Abstract

The UGRF which is Uganda's modernised geodetic datum is based on ITRF2005 epoch 2010.0. This geodetic datum is realised through the establishment of the 12 GNSS CORS network in the major cities or towns. This paper assesses the precision of this network in regards to latest released ITRF2020. Six (06) stations were randomly selected and investigated. The results indicate that there is urgent need for the upgrade of the datum to meet international standards.

ENHANCING GEODETIC CONTROLS FOR SECURE GEOSPATIAL DATA QUALITY AND INTEGRITY IN UGANDA

INTRODUCTION

Uganda's long historic geodetic reference datum has been the famous Arc1960 based on Clarke 1880 modified ellipsoid for the horizontal component. While for the vertical component Uganda still utilizes the mean sea level (MSL) derived from the so-called Khartoum Datum. However, a new reference system called the Uganda Geodetic Reference Network (UGRN) has been developed aligned to the ITRF2005@2010.0. In the effort to cope with the technological advancements, 12 Global Navigation Satellite System (GNSS) Continuous Operating Reference Stations (CORS) were installed in the first phase (IGN, 2011; IGNFI, 2019) . The 12 GNSS CORS coordinates were computed as shown in Table 1, based on the ITRF2014 epoch 2019.21 (ITRF2014@2019.21) and transformed to UGRF using the 7 Helmert transformation parameters (IGNFI, 2019).

Now, a total of 38 CORS stations to make them 40 in number are being installed in the second phase. As alluded by (Christopher, 2006) the adoption of global terrestrial reference systems and frames allows countries to take advantage in consistency at a universal perspective. The global geodetic reference system is now the only fundamental recognized system and it was through a resolution by the International Union of Geodesy and Geophysics (IUGG) in 2007. The ITRF is supposed to be updated in every 3 – 5 years, with the current updated version being ITRF2020 (Zuheir, 2013).

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Ibrahim Magemeso, Richard Oput, Godfrey Toko (Uganda), Cyril Romieu (France) and John Bosco Ogwang (Uganda)

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UGRN is considered as the most accurate, consistent and a lasting reference frame that is established and maintained by the Department of Surveys and Mapping (DSM), Ministry of Lands, Housing and Urban Development (MLHUD) (Bordas & Lacombe, 2021). This reference frame is to facilitate all aspects to do with spatial data in Uganda, which may include cadastral, engineering, geodetic, GIS, remote sensing, photogrammetry and other fundamental spatial datasets (Toko, Oput, Kagoro, Kambugu, & Magemeso, 2022).

Table 1: Geographic coordinates of 12 GNSS CORS Sites at ITRF2005 epoch 2010.00 (IGNFI, 2019)

Station	Latitude (^{0})	Longitude (^{0})	He (m)
ARUA	3.017143521	30.909914062	1208.8899
ENTB	0.059980991	32.476011896	1164.9160
FPRT	0.652455592	30.298304056	1522.1652
GULU	2.779525162	32.295855600	1099.0340
JING	0.418319436	33.213899857	1134.5039
KBLE	0.795187975	31.083240395	1334.4363
LIRA	2.247076555	32.901580766	1087.7116
MBAL	1.069771501	34.168688149	1117.0668
MRTO	2.531475711	34.657141630	1354.1900
MSKA	-0.338771247	31.719233545	1197.5288
MSND	1.686467071	31.717680214	1142.8215
SRTI	1.721941881	33.620010269	1111.3274

GNSS and other modern geodetic technologies have completely revolutionized the way in which Geodetic control at international, regional and local levels can be achieved with capabilities without limitations in scales and everywhere. It is now a routine for all countries and of course regions to continuously revise and update their geodetic networks to benefit from the enormous benefits of ITRF latest editions such as the ITRF2020 edition. These benefits may include; high accuracy, ease in establishment and densification, and uniformity in accuracy at a global scale. The uniformity in accuracy is the most critical benefit that arises in alignment of geodetic control to the ITRF editions (Christopher, 2006).

The International Terrestrial Reference System (ITRS) is now the globally recognized principal geodetic coordinate system having been accepted by the International Union of Geodesy and Geophysics (IUGG). This ITRS is hypothetically fixed to the revolving Earth and unequivocally determined according to these aspects: Origin, Scale and lastly the Orientation of the three (03) coordinate axes as determined by

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conventions of the International Earth Rotation and Reference Systems Service (IERS) (Angermann, Pail, Seitz, & Hugentobler, 2022). Now, the ITRF2020 which is the latest model is urged as an improved terrestrial reference frame that truly and exactly models nonlinear station motions for both annual and semi – annual signals present in the station position time series and Post-Seismic Deformation (PSD) for sites that are impinged on by earth quakes. Four space geodetic techniques that is Doppler Orbitography and Radiopsoitioning Integrated by Satellite (DORIS), Global Navigation Satellite Systems (GNSS), Satellite Laser Raging (SLR) and Very Long Baseline Interferometry (VLBI) contributed to the realization of the ITRF (Angermann, Pail, Seitz, & Hugentobler, 2022) . In summary long term periods of data were used ranging from 1993 up to 2021. The ITRF2020's accuracy and reliability has been assessed in contrast to the earlier editions such as ITRF2014, ITRF2008 and ITRF2005 and it was found to be within the levels of 5mm and 0.5mm/yr, respectively (Altamimi, Rebischung, Collilieux, Metivier, & Chanard, 2023).

Now, this paper assesses the performance of these 12 GNSS CORS UGRN stations using the free online Précised Point Positioning (PPP) services. For this specific paper 6 stations data was analyzed to test how they can be enhanced with ITRF2014 and most recent ITRF2020. Among the tools chosen were CSRS-PPP, AUSPOS, Trimble CenterPoint RTX, and APPS. The results were compared with the two reference reframes that is ITRF2014 and ITRF2020 depending on the capabilities of the tool or service used.

Materials And Methods

As stated above data from the 12 stations was collected from the UGRF website http://ugrf.go.ug/SBC/User/Xpos/RinexDataRequest for days 310, 311, 312, 313, 314, 315, 316, and 338. The screen shot of the interface is shown in Figure 1 All the 12 stations as indicated Table 1 are equipped with Leica GR50 receivers and Leiar20 Leim Antennas which provide cutting-edge technology for outstanding performance. These receivers are enabled to collected all the four GNSS global constellations that's GPS, GLONASS, Galileo and BeiDou.

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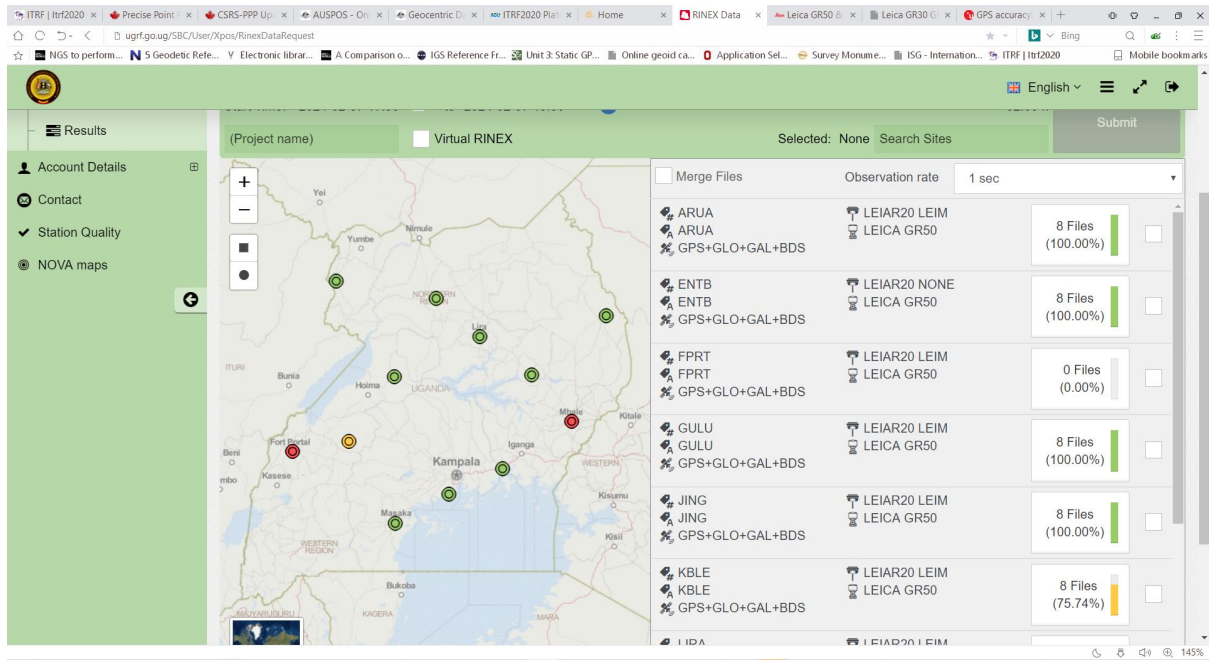Accra, Ghana, 19–24 May 2024

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Figure 1 Screen shot of the UGRF Spider Business Centre Interface used to download the data.

The online tools that were used are briefly described below:

Trimble Center Point RTX service uses Trimble's global network of reference stations to compute precise satellite orbits and clocks (Trimble, 2024) . This service is dual-frequency GNSS measurement processing service for static sessions with limitations of 1 hour up to 24 hours. It's reported that it can achieve an accuracy ranging from 2 to 6cm for horizontal and vertical coordinate values respectively. This Trimble service is discriminative in that it does not allow any antennas that not in its database (Nardo, et al., 2015).

Automatic Precise Positioning Service (APPS) accepts GPS measurement files and uses the most advanced positioning technology from the re-known NASA Jet Propulsion Laboratory (JPL). This APPS service can perform PPP of any GPS receivers whether they are in motion, static or even in air. APPS uses real-time, daily and weekly precise GPS orbit and clock products (JPL, 2024).

The Australian Positioning Service (AUSPOS) is an online GPS Processing Service currently using version AUSPOS 2.4. AUSPOS uses the International GNSS Service (IGS) products that is the ultra-rapid, rapid and final orbits contingent on their readiness during the time of processing (Geoscience, 2024). This service only admits

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to process dual frequency GPS phase data. The results or report as they call it is segmented into five sections that include; User Data, Processing Summary, Computed Coordinates, Ambiguity Resolution, and Computation Standards.

The modernized Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP) service provided freely by the Canadian Geodetic Survey of Natural Resources Canada. The modernization of CSRS-PPP as of Janu, 2018 involved mainly the inclusion of PPP with Ambiguity Resolution (PPP-AR). The other development was that all output solutions are based on International GNSS Service 2020 (IGS20) reference frame which is the actual realization of ITRF2020 (Canada, 2024). It's also worth to note the CSRS-PPP outputs, which include; solution report, summary file, position file, tropospheric zenith delay, Rinex_Clock format file, comma-separated format text file, JSON format residual file and an error file.

The GNSS observation files were selected in such a manner that only precise products are used during the processing with the online tool. Take not that these online tools have varying requirements in their processing strategy as shown in the Table 2. In all the processing the default settings were used without any alternations.

Table 2 Summary of key online tools processing strategies

Strategy	APPS	CSRS-PPP	Trimble Center Point RTX	AUSPOS
Processing Mode	Static, kinematic	Static, kinematic	Static	Static
Frequency	Dual frequency	Singal, Dual frequency	Dual frequency	Dual frequency
Software	GIPSY-OASIS v5	CSRS-PPP SPARK 3.54.2	8.5.1.20196	AUSPOS 2.4
Constellation	GPS	GPS + GLONASS	GPS + GLONASS + Galileo	GPS
Coordinate Frame	ITRF2014	IGS20/ITRF2020	ITRF2005 & ITRF2014	ITRF2014
Ambiguity Resolution (AR)	Yes	Yes	No	Yes
Tropospheric delay model	GMF: troposphere mapping function	Dry delay: Davis Wet delay: Hopf MF: GMF	NA	GMF mapped with the DRY-GMF.
Orbits source	JPL final	IGS and NRCan	Trimble	IGS

Results and discussion

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The results were produced and presented in tabular form for clear and elaborate presentation. The geodetic coordinates of the stations were computed from four

online processing tools that is Trimble CenterPoint RTX, APPS, CSRS-PPP and AUSPOS. Among these tools AUSPOS and Trimble CenterPoint RTX provide their results in ITRF2014 while APPS and CSRS-PPP have results in ITRF2020. The results are tabulated in Table 3 to Table 6.

Table 3 Trimble CenterPoint RTX (ITRF2014 @ Epoch 2023.92)

DAY	SRTI		ARUA		MSND		MSKA		JING		ENTB
338	1.769442333		3.021410861		1.714693639		-0.387689583		0.433217889		0.149832917
	33.65013231		30.99910711		31.72683183		31.74236644		33.33902942		32.56014908
	1111.323		1208.912		1142.816		1197.513		1134.501		1164.853
316	1.769442694		3.021458250		1.714693889		-0.387689389		0.433218028		0.149832917
	33.65006958		30.99916983		31.72683183		31.7423665		33.33902906		32.56014919
	1111.341		1208.890		1142.823		1197.525		1134.510		1164.850
315	1.769442667		3.021458528		1.714693833		-0.387689167		0.433218		0.149833250
	33.65013164		30.99917003		31.72683156		31.74236622		33.33902881		32.56014900
	1111.340		1208.889		1142.819		1197.53		1134.510		1164.851
314	1.769442833		3.021458722		1.714694222		-0.387689222		0.433218056		0.149832944
	33.65013203		30.99916942		31.72683117		31.74236578		33.33902925		32.56014853
	1111.346		1208.897		1142.817		1197.527		1134.513		1164.817
313	1.769442694		3.021458472		1.714693972		-0.387689389		0.433217778		0.149833083
	33.65013219		30.99916944		31.72683161		31.74236617		33.33902906		32.56014900
	1111.340		1208.896		1142.820		1197.528		1134.516		1164.846
312	1.769442361		3.021458333		1.714693667		-0.387689444		0.43321775		0.149833028
	33.65013228		30.99917006		31.72683156		31.74236667		33.3390295		32.56014931
	1111.349		1208.897		1142.823		1197.523		1134.519		1164.873
311	1.769442639		3.021458278		1.714693611		-0.387689417		0.433217972		0.149833028
	33.65013200		30.99917006		31.72683178		31.74236619		33.33902886		32.56014931
	1111.338		1208.909		1142.831		1197.530		1134.515		1164.874
310	1.769442472		3.021458194		1.714693556		-0.387689667		0.433217861		0.149832750
	33.65013211		30.99916961		31.72683139		31.74236597		33.33902878		32.56014889
	1111.329		1208.892		1142.820		1197.525		1134.508		1164.840

Table 4 APPS Solution ITRF2020 epoch 2023.9

DAY	SRTI		ARUA		MSND		MSKA		JING		ENTB
338	1.721944393		3.017145991		1.686469526		-0.338768843		0.418321905		0.059983404

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	SRTI	ARUA	MSND	MSKA	JING	ENTB
	33.62001324	30.90991696	31.71768319	31.71923665	33.21390293	32.47601495
	1111.7337	1209.2888	1143.2244	1197.9281	1134.9095	1165.2604
316	1.721944368	3.017145977	1.686469493	-0.338768865	0.418321877	0.059983406
	33.62001322	30.90991692	31.71768317	31.71923664	33.21390292	32.47601494
	1111.7440	1209.3082	1143.2327	1197.9323	1134.9035	1165.2652
315	1.721944378	3.017145968	1.686469509	-0.338768835	0.418321893	0.059983401
	33.62001324	30.90991695	31.71768319	31.71923666	33.21390291	32.47601495
	1111.7358	1209.2964	1143.2125	1197.9394	1134.9159	1165.2547
314	1.721944371	3.017145969	1.686469500	-0.338768857	0.418321874	0.059983375
	33.62001323	30.90991695	31.71768315	31.71923664	33.21390293	32.47601494
	1111.7433	1209.3004	1143.2265	1197.9367	1134.9123	1165.2154
313	1.72194439	3.017145969	1.68646951	-0.338768838	0.418321898	0.059983411
	33.62001324	30.90991695	31.71768317	31.71923665	33.21390293	32.47601495
	1111.7365	1209.2904	1143.2197	1197.9312	1134.9159	1165.2471
312	1.721944385	3.017145981	1.686469499	-0.338768845	0.418321903	0.059983428
	33.62001325	30.90991694	31.71768318	31.71923666	33.21390294	32.47601496
	1111.7543	1209.3009	1143.2134	1197.9266	1134.9239	1165.2680
311	1.721944432	3.017146006	1.686469528	-0.338768822	0.418321918	0.059983432
	33.62001322	30.90991696	31.71768315	31.71923664	33.21390291	32.47601494
	1111.7412	1209.3059	1143.2153	1197.9283	1134.9179	1165.2631
310	1.721944421	3.017146001	1.686469537	-0.338768822	0.41832193	0.059983417
	33.62001322	30.90991696	31.71768318	31.71923665	33.21390293	32.47601494
	1111.7361	1209.2928	1143.2150	1197.9326	1134.9173	1165.2398

Table 5 AUSPOS V2.4 ITRF2014 solutions

DAY	SRTI	ARUA	MSND	MSKA	JING	ENTB
338	1.769443444	3.171459167	1.715903611	-0.387688528	0.433218639	0.149833611
	33.65013247	30.99916958	31.72683186	31.74236669	33.33902947	32.56014936
	1113.456	1209.012	1142.947	1197.640	1134.633	1166.980
316	1.7694435	3.021458944	1.714694583	-0.38768842	0.433218889	0.149833917
	33.65013253	30.99916981	31.7268315	31.74236664	33.33902939	32.56014897
	1113.471	1209.002	1142.941	1197.647	1134.638	1166.978
315	1.7694435	3.021459333	1.714694667	-0.38768836	0.433218972	0.149833889
	33.65013253	30.99916925	31.72683222	31.74236609	33.33902941	32.56014925
	1113.471	1209.019	1142.961	1197.664	1134.665	1166.976

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DAY	SRTI	ARUA	MSND	MSKA	JING	ENTB
314	1.769443556	3.021459167	1.714694750	-0.38768839	0.433219089	0.149833611
	33.65013211	30.99916917	31.72683122	31.74236628	33.33902894	32.56014969
	1113.477	1209.024	1142.954	1197.660	1134.642	1166.946
313	1.769443528	3.021459306	1.714694806	-0.38768853	0.433218889	0.149833889
	33.65013233	30.99916958	31.72683161	31.74236653	33.33902925	32.56014958
	1113.467	1209.01	1142.945	1197.650	1134.640	1166.961
312	1.769443444	3.021459417	1.714694694	-0.38768844	0.433218972	0.149833972
	33.65013236	30.99916972	31.72683169	31.74236639	33.33902931	32.56014925
	1113.479	1209.022	1142.951	1197.652	1134.655	1166.988
311	1.769443556	3.021459361	1.714694750	-0.38768836	0.433218833	0.149833639
	33.65013261	30.99916964	31.72683183	31.74236675	33.33902925	32.56014964
	1113.473	1209.024	1142.927	1197.655	1134.633	1166.985
310	1.769443694	3.021459111	1.714694806	-0.38768847	0.433218778	0.149833833
	33.65013211	30.99916922	31.72683153	31.74236625	33.33902906	32.56014911
	1113.460	1209.008	1142.94	1197.652	1134.632	1166.956

Table 6 CSRS-PPP 3.54.2 - ITRF20 (2023.9) solutions

DAY	SRTI	ARUA	MSND	MSKA	JING	ENTB
338	1.769443028	3.021459056	1.714694333	-0.38768881	0.433218556	0.149833611
	33.76679914	30.99916967	31.72683183	31.74236681	33.33902942	32.56014950
	1111.338	1208.903	1142.832	1197.529	1134.518	1164.872
316	1.769443139	3.021458861	1.714694278	-0.38768881	0.433218500	0.149833556
	33.76679900	30.99916958	31.7268315	31.74236658	33.33902933	32.56014922
	1111.336	1208.887	1142.831	1197.528	1134.517	1164.854
315	1.769443111	3.021459111	1.714694333	-0.38768867	0.433218583	0.149833694
	33.76679897	30.99916956	31.72683175	31.74236664	33.33902922	32.56014942
	1111.341	1208.902	1142.826	1197.533	1134.516	1164.854
314	1.769443222	3.021458944	1.714694417	-0.38768872	0.433218444	0.149833472
	33.76679911	30.99916961	31.72683172	31.74236664	33.33902942	32.56014961
	1111.350	1208.898	1142.829	1197.536	1134.521	1164.831
313	1.769443278	3.02145906	1.714691669	-0.38768864	0.433218361	0.149833778
	33.76679903	30.99916950	31.72683169	31.74236667	33.33902933	32.56014942
	1111.344	1208.896	1142.828	1197.531	1134.520	1164.853
312	1.769443167	3.02145922	1.714691669	-0.38768864	0.433218528	0.149833833

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	33.76679889		30.9991695		31.72683169		31.74236672		33.33902939		32.56014942
	1111.353		1208.896		1142.825		1197.525		1134.525		1164.871
311	1.769443417		3.02145900		1.714694250		-0.38768869		0.433218639		0.149833750
	33.75013217		30.99916939		31.72683156		31.74236644		33.33902939		32.56014922
	1111.345		1208.907		1142.830		1197.536		1134.518		1164.877
310	1.769443333		3.021459083		1.714694389		-0.38768878		0.433218722		0.149833611
	33.75013231		30.99916956		31.72683178		31.74236658		33.33902911		32.56014925
	1111.334		1208.895		1142.822		1197.532		1134.513		1164.843

From the above results the variations in the geodetic coordinates for the processed coordinates shows that there are huge differences most especially between UGRF and ITRF2020 as was expected. On the latitude and longitude, the differences are in the ranges of degrees to minutes while in the ellipsoidal heights the difference is in metres. This is really proof that the techniques used in the computation of ITRF are much better that those of ITRF2005 which the UGRN was based on.

Whereas with ITRF2014 the differences in the coordinate latitude and longitude are minimal as in that the differences are in minutes to seconds. For the ellipsoidal heights the difference between the heights was in millimeters. This shows that ITRF2005 and ITRF2014 were fairly close to each other. However, we have pointed out that the results that were produced from APPS shown a bigger difference as compared to those from the other tools yet all of them used the final satellites with the only difference in the combinations.

Conclusion

The paper assessed the performance of UGRF station geodetic coordinates using the four free online tools that's is APPS, CSRS-PPP, AUSPOS and CenterPoint RTX. Six stations were randomly picked and data for eight days processed. Seven consecutive days that is 310 to 316 then a distant day of 338.

The mean difference in the geodetic latitudes and longitudes is approximately 2 minutes in both while in the ellipsoidal heights it was 3.5m between UGRN and

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ITRF2020, While the difference in ITRF2014 and UGRN it was approximately in the

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regions of 3 minutes in the geodetic latitudes and longitudes, the for the ellipsoidal height difference was at 1cm.

With this it is imperative that UGRN geodetic reference of Uganda be enhanced to the ITRF2020 so that the reference frame is modernized just like what Canada and of course the National Spatial Reference System (NSRS) of National Geodetic Survey (NGS). UGRN should be consistent, accurate and up-to-date with the current developments with international standards.

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