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Evaluation of the Tropospheric influence on Positioning Accuracy Using Igs03 Data Stream Compared to Static Precise Point Positioning in Abuja, Nigeria.

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ABSTRACT
International Association of Geodesy (IAG) as a service provider, designed an International GNSS Service-Real Time Service (IGS-RTS) which gives access to real-time precise products such as orbits, clock corrections and code biases, which is also to serve as an alternative for ultra-rapid products in real-time applications. The performance of these products is assessed through daily statistics from Analysis Centres, which are based on comparisons with IGS rapid products. The accuracy of real-time GPS corrections for satellites during eclipses was somewhat reduced, and this decrease in accuracy can be attributed to environmental factors affecting the services. GNSS signal speed can be impacted by atmospheric conditions like troposphere, temperature, pressure, and humidity, resulting in positioning errors. However, the unique weather conditions of the African continent are often overlooked when developing algorithms and parameters to mitigate these errors, leading to potential inaccuracies in the region. The purpose of this study is to evaluate the tropospheric influence on positioning accuracy using IGS03 data stream, compared to Static Precise Point Positioning in Abuja, Nigeria. This study uses GNSS Static observations, with a minimum duration of two hours per session, as the reference data for the selected stations.For this study, GNSS Static observations lasting at least two hours per session serve as the benchmark data for the designated stations; Data collection was conducted using IGS03, and subsequent statistical analysis was performed to examine the results.The accuracy of GNSS Static coordinates and IGS03 coordinates was assessed by accounting for errors caused by tropospheric conditions, temperature, pressure, and other factors. The results showed similar levels of precision, with mean horizontal and vertical uncertainties differing by only a few centimeters. The Root Mean Square (RMS) difference between IGS02 and Static-PPP was found to be 0.028 meters during the Wet season and 0.010 meters during the Dry season, indicating a relatively small discrepancy between the two.
Key Words: IGS-RTS Data, GNSS Static positioning, Tropospheric influence.

I. INTRODUCTION

Since its inception in 1994, the International GNSS Service (IGS) has continually identified areas for improvement. Initially known as the International GPS Service for Geodynamics, the organization's name was shortened to International GPS Service in 1999 to reflect the expanding applications of GPS beyond geodynamics. In 2005, the IGS officially broadened its scope to include other Global Navigation Satellite Systems (GNSS) like GLONASS, GALILEO, BeiDou, and QZSS, leading to its current name, International GNSS Service, to acknowledge its integrated approach to multiple GNSS systems, as detailed by Bahadur and Nohutcu(2020); Charles (2022). As researchers explored the scientific potential of this technology, numerous organizations recognized its vast capabilities for precise positioning at a relatively low cost. However, it became clear that no single entity could bear the significant capital and operational expenses required for a global system. In response, leading international bodies formed a collaborative partnership to share resources, establish standards, and ensure the success of this endeavor, ultimately aiming to advance high-quality scientific research and achievements through collective efforts. Global Navigation

Satellite Systems (GNSS) have been widely used for positioning and navigation over the years, offering continuous, real-time information unaffected by weather conditions. Although various techniques can easily mitigate most errors, atmospheric refraction remains a significant challenge, causing persistent inaccuracies in GNSS positioning.The accuracy of GNSS observations made at or near the Earth's surface is compromised by tropospheric errors, which occur when GNSS signals are delayed and refracted as they travel from the satellite to the receiver, resulting in substantial positioning errors and reduced precision, as was opined by Nzelibe, Tata and Idowu (2023).

Tropospheric delay is a challenging error to model in space geodesy, and its impact is most pronounced on the vertical component of positioning. This poses a significant concern for applications like sea level monitoring, earthquake hazard mitigation, and plate tectonics research, where precise positioning is crucial. Therefore, refining tropospheric delay models is vital to achieving the highest accuracy in these fields as opined by Faruna and Ono (2019).

The Tropospheric delay varies with the receiver's elevation and altitude, influenced by atmospheric conditions like temperature, pressure, and humidity. This temperature gradient changes with height, season, and location. To compensate for this delay, various Global Tropospheric Models (e.g., Saastamoinen, Hopfield, and Neil models) have been developed and integrated into GPS receivers to provide corrections, as experimented by Tsebeje and Dodo (2019).

In the realm of Global Navigation Satellite Systems (GNSS), tropospheric and temperature conditions exert distinct influences on signal propagation. Temperature, in particular, has a multifaceted impact on GPS signals, leading to variations in accuracy. During satellite eclipses, the precision of real-time corrections for GPS satellites was marginally compromised. However, for GLONASS satellites undergoing eclipses, the accuracy of corrections was substantially degraded compared to other satellites as assessed by Jeffrey (2015); Byung, Kyung and Sang (2013); Cai and Gao (2013). The decline in accuracy can be attributed to the impact of climate on GNSS services. Temperature, pressure, and humidity fluctuations alter the speed of GNSS signals, resulting in positioning errors. Notably, Africa is often overlooked in the design of error mitigation strategies, despite its unique climate characteristics. Unlike other continents with more temperate conditions, Africa experiences a predominantly hot climate with only dry and wet seasons, highlighting the need for region-specific error mitigation approaches.

Gwagwalada, Nigeria experiences a relatively consistent tropical climate, with temperatures ranging from 63°F to 95°F throughout the year, rarely dipping below 57°F or rising above 102°F. As the second hottest region in Nigeria, after Adamawa and Sokoto States, Gwagwalada's hot season spans from November to April, with daily highs often exceeding 92°F. March stands out as the warmest month, with average highs of 94°F and lows of 73°F, making Gwagwalada an ideal location for this research.

The accuracy and performance of this Precise Point Positioning (PPP) solution, which utilizes the IGS-Real Time Service (RTS), is currently being assessed and analyzed by numerous researchers in both static and dynamic (kinematic) modes to evaluate its effectiveness,(Elsobeiey and Al-Harbi, 2015; and El-Diasty and Elsobeiey, 2015). While the International GNSS Service (IGS) claims that its Real-Time Service (RTS) provides orbit and clock parameters with an accuracy of 5cm and 0.5ns (approximately 15cm), respectively, 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 in different regions, while GLONASS orbit and clock errors can be as high as 50cm and 75cm, respectively. Here's a paraphrased version:

A study by El-Diasty and Elsobeiey (2015) on the suitability of IGS-RTS for maritime applications reported mean and maximum errors of 0.07m and 0.22m, respectively. They also achieved a 2D horizontal accuracy (RMS) of 0.08m at a 39% confidence level and 0.19m at a 95% confidence level. This highlights the importance of surveyors and geodesists determining the actual achievable positioning accuracy in their specific location to assess the reliability of RTS data. This current study aims to evaluate the accuracy of RTS-IGS02 and IGS03 in Gwagwalada's climatic conditions. Our research involved establishing the precise positions of six ground control points (GCPs) in the Gwagwalada Area Council, Abuja, Nigeria, using two methods: IGS Real-Time Service (RTS) and differential static GPS. We then compared and analyzed the results from both techniques.

1.1 Study Area

This research was conducted in Gwagwalada Area Council, Abuja, Federal Capital Territory (FCT), Nigeria. Gwagwalada is one of the six administrative Area Councils in the FCT, situated in the north-central region of Nigeria. The area is bounded by latitudes 8.05515211°N to 9.0113411°N and longitudes 6.05113611°E to 7.01113511°E, defining its geographic location, (fig.1.1). Gwagwalada Area Council covers an extensive area of roughly 1,043 square kilometers.

Fig. 1.1: Study area in Gwagwalada, Nigeria

II. IGS-REAL TIME SERVICE DATA

The Real-Time Service (RTS) 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. The corrected orbits are referenced to the International Terrestrial Reference Frame 2008 (ITRF08), ensuring accurate and reliable positioning as explained by Kazmierski, Sośnica and Hadas(2017); Wenju,Jin,Lei and Ruizhi(2022). The Real-Time Service (RTS) offers combined solution streams, generated by processing individual real-time solutions from various Real-Time Analysis Centers (RTAC). These product streams are accessible on the IGS website and currently comprise three official products: IGS01, IGS02, and IGS03, which provide corrections for GPS satellite orbits and clocks, Bingbing, Urs, Junping, Inga, and Jiexian (2019).

2.1 Tropospheric Delay

According to research by Dodo, Ekeanyanwu, and Ono (2019) and Lu et al. (2017), the troposphere's effect on GNSS signals results in an additional delay in signal transmission from the satellite to the receiver. This delay is primarily caused by variations in humidity, temperature, and atmospheric pressure within the troposphere, as well as the specific locations of the transmitter and receiver antennas, as noted by Olayemi et al. (2015). The understanding of Tropospheric delay enables differential GNSS and RTK systems to correct for its effects, while GNSS receivers can utilize Tropospheric models to estimate and mitigate the resulting errors. The primary error sources in GNSS measurements include satellite and receiver clock biases, satellite orbit inaccuracies, multipath effects, and atmospheric interference from both the ionosphere and troposphere, Osah, Acheampong, Fosu and Dadzie (2021).

The tropospheric delay is assessed vertically above a GPS station, referred to as Zenith Tropospheric Delay (ZTD), which comprises two parts: Zenith Dry Delay (ZDD) and Zenith Wet Delay (ZWD). These two components, also known as the hydrostatic (dry) and nonhydrostatic (wet) components, are combined to calculate the total tropospheric delay, i.e. (ZTD) = (ZDD) + (ZWD), as detailed by Michal and Andrzej (2013); Mohd and Kamarudin (2007).

The Tropospheric delay varies with the receiver's elevation and altitude, influenced by atmospheric conditions like temperature, pressure, and humidity. Unlike ionospheric delay, which is frequency-dependent and can be mitigated by combining L1 and L2 signals, tropospheric delay remains unaffected by frequency and requires alternative correction methods. According to research by Dodo et al. (2019) and Dodo, Ojigi, and Tsebeje (2015), various Tropospheric models, including the Saastamoinen, Hopfield, and Niell models, have been developed and successfully applied in GPS timing receivers to compensate for Tropospheric delay. Meanwhile,According to Pan and Guo (2018), daily variations in temperature, pressure, and humidity can introduce errors in Tropospheric delay estimates obtained from global

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models. Nigeria's location in the equatorial and tropical region makes it particularly susceptible to significant Tropospheric effects, which can degrade GPS signal quality and impact point positioning accuracy (Ana, 2011). To assess positioning using IGS-RTS data, it is crucial to investigate the impact of tropospheric effects on the network system using global models (Zhao, Cui, and Song, 2023). This study employs the Refined Saastamoinen model to estimate global Tropospheric delays.

2.2 Mathematical Analysis of the IGS_RTS Corrections

According to Kim and Kim (2015), the broadcast orbit can be refined by applying the RTS satellite position correction ($\delta\vec{X}$) to obtain a more accurate orbit, as expressed by the equation

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

Where $\delta\vec{X}$ is the RTS satellite position correction expressed in earth-centered earth-fixed (ECEF) coordinates, $\vec{X}_{orbit}$ is the satellite position vector corrected by the RTS correction, and $\vec{X}_{broadcast}$ 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

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

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

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

where $\vec{e}_{radial}$, $\vec{e}_{along}$, and $\vec{e}_{cross}$ 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

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

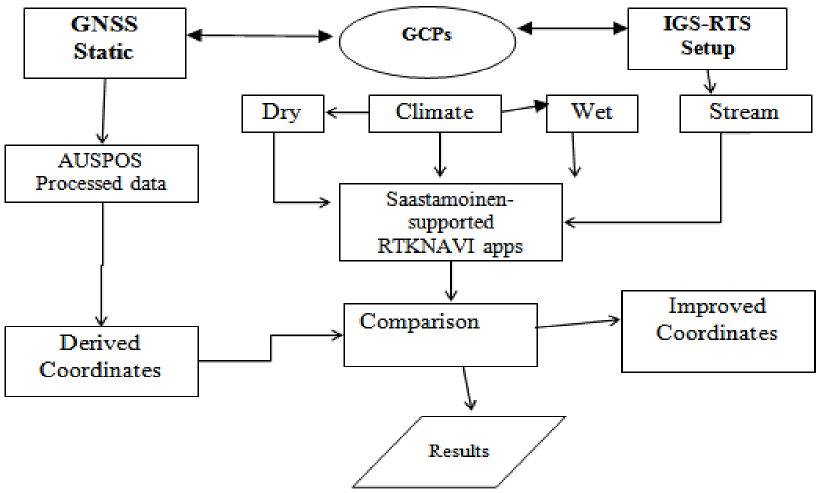
$\delta C\,(t) = C_0 + C_1\,(t - t_0) + C_2\,(t - t_0)^2$ (2.4)

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:

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

III. METHODOLOGY

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



3.1 GNSS Static Positioning Technique

A Hi-Target 90 GNSS dual-frequency receiver was utilized for static observations at each ground control point (GCP), with the technical specifications of the device detailed in Table 3.1. After verifying the receiver's functionality, observations were conducted for a minimum of two hours at each GCP from July 18 to 19, 2023 (DOY 199 to 200). The receiver was set to collect data at 15-second intervals with a mask angle of 15

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degrees for each setup. The collected data was converted to RINEX (Receiver Independent Exchange) format and submitted for online processing on August 13, 2023 (DOY 225) using AUSPOS 2.4, which employs IGS products (final, rapid, or ultra-rapid, depending on availability) to calculate precise coordinates in the International Terrestrial Reference Frame (ITRF). AUSPOS processes GNSS data using the Bernese GNSS Software Version 5.2. For further details about AUSPOS, please visit its website at (http://www.ga.gov.au/geodesy/sgc/wwwgps/). All data were processed optimally, and the resulting positions were provided in the International Terrestrial Reference Frame 2014 (ITRF14).

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

3.2 IGS-RTS Positioning Technique

The IGS-RTS PPP method utilized the dual-frequency Hi-Target V90+ GPS receiver, which was equipped with all the necessary accessories for the procedure. Technical details of the device are provided in Table 3.1. RTKLIB/RTKNAVI software was installed on a laptop, and the Hi-Target V90+ receiver was connected to the laptop through a serial port. The RTKNAVI real-time navigation software was then activated, and the receiver was set up to receive corrections from IGS servers as shown in Fig. 3.2.

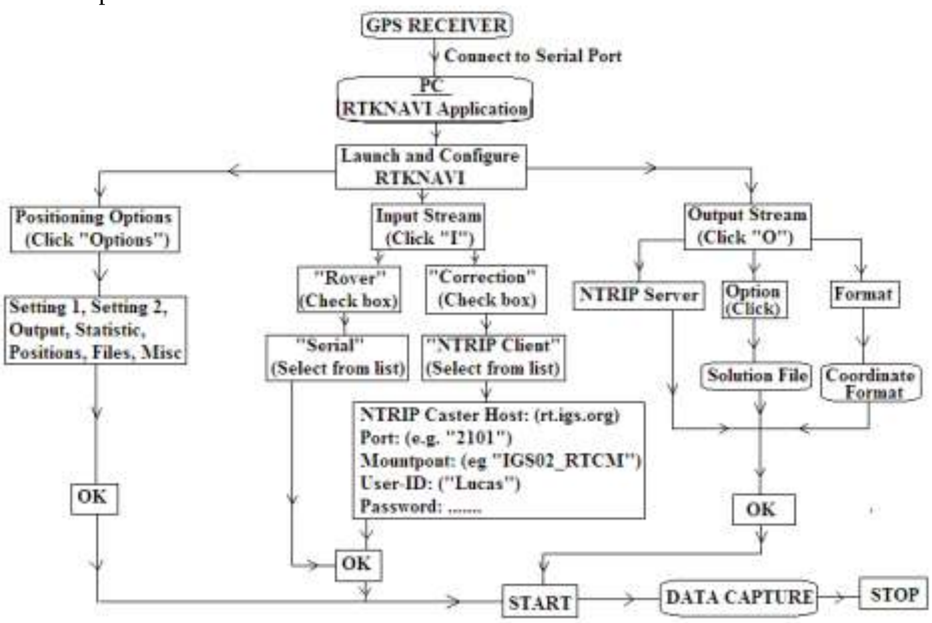

Fig 3.2: Configuration of RTKNAVI

IV. RESULTS AND DISCUSSIONS

4.1 Results for Differential GNSS Static Positioning

The results of the differential GNSS static positioning, conducted with the Hi-Target V90 dual-frequency receiver and processed online using AUSPOS with Bernese software v5.2, are presented in Table 4.1. The Cartesian (X, Y, Z) and geodetic (latitude φ, longitude λ, and ellipsoidal height h) coordinates of the six ground control points (ZIK1, ZIK2, ZIK3, ZIK4, ZIK5, and ZIK6) were provided in the ITRF 2014 datum. Among the IGS reference stations used in the processing (ADIS, ASCG, CPVG, DYNG, EBRE, LPAL, MAS1, MAT1, NKLG, SFER, STHL, VILL, WIND, and YEBE), NKLG, being the closest to the study area with a baseline length of approximately 990 km, was chosen as the reference station to establish baselines with the network stations in AUSPOS.

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

The percentage (%) of ambiguity resolution (A.M.) in the solution reflects the success rate of the processing. A baseline with 50% or higher resolution indicates a reliable result (AUSPOS Report, 2023). For all ground control points (GCPs), the success rates exceeded 55%, except for station ZIK4, which had a success rate of 46.6%. Therefore, the coordinates for ZIK4 obtained from the static method are considered a float solution and are not reliable (refer to Table 4.1).

The geodetic positional uncertainties of the GCPs were assessed at a 95% confidence level, according to the AUSPOS processing report (2023). The mean horizontal and vertical errors were calculated as follows;

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

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

The mean uncertainties for horizontal and vertical positions are ±0.036m and ±0.064m respectively; while the maximum are ±0.058m and ±0.089m respectively.

4.3 Results of IGS-RTS Positioning Using IGS03 Data Stream

The real-time service data was transmitted via NTRIP caster 2.0.21/2.0, with the NTRIP caster host for our RTS positioning being (rt.igs.org). The coordinates are provided according to the World Geodetic System 1984 (WGS84), as RTKNAVI version 2.4.3_b3 was used for the operation. IGS03 utilized stream message formats 1057(60), 1058(10), 1059(10), 1063(60), 1064(10), and 1065(10). Geodetic positional uncertainties for the ground control points (GCPs) were assessed, and tropospheric effects were estimated using the Saastamoinen model for both wet and dry seasons. Observations for the wet and dry seasons were conducted on August 31, 2023, and February 17, 2024, respectively.

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Table 4.2: Coordinates of points streamed by IGS-RTS with IGS03 during 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	6252855.925	778709.081	986131.778	8 57 13.036±0.049	7 05 55.930±0.052	233.055±0.022
ZIK2	6252867.454	778887.670	985906.163	8 57 05.612 ± 0.036	7 06 01.685 ± 0.108	231.051±0.138
ZIK3	6252883.295	778999.643	985709.493	8 56 59.139 ± 0.020	7 06 05.258 ± 0.019	229.653±0.060
ZIK4	6252830.970	779255.871	985836.166	8 57 03.314 ± 0.078	7 06 13.792 ± 0.029	229.366±0.095
ZIK5	6252749.717	779693.668	985930.568	8 57 06.484 ± 0.022	7 06 28.342 ± 0.068	217.905±0.039
ZIK6	6252940.054	778711.938	985560.098	8 56 54.231 ± 0.032	7 05 55.682 ± 0.073	226.923±0.117

From the Table 4.2, the mean uncertainties for horizontal and vertical positions at the **Wet season** were computed as ±0.079m and ±0.089m respectively; while the maximum are ±0.108m and ±0.138m respectively.

Table4.3: Coordinates of points streamed by IGS-RTS with IGS03 during 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	6252855.907	778709.082	986131.768	8 57 13.035±0.026	7 05 55.930±0.010	233.036±0.041
ZIK2	6252867.431	778887.668	985906.155	8 57 05.612 ± 0.022	7 06 01.685 ± 0.012	231.027±0.051
ZIK3	6252883.247	778999.713	985709.506	8 56 59.140 ± 0.024	7 06 05.260 ± 0.012	229.617±0.049
ZIK4	6252830.952	779255.835	985836.153	8 57 03.314 ± 0.019	7 06 13.791 ± 0.010	229.342±0.050
ZIK5	6252749.706	779693.683	985930.584	8 57 06.484 ± 0.025	7 06 28.343 ± 0.011	217.898±0.055
ZIK6	6252939.977	778711.975	985560.110	8 56 54.231 ± 0.030	7 05 55.684 ± 0.012	226.854±0.062

Also, Table 4.3 shows that the average uncertainties for horizontal and vertical positions during the dry season were calculated as ±0.027 m and ±0.051 m, respectively. The maximum uncertainties were ±0.030 m and ±0.062 m, respectively.

4.3 Comparison of IGS-RTS and GNSS Static Results

Tables 4.1, 4.2, and 4.3 present positions derived from GNSS static data and IGS03 data, reported in ITRF 2014 and WGS84, respectively. For accurate comparison between the two reference frames, it is noted that the new WGS84 realizations align with ITRF within approximately 10 centimeters. Consequently, no official transformation parameters were established for these realizations. This implies that ITRF coordinates can be considered equivalent to WGS84 coordinates at a 10 cm level. However, ITRF2014 and WGS84 are expected to match within the centimeter range, leading to conventional 0-transformation parameters as suggested by Dave (2022).

Table 4.6b: The difference in coordinates of GNSS Static and IGS03

Station	IGS03 REFERENCE FRAME							
	WET (m)				DRY (m)			
	ΔX	ΔY	ΔZ	3-D Error	ΔX	ΔY	ΔZ	3-D Error
ZIK1	0.005	0.005	-0.010	0.012	0.023	0.004	0.000	0.023
ZIK2	-0.037	-0.004	-0.011	0.039	-0.014	-0.002	-0.003	0.015
ZIK3	-0.016	0.070	0.012	0.073	0.032	0.000	-0.001	0.032
ZIK4	-0.002	-0.044	-0.011	0.045	0.016	-0.008	0.002	0.018
ZIK5	-0.009	0.012	0.010	0.018	0.002	-0.003	-0.006	0.007
ZIK6	-0.098	0.035	0.005	0.104	-0.021	-0.002	-0.006	0.022
	$RMS_{Discrepancy = 0.028}$				$RMS_{Discrepancy = 0.010}$			

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

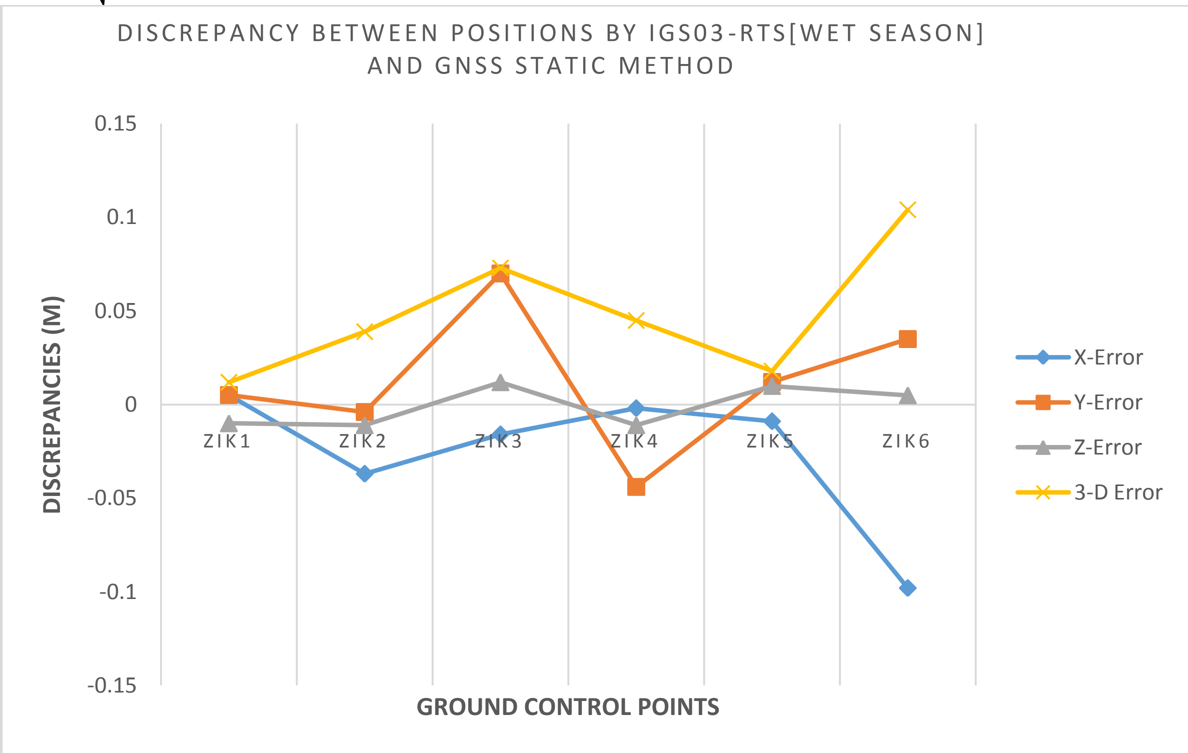

Fig. 4.1a: Discrepancies between positions from RTS and GNSS Static methods (Wet season)

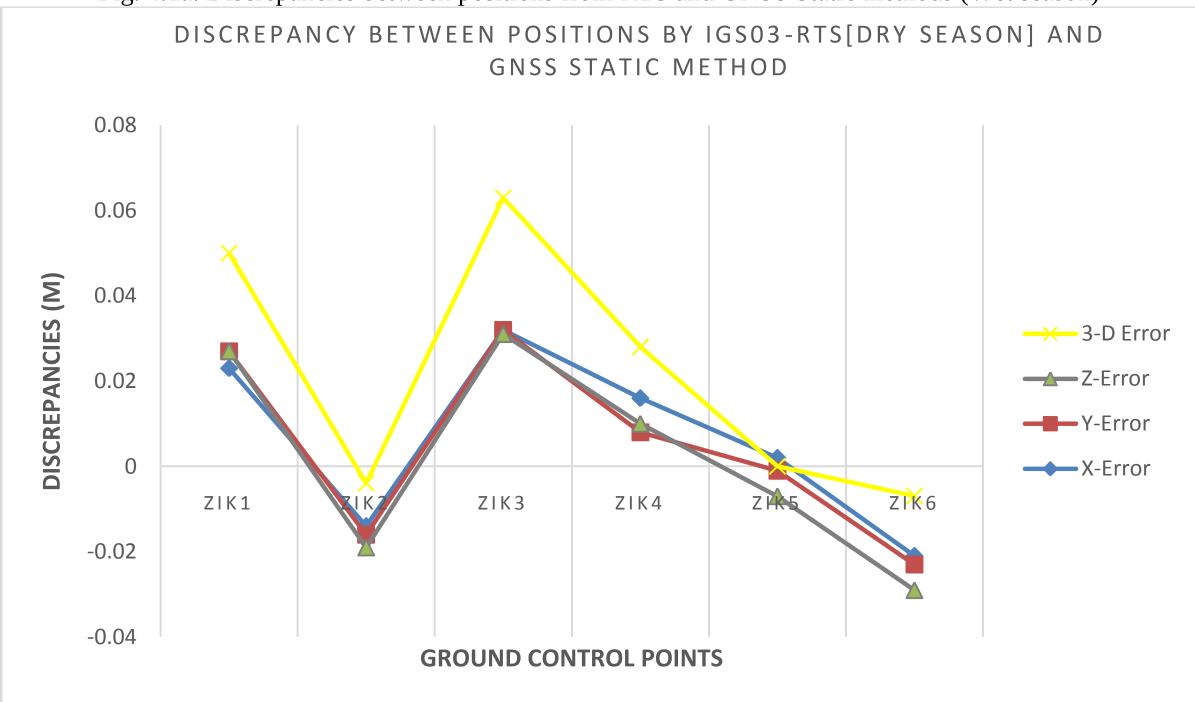

Fig. 4.1b: Discrepancies between positions from RTS and GNSS Static methods (Dry season)

The RMSE indicates that observations made during the dry season, with a value of 0.010 m, are more accurate compared to those made during the wet season, which have a value of 0.028 m. This difference is attributed to the fact that atmospheric pressure is lower in the wet season compared to the dry season. Since dry tropospheric delay is directly related to atmospheric pressure in

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the Saastamoinen model used, this results' variations was noted by Dodo (2019).

The RMSE also shows that the observations obtained using the IGS03 approach, with values of 0.028 m in the wet season and 0.010 m in the dry season, exhibit better accuracy compared to those obtained with the Static-PPP approach. This improved accuracy may be attributed to the additional three message formats used by IGS03—1057(60), 1058(10), 1059(10), 1063(60), 1064(10), 1065(10). The systems employed a Kalman filter approach, as noted by Mervart and Weber (2011). Figures 4.1a and 4.1b provide visual representations of the discrepancies between the positions obtained from IGS-RTS and GNSS Static-PPP during the dry and wet seasons. They also illustrate that IGS-RTS exhibits consistent results across both wet and dry seasons at all study stations, in comparison to GNSS Static-PPP. In Figures 4.1a and 4.1b, which reflect the IGS03 data stream, the charts show that the maximum and minimum 3-D errors during the wet season were observed at stations ZIK6 and ZIK1, respectively. Similarly, during the dry season, the maximum and minimum 3-D errors were found at stations ZIK3 and ZIK5, respectively. Furthermore, the calculated RMSE values of 0.028 m and 0.010 m are consistent with each other, leading to the conclusion that there is no significant difference between the IGS-RTS observations in the dry and wet seasons when compared to the GNSS Static-PPP observations.

V. CONCLUSION AND RECOMMENDATIONS

The results show the RMSE of IGS03 for the Wet season and Dry season, as compared with the GNSS Static (AUSPOS) services to be within 0.028(m) and 0.010(m) respectively, which can as well be approximated to 3cm and 1cm respectively.

The IGS03 data products had the best performance in both seasons, with mean RMSE lower than 3m at both seasons, which indicates the best data stream to other data streams such as IGS01 and IGS02, which is highly suitable for the mitigation of climatic influence on all GNSS observations.

It is also advisable to discard results for stations with low ambiguity resolution (i.e., below 50%) and to repeat the observations for those stations.

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