NOT1 & SFER) as stabilizing stations.

Their findings were found to be consistent with Altamimi et. al. (2011)'s result; and McGregor (2018)'s map (fig. 1) that indicates a general movement in the North-East direction for the Nubia plate. The Velocities of the stations and their respective uncertainties are as shown in Table 1. The average velocity of the Nigerian region in the Noth Direction was found to be 19.24 $\pm$0.14mm/yr and the East direction was found to be 22.09 $\pm$0.19mm/yr.

Table 1: Velocity Field of NigNet CORS in ITRF 2008

Stations	Lat`	Long	Height	Vn	svN	Ve	svE	vU	svU	$\vec{V}_{NE}$ Degree
ABUZ	7.6487	11.1517	705.061	19.4	0.04	21.83	0.05	1.73	0.15	48.37298
BKFP	4.2292	12.4686	250.004	19.1	0.03	22.01	0.05	1.46	0.14	49.04897
CGGT	9.1183	10.1231	916.43	15	0.08	25.22	0.11	-2.51	0.36	59.25725
CLBR	8.3516	4.9503	57.1741	19.8	0.06	22.47	0.08	1.39	0.25	48.61431
FPNO	7.0332	5.43475	88.3109	18.2	0.26	21.17	0.34	3.54	1.14	49.31412
FUTA	5.1364	7.29864	410.585	19.6	0.63	21	0.88	-3.29	2.76	46.97493
FUTY	12.498	9.34974	247.392	19.4	0.03	22.38	0.05	0.22	0.13	49.07977
GEMB	11.184	6.9172	1795.65	19.7	0.27	22.25	0.37	3.63	1.05	48.47854
HUKP	7.5909	12.9212	559.619	18.9	0.09	22.04	0.13	0.26	0.41	49.38586
MDGR	13.131	11.8381	348.235	21.2	0.08	22.24	0.12	0.7	0.34	46.37146
OSGF	7.4863	9.02767	532.643	19.8	0.06	21.97	0.08	2.25	0.25	47.97391
RUST	6.9785	4.80184	45.5741	20.5	0.21	19.69	0.27	0.33	0.89	43.8454
ULAG	3.3976	6.51733	44.5598	19.1	0.07	22.87	0.1	0.4	0.3	50.13288
UNEC	7.505	6.42481	524.395	19.7	0.05	22.14	0.07	0.57	0.2	48.33756

Source: Bawa, Ojigi and Dodo (2018) (Direction ($\vec{V}_{NE}$) computed by the author)

However, Ayodele et. al. (2018) in their evaluation of the NigNet data for the definition of geodetic reference frame does not agree with Altamimi *et. al.* (2011) nor Bawa, Ojigi and Dodo (2018). In their study, seven (7) NigNet stations: ABUZ, BKFP, CLBR, FUTY, OSGF, ULAG and UNEC were used. The Velocities obtained by Ayodele et. al indicates a general North-West motion, hence the azimuths of the motions are between 334.18^o and 340.67^o. The Velocities and directions of the stations obtained by Ayodele et. al. (2018) are shown in Table 2.

It can be seen from the Tables 1 and 2, that the directions of motions for the two studies are not

the same. Whereas Bawa, Ojigi and Dodo (2018)'s direction is North East wards, Ayodele et. al. (2018)'s direction is North West wards.

Table 2: Initial Positions (Cartesian) of the NigNet CORS and their velocities

Station	Easing (m)	Northing (m)	$\bar{V}_X$ (mm/yr)	$\bar{V}_Y$ (mm/yr)	$\|\bar{V}xy\|$ (mm/yr)	$\vec{V}_{XY}$ (degree)
ABUZ	574835.7	792493	-9.4727	21.0113	23.05	335.73
BKFP	201396.6	936320.6	-9.3145	21.9245	23.82	336.98
CLBR	658204	106220.2	-1.4275	13.3896	13.47	353.91
FUTY	1111900.7	601441.7	-10.766	22.2543	24.72	334.18
OSGF	555563.6	557102.9	-7.1715	18.7359	20.06	339.05
ULAG	108918.2	278360	-8.1034	23.1007	24.48	340.67
UNEC	563318.7	268974	-8.8857	22.6624	24.34	338.59

Source: Ayodele *et. al.* (2018)

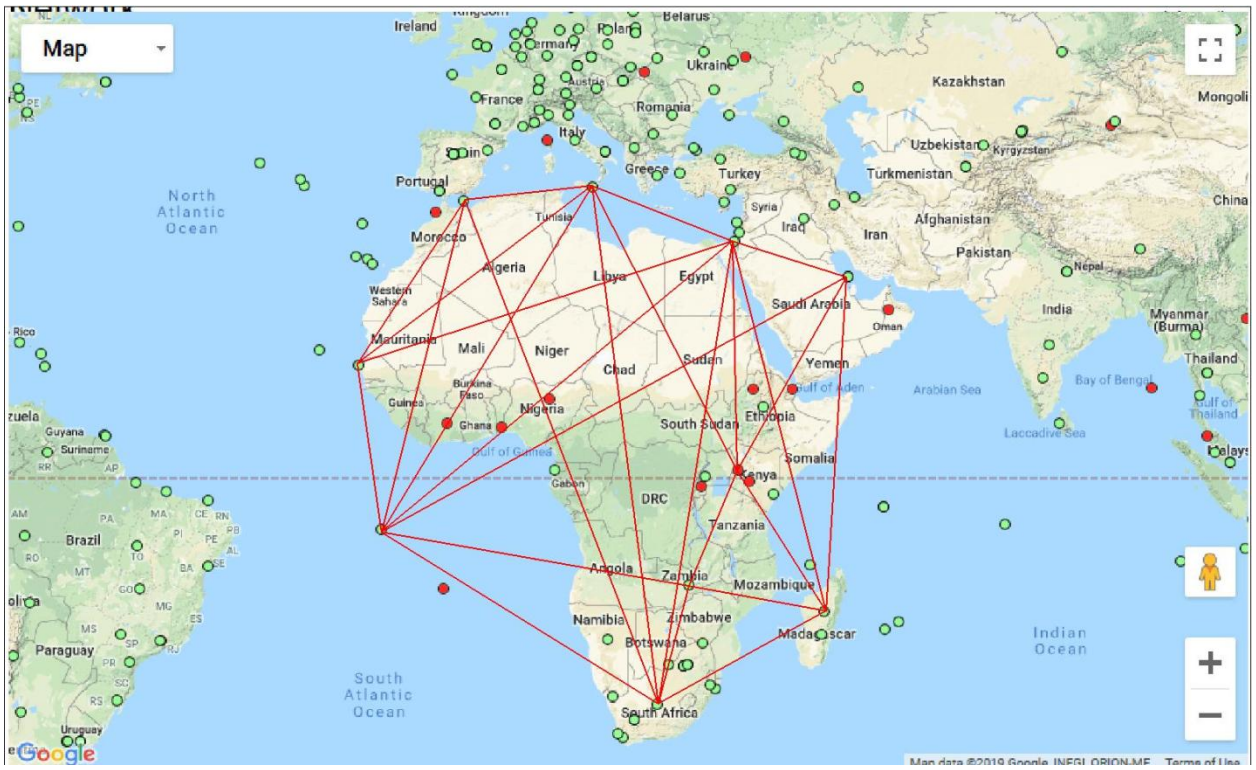


Figure 1: IGS Stations for Stabilization Network
Source: Modified from IGS (2019)

Validation

The RINEX data of fourteen NIGNET CORS were obtained from the Office of the Surveyor General of the Federation (OSGOF). Only data for 2012 through 2014 were provided out of the 2010 through 2016 requested. The available data were used to determine the velocities of the NIGNET Stations using GAMIT/GlobK Software. ITRF 2014 was used as the reference frame for the study. A total of ten (10) IGS stations shown in Table 3 and Figure 1 were adopted for this experiment. The IGS stations were chosen with geometric balance and activeness of the station as the criteria.

The Velocities of the NIGNET Stations from the experiment is as shown in Table 4. It was discovered that the results from MDGR Station were abnormal. This abnormal behavior was

traced to the paucity of log files. It was discovered that for the three years under review, the station only logged for nine (9) days. The station was therefore eliminated from further processes.

Table 3: Stabilization Stations

S/N	IGS Station	Country	Tectonic Plate
1	DEAR	South Africa	NUBIAN
2	ABPO	Madagascar	NUBIAN
3	RAMO	Israel	NUBIAN
4	DARK	Senegal	NUBIAN
5	MELI	Spain	NUBIAN
6	ASCG	Saint Helena, Ascension and Tristan Da Cunha	SOUTH AMERICAN
7	MOIU	Kenya	SOMALI
8	ZAMB	Zambia	NUBIAN
9	NOT1	Italy	EURASIAN
10	BHR4	Bahrain	ARABIAN

Results and Discussion.

The mean horizontal velocity of the Nigerian Region of the Nubia Plate was found to be 22.5625 ± 0.32583mm/yr East, and 18.93 ± 0.23417mm/yr North. For the Up Component, some of the stations were found to be subsiding, while others were experiencing uplift. It is however interesting to note that asides CLBR and FPNO, the other Southern stations UNEC, ULAG, and FUTA are subsiding. On the other hand, all the Northern stations: ABUZ, BKFP, OSGF, GEMB, and HUKP are all uplifting, except for FUTY. Figure 2 indicates the velocity plot of the experiment as plotted with the Generic Mapping Tool (GMT).

Table 4: Summary of Velocity Solutions from GLOBK Ver 5.3

SITE	Long. (deg)	Lat. (deg)	E & N Rate(mm/yr)		E & N Adj. (mm/yr)		E & N ±		RHO	H Rate (mm/yr)	H adj. (mm/yr)	±	$\vec{V}_{XY}$ degree
			E	N	E	N	E	N					
ABUZ_GPS	7.64869	11.15174	21.97	19.19	21.97	19.19	0.12	0.09	-0.008	0.86	0.86	0.41	**45.868**
BKFP_GPS	4.22924	12.46858	21.98	18.39	21.98	18.39	0.13	0.1	-0.016	1.66	1.66	0.45	**54.097**
CGGT_GPS	9.11831	10.1231	28.25	14.06	28.25	14.06	0.24	0.18	0.008	10.72	10.72	0.8	**67.094**
CLBR_GPS	8.35157	4.9503	23.1	19.91	23.1	19.91	0.26	0.19	0.011	0.91	0.91	0.82	**53.659**
FPNO_GPS	7.03324	5.43457	21.31	18.03	21.31	18.03	0.4	0.3	0.005	2.2	2.2	1.35	**56.545**
FUTA_GPS	5.13644	7.29864	21.23	19.87	21.23	19.87	0.92	0.64	0.016	-1.72	-1.72	2.82	**47.656**
FUTY_GPS	12.4978	9.34974	23.16	19.7	23.16	19.7	0.17	0.12	0.004	-0.32	-0.32	0.54	**52.964**
GEMB_GPS	11.18394	6.9172	20.16	20.31	20.16	20.31	0.74	0.53	0.016	2.82	2.82	2.27	**49.895**
HUKP_GPS	7.59091	12.92115	21.6	19.23	21.6	19.23	0.34	0.24	0.016	1.11	1.11	1.11	**46.977**
#MDGR_GPS	13.13100	11.83809	76.94	-40.49	76.94	-40.49	146.4	102.05	-0.016	17.16	17.16	421.14	**-56.939**
OSGF_GPS	7.48634	9.02767	22.31	19.47	22.31	19.47	0.18	0.13	0.008	0.44	0.44	0.58	**54.284**
RUST_GPS	6.97852	4.80184	19.01	6.6	19.01	6.6	0.73	0.56	0.004	14.21	14.21	2.42	**83.266**
ULAG_GPS	3.39762	6.51733	22.99	18.77	22.99	18.77	0.22	0.15	-0.001	-0.57	-0.57	0.67	**55.991**
UNEC_GPS	7.50499	6.42481	22.69	20.23	22.69	20.23	0.19	0.14	0.012	-1.52	-1.52	0.6	**54.200**

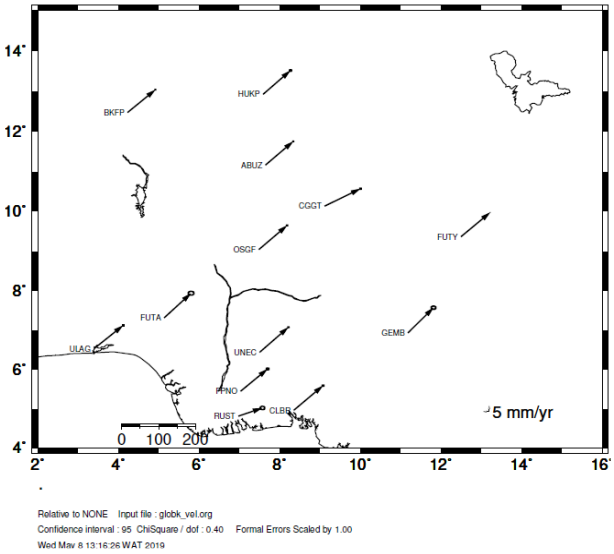


Figure 2: NigNet Velocity Model for 2012 – 2014

Conclusion

It is evident that from the Validation Experiment, the Nigerian crustal motion is in the North East direction. The experiment therefore agrees with Altamimi *et. al.* (2011) and Bawa, Ojigi and Dodo (2018) but disagrees with Ayodele *et al* (2018). It is therefore important to re-evaluate the methodology used by Ayodele *et al* (2018) as it might be faulty or wrong. Another factor that might have contributed to the error might be that the data used is either too few or even erroneous as was discovered in our experiment for the MDGR station.

It is recommended that the volume of data needed for velocity evaluations are at least two and half years (Floyd, 2018) and that special motion software packages such as Gamit/GLOBK, Bernese, GIPSY and a host of others be employed in such evaluations.

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