International Journal of Scientific Engineering and Research (IJSER)
ISSN (Online): 2347-3878
Index Copernicus Value (2015): 56.67 | Impact Factor (2017): 5.156

Enhancing the Kinematic GPS Solution by Ionosphere Model

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Abstract: ***Kinematic precise positioning is one of the main constraints of Global Positioning System. Double differencing and Precise Point Positioning method (PPP) is the most accurate positioning in GPS committee. The ionospheric delay in the propagation of global positioning system (GPS) signals is one of the main sources of errors in GPS precise positioning and navigation. This error is cancelled in PPP approach by ionosphere free combination and reduced relatively in the approach of double differencing in case of short line (50 km), what about base line over 50 km. In this paper, Ionospheric delay has been eliminated with the availability of global or a local ionospheric map produced by varies organizations (e.g., International GNSS service (IGS)). [1], evaluate the ionospheric correction by Global Ionospheric Maps, provided in (IONEX) files produced by IGS. He shows that there is no significant effect of the provided GIM values on the solution of kinematic processing. The primary goal of this paper is to test the effect of evaluated Global Ionospheric Maps (GIMs), Modified–GIM, on precise relative kinematic positioning over varies baselines lengths extended up to hundreds km throughout comparing the relative kinematic solution with modified GIM for several baselines and kinematic PPP solution for the rover station. More accurate results were obtained by correcting ionospheric error over kinematic solution of many baseline lengths up to 300 km. The kinematic PPP solution for the rover stations was evaluated. It can be concluded that, PPP still the more accurate than relative approach even after correcting ionospheric error over longer baseline.***

Keywords: DGPS, Global ionospheric maps “GIM”, kinematic PPP, Long baselines

1. Introduction

The development of the GPS kinematic technique has enabled real-time accurate positioning of a mobile platform to be performed. For precise GPS kinematic positioning, it is necessary to determine the integer ambiguities of the carrier phase observations. Over short baselines, the GNSS differencing technique can be applied to remove the correlated errors. However, in case of long-baseline kinematic positioning, the ionospheric effect increases and becomes more decorrelated. Its effect obstacles the ambiguity resolution process. Therefore, to improve the ambiguity fixing resolution for kinematic positioning over medium and long-range baselines, the ionospheric effect should be reduced [2].

In recent years, many approaches have been developed to enable high-accuracy GPS kinematic positioning over longer distances [3],[4], and [5]. These investigations involved the use of multi-reference stations networks. The main purpose of using these networks is to compute the ionospheric delay and other GPS errors. However, a local network of GPS reference stations is not always available and its implementation is costly. The alternative solution is using the Global Ionosphere Maps (GIM) that are generated daily at CODE using data from about 400 GPS/GLONASS sites of the IGS and other institutions, see figure (1). So, by incorporating the derived GIM-VTEC values into the process of different baselines lengths (up to 650 km) in kinematic mode should enhance the ambiguity resolution and the processing results should be improved.

[1]Evaluate the ionospheric correction by Global Ionospheric Maps, GIM, provided in (IONEX) files produced by IGS. The evaluation is done based on investigating the effect of given GIM ionospheric correction on kinematic relative positioning solution. The evaluation is performed on several baselines with different lengths in Egypt. The results show that there is no significant effect of the provided GIM values on the solution of kinematic processing. The results confirm that due to the lack of International GNSS Service (IGS stations) over the North Africa, GIMs have no effect for mitigating ionospheric error. A new value for the ionosphere correction VTEC values obtained by a regional developed algorithm based on zero-differenced phase ionospheric delay (ZDPID) [6]. These new values of VTEC can be feeded into GIMs-IONEX file for the specified stations data. A fruitful result obtained for correcting ionospheric error over kinematic solution of many baseline lengths up to 300 km which show the validity of the evaluation proposed method.

To see the feasibility study of using PPP for precise determination of the CORS, [7] carried out a comparable investigation between the coordinates obtained from Bernese software processing of 14 days of GNSS data for the 13 Kuwaiti CORS stations integrated with 27 IGS stations, and the coordinates resulted from the PPP processing of three days of these data. The comparison proved the high level of agreement between the coordinates within few mm. Based on their results; the

PPP was deployed to give the required static solution for the specified stations. The results of the static PPP of all 24-hours data of all stations are used as a threshold reference values for evaluation process.

Figure 1: IGS directly manages ~400 permanent GNSS stations observing 4-12 satellites at 30 s rate: more than 250,000 STEC observations/hour worldwide, but there is lack of stations at some areas (e.g., over the oceans).

Because of the results of [6] is considered as a milestone of the current study, the proposed method was tested on a baseline of Borg ~ Said 264.982 km. The kinematic processing of the specified baseline was done twice by Trimble Total Control 2.7 “TTC”, one by standard default processing parameters (D.D) and the second time with using modified IONEX-GIM values (D.D.M-GIM). The differences between the CRCS-PPP static solution and the two TTC kinematic epoch by epoch positioning solutions are computed and depicted in figure(2).

As it is shown in figure (2), the differences between the two solutions were improved (as a minimum & maximum values) from (-11.36 cm & 36.74 cm) with RMSE 27.3 cm to (-0.88 cm & -0.20 cm) with RMSE of 0.59 cm for Easting component. For north component, the improving was ranged between (-50.1 to -.04 cm) for the minimum value and (7.54 to 1.04 cm) for the maximum values, and for RMSE, it is improved from 22.77 cm to 0.42 cm. Finally, for the height components the differences were improved from (-70.55 &156.79 cm) to (-1.72 cm & 1.86 cm) with improving the RMSE from 64.04 cm to 1.13 cm.

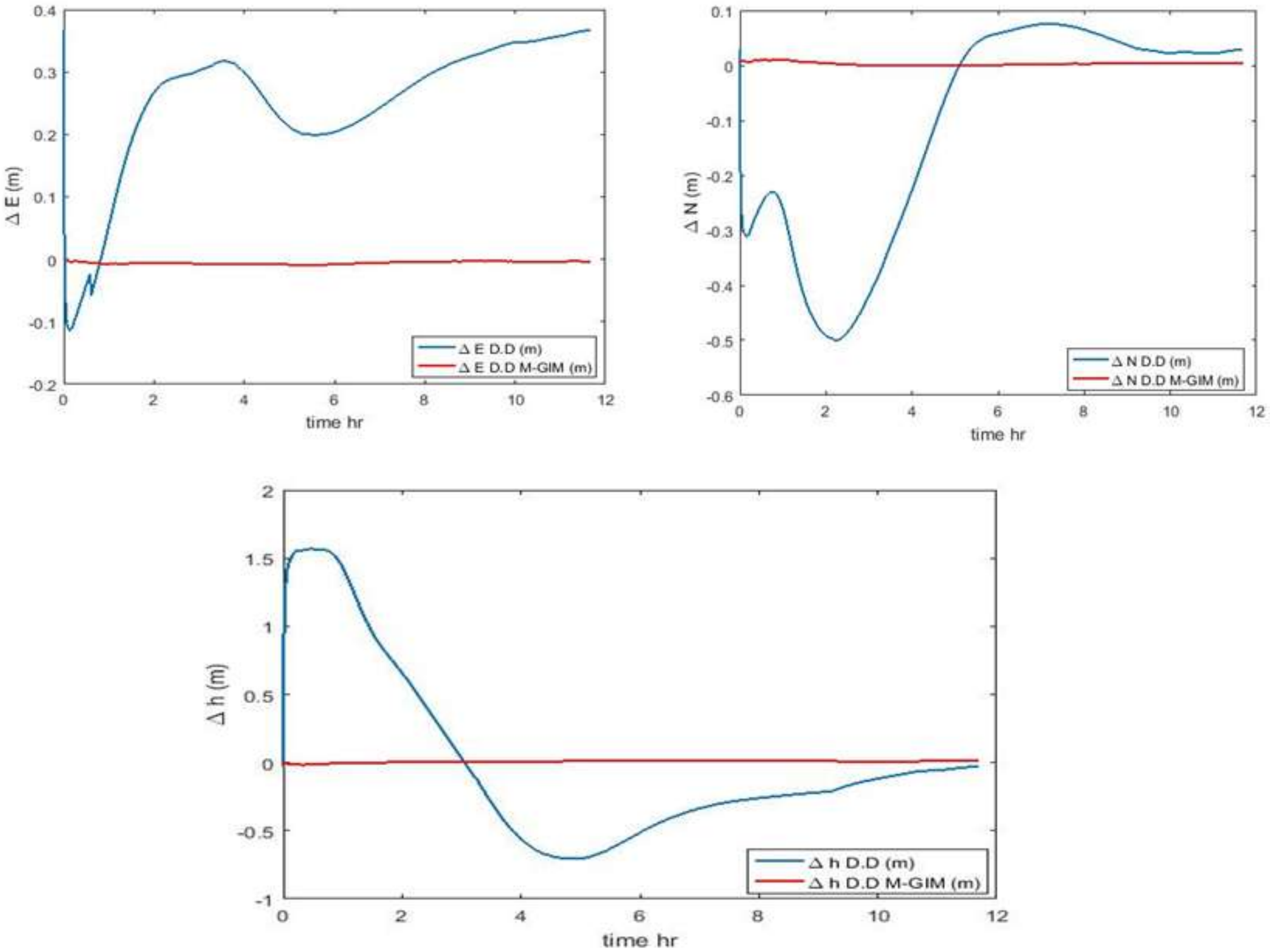

Figure 2: Positioning error with and without Mod-GIM in (East, North, Up) components between static PPP solution and relative kinematic positioning for baseline Borg ~ Said 264.982 km

2. Methodology

2.1 GPS Observation equations

The observation equations for code and carrier phase measurements on the Li frequency (i = 1, 2) can be formulated as follows [8]

$$P(L_i) = \rho + c(dt - dT) + d_{orb} + d_{trop} + d_{ion/li} + d_{mult\,(P_{li})} + \epsilon(P_{li}) \quad (1)$$

$$\varphi(L_i) = \rho + c(dt - dT) + d_{orb} + d_{trop} + d_{ion/li} + \lambda_i N_i + \lambda_i(\varphi_r(to, li) - \varphi_s(to, li)) + d_{mult\,(\varphi_{li})} + \epsilon(\varphi_{li}) \quad (2)$$

Where:

$P(L_i)$: Measured pseudo range on Li (m).
$\varphi(L_i)$: Measured carrier phase on Li (m).
ρ : True geometric range (m).
c : Speed of light (m/s).
dt : Satellite clock error (s).
dT : Receiver clock error (s).
d_{orb} : Satellite orbital error (m).
d_{trop} : Tropospheric delay (m).
$d_{ion/li}$: Ionospheric delay on Li (m).
λ_i : Wavelength (m).
Ni : Integer ambiguity on Li (cycle).
$\varphi_r(to, li)$: Initial phase of receiver oscillator.
$\varphi_s(to, li)$: Initial phase of satellite oscillator.
$d_{mult\,(P_{li})}$: Multipath effect in measured pseudo range on Li (m).
$d_{mult\,(\varphi_{li})}$: Multipath effect in measured carrier phase on Li (m).
$\epsilon(P_{li})$: Measurement noise (m).

Denoting the stations by a and b and the satellites involved by j and k, the double difference model for long baselines when there is a significant difference in the atmospheric effect between the two baselines ends and elevation angles at both station are different can be expressed:

$$\nabla\Delta\varphi_{ab}^{jk}(t) = \rho_a^j(t) - \rho_a^k(t) - \rho_b^j(t) + \rho_a^k(t) + \lambda\nabla\Delta N_{ab}^{jk}(t) + \nabla\Delta dorb_{ab}^{jk}(t) + \nabla\Delta dtrop_{ab}^{jk}(t) - \nabla\Delta dion_{ab}^{jk}(t) + \nabla\Delta dmult_{ab}^{jk}(t) + \nabla\Delta\varepsilon_{ab}^{jk}(t) \quad (3)$$

The term $\nabla\Delta N_{ab}^{jk}(t)$ is called the double difference integer ambiguity, that must be determined (as an integer) during the double difference carrier phase processing procedure. If the individual carrier phase observations are continuously made over time (no cycle slip), the integer ambiguity terms remain constant. If these terms can be successfully determined to integer values, the fixed solution to the baseline is achievable. In case of short base line, the residual orbital errors ($\nabla\Delta dorb_{ab}^{jk}(t)$), residual ionospheric errors ($\nabla\Delta dion_{ab}^{jk}(t)$), and residual tropospheric errors ($\nabla\Delta dtrop_{ab}^{jk}(t)$) these residual errors can be considered negligible [9]. Multipath errors are not mitigated by differencing observations and hence a user should try to avoid multipath environments whenever possible as the best approach to mitigating their effects [10]. Using precise orbit and clock products with centimeter level accuracy, the two errors related with the broadcast orbits and clocks can be significantly reduced. Satellite and receiver clock error doesn't depend on baseline length so it cancelled by differencing. For the tropospheric residual errors, the best standard method to computing is to apply a tropospheric error model at the locations of the reference and remote stations. Examples of such models include the Hopfield model and the Saastamoinen model [9].

2.2 Data Description

The used data see figure (3), for the evaluation study were collected on April 15, 2015 at six stations located between Latitudes 29 °& 32° and Longitudes 25°& 33°. They are considered as the northern part of the Egyptian Permanent GNSS Network (EPGN) established by the National Research Institute of Astronomy and Geophysics NRIAG at 2006. All Stations are equipped with Trimble Net R5 Dual frequency GNSS receivers. The data sample rate was 30 seconds epoch interval. The number of visible satellites was varied between 6 and 10 during the test period. As it is shown in figure (3), all the used GNSS stations are.

To investigate the effect of the modified IONEX of the Global Ionospheric Maps (GIM's) on relative positioning kinematic applications, six baselines with different lengths (see table 1) ranged from 49 km to 614 km were processed in kinematic mode.

Table 1: The processed baselines and the static PPP solution of the used stations

Station Id	Static PPP Solution		
	Northing (m)	Easting (m)	Ell. Hgt. (m)
Alex(UTM35)	3455094.198	777383.846	57.957
Mnsr (UTM 36)	3435314.492	342786.883	39.555
Said (UTM 36)	3457034.377	434710.473	41.944
Borg (UTM 35)	3417295.426	746090.345	98.083
Slum (UTM 35)	3485451.565	330194.431	91.441
Helw (UTM36)	3304595.873	339992.150	148.781

Baseline	Baseline Length (km)
Borg-Alex	49.05
Helw-Mnsr	130.757
Helw-Said	179.504
Borg-Said	264.982
Borg-Slum	421.459
Helw-Slum	614.349

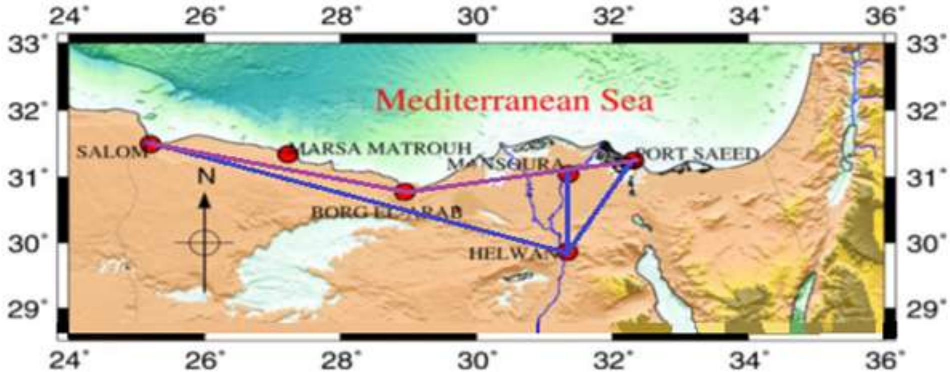

Figure 3: The geometric location of the used baselines in the evaluation process

3.2 Processing Software

For baseline processing, Trimble Total Control (TTC2.5) was the main processing software package that was used for kinematic processing of data. TTC has the capability to implement precise ephemeris and global ionospheric maps (IONEX). On the other hand, for static and kinematic Precise Point Positioning (PPP), the online service provided by Natural Resources Canada (NRCan) was utilized to give us the threshold values for comparison [7].

The **NRCan Online Precise Point Positioning Software** is developed by NRCan to supply various users' application requirements. The PPP service can be used to process data collected by any single-or dual-frequency receiver, and the data can be observed in static or kinematic modes. PPP is accessible via the Internet by logging into the NRCan website (http://www.geod.nrcan.gc.ca/online_data_e.php).

3. Results and Discussion

3.1 Evaluation Process

A comparative study was done between the obtained positioning of the two kinematic solutions. The first solution is based on the differential GPS kinematic solution provided with modified ionospheric correction within the IONEX file performed by TTC version 2.7 as mentioned before. The second solution is done by applying the kinematic epoch-wise precise point positioning (PPP) technique i.e. ionospheric free. The static PPP solution of the used stations is also given in table (1). Again, we confirmed that the results of the static PPP of all 24-hours data of all stations are used as a threshold reference values for evaluation process.

The differences between the CRCS-PPP static solution and the TTC DGPS kinematic epoch by epoch positioning solutions for the five specified baselines and the kinematic PPP solution for the five rover stations are computed and depicted in figures 4, 5, 6, 7, 8& 9. The statistical parameters, represented by the minimum, maximum, mean and Root Mean Square Errors are outlined in table (2).

3.2 Discussion

Recall that the data were processed two times: the first run was done by using modified GIM as a source for the ionospheric delay correction, computed by ZDPID algorithm and the second run was using kinematic precise point positioning. The differences between the static PPP and both solution was computed and tabulated in table 2 and depicted in figure 4, 5, 6, 7 , 8and 9. Keep in mind that the TTC solutions are obtained without fixing the ambiguities i.e. float ambiguity solution. The TTC could not fix the ambiguities for the specified baselines.

As it is shown in figures 4, 5, 6, 7, 8 and 9, the tabulated statistical parameters of position differences in Easting, Northing and Ellipsoidal height between the computed static NRC an PPP and the kinematic epoch by epoch solution of relative positioning using modified IONEX values (D.D.M-GIM) and kinematic precise point positioning (PPP ionosphere free model) for rover station of specified base lines show that kinematic PPP solution for rover station is more accurate than relative kinematic solution using the modified IONEX, (Mod-GIM) which used to correct the ionosphere error (largest error source) if the base line length over 50 km. The kinematic epoch by epoch solution of relative positioning using modified IONEX values (D.D.M-GIM) shows a good mapping solution than kinematic PPP solution for station for the baseline still 50 km. Keep in mind that for baselines over 300km, the kinematic (D.D.M-GIM) solution is based mainly on code solution of RMS exceeds the meter. Based on the aforementioned discussion, it is easily to see that the PPP is the more accurate positioning technique for precise kinematic positioning applications than kinematic relative positioning when baseline length over 50km. For base line less than 50 km relative kinematic positioning more accurate than kinematic PPP positioning when using ionosphere correction model. It's also declared that, the height is usually less accurate compared to the horizontal coordinates due to the worse geometry of the GPS satellites with respect to the receiver in height direction. It was observed that, most Commercial software's like Leica Geo-Office, Trimble Total Control, Trimble Business Center failed to get accurate results for kinematic solution using Mod-GIM for baseline lengths over 300 km. So, PPP technique is the most suitable positioning method if the base line over 300 km even we used ionospheric correction (Mod-GIM).

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Table 2: The descriptive statistics between PPP kinematic and Relative kinematic positioning with Mod-IONEX

Base-line	*Length (km)*	*Statistics Propert.*	*Kinematic PPP Solution (Ion-Free) for Rover Station*			*Double Difference kinematic solution with Modified -IONEX*		
			Δ E (mm)	*ΔN (mm)*	*Δh (mm)*	*ΔE (mm)*	*ΔN (mm)*	*Δh (mm)*
Borg-Alex	49.05	Min	-8.7	-6.5	97.9	-7.5	-5.1	43.4
		Max	-3.9	-3.6	114.2	2.2	2.2	58.3
		Mean	-4.6	-4.5	110	-1.7	-2.4	45.9
		RMS	4.7	4.6	110	2.5	3	46.1
Helw -Mnsr	130.757	Min	-7.5	0.1	-2.4	-31	-115.6	-194.6
		Max	7.5	6.9	15.5	88	32.9	431.8
		Mean	-0.6	2.3	2.7	55.8	-22.5	-70.7
		RMS	3.7	3	4.5	59.8	46.8	188.5
Helw -Said	179.504	Min	-7.3	-1.1	-10	-52.6	-9.8	-121
		Max	5.9	6.9	7.2	8.1	33.8	-62.5
		Mean	-1.8	0.7	1.4	-24.2	3.8	-8.21
		RMS	3.2	2.3	2.9	30.1	11.6	8.35
Burg - Said	264.982	Min	-7.3	-1.1	-4.4	-15.8	-24.8	-4.9
		Max	5.9	3.1	7.2	8.2	3.1	113.2
		Mean	-1.8	-0.1	1.4	-0.7	-3.5	23.6
		RMS	3.2	1	2.9	6.3	6	36.1
Burg -Slum	421.459	Min	-24.8	-4.2	-45.3	-479.1	-55.9	-350.6
		Max	13.2	19.1	2.6	568.8	2106.4	3199.3
		Mean	-13	-0.3	-15.2	-127.7	396.4	958.8
		RMS	15.4	3.8	21.5	303.4	604.6	1207.7
Helw -Slum	614.349	Min	-24.8	-4.2	-45.3	-793.6	-832.5	-1119.5
		Max	13.1	19.1	2.5	567.5	1704.3	3400.1
		Mean	-13.2	-0.3	-16.3	-324.7	-216	1064
		RMS	15.6	3.9	22.3	501.5	602.3	1335.7

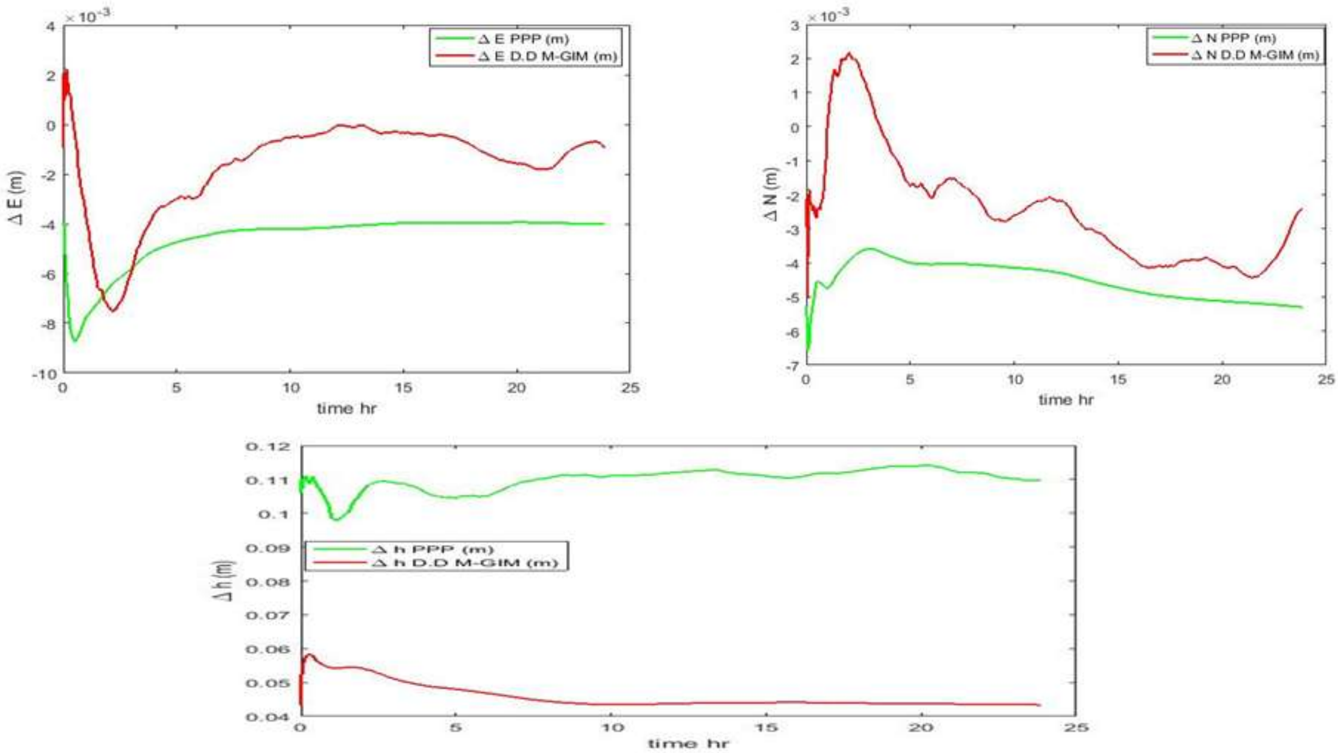

Figure 4: The position differences between static PPP for rover station Mnsr and relative kinematic solution with modified GIM for baseline Borg-Alex (49.05km) and kine3matic PPP solution.

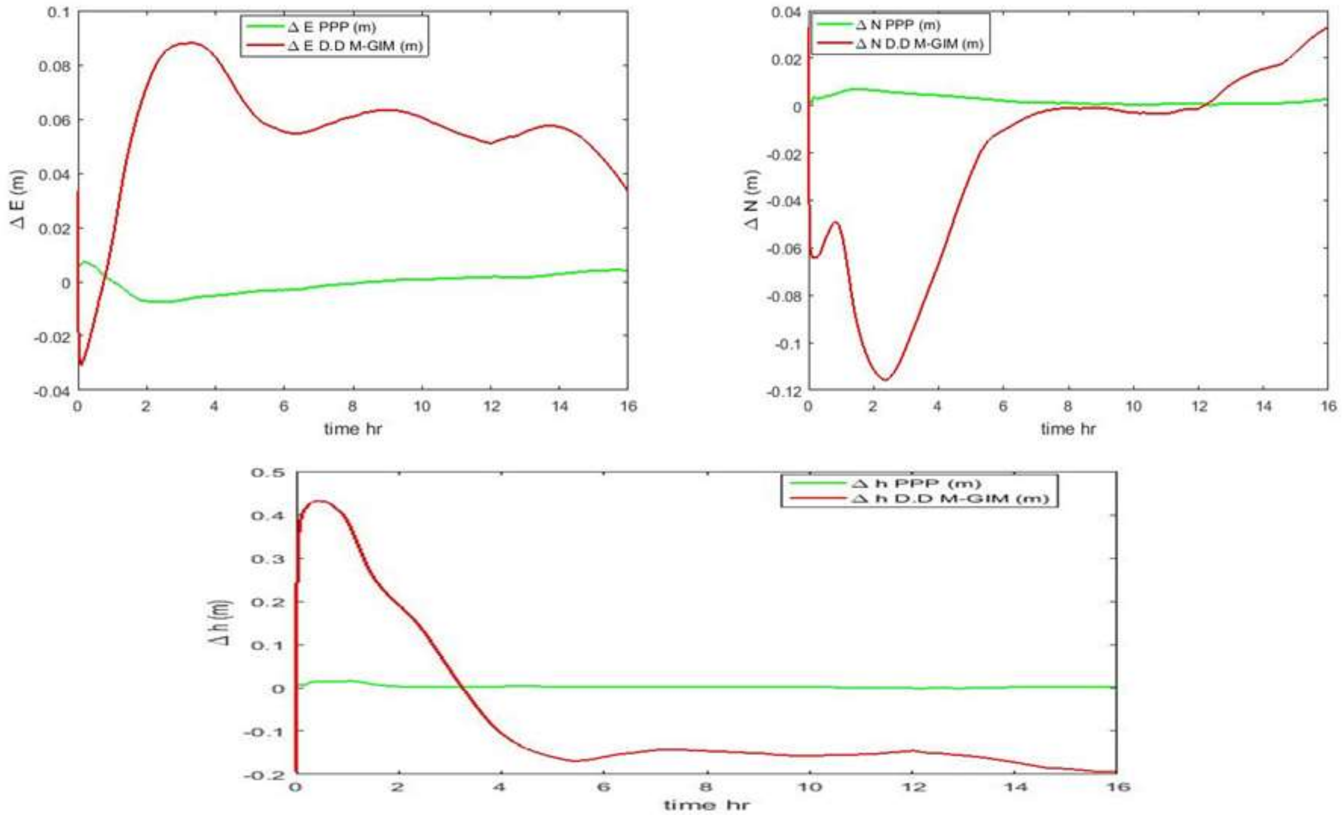

Figure 5: The position differences between static PPP for rover station Mnsr and relative kinematic solution with modified GIM for baseline Helwan-Mnsr (130.757km) and kinematic PPP solution.

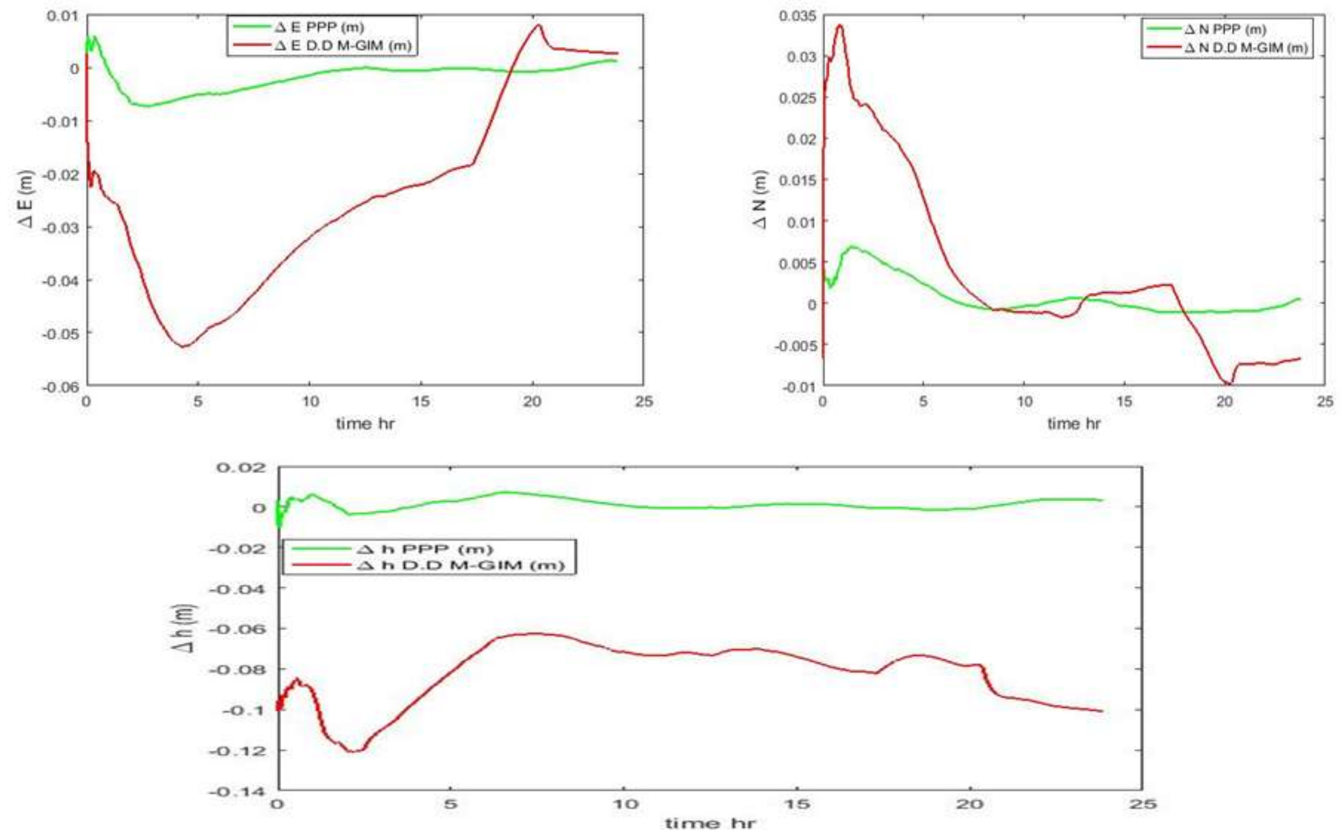

Figure 6: The position differences between static PPP for rover station Said and relative kinematic solution with modified GIM for baseline Helwan-Said (179.504km) and kinematic PPP solution.

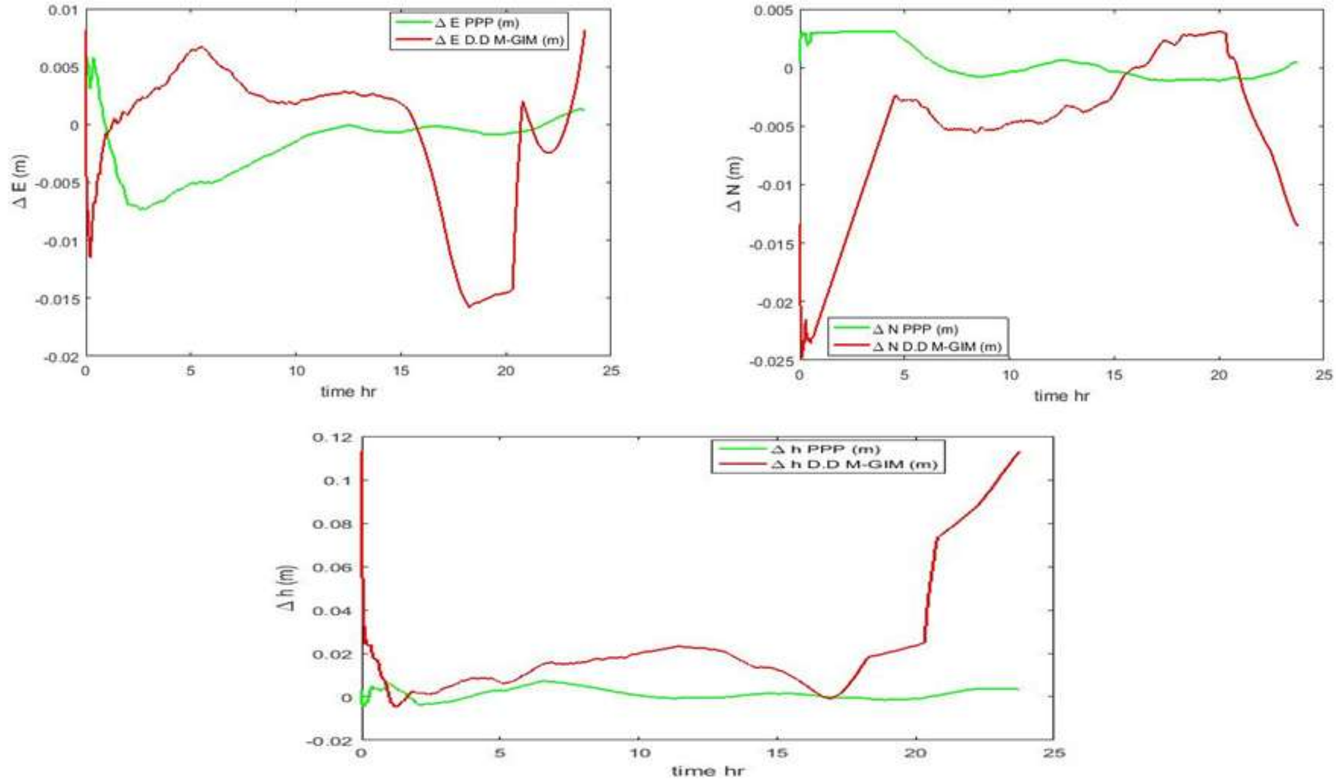

Figure 7: The position differences between static PPP for rover station Said and relative kinematic solution with modified GIM for baseline Borg-Said (264.982km) and kinematic PPP solution.

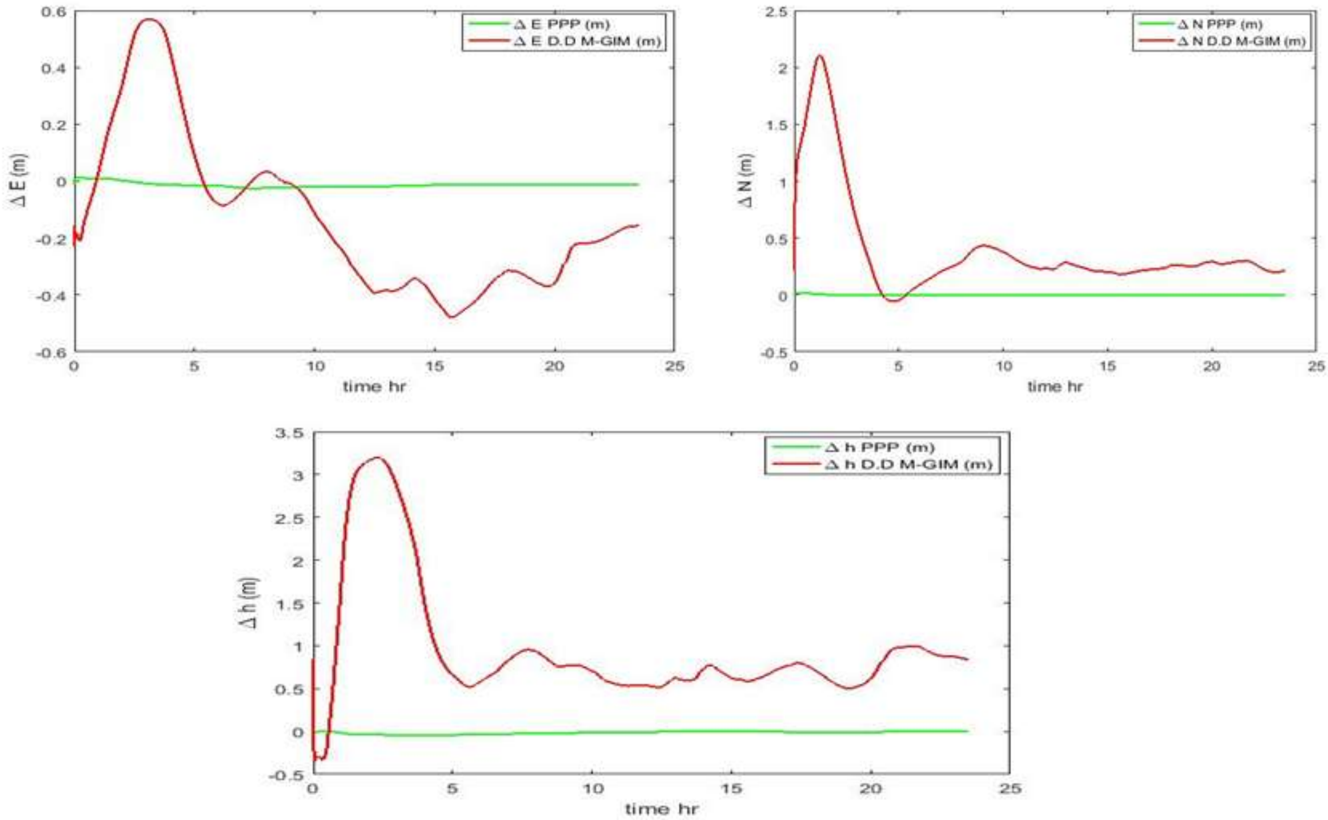

Figure 8: The position differences between static PPP for rover station Slum and relative kinematic solution with modified GIM for baseline Borg-Slum (421.459km) and kinematic PPP solution.

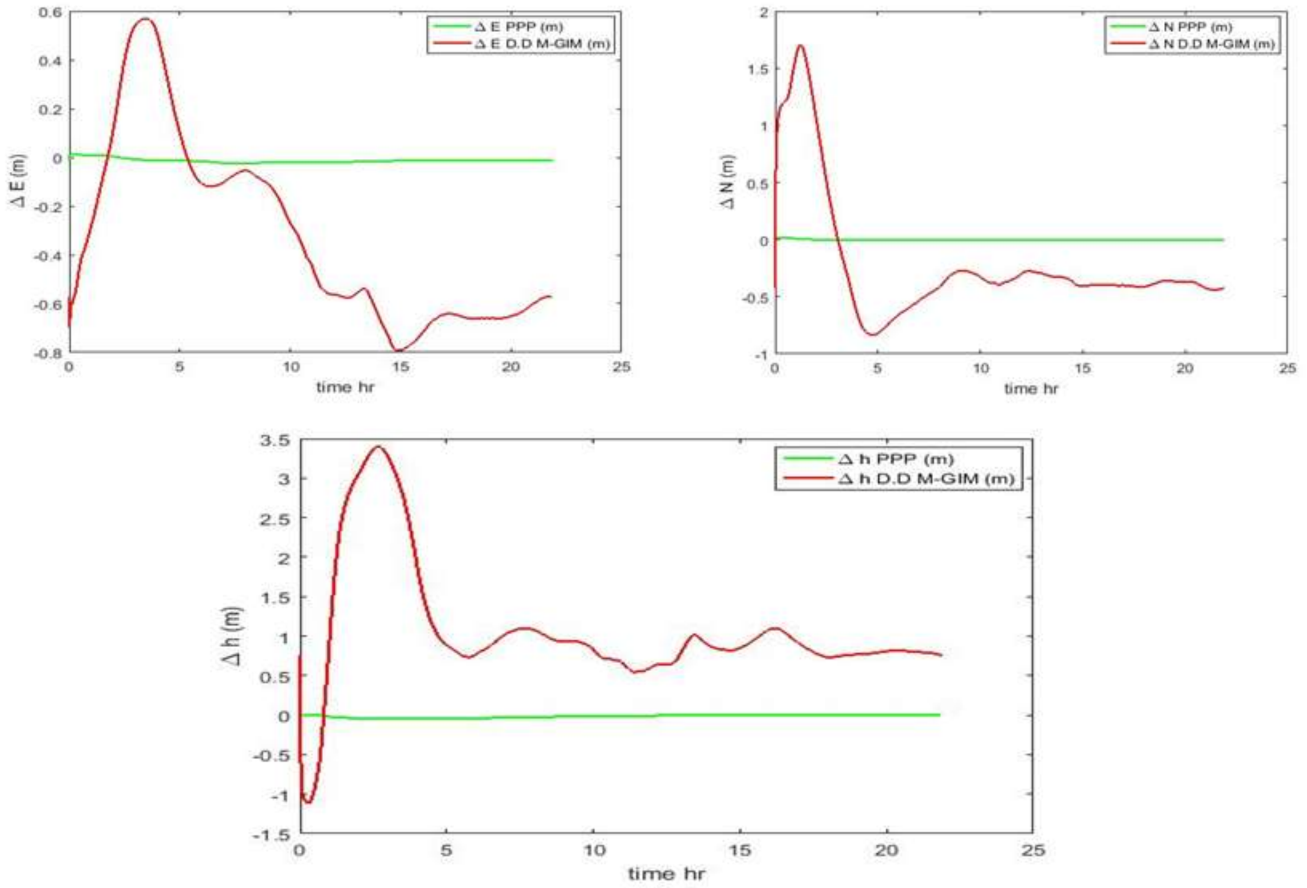

Figure 9: The position differences between static PPP for rover station Slum and relative kinematic solution with modified GIM for baseline Helwan-Slum (614.349km) and kinematic PPP solution.

4. Conclusions

The current paper investigates the effect of the modified IONEX of the Global Ionospheric Maps (GIM's) on relative positioning kinematic applications. The evaluation is performed on several baselines with different lengths in Egypt. Based upon the baselines processing results, the following conclusions can be drawn:

1. PPP is the more accurate positioning technique for precise kinematic positioning applications than kinematic relative positioning when baseline length over 50km between the rover station and base station.
2. The accuracy of relative positioning with Mod-GIM more than the accuracy of PPP for base lines less than 50 km.so, relative positioning using Mod-IONEX can used for kinematic application till 50 km.
3. Commercial software's like Leica geo-office, Trimble total control, Trimble Business Center failed to get accurate results for kinematic solution using Mod-GIM for baseline lengths over 300 km. So, PPP technique is the most accurate positioning method if the base line over 300 km even we used ionospheric correction (Mod-GIM).
4. Using scinetifical software's for kinematic positioning for base line over 300 km with M-GIM enhancing the relative positioning ,will be more accurate than kinematic positioning using PPP method and to what extent ,this is afuture question.

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