Comparison of Free and Open PPP Services for Master-base Positioning in Geodetic Disadvantaged Areas: Case Study along the Sirba River in Sub-Saharan Africa

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Keywords: Point Positioning, High-precision GNSS, NRTK, Free and Open Services, Sub-Saharan Africa, Niger, Sirba River, Sahel, Topographic Survey, Geodetic Disadvantaged Areas.

Abstract: The Precise Point Positioning (PPP) is a Global Navigation Satellite System (GNSS technique) for post- and real-time processing. PPP has recently spread thanks to the high precision and accuracy positioning results that it provides. Until some years ago, this technique was limited by long sessions of measurements and professional software to obtain results with centimetre-level precision, using only one GNSS dual frequency receiver. Nowadays, the PPP technique is well established among GNSS experts, and many software exists to perform it. The PPP technique uses data from continuously operating reference stations (CORS) to process the pseudo-range and carrier phase measurements. CORS can also be located very far from the surveyed area. This makes PPP particularly suitable for GNSS surveys in areas considered disadvantaged for the lack of geodetic infrastructures, such as CORS and known-coordinates points. Recently, PPP online free and open tools have been made available by national agencies worldwide. This contribution analyses the PPP online services as potential solutions for realising GNSS surveys in geodetic disadvantaged areas. Specifically, it compares two PPP online services: the Canadian Spatial Reference System Precise Point Positioning tool (CSRS-PPP) and Automatic Precise Positioning Service (APPS). In the analysis, the AUSPOS Online GPS processing service that applies relative positioning technique based on the closest CORS was considered a non-PPP post-processing online tool to compare results. Data were collected in South-West Niger, along Sirba River, 900 km away from the closest CORS and 250 km far from the closest known-coordinates point. The estimated coordinates' precision was tested for different session lengths (three scenarios of 3 hours, 1 hour, and 30 minutes) over 17 sessions. Then, the precision was validated by analysing the one-year daily acquisitions dataset (from CORS). The results revealed precisions and relative accuracies lower than 5 cm for three hours' sessions. From the analysis of the short stationing sessions (i.e., one hour and half hour) emerged that APPS provides the most confident solutions. As expected, the less performant service in CORS-depressed areas is the relative positioning service AUSPOS.

1 INTRODUCTION

In the past years, the Global Navigation Satellite System (GNSS) has overcome traditional survey methods, becoming a standard tool in many surveying sectors. Nowadays, GNSS systems play a lead role in data acquisition thanks to the increasing number of satellites, the low costing, the efficiency, and the variety of available products. From 2002 forward (Eren Kamil *et al.*, 2009) Real-Time Kinematic networks (NRTK) have spread. These networks are composed of GNSS stations of known coordinates,

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Belcore, E., Piras, M., Dabove, P., Massazza, G. and Rosso, M.
Comparison of Free and Open PPP Services for Master-base Positioning in Geodetic Disadvantaged Areas: Case Study along the Sirba River in Sub-Saharan Africa.
DOI: 10.5220/0011039600003185
In *Proceedings of the 8th International Conference on Geographical Information Systems Theory, Applications and Management (GISTAM 2022)*, pages 37-47
ISBN: 978-989-758-571-5; ISSN: 2184-500X

called Continuously Operating Reference Station (CORS), and managed by a network software installed in a control centre. The introduction of the CORSs has allowed users to collect data using one GNSS multi-frequency receiver (instead of two). This is possible thanks to the direct connection between the CORS and the dual-frequency receiver through the control centre. Today, a dense world network of permanent stations to process GNSS data exists (Kim, Seo and Lee, 2014), and it has revolutionised the data acquisition modalities (Grejner-Brzezinska *et al.*, 2007; Rizos, 2007).

Despite today CORSs cover most of the world's countries, some areas are still not included in the network, such as some sub-Saharan countries (Figure 1). Considering the real-time positioning and the NRTK method, the rover receiver needs to be within a short distance (less than 60 km) from the reference stations (Dabove and Manzino, 2014; Dabove, Cina and Manzino, 2018).

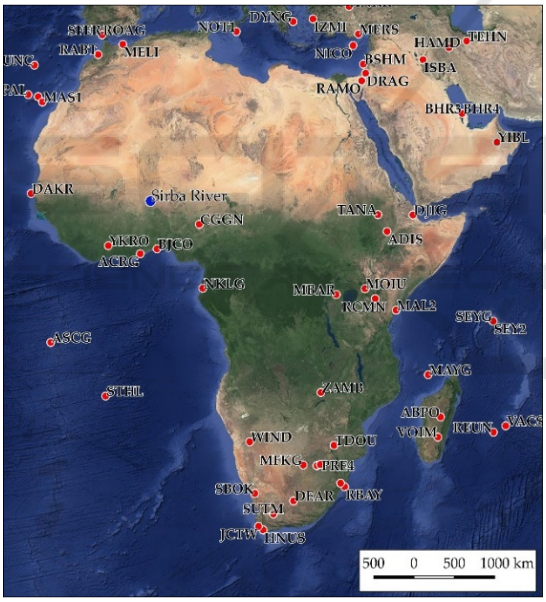

Figure 1: CORS in Africa. The red dots indicate the stations that provide observations to the International GNSS Service (IGS), while the blue one is the study area. Data Source: International GNSS Service (IGS), (https://www.igs.org/).

A short baseline is fundamental to minimise the distance-dependent errors induced by the troposphere, the ionosphere, and the orbital errors (El-Mowafy, 2012, p.). This specific requirement can be an obstacle for realising NRTK surveys where there are no CORS within hundreds of kilometres (Elmezayen and El-Rabbany, 2019). A possibility to overcome the lack of CORS is resorting to two GNSS dual-frequency receivers in the rover-base modality. This data collection method requires two GNSS receivers communicating with each other (usually via radio): one works as "base" or "master" (substituting the permanent station) and the other as "rover" that collects the coordinates of the points of interest for the survey. The coordinates of the base station must be known.

When a known-coordinates point is not available, post-processing operations are compulsory to obtain the base's correct position. One of the most common post-processing methods is the PPP (Precise Point Positioning). To perform it, data regarding satellites' orbits and the ionosphere are needed to process the pseudo-range and carrier phase measures of GNSS multi-frequency receivers (Zumberge *et al.*, 1997; Kouba and Héroux, 2001; Bisnath and Gao, 2009). These data are collected by permanent stations that can also be located very far from the surveyed area (Kouba and Héroux, 2001). In terms of East, North, and Up components, the PPP can provide centimetre-level precisions in static mode (Bisnath, Wells and Dodd, 2003; Pan *et al.*, 2015), if the phase ambiguities are correctly fixed as integer values (Ge *et al.*, 2008; Collins and Bisnath, 2011). The PPP corrections precision is also strictly dependent on the measurement session's duration (Yigit *et al.*, 2014; Mohammed *et al.*, 2018). Its effectiveness for the estimation of the positions has been demonstrated by several authors, e.g. (Zumberge *et al.*, 1997; Kouba and Héroux, 2001; Gao and Shen, 2002; Gao, Harima and Shen, 2003) using precise orbits and satellite clocks from IGS (Gao and Chen, 2004; IGS, 2019) and many other providers (Jamieson Marian and Gillins Daniel T., 2018; Mohammed *et al.*, 2018; Wang *et al.*, 2018). RTK is a relative positioning technique based on carrier-phase. A minimum of four common satellites between the two receivers is required. Tracking more than four satellites improves the GPS position solution's precision and allows it to obtain a sub-centimetre accuracy level. The excellent accuracy results are also because errors and bias deriving from the same satellite should be equals. Thus, shorter is the baseline, and more similar are the errors. Several error sources affecting positioning accuracy in GNSS surveys exist (Karaim, Elsheikh and Noureldin, 2018). Today relative technique provides better solutions than the PPP technique in terms of accuracy (Ocalan *et al.*, 2016). The primary reason is attributable to the lower effects of satellite orbit errors over relative techniques than the PPP technique.

Moreover, clock errors can be eliminated in relative techniques using double differencing phase measurements (Nistor and Buda, 2015). The primary error sources of PPP (such as ionospheric and tropospheric delay, clock bias) are usually mitigated by: i) employing the combinations of dual-frequency GNSS measurements to eliminate the first-order ionospheric delay (Kouba and Héroux, 2001; Ocalan *et al.*, 2016); ii) applying external error correction data (including satellite orbit and clock corrections); and iii) modelling the tropospheric delay to correct it. Since a part of tropospheric delay cannot be efficiently modelled because of its high variability, it is estimated (wet component of tropospheric delay). Precise satellite orbit and clock information are used to estimate the tropospheric residuals, and associated gradients with proper stochastic models, which means that the estimates are constrained by the prior variance and its propagation value. Thus, PPP depends on the accuracy level of this information (Ocalan *et al.*, 2016).

Even if RTK and PPP techniques provide similar precision and accuracy, they require different setups. On the one hand, RTK needs a complex configuration and (generally) expensive equipment, but it rapidly provides higher accuracy. It is worth remembering that the base station must be placed very precisely on a known-coordinate point to achieve high accuracy. On the other hand, the PPP technique needs a more straightforward setup, but it has lower accuracy and longer initial convergence time (Nistor and Buda, 2015; Ocalan *et al.*, 2016). Also, since PPP does not use a base station, it is not affected by baseline length bias and can provide full accuracy anywhere in the world.

Until some years ago, the satellites' data, the ionosphere information, and the specific software necessary to perform PPP were not easily obtainable, and the PPP was limited to few expert users, such as academia and research institutes. Today, some commercial and scientific solutions to perform PPP exist (e.g., Bernese, GIPSY, and GAMIT). Such software can efficiently perform PPP as long as infrastructures with adequate computational power, and skilled users are available. The PPP technique has raised the attention of academia, industry, and governments (Bisnath and Gao, 2009). In particular, the last ones have dedicated specific attention to PPP, and some of them shared the socio-economic benefits of PPP with the public, providing ad hoc coordinates online estimation services (Bisnath and Gao, 2009). Some governmental research centres provide PPP online free services. It is sufficient to upload the GNSS raw data to obtain correct position data from the services. These free web-solutions for PPP do not require high computational power or particularly skilled users, but each service uses its estimation algorithms. Thus, the results provided can be very different. The scientific literature provides some interesting analysis of PPP online services, where known coordinates points are processed with different PPP online services (Ozgur Uygur *et al.*, 2016; Arabi and Nankali, 2017; Oluyori, Ono and Okiemute, 2019), and the estimated coordinates are compared with known ones. Nevertheless, few of these studies analyse data collected in geodetic disadvantaged areas as far as the authors know. Indeed, the lack of CORS and known coordinates points is quite a frequent condition in sub-Saharan rural areas, strongly affecting topographic surveys.

This work proposes a comparison between two PPP online free services to correct RTK data collected through rover-base modality (i.e., static mode) in low-density CORS areas. The PPP services considered are the Canadian Spatial Reference System Precise Point Positioning tool (CSRS-PPP) and the Automatic Precise Positioning Service (APPS). A CORS-based post-processing free service is considered in the analysis as a non-PPP post-processing online tool: the AUSPOS Online GPS processing service (AUSPOS). The precision, the convergence time (meant as the length of time required to reach centimetre-level positional solutions), and the structure and condition of the services' use are analysed in this paper. The data used for the comparison were collected in February 2018 along Sirba River (southwest Niger) in the framework of the ANADIA 2.0 project[1].

2 INVESTIGATED SITE AND SURVEY

ANADIA 2.0 project was born in 2017 to develop an early warning system against floods and strengthen the local technicians' competencies on monitoring and forecasting river floods (Massazza *et al.*, 2019). Indeed, in the last decades, Sahelian floods have become a relevant issue due to the ongoing climatic

[1] ANADIA 2.0 (Adaptation to climate change, disaster prevention and agricultural development for food security) is a project funded by the Italian Agency for Development Cooperation (AICS) and executed by Institute of BioEconomy of the National Research Council of Italy (IBE-CNR) in partnership with the Department of Regional and Urban Studies and Planning of the Politecnico di Torino (DIST) and the National Directorate for Meteorology of Niger (DMN).

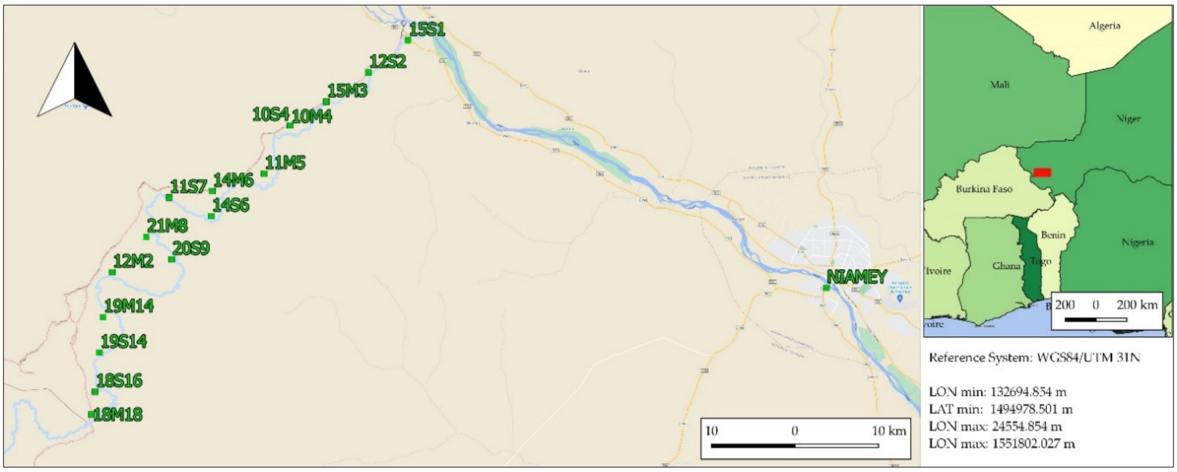

Figure 2: Section of Sirba River interested by the survey. The green squares identify the locations of the stations along the river. The arrows indicate the flow direction of the rivers. OSM background.

and land use changes (Bigi, Pezzoli and Rosso, 2018; Tamagnone *et al.*, 2019). In this framework, high-precision surface and hydraulic numerical models are necessary as inputs for the development of forecasts flood models (Massazza *et al.*, 2020; Passerotti *et al.*, 2020; Tarchiani *et al.*, 2020). Hence, to meet the project's data requirements, a topographic survey was carried out on the Middle Niger River Basin's main tributary, the Sirba River (Figure 2). More than 100 cross-sections were measured along a reach of 108 km (one section per km), and flood-risked-exposed infrastructures were measured during the dry period (February) to take advantage of the intermittent flow (Belcore *et al.*, 2019; Tiepolo *et al.*, 2019). 10 cm accuracy for the Up component was required (Massazza *et al.*, 2019).

Despite the closest CORS to the study area are in Nigeria and Ivory Coast, they are more than 900 km away from the study region.

As discussed in the previous section, 900 km is a too large baseline to guarantee centimetre-accuracy. Besides, the closest known-coordinates points are around 200 km away from the surveyed area. Considering these particular conditions, the only feasible way to collect data was an RTK survey in master-rover modality with a radio-modem connection. The PPP technique was used to post-process the data and to estimate the coordinates of the base stations. The data were collected with two STONEX S10 dual-frequency receivers. The master receiver was placed in 17 different stations along the Sirba River (Figure 2), and 3,150 points were measured with the rover receiver. Each master station acquired data for at least two hours, considering a session length of 3 hours and 22 minutes as maximum. GPS, GLONASS, BEIDOU and SBAS constellations were tracked.

Some instruments malfunctioning, attributed to the high temperature, slowed down the data collection. In the hottest hours of the day, the temperature reached 40°C, and the master receiver often overheated and stopped the communication with the rover receiver. The communication happened via radio using RTCM communication protocol at 410-470 MHz frequency. The overheating prevented acquisition longer than 3 hours for most of the acquisition station. The receivers' communication was even more limited by the local topography and the abundant vegetation along the river. Regularly, if the receivers were more than 3 km away from each other, the communication stopped. In 9 days, were measured 103 cross-sections along a river reach of 108 km. The raw measurements were saved in the Receiver Independent Exchange Format (RINEX) 3.01 version with a sampling rate of 1s.

3 METHODOLOGIES

As previously discussed, two main possible techniques are available for post-processing purposes: the phase-based relative solution (base-rover) or the PPP one (Dabove and Manzino, 2014). In this paper, we will focus on the PPP approach (Cai and Gao, 2007). Today many possibilities for obtaining PPP solutions from online services exist (Dawidowicz and Krzan, 2014; Dabove, Piras and Jonah, no date): some of them consider only GPS constellation (e.g., APPS), other ones also the GLONASS satellites (CSRS-PPP). To exploit the use of more than two GNSS constellations, the data collected by the master receiver were stored in RINEX 3.01 version and then post-processed using two online PPP free services: 1) The Canadian Spatial Reference System (CSRS-PPP), and 2) the Automatic Precise Positioning Service of the Global Differential GPS System (APPS). Additionally, data were processed using a relative positioning online service, 3) Online GPS Processing Service (AUSPOS), as a comparison against PPP technique geodetic disadvantaged areas. A summed table was created (Table 1) to recap the functioning of the three services.

Table 1: Summary of the main characteristics of the three services at the processing time, calculated on 10Mb file. *If users submit RINEX V3 file, C2S (code measurement) and L2S (phase measurement) from L2 frequency will NOT be accepted.

	CSRS-PPP	**APPS**	**AUSPOS**
RINEX version	3.x	2.x	2.11*
Maximum file size	300 Mb	10 Mb	Not specified
Multi-file upload	Yes	Yes	Only via FTP
FTP	No	Yes	Yes
Height of the antenna	Automatically detected	Automatically detected	Manually set
User-defined elevation-dependent data weighted	No	Yes	No
User-defined cut-off angle	No (default 7.5)	Yes	No
L1 code	Yes	Yes	No
Upload of pressure model	No	Yes	No
Direct results	No	Yes	No
Compulsory registration to the website	Yes	No	No
Processing time (minutes)*	20	3	20
Reference system(s) of the results	ITRF 2014, NAD83	ITRF 2014	ITRF 2014
Orthometric heights	Yes	No	Yes
Elaboration report	Yes	No	Yes
Graphic restitution of the elaboration statistics	Yes	No	Yes
Ambiguity resolution	No	Yes	Yes
GNSS constellations processed	GPS+GLONASS	GPS	GPS

4 RESULTS AND DISCUSSION

Before the PPP processing, the RINEX data were pre-processed. The RINEX files version 3 were converted into RINEX version 2.11 with the RTKCONV tool that is part of the open source software RTKLIB (http://www.rtklib.com/) (Takasu and Yasuda, 2009). Furthermore, the frequency rate of acquisition was reduced to one observation every 5 seconds to have files of less than 10 Mb of size, which is the file size limit of APPS service. The analysis considers the precisions of the estimation of each service and the relative accuracy (measured as the difference between coordinates) of 17 stations (one station of ANADIA 2.0 was excluded from this analysis because it is located outside the Sirba River basin). The final coordinates have been converted into WGS84/UTM31N coordinates system. The APPS service provides the σ values with 68% confidence, while CSRS-PPP and AUSPOS calculates 95% uncertainties. Therefore, the uncertainty values of APPS were related to 2σ confidence. Table 2 shows the session length and the date of acquisition for each station. For the analysis, the stations were distributed in three groups of uniform acquisition length: *group 1* less than 2,5 hours acquisition length; *group 2* between 2,5 and 3 hours; and *group 3* more than 3 hours. The CSRS-PPP values had been taken as a reference for comparing the services, as shown in Equations 1 and 2.

$$\Delta CSRS\text{-}APPS = EC\_CSRS - EC\_APPS \quad (1)$$

$$\Delta CSRS\text{-}AUSPOS = EC\_CSRS - EC\_AUSPOS \quad (2)$$

Where *EC_ CSRS* are the North, East and Ellipsoidal height coordinates of each sample points estimated by CSRS; *EC_ APPS* are the North, East and Ellipsoidal height coordinates of each sample points estimated by APPS; *EC_ AUSPOS* are the North, East and Ellipsoidal height coordinates of each sample point estimated by AUSPOS.

According to (Choy, Bisnath and Rizos, 2017), a minimum of one hour is required for the horizontal solution from a standard PPP static processing to converge to 5 cm, and approximately 20 minutes are required for 95% of solutions to reach a horizontal accuracy of 20 cm (Seepersad and Bisnath, 2014). Thus, three different scenarios of time acquisition were created using RTKLIBCONV (Takasu and Yasuda, 2009) to investigate the effectiveness of the services on short acquisition time: full acquisition length, session of one hour, session of half-hour.

Table 2: Characteristics of the positions of the master receivers (Stations) analysed. Gr =group, *dd/mm/yyyy.

Station ID	Date of acquisition*	Starting time	Ending time	Session length	Gr
12S2	12/02/2018	12:58	14:49	01:51	1
10S4	10/02/2018	15:08	17:07	01:59	
14M6	14/02/2018	09:28	11:43	02:15	
10M4	10/02/2018	10:28	12:54	02:26	
15S1	15/02/2018	13:46	16:30	02:44	2
19S14	19/01/2018	14:02	16:49	02:47	
20S9	20/01/2018	14:24	17:12	02:48	
15M3	15/01/2018	08:17	11:08	02:51	
18S16	18/01/2018	14:09	17:02	02:53	
21M8	21/01/2018	08:53	11:46	02:53	
14S6	14/01/2018	13:38	16:35	02:57	
11M5	11/01/2018	09:05	12:05	03:00	
11S7	11/01/2018	13:43	16:52	03:09	3
12M2	12/01/2018	08:50	12:05	03:15	
18M18	18/01/2018	08:05	11:28	03:23	
20M12	20/01/2018	08:45	12:09	03:24	
19M14	19/01/2018	08:25	11:52	03:27	
12S2	12/02/2018	12:58	14:49	01:51	

Table 3 presents the minimum, maximum and average values of Δ CSRS-APPS and ΔCSRS-AUSPOS, calculated as illustrated in equations 1 and 2. The difference between CSRS and AUSPOS of the East component ranges between 0 cm and 6.7 cm, which is a clue of high data dispersion. This is particularly evident from distances between the average values of Groups 1 and 2, and it is a clear indicator of the importance of stationing time longer than 1 hour for improved precision. On the contrary, the North component of the Δ CSRS-AUSPOS (and the Δ CSRS-APPS too) is more stable.

Regarding the coordinates' precision, the calculated uncertainties values range from 0.2 cm (East and North of APPS) to 65 cm (Up component of AUSPOS). The latter is not representative of the analysis, and it was interpreted as an exceptional event; thus, it was excluded in the computation of the average. For AUSPOS, the distance from the reference CORS plays a crucial role in estimating the coordinate. In these analyses, the baseline ranges from 500 km to 1500 km on 14 reference stations. From the reference literature, we aspect Root Mean Square (RMS) values of position errors for baseline around 500 km less than 4 cm, and less than 6 cm on each component (E, N, U) for baseline more than 1000 km. Such values are calculated over 24 hours of acquisitions (Choi, Roh and Lee, 2014). For shorter stationing time, the precisions fall down.

Table 3: Minimum, Maximum, and Average of the differences between the coordinates estimated by CSRS, APPS, and AUSPOS for each station in meters.

Group 1				
		Min	Max	Av
Δ CSRS-APPS	East	0.007	0.019	0.014
	North	0.008	0.014	0.011
	Up	0.005	0.046	0.024
Δ CSRS-AUSPOS	East	0.005	0.067	0.023
	North	0.001	0.014	0.007
	Up	0.018	0.046	0.032
Group 2				
		Min	Max	Av
Δ CSRS-APPS	East	0.001	0.026	0.01
	North	0.002	0.011	0.006
	Up	0.006	0.037	0.016
Δ CSRS-AUSPOS	East	0.001	0.013	0.008
	North	0.002	0.005	0.003
	Up	0.006	0.069	0.029
Group 3				
		Min	Max	Av
Δ CSRS-APPS	East	0.003	0.029	0.016
	North	0.001	0.008	0.003
	Up	0.001	0.024	0.011
Δ CSRS-AUSPOS	East	0.000	0.04	0.021
	North	0.002	0.004	0.003
	Up	0.006	0.031	0.017

According to the report produced by Novatel (NovAtel, 2019), we can expect around 10 cm RMS values of the position errors for baseline length between 700 km and 1000 km in 3-hours stationing. These values reflect our measures: AUSPOS is closed 8 cm on the Up component. For groups 1 and 2, the uncertainties on the East component estimated by APPS are slightly lower than those of other services (Figure 3). Figure 3 shows the graphical analysis of East, North, and Up components' uncertainties values and considers the full acquisition time and on 1-hour acquisition time both. Similarly to Table 3, what stands out in Figure 3 is the decrease of uncertainties from Full-time acquisition (Group 3) and one hour sessions (Group 1). CSRS-PPP and APPS provide the lowest uncertainties values. With shorter acquisition time, the confidence levels of CSRS-PPP and APPS

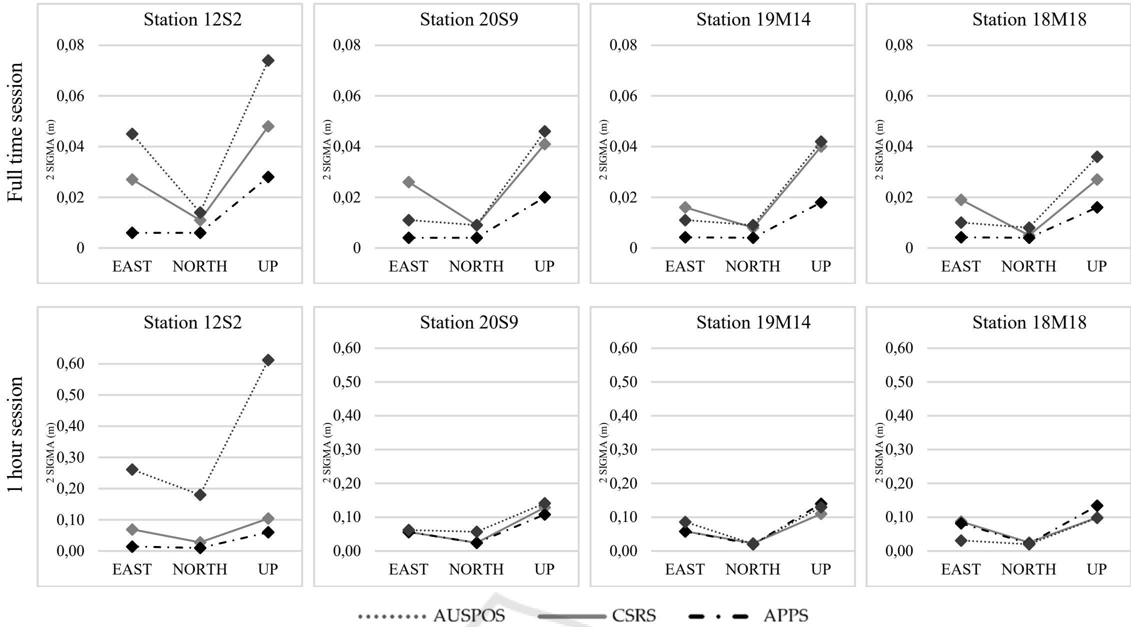

Figure 3: Graphical analysis of the uncertainties values of East, North, and Up coordinates of the three services, obtained considering the full acquisition time and 1-hour acquisition time.

get closer (Figure 3), while AUSPOS shows similar trends for some stations (i.e., 19M14 and 18M18) and very different for other (station 12S2). Table 4 lists the values of the difference between the coordinates elaborated with the services on the 1-hour session. Even if these trends are similar to full-acquisitions, a significant distance between the Up components can be observed: the ΔCSRS-APPS peaks 40 cm. For 30 minutes-acquisition time, AUSPOS did not provide any results because one hour is the minimum acquisition time required to perform the coordinates estimations.

Table 4: Minimum, Maximum, and Average of the difference between the coordinates estimated by CSRS, APPS, and AUSPOS for each sample station (1hour session).

Service	ITRF	1 h session Δ (m)		
		Min	Max	Av
Δ CSRS-APPS	East	0.001	0.140	0.030
	North	0.000	0.374	0.032
	Up	0.005	0.108	0.044
Δ CSRS-AUSPOS	East	0.006	0.432	0.099
	North	0.002	0.403	0.037
	Up	0.033	0.286	0.165

CSRS-PPP and APPS's performances peak in the East component of 20 cm and reach 50 cm on the Up component.

5 DATA VALIDATION

The lack of CORS in Niger makes it challenging to test the accuracy of PPP services. Since there are no known-coordinates points to be used as a reference for accuracy analysis, only the precision values can be evaluated. To overcome this major constraint, we analysed accuracies of post-processing services solutions in sub-Saharan areas considering the data of CORS settled in countries close to Niger. CORS at the same latitude of the study area sought to guarantee both the mean atmospheric conditions (in terms of ionospheric and tropospheric delays) and satellite geometry distribution. Another possible approach could be to collect 24-hours of data to obtain results independent of the satellite geometry distribution and guarantee the solution's convergence, as described in the literature (Li and Zhang, 2014; Ren *et al.*, 2015). However, it was impossible to realise long-session sessions due to weather conditions. Hence, to check the estimations' accuracy, raw-observations of a CORS close to the surveyed area were analysed with online services. The selected CORS was the YKRO station (Yamoussoukro Tracking Station) in Cote d'Ivoire (1000 km away from the study area) and part of the IGS network (Table 5).

Table 5: Main characteristics of YKRO. Source: IGS website.

YKRO Site Information	
City	Yamoussoukro
Country	Cote d'Ivoire
Tectonic Plate	African Plate
Approximate Position, DMS (ITRF)	LAT: +06°52' 14.0170" LON: -05°14' 24.3347"
Elevation ellipsoid (m)	270.263
Date Installed	18-07-1999

This station was chosen because it is the closest station (considering latitude) to the investigated area, and it was operative at the time of the survey, February 2018. Besides, it is away from the sea. This may ensure atmosphere conditions as similar as possible to the ones of the study area. YKRO data of the survey days and the daily observations (12^{th} of each month of 2018) were downloaded from the IGS website. The YKRO dataset was reduced to 3 hours-lasting RINEX from 14.00 to 17.00, as the average lasting and representative time for Sirba River acquisitions. Data were processed with the online free services and estimated coordinated compared to the reference ones of the YKRO CORS (Table 5). The results show relatively constant performances for the North component and more disperse results for the East and Up components. Figure 4 compares summary statistics (average, minimum and maximum values) for the differences calculated between real and estimated coordinates. The highest dispersion of the East component stands out in the graphs. CSRS and APPS have similar trends on the components, while AUSPOS, even if it has average values close to one of the PPP, provided very unstable results for the Up and East components. The results are never below the 10 cm on East and North components while reaching 1 cm on the Up component. According to the literature, we should obtain precision under 20 cm on horizontal components in 20 minutes. In our case, CSRS-PPP did not provide results under 20 cm in a half-hour on the East component. For example, in 30 minutes of session length, we reach the average precision of 0.247 cm on the East component. The results expected for one-hour sessions are approximately 5 cm on horizontal components. APPS fits well these general rules on East and North components, while CSRS only focuses on the North component.

The coefficients of determination (R^2, listed in Table 6) confirm these observations. They verify that the estimated East component is the closest to the three services' reference values, reaching 0.737 for the CSRS-PPP service. AUSPOS records the most disperse results in the Up component. In parallel, the Root Mean Square Error (RMSE) calculated over each service's estimations' position errors provides a view of the accuracy. The East component presents the highest values, followed by the North components. The lowest-RMSE service is the APPS for Up component.

Table 6: R^2 and RMSE values for the 2018 monthly dataset of solutions provided by the analysed services.

R^2			
Online Service	**East**	**North**	**Up**
CSRS	0.235	0.737	0.273
AUSPOS	0.070	0.292	0.017
APPS	0.253	0.391	0.104
RMSE (m)			
CSRS	0.220	0.193	0.016
AUSPOS	0.221	0.192	0.040
APPS	0.223	0.193	0.015

Regarding YKRO analysis, even if remarkable differences between the coefficients of determination are present, the RMSE values differ for no more than 0.2 centimetres in North and East components. The estimated height above the ellipsoid by APPS is the closest to the YKRO reference, only 1 mm on average values from CSRS-PPP. It is worth mentioning that AUSPOS does not use YKRO for the ambiguity resolution, but it relies on stations that are placed approximately 500-2000 km far from YKRO.

CSRS-PPP and APPS use different ephemerids. This may affect the estimated coordinates because they strongly affect PPP results, thus in the case of very different products, we might have different results. Besides this, the ephemerids seem not to interfere in the estimations. Additional considerations in terms of efficiency on the PPP online free services can be addressed. APPS is the most rapid service in terms of data processing, and it permits the analysis of the large quantity of data (industrial application) uploading the RINEX files on an FTP provided by JPL (not tested in this contribute). APPS results are provided directly from the website after a few seconds (depending on the data size), while AUSPOS and CSRS send the results via email. Nevertheless, APPS has an interface that may look complicated for non-GIPSY-expert users, and it does not provide the results in a report. CSRS-PPP is very functional because the upload process is intuitive, and the results report is easily interpretable.

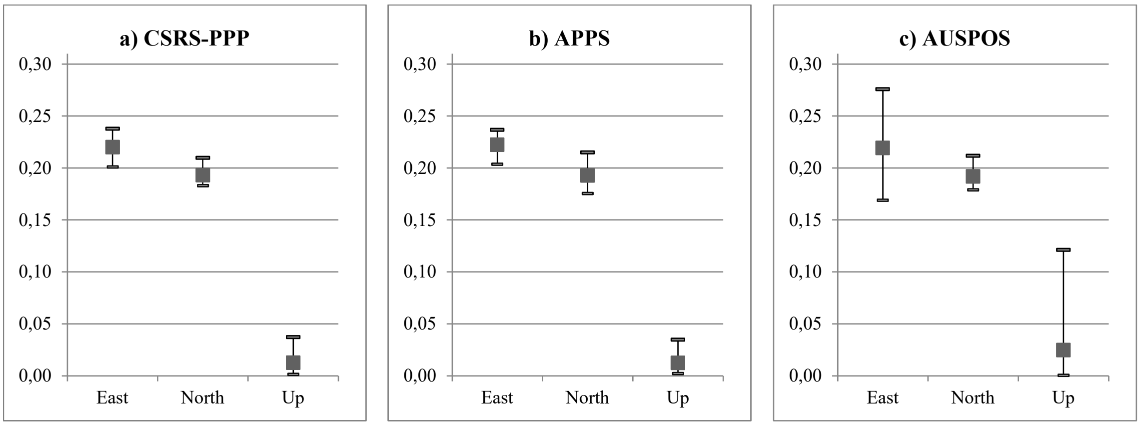

Figure 4: Average (square), Minimum and Maximum values of the difference between the coordinates estimated by online post-processing services and the real coordinates. Average, minimum, and maximum are calculated for AUSPOS (a), CSRS (b), and APPS (c).

6 CONCLUSIONS

The present work aimed to assess PPP online services' quality as free solutions for topography surveys in critical areas, based on a real case study's performances. According to the analysis we performed in the Niger area, the online PPP services are adequate and useful for the post-processing corrections of the master-rover RTK survey. The relative accuracy analysis of the services results in closer estimations of coordinates between CSRS-PPP and APPS. CSRS-PPP guarantees satisfying performances and provides steady results also for short sessions. As expected, the relative positioning technique (performed by AUSPOS) provides the least precise results due to the study area's geodetic remoteness. Besides this, AUSPOS performance is quite good, considering the analysis's baseline length is never below 500 km. These considerations, confirmed by the one-year YKRO analysis, underline the PPP technique's excellent reliability in areas outside the CORS network. It is worth underlining that it was impossible to perform a complete and exhaustive statistical analysis since the available dataset is relatively poor. Moreover, the lack of known-coordinates points and session's impossibility for more than 3 hours prevented a proper accuracy analysis of PPP services by real framework comparison. The difficulty of data gathering is part of the criticality of the study area.

Even if the estimated coordinates of YKRO CORS showed poor accurate results, they were acceptable for the ANADIA 2.0 project, which needed at least 10 cm precision on the Up component. In the framework of the project, the Canadian CSRS-PPP was used, which, although it is less precise than APPS, provides detailed statistics regarding the coordinates' corrections and is user-friendly. The cross-sections measured were elaborated and interpolated in a Digital Terrain Model used for the high-precision hydraulic numerical model. Nigerien technicians of the ministerial office in charge of meteorology and water resources have actively participated in the field surveys, appreciating the RTK master-rover survey's potential and the PPP online services. Furthermore, the 18 known and correct coordinate stations used for surveying could be the basis for a future local framework. In conclusion, the PPP has proved to be an effective, efficient, and economical solution to realise precision surveys in critical areas such as sub-Saharan ones.

ACKNOWLEDGEMENTS

A special thanks to the National Directorate for Meteorology of Niger (DMN) and the Directorate for Hydrology of Niger (DH) for the precious work realised for the survey. The authors would like to thank Vieri Tarchiani (IBE-CNR) and Maurizio Tiepolo (POLITO-DIST) for supporting field activities during the project.

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