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Precise Point Positioning and Differential Solutions by Online GNSS Calculation Tools and RTKLIB: A Comparative Study

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Abstract

The recent advances in GNSS positioning of the recent decades have been possible by the development of increasingly efficient software and online calculation tools. The differences between these online PPP calculation tools result in a different level of performance. Our study shows that for 24-hour or 6-hour observation time, the Canadian Spatial Reference System for PPP (CSRS-PPP), CenterPoint RTX Post-Processing (RTX), Magic/GNSS, *Institut Geographique National*-PPP (IGN-PPP) and RTKLIB tools have almost similar level of performance with International Terrestrial Reference Frame (ITRF) solutions considered as reference solution. Average deviations on the three components X, Y and Z for the different tools compared to ITRF solutions do not exceed 1 cm. However, the CSRS-PPP tool gives deviations of less than 5 mm. Calculations from the observations of 2 h and 1 h show that the RTX and CSRS-PPP tools keep deviations similar to those obtained with 24 h and 6 h, while RTKLIB and IGN-PPP give deviations exceeding 6 cm and sometimes failures of some calculations for IGN-PPP.

Keywords

PPP, GNSS, CSRS-PPP, RTX, MAGIC/GNSS, IGN-PPP, RTKLIB

1. Introduction

GNSS positioning has achieved many advances in recent years related to the availability of new equipment, the multiplication of constellations and frequencies, the implementation of new positioning and processing techniques [1] [2] [3] [4]. Differential positioning has for a long time remained the unique technique or strategy for accurate GNSS positioning. Nevertheless, it should be noted that this accuracy depends on the length of the baseline and the necessity of using at least two receivers. This may, in some cases, require more resources and qualification to achieve a certain level of accuracy. The differences in measurements between the two receivers make it possible to eliminate certain errors with single and double differences and to make negligible others more difficult to model. This makes it possible today, with the associated phase measurement by fixing integer ambiguities, to achieve centimetric or even millimetric accuracy in GNSS positioning [5] [6] [7].

It was not until the implementation of precise point positioning (PPP) also called zero-difference positioning to see absolute positioning, tending to differential positioning in terms of accuracy [8]. The GNSS data processing methods have also evolved with scientific and commercial calculation software. This led to the implementation of online GNSS calculation tools [9] and [10].

PPP, based on pseudo-distance and phase measurements, has occupied much of the scientific research in GNSS positioning over the past two decades [11]. The centimeter-to-millimeter accuracy that can be achieved in PPP has generated interest, thanks to the more accurate external products (orbits and clocks) provided by the International GNSS Service (IGS). In addition, there is the availability of atmospheric, tropospheric and ionospheric models, more accurate to take into account some errors previously eliminated by double differences in relative positioning [12] and [13].

The development of networks of permanent GNSS stations, the technological advances and the multiplication of constellations, have considerably reduced the convergence time of PPP solutions. However, it should be noted, that PPP performance depends on the ability of the used tool to eliminate or make negligible certain errors and resolve entire ambiguities [5] [12] [13] [14] and [15].

The purpose of this study is to evaluate the level of performance and convergence of some online PPP calculation tools and RTKLIB open source software [16] compared to ITRF solutions for various GNSS observation durations. The evaluation aims to analyze the sensitivity of the tools and their limits to provide adequate solutions, and thus better assessing their ability to meet the requirements according their area of use.

2. Tools and Methods

In this study, we considered 1, 2, 6 and 24 hours observation time and process the data using RTKLIB software with the following online PPP calculation tools:

- CenterPoint RTX (Real Time eXtended) developed by Trimble [17], than can process data measured with dual-frequency antennas on the constellations GPS, GLONASS, QZSS, GALILEO and BEIDOU. Antennas used for observations should match the listed antennas in the supported IGS antenna calibration file [18].
- The CSRS-PPP tool is developed by Natural Resources Canada—NRCan [19].

It can process both single-frequency and dual-frequency GPS and GLONASS observations in static and kinematic PPP modes. CSRS-PPP uses IGS or NRCan satellite orbit, clock and bias corrections calculated from a CORS global network to obtain exact positions from users around the World [20]. The calculations performed by SCRS-PPP Version 3, provide solutions with PPP ambiguity resolution (PPP-AR) for data collected after January 1st, 2018. This new technique makes it possible to have a faster convergence of solutions and a multi-GNSS processing.

- IGN-PPP is an online PPP calculation service provided by the National Institute of Geographic and Forest Information of France via the website of the Permanent GNSS Network—RGP [21]. IGN-PPP can process only dual-frequency GPS data for static or kinematic observations from anywhere in the World.
- MagicGNSS/PPP or simply Magic/GNSS, is a PPP calculation tool provided by a consortium of private companies based in Spain [22]. Magic/GNSS can process GPS, GLONASS and GALILEO measurements from a dual-frequency receiver, but it is possible to perform calculation with the GPS or GPS + GLONASS constellation. It uses IGS orbits and clocks for PPP calculations.

RTKLIB is an open source package developed at the University of Tokyo for position calculation and GNSS data analysis [16]. Unlike online tools, the choice of parameters and calculation options must be defined by the user. For example, it will be able to import precise orbit and clock files, ocean overload files, tidal models and antenna calibration file. The user also chooses an ambiguity resolution method and output data format.

The various input files mentioned above have been integrated into our calculations. In our study, we chose a "Fixed" ambiguity resolution method, the "iono-free combination" for ionospheric error corrections, and the "ZTD estimation" option for tropospheric corrections.

The characteristics of the tools used in this study are summarized in the following table (**Table 1**).

In this study, eight stations from the IGS network were selected. The stations are distributed over different parts of the Globe (**Figure 1**), but with a focus on stations located on the African continent, including DAKR, the unique Senegalese CORS station integrated in the IGS network. This choice makes it possible to detect a possible dependence between the results obtained and the geographical position of the stations, particularly those located in Africa.

All solutions were calculated in ITRF2014 at the epoch 2019.2.

The different solutions were compared to the daily solutions of the stations provided by ITRF calculation $\left(\text{coord}_{\text{ITRF}} - \text{coord}_{\text{tool}}\right)$.

3. Results and Discussion

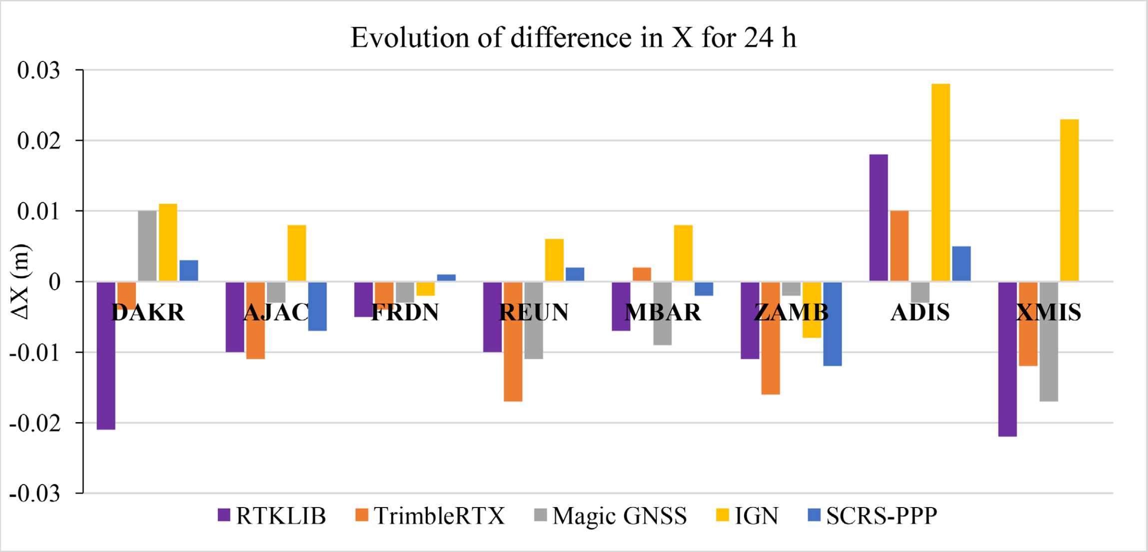
The obtained results, corresponding to the difference between a given tool and the ITRF solution for different observation durations, are presented in the figures (**Figure 2** and **Figure 3**) and tables (**Tables 2-5**) below.

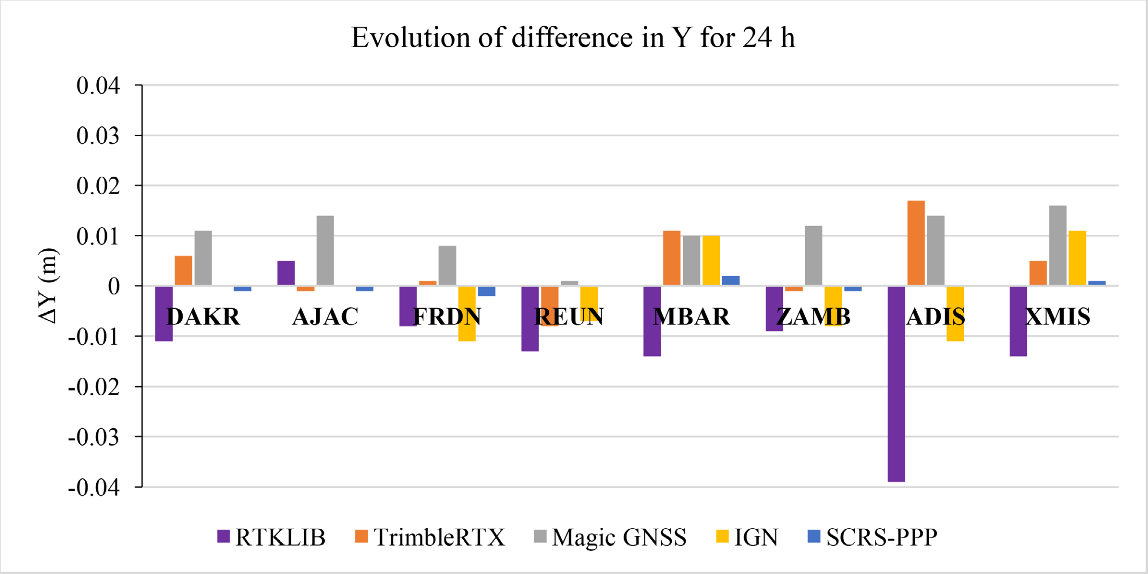
Table 1. Some characteristics of the calculation tools used

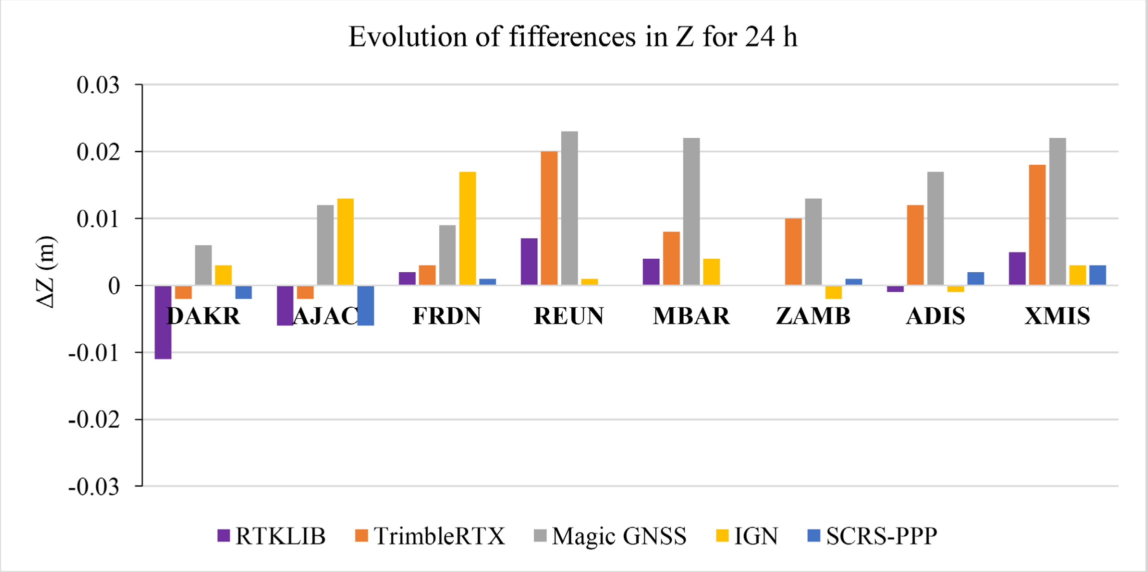
Tools	Provider	Type of GNSS	Minimum observation time (recommended)	Fastest sampling	Orbital source	Batch processing	Antenna calibration file
Center Point RTX	Trimble Navigation https://trimblertx.com/UploadForm.aspx	GPS, GLONASS, GALILEO, QZSS, BEIDOU	10 min	10 s	Trimble	no	Igs.atx
SCRS-PPP	Natural resource Canada https://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php?locale=fr	GPS, GLONASS	Aucune (>2 h)	1 s	IGS et RNCan	yes	Igs.atx et ngs.atx
IGN-PPP	IGN http://rgp.ign.fr/	GPS	Aucune (2 - 3 h)	1 s	IGS	no	Igs.atx
MagicGNSS/PPP	GMV https://magicgnss.gmv.com	GPS and GPS/GLONASS		1 s	IGS	yes	Igs.atx
RTKLIB	Tokyo University for Marine Science and Technology http://www.rtklib.com/	GPS		1 s	user	no	user

Figure 1. Distribution of the eight IGS stations used in this study represented by red triangles.

We calculated average deviations, RMS error and standard deviations according to components X, Y and Z. The results are shown in the following tables (Table 2 and Table 3).


Evolution of difference in X for 24 h
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
ΔX (m)
DAKR
AJAC
FRDN
REUN
MBAR
ZAMB
ADIS
XMIS
RTKLIB
TrimbleRTX
Magic GNSS
IGN
SCRS-PPP


Evolution of difference in Y for 24 h
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
ΔY (m)
DAKR
AJAC
FRDN
REUN
MBAR
ZAMB
ADIS
XMIS
RTKLIB
TrimbleRTX
Magic GNSS
IGN
SCRS-PPP


Evolution of fifferences in Z for 24 h
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
ΔZ (m)
DAKR
AJAC
FRDN
REUN
MBAR
ZAMB
ADIS
XMIS
RTKLIB
TrimbleRTX
Magic GNSS
IGN
SCRS-PPP

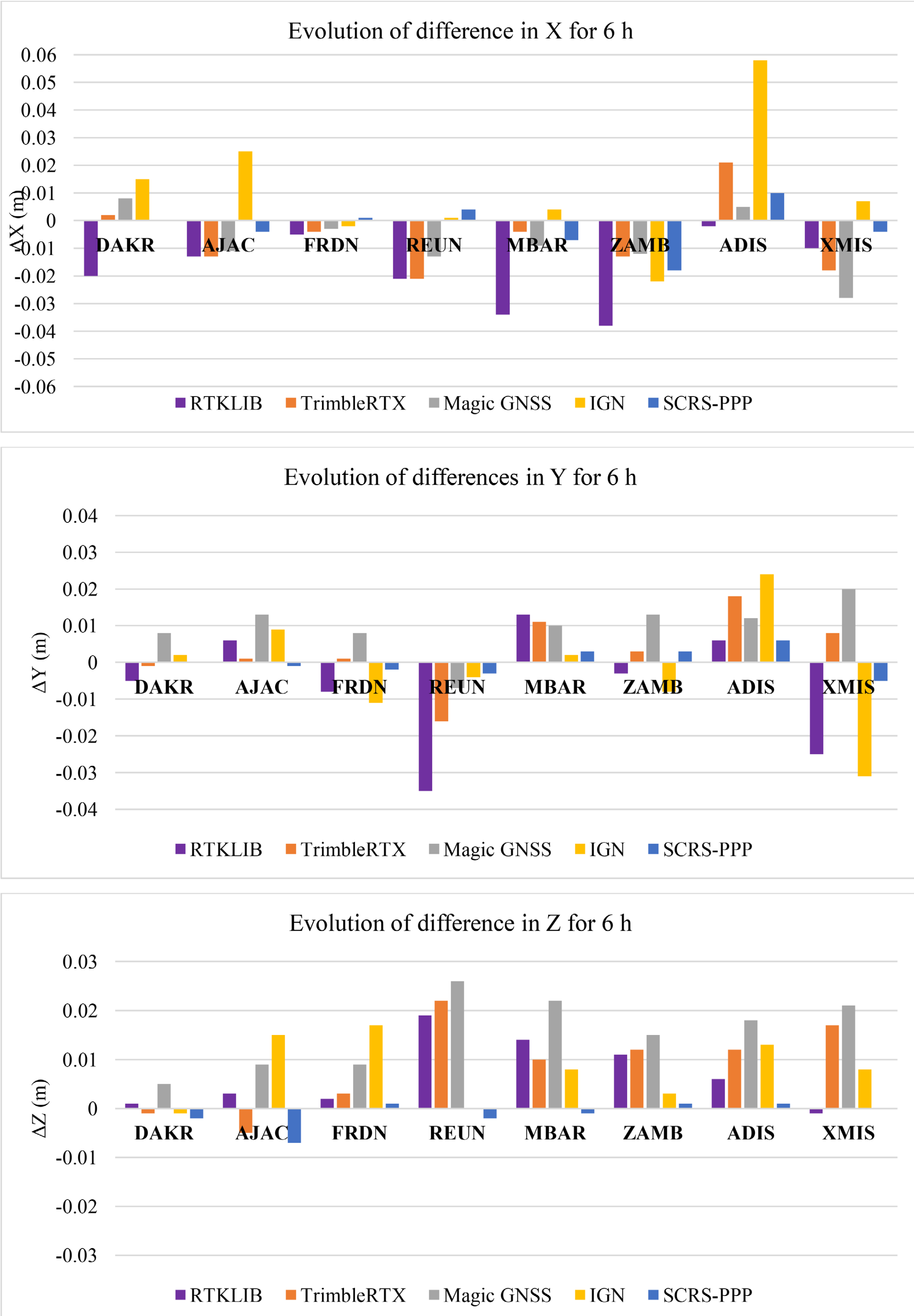
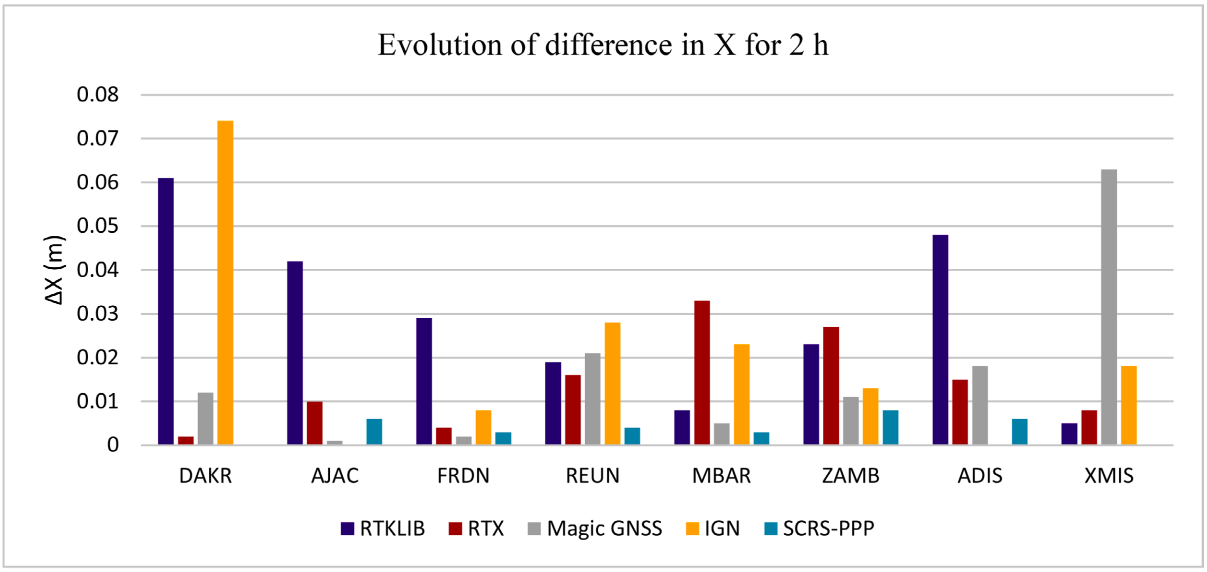
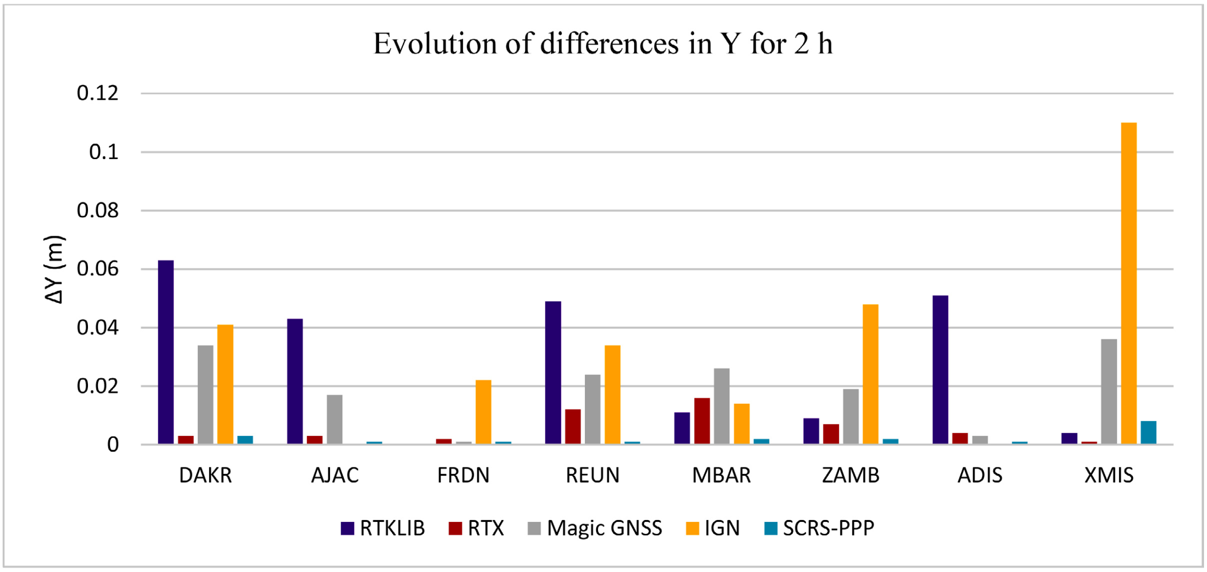
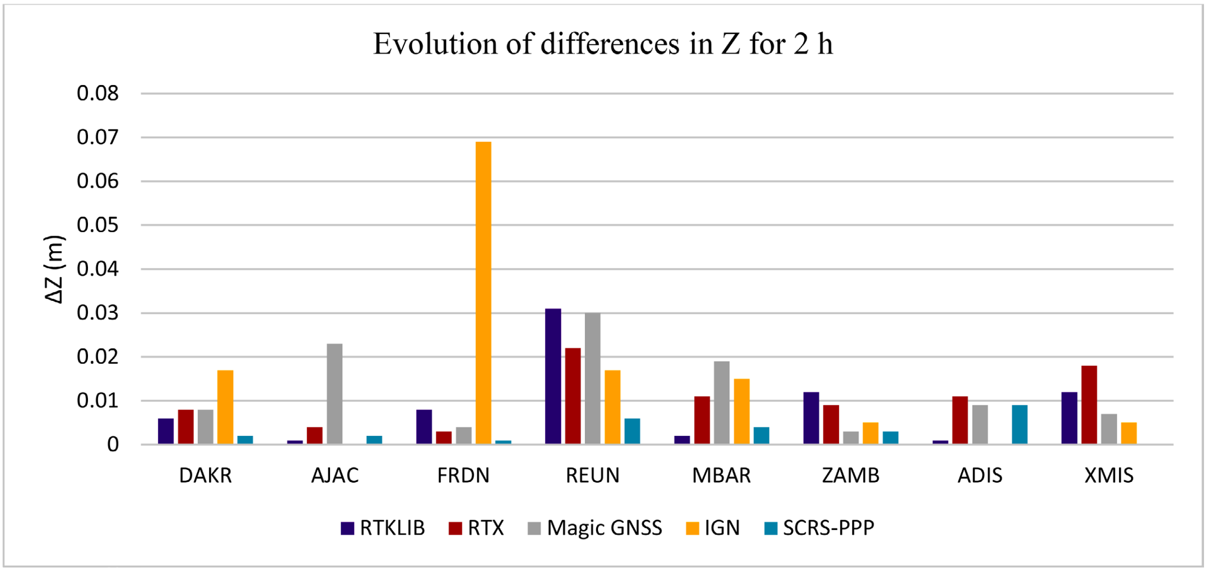


Figure 2. Discrepancies on components X, Y and Z from ITRF2014 coordinates and coordinates provided by RTKLIB, RTX, Magic GNSS, IGN, CSRS-PPP tools for 24 h and 6 h of observations.


Evolution of difference in X for 2 h
ΔX (m)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
DAKR
AJAC
FRDN
REUN
MBAR
ZAMB
ADIS
XMIS
RTKLIB
RTX
Magic GNSS
IGN
SCRS-PPP


Evolution of differences in Y for 2 h
ΔY (m)
0.12
0.1
0.08
0.06
0.04
0.02
0
DAKR
AJAC
FRDN
REUN
MBAR
ZAMB
ADIS
XMIS
RTKLIB
RTX
Magic GNSS
IGN
SCRS-PPP


Evolution of differences in Z for 2 h
ΔZ (m)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
DAKR
AJAC
FRDN
REUN
MBAR
ZAMB
ADIS
XMIS
RTKLIB
RTX
Magic GNSS
IGN
SCRS-PPP

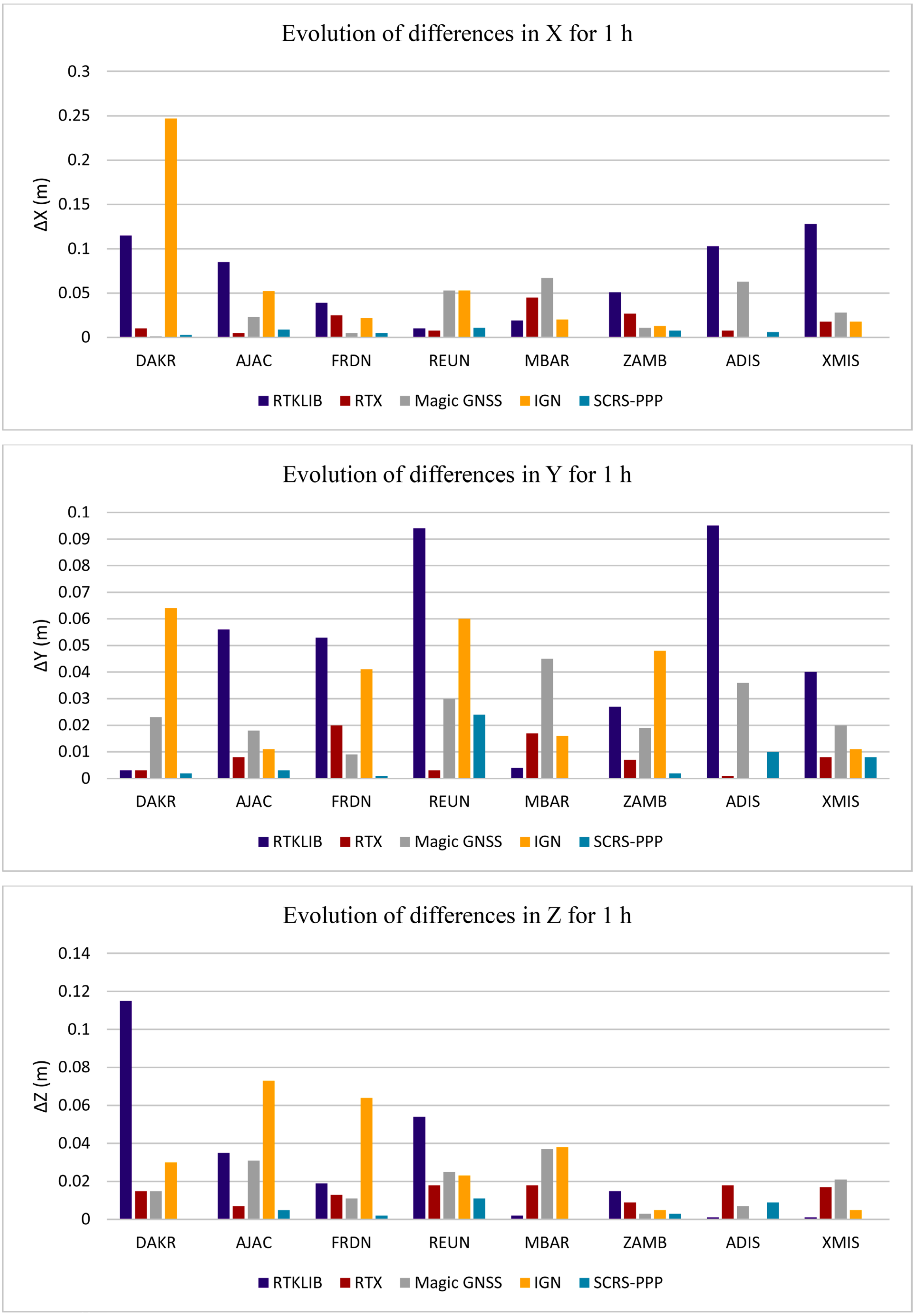


Figure 3. Discrepancies on components X, Y and Z from ITRF2014 coordinates and coordinates provided by RTKLIB, RTX, Magic GNSS, IGN, SCRS-PPP tools for 2 h and 1 h of observations.

Table 2. ITRF solutions and PPP tool solutions for 24-hour observations.

Tools	Means (m)			EMQ	STD (m)		
	$\overline{\Delta X}$	$\overline{\Delta Y}$	$\overline{\Delta Z}$		σ_X	σ_Y	σ_Z
RTX	0.0095	0.0063	0.0094	0.0148	0.0057	0.0057	0.0070
SCRS-PPP	0.0036	0.0009	0.0019	0.0042	0.0042	0.0008	0.0020
IGN-PPP	0.0118	0.0073	0.0055	0.0149	0.0090	0.0047	0.0060
Magic/GNSS	0.0073	0.0108	0.0155	0.0203	0.0054	0.0047	0.0065
RTKLIB	0.013	0.0141	0.0045	0.0197	0.0065	0.0105	0.0036

Table 3. ITRF solutions and PPP tool solutions for 6-hour observations.

Tools	Means (m)			EMQ	STD (m)		
	$\overline{\Delta X}$	$\overline{\Delta Y}$	$\overline{\Delta Z}$		σ_X	σ_Y	σ_Z
RTX	0.012	0.0074	0.0103	0.0175	0.0078	0.0070	0.0071
SCRS-PPP	0.006	0.0029	0.0019	0.0069	0.0058	0.0020	0.0022
IGN-PPP	0.0168	0.0114	0.0081	0.0219	0.0190	0.0106	0.0065
Magic/GNSS	0.0111	0.0114	0.0156	0.0223	0.0076	0.0042	0.0074
RTKLIB	0.0179	0.0126	0.0071	0.0230	0.0130	0.0114	0.0068

Table 4. ITRF solutions and PPP tool solutions for 2-hour observations.

Tools	Means (m)			EMQ	STD (m)		
	$\overline{\Delta X}$	$\overline{\Delta Y}$	$\overline{\Delta Z}$		σ_X	σ_Y	σ_Z
RTX	0.014	0.006	0.011	0.0188	0.011	0.005	0.006
SCRS-PPP	0.004	0.005	0.003	0.0071	0.003	0.004	0.003
IGN-PPP	0.027	0.045	0.021	0.0565	0.024	0.034	0.020
Magic/GNSS	0.017	0.020	0.013	0.0293	0.020	0.013	0.010
RTKLIB	0.029	0.033	0.010	0.0451	0.020	0.023	0.009

Table 5. ITRF solutions and PPP tool solutions for 1-hour observations.

Tools	Means (m)			EMQ	STD (m)		
	$\overline{\Delta X}$	$\overline{\Delta Y}$	$\overline{\Delta Z}$		σ_X	σ_Y	σ_Z
RTX	0.018	0.008	0.014	0.0242	0.014	0.007	0.004
SCRS-PPP	0.006	0.007	0.004	0.0100	0.004	0.008	0.005
IGN-PPP	0.061	0.050	0.034	0.0859	0.084	0.033	0.027
Magic/GNSS	0.031	0.025	0.019	0.0441	0.026	0.011	0.012
RTKLIB	0.069	0.047	0.033	0.0898	0.045	0.036	0.037

For the different observation durations, the results obtained on the different stations for each tool show that:

- For the CSRS-PPP tool, average deviations of 2 mm, 4 mm, 4 mm and 6 mm are obtained respectively with observations of 24 h, 6 h, 2 h and 1 h for average standard deviations of 2 mm, 3 mm, 6 mm and 6 mm, respectively. A maximum deviation of 10 mm on X component and 24 mm on Y component was obtained respectively for 2 h and 1 h of observation;
- For the RTX, average deviations of 8 mm, 10 mm, 10 mm and 14 mm were obtained respectively with the observations of 24 h, 6 h, 2 h and 1 h for respective standard deviations of 6 mm, 7 mm, 8 mm and 8 mm. A maximum deviation on the x component of MBAR station of 33 mm and 45 mm was obtained respectively for 2 h and 1 h of observation;
- For Magic/GNSS, average deviations of 11 mm, 13 mm, 17 mm and 27 mm is obtained respectively for observations of 24 h, 6 h, 2 h and 1 h with average standard deviations of 6 mm, 6 mm, 14 mm and 17 mm respectively. The largest deviations were noted on X component with respective values of 63 mm and 67 mm for 2 h and 1 h of observation;
- Regarding the IGN-PPP tool, average deviations of 8 mm, 10 mm, 31 mm and 48 mm were obtained respectively for observations of 24 h, 6 h, 2 h and 1 h with respective standard deviations of 6 mm, 7 mm, 26 mm and 48 mm. The largest deviations were noted on the X component of DAKR with values of 7 cm and 25 cm respectively for the 2 h and 1 h of observation;
- For RTKLIB software, average deviations of 11 mm, 13 mm, 24 mm and 49 mm were obtained respectively with observations of 24 h, 6 h, 2 h and 1 h for average standard deviations of 7 mm, 10 mm, 17 mm and 39 mm respectively. The larger deviations of 6 cm on Y component and 13 cm on X component were obtained with 2 h and 1 h of observation respectively.

For all the tools, an almost non-significant difference is noted on the average deviations and standard deviations for the 24-h and 6-h observations (**Table 2** and **Table 3**), even if the RTKLIB and IGN-PPP tools records, in some stations, exceed 3 cm compared to the ITRF solutions. This situation should justify the relatively high standard deviations noted with these two tools. These differences concern:

- For IGN-PPP tool, the ADIS and XMIS CORS on X component (58 mm) and Y component (31 mm);
- For RTKLIB, the differences of 34 mm and 38 mm in X component were respectively obtained for MBAR and ZAMB CORS, and 39 mm in Y component for ADIS CORS (**Figure 2**).

These few discrepancies noted with these two tools could be explained by the quality of some models used on the concerned stations, the sensitivity of the parameters and calculation algorithms to the specific environment conditions of the station. The Magic/GNSS, IGN-PPP and RTKLIB software have the largest mean and standard deviations (around 1 cm for 24 h and 6 h of observation and 5 cm for 2 h and 1 h of observation), although the Magic/GNSS tool shows a fairly low dispersion of 6 mm for 24 h and 6 h of observation.

The CSRS-PPP and RTX have proven to be the tools that provide solutions closer to the reference solutions and should be therefore considered as more accurate and stable with nonsignificant differences for 24 hours and 6 hours of observation.

We can note that, with IGN-PPP and RTKLIB, the quality of the solutions became relative for 2 h and 1 h of observation. The solutions obtained with such observation durations for these two tools can quickly exceed 3 cm, and even more for 1 hour of observation. The Magic/GNSS tool, even if it presents more stable quality solutions for 2 h and 1 hour of observation, compared to the two previous tools, can quickly exceed 5 cm for 1 hour of observation.

The RTX and SCRS-PPP tools maintain an overall satisfactory accuracy and accuracy on all stations with 2 h and 1 h of observation even if deviations greater than 3 cm were observed on the MBAR station with 2 h and 1 h of observation (**Figure 3**).

It can therefore be found from the performed calculations that the CSRS-PPP tool maintains an almost identical level of performance, with millimetric deviations overall, for observations of 1 h, 2 h, 6 h and 24 h.

4. Conclusions

This study made it possible to highlight, through the carried-out calculations, for observation durations of 24 h, 6 h, 2 h and 1 h using the PPP online calculation tools CSRS-PPP, RTX, Magic/GNSS, IGN-PPP and the RTKLIB open-source software, the level of convergence of these tools compared to ITRF solutions and their level of performance according to the duration of observation.

It can be noted that, the lags between CSRS-PPP solutions and ITRF solutions remain smaller overall. This tool can therefore be considered to be the most stable and providing more accurate PPP solutions for the different observation durations, resulting in practically the same level of quality solutions.

It also emerged from the analysis of these results, that, the only open source tool RTKLIB used, is able to provide solutions comparable to the solutions provided by the online tools used for 24 h and 6 h data even if some deviations of more than 3 cm, that sometimes become more important for 1 hour of observation, were noted on some points as for the IGN-PPP tool. This software could therefore be a real alternative for automatic calculations, in auscultation for example, or even a real option.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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