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Evaluation of the IGS-Global Ionospheric Mapping model over Egypt

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Abstract:

Global ionosphere maps (GIM) are generated on a daily basis at CODE using data from about 400 GPS/GLONASS sites of the IGS and other institutions. The vertical total electron content (VTEC) is modeled in a solar-geomagnetic reference frame using a Spherical Harmonics Expansion "SHE" up to degree and order 15. To cover the holes of the first GIM computation stage existing in the North Africa and over the Oceans resulting a shortage of GNSS station in North Africa, an optimum spatial-temporal interpolation technique was developed to cover these holes (Krankowski and Hernandez-Pajares, 2016).

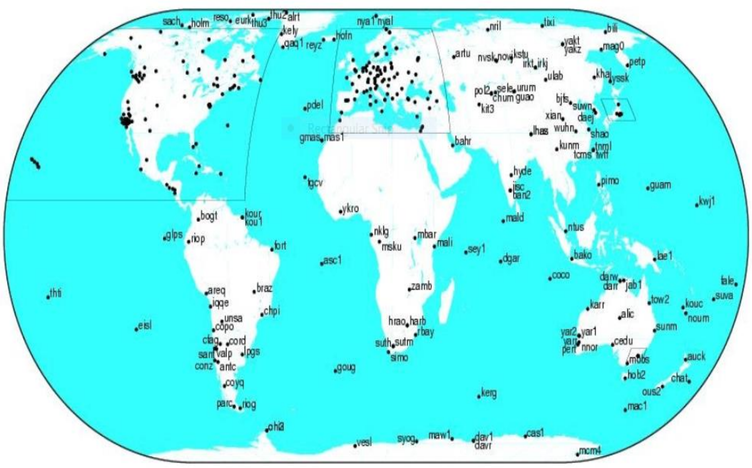
The current paper evaluates the ionospheric correction by Global Ionospheric Maps, GIM, provided in (IONEX) files produced by International GNSS Services "IGS". The evaluation is performed based on investigating the effect of a given GIM ionospheric correction on kinematic relative positioning solutions. The evaluation was done using several baselines of 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 although there is a lack of International GNSS Service (IGS stations) over North Africa, GIMs have no effect in mitigating ionospheric error. A new value for the ionosphere correction VTEC values was obtained by a regional, developed algorithm based on zero-differenced phase ionospheric delay (ZDPID) (Tawfeek et.al., 2018). These new values of VTEC were fed into GIMs for the specified stations data. A useful result was obtained for correcting the ionospheric error over kinematic solution of many baseline lengths up to 300 km which demonstrates validity of the proposed evaluation method.

Key words: International GNSS Services "IGS", Global ionospheric maps "GIM", vertical total electron content (VTEC), Zero-differenced phase ionospheric delay

1. Introduction

Global ionosphere maps (GIM) are generated on a daily basis at CODE using data from about 400 GPS/GLONASS sites of the IGS and other institutions, see figure (1). The vertical total electron content (VTEC) is modeled in a solar-geomagnetic reference frame using a Spherical Harmonics Expansion "SHE" up to degree and order 15. Piece-wise linear functions are used for representation in the time domain. The time spacing of their vertices is 2 hours, conforming with the epochs of the VTEC maps. Instrument biases, so-called differential P1-P2 code biases (DCB), for all GPS satellites and ground stations are estimated as constant values for each day, simultaneously with the 3328 parameters used to represent the global VTEC distribution. The DCB datum is defined by a zero-mean condition imposed on the satellite bias estimates. P1-C1 bias corrections are taken into account if needed. To convert line-of-sight TEC into vertical TEC, a modified single-layer model (MSLM) mapping function approximating the JPL extended slab model mapping function is adopted. The global coverage of the GPS tracking ground stations considered at CODE is shown in figure (1).

According to Hernández-Pajares et al. (2017), broadly used Global Ionosphere Maps (GIMs) provided by the IGS are characterized by estimated accuracy ranging from a few TECU to approximately 10 TECU in VTEC. This IGS product offers 2.5 by 5.0 degrees spatial resolution, and temporal resolution of 2 h. IGS GIMs are developed as an official product of the IGS Ionosphere Working Group by performing a weighted mean of the various Analysis Centers (AC) VTEC maps: CODE, ESA, JPL, UPC, and NRCan. CODE GIM (CODG) comes from processing double-differenced carrier phase data and TEC parametrization using Spherical Harmonics Expansion "SHE" functions and Bernese software (Schaer, 1999). ESA GIM is based on processing carrier phase-smoothed pseudoranges and TEC parametrization using SHE functions (Feltens, 2003). JPL GIM is derived from a three-shell model that is based on spline functions.



Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2018-92
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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 in some areas (e.g., over the oceans).

According to Hernández-Pajares et al. (2009), the highest accuracy is offered by the UQRG model provided by UPC, and is produced by combining a tomographic modelling of the ionosphere with kriging interpolation using the TOMION software developed at UPC. UQRG offers 2.5 by 5.0 degrees spatial resolution, and high temporal resolution of 15 min (Orùs et al., 2005). It should also be noted that vertical TEC values estimated by using smoothed pseudoranges have lower accuracy than values offered by methods based on the precise carrier phase observations.

The majority of various global and regional ionosphere models currently available are characterized by low temporal and spatial resolutions. Most of them are based on carrier phase-smoothed pseudorange data, which presents low accuracy and requires strong smoothing filters. As a result, the obtained ionospheric delay represents relatively low accuracy of several TEC units (1 Total Electron Content Unit = 1 TECU = 10^{16} el/m^2, and it is equivalent to 0.162 m of L1 signal delay). This is one of the reasons why spherical harmonics expansion (SHE) is used for the global and regional TEC parameterization (Rovira-Garcia, 2017). The smoothing effect of SHE undoubtedly results in the low accuracy of the ionospheric models. Also, the ionosphere models often use GPS-only data. Another important aspect is using a single layer model (SLM) ionosphere approximation and its associated relatively simple mapping function, which results in a rather low relative accuracy of publically available models that amounts to 20–30%, as was shown in Hernández-Pajares et al. (2011).

Precise kinematic positioning to centimeter level accuracy requires using the carrier phase observations with the correct resolution of the integer ambiguities. Conclusions previously published for solving the ambiguities of medium baselines On-The-Fly can be summarized in the following two different approaches (El-Hattab et al., 2003):

1. The main layout of the first approach can be represented by the following two steps: The first step is a static initialization for the rover receiver at the beginning of the mission within a short distance with respect to a reference receiver. This will facilitate the processing of the ambiguity fixing. In the second step, a technique for ambiguity recovery On-The-Fly is introduced to recover the integer ambiguities when cycle slips or data gaps shorter than a few minutes occur.
2. The second approach mainly depends on the condition that the dominant source of distance-dependent errors is the ionospheric refraction compared to the orbit error as well as the tropospheric error. As is known, the tropospheric error is mostly affected by the height difference

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Discussion started: 30 August 2018

between the ends of the baseline rather than the distance. Hence, the ionospheric error produces the dominant contribution in complicating the ambiguity resolution of a medium baseline compared to the other errors. Therefore, providing a proven correct ionospheric correction to the processing will enhance the ambiguity resolution process.

The current study evaluates the possibility of using Global Ionospheric Maps for mitigating ionosphere effect (large error source) over Egypt. The evaluation process is undertaken by incorporating the derived GIM-VTEC values into the processing of baselines different lengths (up to 300 km) in kinematic mode to check how the processing results are improved. Finally, the analysis of the obtained results and graphs supported with the statistical analysis is discussed and presented, from which the important conclusions and recommendations are drawn.

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 (Hoffmann et al., 2013):

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

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

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, 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 stations 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 the case of short base lines, the residual orbital errors ($\nabla\Delta dorb_{ab}^{jk}(t)$), residual ionospheric errors ($\nabla\Delta dion_{ab}^{jk}(t)$), and residual tropospheric errors ($\nabla\Delta dtrop_{ab}^{jk}(t)$) can be considered negligible (Hofmann, 2008). 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 (Abu Galala et al., 2018).

For medium and long baselines common error does not cancelled out. Because of different elevation angles on both ends of baseline there is no correlation between the errors. 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 does not depend on baseline length, so it can be cancelled by differencing. For the tropospheric residual errors, the best standard method of 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 (Hoffman, 2008).

2.2 Ionospheric modelling

Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2018-92
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Discussion started: 30 August 2018

The ionospheric delay has an intensive impact on the GNSS observations by driving an additional transmission time delay. The magnitude of this effect is determined by the amount of total electron content (TEC) and the frequency of signal. Under normal solar activity conditions, this effect on GPS signals is usually in the range from a few meters to tens of meters, but it can reach more than 100 m during severe ionosphere storms (Rovira-Garcia, 2015). TEC is quantified from GPS measurements by a linear combination of the measured pseudo range and phase observables registered by the receiver on two carrier frequencies (f1 = 1575.4 MHz and f2 =1227.6 MHz). TEC is measured in TECU units with 1 TECU =10^{16} el/m2.

The geometry-free linear combination of GPS observations is used for ionospheric estimation and it is obtained by subtracting simultaneous pseudo range (P_1-P_2 or C_1-P_2) or carrier phase observations ($\varphi_1 - \varphi_2$). Code-based TEC (TEC $_P$) is noisier than phase-based TEC (TEC φ), largely due to multipath, but the phase-based suffers an unknown integer ambiguity offset and is subject to cycle slips associated with rapid ionospheric scintillations. The resultant TEC is the GPS-derived slant TEC along the signal path between satellite and receiver (Zus et al., 2017). In this combination, the satellite – receiver geometrical range and all frequency independent biases are removed. The geometry-free linear combination for carrier phase observations is obtained:

$$L_4(t) = \varphi_{GF} = \varphi_1 - \varphi_2 = (\gamma - 1)dion_1 + \lambda_1 N_1 - \lambda_2 N_2 + \varepsilon(\varphi_1 - \varphi_2) \qquad (4)$$

Where: $\varepsilon(\varphi_1 - \varphi_2)$ is the noise term in phase equation can be neglected for simplicity, the factor γ is the factor to convert the ionospheric delay from L2 to L1frequency.

$$dion_2 = \frac{40.3\, STEC}{f_2^2} = \frac{f_1^2}{f_2^2}\, dion_1 = \gamma\, dion_1 \qquad \gamma = \frac{f_1^2}{f_2^2} \qquad (5)$$

2. 3 VTEC Estimation

The ionosphere may be considered as a thin single layer surrounding the earth at a fixed height from the earth for which all free electrons in the ionosphere are assumed to be concentrated, in this single-layer having a maximum electron density (10^{11}:10^{12} e/m^2 around 300-500 km) (Feltens, 2003). IPP is the intersection point between the satellite receiver line-of-sight, and the ionosphere shell (Figure 2). Slant total electron content (STEC) can be translated into VTEC using Single Layer Model (SLM).

$$VTEC = F(E)\, STEC$$

Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2018-92
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Discussion started: 30 August 2018

Annales Geophysicae Discussions

$$VTEC = F(E)\frac{dion_1 . f_1^2}{40.3}$$

Where: *F (E)* is the mapping function.

Mapping function model:

To compute elevation and azimuth angle for any satellite, the satellite position coordinate (x_s, y_s, z_s) in ECEF at the specified epoch is deduced from the IGS final orbits. The interpolated satellite position is then transformed to a local coordinate frame, East, North, and Up (ENU) system. The transferred ENU is used to calculate elevation and azimuth angles as follows (Sedeek et al., 2017):

$$\mathrm{E} = \arctan\left(\frac{\mathrm{x_U}}{\sqrt{\mathrm{x_N^2} + \mathrm{x_E^2}}}\right) \qquad \mathrm{A} = \arctan\left(\frac{\mathrm{x_E}}{\mathrm{x_N}}\right)$$

Where: E and A are elevation angle and Azimuth angle of satellite at the receiver, respectively. The receiver position in Earth Centered Earth Fixed (ECEF) is converted to geodetic coordinates. Ionospheric Pierce Point (IPP) is the intersection point between the satellite and the receiver line-of-sight. Ionospheric Pierce Point (IPP) location can be computed by providing reference station coordinates (ϕ_r, λ_r), from which the geographic latitude and longitude of IPP can be computed according to elevation and azimuth angle of satellite as follows (Sedeek et al., 2017):

$$\psi = \pi / 2 - E' - E$$

Where ψ : The offset between the IPP and the receiver; E' and E: the elevation angles of the satellite at the IPP and receiver.

$$E' = \sin^{-1}\left(\left(\frac{R_E}{R_E + H}\right)\cos E\right)$$

R_E: is the mean radius of the spherical Earth (6371 km)

H: is the height of IPP (taken to be 450 km)

$$\phi_{IPP} = \sin^{-1}(\sin(\phi_r).\cos(\psi) + \cos(\phi_r).\sin(\psi).\cos(A))$$

$$\lambda_{IPP} = \lambda_r + \frac{\psi.\sin(A)}{\cos(\varphi_{IPP})}$$

Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2018-92
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3. GIM Evaluation

To evaluate the obtained ionospheric TEC values that are produced by IGS, the IONEX data file for a specified time is imported. This data if used with GNSS data should improve the position solution and/or enhance ambiguity resolution of a specified baseline that cannot be fixed under normal conditions, otherwise the quality of the imported ionospheric data is not good enough to support the positioning works. However, our evaluation approach is built on applying the imported INOEX data on a third-party processing SW, Trimble Total Control, known as TTC, for collected baselines of different engths. The processing is performed on a kinematic mode. Alternative ion TEC data, generated by regional model was applied to evaluate the validity of the proposed evaluation approach.

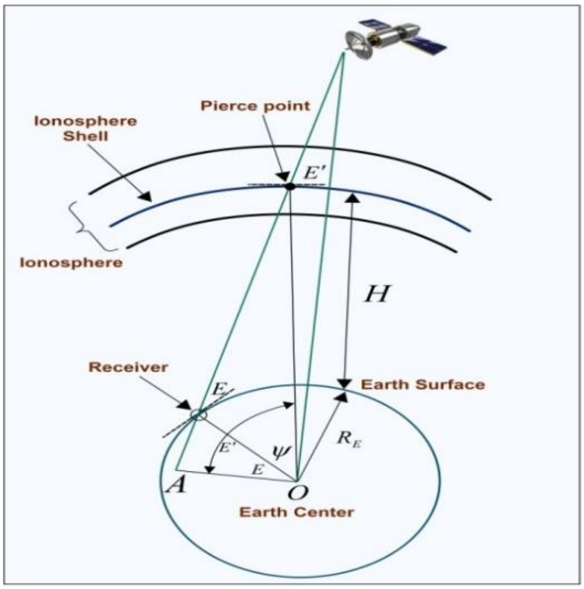

Figure (2): Elements of the spherical ionospheric shell model (Sedeek et al., 2017).

3.1 Data Description

The data used for the evaluation study, refer to figure (3), were collected on April 15, 2015 at seven stations: six of them, is the northern part of the Egyptian Permanent GNSS Network (EPGN) established by the National Research Institute of Astronomy and Geophysics NRIAG at 2006 and the seventh station in Alexandria managed by the French institute, Centre d'Études Alexandrines (CEALX). All NRIAG Stations are equipped with Trimble Net R5 Dual frequency GNSS receivers whilst Alexandria is equipped with a LEICA GRX1200 GG-Pro Dual frequency GNSS Receiver.

The data sample rate was 30 seconds epoch interval. The number of visible satellites varied between 6 and 10 during the test period. As is shown in figure (3), all the used GNSS stations are located between Latitudes 30 º & 32º and Longitudes 25º & 33º.

3.2 Processing Software

For baseline processing, Trimble Total Control 2.7 (TTC2.7) was the main processing software package that was used for the kinematic processing of the data. TTC has the capability to implement precise ephemeris and global ionospheric maps (IONEX). On the other hand, for Precise Point Positioning (PPP), the online service provided by Natural Resources Canada (NRCan) was utilized to provide the threshold values for comparison (Rabah et al., (2016). 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).

3.3 GIM data

Table (1) shows a part of the IONEX data that was assigned for the specified latitude location of first epoch of day April 15, 2015. The evaluation process is carried out by incorporating the derived GIM-VTEC values into the processing of different baseline lengths (up to 300 km), in kinematic mode and check how the processing results are improved. The evaluation was performed on several lengths of baselines, see table (2), and processed with TTC software, with and without IONEX in Kinematic mode. Unfortunately, the results show that the IONEX file did not affect the results at all: no differences were found in solutions with and without IONEX. The results confirm that there is no significant effect of the provided GIM values on the solution of kinematic processing. The results of GIM values forced us to check the validity of Ion TEC values in the IONEX file for the specified area. A trial was undertaken to compute alternative regional TEC values using another model.

Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2018-92
Manuscript under review for journal Ann. Geophys.
Discussion started: 30 August 2018

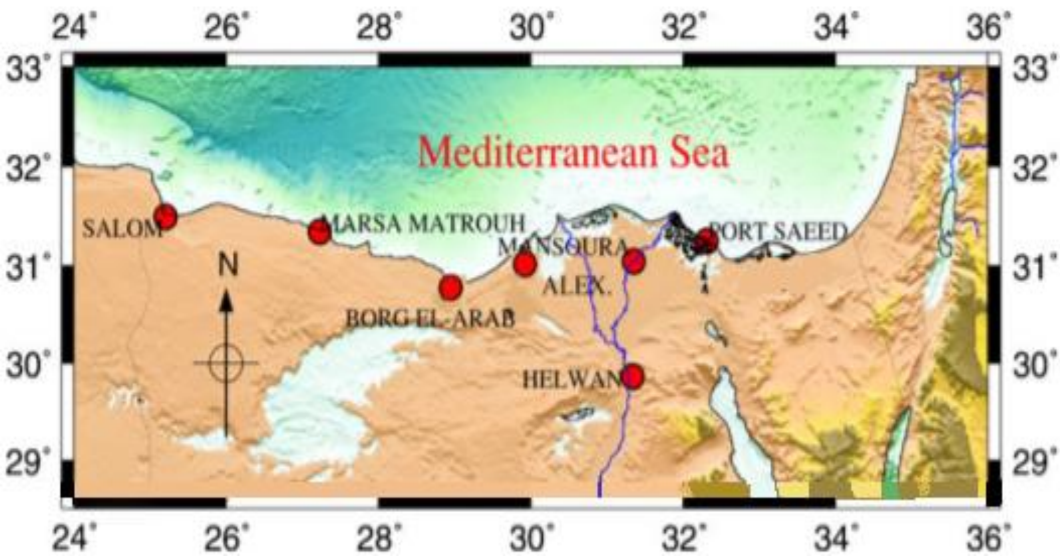

Figure (3): The location of the used stations

Table (1): Sample of the used IONEX file

2015	4	15	0	0	0					EPOCH OF CURRENT MAP					
32.5-180.0 180.0 5.0 450.0										**LAT/LON1/LON2/DLON/H**					
621	632	633	630	628	630	630	621	594	553	508	471	448	438	436	434
433	429	422	414	404	390	372	351	331	318	315	320	333	348	360	363
352	330	305	283	263	247	230	215	208	209	215	221	221	215	202	186
170	156	149	153	169	196	228	253	269	277	287	301	319	337	352	364
373	384	404	435	475	521	564	598	621							
30.0-180.0 180.0 5.0 450.0										**LAT/LON1/LON2/DLON/H**					
657	668	669	664	660	659	657	648	623	585	542	507	485	474	469	466
461	456	449	439	424	404	378	351	330	321	328	347	376	406	430	438
425	396	361	330	304	280	256	233	218	213	216	220	221	214	202	187
173	161	154	158	174	201	231	256	270	277	285	300	320	341	360	374
385	397	419	453	497	546	593	631	657							

Table (2): The baseline used in verification

Baseline		
From	To	Length (Km)
Borg-Alarab (Borg)	Alexandria (Alex)	49.05
Port-Said (Said)	Mansura (Mnsr)	94.47
Helwan	Mansura (Mnsr)	130.76
Borg-Alarab (Borg)	Mansura (Mnsr)	171.11

Helwan	Port-Said (Said)	179.51
Helwan	Borg-Alarab (Borg)	203.05
Port-Said (Said)	Alexandria (Alex)	229.05
Borg-Alarab (Borg)	Port-Said (Said)	264.98

A new algorithm based on Zero-differenced phase Ionospheric Delay (ZDPID) was developed (Tawfeek et.al., 2018). The core of this algorithm is mainly dependant on computing the TEC values by using carrier phase and GPS phase ambiguity resolution model by using Sequential Least Square Adjustment. The proposed algorithm has been written using MATLAB code. The TEC values are computed for the aforementioned stations every epoch, 30 sec., then an average TEC values were computed every two hours similar to the GIM in IONEX file. The TEC values of the ZDPID with IONEX-IGS are depicted in figure (4). As is shown in figure (4), the TEC differences between the regional ZDPID values and the IONEX-IGS values exceed several tens of TEC units especially in the early morning with reduced values given at noon.

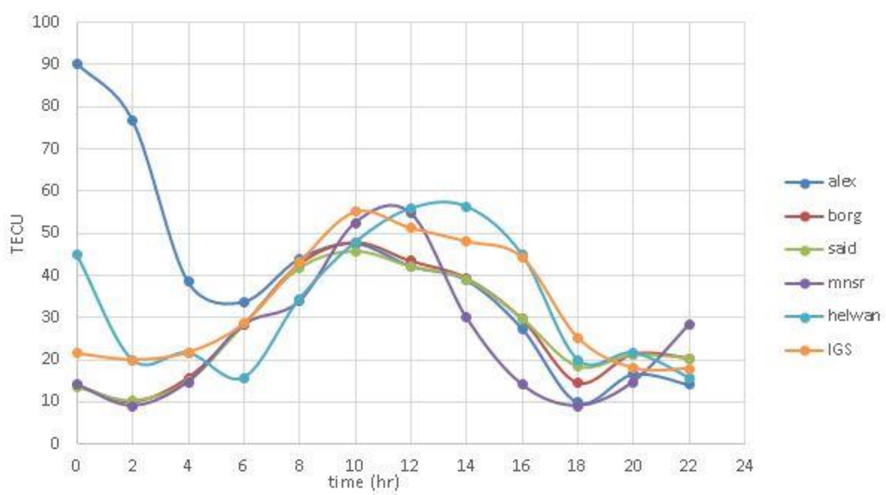

Figure (4): Mean TEC results every 2 hours of the study stations with comparison to IGS GIMs Day 105, 2015

Krankowski and Hernandez-Pajares (2016) confirmed that due to the shortage of GNSS stations in North Africa, the first GIM computation stage suffered from the hole existing in North Africa and over the Oceans, see figure (5). They deployed an optimum spatial-temporal interpolation technique to cover these holes. Based upon the above discussion, it is easy to confirm that the derived

Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2018-92
Manuscript under review for journal Ann. Geophys.
Discussion started: 30 August 2018

ionospheric TEC values derived from IONEX GIM products are not feasible and useless for use in precise positioning.

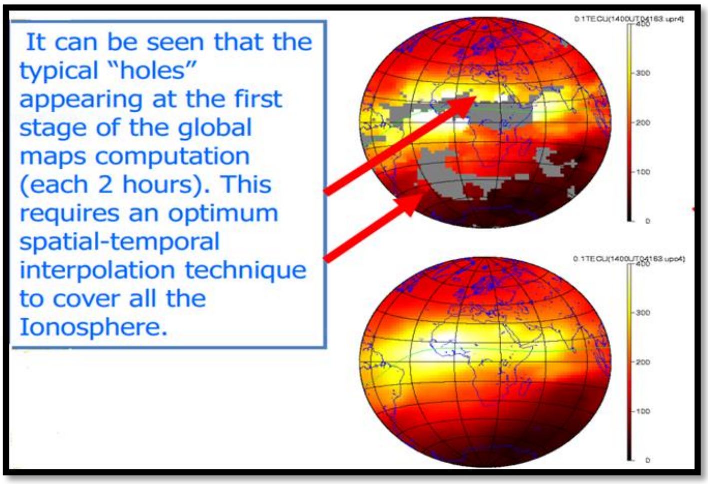

Figure (5): The holes of the GIM computation as indicated by (Krankowski and Hernandez-Pajares, 2016)

3.4 Modifying GIM-IONEX data

To modify the TEC data given in the IONEX file, the procedures described in the flow chart depicted in figure (6) were applied. Table (3) demonstrates a sample of the original TEC values as given in IONEX file and the modified values for Borg and Port Said stations at April 15, 2015. However, to see the validity of the computed regional Ionospheric TEC against the IONEX values, four baselines, namely Baseline Helwan ~ Mnsr 130.76 km, baseline Helwan ~ Said 179.51 km, baseline Helwan ~ Borg 203.16 km and baseline Borg ~ Said 264.98 km, were processed twice by TTC. The first processing was done without using any ionospheric correction and the second by using the modified IONEX files. The following chapter demonstrates the results of the processing of different baseline varying from 100 km to 270 km.

Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2018-92
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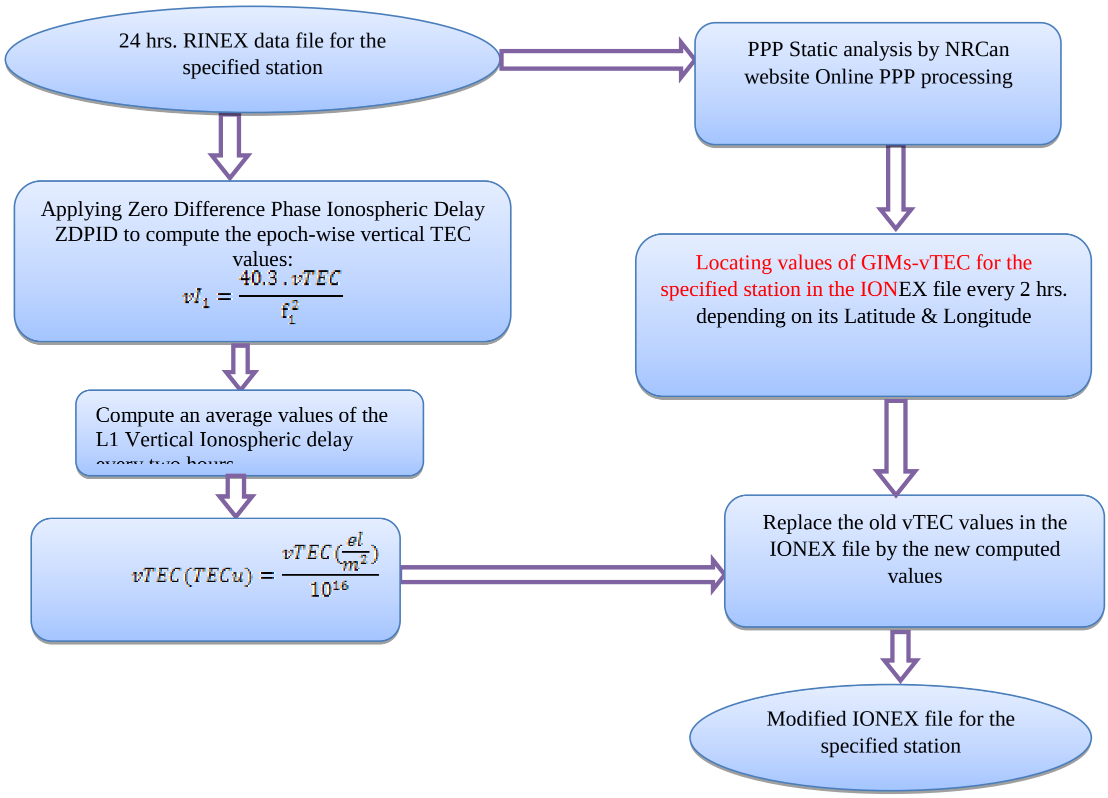

Figure (6): A description of the procedures that were used in modifying the VTEC values in the IONEX file.

Table (3): A sample Modified TEC values in IONEX file for the specified area in Egypt

32.5-180.0 180.0 5.0 450.0												LAT/LON1/LON2/DLON/H			
153	136	130	133	146	168	197	231	269	308	342	369	389	403	413	423
435	445	456	471	491	512	532	544	548	545	540	540	545	550	552	549
544	539	546	562	580	586	577	551	516	478	444	415	387	363	343	327
313	296	278	266	263	269	274	271	258	239	223	216	216	218	222	227
232	237	240	239	232	217	196	173	153							

The original TEC values given by IONEX at April15, 2015

Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2018-92
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32.5-180.0 180.0 5.0 450.0 LAT/LON1/LON2/DLON/H

153	136	130	133	146	168	197	231	269	308	342	369	389	403	413	423
435	445	456	471	491	512	532	544	548	545	540	540	545	550	552	549
544	539	546	562	580	586	577	551	516	478	141	415	387	363	343	327
313	296	278	266	263	269	274	271	258	239	223	216	216	218	222	227
232	237	240	239	232	217	196	173	153							

The TEC values given by ZDPID program at April15, 2015 for MNSR

32.5-180.0 180.0 5.0 450.0 LAT/LON1/LON2/DLON/H

153	136	130	133	146	168	197	231	269	308	342	369	389	403	413	423
435	445	456	471	491	512	532	544	548	545	540	540	545	550	552	549
544	539	546	562	580	586	577	551	516	478	298	415	387	363	343	327
313	296	278	266	263	269	274	271	258	239	223	216	216	218	222	227
232	237	240	239	232	217	196	173	153							

The TEC values given by ZDPID program at April15, 2015 for Port-Said Station

4. Results and Discussion

The processing of the RINEX data was conducted using Trimble Total Control 2.7. The data were processed three times: the first run was performed by using the specified baselines data with normal default processing parameters, i.e. without using GIM. The second run was carried out using modified GIM and the third run was made using static precise point positioning for all 24-hours data of all stations to be used as a threshold reference values for comparison. The CSRS-PPP was deployed to give the required static solution for the specified stations, (Rabah et al., 2016). It should be borne that the two runs of TTC solutions were obtained without fixing the ambiguities i.e. float ambiguity solution. The TTC could not fix the ambiguities for the specified baselines. The discussion is therefore based on only how the Modified IONEX files provided with the TEC values computed by the ZDIPD algorithms improve the positioning.

The differences between the CRCS-PPP solution and the two TTC positioning solution were computed and are depicted in figures 7, 8, 9 & 10. Figures 7, 8, 9 and 10 show the position differences in easting, northing and ellipsoidal height between the computed static NRCan PPP and the kinematic epoch by epoch solution in case of normal default processing parameters (D.D) and with using modified IONEX values (D.D.M-GIM). Figure (7) demonstrates how the modified IONEX, Mod-GIM, improve the kinematic solution of the baseline Borg-Mansura with length of

Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2018-92
Manuscript under review for journal Ann. Geophys.
Discussion started: 30 August 2018

Annales Geophysicae Discussions
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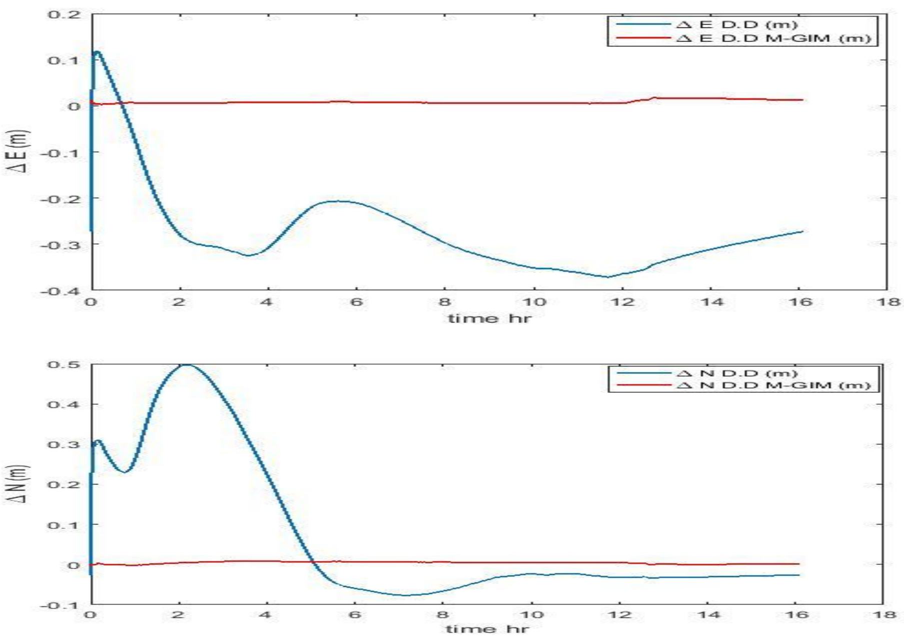
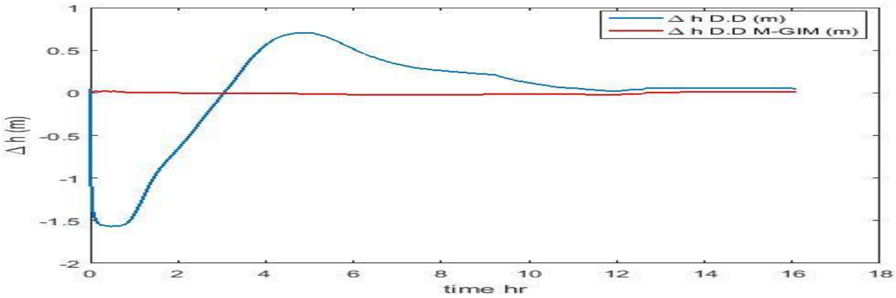
171.11 km. The differences between the two solutions were improved from (-37.11 & 11.89 cm) with RMSE 29.07cm to (0.33& 1.79 cm) and RMSE of 0.93 cm for Easting component, and for the northing component, the improvement ranged between the minimum value (-7.66 to -0.32 cm) and the maximum values was reduced from (49.71 to 0.81cm), with the RMSE improved from (19.40 cm to 0.5 cm). For the height components the differences were improved from (-156.74 & 70.55 cm) to (-2.20 & 2.00cm) with an improvement the RMSE from 54.61cm to 1.43cm.

Figure (8) shows the effect of the modified Ion TEC value on improving the three components of positioning of the baseline Helwan ~ Said of length 179.51 km. The figure depicts how the Ionospheric value improve the quality and the quantity of the three positioning components. Figure (9) demonstrates how the modified Ion TEC value improved the positioning solution of the Helwan ~ Borg baselines of length 203.16 km. Finally, as it is seen in figure (10), the three components of positioning of the baseline Borg ~ Said of length 264.98 km were improved.

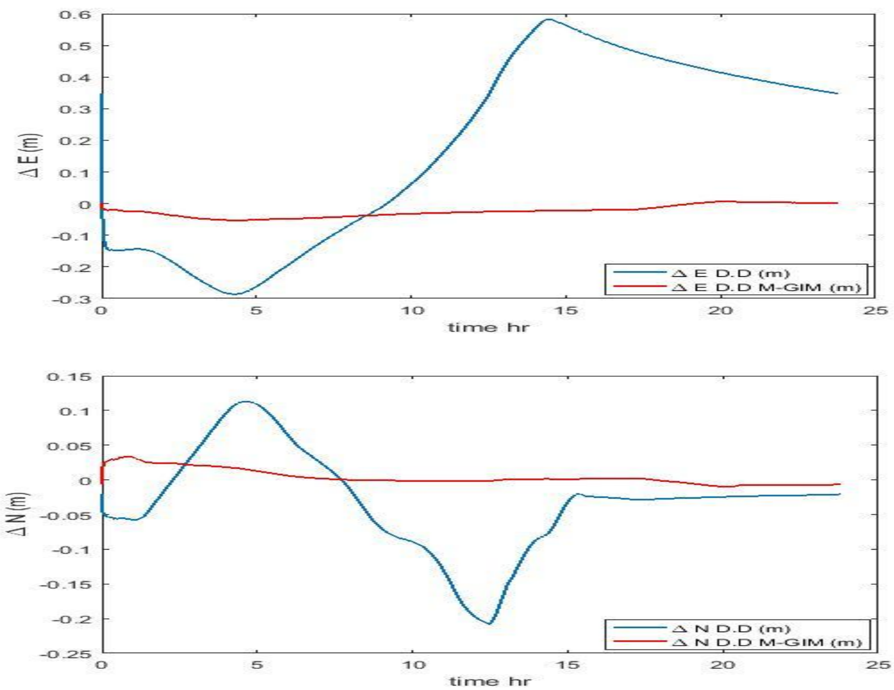


Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2018-92
Manuscript under review for journal Ann. Geophys.
Discussion started: 30 August 2018

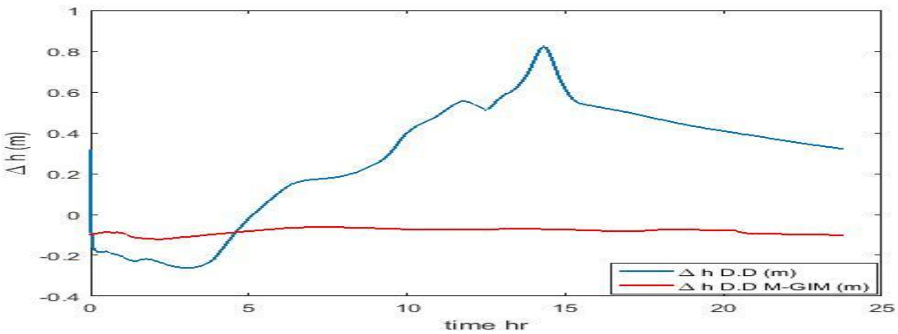


Statistical Item	Double Diff			Double Diff with Mod-IONEX		
	ΔE	ΔN	Δh	ΔE	ΔN	Δh
Min(cm)	-37.11	-7.66	-156.74	0.33	-0.32	-2.20
Max(cm)	11.89	49.71	70.55	1.79	0.81	2.00
Mean(cm)	-27.42	7.07	1.03	-0.84	0.42	-0.73
Rms(cm)	29.07	19.40	54.61	0.93	0.50	1.43

Figure (7): Positioning error with and without Mod. GIM in (East, North, Up) components between static PPP solution and relative kinematic positioning with Statistics for base line Borg~ Mnsr 171.11 km

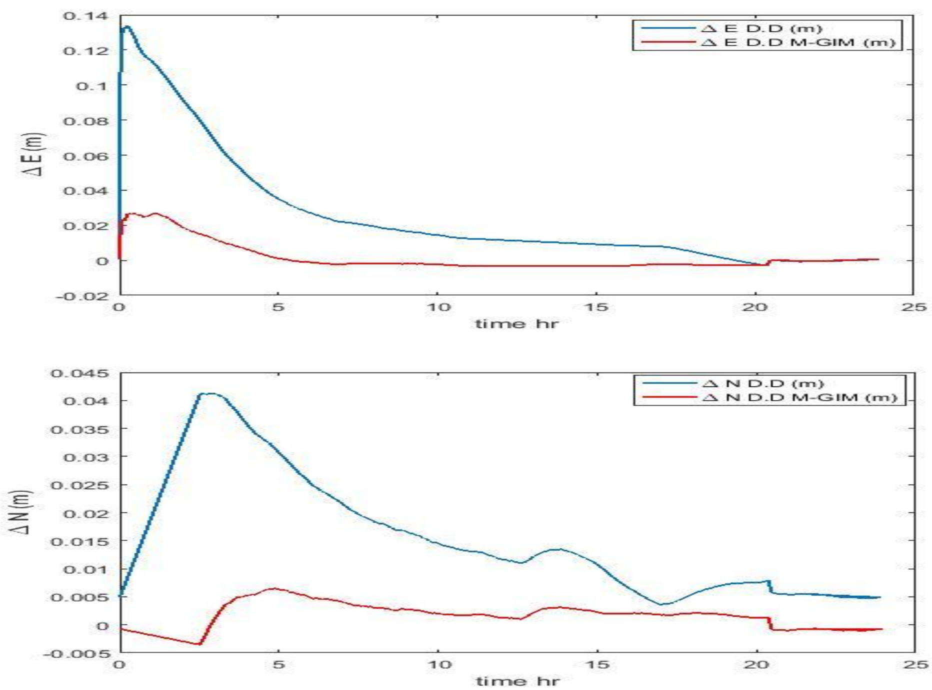


Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2018-92
Manuscript under review for journal Ann. Geophys.
Discussion started: 30 August 2018

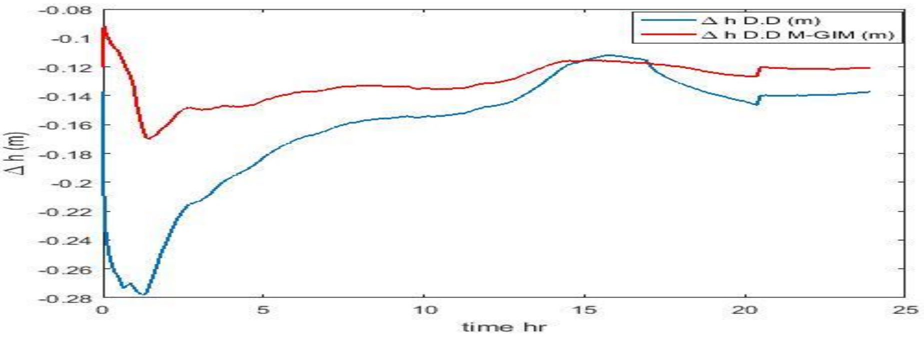


Statistical Item	Double Diff			Double Diff with Mod-IONEX		
	ΔE	ΔN	Δh	ΔE	ΔN	Δh
Min(cm)	-28.60	-20.80	-26.17	-5.26	-0.98	-12.10
Max(cm)	58.28	11.31	82.24	0.81	3.38	-6.25
Mean(cm)	17.00	-3.19	27.78	-2.42	0.38	-8.21
Rms(cm)	34.17	7.76	40.24	3.01	1.16	8.35

Figure (8): Positioning error with and without Mod-GIM in (East, North, Up) components between static PPP solution and relative kinematic positioning with Statistics for baseline Helwan ~ Said 179.51 km.

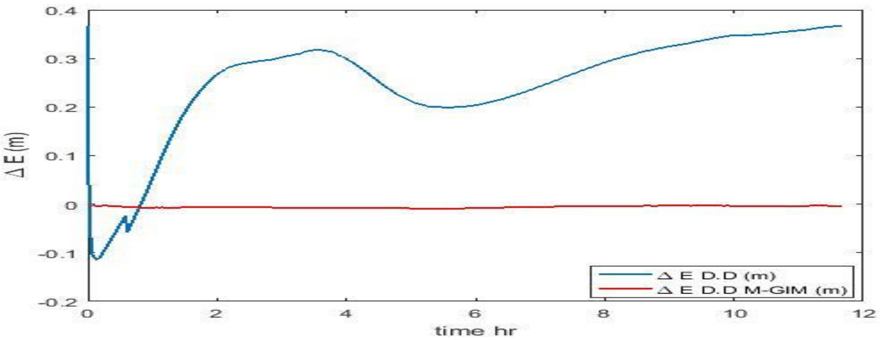


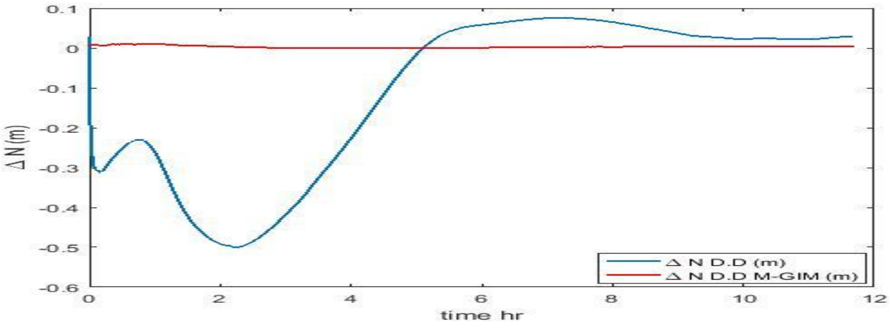
Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2018-92
Manuscript under review for journal Ann. Geophys.
Discussion started: 30 August 2018



Statistical Item	Double Diff			Double Diff with Mod-IONEX		
	ΔE	ΔN	Δh	ΔE	ΔN	Δh
Min(cm)	-0.30	0.36	-27.80	-0.30	-0.36	-17.00
Max(cm)	13.37	4.13	-11.21	2.68	0.64	-9.21
Mean(cm)	2.90	1.36	-16.05	0.30	0.18	-13.02
Rms(cm)	4.65	1.70	16.55	0.92	0.27	13.08

Figure (9): Positioning errors with and without Mod-GIM in (East, North, Up) components between static PPP solution and relative kinematic positioning with Statistics for baseline Helwan ~ Borg 203.16 km. 371 372 373





Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2018-92
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Annales Geophysicae Discussions
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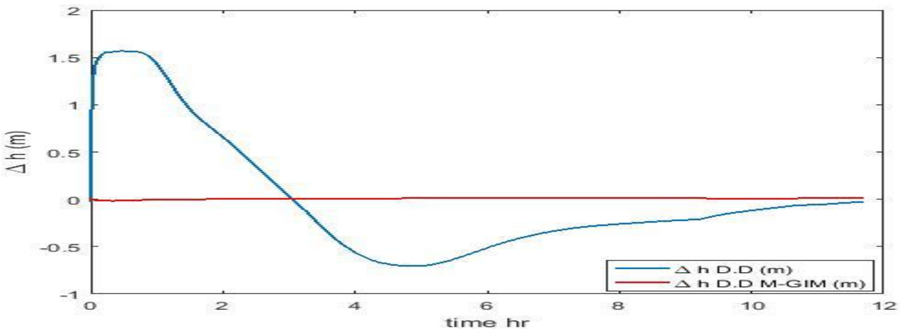

Statistical Item	Double Diff			Double Diff with Mod-IONEX		
	ΔE	ΔN	Δh	ΔE	ΔN	Δh
Min(cm)	-11.36	-50.09	-70.55	-0.88	-0.04	-1.72
Max(cm)	36.74	7.54	156.79	0.20	1.04	1.86
Mean(cm)	25.07	-11.01	0.43	-0.56	0.32	0.84
Rms(cm)	27.32	22.77	64.04	0.59	0.42	1.13

Figure (10): Positioning error with and without Mod-GIM in (East, North, Up) components between static PPP solution and relative kinematic positioning with Statistics for baseline Borg ~ Said 264.98 km.

5. Conclusions

The current paper evaluates the ionospheric correction by Global Ionospheric Maps, GIM, provided in (IONEX) files produced by International GNSS Services “IGS”. The evaluation is done based on investigating the effect of given GIM ionospheric correction on kinematic relative positioning solution. The evaluation has been performed on several baselines with different lengths in Egypt. Based upon the baselines processing results, the following conclusions can be drawn:

1. Due to the lack of GPS stations over the equatorial, North Africa and Atlantic in IGS network, the produced Global Ionospheric maps (GIMs) have poor effect for mitigating ionospheric error for precise positioning.
2. Evaluation of the TEC values in IONEX map by using estimated TEC values provided by Zero-differenced phase Ionospheric Delay (ZDPID) algorithm, a fruitful result is obtained for correcting ionospheric error over kinematic solution of many baseline lengths up to 265 km.
3. Most commercial software's such Leica Geo-Office, Trimble Total Control, Trimble Business Center failed to obtain accurate results for the kinematic solution of baseline lengths over 300 km.

Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2018-92
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