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Assessing the Tropospheric Impacts on Positioning Accuracy Using IGS02 Real-Time Service Data Versus Long-Convergence Static PPP in Gwagwalada, Abuja, Nigeria

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Abstract: The International Association of Geodesy (IAG) has established the International GNSS Service-Real Time Service (IGS-RTS) as a service provider, offering real-time access to precise products like orbits, clock corrections, and code biases regarding satellite navigation and positioning system. These products serve as an alternative to ultra-rapid products in real-time applications. The performance of these products is assessed through daily statistics from Analysis Centres, which compare them to IGS rapid products. However, the accuracy of GPS real-time corrections for satellites during eclipsing periods was slightly reduced, attributed to the impact of environmental factors on the services. The speed of GNSS signals can be impacted by various atmospheric factors, including troposphere, temperature, pressure, and humidity, resulting in positioning inaccuracies and even giving rooms for signal jamming and hijacking. However, the unique weather conditions prevalent in the African continent are often overlooked during the development of error mitigation parameters and algorithms, which can lead to reduced accuracy in GNSS positioning in a region like Nigeria. The purpose of this study is to estimate the tropospheric impact on positioning with IGS02 Real Time Service data compared to long convergence Static-PPP in Gwagwalada Area Council, Abuja, Nigeria. The study adopts the determination of the GNSS Static observations (minimum of two hours per session) on the chosen stations as standard, determination of the IGS-RTS data observations using RTKLIB software; observations were done with IGS-RTS data stream of IGS02 and statistical tests were performed. The GNSS Static coordinates and IGS-RTS coordinates were validated from error due to troposphere, temperature, pressure, etc., with the computation of their mean horizontal and vertical uncertainties which have a similar level of accuracy but slightly differ at centimeter levels. The result shows the Root Mean Square (RMS) Error discrepancy of IGS02 at the Wet and Dry season, as compared with the Static-PPP was within 0.065(m) and 0.046(m) respectively.

Key Words: IGS-RTS Data, Static-PPP, Tropospheric impact.

I. Introduction

The International GNSS Service (IGS) was established in 1994 by the International Association of Geodesy (IAG) as a service provider, and since then, researchers have persistently identified and addressed existing gaps. Originally named the International GPS Service for Geodynamics, the organization underwent a name change in 1999 to International GPS Service, acknowledging the growing scope of GPS applications and functions in the scientific field. The International GNSS Service (IGS) has rebranded to reflect its broader mission, which now includes integrating multiple Global Navigation Satellite Systems (GNSS) beyond just GPS. This expansion, formalized in 2005, recognizes the important contributions of GLONASS, GALILEO, BeiDou (developed by China), and QZSS (monitored by Japan), as discussed by (Bahadur and Nohutcu 2020; Charles 2022). As scientists explored the technology's potential for various applications, numerous organizations recognized the vast possibilities offered by its precise positioning capabilities at a relatively low cost. Consequently, it became clear that no single entity could bear the significant capital investment and ongoing operational expenses required to maintain a global system of this scope. In response to this realization, major international organizations formed a collaborative partnership to foster global cooperation, establish unified standards, and ensure the achievement of their shared objectives. This collective effort aimed to promote exceptional scientific accomplishments and guarantee the success of their endeavors. For years, Global Navigation Satellite Systems (GNSS) have been utilized for positioning and navigation, offering continuous, weather-resistant real-time information. Although many errors can be easily corrected using techniques like differencing or precise point positioning, atmospheric refraction remains a significant challenge in GNSS positioning. As noted by Nzelibe, Tata, and Idowu (2023), GNSS signals traveling from satellites to receivers near the Earth's surface are affected by tropospheric errors, causing signal slowing and refraction. This leads to substantial positioning errors, ultimately reducing accuracy. The tropospheric delay is a complex error that poses significant challenges in space geodetic techniques, particularly affecting the accuracy of height measurements. As a result, it is a pressing concern in applications requiring high-precision positioning, such as monitoring sea levels, mitigating earthquake hazards, and studying plate tectonic margin deformation. According to Faruna and Ono (2019), improving tropospheric delay modeling is essential to achieve the necessary level of accuracy in these critical fields.

The Tropospheric delay is influenced by the receiver's elevation and altitude, and is dependent on various atmospheric conditions including temperature, pressure, and humidity. The temperature gradient, which affects the delay, varies with height, season, and geographical location. To compensate for this delay, several Global Tropospheric Models, such as the Saastamoinen, Hopfield,

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and Neil models, have been developed and implemented in GPS timing receivers, as demonstrated by Tsebeje and Dodo (2019). In the realm of GNSS, the troposphere and temperature exert distinct influences on signal propagation. Temperature, in particular, has a multifaceted impact on GPS signals. Notably, the precision of real-time corrections for GPS satellites during eclipsing periods was somewhat compromised. Furthermore, the accuracy of corrections for eclipsing GLONASS satellites was substantially lower compared to other satellites as assessed by (Jeffrey 2015; Byung, Kyung and Sang 2013; Cai and Gao 2013). As a result, the decline in accuracy can be attributed to the impact of climate on these services. GNSS signals are susceptible to atmospheric conditions such as temperature, pressure, and humidity, which can alter their speed and lead to positioning errors. Notably, Africa is often overlooked in the design of error mitigation strategies, despite its unique weather patterns. Unlike other continents with more temperate conditions, Africa primarily experiences hot and humid weather year-round, with only dry and wet seasons.

Gwagwalada, Nigeria experiences a relatively consistent temperature range throughout the year, fluctuating between 63°F and 95°F, with rare instances below 57°F or above 102°F. This region is the second hottest in Nigeria, after Adamawa and Sokoto States. The hot season, spanning from November to April, is characterized by average daily highs above 92°F. March stands out as the hottest month, with average highs reaching 94°F and lows of 73°F, making Gwagwalada an ideal location for this study due to its distinct temperature profile.

The accuracy and performance of the PPP-based positioning solution utilizing the real-time IGS-RTS service are currently being assessed and analyzed by numerous researchers in both static and kinematic modes, as highlighted in studies by Elsobeiey and Al-Harbi (2015) and El-Diasty and Elsobeiey (2015). While the International GNSS Service (IGS) suggests that the Real-Time Service (RTS) provides orbit and clock parameters with an accuracy of 5cm and 0.5 nanoseconds (approximately 15cm), various studies have found that this is not always the case. For example, research by Hadas and Bosy (2015) revealed that GPS orbit and clock errors can reach up to 30cm and 20cm, respectively, in different regions worldwide. Furthermore, GLONASS orbit and clock errors can be even higher, reaching up to 50cm and 75cm, respectively. In a study on the feasibility of using IGS-RTS for maritime applications, El-Diasty and Elsobeiey (2015) reported mean and maximum errors of 0.07m and 0.22m, respectively. Additionally, they achieved a 2-dimensional horizontal accuracy (RMS) of 0.08m at a 39% confidence level and 0.19m at a 95% confidence level. These findings highlight the importance of surveyors and geodesists verifying the achievable positioning accuracy in their specific location to determine the reliability of RTS data for their purposes. This research focuses on assessing the accuracy of RTS-IGS02 in the context of Gwagwalada's climate. To achieve this, we conducted a study in the Gwagwalada Area Council, Abuja, Nigeria, where we determined the positions of six ground control points (GCPs) using both IGS-RTS and differential static GPS methods, and subsequently analyzed the results to evaluate the achievable accuracy.

Study Area

This study was conducted in Gwagwalada Area Council, located in the Federal Capital Territory (FCT) of Abuja, Nigeria. Gwagwalada is one of the six administrative Area Councils in the FCT. Geographically, it is situated in the north-central region of Nigeria, bounded by latitudes 8.05515211N to 9.0113411N and longitudes 6.05113611E to 7.01113511E (as shown in Figure 1.1). The area spans approximately 1,043 square kilometers.

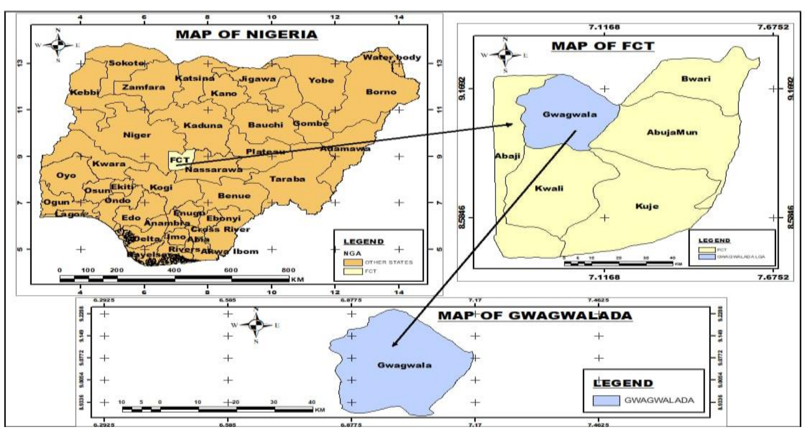

Fig. 1.1: Study area in Gwagwalada, Nigeria.

IGS-Real Time Service Data

The Real Time Service Products provide corrections to the broadcast ephemeris, including GNSS satellite orbit and clock adjustments. These corrections are formatted according to the RTCM State Space Representation (SSR) standard and transmitted via the NTRIP protocol. As noted by (Kazmierski, Sośnica, and Hadas 2017; Wenju, Jin, Lei, and Ruizhi 2022), the corrected orbits are referenced to the International Terrestrial Reference Frame 2008 (ITRF08), ensuring a precise and standardized framework for real-time positioning. The combined solution provided by processing the individual Real-Time solutions from Real-time Analysis Centers (RTAC), are the product streams readily available in the RTS. (www.igs.org/rts/products). The three

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official products currently include corrections to the GPS satellite orbits and clocks, such as IGS01, IGS02 and IGS03, Bingbing, Urs, Junping, Inga, and Jiexian (2019).

Tropospheric Delay

The studies by Dodo, Ekeanyanwu, and Ono (2019) and Lu et al. (2017) reveal that the troposphere's impact on GNSS signals manifests as an extra delay in signal propagation from the satellite to the receiver. This delay is attributed to changes in tropospheric conditions, including humidity, temperature, and atmospheric pressure, as well as the geographical locations of the transmitter and receiver antennas, as highlighted by Olayemi et al. (2015). The ability to account for Tropospheric delay enables differential GNSS and RTK systems to correct for this error. Additionally, GNSS receivers can utilize Tropospheric models to predict the magnitude of error caused by Tropospheric delay. According to Osah, Acheampong, Fosu, and Dadzie (2021), the primary sources of errors in GNSS positioning are satellite clock bias, receiver clock bias, satellite orbit errors, multipath effects, and atmospheric interference, including ionospheric and tropospheric delays. Tropospheric delay is evaluated in the zenith direction over the GPS station, hence the term Zenith Tropospheric Delay (ZTD), which is the combination of the Zenith Dry Delay (ZDD) and Zenith Wet Delay (ZWD). The tropospheric delay is expressed as the sum of two components. The Hydrostatic component which is also known as Dry part, and the other one is Nonhydrostatic component also known as Wet part, i.e. (ZTD) = (ZDD) + (ZWD), as detailed by Michal and Andrzej (2013); Mohd and Kamarudin (2007).

The Tropospheric delay is affected by the receiver's height and atmospheric conditions like temperature, pressure, and humidity. Unlike the ionospheric delay, which can be reduced by combining L1 and L2 signals because it varies by frequency, the Tropospheric delay remains constant across frequencies and cannot be removed by combining observations, making it a more persistent source of error. Research by Dodo et al. (2019, 2015) highlights the use of various Tropospheric models, such as Saastamoinen, Hopfield, and Niell, in GPS timing receivers to correct for Tropospheric delay. However, as Pan and Guo (2018) point out, these global models can be flawed due to daily variations in temperature, pressure, and humidity, leading to errors in calculated Tropospheric delays. Moreover, Nigeria's location near the equator and in the tropics makes it particularly susceptible to significant Tropospheric effects, which can degrade GPS signal quality and impact precise point positioning, as noted by Ana (2011).

To estimate the accuracy of positioning using IGS-RTS data, it's crucial to examine how the troposphere affects the network system using global Tropospheric models, as emphasized by Zhao, Cui, and Song (2023). This research utilizes the Refined Saastamoinen model, a global Tropospheric delay model, to investigate this impact and improve positioning precision.

Mathematical Analysis of the IGS_RTS Corrections

A broadcast orbit using the RTS satellite position ($\delta\vec{X}$) correction can be corrected as given by Kim and Kim (2015);

$$\vec{X}_{\text{Orbit}} = \vec{X}_{\text{broadcast}} - \delta\vec{X} \qquad (2.1)$$

Where $\delta\vec{X}$ is the RTS satellite position correction expressed in earth-centered earth-fixed (ECEF) coordinates, $\vec{X}_{\text{orbit}}$ is the satellite position vector corrected by the RTS correction, and $\vec{X}_{\text{broadcast}}$ is the satellite position vector computed from GNSS broadcast ephemeris. The raw RTS correction data is expressed in radial, along-track, and cross-track (RAC) coordinates, also the broadcast orbit is expressed in ECEF coordinates. These differences demand a transformation of the correction from RAC to ECEF coordinate. Unit vectors $\vec{r}$ representing the RAC components can be computed from the broadcast position and velocity vectors $\dot{\vec{r}}$ as

$$\vec{e}_{\text{Along}} = \frac{\dot{\vec{r}}}{[\dot{\vec{r}}]}, \quad \vec{e}_{\text{cross}} = \frac{\vec{r} \text{ x } \dot{\vec{r}}}{[\vec{r} \text{ x } \dot{\vec{r}}]},$$

$$\vec{e}_{\text{radial}} = \vec{e}_{\text{along}} \times \vec{e}_{\text{cross}} \qquad (2.2)$$

$$\delta\vec{X}\,(t) = [\vec{e}_{\text{radial}}, \vec{e}_{\text{along}}, \vec{e}_{\text{cross}}]\, \delta\vec{O}\,(t), \qquad (2.2a)$$

where $\vec{e}_{\text{radial}}$, $\vec{e}_{\text{along}}$, and $\vec{e}_{\text{cross}}$ are the unit vectors for radial, along-track, and cross-track coordinates, respectively $\delta\vec{O}\,(t)$ is the orbit correction represented in RAC coordinates. All the correction components consist of transmitted orbit correction, δO_i, and its rate of change, $\delta\dot{O}_i$, as

$$\delta O_i\,(t) = \delta\,(t_0) + \delta\dot{O}_i\,(t - t_0) \qquad (2.3)$$

Where i = radial, along-track, and cross-track, also t is the current time to compute the correction, and t_0 is the time of applicability that is included in the RTS message, Hadas and Bosy, (2015); El-Mowafy, Deo and Kubo (2019).

The RTS clock correction, δC (t), is given as a correction to the broadcast clock offset. And for the orbit correction, the clock correction consists of the transmitted correction and its rate of change:

$$\delta C\,(t) = C_0 + C_1\,(t - t_0) + C_2\,(t - t_0)^2 \qquad (2.4)$$

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Where C_0, C_1, and C_2 represent the transmitted clock corrections. (t) is expressed as a correction-equivalent range unit, and where $\delta t\ (t)$ is expressed as the clock offset, which can be obtained by dividing it by the speed of light c:

$$\delta t\ (t) = (\delta C\ (t) c\ )/c \quad (2.5)$$

II. Methodology

A work flow-diagram for the research methodology is shown in Fig. 3.1.

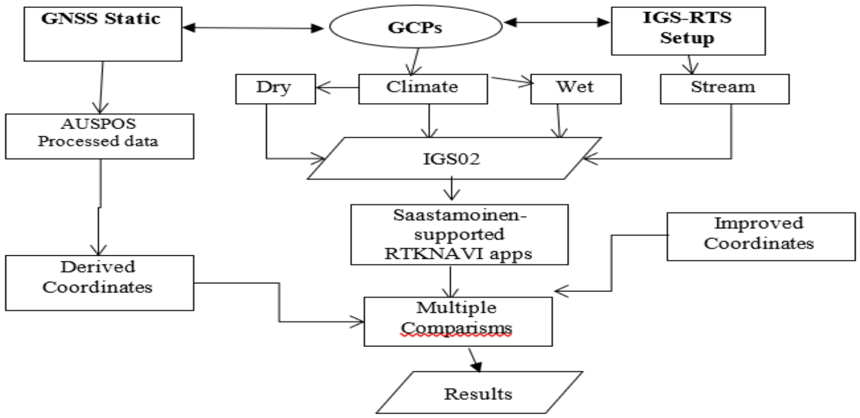

Figure 3.1: A flowchart of the design.

III. GNSS Static Positioning Method

A Hi-Target 90 GNSS dual-frequency receiver was employed for static observations at each ground control point (GCP), with technical details listed in Table 3.1. After ensuring the receiver's functionality, observations were conducted for a minimum of two hours at each GCP between July 18-19, 2023 (DOY 199-200). The receiver was set to collect data at 15-second intervals with a 15° mask angle. The data was then converted to RINEX format and submitted for online processing on August 13, 2023 (DOY 225), using AUSPOS 2.4, which utilizes IGS products to compute precise coordinates in the International Terrestrial Reference Frame (ITRF). AUSPOS leverages the Bernese GNSS Software Version 5.2 for data processing. All data was optimally processed, yielding positions in the ITRF14 reference frame.

Table 3.1: Technical Specifications of GPS Receivers

ITEM	HI-TARGET V90+ GPS RECEIVER
Type	Dual frequency
Channels	220 Channels (GPS, GLONASS, SBAS, GALILEO, BDS, QZSS)
Ports	1 mini USB, 1 5-pin serial for NMEA output, external devices, power, etc
Bluetooth	Dual mode BT4.0
Kinematic Accuracies	Horizontal: 10mm + 1ppm RMS Vertical: 2.5mm + 1ppm RMS **RTK:** Hor.: 8mm+1ppm; Vert.: 15mm+1ppm
Static Accuracies	Horizontal: 2.5mm + 1ppm RMS Vertical: 5mm + 1ppm RMS
Transmission/ Reception Formats	CMR, CMR+, sCMRx RTCM: 2.1, 2.3, 3.0, 3.1, 3.2
DGPS	NMEA 0183GSV, AVR, RMC, HDT,VGK, VHD, ROT, GGK, GGA, GSA, ZDA, VTG, GST, PJT, PJK, etc
Communication (Data Links)	Radio modem, Internal 3G, compatible with GPRS, GSM, and Network RTK

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IGS-RTS Positioning Method

The Hi-Target V90+ dual-frequency GPS receiver was selected for the IGS-RTS PPP method due to its compatibility with the required accessories. The receiver's technical specifications are outlined in Table 3.1. To facilitate real-time processing, the RTKLIB/RTKNAVI software was installed on a laptop PC, and the Hi-Target V90+ receiver was connected to the PC via a serial port. The RTKNAVI real-time navigation program was then launched, and the receiver was configured to receive corrections from IGS servers, as illustrated in Figure 3.2.

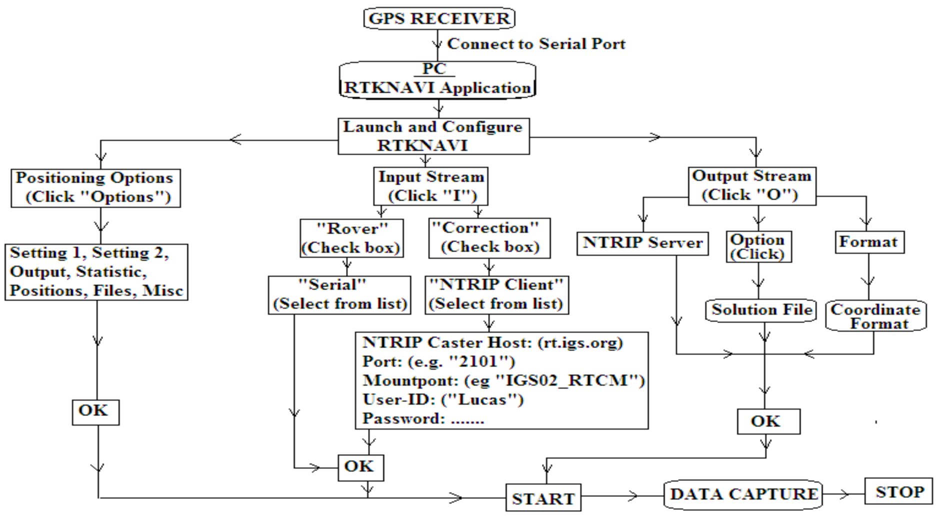

Fig 3.2: Configuration of RTKNAVI

IV. Results and Discussions

Results for Differential GNSS Static Positioning

Table 4.1 presents the results of differential GNSS static positioning using the Hi-Target V90 GNSS dual-frequency receiver, processed online by AUSPOS with Bernese software v5.2. The results include the Cartesian (X, Y, Z) and geodetic (latitude, longitude, and ellipsoidal height) coordinates of six ground control points (ZIK1-ZIK6) in the ITRF 2014 datum. Among the IGS reference stations used for processing, NKLG is the closest to the study area, with a baseline length of approximately 990km. Consequently, AUSPOS utilized NKLG as the reference station to form baselines with the network stations.

Table4.1: ITRF2014 Coordinates from GNSS Static method processed by AUSPOS

Station	ITRF 2014 COORDINATES						Ambiguity Resolution (%)
	CARTESIAN (m)			GEODETIC (±2σ)			
	X (m)	Y (m)	Z (m)	ϕ (DMS±m)	λ (DMS±m)	h (m)	
ZIK1	6252855.930	778709.086	986131.768	8 57 13.035 ± 0.022	7 05 55.930 ±0.008	233.059 ±0.036	64.5
ZIK2	6252867.417	778887.666	985906.152	8 57 05.612 ± 0.028	7 06 01.685 ± 0.016	231.012± 0.078	59.6
ZIK3	6252883.279	778999.713	985709.505	8 56 59.139 ± 0.058	7 06 05.260 ± 0.013	229.648 ±0.061	58.7
ZIK4	6252830.968	779255.827	985836.155	8 57 03.314 ± 0.027	7 06 13.791 ± 0.016	229.356 ±0.089	46.6
ZIK5	6252749.708	779693.680	985930.578	8 57 06.484 ± 0.022	7 06 28.343 ± 0.010	217.899 ±0.050	59.0
ZIK6	6252939.956	778711.973	985560.103	8 56 54.231 ± 0.030	7 05 55.684 ± 0.012	226.832±0.057	61.5

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The ambiguity resolution (A.M.) percentage indicates the processing success rate, with 50% or higher considered reliable (AUSPOS Report, 2023). All GCPs achieved success rates above 55%, except ZIK4 (46.6%), making its static method coordinates unreliable (Table 4.1). Geodetic positional uncertainties for the GCPs were determined at a 95% confidence limit (AUSPOS processing report, 2023). The mean horizontal and vertical errors were calculated as follows;

$$\text{rms vertical error} = \sqrt{\frac{\sum_{i=1}^{n}(\Delta U^2)i}{n}} \quad (4.1)$$

$$2 - \text{D rms horizontal error} = \sqrt{\frac{\sum_{i=1}^{n}(\Delta E i^2 + \Delta N i^2)}{n}} \quad (4.2)$$

Where ΔE is the change in easting coordinates, ΔN is the change in northing coordinates and n is the total number of the observation's points

The mean uncertainties for horizontal and vertical positions were therefore calculated using the above equations 4.1 and 4.2 as ±0.036m and ±0.064m respectively; while the maximum are ±0.058m and ±0.089m respectively.

Results for IGS-RTS Positioning

Real-time service data was transmitted via NTRIP caster version 2.0.21/2.0, with the host server being (rt.igs.org) The coordinates were referenced to the World Geodetic System 1984 (WGS84) framework, as the operation utilized RTKNAVI software version 2.4.3_b3. The data streaming employed IGS02 format, using message codes 1057(60), 1059(5), and 1060(5). Geodetic positional uncertainties for the GCPs were calculated, and tropospheric effects were estimated using the Saastamoinen model. The data collection consisted of two sessions: Wet observations on August 30, 2023, and Dry observations on February 16, 2024.

Table4.2: The Coordinates of points streamed by IGS-RTS with IGS02 at the **Wet season**

Station	WGS84 COORDINATES					
	CARTESIAN (m)			GEODETIC (±2σ)		
	X (m)	Y (m)	Z (m)	ϕ (DMS±m)	λ (DMS±m)	h (m)
ZIK1	6252856.023	778709.188	986131.761	8 57 13.035± 0.098	7 05 55.933± 0.157	233.161±0.144
ZIK2	6252867.662	778887.667	985906.211	8 57 05.613 ± 0.080	7 06 01.684 ± 0.041	231.262±0.347
ZIK3	6252883.192	778999.718	985709.468	8 56 59.139 ± 0.055	7 06 05.260 ± 0.159	229.558±0.184
ZIK4	6252830.985	779255.831	985836.137	8 57 03.313± 0.036	7 06 13.791 ± 0.027	229.371±0.104
ZIK5	6252749.758	779693.753	985930.618	8 57 06.485 ± 0.044	7 06 28.345 ± 0.119	217.963±0.151
ZIK6	6252939.952	778711.926	985560.082	8 56 54.231 ± 0.032	7 05 55.682 ± 0.073	226.820±0.117

From the Table 4.2, the mean uncertainties for horizontal and vertical positions at the **Wet season** were computed as ±0.126m and ±0.192m respectively; while the maximum were ±0.159m and ±0.347m respectively.

Table4.3: The Coordinates of points streamed by IGS-RTS with IGS02 at the **Dry season**

Station	WGS84 COORDINATES					
	CARTESIAN (m)			GEODETIC (±2σ)		
	X (m)	Y (m)	Z (m)	ϕ (DMS±m)	λ (DMS±m)	h (m)
ZIK1	6252855.850	778709.091	986131.750	8 57 13.035± 0.020	7 05 55.930± 0.015	230.914±0.050
ZIK2	6252867.311	778887.676	985906.182	8 57 05.613 ± 0.045	7 06 01.685 ± 0.019	231.027±0.116

ZIK3	6252883.235	778999.736	985709.494	8 56 59.139 ± 0.038	7 06 05.261 ± 0.011	229.606±0.058
ZIK4	6252831.100	779255.921	985836.179	8 57 03.314 ± 0.021	7 06 13.794 ± 0.011	229.502±0.059
ZIK5	6252749.657	779693.694	985930.587	8 57 06.484 ± 0.014	7 06 28.343 ± 0.010	217.851±0.050
ZIK6	6252939.986	778711.940	985560.102	8 56 54.231 ± 0.029	7 05 55.683 ± 0.014	226.857±0.048

Also, from the Table 4.3, the mean uncertainties for horizontal and vertical positions at **Dry season** were computed as ±0.033m and ±0.068m respectively; while the maximum are ±0.045m and ±0.116m respectively.

Comparison of IGS-RTS and GNSS Static Results

Tables 4.1, 4.2, and 4.3 present the positions obtained from GNSS Static and IGS02 data in both ITRF 2014 and WGS84 reference frames. To facilitate a precise comparison between the two frames, note that the WGS84 realizations are consistent with ITRF at a level of approximately 10 centimeters. As a result, no official transformation parameters were established, implying that ITRF coordinates can be considered equivalent to WGS84 coordinates at a 10-centimeter level. According to Dave (2022), ITRF2014 and WGS84 are expected to align at the centimeter level, effectively rendering transformation parameters unnecessary.

Table 4.4: The difference in coordinates of GNSS Static and IGS02

Station	IGS02 REFERENCE FRAME							
	WET (m)				DRY (m)			
	ΔX	ΔY	ΔZ	3-D Error	ΔX	ΔY	ΔZ	3-D Error
ZIK1	-0.093	-0.102	0.007	0.138	0.080	-0.005	0.018	0.082
ZIK2	-0.245	-0.001	-0.059	0.252	0.106	-0.010	-0.030	0.111
ZIK3	0.087	-0.005	0.037	0.095	0.044	-0.023	0.011	0.051
ZIK4	-0.017	-0.004	0.018	0.025	-0.132	-0.094	-0.024	0.164
ZIK5	-0.050	-0.073	-0.040	0.097	0.051	-0.014	-0.009	0.054
ZIK6	0.004	0.047	0.021	0.052	-0.030	0.033	0.001	0.045
	RMS Discrepancy = 0.065				RMS Discrepancy = 0.046			

$$RMS = \sqrt{\frac{\sum_{i=1}^{n}(\Delta x)2}{n}} \qquad (4.3)$$

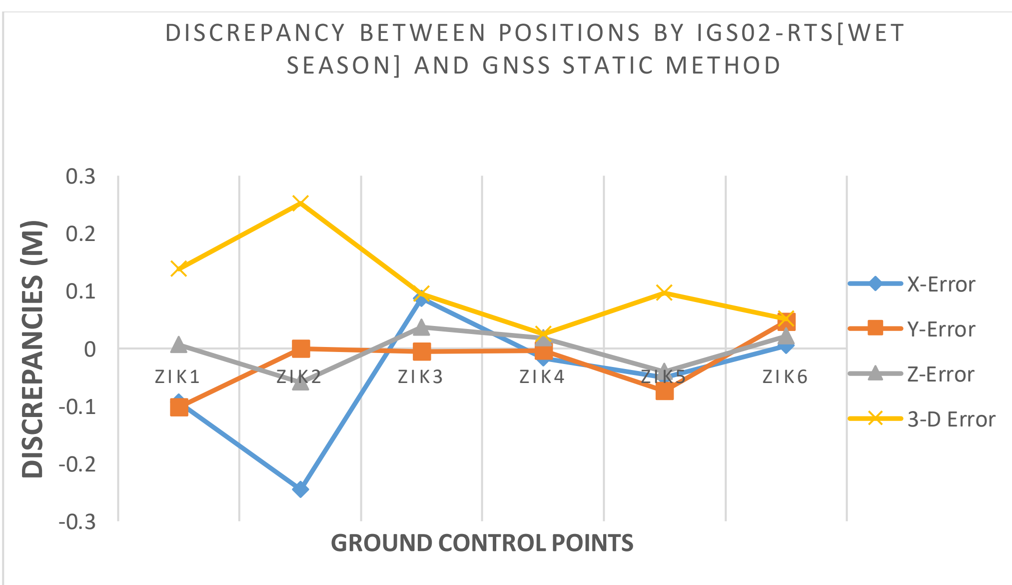

Fig. 4.1: Discrepancies between positions from RTS and GNSS Static methods (wet season)

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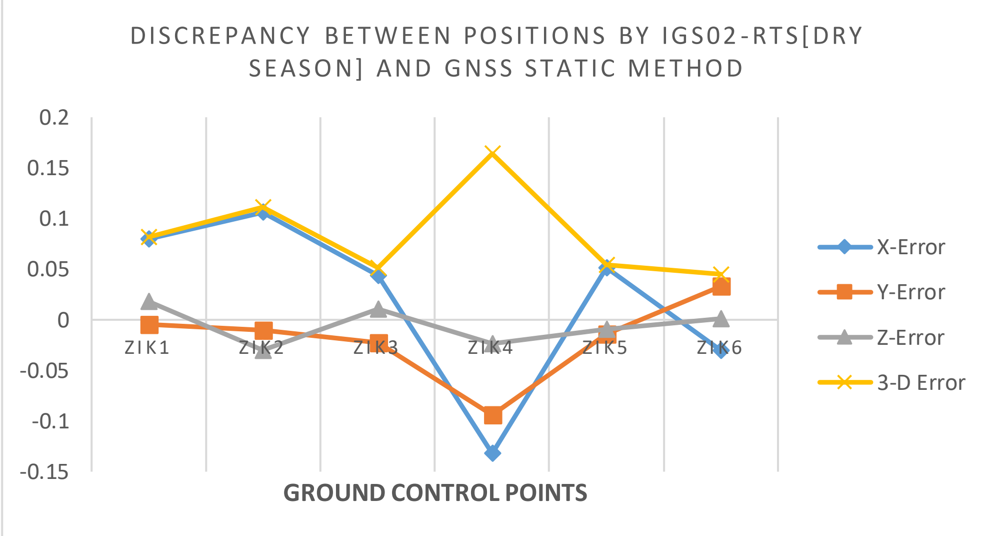

Fig. 4.2: Discrepancies between positions from RTS and GNSS Static methods (Dry season)

The Root Mean Square Error (RMSE) values indicate that the dry season observations (IGS02: 0.046m) achieved higher accuracy compared to the wet season observations (IGS02: 0.065m). This discrepancy is attributed to the lower atmospheric pressure during the wet season, which affects the tropospheric delay in the Saastamoinen model used (Dodo, 2019). Figures 4.1 and 4.2 illustrate the differences between IGS-RTS and GNSS Static-PPP positions in both seasons, showing a consistent relationship between IGS-RTS observations in both wet and dry seasons across all stations, unlike GNSS Static-PPP. The figures also reveal that the maximum and minimum 3-D errors occurred at stations ZIK2 and ZIK4 (wet season) and ZIK4 and ZIK6 (dry season), respectively. Despite the slight differences in RMSE values (0.065m and 0.046m), the study concludes that there is no significant difference between IGS-RTS observations made in dry and wet seasons compared to GNSS Static-PPP observations.

V. Conclusion and Recommendations

The results reveal that the Root Mean Square Error (RMSE) of IGS02 in the Wet and Dry seasons, compared to GNSS Static (AUSPOS) services, is approximately 7cm (0.065m) and 5cm (0.046m), respectively. The IGS-RTS products performed optimally during the dry season, indicating that it is the best time to minimize the impact of climate on GNSS observations. The research suggests that IGS-RTS data performs effectively in Nigeria's climate, as the study found no substantial differences in IGS-RTS observations between dry and wet seasons when compared to GNSS Static-PPP observations, indicating its reliability and adaptability to the region's varying weather conditions.

It is essential to reject results from stations with poorly resolved positions (ambiguity resolution below 50%) and repeat the observations to ensure more accurate data. This approach will help maintain high-quality results and mitigate potential errors.

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