

Enhancement of Precise Point Positioning Using GPS Single Frequency Data

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Abstract— Global Positioning System (GPS) is one of the most essential tools in many engineering applications, and is rapidly replacing traditional surveying techniques. It is very important to get the position using GPS with high possible accuracy while considering cost, effort and time. Precise Point Positioning (PPP) is a technique that depends on data of a single receiver and GNSS precise products to decrease different types of errors to improve the positional accuracy and to overcome the limitations of relative techniques. This has been used recently as a suitable technique for many applications having the excellence of obtaining precise location using only a single receiver. On the other side, the technique needs scientific software or online services to reach the prospective precision. PPP precision depends on different parameters such as session length, mask angle, used frequencies ...etc.

This study depends on three different data sets. The first set located in New Cairo, Egypt, the second is in Kalabsha region, south of Egypt, and the third set contains stations from the National Geodetic Survey (NGS) organization west of USA.

The main goal of the current research is to select the best parameters and services which used in post processing stage to reach the highest possible precision of static PPP based on single frequency GPS data using two different scientific software.

Index Terms— Precise Point Positioning (PPP), single frequency, National Geodetic Survey (NGS), gLAB, RTKLIB, GPS, NRIAG.

1 INTRODUCTION

GPS is the American navigation satellite system which has different civilian and military purposes. GPS receivers vary in expected accuracy and cost which are function of various parameters like the type of received observations, type of used receiver, hardware stability and the ability to measure more than one satellite positioning constellation [1]. Geodetic receivers are classified into single and dual frequency categories. The first category can only obtain code and carrier ranges from L1 [2]. Dual-frequency category is the more accurate and expensive. This category can obtain the whole components of GPS signal (i.e., L1 and L2 carriers, C/A-code, P-code) [3].

GPS observables are the resulted range from differences of measured time or phase depending on a comparison among received and generated signals. The two categories of observations are the pseudo-range and the carrier phase.

The carrier phase accuracy is higher than the pseudo-range. The obtained accuracy can reach centimeters' level using phase data, and few meters in the pseudo-range case [4]. GPS measurements are subjected to some errors, which affect the resulted accuracy. The two basic categories of errors are the systematic and the random errors [5]. These errors affect the GPS positional accuracy. Prominent among them are

ephemeris errors, satellite and receiver clock errors, multipath errors, signal propagation errors such as ionospheric delay, tropospheric delay, and instrumental biases of the satellite and receiver [6]. These errors must be considered for more expected positional accuracy.

Point positioning and relative positioning are the two techniques which can be used to determine the location of a ground point. The first technique depends on trilateration in space using code-based GPS pseudo-range observations by one receiver. This technique uses the satellite's broadcast orbits and has no access to any reference stations. The expected accuracy of the current technique is low because of the Un-modeled different types of errors. The positional accuracy is in few meters range. The GPS carrier phase relative positioning has been the most accurate technique which is suitable for earth sciences. This technique depends on simultaneous observations from two or more receivers. One of them -at least- is on a reference station with known coordinates [7].

Another type of point positioning technique available in post processing mission is the Precise Point Positioning (PPP), which uses pseudo-range and/or carrier phase measurements with precise GPS orbits and precise clocks, applying different models to adjust the effects of the satellite antenna offset, earth and ocean tide loading, etc. [8].

The PPP technique aims to correct the observational errors and to avoid the differential GPS limitations. This technique is an enhanced single point positioning for both code and/or phase observables using precise orbits and clocks instead of broadcast data. PPP became available with the existence of the precise orbits and clock corrections, produced by different organizations such as the International GNSS Service (IGS) [9].

The PPP technique has a vital advantage over differential methods. It needs only one receiver to obtain accurate location. Unfortunately, current commercial software does not provide processing of taken observations using PPP. It requires one of on-line PPP services or scientific software for post processing [10].

PPP positioning technique has been used in the recently as a cost-effective alternative for the ordinary differential GPS. It requires to collect observations at the unknown point and correcting them for different types of errors using special models and precise products [11].

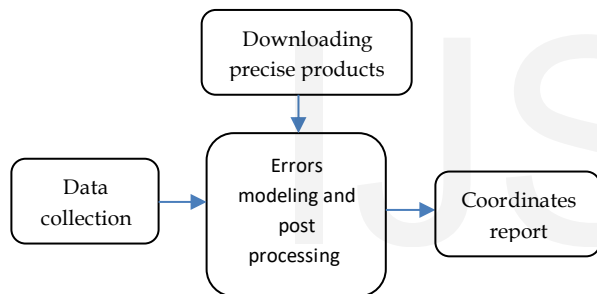


Fig. 1. PPP positioning using scientific packages

Different universities and institutes have innovated PPP software packages and released online PPP processing services. These online PPP services are free of charge and available 24-h per day. The user only needs to upload GNSS observational files in standard or compressed RINEX format to the designated servers [12].

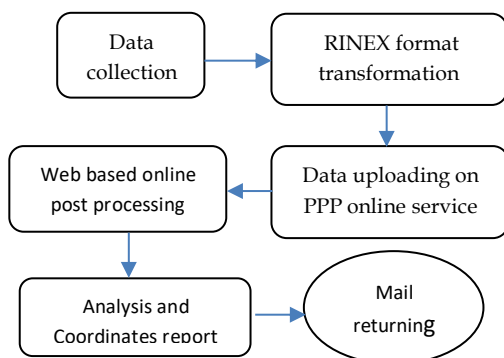


Fig. 2. General steps of PPP online positioning

This research investigates the accuracy of the discrepancies in Cartesian coordinates X, Y, and Z using single frequency GPS data depending on two different scientific software packages by static PPP technique. In the current paper, the observables of GPS are reviewed, the static PPP GPS technique with its field procedure and accuracy are introduced, and the methodology of investigation and the description of the field test are presented. At the end, the analysis of the obtained results supported with the statistical analysis are presented.

2 METHODOLOGY OF INVESTIGATION

The main objective of this research is to statically analyze the difference in 3-d coordinates static PPP GPS technique, using single frequency data. The current research depends on 17 GPS stations, which are divided into 3 sets.

The first set contains 3 stations located in New- Cairo, Egypt. The second set contains 8 stations located in Kalabsha region, south of Egypt. The third set contains 6 stations from the National Geodetic Survey CORS network located in west of USA. The whole used data has 30seconds sampling rate.

The goal of the New-Cairo campaign is to choose the best factors used during processing to enhance the static PPP accuracy depending on gLAB and RTKLib scientific software. The importance of the second and the third sets is to validate the results of the New-Cairo campaign in different conditions.

The discrepancies of static PPP Cartesian coordinate can be obtained as:

$$dX = |X_{PPP} - X_{adj}| \tag{1}$$

$$dY = |Y_{PPP} - Y_{adj}| \tag{2}$$

$$dZ = |Z_{PPP} - Z_{adj}| \tag{3}$$

$$dP = \sqrt{dX^2 + dY^2 + dZ^2} \tag{4}$$

where;

dX: X discrepancy (Absolute value)

dY: Y discrepancy (Absolute value)

dZ: Z discrepancy (Absolute value)

dP: The positional error

(X_{PPP} , Y_{PPP} , Z_{PPP}): Static PPP solution coordinates

(X_{adj} , Y_{adj} , Z_{adj}): The reference coordinates

3 USED GPS DATA

The first campaign contains 3 stations (NCA, NCO and NCP) located in New-Cairo region east of Cairo, Egypt. The research group observed these stations simultaneously on the 28th, August, 2015, from 00:00 to 18:00. Distances between stations vary from 1.4km to 4.9km. Fig.3 shows the stations of New-Cairo.



Fig. 3. Stations of New-Cairo

Kalabsha campaign -shown in Fig. 4- contains 8 stations (KL14, KL53, KL71, KL73, KL52, KL72, KL11 and KL61) located in south of Egypt, west of Nasser lake. These stations were observed simultaneously by National Research Institute of Astronomy and Geophysics (NRIAG) on the 27th January, 2012, from 09:00 to the end of the day. Distances between stations vary from 1.4km to 5.6km.



Fig. 4. Stations of Kalabsha

The last campaign contains 6 stations (P690, P693, P695, P696, P697 and P698) downloaded from the official site of the National Geodetic Survey CORS network (<http://www.ngs.noaa.gov/CORS>). These stations are located on Mount St. Helens, Skamania country, Washington, in the pacific northwest region of USA. The used data are for the whole days of the 4th and 6th October, 2015. Distances between stations vary from 1.1km to 5.2km (Fig.5).



Fig. 5. Stations of USA

4 THE USED SOFTWARE PACKAGES

Two different scientific software packages are used in the current research, which are RTKLIB 2.4.2 and gLAB 2.2.8.

RTKLIB is an open source package for standard and precise positioning with different global navigation satellite system. It supports precise and standard positioning algorithms, various positioning modes with GNSS for both real-time- and post-processing, and many standard formats and protocols for GNSS [13].

The GNSS-Lab Tool suite (gLAB) is an interactive multipurpose package to process GNSS data. This software package is targeting the different groups of users. The current software can read GNSS RINEX data, process it and show the results in the form of data files and graphics. The processing options is fully parametrizable through a GUI that is easy to understand the tool and its different options. The software can work in Windows and Linux Operating Systems [14].

5 SELECTION OF OPTIMUM FACTORS OF SOFTWARE

The main role of New Cairo campaign is to select the best precise product service, models, filters, and other factors to enhance the static PPP accuracy depending on the mentioned two software. The current campaign data is divided into three sessions, start at 00:00, 06:00 and 12:00 respectively.

The first stage of the New-Cairo campaign is to select the optimum factors of RTKLIB software. The following figure illustrates the steps of the first stage.

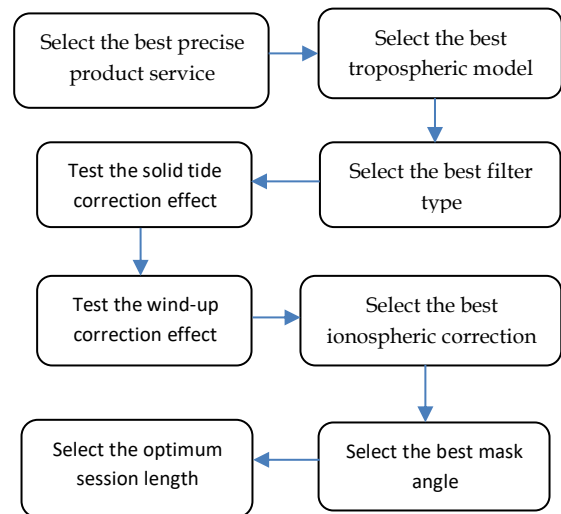


Fig. 6. General steps of RTKLIB Stage

The first step is to select the best precise product service depending on 3hours session length, 15° mask-angle and forward filter type. All other models and corrections are off. The tested products are precise orbits and clocks from the European Space Agency (ESA), IGR and IGS products from the International GNSS Service. Fig. 7 contains the results of the first step.

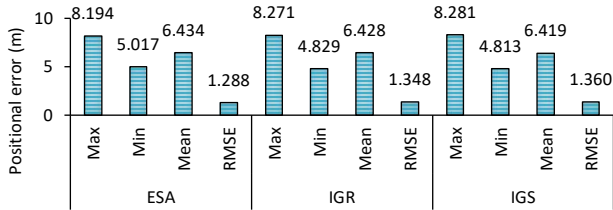


Fig. 7. Results of Precise Product services using RTKLIB

Depending on the previous results (Fig. 7), the three services gave convergent positional error, but ESA service produced the smallest RMSE with 1.288m. For that, ESA service is selected for precise products.

The second step is to select the best tropospheric model from the estimate Zenith Total Delay (ZTD) and Saastamoinen, depending on ESA precise products and other parameters in step 1. The next figure contains the current step results.

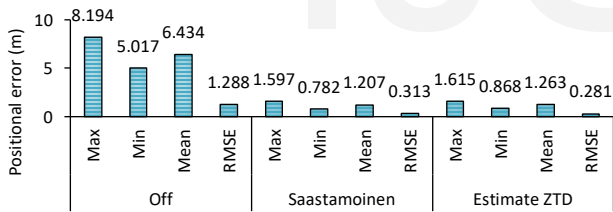


Fig. 8. Results of tropospheric models using RTKLIB

Referring to Fig. 8, Estimate ZTD and Saastamoinen tropospheric models gave convergent positional error, but Estimate ZTD model produced the smaller RMSE with 0.281m. Estimate ZTD model will be chosen to treat the tropospheric error in next processing.

The third step is to select the best filter type from the forward, backward and combined filters depending on the previous chosen parameters.

Relating to the results in Fig. 9, the three filters gave approximately the same positional error. For that, the forward filter is chosen from this step.

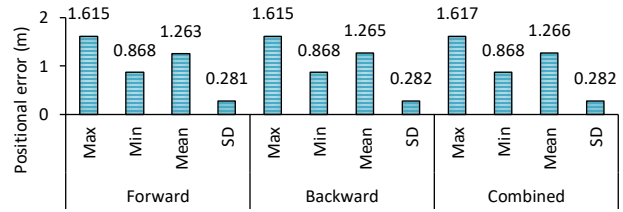


Fig. 9. Results of filter types using RTKLIB

The fourth step is to test the effect of the solid tide model, depending on the chosen factors and parameters in the previous steps. The next figure contains the results of the tide effect step.

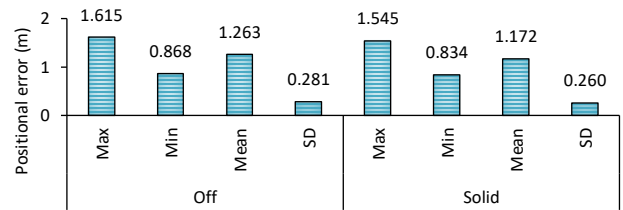


Fig. 10. Effect of solid tide correction using RTKLIB

Fig. 10 shows the effect of positioning using the solid tide correction. The average positional error decreased to 1.172m with 0.260m RMSE. For that, the solid tide correction will be considered in further processing.

The fifth step is to test the effect of the wind-up correction, depending on the selected factors. The results are presented in Fig. 11.

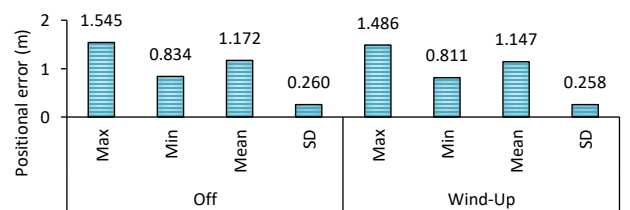


Fig. 11. Effect of wind-up correction using RTKLIB

The results of the fifth step Fig. 11 show the good effect of the wind-up correction. The average positional error reduced to 1.147m with 0.258m RMSE. For that, the current correction will be used in the following processes.

The sixth step is to test the effect of the different ionospheric corrections to select the best, considering the chosen factors in previous steps. The tested ionospheric corrections are the broadcast, IGR and

IGS Ionex files. The results of this step are presented in the next chart.

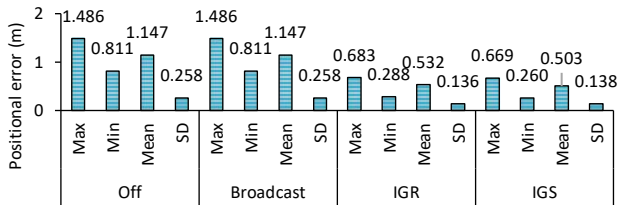


Fig. 12. Effect of ionospheric corrections using RTKLIB

Depending on the results in Fig. 12, the usage of IGS ionex file gives the minimum average positional error of 0.503m with 0.138m RMSE. The IGS ionex files will be chosen for the next processes.

The seventh step is to test the effect of mask-angle to select the its best value, depending on the previous chosen factors. The next figure shows the results of the current step.

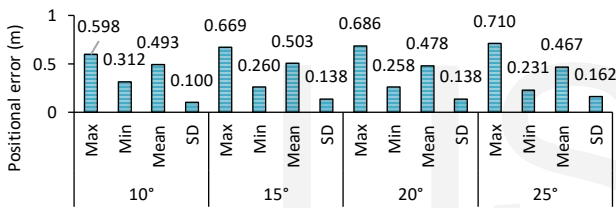


Fig. 13. Effect of mask-angle using RTKLIB

Referring to Fig. 13, the results is very convergent, the 10° mask is chosen for its smallest average positional error of 0.493m and RMSE with value of 0.100m.

The last step is to choose the optimum session length depending on the previous chosen parameters, corrections and services. The tested session lengths are 1hour, 2hours, 3hours, 4hours, 5hours and 6hours respectively. The results are shown in Fig. 14.

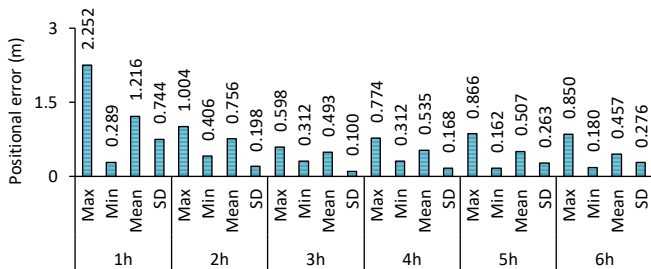


Fig. 14. Effect of session length using RTKLIB

From the current step, -depending on Fig. 14- optimum session length is 3hour, which gives average positional error of 0.493m with 0.100m RMSE.

At the end of the RTKLIB stage, the scientific program provides an average positional error of 0.493m with 0.100m RMSE depending on the selected factors in Table (1).

Table (1)
Final factors of RTKLIB

Factor	Selection
Precise products service	ESA
Tropospheric model	Estimate ZTD
Filter solution type	Forward
Solid tidal correction	On
Wind-up correction	On
Ionospheric correction	Ionex IGS file
Mask angle value	10°
Session length	3hours

The second stage target is to select the best factors used in gLAB software processing. The following figure illustrates the steps of the current stage.

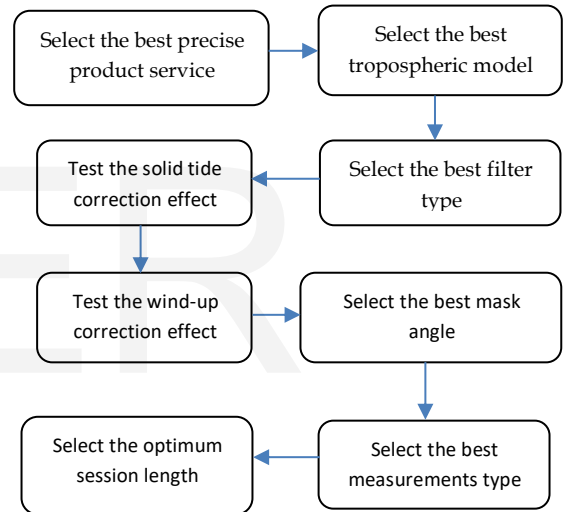


Fig. 15. General steps of gLAB Stage

The first step is to select the best precise product service depending on 3hour session length, 15° mask-angle, IGS ionex file, code and phase measurements, and forward filter type. All other models and corrections are off. The tested services are ESA, IGR and IGS. The next chart shows the result of the first step.

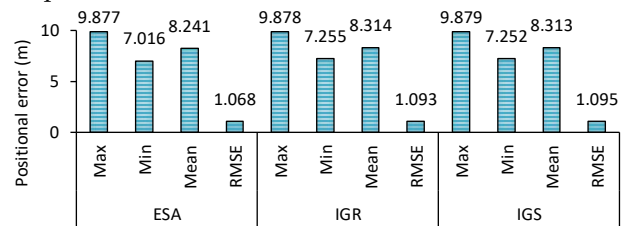


Fig. 16. Results of Precise Product services using gLAB Referring to Fig. 16, the three tested services give convergent positional error. ESA is chosen because it has the smallest average positional error of 8.241m

and 1.068m RMSE.

The second step is to select the best tropospheric model depending on the previous selected factors. All other models and corrections are off. There are two tested tropospheric nominals (simple and UNB-3) depending on two tropospheric mappings (simple and Niell).

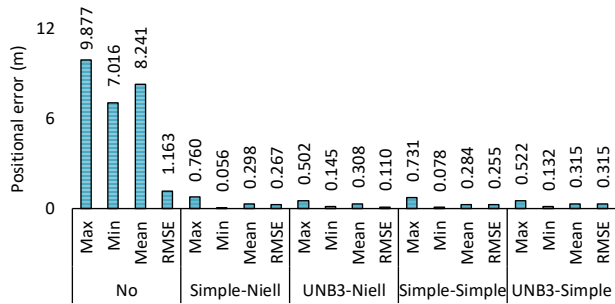


Fig. 17. Results of tropospheric models using gLAB

Referring to Fig. 17, the tropospheric UNB-3 nominal using Niell mapping gives the best results with 0.308m positional error and 0.110m RMSE. So, the UNB-3 Niell troposphere will be used in the following processing.

The third step is to select the best filter type depending on the mentioned and selected factors. The two tested filters are the forward and backward. Fig. 18 presents the results of the third step which shows that backward filter gives better results with average positional error of 0.302m and 0.108m RMSE. The backward filter will be chosen in the following processes.

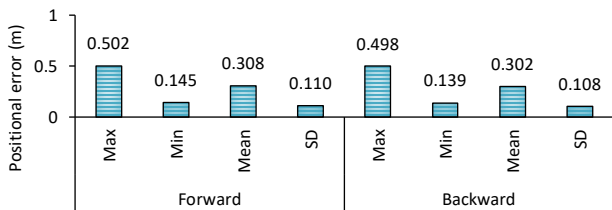


Fig. 18. Results of filter types using gLAB

The fourth step is to test the effect of the solid tide correction, depending on the previous chosen factors. The following figure contains the results of the current step.

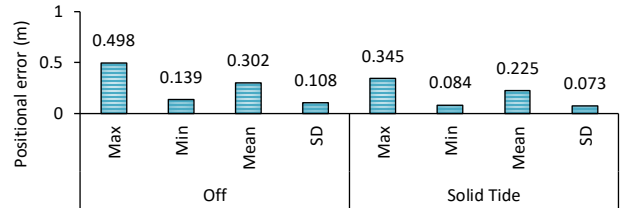


Fig. 19. Effect of solid tide correction using gLAB

Referring to Fig. 19, the solid tide correction has a good effect on positioning. It decreased the mean positional error to 0.225m and 0.073m RMSE. This factor will be considered during processing.

The fifth step is to test the effect of the wind-up correction, depending on previous selected factors. The following figure shows the good effect of the wind-up factor.

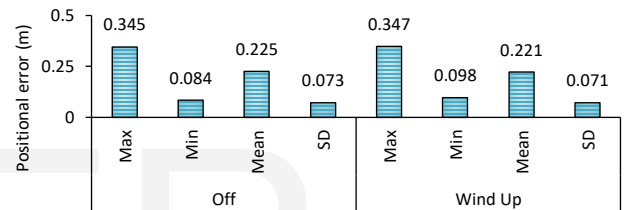


Fig. 20. Effect of wind-up correction using gLAB

The average error of positioning decreased to 0.221m with 0.071m taking into consideration the wind-up factor. For that, the current correction will be considered during further processing.

The sixth step is to test different values of mask-angles to select its optimum value depending on the previous chosen factors. The next chart contains the results of the current step.

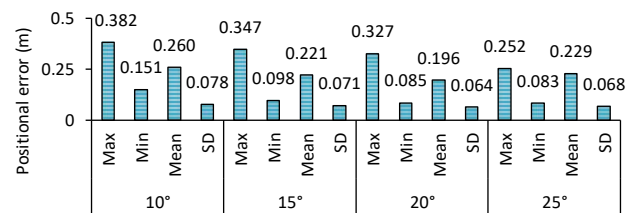


Fig. 21. Effect of mask-angle using gLAB

Depending on Fig. 21, the 20° mask-angle gives the lowest mean positional error with value of 0.196m and 0.064 RMSE. For further processing, 20° mask-angle will be chosen instead of 15°.

The seventh step is to test different measurements (C/A, C/A and L1, Smoothed C/A) to choose the best

of them depending on the previous selected factors. The results are shown in Fig. 22.

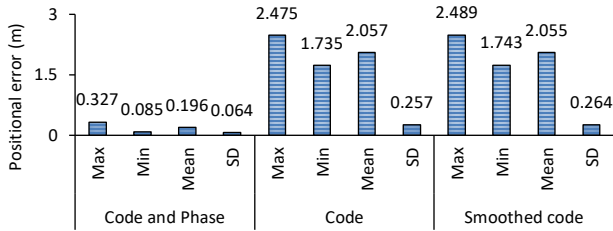


Fig. 22. Results of different measurements using gLAB

It is very clear that the processing using both C/A and L1 measurements gives the best solution with average positional error of 0.196m and 0.064 RMSE.

The last step is to choose the optimum time session length depending on the previous chosen factors. See Fig. 23.

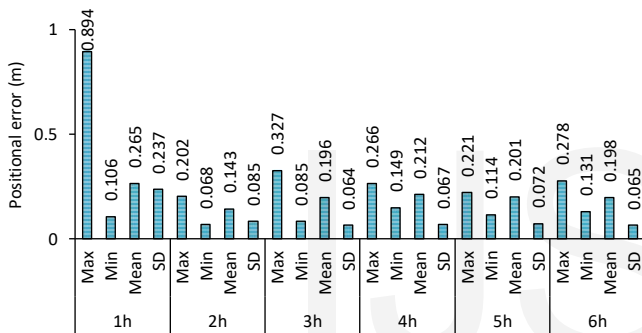


Fig. 23. Effect of session length using gLAB

Depending on the previous chart, the optimum length of session is 3hours, which gives average positional error of 0.196m and 0.064 RMSE.

At the end of gLAB stage, the selected parameters are presented in the next table.

Table (2)
Final factors of gLAB

Factor	Selection
Precise products service	ESA
Tropospheric model	UNB-3 and Niell
Filter solution type	Backward
Solid tide correction	On
Wind-up correction	On
Ionospheric correction	Ionex IGS file
Mask angle value	20°
Used measurements	C/A and L1
Session length	3hours

Finally, gLAB package provides an average positional error of 0.196m with 0.064m RMSE depending on the selected factors.

Fig. 24 represents the final discrepancies of New-Cairo campaign using RTKLIB software.

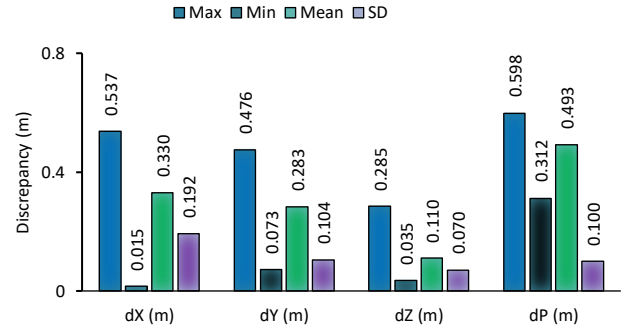


Fig. 24. Final discrepancies of New-Cairo using RTKLIB

Fig. 25 represents the final discrepancies of New-Cairo campaign using gLAB package.

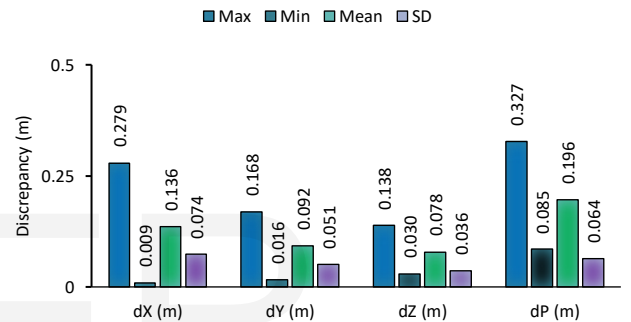


Fig. 25. Final discrepancies of New-Cairo using gLAB

Referring to the previous two charts, it can be said that gLAB has better results than RTKLIB. It provides an average positional error of 0.196m with 0.064m RMSE considering the shown factors in Table (2) during processing.

6 VALIDATION OF OBTAINED RESULTS

To validate the selected factors of the two software, it is necessary to apply such factors on other campaigns in different conditions.

6.1 Kalabsha campaign

The goal of this campaign is to validate the chosen New-Cairo factors using RTKLIB and gLAB software.

The current campaign data is divided into five successive sessions with 3hours length. The first and the last sessions start at 09:00 and 21:00 respectively. Fig. 26 and Fig. 27 represent the resulted discrepancies from RTKLIB and gLAB considering the chosen factors.

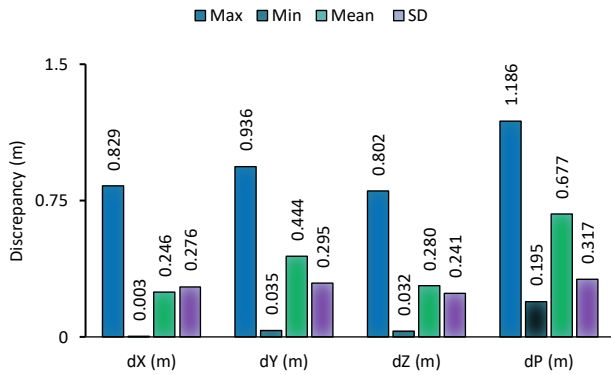


Fig. 26. Discrepancies of Kalabsha using RTKLIB

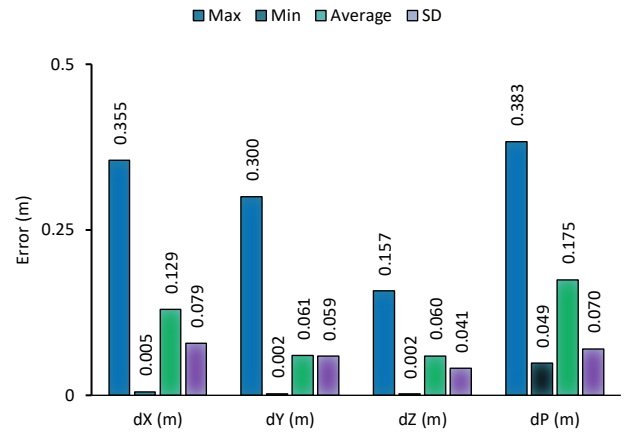


Fig. 29. Discrepancies of USA using gLAB

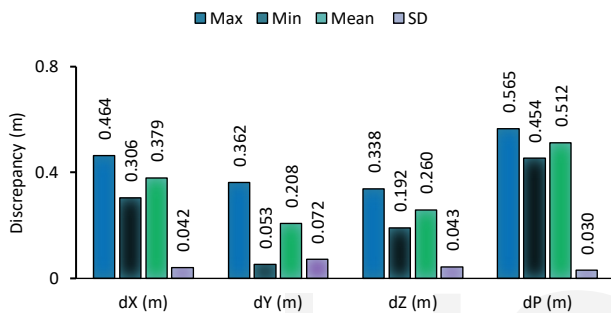


Fig. 27 Discrepancies of Kalabsha using gLAB

At the end of the current campaign, we can say that gLAB produces the better results than RTKLIB. It has an average positional error of 0.512m with 0.030m RMSE.

6.2 USA Campaign

The data of the current campaign is divided into 16 successive sessions with session length of 3hours. The first session starts at 00:00 on the 4th October, 2015 and the last session starts at 21:00 on the 6th October, 2015. Fig. 28 and Fig. 29 represent the discrepancies resulted from the current campaign.

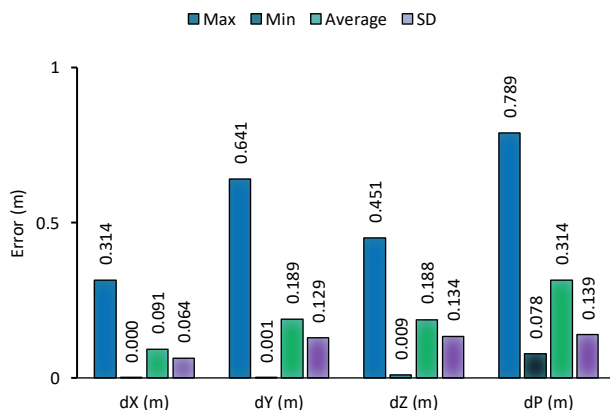


Fig. 28. Discrepancies of USA using RTKLIB

At the end of the current campaign, it is very clear that gLAB produces the better results with an average positional error of 0.175m and 0.070m RMSE.

7 CONCLUSIONS

Depending on the selected factors of the two-software and the gained results from the three campaigns, many important conclusions can be extracted:

- ESA service is the best for both RTKLIB and gLAB.
- The estimate ZTD tropospheric model is suitable for RTKLIB, while the UNB-3 Niell tropospheric correction is the best for gLAB.
- The filter solution type does not affect the results in RTKLIB, while backward filter has a good effect in case of gLAB compared with the forward.
- Solid tide and wind-up corrections enhance the positioning using both RTKLIB and gLAB.
- The optimum mask-angle is 10° using RTKLIB, while it is 20° in case of gLAB.
- The optimum session length equals 3hours using both RTKLIB and gLAB software.
- Processing using both C/A and L1 measurements produces the best results using gLAB.
- IGS ionex file has the best effect to minimize the ionospheric error in RTKLIB.
- gLAB is preferred over than RTKLIB due to its lower positional discrepancies in the three campaigns.
- The selected parameters in the first campaign can be generalized in any static PPP campaign using single frequency GPS data.

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