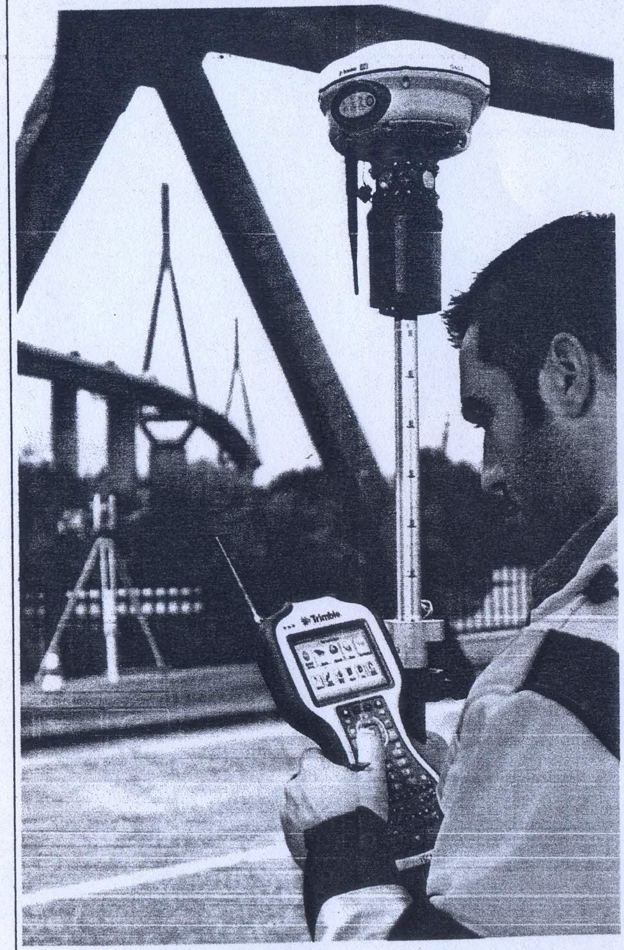

March 2016 Volume 5 Number 1 ISSN: 0189-8914

Nigerian Journal of Surveying and Geoinformatics

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March 2016 Volume 5 Number 1

The Nigerian Institution of Surveyors

Published by

The Nigerian Institution of Surveyors (NIS)
30 S. O. Williams Crescent, off Anthony Enahoro Street,
off Ngozi Okonjo-Iweala Way, Utako, Abuja, Nigeria
P. M. B. 763, Garki, Abuja
Website: www.nisngr.net
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ISSN: 0189-8914

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(2) Petrie, G. 1984. "Hardware aspects of digital mapping". *Journal of Photogrammetric Engineering and Remote Sensing*, 47/3, pp. 307-320.
(3) USGS. 1994. "Spatial Data Transfer Standard," available from http://nsdi.usgs.gov/nsdi

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Nigerian Journal of Surveying and Geoinformatics

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Analysis of the Effect of Orbital Perturbation on Global Navigation Satellite System Precise Point Positioning Technique

J. O. Odumosu[1], A. S. Alademomi[2],
O. G. Ajayi[1], C. V. Okorocha[3], E. A. Adesina[1], K. Sanni[1]

Abstract

Post-processing of Global Navigation Satellite System (GNSS) observations from Continuosly Operating Reference Stations (CORS) require that, corrections for satellite orbital perturbation be applied to the downloaded CORS ephemeris data prior processing. This study aims at investigating the extent of the effect of orbital perturbations on Precise Point Positioning (PPP). Four (4) processing techniques adopted include the direct broadcast ephemeris Only, IGS ultra-rapid orbit solution, IGS rapid orbit solution, and IGS final orbit solution. The solutions from the four approaches were compared and the results showed estimated errors of 7m, 1m and 1m for East, North and Height components respectively.

Key Words: *PPP, Orbital perturbation, GNSS, International GNSS Services (IGS)*

Introduction

AMIDST several limitations of the conventional terrestrial positioning techniques some of which include; requirement for station intervisibility, inconsistent global datum, variations in projection system adopted in different belts etc., [2, 1], the Global Positioning System (GPS) for about two decades has presented the geodetic community with a highly sophisticated equipment that overcome the problems associated with terrestrial survey methods. GNSS is made up of three segments (Space Segment, Control Segment and User Segment), and all its equipment are able to provide superior precision and accuracy position estimates which can be verified more repeatedly compared to terrestrial surveying results [1].

To achieve the desired accuracy in satellite positioning, highly accurate atomic clocks are required as the accuracy of GNSS point determination depends on the accuracy of the time measured by these clocks and also other factors such as clock errors, orbit perturbations, atmospheric effects etcetera are to be taken into consideration so as to obtain a more precise or ultra-precise accuracy in positioning [10]. Orbit correction is achieved through satellite tracking and orbit determination which are essential elements for most satellite missions [7].

The advent of active controls (e.g. Continuously Operating Reference Stations-CORS) has popularized the Precise Point Positioning technique (PPP). Investigations on the effect of orbit error on Pseudo-range GNSS measurements (static and differential positioning) reported by [3] and the summary of related research results is contained in Table 1.

Table 1: Estimated quality of Orbits in 2003 [3]

Orbit Type	Quality	Delay of Availability	Available at
Broadcast Orbits	2 m	Real-time	Broadcast message
CODE Ultra Rapid	<10 cm	Orbits Real-time	CODE through FTP
CODE Rapid Orbits	<5 cm	After 12 hours	CODE through FTP
CODE Final Orbits	<5 cm	After 5–11 days	CODE,IGS Data Centers
IGS Ultra Rapid Orbit (pred)	10 cm	Real-time	IGS Data Centers and CBIS
IGS Ultra Rapid Orbit (obs)	<5 cm	After 3 hours	IGS Data Centers and CBIS
IGS Rapid Orbit	<5 cm	After 17 hours	IGS Data Centers and CBIS
IGS Final Orbit	<5 cm	After13 days	IGS Data Centers and CBIS

Satellite Orbit Determination

Appropriate mathematical description of a satellite's orbit requires that six quantities (orbital parameters) are first defined. These quantities could either be the state Vector (Velocity and Position Vectors) or the Keplarian elements. The Keplarian elements are: Semi-major Axis (a), Eccentricity (e), inclination (i), Argument of Peri-apsis (w), Time of Peri-apsis (T_p) and Longitude of ascending Node (Ω) [5].

The computation of orbital elements is a fundamental problem on positional astronomy and can be divided into two (2) major areas; orbit determination and orbit improvement [4]. [6] describe the mathematical models and algorithms for calculating the position of GLONASS satellites from their broadcast orbits; notwithstanding mathematical formulation behind the classical Gauss and Laplace methods of satellite orbit determination are herein briefly presented.

Given the Latitude and Longitude (φ, λ) ~~of the satellite at a~~ minimum of two (2) epochs, the Laplace method used to determine the direction cosines (ψ, μ, ν) is given by equation 1.

---

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[3] Lordsfield Surveys Nig. Ltd, Lagos.

$$\left.\begin{aligned}\psi &= \cos\varphi \ \cos\lambda\\ \mu &= \cos\varphi \ \sin\lambda\\ v &= \sin\varphi\end{aligned}\right\} \quad (1)$$

The Gaussian method on the other hand is based on the integral of the equation of motion and requires only two (2) polar co-ordinates for three (3) observations thereby determine three (3) co-ordinates of the unknown body at two times using the Gaussian equation. These direction cosines are thereafter converted into the regular Keplerian elements by means of equations 2-6 below (modified after [8 and 4] once the positions of the body at times t_1 and t_2 are known:

$$\tan i \cos(\varphi - \Omega) = \frac{\tan\varphi_2 - \tan\varphi_1 \cos(\lambda_2 - \lambda_1)}{\sin(\lambda_2 - \lambda_1)} \quad (2)$$

$$\sin\omega_j = {}^{\sin\varphi_j}/_{\sin i} \quad (3)$$

$$a = \frac{r_1 + r_2 - 2\sqrt{r_1 r_2}\cos g \cos f}{2\sin^2 g} \quad (4)$$

Where: $2f = \omega_2 - \omega_1$

$2g = E_2 - E_1$

E = Eccentricity Anomalies

$$r = \frac{\rho}{1 + e\cos\varphi}$$

$$\rho = a\left(1 - e^2\right) \quad (5)$$

$$k\left(t - t_p\right) = \frac{1}{2}\rho^{\frac{3}{2}}\left(\tan 0.5\,\varphi - 0.33333\tan^3 * 0.5\,\varphi\right) \quad (6)$$

Where:

ρ = ***Semiparameter***

i = ***orbital inclination***

e = orbital eccentricity

ω = ***argument of perigee***

Ω = ***Right ascension of ascending node***

t_p = time anomaly

Many analysis centers worldwide independently carry out orbit processing for GNSS spacecraft [11]. These centres include the Centre for Orbit Determination in Europe (CODE), European Space Agency (ESA), Jet Propulsion Laboratory (JPL) and others. These centres being members of the International GNSS Service (IGS), submit their results to the IGS which combine all these data to provide an official GPS orbit, along with other high quality GNSS data and data products. Three level of orbit solutions are available namely the (1) Ultra-rapid Orbit (After 3 hours) (2) Rapid Orbit (After 17 hours) (3) Final Orbit (After 13 days).

The Justification of Study

Satellite positioning is affected basically by clock, orbit, troposphere and multipath. As the tropospheric delay is optimally estimated using the Saastamoinen model, the clock and orbit error also need to be estimated. Most COR Station users however do not consider orbit while downloading a COR Station data to be used for processing observations and this results in erroneous values in the final solution obtained. *This paper therefore aims at investigating the orbital effects on PPP technique using one of the NigNet CORS (ABUZ).*

The Study Area

The study location is ABUZ in Nigeria. ABUZ is the Prefix name of the CORS located at the department of Geomatics, Ahmadu Bello University, Samaru Campus, Zaria in Kaduna State of Nigeria. It is one of the fifteen (15) CORS established across Nigeria by the Office of the Surveyor General of the Federation (OSGoF). Figure1 shows the spatial distribution of CORS in Nigeria.

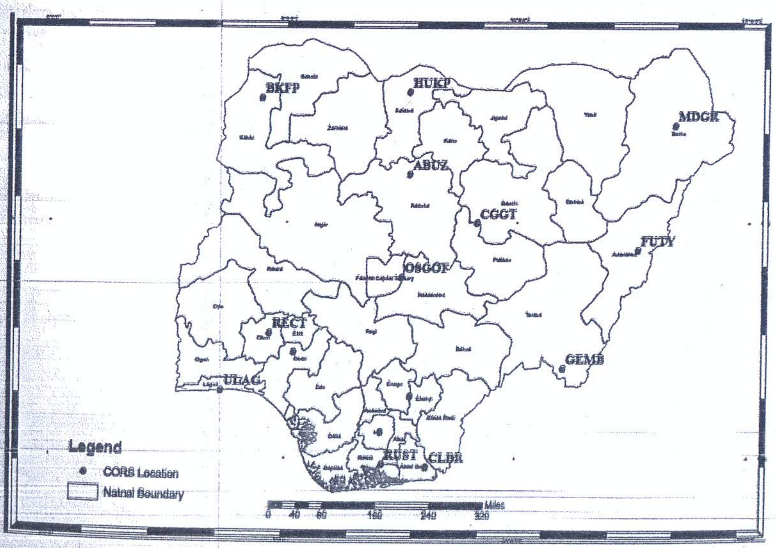


Fig. 1: Spatial Distribution of CORS Network in Nigeria (modified after [9])

Methodology

Data Used

Three days ephemeris data (navigation and rinex files) from June 1st to 3rd 2014 for ABUZ CORS was downloaded from the NigNet website (http://server.nignet.net/data/). Similarly, the orbit corrections (Ultra-Rapid, Rapid and Final Solutions) for same GPS DOY (Day of the Year) were also downloaded from the IGS website (www.igscb.jpl.nasa.gov/components/data.html)

Procedure

The rtkLib software was used for the analysis. The analysis was done in PPP static mode with result output options selected in Eastings, Nothings and Up format. Besides, an elevation mask angle of 15° was selected to allow us provide results in an optimum situation scenario. Four level of data processing was carried out. The ephemeris data was first processed without any IGS orbit solution (Broadcast Solution). Thereafter the IGS solutions were then applied (Ultra-Rapid Solution, Rapid Solution and Final Solution).

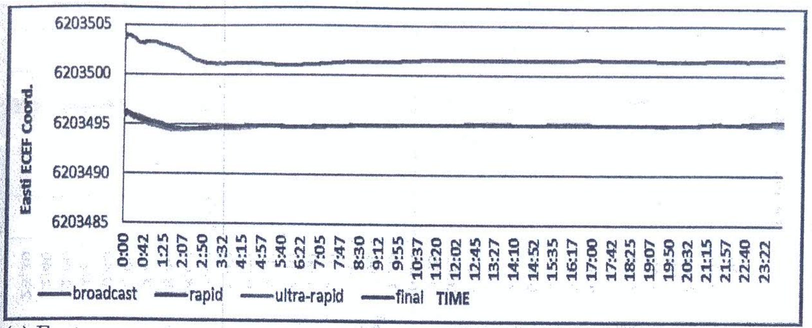
Results and Discussions

Results

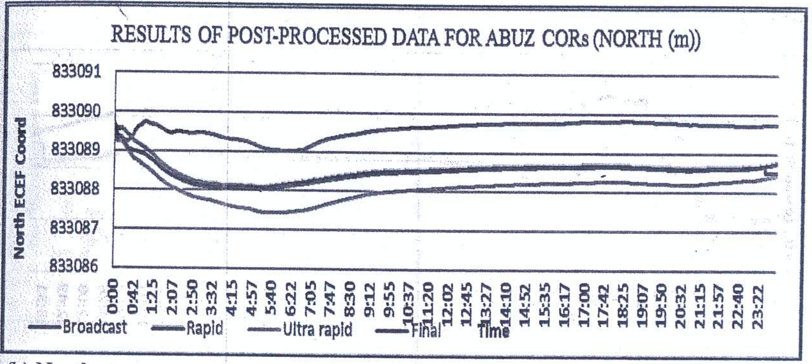
Four results were obtained after processing of the RINEX data for each day. An extract of the results obtained are numerically presented in table 2, while Figure 2 (a – c) and Figures 3 - 5 (a – c) show the graphical views of the coordinate variations and residuals in the results obtained in the use of the various orbital solutions (i.e. the broadcast, ultra-rapid, rapid and final solutions respectively). In order to aid proper analysis, the procedure was repeated for three days (July 1st – 3rd, 2014). Table 3 shows the root mean square error (RMSE) analysis of the discrepancies between each IGS orbital solution and the direct Broadcast Ephemeris for each of the days under study.

Table 2: Extract of Results of post processed data for ABUZ in RTKLib using the direct Broadcast Ephemeris, Ultra Rapid, Rapid and Final IGS Orbit Solutions for July 1st, 2014.

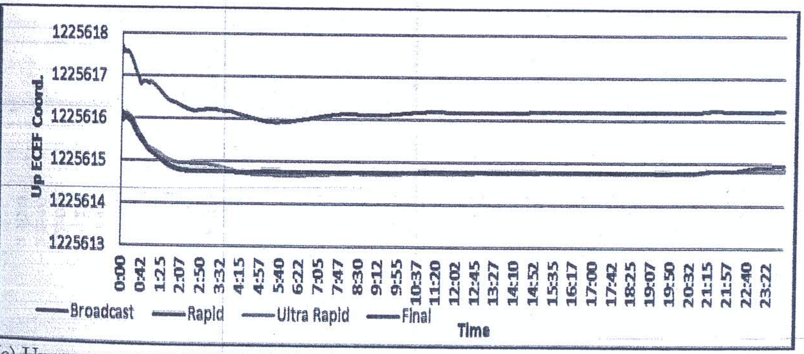
	East (m)				North (m)				Up (m)			
TIME	BROADCAST	ULTRA RAPID	RAPID	FINAL	BROADCAST	ULTRA RAPID	RAPID	FINAL	BROADCAST	ULTRA RAPID	RAPID	FINAL
0:00:00	6203503.678	6203495.869	6203496.073	6203495.970	833089.718	833089.356	833089.686	833089.447	1225617.707	1225616.036	1225616.159	1225616.051
0:00:30	6203503.652	6203495.804	6203496.017	6203495.906	833089.632	833089.296	833089.638	833089.387	1225617.669	1225616.026	1225616.154	1225616.041
0:01:00	6203503.725	6203495.879	6203496.091	6203495.982	833089.591	833089.287	833089.623	833089.377	1225617.650	1225616.019	1225616.144	1225616.034
0:01:30	6203503.915	6203496.068	6203496.269	6203496.172	833089.562	833089.281	833089.596	833089.371	1225617.586	1225615.970	1225616.084	1225615.984
0:02:00	6203503.908	6203496.050	6203496.245	6203496.155	833089.595	833089.328	833089.630	833089.417	1225617.571	1225615.958	1225616.067	1225615.973
0:02:30	6203503.917	6203496.051	6203496.251	6203496.157	833089.581	833089.321	833089.626	833089.409	1225617.596	1225615.979	1225616.089	1225615.994
0:03:00	6203504.027	6203496.138	6203496.338	6203496.245	833089.559	833089.331	833089.634	833089.419	1225617.612	1225616.002	1225616.110	1225616.017
0:03:30	6203504.036	6203496.144	6203496.344	6203496.252	833089.542	833089.337	833089.637	833089.423	1225617.624	1225616.019	1225616.126	1225616.034
0:04:00	6203504.015	6203496.115	6203496.321	6203496.224	833089.495	833089.295	833089.600	833089.381	1225617.611	1225616.008	1225616.118	1225616.023
0:04:30	6203503.991	6203496.085	6203496.297	6203496.195	833089.482	833089.283	833089.593	833089.368	1225617.614	1225616.015	1225616.127	1225616.030
0:05:00	6203503.944	6203496.036	6203496.251	6203496.146	833089.459	833089.260	833089.574	833089.345	1225617.603	1225616.009	1225616.122	1225616.024
0:05:30	6203503.947	6203496.038	6203496.254	6203496.149	833089.453	833089.265	833089.576	833089.350	1225617.605	1225616.015	1225616.127	1225616.032
0:06:00	6203503.950	6203496.038	6203496.257	6203496.150	833089.446	833089.266	833089.579	833089.350	1225617.596	1225616.009	1225616.122	1225616.026
0:06:30	6203503.908	6203495.993	6203496.214	6203496.106	833089.424	833089.252	833089.564	833089.335	1225617.582	1225616.001	1225616.114	1225616.018
0:07:00	6203503.909	6203495.995	6203496.214	6203496.108	833089.404	833089.247	833089.553	833089.328	1225617.571	1225615.995	1225616.106	1225616.013
0:07:30	6203503.919	6203495.994	6203496.219	6203496.108	833089.414	833089.258	833089.568	833089.339	1225617.574	1225616.001	1225616.113	1225616.019
0:08:00	6203503.926	6203495.996	6203496.220	6203496.110	833089.405	833089.260	833089.566	833089.340	1225617.580	1225616.007	1225616.117	1225616.024
0:08:30	6203503.930	6203495.990	6203496.217	6203496.105	833089.397	833089.259	833089.565	833089.339	1225617.578	1225616.004	1225616.114	1225616.022



(a) East

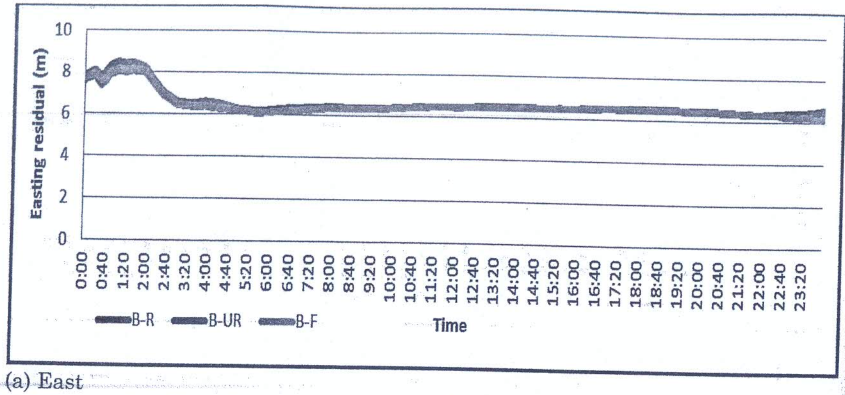


(b) North

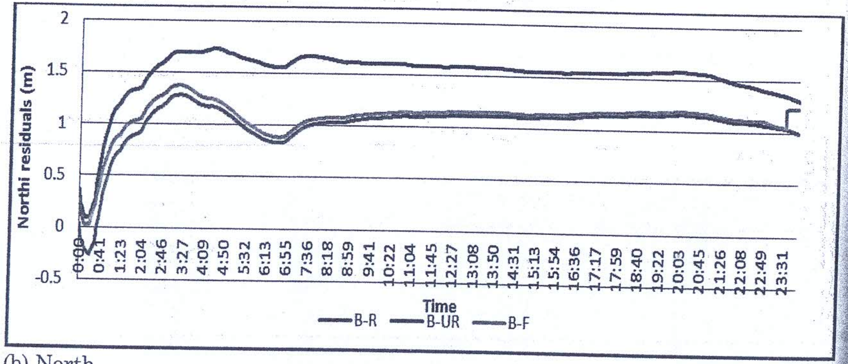


(c) Up

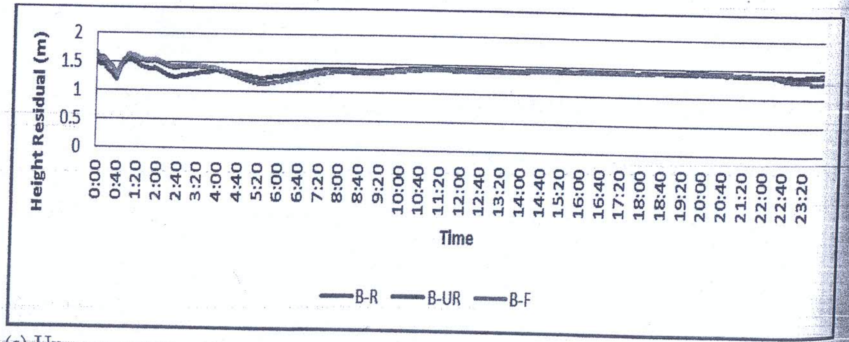
Fig. 2 (a-c): Coordinates variations obtained from the various orbital solutions at ABUZ CORS (July 1, 2014)



(a) East

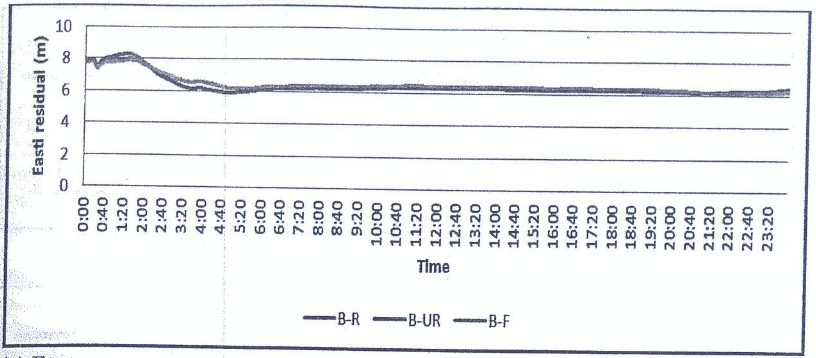


(b) North

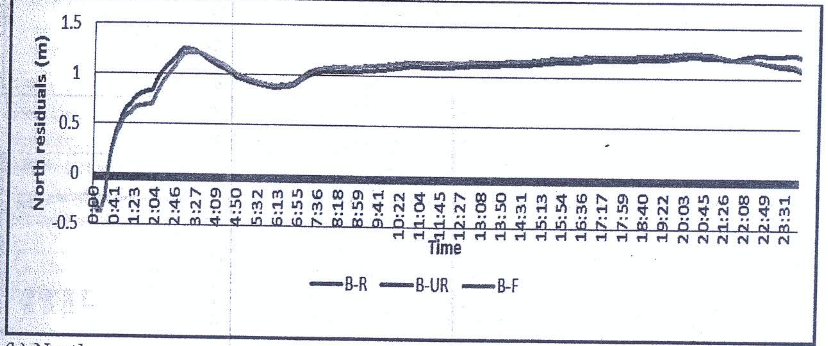


(c) Up

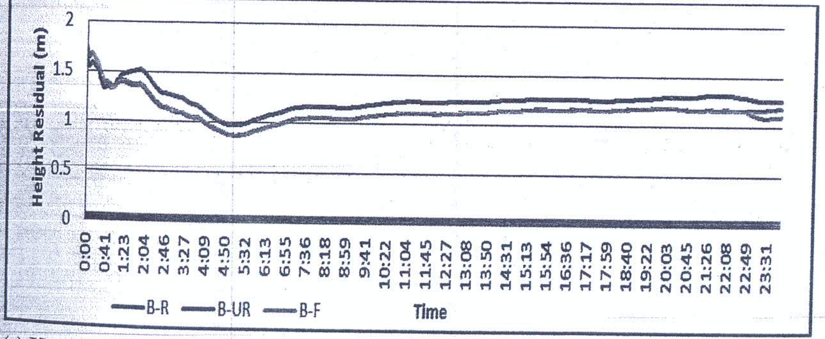
Fig. 3(a-c): Comparison of the Residuals of the Ultra-Rapid (UR), Rapid (R) and Final (F) Orbits with the Broadcast (B) Solutions at ABUZ CORS (July 1, 2014)



(a) East

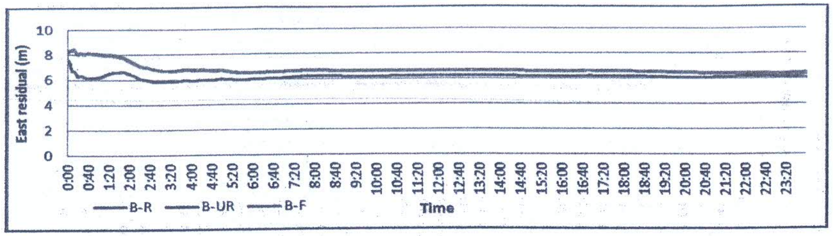


(b) North

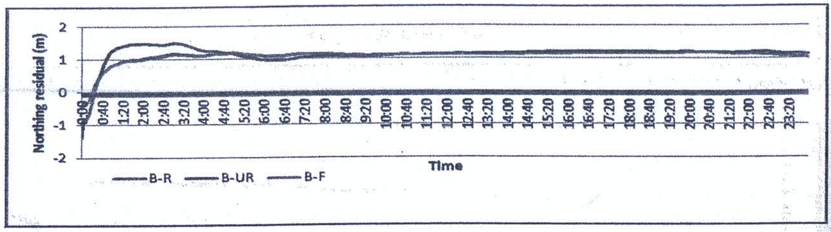


(c) Up

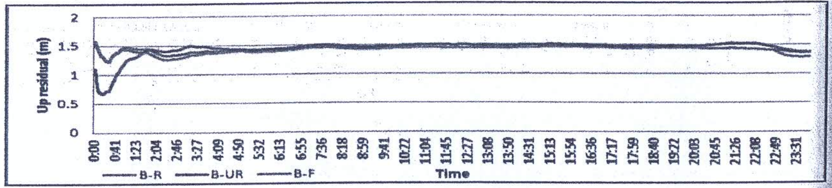
Fig. 4(a-c): Comparison of the Residuals of the Ultra-Rapid (UR), Rapid (R) and Final (F) Orbits with the Broadcast (B) Solutions at ABUZ CORS (July 2, 2014)



(a) East



(b) North



(c) Up

Fig 5(a -c): Comparison of the Residuals of the Ultra-Rapid (UR), Rapid (R) and Final (F) Orbits with the Broadcast (B) Solutions at ABUZ CORS (July 3, 2014)

Table 3: Root Mean Square Error (RMSE) Analysis

	BROADCAST- FINAL			ULTRA RAPID- FINAL			RAPID- FINAL		
DAY	X(m)	Y(m)	Z(m)	X(m)	Y(m)	Z(m)	X(m)	Y(m)	Z(m)
7/1/2014	6.551818	1.095173	1.39576	-0.0759	-0.41365	-0.00881	0.007079	0.059679	0.005705
7/2/2014	6.517524	1.065958	1.133272	0.104684	0.012038	-0.10793	-0.01279	-0.00059	-0.00502
7/3/2014	6.732692	1.076569	1.4147	0.572311	-0.06442	-0.03162	0.031885	-0.01003	-0.01251

Discussion of Results

As shown in Figure 2 (a-c), there exists a very significant difference between the coordinates obtained from the broadcast and the IGS-orbit based solutions, which is further validated by the root mean square error analysis (Table 3). It is therefore evident that, the use of direct broadcast ephemeris data for processing of GNSS-PPP observations was responsible for the positional error of about 7m in East, 1m in North and 1m in Up co-ordinates.

Figures 3-5 indicate that, the discrepancy obtained by using the final and rapid orbit solutions instead of the broadcast orbit has a fairly consistent pattern of variation. This is further validated by Table 3 (Broadcast-Final), where RMSE values show minimum temporal deviation. This therefore provides a measure of reliability in terms of the temporal integrity of the results in this study.

Also from Table 3, a rather haphazard variation in the daily RMSE values is seen in the use of Ultra-Rapid orbit Solution. This therefore further shows that, the three hourly solutions provided for GNSS users may not be too reliable for high precision scientific jobs as the temporal consistency of its accuracy is unpredictable. Therefore the expected error estimate cannot be generalized as it varies with time.

Conclusions

This study investigated the effects of orbital perturbations on Precise Point Positioning (PPP), in which four (4) processing techniques, namely the direct broadcast ephemeris Only, IGS ultra-rapid orbit, IGS rapid orbit, and IGS final orbit solutions were adopted. The study is therefore a classical validation and emphasis of the need to use the appropriate orbit solutions in GNSS-PPP data processing.

As the use of active controls become more prominent in surveying and mapping, and navigation, this study supports the incorporation of the IGS rapid or final orbit solution during post processing of GNSS observations when CORs stations are being used as reference stations. This work also supports existing literature and studies which established the fact that, the use final orbit is the most adequate solution for post-processing of PPP mode observations.

Acknowledgements

The authors express gratitude to NIGNET (http://server.nignet.net/data/) and the IGS (www.igscb.jpl.nasa.gov/components/data.html) for making available the ephemeris data and orbit corrections respectively for GPS DOY (1799:2775:172800182) used in conducting this research.