Chapter 1

Introduction

Nigeria, officially the Federal Republic of Nigeria, is a Federal Constituted Republic comprising 36 states and one Federal Capital Territory, Abuja. The Country is located in West Africa and shares borders with the Republic of Benin in the West, Chad and Cameroon in the East, and Niger Republic in the North. Its coast in the south lies on the Gulf of Guinea on the Atlantic Ocean.

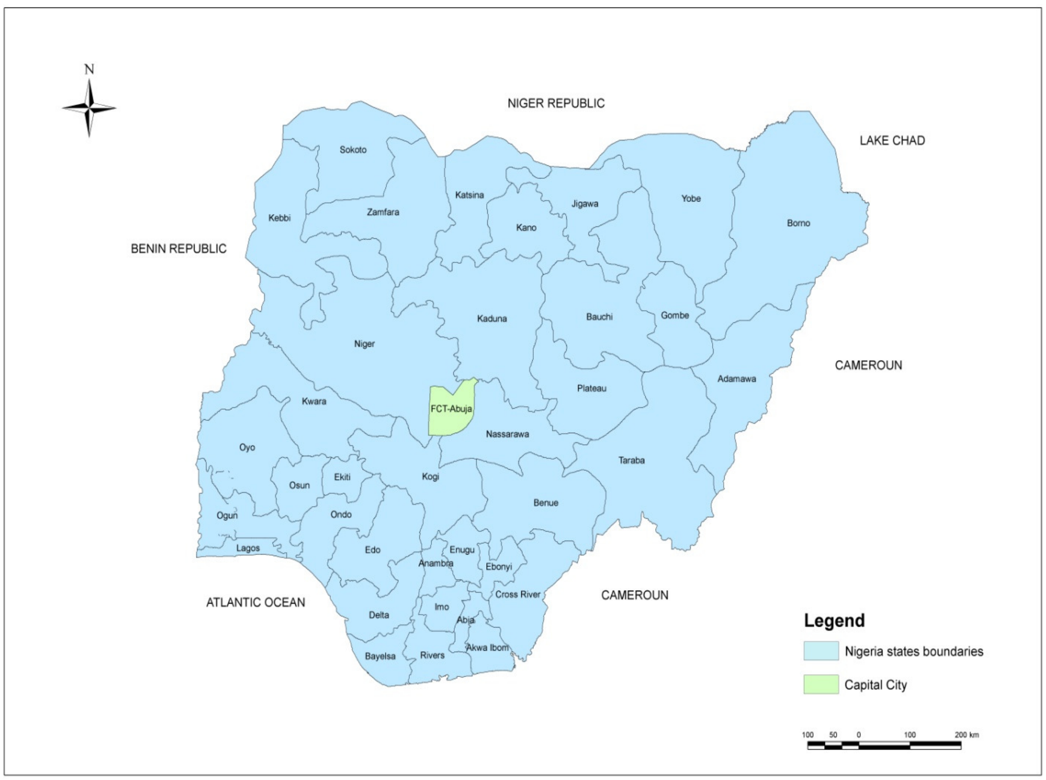

Fig. 1.1: Map of Nigeria Showing the 36 Administrative States Boundaries and Federal Capital City.

In Nigeria, available records have shown of some reported cases of tectonic instability in the past, particularly along the major fault line popularly referred to as Ifewara – Zungeru Megalineament *[Anifowose et al., 2006],* as well as in the coastal region of Nigeria. Detail on this will be presented in section 1.3. The above reason prompted the initiation of this research entitled: Data Quality Assessment of NIGNET Network, in order to ascertain whether the data from the NIGNET Network has the quality for use in geodynamics studies along the areas mentioned above.

NIGNET Network is a project initiated in 2009 by the OSGoF (Office of the Surveyor General of the Federation), which is the National Mapping Agency of Nigeria. The network, formed by state-of-art CORS (Continuously Operating Reference Systems) GNSS (Global Navigation Satellite Systems) equipments, intends to implement the new fiducial geodetic network of Nigeria. NIGNET was established to serve many different applications at both national and international levels; the first motivation for the implementation of the NIGNET was to contribute to the AFREF (African Reference Frame) project in line with the recommendation of the United Nation Economic Commission of Africa (UNECA) through its committee on Development, Information Science and Technology (CODIST), *[Jatau, B.et al., 2010]*. Presently, there are twelve (12) stations that formed the network (Fig.1.2), the network was established with a good geographical distribution. More details on the NIGNET Network will be discuss in section 2.3.

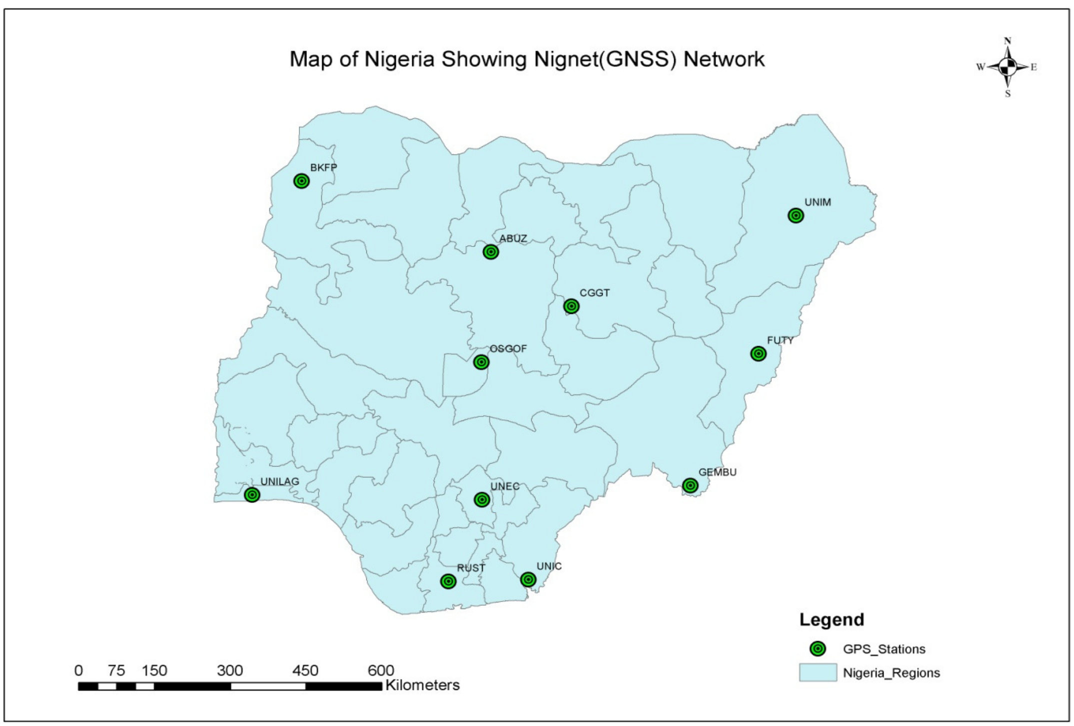

Fig. 1.2 : Map of Nigeria showing NIGNET Network.

The data quality of NIGNET Network will be assessed through GPS solutions; modeling of errors, processing of the Time Series and Time Series Analysing (TSA). This process will aid or assist to prove the certainty of using the data from the Network for geodynamics studies in Nigeria, similar to what is done in other parts of the world.

GPS Observables is satellite navigational observables in ranges which are deduced from the time or phase differences based on a comparison between GPS receiver signals and receiver generated signals. Unlike the terrestrial Electronic Distance Measurements, satellite navigation uses one way concept where two clocks are involved, one in the satellite and the other in the receiver. Thus, the ranges are biased by satellite and receiver clock errors. There are several errors that are associated with the GPS Observables, some of these errors are said to be random while some are not random in nature, and the errors are: Satellite and Receiver clock bias, Satellite and Orbital errors, Multipath errors, Antenna Phase Centre errors, Ionosphere errors, Troposphere errors and Relativistic errors. Modelling of these errors are done with some software packages such as GIPSY-OASIS *[Seeber, 1993],* BERNESE *[Rothacher and Merbart, 1996]* and GAMIT *[King and Bock, 1999]* for processing position coordinates.

Time Series are the values taken by a variable over time (such as daily, weekly, monthly, or yearly and tabulated or plotted in a chronologically ordered numbers or data points. To yield valid statistical inferences, these values are repeatedly measured, often over reasonable number of years. Time series consist of some components: (1) Seasonal variations that repeat over a specific period such as a day, week, month, season, etc, (2) trend variations that move up or down in a reasonably predictable pattern, (3) Cyclical variations that correspond with their own peculiar cycle. Detail description on these will be presented in the subsequent chapters 3 & 4. Figures 1.3a, 1.3b and 1.3c below shows Time Series (TS) of a GPS Station (CGGT) located in Toro, Nigeria which forms part of the NIGNET Network.

Station CGGT Time Series

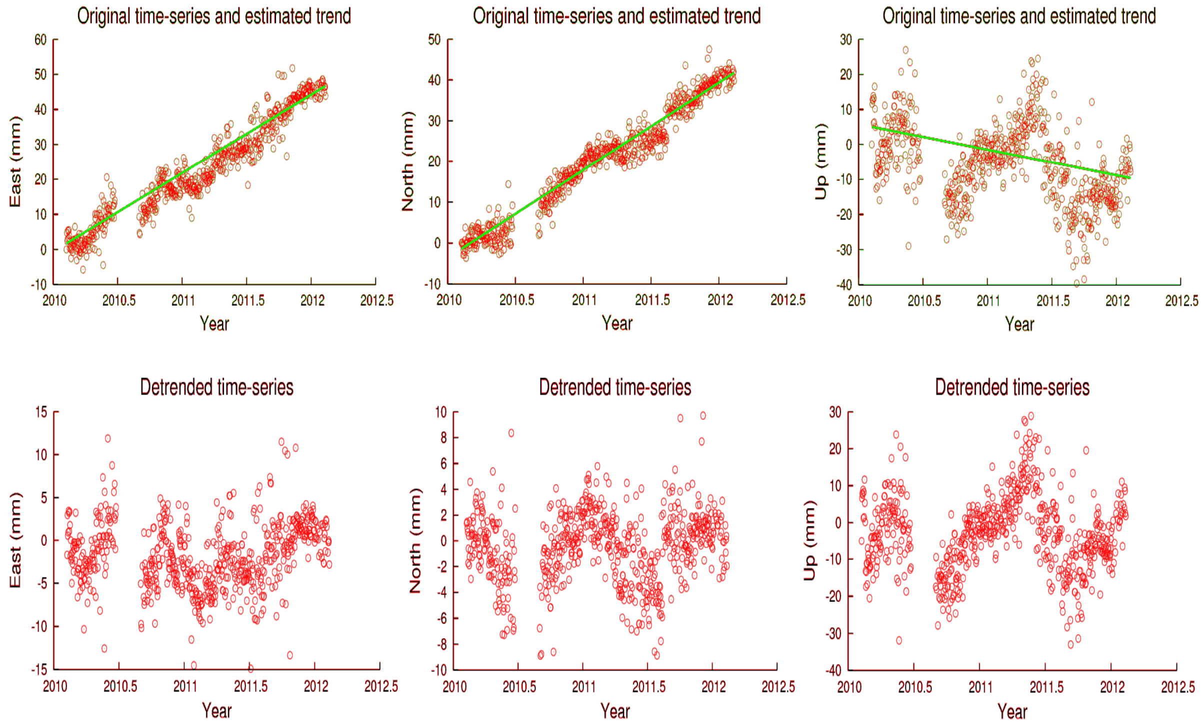

Fig.1.3a, 1.3b and 1.3c above is Time Series of CGGT station which forms part of the NIGNET Network.

Time Series Analysis (TSA) can be described as a trend forecasting (extrapolation) techniques (such as autoregression analysis, exponential smoothing, moving average) based on the assumption that 'the best estimate for tomorrow is the continuation of the yesterday's trend. TSA aims to isolate the sources of variations in a set of data so that their effect on a variable can be determined. *[George E.P. Box et, al.].*

1.1 Objectives

The principal objective of this research project is to assess the data quality of NIGNET Network through the following process(s):

- Process the Time Series (TS) of the NIGNET Network.
- Carry out Time Series Analysis (TSA) on the processed Time Series.
- Computation of the GPS stations velocities and other parameters.
- Computation and comparison of relative estimated motions (with respect to the Nubia plate) of all GNSS stations in the NIGNET network using different tectonic plate models.

1.2 The Geology of Nigeria

Nigeria lies within the mobile belt of Africa and is bordered at the Western part by West Africa craton, and Congo craton at the Southeastern part and Atlantic Ocean at the South. Geologically, (Fig.1.4): The Basement Complex covers about 50% of the total surface of Nigeria. It composed of the following lithostructural units. The Migmatite-Gneiss complex (MGC) has for long been regarded as basement sensu stricto (S.S.) and it is the most widespread of the main rock units in both northwestern and southwestern Nigeria. The various rock types in this complex are exposed in the north central, north eastern, southwestern and a narrow zone parallel to the eastern boundary of the country, east of River Benue. K*ogbe, C. A. [1989].*

The Younger Granite Complexes occupies about 5% of the total surface area of Nigeria. It covers an area of about 8600sq km in central Nigeria and located in N-S rectangular province 400km long and 160 km wide. The complexes concentrated on the Jos Plateau area with few numbers scattered in the north and south of the Plateau extending to Bauchi, Kaduna, Kano, Gombe and Nassarawa states.

Nigeria is underlain by seven major sedimentary basins ranging in age from middle Mesozoic to Recent age. The basins are from Oldest to Youngest: the Calabar flank, the Benue Trough, the Chad Basin, the Sokoto basin (SE Illumeden basin, the Dahomey Basin). The basins are broadly divided into coastal Calabar flank, Niger Delta, Dahomey Basin and interior basins (Benue Trough, Chad Basin, Nupe Basin, SE Iullemmedin Basin). *Kogbe, C. A. [1989].*

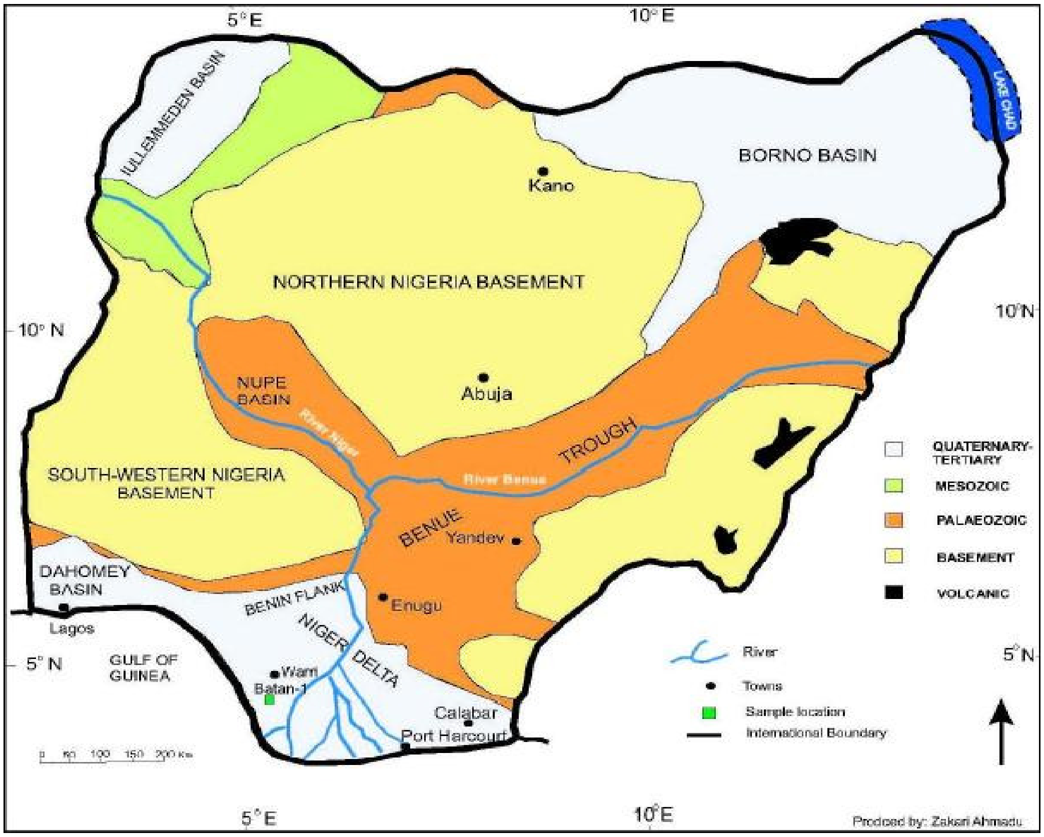

Fig. 1.4**:** Geologic Map of Nigeria *(Source: Enam, et al., 2012)*

1.3 The State of the Art on Geodynamics activities in Nigeria

Even when Nigeria is considered to be stable or a free zone in terms of some natural hazards records have shown of some instability or some events that have occurred in the past. From the results of some investigations carried out by some relevant research organizations and some scientists *[Adepelum A.A. et al,. Nov.2008] and Nwilo, P.C, [1995]*, the reports proves that more research work is needed to be carried out for detail understanding of the geodynamics in Nigeria using various technologies in these areas: The two areas that of great concerned to Nigeria are: The Ifewara – Zungeru Megalineament Fault system and Coastal region of Nigeria.

1.3.1 Ifewara – Zungeru Fault System

Earth tremors have been experienced in some parts of Nigeria since the last century. Documented occurrences were in 1939, 1963, 1984, 1990, and 2000. Recently in years 2004 and 2005*[O.Akpan et al., 2010],* cases of earth tremors were reported near Ijebu Ode and Ibadan in Ogun and Oyo State respectively, similarly, there was also a report at Lupma near Paiko, Minna, Niger state all along the Mega lineament Faults system that cut across Nigeria through the Mid

Atlantic Ocean. From South west to North West Nigeria which is often referred to as Ifewara – Zungeru Fault. See Fig. 1.5 below

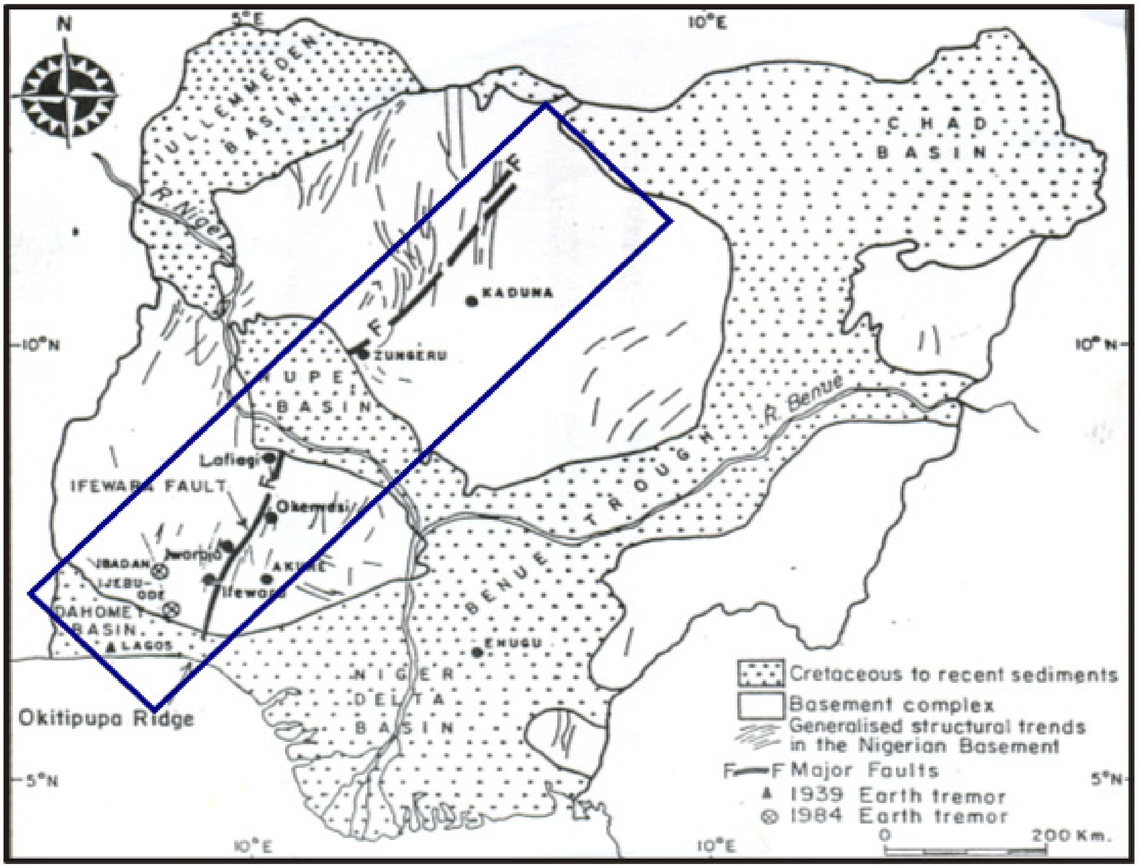

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Fig. 1.5: Generalized Geologic Map of Nigeria showing the Position of Ifewara – Zungeru Megaleament Fault System *[Anifowose et al., 2006]*

1.3.2 Subsidence in Coastal Region of Nigeria

The sedimentary nature of the coastal region of Nigeria contributes to the constant failure of Structures which often results to loss of lives and property. The failure of structures along this region (Niger Delta) is also suspected to be as a result of mass oil exploration activities in this region, the excessive withdrawal of Crude Oil and Gas in this region can lead to Subsidence. Most records of the structural failure can be found in *[Folagbe, 1997] and Nwilo, P.C, [1995].* Below is the Administrative States Map of Nigeria showing some of the coastal states in red code.

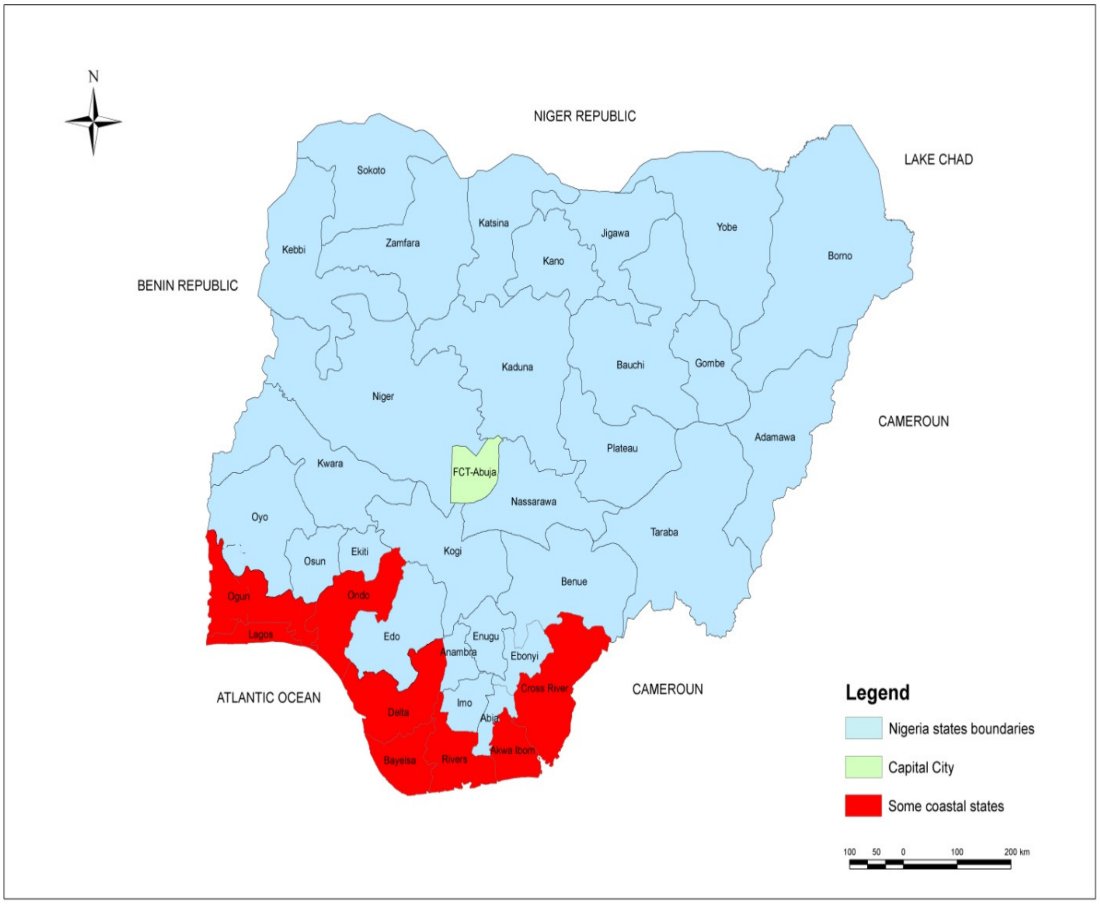


Fig. 1. 6 : Administrative Map of Nigeria showing coastal States in Red

Chapter 2

Methodology

The methodology that was adopted in this research titled *''Data Quality Assessment of the NIGNET Network ''* was by processing and analyzing the Position Time Series of all the GPS stations in the network using GIPSY/OASIS II Software. The full name of the package is GIPSY/OASIS II (GPS Inferred Positioning System/Orbit Analysis and Simulation Software), it is academic software. The main goal of using GIPSY Processing Software in this research was to process the GPS Observables in order to estimates the best values for the parameters of interest which are the receiver positions, satellite orbits by minimizing the discrepancies between the actual observations and their models counterparts in a general least squares approach. To improve the modeling, GIPSY uses a variety of earth and observation models. The GPS positions Time Series computed for all the stations in the NIGNET network were mapped in the ITRF2008 Reference Frame*[Altamimi et al,. 2008].*

2.1 GPS Observables

The idea behind the Global Positioning System (GPS) Observables are the ranges which are deduced from measured time or phase differences based on comparison between received signals and receiver generated signals, unlike the terrestrial Electronic Distance Measuring (EDM) equipment. Global Positioning System (GPS) uses one way concept in which two (2) clocks are involved, one of the clocks in the satellite and the other in the receiver at the user's end. GPS observables is made up of three fundamental quantities Time, Phase, and Range, the observables are stored in receivers' proprietary format called RINEX (Receiver Independent Exchange) format. Basically there are two (2) major types of GPS observables: Pseudorange (Code) Range and Carrier Phase Measurements, see flowchart below:

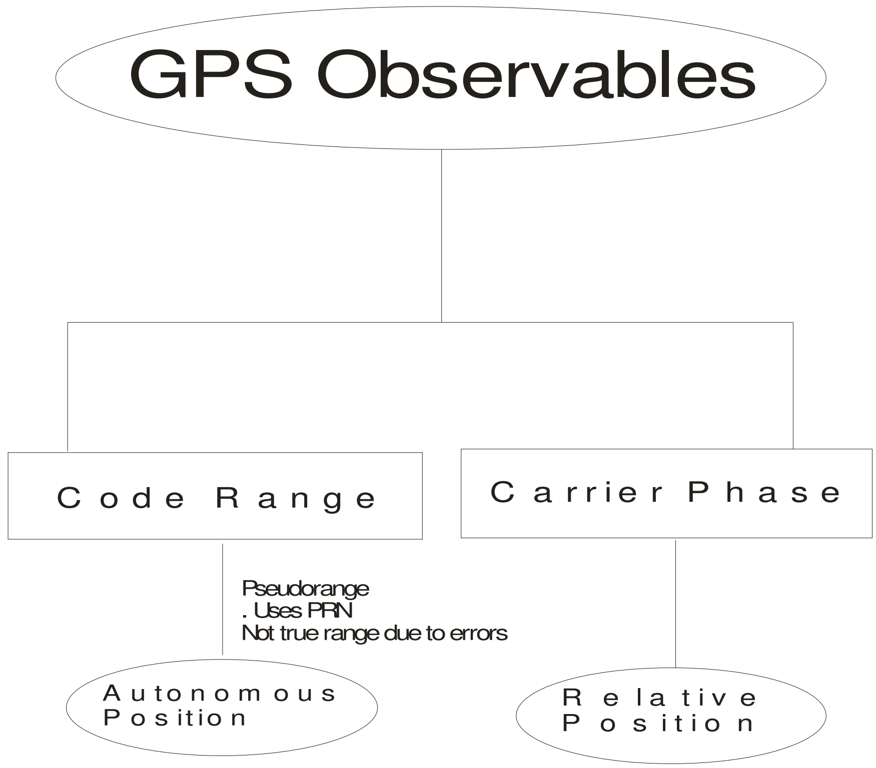


Fig. 2.1: GPS Observables Flow chart

2.1.1 Pseudorange (Code) Measurement

In this measurement, let us consider the sign $t^s(sat)$ time from the satellite clock and sign $t_r(rec)$ reception time referred to the reading from the receiver clock. Remember that the satellite clock $t^s(sat)$ reading is transmitted in the navigation message via pseudorange noise Code. The errors (or biased) of the clocks with respect to a common time system (i.e. the respective system time) are errors or referred to as $\delta^s$and δ_r. The variations between the two (2) clocks readings are equivalent to the shift in time which is represented as Δt.

$$t_r(rec) - t^s(sat) = [t_r + \delta_r] - [t^s + \delta^s] = \Delta t + \Delta\delta. \quad (2.1)$$

t^s on the from equation (2.1) above, it means that two (2) different time systems are involved while t_r and right-hand side refer to the common time system, $\Delta t = t_r - t^s$ and $\Delta\delta = \delta_r - \delta^s$. The errors δ^s of the satellite clock can be modeled if the respective information is transmitted accordingly, e.g by a polynomial with the coefficients being transmitted in the navigational message. Considering that the correction δ^s has been applied. $\Delta\delta$ equal to the receiver clock errors.

When multiplying the time interval $t_r(rec) - t^s(sat)$ of Eq. (2.1), which is affected by the clock errors, by the speed of light c, the code pseudorange is given as:

$$R = c\,[t_r(rec) - t^s(sat)\ ] = c\,\Delta t + c\Delta\delta = \varrho + c\,\Delta\delta \qquad (2.2)$$

Where $\varrho = c\,\Delta t$ has been introduced. The range ϱ is calculated from the true signal travel time. Meaning ϱ corresponds to the distance between the position of the satellite at epoch t^s and the position of the antenna of the receiver at epoch t_r. The two epochs here refers to the common time system. Since ϱ is a function of two different epochs, this is often expanded into Taylor series with respect to, e.g., the emission time.

$$\varrho = \varrho(t^s, t_r\ ) = \varrho(t^s,\ (t^s + \ \Delta t\ )) = \varrho(t^s) + \varrho(t^s)\ \Delta t \qquad (2.3)$$

While ϱ denotes the time derivative of ϱ or the radial velocity of the satellite relative to the receiving antenna. All epochs in eq. (2.3) refers to the same common system time. *[Hoffman and Wellenhof, 2001]*.

2.1.2 Carrier Phase Measurement

Another way of measuring satellite receiver distance is by phase measurements which is consider to be more precise than the Pseudorange, but ambiguous, to fully exploit the phase measurements one must correct for propagation effects. Phase measurement can be converted to a distance by multiplying the wave length, phase can measured to approximate 1% of wavelength with an accuracy of 2mm for L1 and 2.4mm for L2 *[Koslov, et a]*.

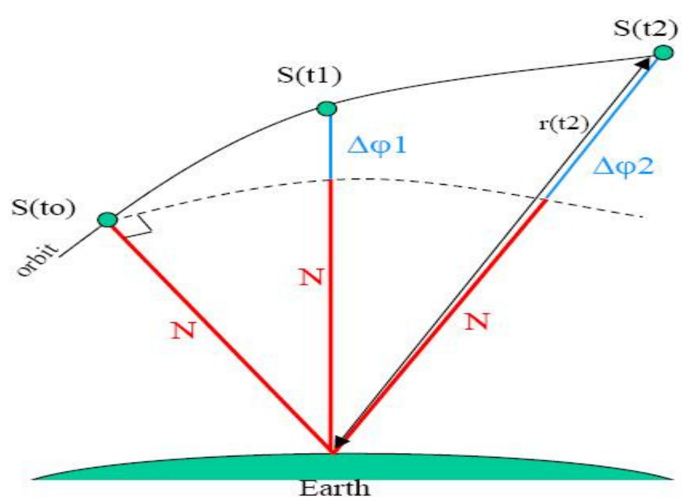


Fig. 2.2: Phase Measurements

Considering when a satellite is locked at (t_0), the GPS receiver starts tracking the incoming phase, it counts the real number of phases as a function of time = $\Delta\varphi(t)$. But the initial number of phases N at t_0 is unknown. However, if no loss of lock, N is constant over an orbit arc. Here the measurement gives relative position.

Note: The time of the measurements mentioned above is the receiver time of the received signals. It is identical for the phase and range measurements and is identical for all satellites observed at that epoch. It is expressed in GPS time (not Universal Time).

2.2 Earth and Observation Models

In order to relate the GPS observables to the parameters by means of the observational model, GIPSY applies several Earth and observation models to the measurements. [*Gregorius*, 1996]. Various types of errors and how they are being mitigated or modeled are discussed below:

2.2.1 Types of Errors and Modeling

It is very important to note that there are several errors that are associated with the GPS Observables, errors such as, satellite and receiver clock bias, satellite orbital errors, multipath errors, antenna phase centre offsets, ionospheric errors, tropospheric errors and relativistic errors, these last errors are specifically for the carrier phase measurements.

- **Satellite and Receiver Clock Bias**

  The satellite clock bias is regarded as a systematic error, which is modeled and transmitted in the navigation message. The receiver clock bias is the differences between the GPS time and the receiver clock time; which is known and can be estimated together with the receiver's position or velocity, with an appropriate linear combination of GPS Observables, both satellite and receiver clock bias can eliminated.

- **Satellite Orbital Errors**

  It is well understood that the broadcast orbital parameters are not perfect so due to this fact they give incorrect satellite location. According to *[Bowen,1986]* the expected contribution of the satellite orbital errors could reach about 2m for 24hrs prediction. The forces, in order of their significance, that contribute to perturbations in the satellite orbit errors are parameterized as: gravity, radiation pressure, atmospheric effects, geoid modeling, solid earth and ocean tides. For detail information about the orbital errors, the reader is referred to the International GPS Service for Geodynamics (IGS). *Website: http://igscb.jpl.nasa.gov.*

- **Multipath Errors**

  Multipath errors are caused as a result of the fact that the signal from the source (satellite) reaches the GPS antenna via multiple paths (direct and indirect paths). The principal causes of these errors are as a result of reflecting surfaces such as water body, buildings around the receiver's neighborhood; its magnitude tends to be random and unpredictable, and can also reach 1 – 5cm for phase and between10 - 20cm for code pseudoranges.

  The multipath errors can largely be reduced by careful antenna location (avoiding reflecting surfaces environments) and proper antenna design (e.g. proper signal – polarization, choke ring or ground plane antenna) *[Langley, 1997]*. A secondary method to avoid multipath effects is the use of digital filtering *[Blezaker, 1985]*.

- **Antenna Phase Centre Offset**

  The Physical (Geometric) centre of the antenna does not usually coincide with the phase centre (electrical centre) of the antenna. Moreover, the phase center for L1 and L2 are usually does not coincide; different types of GPS antennas also have different locations of their phase centers. It is very important to mention here that the systematic variation of this offset is difficult to model since it differs from one antenna to the other. Nevertheless, model for antenna offsets were proposed based on the azimuth and elevation of the satellite signal *[Schupler et al. 1991]*.

- **Ionosphere Errors**

  Ionosphere can be defined as that part of the atmospheric layer extending for about 50 – 1000km above the earth surface. The ionospheric conditions can vary significantly during the day, the effect of ionosphere is less intense at night, as a result of the presence of the free electrons in this layer, a delay in the satellite signal are observed in code pseudorange and as well as in carrier phase – pseudorange. Change in the ionopheric conditions might causes GPS losses of lock, especially on the L2 frequency under Anti – Spoofing.

The estimated maximum rate of charge of ionospheric delay under conditions where tracking is still possible is about 19cm per sec and , which corresponds to about 1cycle on L1*[Goureviteh,1996]*.

Many methods are used in eliminating the ionospheric errors, the most common methods is the use of a linear combination of both GPS frequencies (L1 and L2) , *[Hofmann – Wellenhoff et al . 2001]*.

- **Troposphere Errors**

The troposphere layer part of the earth atmosphere extends up to 50km above the surface of the earth, compare to the ionosphere, troposphere errors are frequently independent. So for this reason, elimination of the troposphere effect by using dual frequency receivers is not possible. Similar to the ionosphere affects the propagation delay of GPS signal depends on the atmospheric conditions and satellite elevation angle. The troposphere errors propagate in to station coordinates estimates with the point positioning and also relative positioning. The troposphere can be divided in to two (2) the dry and wet part.

2.2.2 Classification of Errors

Various types of errors associated with the GPS Observables for both pseudorange (code) measurements and that of carrier phase measurements and how they are mitigated have already been discussed in above section 2.2.1, however, these errors are emanated from different sources, which I will be interested to discuss in this section, the sources of these errors can be classified in to three (3) principal categories namely: Satellite Based Errors, Signal Propagation Based Errors and Receiver Based Errors.

- **Satellite Based Errors**

The true and actual understanding of the position and time that the satellite antenna broadcasts is very crucial for obtaining an accurate user position on the surface of the earth. Ephemeris errors result when the GPS message does not transmit the correct satellite location. It is typical that the radial component of this error is the smallest: the tangential and cross-track errors may be larger by an order of magnitude. Fortunately, the larger components do not affect ranging accuracy to the same degree. This can be seen in the fundamental error. The AW represents each satellite position error, but when dot-multiplied by the unit satellite direction vector (in the A matrix), only the projection of satellite positioning error along the line of sight creates a ranging error. Because satellite errors reflect a position prediction, they tend to grow with time from the last control station upload. It is possible that a portion of the deliberate SA error is added to the ephemeris as well. However, the predictions are long smooth arcs, so all errors in the ephemeris tend to be slowly changing with time. Therefore, their utility in SA is quite limited. As reported during phase one, (Bowen, 1986) in 1984, [5] *for predictions of up to 24 hours, the rms ranging error attributable to ephemeris was 2.1 m*. These errors were closely correlated with the satellite clock, as we would expect. Note that these errors are the same for both the P- and C/A-codes.

Another error which falls under this category is the antenna phase center. Because the force models used for the modeling of the satellite orbit refer to its centre of mass, the precise satellite coordinates and clock products also refer to the satellite centre of mass. However, the signal is broadcast from the L – Band antenna phase centre, which changes with the off – axis – angle, and is influenced by the local environment around each satellite. The correct location of this centre with respect to the satellite's centre of mass is critical for accurate orbit determination *[Mader and Czopek, 2002]*.

The relativistic effects are to the velocity of the GPS space craft (time) and Earth rotation (space). The geometrical error introduced by assuming a simple three – dimensional Euclidean space amount to about 2cm in the distance between satellites and receivers *[Blewitt, 1998]*.

- **Signal Propagation Based Errors**

The distance between the satellite and the receiver on the surface of the Earth which ordinarily can be computed or calculated using an a logarithms **Distance = Velocity x Time** never correct as applied to the GPS Measurements, this is because the signal propagated from the satellite is transmitted to the receiver through a media (Earth's atmosphere), the interaction of the signal with the ionosphere and troposphere causes a change in the speed and direction of the signal propagation. The delay caused by these media can reach 10-100m in the ionosphere depending on the ionospheric activity, time (day or night) of transmission and 2.3 – 30m in the neutral atmosphere, depending on the angle of elevation *Fernandes [2004].* Detailed literature on ionospheric and tropospheric propagation delay is provided by *Langley [1996].* Another major source of errors in the pseudorange measurements is the multipath effect, this is due to the reflecting surfaces such as water body and buildings within the receiver environment, and the signal from the satellite reaches the antenna from more than one path. On the phase measurements the effect of the multipath can bias carrier phase processing reflects at the few centimeter leve*l [Well, 1997].*

- **Receiver Based Errors**

The resolution of the measurements (measurement noise) depends on the type of the receiver electronic and firmware and is inversely proportional to the bandwidth of the signal. The peak of the correlation function on the pseudorange measurements can be determined with 1% of the width using of the optimized techniques, which corresponds to 3m and 0.3m for C/A and P Code respectively, on carrier, the GPS can measure the phase with an accuracy of up to 0.005 cycles. Since L1 (L2) wavelength is approximately 0.19m (0.24m), the level of measurement noise in the carrier phase observation is 1mm, more detail on this can be found in *Fernandes [2004],* the variation of the phase centre is a function of both elevation and azimuth, offsets and variation differences of several millimeters can exist between two antenna of the same type *[Mader and Czopek, 2002].*

2.3 NIGNET Network

Introduction to the NIGNET Network has already been presented in chapter 1 (Introduction), however, detail descriptions or discussion on the other aspects of the network is still very essential, particularly, on the instrumentation, site selection, and the geology of each station (location).

2.3.1 Instrumentation

The instrumentation in the NIGNET comprises of the state-of-art geodetic equipments, namely the version of Trimble CORS (Continuously Operating Reference Stations), NetR8 and latest NetR9 with Choke-ring antennas were installed in all the stations in the network. The complete system is composed by the receiver/antenna plus a USB modem (for communications with the Central Control (Base) using the GSM cellular network), a router (to manage the communications), and a solar panel system (the systems are completely independent of the national electricity grid). The optimization of the power consumption was a priority in the design of the system.

The solar panels have 160W of power (charging a battery with 100AH as a backup) that permit to support consumptions up to 20W for an expected constant consumption of 11W. Since the design of the network is not a major constraint when establishing a fiducial network (as it was on the classical triangulations), the network was designed and covered Nigeria with a relative homogenous distribution in order to optimize the densification of the network in the future (with permanent or sporadic points). *[Jatau, B. et al,2010].*

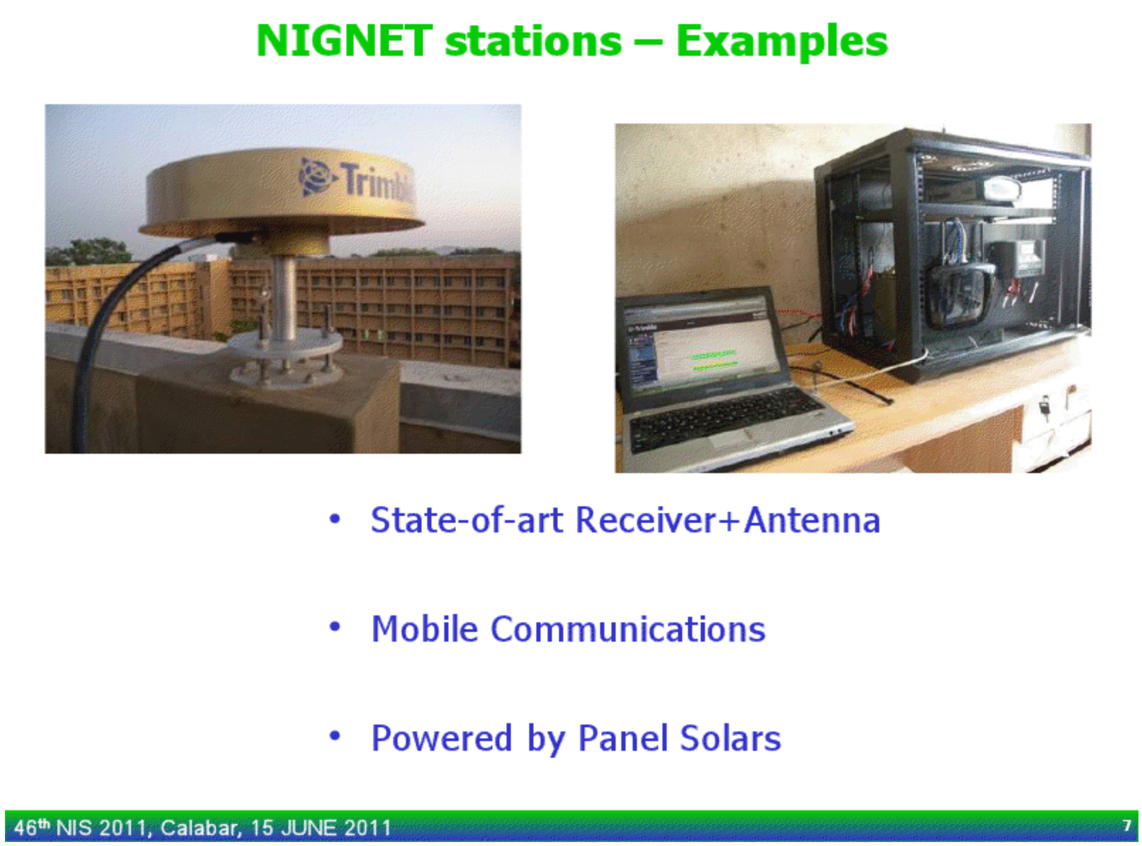


Fig. 2.3: Trimble NetR8 Receiver and Choke Ring Antenna

2.3.2 Sites Selection and Installation

The sites were selected in order to have a reasonable spread so that the entire country is covered, the principle of triangulation was also put in to consideration, most of the sites were located at the Universities and Research Centers so as to link the Network to the scientific community and foster the use of this network by more applications. In addition, the selected partners also offer more guarantees of local support for the installation, security and maintenance of the network.

Last but not least, the location close to large urban areas also contributes to optimize the use of NIGNET (Planning and Surveying Applications). *[Jatau, B. et al 2010].*

2.3.3 Geology of the NIGNET Sites

The Geology of the environment where GPS station is located also plays a greater role during the analysis of time series of every station. Therefore, knowledge of the geology of the environment in which the stations were located is required in this research. A Geologic Map of Nigeria superimposed on a Map of Nigeria showing the NIGNET Network (Fig 2.4 below) was produced by the researcher, the overlay or superimposition of the two maps has assist in detail description of the geology of each site, a table (Table 2.1) which also gives a brief description of the geology of where each GPS station is located and some activities around the environment where each sites were located which will also aid in the analysis of the time series in each station.

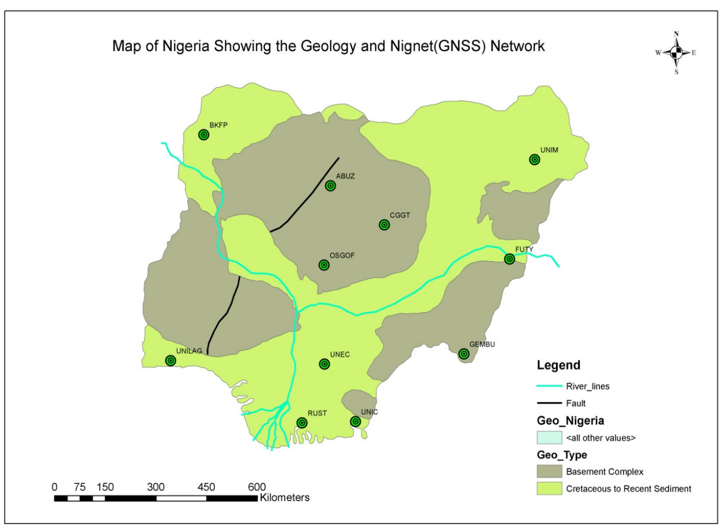


Fig. 2.4: Map of Nigeria Showing Geologic settings, NIGNET Network, Fault line, Major Rivers.

S/no	Station ID	State /Location	Geology of the Site	Remarks
1	ABUZ	Kaduna/Zaria	Basement Complex	Near the major fault line
2	BKFP	Kebbi/BKebbi	Sedimentary	Near lead mining site and major Fault line
3	CGGT	Bauchi/Toro	Basement Complex	Mining activities but not near to the site
4	CLBR	C. River/ Calabar	Sedimentary	Near the coast /Oil exploration area
5	FUTY	Adamawa/Yola	Sedimentary	Not near the Coast
6	GEMBU	Taraba State	Basement	
7	MDGR	Borno/Maiduguri	Sedimentary	Not near the Coast
8	OSGOF	FCT/Abuja	Basement Complex	Heavy traffic & densely populated
9	RECT	Ile - Ife	Basement Complex	
10	RUST	River/Portharcourt	Sedimentary	Major Oil Exploration area ,near the coast, highly industrialization .
11	ULAG	Lagos/Unilag	Sedimentary	Near the coast, Minor oil exploration, near the fault line, industrialized
12	UNEC	Enugu/Enugu	Sedimentary	Tin Mining area

Table 2.1: Important Information around the NIGNET Sites.

2.4 GIPSY Processing Software

GIPSY uses Square Root Information Filter (SRIF) algorithms *[Bierman, 1977]* to process the GPS Observables in order to estimates the best values for parameters (receiver positions, satellite orbits, e.t.c). For detail explanation the reader can refer to. *[Hofman Wellehof et al., 2001].*

2.4.1 Fiducial Free Approach

Fiducial Free Approach can also create errors in the position which was not discussed in section 2.2. It occurs as a result of non- alignment or integration of a receiver position within a specific reference frame. The relative position given by the GPS can only be absolute when the coordinates are mapped and integrated in to a known reference frame. This can be achieved by using a network of fiducial sites, the coordinates of which are held fixed during the analysis. However, the use of tight constraint or on the fiducial site coordinates can bias the solutions significantly, introducing apparent strains in the network *[Larson et al., 1991].* Fiducial solution also requires reprocessing the entire data set when a change of reference frame becomes absolute very necessary since discontinuities cannot be eliminated entirely *[Zumberge et al. 1997].* Therefore, the used approach is to compute the solutions using the fiducial free approach and after convert the coordinates in to the desired reference frame (ITRF 2008) by applying estimated transformation parameters.

2.4.2 Orbit and Associated Parameters

Post processed satellite ephemeries and their associated parameters such as satellite clock parameters and Earth Orientation parameters (EOPS) can be obtained from both carrier phase and pseudorange observables obtained from a network of globally distributed GPS stations

The Earth Orientation Parameters (EOPS) are very crucial for the transformation of the ephemerides from the Earth fixed reference frame. The inertial reference frame is used for the numerical integration of the satellite position and velocity. The consistency between the satellite orbits and Earth Orientation models is essential. The former are the results of integration using models from solar radiation pressure, gravity (from Earth, Sun, Moon and other planets), relativistic effects, Earth rotation, nutation, precession and tidal Earth deformation effects *[Zumberge and Bertiger, 1996; Gregorious, 1996].*

Most GPS user's today do no longer worry to improve the orbits of the GPS satellites because, precise orbit solutions are now available from several services such as IGS in particular. The IGS orbits (and associated products) are produced since 1994 by combining solutions delivered by seven (7) groups. The quality of the IGS final orbits has improved from 30cm to the 3-5cm precision level, which currently realized by some of the analysis centers *[Kouba, 2003a]*.

2.4.3 Processing Strategies

Basically, there are two (2) strategies involved in the use of GIPSY for processing GPS data for Fiducial Free Network and are: Free Network Solution (FN) and Precise Point Positioning (PPP). The strategy that was adopted for the processing in this research is Precise Point Positioning (PPP), but I want to use this opportunity to explain Fiducial Free Network (FN) strategy.

Free Network Solution (FN) When using this strategy for processing, the whole network is processed simultaneously in a computation, this is done without fixing the coordinates of any station. Only orbits are kept fixed in fiducial free reference frame. The parameters to be simultaneously estimated are station specific parameters (e.g receiver position, receiver clock bias and drift, zenith tropospheric delay) and common parameters (orbital satellite clock bias and drift; EOPS).

Precise Point Positioning (PPP) This strategy was adopted in the computation of GPS data in this research; in this strategy two (2) steps were considered. The first step is the use of a global network for the computation of common parameters such as orbit, satellite clock, and Earth Orientation Parameters (EOPs). For the second approach the computed global parameters are kept fixed to compute each set of station specific parameters independently *[Zumberge et al., 1997]*. However, the second step was adopted in this research this is because of the numbers of stations involved in the network (Few stations). The Precise Point Positioning (PPP) is considered to be much more effective than FN the determination of positions consisting of several stations one after the other. However, JPL provides daily estimates of fiducial free orbits, satellite clock and EOPS (plus satellite clock information).

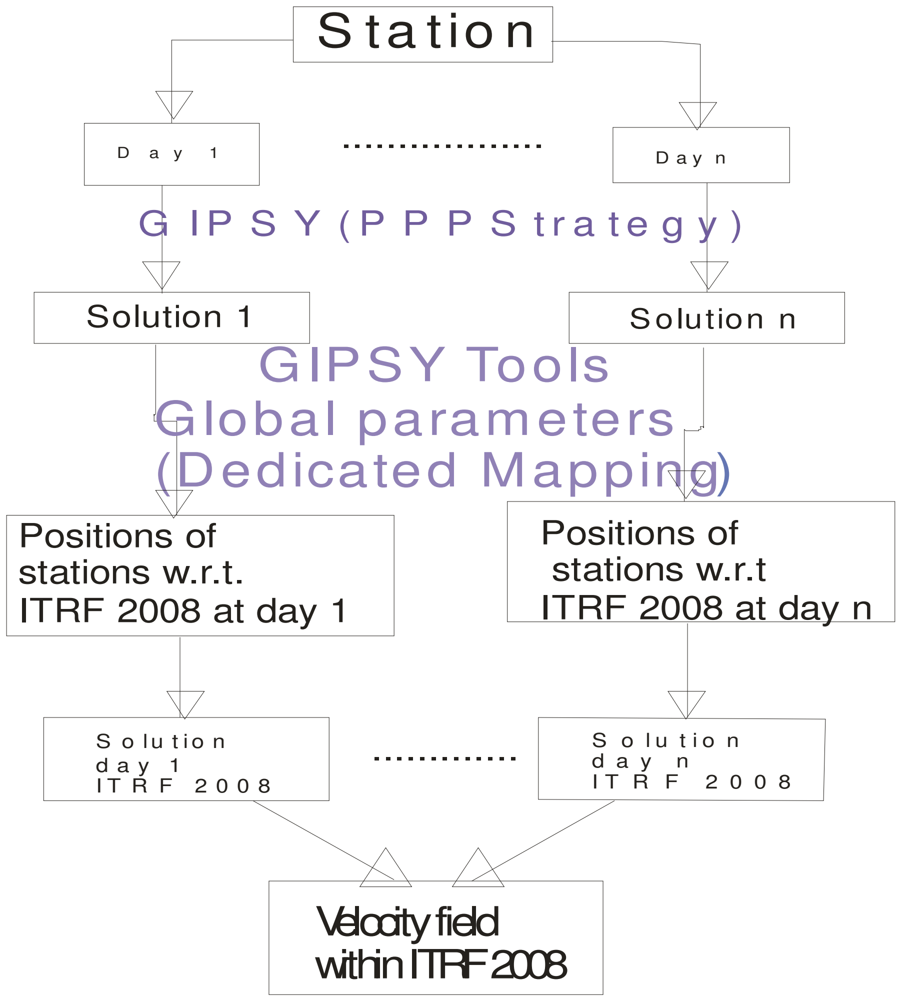


Fig. 2.5: Flow chart showing the processing structure in GIPSY (PPP strategy).

The flow chart shown above is the designed structure describing the processing or techniques involved in the processing data from GPS permanent network, by Precise Point Positioning (PPP) using GIPSY/OASIS software(Webb and Zumberge, 1995).The mapping was done in ITRF 2008 (Altamimi et al,. 2008) reference frame. ITRF 2008 is the new realization of the International Terrestrial Reference System. Following the procedure already used for the ITRF2005 formation, the ITRF 2008 uses as input data time series of station positions and Earth Orientation Parameters (EOPs) provided by the Technique Centers of the four space geodetic techniques (GPS, VLBI, SLR, DORIS). Based on completely reprocessed solutions of the four techniques, the ITRF 2008 is expected to be an improved solution compared to ITRF 2005.

During processing, the daily solutions are first combined in to a single weekly solution n numbers of days of observations, each point or station in the network are independently processed with available data using GIPSY tools and global transformation parameters are applied to compute the position of each station with respect to ITRF 2008, refer to diagram 2.5 above.

2.4.4 Ambiguity Resolution

Regardless of the strategy adopted or used for the processing of GPS data either Precise Point Positioning (PPP) or Free Network Solution (FN), the ambiguities are not necessarily integer after normal processing; this is as a result of the inability to model all errors properly, the integer ambiguities meaning assigning the correct integer numbers to the real values estimated.

The Phase ambiguities are initially computed as real values in Kalman filter adjustment. When Precise Point Positioning (PPP) is used like the case in this research, it should be noted that the individual information for each station was stored during the processing to form double difference observables, this is because the integer ambiguities cannot be estimated using single receiver (i.e, using PPP), the phase biases will be integers *[Zumberge et al., 1997]*.Obviously, most of the computational advantage of PPP disappear when an integer solution is performed. Conversely, the variance – o variance matrix is now a full matrix since correlations are computed during the ambiguity resolution process *Fernandes [2004]*.

The integer ambiguity solutions tends to improve the estimated position for shorter baselines or shorter observing times, the lengths of the observations sessions are sufficient to ensure a reliable ambiguity free solution *[Rizos, 1999]*. Moreover, the success rate of ambiguity resolution correlates inversely with the length of the baselines; for baselines of several thousand kilometers, these values can be very small *Fernandes [2004]*. The successful resolution of the ambiguities to their integer values for long static observations is useful since it improves the repeatability of the coordinates (particularly the East component) *[Blewitt, 1989]*.

Chapter 3

Results and Analysis

The results in this research were obtained after the analysis of GPS data collected in the NIGNET Network was performed, these analyses which includes processing of time series (GPS solutions and using GIPSY/OASIS II software.

3.1 Error Analysis

The similarities or correlation have in the GPS residuals to one another has been proved, and these similarities or correlation have to be taken in to account in the computational process to enable the proper quantification of existing errors in all the GPS derived velocities in the network to be achieved. The similarities or correlations of the noise in the time series are usually defined by a power- law plus white noise model. All the frequencies of the white noise have equal power, while the power-law is defined by its power spectrum *[Agnew 1992; Kasdin 199]:*

$$P(f) = Po / f \alpha \qquad \text{Equ.(3.1)}$$

Considering f in the equ.(31), as the frequency, *P*o as a constant and α spectral index. The problem for estimating both the spectral index of the power-law and the amplitudes of the power-law and white noise random variables will be reduced. *Mao et al[1999]* Proved that the best results are obtained using Maximum Likelihood Estimation (MLE) method. However, the derivation of the Maximum Likehood Estimation (MLE) formulae or algorithms for GPS time-series data is computationally demanding, time consuming and grows with the cube of the number of observations. But a simple modification of the MLE equations or algorithms, that will enable to minimize the required number of processes or procedures to a quadratic function. The figure below shows the definition of the three parameters that describe the power-law plus white noise model:

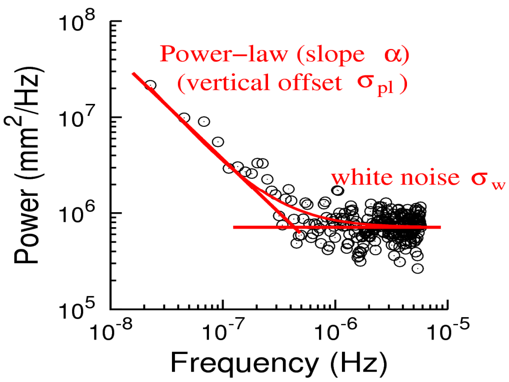


Fig. 3.1: Power spectrum of the GPS residuals, North component. The *circles* denote the spectrum computed from the observations and the *solid line* is the fitted power-law plus white noise model *[Source: http://www.geodac.net]*.

3.1.1 Error Analysis Techniques

In this technique, let us consider each data point xi to be independent, normally distributed and has a standard deviation of σi, and then the following equation follows X^2 probability distribution with *N*–*M* degrees of freedom:

$$X^2 = \sum_{\iota=1}^{N} \left(\frac{x_1 - \hat{x}_1}{\sigma_1}\right)^2 \tag{3.2}$$

N in the above equation is considered to be the number of observations and *M* is the number of parameters used for the estimation of ˆ**x**.

The Equ. (3.2) above involves finding or computing the difference between the observations and the estimated model. When there is a large number of data points, the value of X^2 approximately becomes N $- M$. The reduced chi-square is defined as $X^2/(N-M)$ and with the estimated value to be around one. If the reduced value of X^2 is much larger than one, it shows that the estimated model is wrong or it may mean that the errors in the time series are very small. The GPS analysis software produced standard deviations for each estimated station position, but in most of the cases these are very small to be realistic. To achieve better error values, these are usually scaled by $X^2/(N-M)$. This technique is widely used and accepted within the geodetic community, but nevertheless is not the best solution for the improvement on the error bars. It is assumed that the GPS residuals are independent of each other, while in the reality they indicates a strong correlation or similarities in time series*[Johnson and Agnew 1995]*. *Mao et al. [1999]* have proved that after the application of the reduction $v$alue of X^2, the real error can still be underestimated by a factor of 5–11. However, there is still high need for an improvement on noise model. In the high frequencies, the noise is flat; the flatness of the noise is an indication that the noise is white, while for low frequencies, the spectrum indicates that the noise is power law noise. The slope of the power-law is around one, and can sometimes be called flicker noise. *Williams et al. [200]* have shown that the power spectrum as indicated in Fig.3.12 is representing many GPS residuals *[Langbein and Johnson (1997) and Langbein (2004)]*.

3.1.2 Maximum Likelihood Estimation (MLE)

For the parameters that describe the trend in the GPS observations and the parameters of the noise model both to be estimated, Detailed on this can be found in *[Langbein and Johnson (1997) and Langbein (2004)]*.

3.1.3 Data Gaps

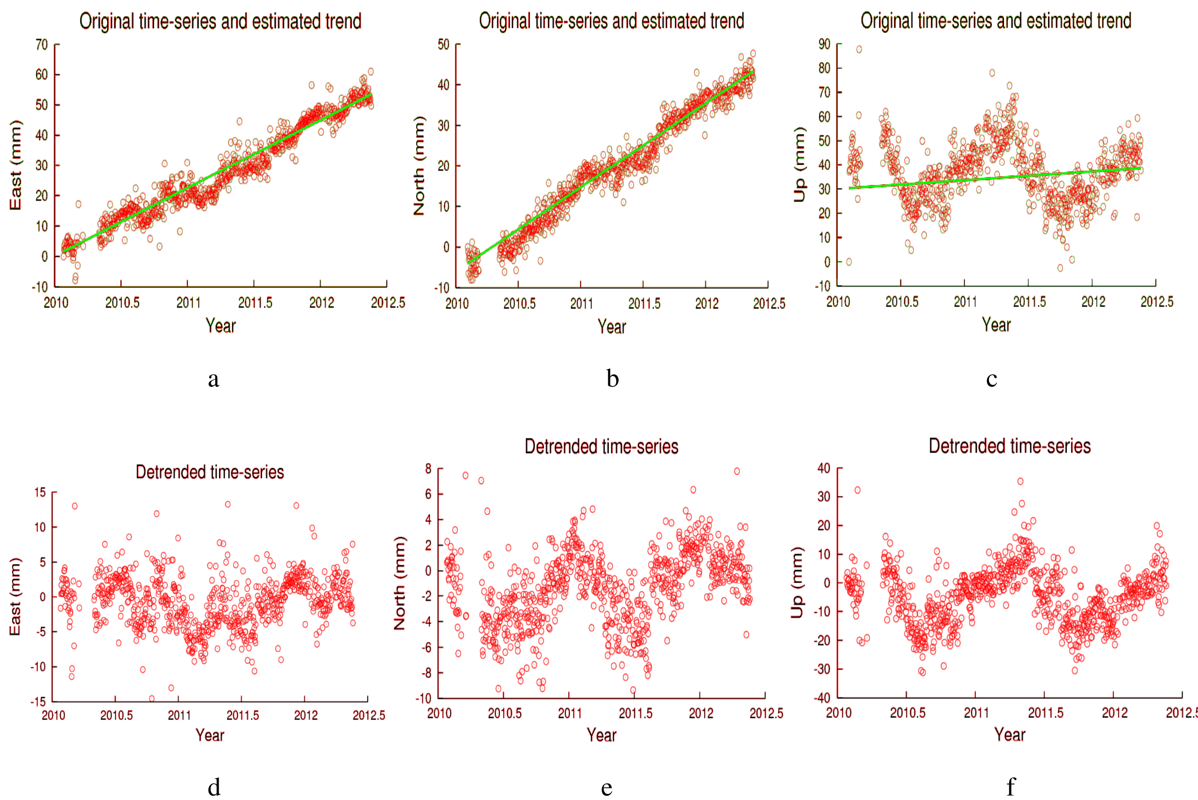
Data gaps is another very important error on the time series, unfortunately the data gaps is commonly found in most of the GPS time-series, this was not mentioned among the errors earlier discussed in the above sections, To correct or eliminate these data gaps on the time series, one have to construct, both for the normal and the first differenced Maximum Likelihood Estimation method, first the full covariance matrix for the complete time-series and afterwards delete the rows and columns for which no data are available *[Williams 2003]*. There are two (2) possible ways for solving the problem of the data gaps on the time series. The first option is by simply filling the data gaps by linear interpolation. This is by analyzing GPS stations with a wide range of observation time and interpolates the data gaps. 90% of the stations, the trends estimated by the normal and the first-differenced method differed by less than one standard deviation from each other in all three components.

The second option is to neglect the gaps in the stochastic model and keeps the Toeplitz covariance matrix. In this option approximately 94% of the trends differed from the normal method by less than one standard deviation. From the descriptions above, it is shown that already with some simple methods, the data gap problem can be resolved to satisfaction.

3.2 Results

The Time Series of all the GPS stations in the network as processed using GIPSY/OAISII software will be presented here. Furthermore, the assessment of the time series, by analyzing the noise characteristics and the apparent seasonal signal and data gaps in the time series. NIGNET Network comprises of twelve (12) GPS stations namely: ABUZ, BKFP, CGGT, CLBR, FUTY, MDGR, OSGF, RECT, RUST, ULAG and UNEC. The data from all the stations were processed. But the results from stations CLBR and MDGR are unreliable so they were not used in this research. The data from the network was processed and mapped in ITRF2008.

1. Station ABUZ Time Series



Figs. 3.2a, b, c, d, e and f above are Original & estimated and Detrended time series at station ABUZ.

An estimated data of 730days from June 2010 to January 2012 was transmitted and processed for the time series in this station. The computational procedure for the characterization of the errors in the Time Series has earlier been discussed in the section 3.1. With this method described above the noise in the time series station ABUZ can be classified in to two categories according to the behaviors of the signal. The signal in the first year (2010 to 2011) is smoother and more disperse in the second year (2011 to 2012) along the linear regression or average trend. This noise according to their behaviors described above can be classified as power law (*slope α)* and white noise (*σw)* on the horizontal components. The vertical (Up) component shows a seasonal signal.

The changes in the amplitudes of the signal in the time series were observed in 2010.4, 2010.8, 2011.4 and 2011.8 years respectively, with the signal amplitudes higher (+32mm) in March and lower (- 38mm) in August of the years. It is always difficult to reach or to arrive at a specific conclusion(s) on the reason(s) for the causes of the variations in the vertical component. Several reasons ranging from processes of climatic changes (wet and dry season) in the station region, ground water changes, solid earth tides, atmospheric tides, incomplete removal of atmospheric effects, thermal expansion of the antenna and dilatation (monument expansion). Data gaps were also observed on the time series shortly after the station started transmitting data, the data gaps as indicated in the time series was estimated to about one month (30days). The cause of the data gaps may be associated to the power failure (electricity) or faulty equipment (Receiver or Antenna). Methods of solving problem of the data gaps in the time series have already been described in section 3.1.3.

Station	Components	Spectral Index	Sigma Power Law	Sigma White Noise	Velocity (mm/y)	Velocity error (mm/y)
ABUZ	East	0.99	2.08	1.82	22.39	1.25
	North	1.25	1.21	1.41	20.24	1.5
	Up	1.46	2.64	5.01	-2.05	6.04
BKFP	East	1.54	0.82	1.87	23.62	2.44
	North	1.39	0.65	1.48	21.33	1.23
	Up	1.42	2.81	4.39	-1.59	5.73
CGGT	East	1.38	1.12	2.42	22.39	2.33
	North	0.97	1.68	1.2	21.46	1.11
	Up	1.34	3.53	4.98	-7.29	6.36
FUTY	East	1.71	0.77	2.12	24.11	3.91
	North	1.08	1.07	1.42	20.34	0.84
	Up	1.88	1.37	5.38	0.64	12.07
GEMB	East	2	0.3	1.28	25.14	4.63
	North	1.02	0.97	0.61	19.72	1.22
	Up	1.85	1.17	3.19	-8.24	11.58
OSGF	East	2	0.42	2.45	19.56	4.99
	North	1.53	0.69	1.5	19.46	1.8
	Up	1.82	1.58	5.5	5.38	10.53
RECT	East	1.36	1.03	0.87	21.73	1.22
	North	1.35	0.89	0.7	17.94	1.02
	Up	1.15	3.72	1.24	-3.02	2.3
RUST	East	1.29	1.7	2.13	23.13	3.32
	North	1.21	1.52	1.82	22.45	2.38
	Up	1.39	4.26	5.85	-9.26	10.83
ULAG	East	1.25	1.55	1.66	23.09	1.7
	North	1.55	0.95	1.65	19.14	2.64
	Up	1.14	4.98	4.33	0.11	3.99
UNEC	East	1.5	1	2.49	22.37	2.61
	North	1.24	0.92	1.83	20.7	1.12
	Up	1.58	2.81	5.89	3.6	9.5

Table 3.1: Final Results of all the GPS stations in the NIGNET Network showing computed values for sigma Index, power law, white noise, velocity and velocity error in each station.

3.2.1 Velocities Map of NIGNET Network.

The velocity map below was produced from current results computed from the up to data obtained in table 3.2.

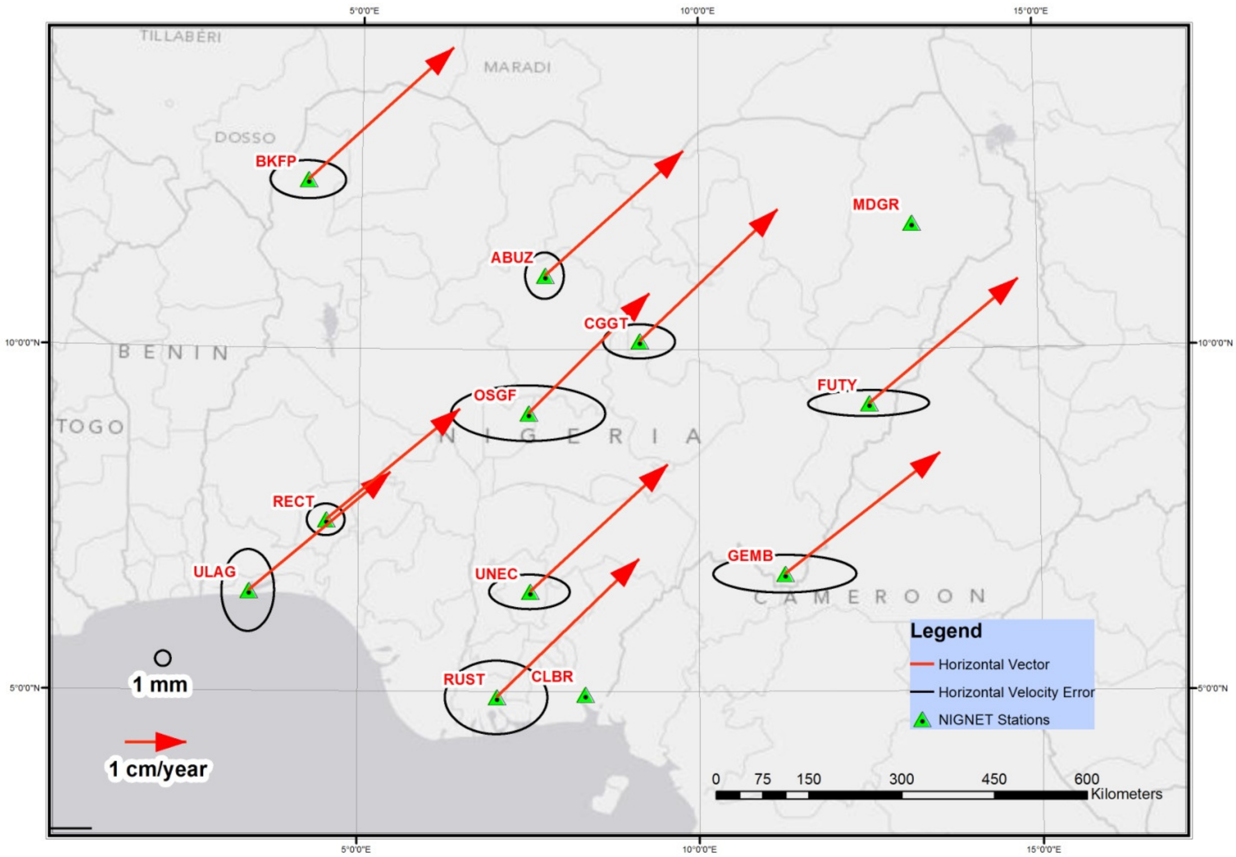


Figure 3.3: Horizontal Velocity Map of Nigeria produced from the final results.

The red arrows in figure 3.4 are representing horizontal velocities and the direction of each station motion, all the stations motion are in the North – East direction, the GPS stations are represented by green triangles. The circle ellipse is the velocity error in each station. Stations ABUZ and RECT from this results are considered the best stations with least amount of errors considering their period of transmission, while stations CLBR and MGDR were both not processed because of the short time data since they were both recently installed.

3.3 Computation and Comparison of estimated relative motions (with respect to the Nubia plate) of all NIGNET Network Stations using different tectonic plate models.

The use of plate tectonic models to compute the relative motions (with respect to Nubia plate) of all the GPS stations in the NIGNET Network will be presented in this section.

Models used for estimating the relative motions of any point on the Earth surface through the use of geologic and geophysical data is kinematic models, *[LePicham, 1986; Minster and Jordan, 1978].* An average of 3-5 Million years' data is needed to be able to use this models. In the past, NUVEL – 1 model *[DeMets et al., 1990]* and its new version, NUVEL – 1A *[DetMets et al., 1994]*, both were considered to be the best models for the estimation of relative motion of 14 major tectonic plates. The two (2) models (NUVEL -1 and NUVEL – 1A) predict the same directions. However, the absolute motion on the surface of the Earth is describe the implementation of the no-net-rotation (NNR- NUVEL – 1A). *[Argus and Gordon, 1990].* NUVEL -1A is mainly used for averaging motions of recent geologic age (past 3Myr). But the accuracy of the results obtained using this model is very limited for some plates this is as a result of few available data, particularly, for the Eurasian plate *[DeMets et al., 1990].*

MORVEL (Mid Ocean Ridge Velocity) Model, is a model that is described as an estimate of geologically recent global plate motions and their uncertainties, it also provide less accurate estimates of crustal motions in some of the wide deforming zones that define some plates boundaries. There are 25 plates that comprises of MORVEL model, 20 of the 25 plates in this model their relative motions are estimated using geologic data ranging from hundreds of thousands to million years. The GPS data were used to integrate the remaining five smaller plates with inadequate or no reliable geologic data for the estimation of their plate motions. Part of the MORVEL that is determined from the geologic data is mathematically isolated from the part determined from GPS to avoid to avoid mixed up between kinematic information between the data types.

GEODVEL is a model determined from four (4) space geodetic techniques namely: GPS, SLR, VLBI and DORIS. This model assumed Earth's Centre (CE) to be the mass centre of the solid Earth *[Argus, D; DeMets, C; Gordon, R.G, 2009].* The velocity of the Earth Centre (CE) is estimated by the assumption that, besides plate motions, the parts of plate interiors near the late Pleistocene ice sheets are not moving relative to Earth Centre (CE). GEODVEL differs from other models because of its space geodetic based. The disadvantages in the use of the first two(2) models is that long time data span of between 3-5Million years is required, and the results is less accurate when compared to the results obtained from space – geodetic observations which requires a short time data span. However, the space- geodetic models are only representative of the present- day movement.

3.3.1 Computation of estimated relative motions of NIGNET Network using HS2 NUVEL

Model			Speed mm/yr	Azimuth (cw from N)	N Vel. mm/yr	E Vel. mm/yr		Site Name
HS2-NUVEL1A	11° 4' N 11.066667°	7° 42' E 7.700000°	31.97	49.72°	20.67	24.39	AF(NNR)	ABUZ
	12° 26' 60" N 12.450000°	4° 10' 60" E 4.183333°	31.47	49.48°	20.45	23.92	AF(NNR)	BKFP
	10° 7' N 10.116667°	9° 5' 60" E 9.100000°	32.17	49.88°	20.73	24.60	AF(NNR)	CGGT
	4° 55' 60" N 4.933333°	8° 19' E 8.316667°	32.52	50.48°	20.70	25.09	AF(NNR)	CLBR
	9° 11' 60" N 9.200000°	12° 28' 60" E 12.483333°	32.47	50.08°	20.84	24.90	AF(NNR)	FUTY
	6° 43' N 6.716667°	11° 15' E 11.250000°	32.57	50.29°	20.81	25.05	AF(NNR)	GEMB
	11° 49' 60" N 11.833333°	13° 7' 60" E 13.133333°	32.31	49.82°	20.85	24.68	AF(NNR)	MDGR
	9° 4' N 9.066667°	7° 28' E 7.466667°	32.14	50.02°	20.65	24.63	AF(NNR)	OSGF
	7° 28' 60" N 7.483333°	4° 31' E 4.516667°	32.06	50.32°	20.47	24.67	AF(NNR)	RECT
	4° 54' N 4.900000°	7° 1' E 7.016667°	32.45	50.53°	20.63	25.05	AF(NNR)	RUST
	6° 27' N 6.450000°	3° 22' 60" E 3.383333°	32.07	50.53°	20.39	24.76	AF(NNR)	ULAG
	6° 27' N 6.450000°	7° 30' E 7.500000°	32.37	50.34°	20.66	24.92	AF(NNR)	UNEC

Table3.2: Computed estimated relative motions of NIGNET Network using HS2 NUVEL -1A Model with respect to African plate.

This model was used to compute the estimated motions for all the GPS stations in the NIGNET Network; this was done through the use of facility provided by Unavco on the site indicated in section 3.4. In each GPS station parameters such as speed, East/North components in mm/yr, and Azimuth computed with reference to African plate.

3.3.2 Computation of estimated relative motions of NIGNET Network using MORVEL 2010 Model.

Model			Speed mm/yr	Azimuth (cw from N)	N Vel. mm/yr	E Vel. mm/yr		Site Name
MORVEL 2010	11° 4' N 11.066667°	7° 42' E 7.700000°	31.02	46.75°	21.25	22.60	NU(NNR)	ABUZ
	12° 26' 60" N 12.450000°	4° 10' 60" E 4.183333°	30.40	46.58°	20.89	22.08	NU(NNR)	BKFP
	10° 7' N 10.116667°	9° 5' 60" E 9.100000°	31.29	46.90°	21.38	22.85	NU(NNR)	CGGT
	4° 55' 60" N 4.933333°	8° 19' E 8.316667°	31.74	47.83°	21.31	23.52	NU(NNR)	CLBR
	9° 11' 60" N 9.200000°	12° 28' 60" E 12.483333°	31.70	47.00°	21.62	23.19	NU(NNR)	FUTY
	6° 43' N 6.716667°	11° 15' E 11.250000°	31.82	47.40°	21.54	23.42	NU(NNR)	GEMB
	11° 49' 60" N 11.833333°	13° 7' 60" E 13.133333°	31.50	46.58°	21.65	22.88	NU(NNR)	MDGR
	9° 4' N 9.066667°	7° 28' E 7.466667°	31.23	47.17°	21.23	22.91	NU(NNR)	OSGF
	7° 28' 60" N 7.483333°	4° 31' E 4.516667°	31.10	47.71°	20.93	23.01	NU(NNR)	RECT
	4° 54' N 4.900000°	7° 1' E 7.016667°	31.63	47.94°	21.19	23.49	NU(NNR)	RUST
	6° 27' N 6.450000°	3° 22' 60" E 3.383333°	31.11	48.03°	20.80	23.13	NU(NNR)	ULAG
	6° 27' N 6.450000°	7° 30' E 7.500000°	31.52	47.65°	21.24	23.30	NU(NNR)	UNEC

Table 3.3: Computed estimated relative motions of NIGNET Network using MORVEL 2010 Model

3.3.3 Computation of estimated relative motions of NIGNET Network using GEODVEL 2010 Model.

Model			Speed mm/yr	Azimuth (cw from N)	N Vel. mm/yr	E Vel. mm/yr		Site Name
GEODVEL 2010	11° 4' N 11.066667°	7° 42' E 7.700000°	28.24	49.76°	18.25	21.56	NU(NNR)	ABUZ
	12° 26' 60" N 12.450000°	4° 10' 60" E 4.183333°	27.93	49.38°	18.19	21.20	NU(NNR)	BKFP
	10° 7' N 10.116667°	9° 5' 60" E 9.100000°	28.36	49.95°	18.25	21.71	NU(NNR)	CGGT
	4° 55' 60" N 4.933333°	8° 19' E 8.316667°	28.54	50.25°	18.25	21.94	NU(NNR)	CLBR
	9° 11' 60" N 9.200000°	12° 28' 60" E 12.483333°	28.52	50.29°	18.22	21.94	NU(NNR)	FUTY
	6° 43' N 6.716667°	11° 15' E 11.250000°	28.56	50.31°	18.24	21.98	NU(NNR)	GEMB
	11° 49' 60" N 11.833333°	13° 7' 60" E 13.133333°	28.44	50.20°	18.20	21.85	NU(NNR)	MDGR
	9° 4' N 9.066667°	7° 28' E 7.466667°	28.35	49.93°	18.25	21.69	NU(NNR)	OSGF
	7° 28' 60" N 7.483333°	4° 31' E 4.516667°	28.30	49.98°	18.20	21.67	NU(NNR)	RECT
	4° 54' N 4.900000°	7° 1' E 7.016667°	28.51	50.22°	18.24	21.91	NU(NNR)	RUST
	6° 27' N 6.450000°	3° 22' 60" E 3.383333°	28.31	50.07°	18.17	21.71	NU(NNR)	ULAG
	6° 27' N 6.450000°	7° 30' E 7.500000°	28.47	50.14°	18.25	21.85	NU(NNR)	UNEC

Table 3.4: Computed estimated relative motions of NIGNET Network using GEODVEL 2010 Model

3.3.4 Comparison between Observed (GPS) versus relative motions Computed from HS2 NUVEL -1A Models.

Station Name	Observed (GPS)		HS2 Nuvel -1A Model		Residuals		Remarks
					East Component	North Component	
	East Vel.	North Vel.	East Vel.	North Vel.			
ABUZ	22.39	20.24	24.39	20.67	-2.00	-0.43	
BKFP	23.62	21.33	23.92	20.45	-0.30	0.88	
CGGT	22.39	21.46	24.60	20.73	-2.21	0.73	
FUTY	24.11	20.34	24.90	20.84	-0.79	-0.50	
GEMB	25.14	19.72	25.05	20.81	0.09	-.1.09	
OSGF	19.56	19.46	24.63	20.65	-5.07	-1.10	
RECT	21.73	17.94	24.67	20.47	-2.94	-2.53	
RUST	23.13	22.45	25.05	20.63	-1.92	1.82	
ULAG	23.09	19.14	24.76	20.39	-1.67	-1.25	
UNEC	22.37	20.70	24.92	20.66	-2.55	0.04	

Table 3.5: Computed residuals between Observed (GPS) and HS2 NUVEL – 1A Model

The table above shows the comparison between the observed and the estimated results obtained by computing and comparing; there is a correlation between the observed and estimated results in the two components, the computed mean average residuals are as shown below:

Mean average velocities residuals: Easting = -1.93mm/yr

Northing = -0.34mm/yr

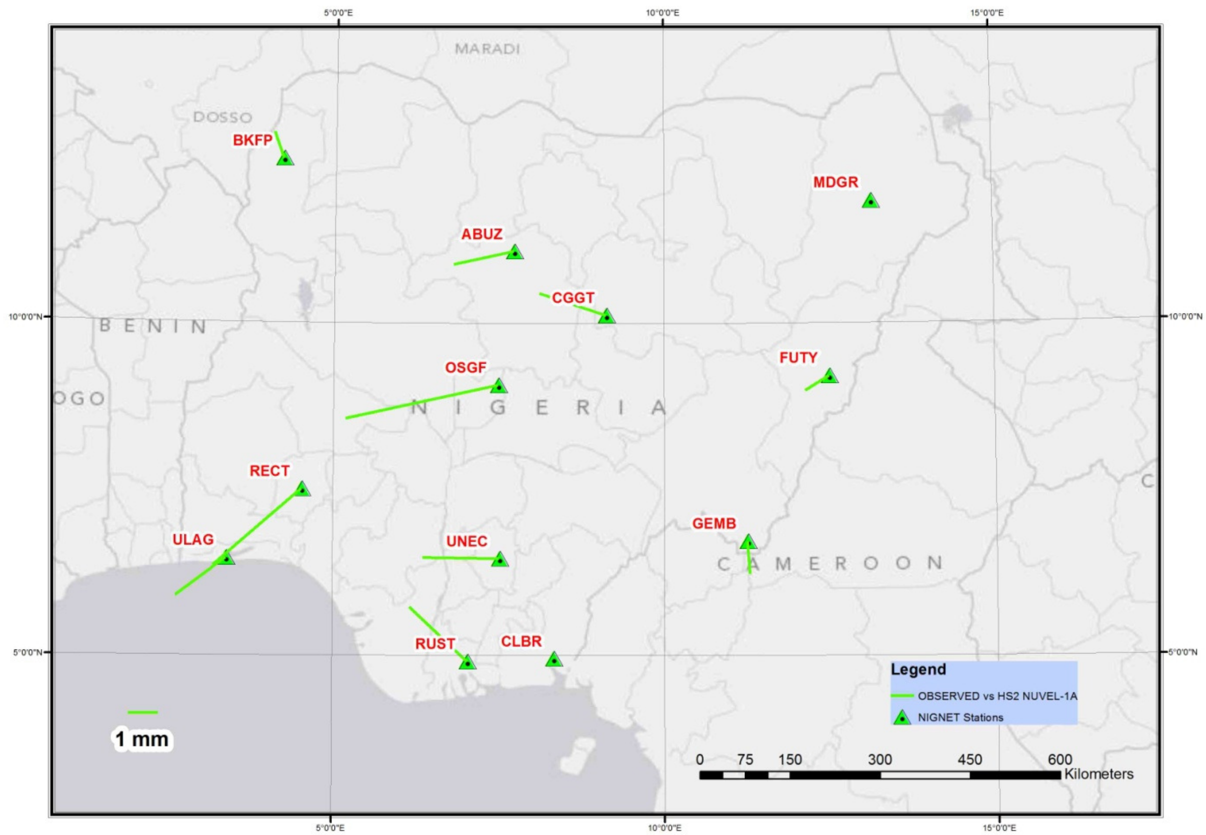


Fig 3.4: Residuals between observed and HS2 NUVEL – 1A Model.

Figure 3.4 above shows the residuals between the observed (GPS) and HS2 NUVEL -1A Model. The large residuals between the observed and estimated relative motion computed from HS2 NUVEL -1A Model was recorded in stations RECT and OSGF, while stations FUTY, BKFP and GEMB have almost the same magnitude of residuals, the residuals in all the stations are not trending towards the same direction.

3.3.5 Comparison between Observed (GPS) and MORVEL 2010 Model from computed residuals.

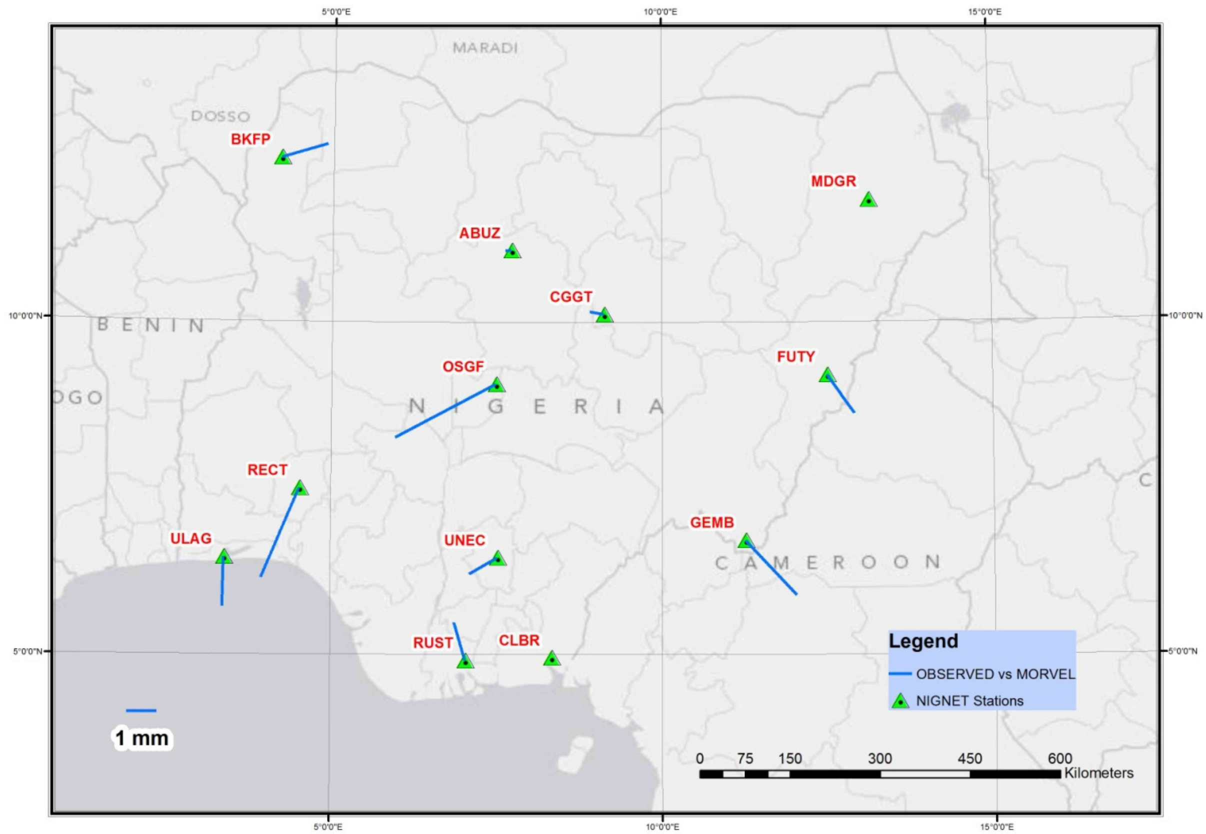


Fig 3.5: Residuals between observed and MORVEL 2010 Model.

Figure 3.5 above shows the residuals computed between observed and MORVEL 2010 Model, There is correlations between the computed residuals. The same situation occurred or can also be observed between observed and HS2 NUVEL – 1A Model, except that stations ABUZ and CGGT has very negligible residuals when compare to the first. The residuals in all the stations are not trending in the same direction.

3.3.6 Comparison between Observed (GPS) and GEODVEL 2010 Models from computed residuals.

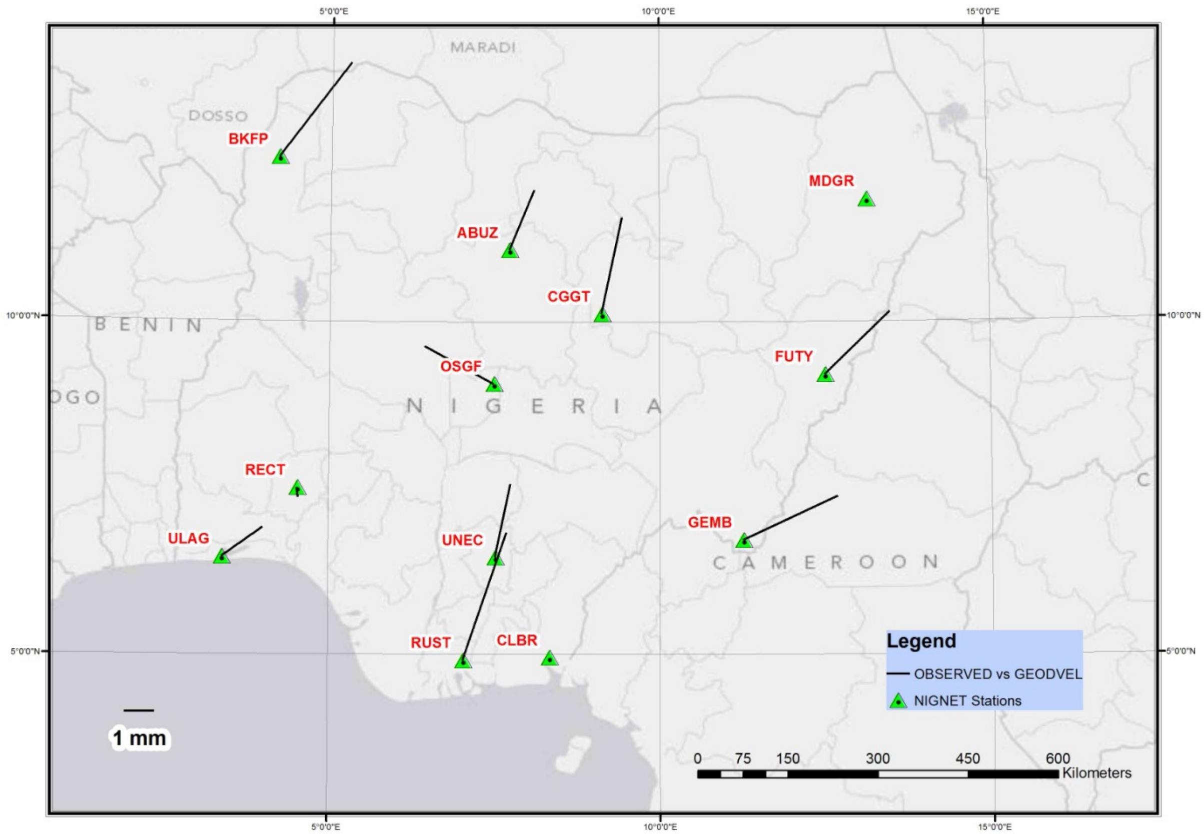


Fig 3.6: Residuals between observed and GEODVEL 2010 Model.

The map above shows the residuals computed between the observed and GEODVEL 2010, the same situation compare to other two (2) models also occurred here. The stations RECT shows a very small residual while the stations with larger residuals are stations RUST. Most of the residual in almost all the stations are trending to the North East direction except for the station OSGF that is trending westward.

3.3.7 Comparison between Observed (GPS), HS2 NUVEL -1A, MORVEL 2010 and GEOD VEL 2010 Models.

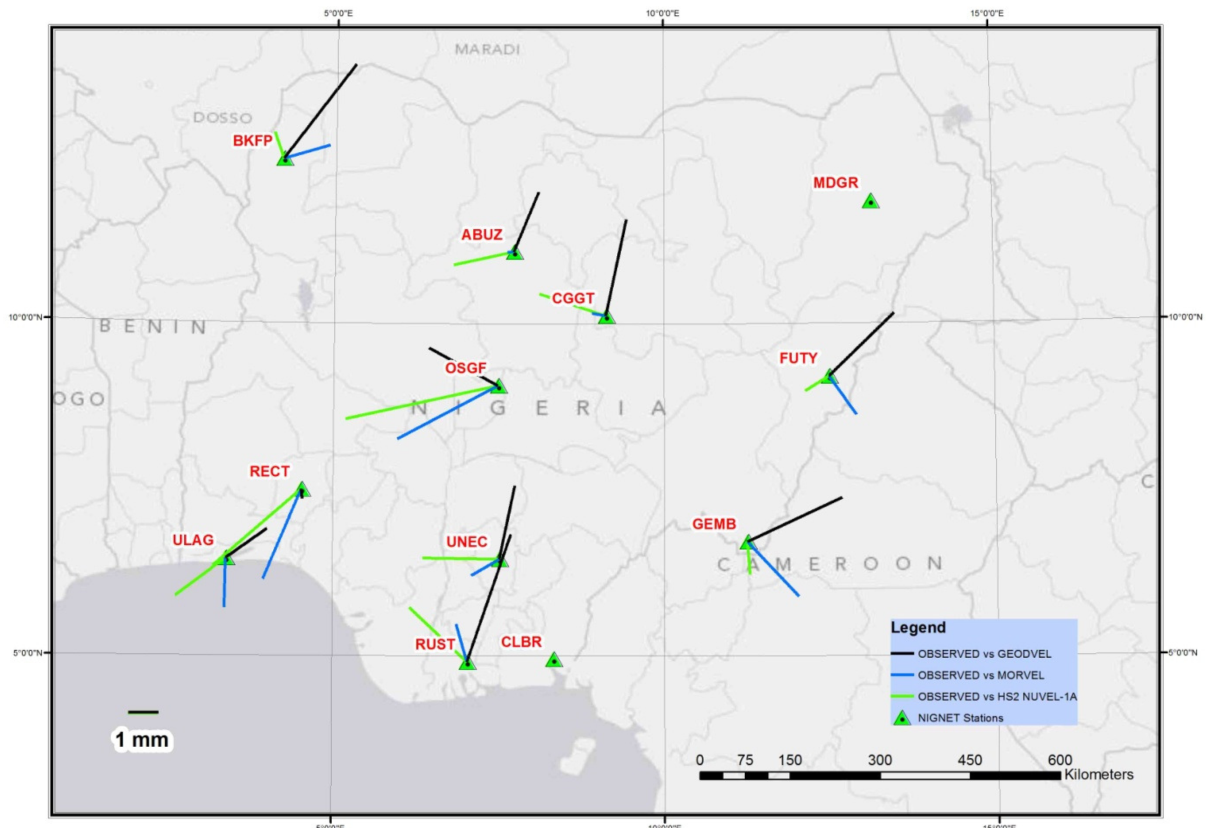


Fig 3.7: Comparisons of residuals between observed and all three (3) Models.

The comparisons between observed and the three (3) Models was done by super imposition of the three (3) maps over each other, this is to see how best the three models fitted to the observed values. The models that fitted better to the observed are MORVEL and GOEDVEL 2010 Models.

3.3.8 Total Mean average residuals between Observed (GPS) and Models.

Observed (GPS)	Model Type (Estimated)	East Component mm/yr	North Component mm/yr	Remarks
	HS2 NUVEL -1A	-1.76	-0.34	
	MORVEL 2010	-0.24	-1.82	
	GEODVEL 2010	1.03	2.05	

Table 3.6: Computed mean summary residuals between Observed (GPS) versus other models.

The above table shows the mean summary of residuals computed between the observed and other models in all the each station in the network. However, the results for the comparison between observed (GPS) versus MORVEL 2010 and that between the observed versus GEODVEL 20101 are as attached in the appendix B.

3.3.9 Comparison between MORVEL 2010 and GEODVEL 2010 Models from computed residuals.

Station Name	MORVEL 2010 Model				GEODVEL 2010 Model				Residuals			
	E. Vel.	**N Vel**	**Speed mm/yr**	**Azimuth (cw from N)**	**E Vel.**	**N Vel.**	**Speed mm/yr**	**Azimuth (cw from N)**	**E.**	**N.**	**Speed mm/yr**	**Azimuth (cw from N)**
ABUZ	22.60	21.25	31.02	46.75°	21.56	18.25	28.24	49.76°	1.04	3.00	2.78	-3.01°
BKFP	22.08	20.89	30.40	46.58°	21.20	18.19	27.93	49.38°	0.88	2.70	2.47	-2.80°
CGGT	22.85	21.38	31.29	46.90°	21.71	18.25	28.36	49.95°	1.14	3.13	1.14	-3.05°
CLBR	23.52	21.31	31.74	47.83°	21.94	18.25	28.54	50.25°	1.58	3.06	3.20	-2.42°
FUTY	23.19	21.62	31.70	47.00°	21.94	18.22	28.52	50.29°	1.25	3.40	3.18	-3.29°
GEMB	23.42	21.54	31.82	47.40°	21.98	18.24	28.56	50.31°	1.44	3.30	3.26	-2.91°
MDGR	22.88	21.65	31.50	46.58°	21.85	18.20	28.44	50.20°	1.03	3.45	3.06	-3.62°
OSGF	22.91	21.23	31.23	47.17°	21.69	18.25	28.35	49.93°	1.22	2.98	2.88	-2.76°
RECT	23.01	20.93	31.10	47.71°	21.67	18.20	28.30	49.98°	1.34	2.73	2.80	-2.27°
RUST	23.49	21.19	31.63	47.94°	21.91	18.24	28.51	50.22°	1.58	2.95	3.12	-2.28°
ULAG	23.13	20.80	31.11	48.03°	21.71	18.17	28.31	50.07°	1.42	2.63	2.80	-1.77°
UNEC	23.30	21.24	31.52	47.65°	21.85	18.25	28.47	50.14°	1.45	2.99	3.05	-2.49°

Table 3.7: Computed residuals between **MORVEL** 2010 **a**nd GEODVEL 2010 Models

The two models here shows better correlation from the results compare to the others. The residuals between the two models were computed .The mean average of the residuals in all the components are:

Mean average velocities residuals: Easting = 1.28mm/yr

Northing = 3.03mm/yr

Mean average Speed residuals = 2.81mm/yr

Mean average Azimuth residuals = 2.72°

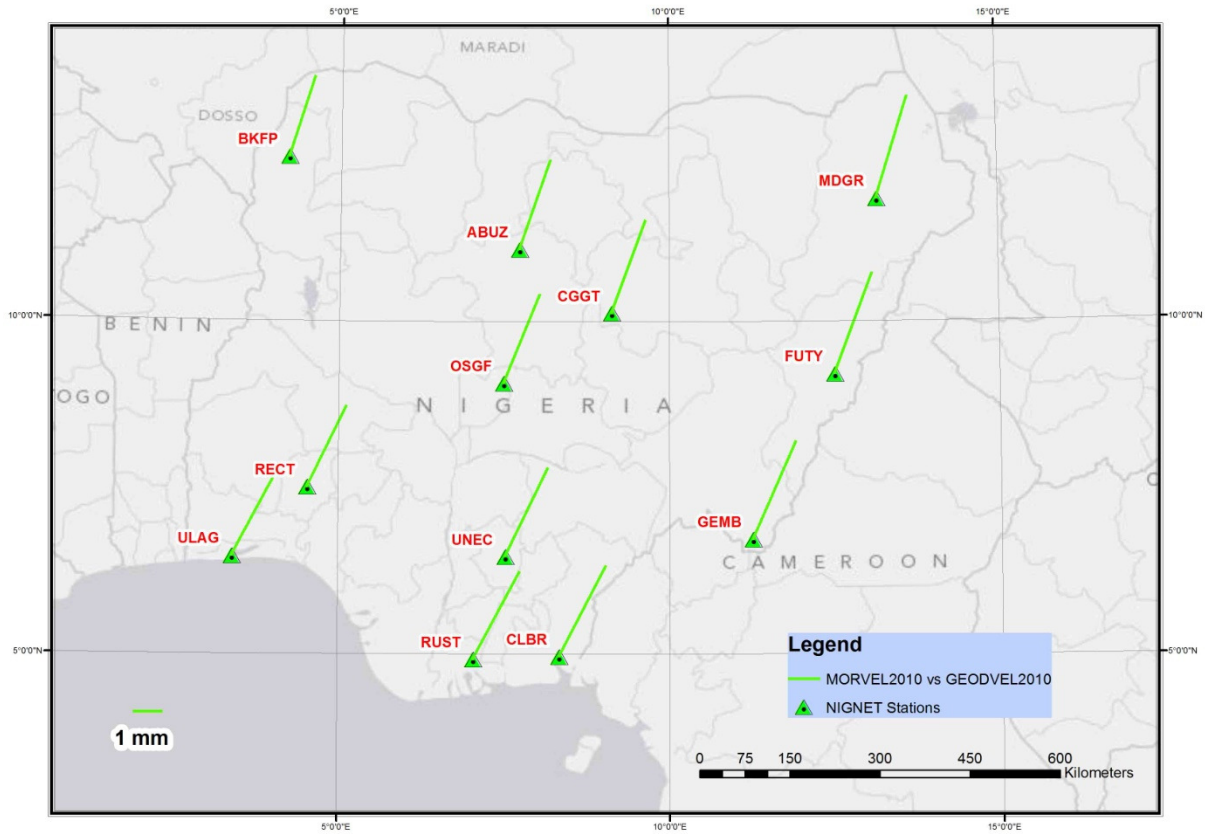


Fig 3.8: Residuals between MORVEL 2010 and GEODVEL 2010 Models.

The two models used here have not indicated much difference between the models, however, all the stations shows approximately equal magnitude of residuals and all trending in the same direction Northward direction. It can be concluded that the two models possessed similar features. Even though five (5) of the 25 tectonic plates are modeled to GPS data while MORVEL 2010 depends solely on the geophysical and geological data of several million years (3-5 million years).

3.3.10 Comparison between HS2 NUVEL -1A and MORVEL 2010 Models from computed residuals.

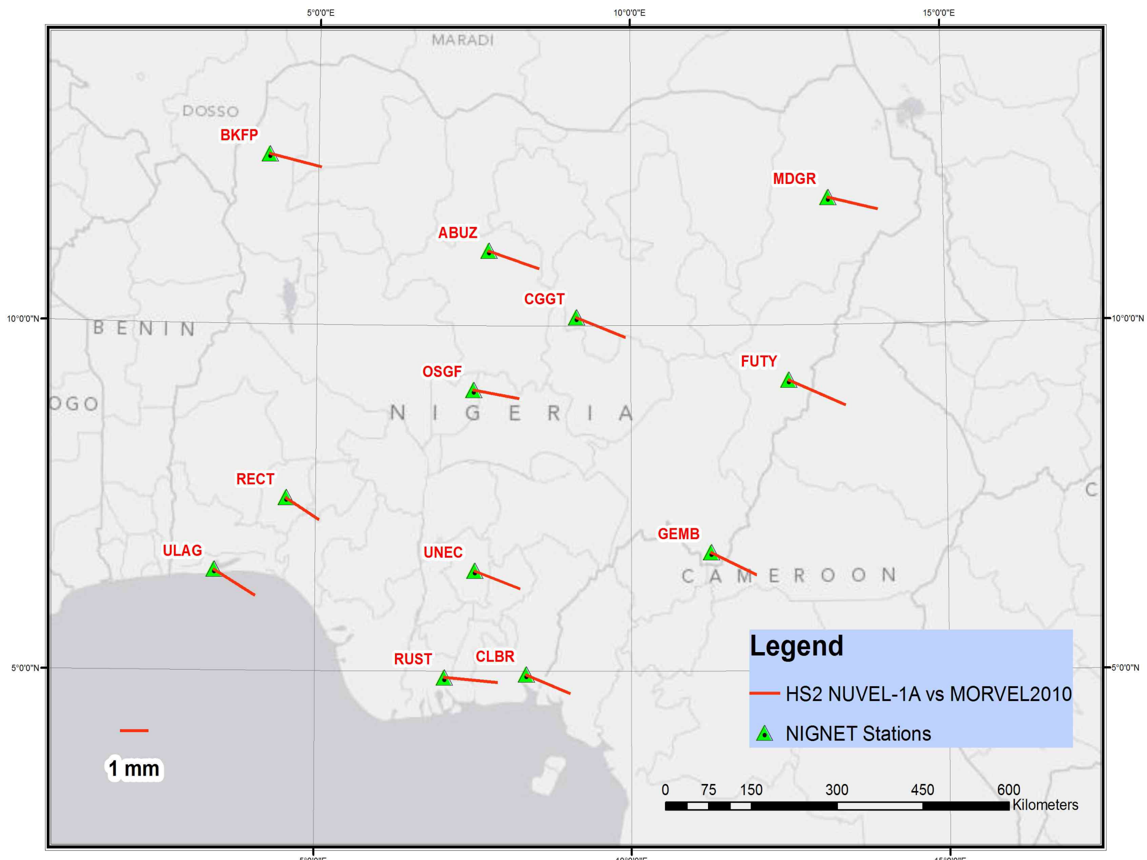


Fig 3.9: Residuals between HS2 NUVEL – 1A and MORVEL 2010 Models.

The residuals between HS2 NUVEL -1A versus MORVEL 2010 Models were computed from the estimated relative motions of all the NIGNET Network and plotted as seen in figure 3.9 above. The residuals in all the stations are trending Eastward direction. The comparison in these models shows complete opposite to that between MORVEL 2010 versus GEODVEL 2010 Models and HS2 NUVEL – 1A and GEODVEL 2010 Models.

3.3.11 Comparisons between HS2 NUVEL -1A and GEODVEL 2010 Models from computed residuals.

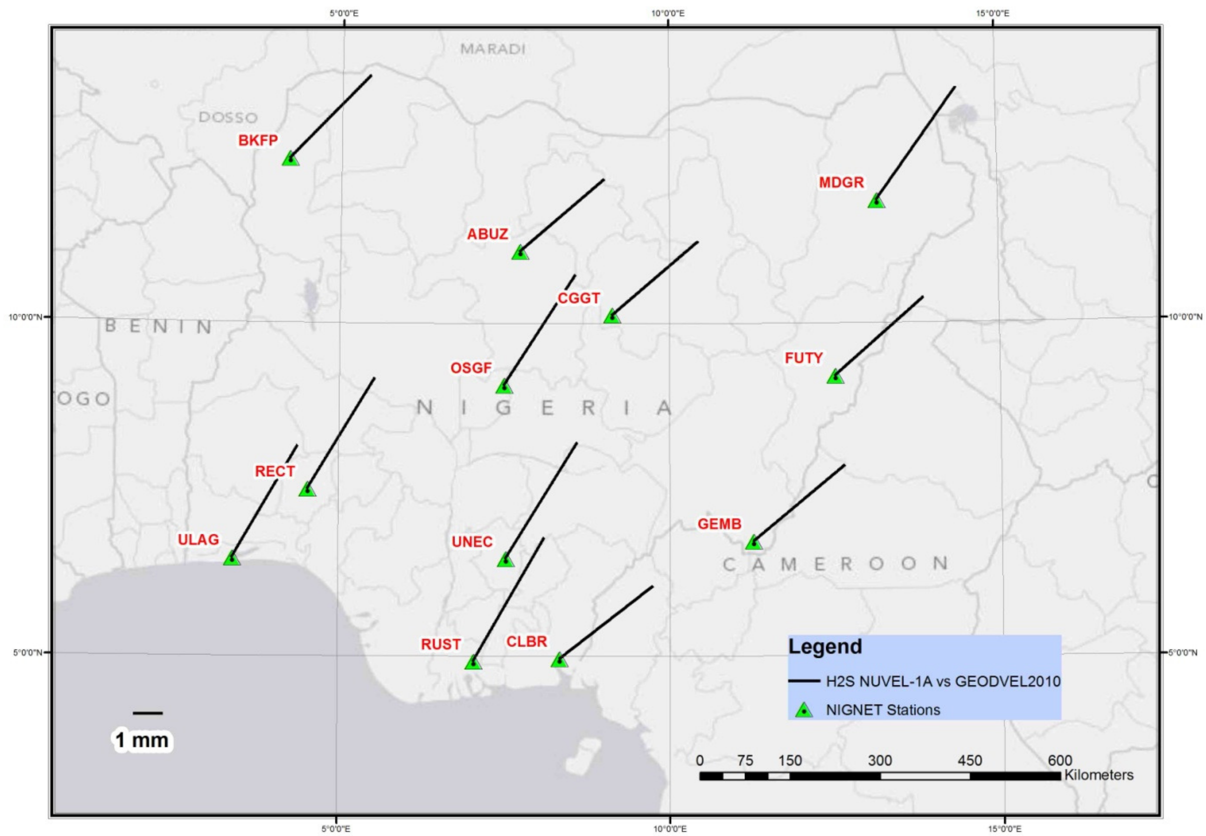


Fig 3.10: Residuals between HS2 NUVEL – 1A and GEODVEL 2010 Models.

The residuals between estimated relative motions computed from HS2 NUVEL – 1A and GEODVEL 2010 Models at each NIGNET Network stations was computed and plotted on a map as shown above. The residuals computed from the two models in each station has not shown much significant differences and are all approximately in the same direction unlike in the figure 3.10 above that shows much disparities and deviations in the directions, this models may not be very good for the relative estimation.

3.3.12 Comparisons between the three (3) Models.

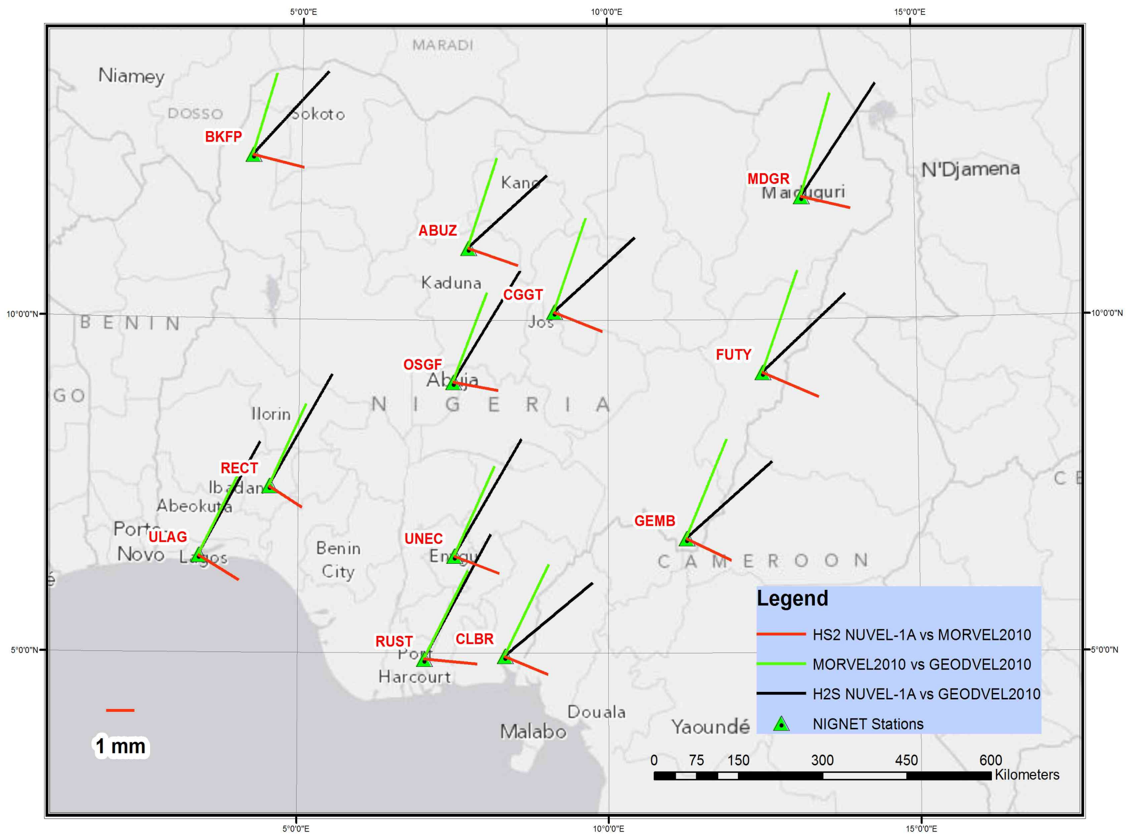


Fig 3.11: Residuals between all the three (3) Models.

The Figure above shows the comparisons of the computed residuals between the three (3) models, a combinations of HS2 NUVEL -1A versus GEODVEL 2010 and MORVEL 2010 versus GEODVEL 2010 shows a very good correlations with nearly the same amount of residuals in each station and approximately in the same direction, more larger residuals when compare to the residuals computed between HS2 NUVEL -1A versus MORVEL 2010.

3.3.13 Total Mean average residuals between different Models.

Versus		East Component mm/yr	North Component mm/yr	Speed mm/yr	Azimuth
HS2 NUVEL -1A	**MORVEL 2010**	**- 1.68**	**-0.56**	**1.16**	**2.59°**
HS2 NUVEL -1A	**GEODVEL 2010**	**2.97**	**2.43**	**3.75**	**0.46°**
MORVEL 2010	**GEODVEL 2010**	**1.28**	**3.03**	**2.81**	**2.72°**

Table 3.8: Computed total mean residuals between different models.

Here the totals mean summary residuals between all the models in all the stations were computed, the combinations the models with the highest total mean residuals in the East component is HS2 NUVEL -1A and GEODVEL 2010 with a value of 2.97mm/yr, while the models with highest value in the North component is MORVEL 2010 and GEODVEL 2010 with 3.03mm/yr, models HS2 NUVEL -1A and GEOD VEL 2010 also recorded the highest speed of 3.75mm/yr and the highest azimuth of 2.59° was recorded by models HS2 NUVEL -1A and MORVEL 2010. The results on the computed residuals between models are attached in the Appendix B.

Chapter 4

Conclusion and Recommendations

4.1 Conclusion

After thorough analysis and in view of the fact that all the stations in the Network are still young (less than 4years), the oldest stations in the network are stations RECT, ULAG and OSGF which were installed in 2009, while the youngest stations in the network as at the time of this research were stations MDGR and CLBR installed in 2011. The data transmission in these stations from the available records started immediately after the installations, so for these reason(s). it will be too early at this moment to reach a logical conclusion on the quality of the data obtained from the Network after the assessment or analysis. Even though the results obtained so far seems to be encouraging but there is still room for the improvement.

The issue identified in the vertical component which is common in all the stations in the NIGNET Network is the seasonal trend of the signal. So many factors ranging from the geologic settings of the sites (sedimentary or basement), the proximity of some stations to the coast such as stations ULAG, CLBR and RUST, some stations that are located on the sedimentary environment but not close to the coast such stations like BKFP, FUTY, MDGR and UNEC may also be affected by the sedimentary nature of their locations, but are likely to be much affected by the ocean tide loading. Other factors such as dilatation (thermal expansion) of the monument since almost all the stations except CGGT have their antenna on top of the buildings. The contraction due to the weather changes (dry and wet) can reflect on the vertical component in the time series. CGGT may be affected by the bedrock expansion during the dry season since the monument was directly constructed on the exposed rockout crop, which may contract during the winter season. These changes can also be visible on the vertical (Up) component in the time series. Other factors that may cause some changes in the vertical component in time series are improper modeling of errors, ocean tide loading, atmospheric, equipment behaviors just to mentioned a few.

However, it is still normal that in every new setup like in the case of NIGNET Network it is pertinent that trouble shooting will always be experienced at the beginning of the implementation, such as failure of equipments (receiver and antenna). But as the network gets older the problems will be overcome and better results will be achieved.

4.2 Recommendations

Haven carefully analyzed the processed GPS time series of NIGNET Network; the recommendation is therefore presented as follows:

- The research be repeated when the Network has attained the ages between 10 – 12 years, in order to achieve acceptable results, since NIGNET Network is still young (less than 4years).

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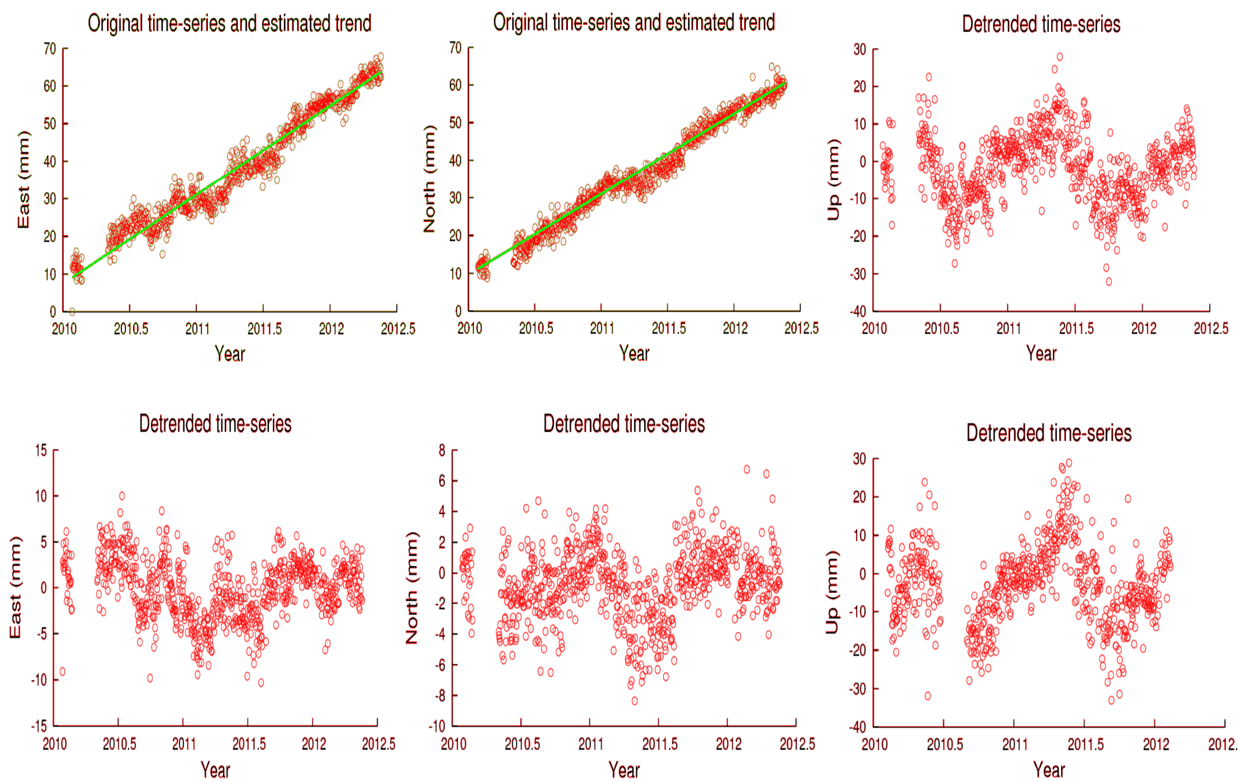
Appendix A

NIGNET Network Time Series

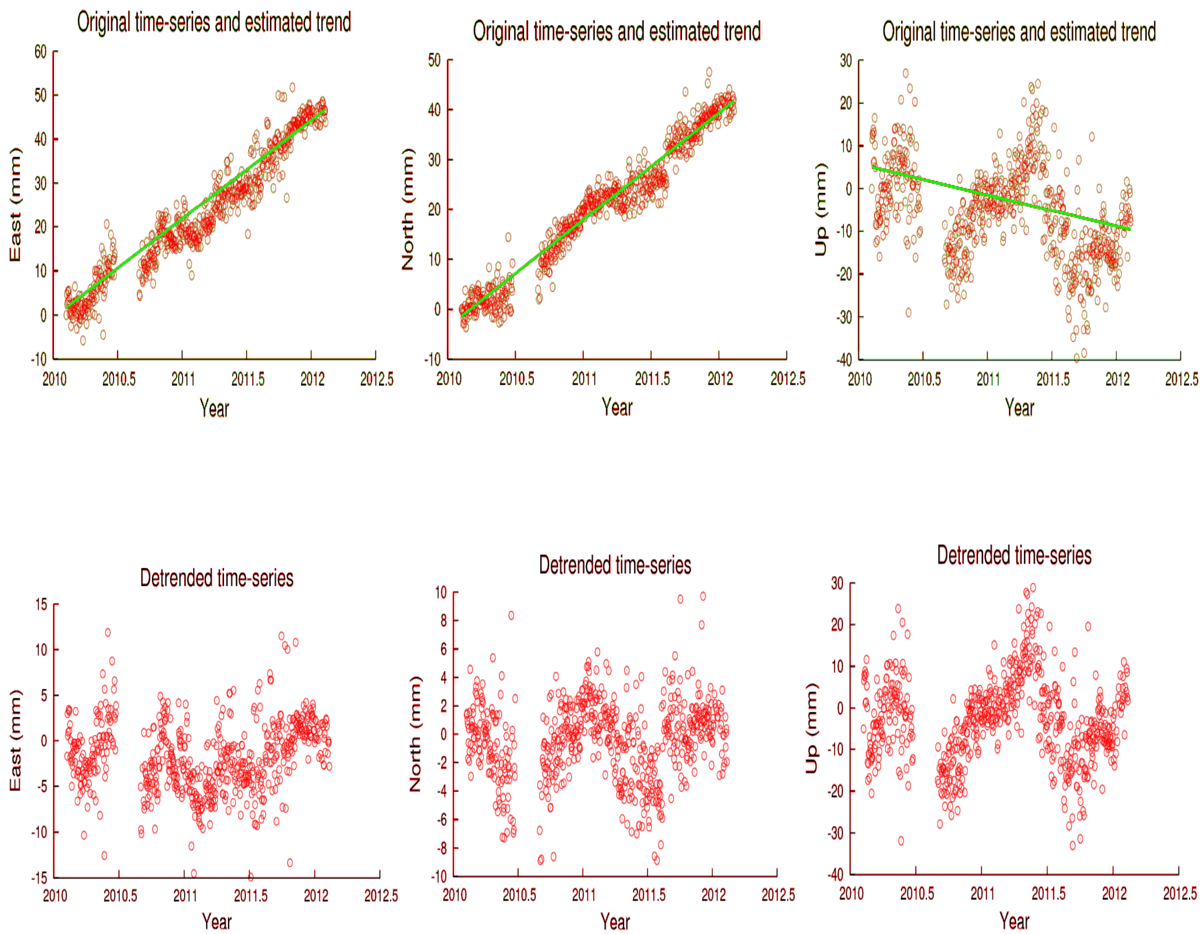
A.1 Station BKFP Time Series



Figures A.1: Above are Original, Estimated and Detrended time series at station BKFP

Station BKFP has transmitted a data of two (2) years and fourth (4) months from January 2010 to May 2012 which was processed for the time series in this station. There is a correlation or similarities in the time series of station BKFP compare to station ABUZ in all the components, the correlation or similarities may have common reasons compare to what was described in station ABUZ. The disparities in the signal on the time series were observed between the first year and second year of the observations (between 2010 to 2011and 2011 to 2012). The vertical (Up) component indicates a seasonal signal recorded in 2010.2, 2010.7, 2011.2 and 2011.7 and 2012.2 respectively. With higher amplitudes of + 40mm observed in 2010.4, 2011.4 and lower amplitudes of -30mm. The reason for seasonal signal may also be as one of the reasons discussed in the station ABUZ. The data gaps in time series was estimated to about two (2) months.

A.2 Station CGGT Time Series

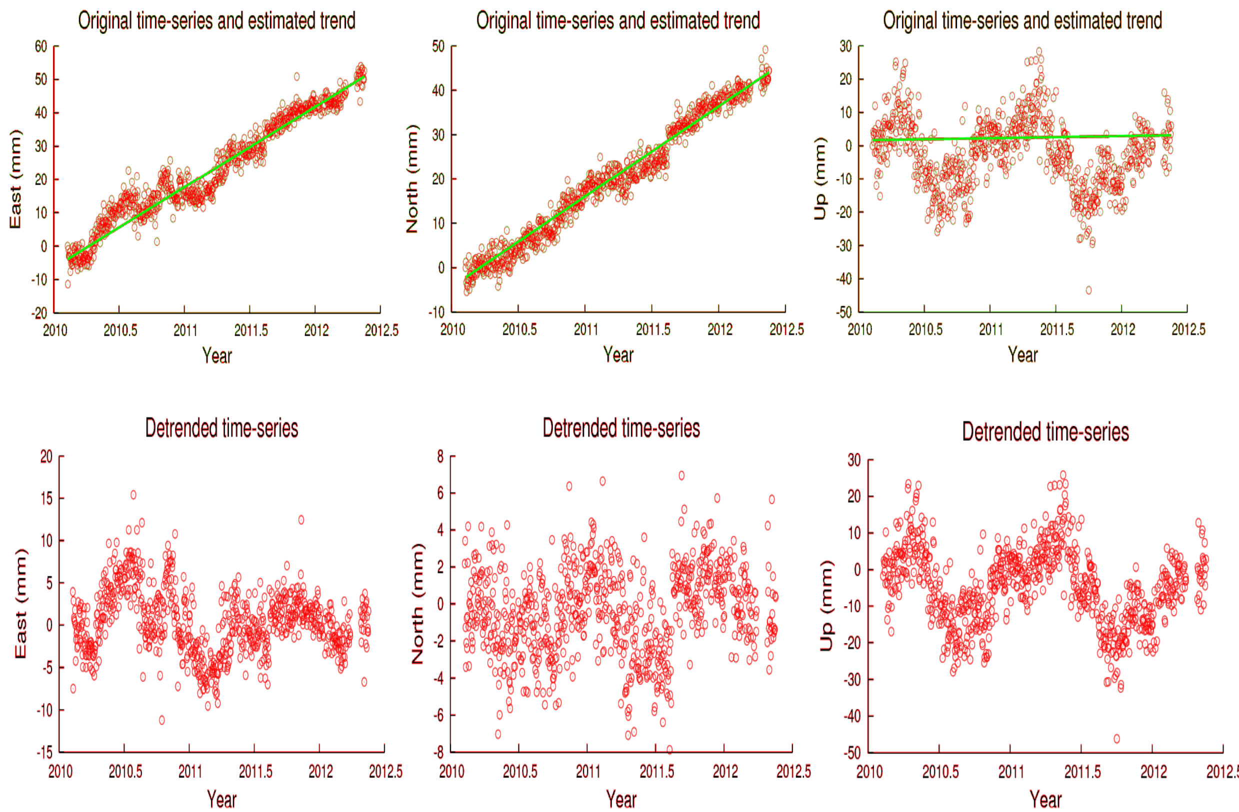


Figures A. 2: Above are Original, Estimated, and Detrended time series at station CGGT.

The data for 850 days (about two years and fourth months) was processed for the time series of the station CGGT. There is a correlation or similarities in the characteristics of the signal trends in all the components similar to other stations in the network, a large deviation of signal away from the average trend or linear regression was observed in East component. The North component trend is better along the average trend or linear regression. A seasonal signal was also observed in the time series on the vertical component in 2010.2, 2010.7, 2011.2, 2011.7 and 2012.2 similar to stations ABUZ and BKFP. The signal amplitudes in the vertical component are higher +60mm/y in 2010.4, 2011.4 and lower (-20mm) in 2010.8, 2011.8. The reason (s) for the seasonal signal in this station may be different compare to other stations in the network, probably, as a result of thermal expansion of the antenna or bedrock expansion since the station monument is located on the rock out crop (exposed rock) which is not common in the network.

The data gaps on the time series were recorded between 2010.4 to July 2010.6 and 2011.6 to 2011.8 respectively. The data gaps on the time series may also be as a result of power failure or equipment problem (receiver or antenna).

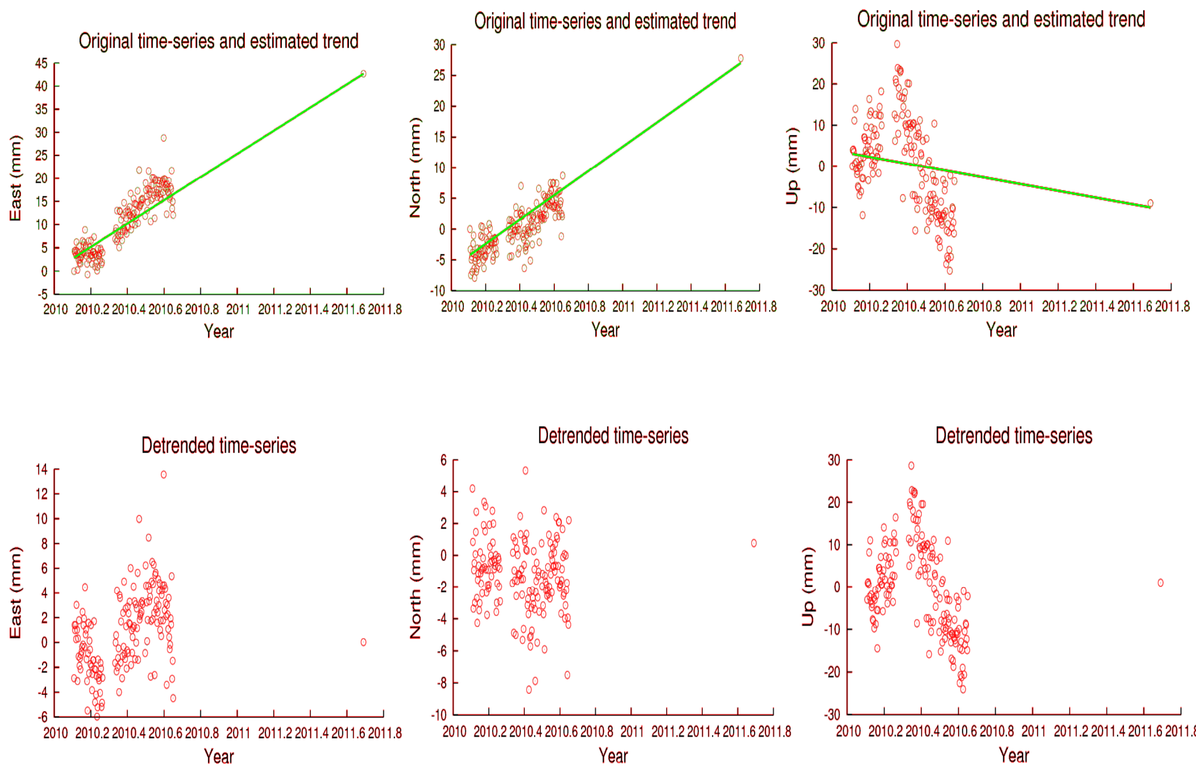
A.3 Station FUTY Time Series



Figures A.3: Above are Original, Estimated, and Detrended time series at station FUTY

Two (2) years (from January 2010 to May 2012) data was processed for the time series in the station. There is a correlation or similarities when compare to stations ABUZ, BKFP and CGGT. The noise in this station can also be classified in to two categories similar to that of station ABUZ, BKFP and others above, the signal in the first year (2010 to 2011) is smoother while in the second year (2011 to May 2012) looks more disperse along the linear regression or average trend. This noise can be classified as power law (*slope α)* and white noise (*σw)* on the time series. The vertical (Up) component shows a seasonal signal. The changes in the amplitudes of the signal in the time series were observed in 2010.4, 2010.8, and 2011.4, 2011.8 years respectively. The higher amplitudes of +25mm/y and the lower amplitudes of – 55mm/y were observed in 2010.2 & 2011.2 and 2010.7 & 2011.7 respectively. The reason (s) for the seasonal signal may also be related to that of station ABUZ. There hasn't been any problem of power failure (electricity) or faulty equipment (receiver or antenna) in the station so for these reasons there was no record of data gaps.

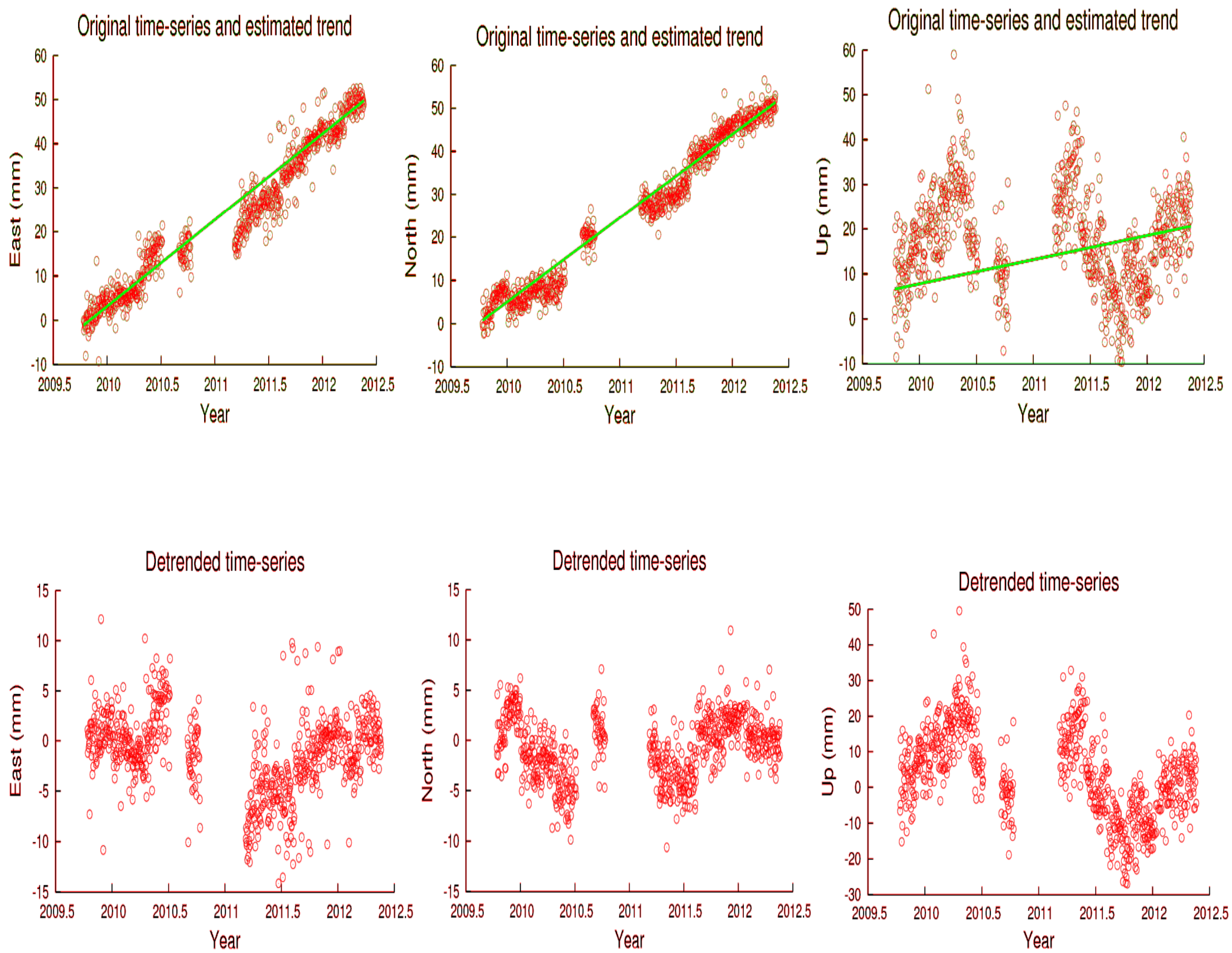
A.4 Station GEMB



Figures A4: Station GEMB

The Station was installed in January 2010, and data of 2years and months was available for this research Project, the station was witnessed a long time gap between June 2010 until 2011 about August 2011, there was a failure of the equipment in the station for this period, also about a month data gap was also recorded between February 2010 and April 2010 just the immediately after the installation. Similar to other stations there is a large disperse of signal was also experience in the North component along the linear regression compare to the East component. There is also an indication of seasonal signal in the time series in the vertical component.

A.5 OSGF Time Series



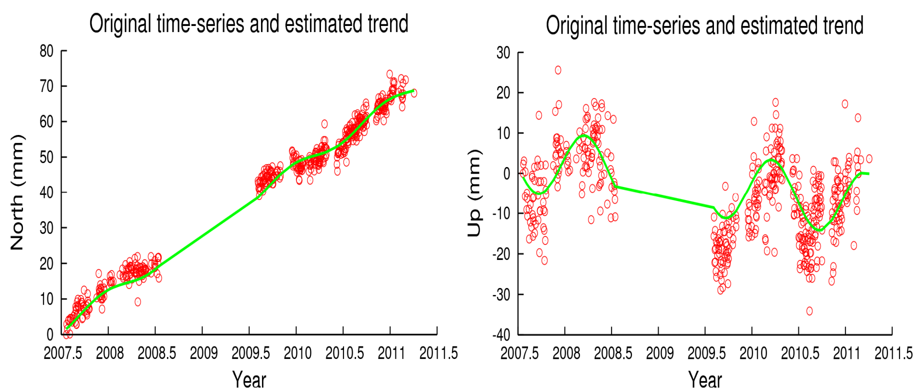
Figures A.5: Above are Original, Estimated and Detrended time series at station OSGF.

OSGF station is one of the three (3) oldest stations in the network, the station was installed in 2009, three 3 years data (May 2009 to May 2012) was processed for the time series in the station, there is a correlation in the time series in the station compare to stations ABUZ, BKFP, FUTY and CGGT. There is more dispersion or deviation of signal in the East compare to the North along the linear regression or average trend, the signal in the horizontal component is smoother in the first year compare to the last year in the time series even though a large data gaps was recorded at the middle of the data transmission, analysis shows more white noise in the East component compare than North component and more power law in the North component than in the East component.

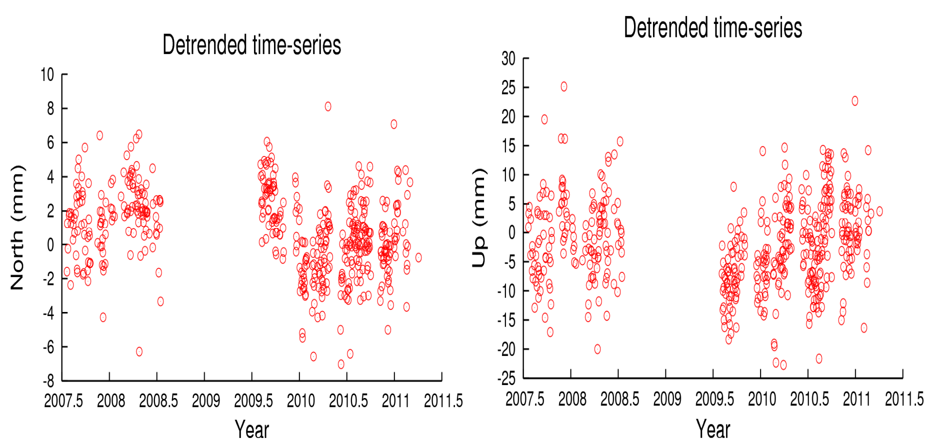
A seasonal signal was observed in the vertical component with the changes in the amplitudes. The highest amplitudes of +40mm/y were recorded in April 2009, 2010 and 2012 while the lowest amplitudes of – 25mm/y. The data gaps in the time series recorded in the time series was quiet a large period, an estimated total data gaps of about seven (7) months was recorded. The presence of the data gaps in the time series may also be associated to the power failure (electricity) or faulty equipment (antenna or receiver) as the case may be in other stations in the network. The solution to the problem of the data gaps in the time series has been explain in section 3.1.3.

A.6 Station RECT Time Series

East



East

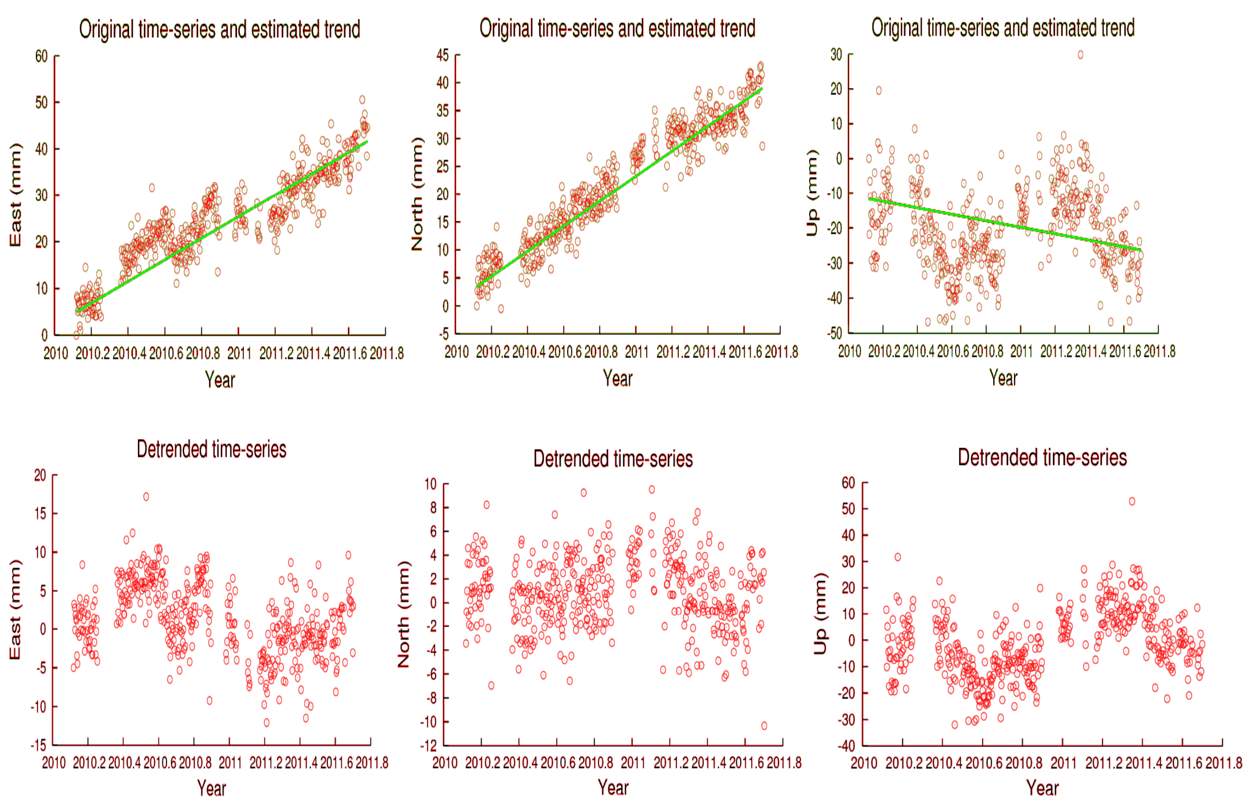


Figures A.6: Above are Original, Estimated, and Detrended time series at station RECT.

Station RECT was installed in the May 2007, and from the record is the oldest station in the network, available of fourth (4) years data was processed for the time series in this station, going by the analysis of the time series there is a correlation in the time series compare to others stations.

The horizontal motion are along the average trend or linear regression, but the deviation or dispersions of the signal is more in the in the East component than the North component, the signal is smoother in the North component. From the analysis the East component contain more white noise compare to the counterpart North component. The best way of assessing the noise types is by using spectral analysis and Maximum Likelihood Estimation method, a combination of white noise and power law noise appears to be the best model for the noise characteristics. The vertical (Up) component shows some a seasonal trend, the fluctuation in the vertical (Up) component were observed with higher amplitude of +30mm while the lowest amplitudes of -30mm on the time series. The changes observed in signal in the station time series may be as a result or reasons similar to that of station ABUZ and others since there is a correlation between the time series in virtually all the stations. The station has recorded data gaps on many occasions estimated to about 270days , the reason (s) for the data gaps may also be associated to power failure (electricity) or equipment failure (receiver or antenna) problem, going by the Geologic settings of Nigeria station is located on the basement complex.

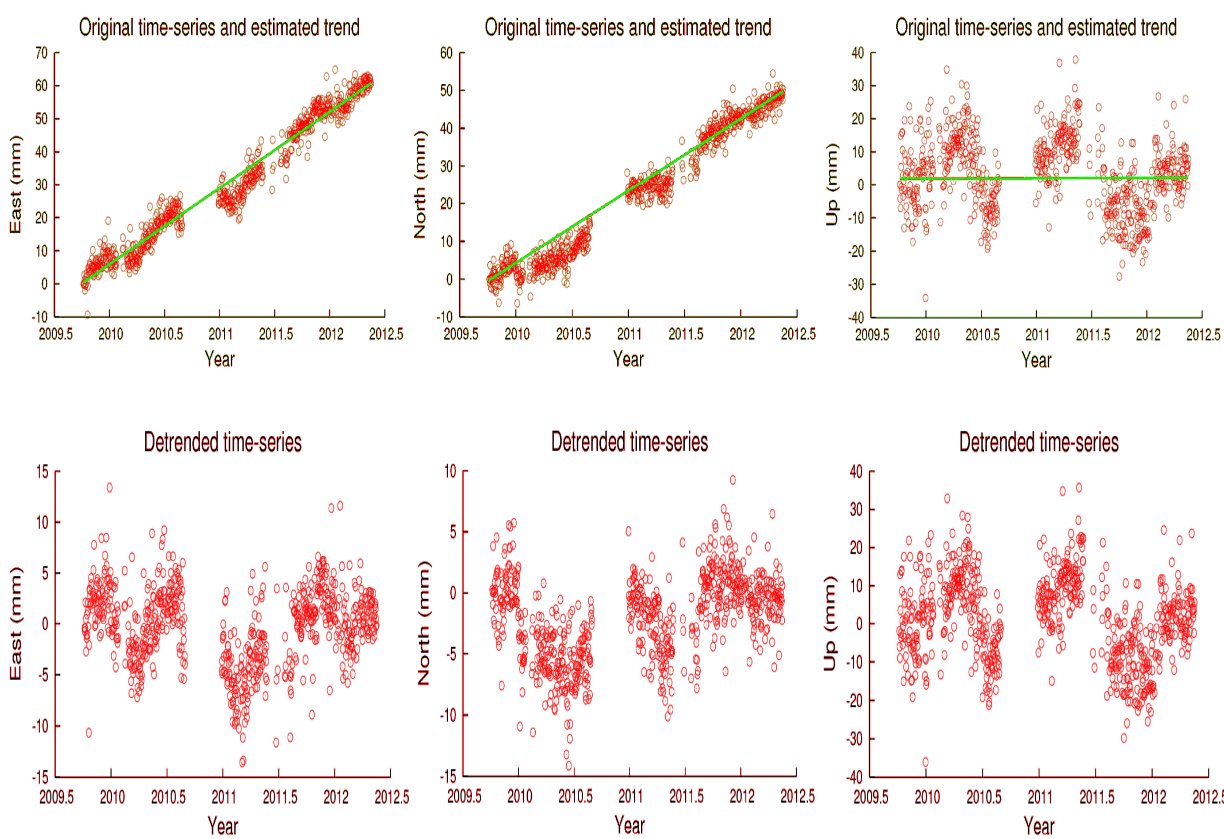
A.7 Station RUST Time Series



Figures A.7: Above are Original, Estimated, and Detrended time series at station RUST

One (1) year and Eight (8) months data (from January 2010 to August 2011) estimated to about 605 days was processed in station RUST, however, there is a correlation in the time series when compare to others, the vertical (Up) component also indicates a seasonal signal which were recorded simultaneously in 2010.2, 2010.6, 2011.2 and 2011.6 respectively. The highest amplitudes of +40mm were observed. The seasonal trend observed may be as a result of the reasons explained in station ABUZ. The data gaps observed in the time series was estimated for a period of one month. The presence of the data gaps may probably be associated to the same reasons in other stations in the network, the station appears to be slightly moving downward, the negative movement observed in the station may be as a result of some environmental factors or the geologic setting of the site, which is purely sedimentary environment and also the nearness of the station to the coast, ocean tide loading may affect the downward movement.

A.8 Station ULAG Time Series

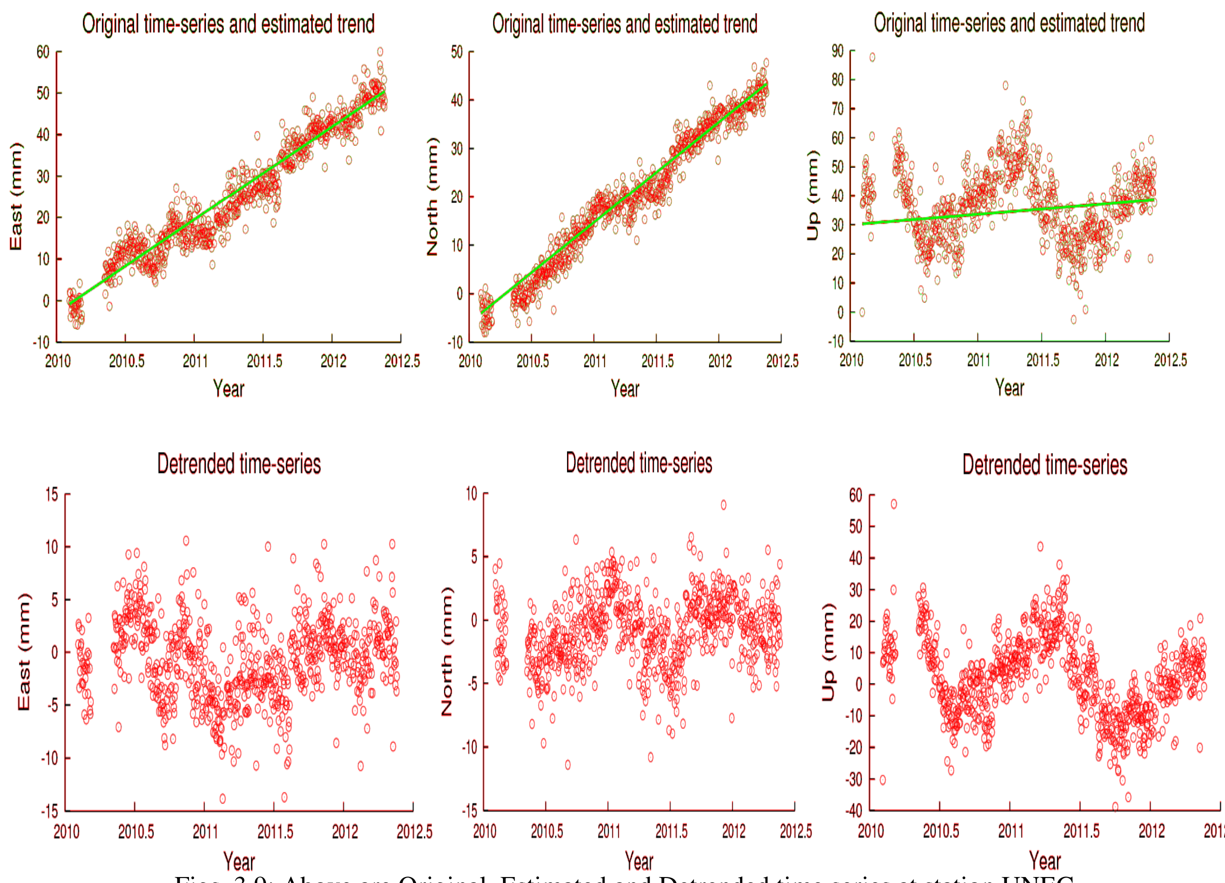


Figures A.8: Above are Original, Estimated, and Detrended time series at station ULAG

This is one of the three (3) oldest stations in the NIGNET Network; the station was installed the same time with station OSGF, fourth (4) data was processed for the time series in this station.

Similar to other stations in the network, there is a correlation in the signal characteristics in the time series compare to other stations and the reasons for the correlation may as well be the same. The seasonal trend is also observed on the vertical component with highest amplitudes of +40mm and lowest amplitudes of -28mm recorded respectively. The station looks slightly subsiding, this may be similar to what was experienced in the station RUST since both stations are located in the sedimentary environment and closed to the coast, even when ocean tide loading is modeled there is still likely hood of the effect on the time series, the time series indicates some data gaps, the data gaps that exist in the time series may be also be associated to the faulty equipment (antenna or receiver) problem

A.9 Station UNEC Time Series



Figs. 3.9: Above are Original, Estimated and Detrended time series at station UNEC

In this station two (2) years and two (2) months data estimated to about 790days, the station UNEC is not an exception in the network when analyzing the time series, while the vertical (Up) component is showing some negative values, even though the station is located on the sedimentary environment form the geologic point of view but not close to the coast as compared to stations RUST, ULAG and CLBR. A seasonal signal is also observed in the time series. The station has recorded data gaps shortly after it started data transmission as indicated in the time series, estimated to about two months, similar reasons such as power failure (Electricity)or Equipment failure may have caused the data gaps. However, the Methods of eliminating the problem of data gaps in the time series have already been described in section 3.1.3 above.

APPENDIX B

B.1 Comparison between Observed (GPS) versus relative motions Computed using Observed (GPS) versus MORVEL 2010 Model

Station Name	Observed (GPS)		MORVEL 2010		Residuals		Remarks
	East Vel.	North Vel.	East Vel.	North Vel.	East Component	North Component	
ABUZ	22.39	20.24	22.60	21.25	-0.21	-0.01	
BKFP	23.62	21.33	22.08	20.89	1.54	0.44	
CGGT	22.39	21.46	22.85	21.38	-0.46	0.08	
FUTY	24.11	20.34	23.19	21.62	0.92	-1.28	
GEMB	25.14	19.72	23.42	21.54	1.72	-1.82	
OSGF	19.56	19.46	22.91	21.23	-3.35	-1.77	
RECT	21.73	17.94	23.01	20.93	-1.28	-2.99	
RUST	23.13	22.45	23.49	21.19	-0.36	1.26	
ULAG	23.09	19.14	23.13	20.80	-0.04	-1.66	
UNEC	22.37	20.70	23.30	21.24	-0.93	-0.54	

Table B.1: Computed residuals between Observed (GPS) and MORVEL 2010 Models.

There is a correlation between the results after the computation, but the same situation was observed as in the case in section 3.5.1 above. Station CLBR show a very a large residuals of 19.28mm/yr in the East component form the observed. The average mean residuals computed from both observed and estimated motions in all the stations are as shown below:

Mean average velocities residuals: Easting = 3.52mm/yr
Northing = 1.30mm/yr

B.2 Comparison between Observed (GPS) versus relative motions Computed using GEODVEL 2010 Model.

Station Name	Observed (GPS)		GEODVEL 2010		Residuals		Remarks
	East Vel.	North Vel.	East Vel.	North Vel.	East Component	North Component	
ABUZ	22.39	20.24	21.56	18.25	0.83	1.99	
BKFP	23.62	21.33	21.20	18.19	2.42	3.14	
CGGT	22.39	21.46	21.71	18.25	0.68	3.21	
FUTY	24.11	20.34	21.94	18.22	2.17	2.12	
GEMB	25.14	19.72	21.98	18.24	3.16	1.48	
OSGF	19.56	19.46	21.85	18.20	-2.29	1.26	
RECT	21.73	17.94	21.69	18.25	0.04	-0.33	
RUST	23.13	22.45	21.67	18.20	1.46	4.25	
ULAG	23.09	19.14	21.71	18.17	1.38	0.97	
UNEC	22.37	20.70	21.85	18.25	0.52	2.45	

Table B.2: Computed residuals between Observed (GPS) and GEODVEL 2010 Model.

In this section the results obtained from the motion estimation computed using GEODVEL 2010 Model is compared with the results from observed (GPS), there is a correlation or similarities compare to that in sections 3.5.1and 3.5.2. However, station CLBR recorded very large residuals of 20.86mm/yr in the East component. The mean average residuals computed in both components in all the stations in the network are as shown below:

Mean average velocities residuals: Easting = 3.73mm/yr

Northing = 1.85mm/yr

B.3 Comparison of computed estimated relative motions of NIGNET Network between HS2 NUVEL – 1Aversus MORVEL 2010 Models.

Station Name	**HS2 NUVEL -1A Model**				**MORVEL 2010 Model**				**Residuals**			
	E. Vel.	**N. Vel.**	**Speed mm/yr**	**Azimuth (cw from N)**	**E Vel.**	**N Vel.**	**Speed mm/yr**	**Azimuth (cw from N)**	**E**	**N**	**Speed mm/yr**	**Azimuth (cw from N)**
ABUZ	24.39	20.67	31.97	49.72°	22.60	21.25	31.02	46.75°	1.79	-0.58	0.95	2.97°
BKFP	23.92	20.45	31.47	49.48°	22.08	20.89	30.40	46.58°	1.84	-0.44	1.07	2.90°
CGGT	24.60	20.73	32.17	49.88°	22.85	21.38	31.29	46.90°	1.75	-0.65	0.88	2.98°
CLBR	25.09	20.70	32.52	50.48°	23.52	21.31	31.74	47.83°	1.57	-0.61	0.78	2.65°
FUTY	24.90	20.84	32.47	50.08°	22.88	21.65	31.50	46.58°	2.02	-0.81	0.97	3.50°
GEMB	25.05	20.81	32.57	50.29°	23.42	21.54	31.82	47.40°	1.63	-0.73	0.75	2.89
MDGR	24.68	20.85	32.31	49.82°	22.91	21.23	31.23	47.17°	1.77	-0.38	1.08	2.65°
OSGF	24.63	20.65	32.14	50.02°	23.01	20.93	31.10	47.71°	1.62	-0.28	1.04	2.31°
RECT	24.67	20.47	32.06	50.32°	23.49	21.19	31.63	47.94°	1.18	-0.72	0.43	2.38°
RUST	25.05	20.63	32.45	50.53°	23.13	20.80	31.11	48.03°	1.92	-0.17	1.34	2.50°
ULAG	24.76	20.39	32.07	50.53°	23.30	21.24	31.52	47.65°	1.46	-0.85	0.55	2.88°
UNEC	24.92	20.66	32.37	50.34°	23.30	21.24	28.24	49.76°	1.62	-0.58	4.13	0.58°

Table B.3: Computed residuals between HS2 NUVEL -1A and MORVEL 2010 Models.

The residuals between all the components in each station were computed from the results obtained from the two models (HS2 NUVEL -1A and MORVEL 2010), the results obtained indicates a very good correlation, the residuals or differences between the two results are significant in the two components (East and North). The mean average velocities in the East/North mean average speed residuals in mm/yr and mean average azimuth residuals were computed as shown below:

Mean average velocities residuals: Easting = -1.68mm/yr

Northing = -0.56mm/yr

Mean average Speed residuals = 1.16mm/yr

Mean average Azimuth residuals = 2.59°

B.4 Comparison of computed estimated relative motions of NIGNET Network between HS2 NUVEL – 1A versus GEODVEL 2010 Models.

Station Name	**HS2 NUVEL -1A Model**				**GEODVEL 2010 Model**				**Residuals**			
	E. Vel.	**N. Vel.**	**Speed mm/yr**	**Azimuth (cw from N)**	**E Vel.**	**N Vel.**	**Speed mm/yr**	**Azimuth (cw from N)**	**E.**	**N.**	**Speed mm/yr**	**Azimuth (cw from N)**
ABUZ	24.39	20.67	31.97	49.72°	21.56	18.25	28.24	49.76°	2.83	2.42	3.73	- 0.04°
BKFP	23.93	20.45	31.47	49.48°	21.20	18.19	27.93	49.38°	2.73	2.26	3.54	0.10°
CGGT	24.60	20.73	32.17	49.88°	21.71	18.25	28.36	49.95°	2.89	2.48	3.81	- 0.07°
CLBR	25.09	20.70	32.52	50.48°	21.94	18.25	28.54	50.25°	3.15	2.45	3.98	0.23°
FUTY	24.90	20.84	32.47	50.08°	21.94	18.22	31.70	47.00°	2.96	2.64	0.77	3.08°
GEMB	25.05	20.81	32.57	50.29°	21.98	18.24	28.56	50.31°	3.07	2.57	4.01	-0.02
MDGR	24.68	20.85	32.31	49.82°	21.85	18.20	28.52	50.29°	2.83	2.65	3.79	-0.47°
OSGF	24.63	20.65	32.14	50.02°	21.69	18.25	28.44	50.20°	2.94	2.40	3.70	0.00°
RECT	24.67	20.47	32.06	50.32°	21.67	18.20	28.35	49.93°	3.00	2.27	3.71	0.39°
RUST	25.05	20.63	32.45	50.53°	21.91	18.24	28.30	49.98°	3.14	2.39	4.15	0.55°
ULAG	24.76	20.39	32.07	50.53°	21.71	18.17	28.31	50.07°	3.05	2.22	3.76	0.46°
UNEC	24.92	20.66	32.37	50.34°	21.85	18.25	28.47	50.14°	3.07	2.41	3.90	0.20°

Table B.4: Computed residuals between HS2 NUVEL -1A and GEODVEL 2010 Models.

The residuals between the results obtained from the two models HS2 NUVEL -1A and GEODVEL 2010 in each station were computed as shown in 3.10 above. There is a significant different in the computed residuals. The mean average residual in all the components is as shown below:

Mean average velocities residuals: Easting = 2.97mm/yr

Northing = 2.43mm/yr

Mean average Speed residuals = 3.57mm/yr

Mean average Azimuth residuals = 0.46°