Evaluating the Egyptian HARN Network by GNSS Precise Point Positioning "PPP"

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Abstract:

One of the fundamental goals of geodesy is to precisely define positions of points on the surface of the Earth, so it is necessary to establish a well-defined geodetic datum for geodetic measurements and positioning computations. Recently, a set of the coordinates established by using GPS and referred to an international terrestrial reference frame could be used as a three-dimensional geocentric reference system for a country. Based on this modern concept, in 1992, the Egypt Survey Authority (ESA) established two networks. The first net is called High Accuracy Reference Network (HARN) and consisted of 30 stations, 200 km spacing. The second network was established to cover the cultivated areas (Nile Valley and Delta) so it is called the National Agricultural Cadastral Network (NACN) with spacing 30 to 40 km. To transfer the International Terrestrial Reference Frame to the HARN, the HARN was connected with four IGS stations. The processing results were 1:10,000,000 (Order A) for HARN and 1:1,000,000 (Order B) for NACN relative network accuracy standard between stations defined in ITRF1994 Epoch 1996.

To evaluate the HARN & NACN, a co-joint team from NRIAG and Mansura University observed the available HARN & NACN stations in the Nile Delta. The Processing of the tested part was done by CSRS-PPP Service based on utilizing Precise Point Positioning "PPP" and Trimble Business Center "TBC". The study shows the feasibility of Precise Point Positioning in updating the absolute positioning of the HARN network and its role in updating the reference frame (ITRF). The study also confirmed the necessity of the absent role of datum maintenance of Egypt networks.

Keywords: ITRF, PPP, Geodetic Datum, HARN, DGPS, IGS, Transformation Parameters.

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1 INTRODUCTION

In space geodetic positioning, where the observation techniques provide absolute positions with respect to a consistent terrestrial reference frame, the corresponding precise definition and realization of terrestrial and inertial reference systems is of fundamental importance. Thanks to significant improvements in receiver technology, to extension and densification of the global tracking network along with more accurate determination of positions and velocities of the tracking stations and to dramatically improved satellite orbits, GPS is today approaching 0.1 ppm precision for longer baselines and it can be considered to be the main global geodetic positioning system providing nearly instantaneous three-dimensional position at the cm accuracy level. One of the fundamental goals of geodesy is to precisely define positions of points on the surface of the Earth, so it is necessary to establish a well-defined geodetic datum for geodetic measurements and positioning computations. Recently, a set of the coordinates established by using GPS and referred to an international terrestrial reference frame could be used as a three-dimensional geocentric reference system for a country [1].

In the classical sense, a geodetic datum is a reference surface, generally an ellipsoid of revolution of adopted size and shape, with origin, orientation, and scale defined by a geocentric terrestrial frame. Once an ellipsoid is selected, coordinates of a point in space can be given in Cartesian or geodetic (curvilinear) coordinates (geodetic longitude, latitude, and ellipsoid height).

Two types of geodetic datum can be defined namely a static and kinematic geodetic datum. A static datum is thought of as a traditional geodetic datum where all sites are assumed to have coordinates which are fixed or unchanging with time. This is an incorrect assumption since the surface of the earth is constantly changing because of tectonic motion. Static datum does not incorporate the effects of plate tectonics and deformation events. Coordinates of static datum are fixed at a reference epoch and slowly go out of the date, need to change periodically which is disruptive.

Datum's can either become fully kinematic (dynamic), or semi-kinematic. A deformation model can be adopted to enable ITRF positions to be transformed into a static or semi-kinematic system at the moment of position acquisition so that users do not see coordinate changes due to global plate motions. GNSS devices which use ITRF or closely aligned systems position users in agreement with the underlying kinematic frame, however, in practice there are a number of very significant drawbacks to a kinematic datum. Surveys undertaken at different epochs cannot be combined or integrated unless a deformation model is applied rigorously, or is embedded within the data, and the data are correctly time-tagged. On the other hand, Semi–Kinematic datum incorporates a deformation model to manage changes (plate tectonics and deformation events). Coordinates fixed at a reference epoch, so the change to coordinates is minimized. Many countries and regions which straddle major plate boundaries have adopted a semi-kinematic (or semi-dynamic) geodetic datum in order to prevent degradation of the datum as a function of time due to ongoing crustal deformation that is occurring within the country.

High precision GNSS positioning and navigation is very rapidly highlighting the disparity between global kinematic reference frames such as ITRF and WGS84, and traditional static geodetic datum. The disparity is brought about by the

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increasingly widespread use of PPP and the sensitivity of these techniques to deformation of the Earth due to plate tectonics. In order for precision GNSS techniques to continue to deliver temporally stable coordinates within a localized reference frame.

2. Transformation Parameters Terrestrial Reference Systems "TRS"

Transformations from kinematic ITRF to a static datum are conventionally done by either using the site velocity (measured directly or computed from a plate motion model) to compute the displacement between the reference and current epochs or by a conformal transformation augmented with time dependent parameters to account for rigid plate motion. Rigid Plate movement is conventionally defined by a rotation rate about an Euler Pole Φ, Λ and ω, where Φ, Λ are the latitude and longitude of the pole, and ω is the rate of rotation of the plate around the pole in degrees per million years. Equivalent rotation rates about the Cartesian axes (Ω_X, Ω_Y and Ω_Z) can be computed from the Euler pole definition using equations (1-3) (Φ,Λ, and ω) are first converted from decimal degrees to radians)[2]:

$$\Omega_X = \cos(\Phi)\cos(\Lambda)\,\omega \qquad (1)$$

$$\Omega_Y = \cos(\Phi)\sin(\Lambda)\,\omega \qquad (2)$$

$$\Omega_Z = \sin(\Phi)\omega \qquad (3)$$

A site velocity in Cartesian format ($X^{\cdot}$, $Y^{\cdot}$, $Z^{\cdot}$) can be computed for any given location (X, Y, Z in meters) on a rigid plate defined by (Ω_X, Ω_Y, Ω_Z) in radians per million years) using:

$$\begin{bmatrix} X^{\cdot} \\ Y^{\cdot} \\ Z^{\cdot} \end{bmatrix} = \begin{bmatrix} \Omega_Y Z - \Omega_Z Y \\ \Omega_Z X - \Omega_X Z \\ \Omega_X Y - \Omega_Y X \end{bmatrix} .\, 1\text{E-}6 \qquad (4)$$

By introducing a reference epoch t_0 and an epoch of measurement t (epochs in decimal years), the ITRF coordinates of any point on a rigid plate at a reference epoch (X_0,Y_0,Z_0 in meters) can be computed from the coordinates at epoch t (X_t, Y_t , Z_t in meters) using:

$$\begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} = \left[\begin{bmatrix} X_t \\ Y_t \\ Z_t \end{bmatrix} + \begin{bmatrix} \Omega_Y Z_t - \Omega_Z Y_t \\ \Omega_Z X_t - \Omega_X Z_t \\ \Omega_X Y_t - \Omega_Y X_t \end{bmatrix} .\, (t_0 - t) 1\mathrm{E} - 6 \right] \qquad (5)$$

For any location on a rigid plate, instantaneous ITRF coordinates can be transformed to a fixed reference epoch using equation (5-18) (**Stanaway and Roberts, 2009).**

$$\begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} = \begin{bmatrix} T_X \\ T_Y \\ T_Z \end{bmatrix} + S.\left[\begin{bmatrix} X_t \\ Y_t \\ Z_t \end{bmatrix} + \begin{bmatrix} \Omega_Y Z_t - \Omega_Z Y_t \\ \Omega_Z X_t - \Omega_X Z_t \\ \Omega_X Y_t - \Omega_Y X_t \end{bmatrix} .\, (t_0 - t)/1000000 \right] \qquad (6)$$

Where:

- (X_0, Y_0, Z_0): are the ITRF Cartesian coordinates at the reference epoch t_0 (in decimal years),
- (X_t, Y_t, Z_t): are instantaneous ITRF Cartesian coordinates at epoch t (epoch in decimal years),
- (T_X, T_Y, T_Z): is the translation of the reference frame origin (from ITRF to local system),
- $(\Omega_X, \Omega_Y, \Omega_Z)$: are the Cartesian rigid plate/block rotation parameters, is the reference frame
- S: is scale factor (from ITRF to local).

The African continent is broadly divided into two major tectonic plates. Most of Africa, west of the East African Rift lies on the Nubian Plate. The Somalian Plate lies east of the African Rift. A very small section of North Africa along the Maghreb coast in Algeria and Morocco lies on the Eurasian Plate and the Dankalia region of Eritrea lies on the Arabian Plate.

Analysis of the ITRF2005 solution [3]; [4] indicates that ITRF site velocities for any location within Africa are between 24 and 31 mm/yr due to rigid motion of the African plates over the underlying mantle. These site velocities degrade the accuracy of absolute positions like PPP if the measurement epoch is misinterpreted as a reference epoch for the underlying datum realization in use at the time Equations (1, 2 and 3) were used to compute(Ω_X, Ω_Y, Ω_Z) for the Nubian Plate using the Euler parameters determined by ITRF2008 PMM "Plate Motion Model" [5], the results were depicted in table (1).

Table (1): The Cartesian angular Velocity of Nubian Plate

Deformation Model	**Absolute Pole Cartesian angular Velocity for Nubian Plate**		
	Ω_X (Rad/Ma)	**Ω_Y (Rad/Ma)**	**Ω_Z (Rad/Ma)**
ITRF2008-PMM	0.000461	-0.00290	0.003506

3. PPP Solution

PPP has received increased attention in the past several years within the GPS community due to its great operational flexibility and accuracy promise. The major advantages of PPP lie in two aspects: system simplicity at the user's end and global consistency in terms of positioning accuracy. PPP-based approach significantly reduces the equipment and personnel costs, pre-planning, and logistics compared to conventional GPS network-based approaches. Applying PPP, a single survey team can establish a CORS network across a PPP has received increased attention in the past several years within the GPS community due to its great operational flexibility and accuracy promise [6].

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Measurements from the IGS global tracking network are processed by the IGS Analysis Centers to provide the highest quality satellite orbit and clock parameters. These parameters are freely available from the Internet and are the basis for PPP development. These IGS products can be applied to significantly reduce the errors in GPS satellite orbits and clocks, which are two of the most significant error sources in GPS positioning. Combining precise satellite positions and clocks with a dual frequency GPS receiver to remove the first order effect of the ionosphere, PPP is able to provide position solutions at centimeter level. Coordinates estimated with PPP will

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be in the same global reference frame as the satellite orbits. When using orbits from IGS, estimated receiver coordinates are referred to the IGS realization of ITRF.

Last decades several PPP post-processing software have been developed based on the above observation models. Also online web services from different organizations such as the Precise Point Positioning Software Center (**http://gge.unb.ca/Resources/PPP/index.htm**) which has been created under the auspices of the Canadian Geomatics for Informed Decisions Network of Centers of Excellence provides users easy access to online PPP services as CSRS-PPP by Natural Resources Canada (NRCan),GPS Analysis and Positioning Software (GAPS) by University of New Brunswick (UNB), Automatic Precise Positioning Service(APPS) by Jet Propulsion Laboratory (JPL), and magic GNSS by GMV (privately owned technological business group).

EVALUATING THE PPP SOLUTION

The solution of CSRS-PPP SW is now used extensively to provide realizations of ITRF globally with a precision of a few centimeters. Four groups of data from IGS stations, namely MALI (Malindi, Kenya) on the Somalian plate, RABT (Moracco) on the Nubian plate, RAMON (occupied Palestine) on the Arabian plate and NICO (Nicosia, Cyprus) on the Eurasian plate, distributed over the different sub-plates of Africa and their positioning was computed and published by the IGS data centers at ITRF 2008 Epoch2005 and given in table (2). The data of the four groups of IGS stations was downloaded from **ftp://garner.ucsd.edu/pub/rinex/2015/100/ for Day 100, 2015** and processed using the Precise Point Positioning module of CSRS-PPP. To transfer the IGS published coordinates from Epoch2005, as: t_0= 2005, to the epoch of the PPP solutions, ITRF 2008 Epoch2015.274 as t, Epoch2015.274, the following formula [7], is used:

$$P(t_0) = P(t) + \dot{P}(t_0 - t) \qquad (7)$$

Where:

$P(t_0)$ = is the positioning at a reference epoch ITRF 2008 Epoch 2005

$P(t)$ = is the positioning value at time t, defined by PPP at epoch 2015.274

$\dot{P}$ = Velocity

The transferred coordinates of the four IGS stations defined in ITRF2008 Epoch 2015.274 are tabulated in table (3) as computed by IGS **http://itrf.ign.fr/.**

To see how the PPP can be used in updating the ITRF of the IGS points, the solution of PPP with the transferred published IGS ITRF2008 at Epoch 2015.274 are given in table (4). The differences between two solutions are computed and outlined in table (4). As it is shown in the table, the absolute value of the maximum differences does not exceed 17mm for the Y component of Nico Station, while does not exceed few mm for the other stations.

By comparing the differences of the two solutions for the four IGS stations, one can easily see that, how the PPP is precise in expressing the epochwise solution of the ITRF frame.

Additionally to see for what extent PPP can be an alternative for the differential techniques, seven test points were processed by Trimble Business Center "TBC" Software, the product of Trimble, with considering the PPP solution of PHLW as a reference station for the processing. The results of the processing were demonstrated in table (5).

As it is shown in table (5), one can easily see the quality of PPP solution compared with the DGPS solution. In spite of the processed baselines are exceed several tens of kilometers to 120 km, PPP shows good harmony with the DGPS in mm level except the station 0Z20 which has differences of 2.3 to 3.2 cm that may be it has the longest baseline as well as it gives the worst accuracy of PPP that is may become from the surrounding environments around the station.

4 THE EVALUATION STUDY

In 1992, an ESA steering committee developed a plan for the creation of new datum for Egypt, with the following approach [8]:

- First, observe approximately 30 stations at approximately 200 km interval, covering all of Egypt, creating a High Accuracy Reference Network (HARN). Both high absolute and relative accuracies are required for these stations.
- Second, establishing the Notational Agricultural Cadastral Network (NACN) relative to these 30 stations, covering the green area of Egypt (Nile Valley and the Delta) at 30-40 km intervals. This station spacing was selected to allow for further densification with single frequency receivers, see figure (1).
- Third, densify this network at a station spacing of approximately 5 km for use as cadastral control at the governorate level.
- Finally, replace the existing Egyptian Mercator grid with a new modified UTM coordinate system.

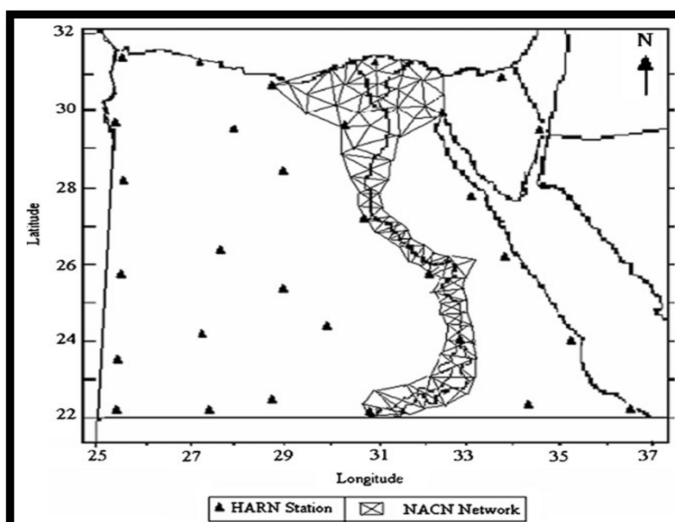

Figure (1): The HARN & NACN Networks

Table (2): ITRF2008 Station Positions at Epoch 2005.0 and Velocities

DOMES	SITE	X/Vx	Y/Vy	Z/Vz	Sigmas		
		---------------------m/m/y---------------------					
35001M002 Rabat	RABT	5255617.683	-631745.687	3546322.552	0.001	0.001	0.001
35001M002		-0.0088	0.0174	0.0142	0.001	0.000	0.0001
33201M001 MALINDI	MALI	4865366.354	4110737.599	-331121.569	0.001	0.001	0.001
33201M001		-0.0172	0.02	0.0167	0.001	0.0001	0.0000
20703S001 Mitz. RAMON	RAMO	4514721.855	3133507.841	3228024.716	0.001	0.001	0.001
20703S001		-0.0205	0.0141	0.0177	0.001	0.0001	0.0001
14302M001 NICOSIA Ath.	NICO	4359415.713	2874117.066	3650777.829	0.001	0.001	0.001
14302M001		-0.0179	0.0116	0.0126	0.001	0.0001	0.0001

**Table (3): DATA SET EXPRESSED IN ITRF2008 FRAME
STATION POSITIONS AND VELOCITIES AT EPOCH 2015/04/10**

DOMES NB	SITE NAME	ID	SOLN	X	Y	Z	SIGMA x	SIGMA y	SIGMA z
35001M002	RABAT	RABT	1	5255617.683	-631745.687	3546322.552	0.001	0.001	0.001
33201M001	MALINDI	MALI	1	4865366.177	4110737.805	-331121.398	0.001	0.001	0.001
14302M001	NICOSIA-ATHALASSA	NICO	1	4359415.525	2874117.189	3650777.949	0.001	0.001	0.001
20703S001	Mitzpe Ramon	RAMO	1	4514721.645	3133507.986	3228024.898	0.001	0.001	0.001

Table (4): the updated positioning for four IGS stations defined in ITRF2008 epoch 2015.274 by IGS & PPP

	Sol. Type	X	Y	Z
Rabat	**PPP- Solution**	5255617.590	-631745.508	3546322.700
	IGS-Solution	5255617.593	-631745.508	3546322.698
	Differences	-0.003	0.000	0.002
Mali	**Sol. Type**	X	Y	Z
	PPP- Solution	4865366.174	4110737.798	-331121.393
	IGS-Solution	4865366.177	4110737.805	-331121.398
	Differences	-0.003	-0.007	0.005
Nico	**Sol. Type**	X	Y	Z
	PPP- Solution	4359415.522	2874117.172	3650777.950
	IGS-Solution	4359415.525	2874117.189	3650777.949
	Differences	-0.003	-0.017	0.001
Ramo	**Sol. Type**	X	Y	Z
	PPP- Solution	4514721.636	3133507.978	3228024.886
	IGS-Solution	4514721.641	3133507.982	3228024.891
	Differences	-0.005	-0.004	-0.005

Table (5): The differences between DGPS & PPP solutions for the observed Stations

St.	DGPS Sol.			PPP Sol.			Differences bet DGPS & PPP		
	X	Y	Z	X	Y	Z	dX	dY	dZ
PHLW	**4728141.180**	**2879662.608**	**3157147.159**	**4728141.180**	**2879662.608**	**3157147.159**	**0.000**	**0.000**	**0.000**
0Z18	**4657081.787**	**2807150.058**	**3322370.152**	**4657081.784**	**2807150.059**	**3322370.156**	**0.003**	**-0.001**	**-0.004**
0Z20	**4796793.729**	**2651830.764**	**3250924.993**	**4796793.697**	**2651830.738**	**3250924.970**	**0.032**	**0.026**	**0.023**
0Z89	**4745737.252**	**2795140.347**	**3205858.805**	**4745737.246**	**2795140.341**	**3205858.797**	**0.006**	**0.006**	**0.008**
0Z94	**4739314.560**	**2828743.551**	**3186027.207**	**4739314.553**	**2828743.544**	**3186027.199**	**0.007**	**0.007**	**0.008**
Burg	**4765954.276**	**2704546.183**	**3252949.202**	**4765954.269**	**2704546.174**	**3252949.193**	**0.007**	**0.009**	**0.009**
O1	**4728219.038**	**2879743.411**	**3156930.682**	**4728219.033**	**2879743.402**	**3156930.676**	**0.005**	**0.009**	**0.006**

The ITRF1994 was transferred to Egypt's HARN network by connecting it with four IGS stations, namely MATE (Italy), KIT3 (Uzbekistan), HART (South Africa) and MASP in (Canary Island). Each HARN's sta-

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tion was observed for six sessions, every session was 6 hours with 30 seconds epoch interval. The observation time was planned to produce 1:10,000,000 (Order A) for HARN and 1:1,000,000 (Order B) for NACN relative network accuracy standard between stations. The results of analyzing both of them were defined in ITRF1994 epoch 1996.

To see for what extent can the PPP be an alternative for the differential techniques and its impact in analyzing the geodetic applications that need an ultimate accuracy like the National High Accuracy Reference Networks, a critical example is given to demonstrate this study. The example is concerned with analyzing a part of Egypt HARN and NACN (National Agriculture Cadastre) Networks that is located in and around Nile Delta. The geometric location of this part is illustrated in figure (2) and the position of the aforementioned points as given in HARN analysis report [8] is depicted in table (6). Additionally, this section deals with the computing techniques that are used in transferring the terrestrial frame from epoch to epoch in to different frames.

Table (6): The coordinates of chosen points of the HARN and

ITRF 1994, epoch 1996 (Scott, 1997)			
Station	**X**	**Y**	**Z**
OZ94	4745737.755	2795140.173	3205858.575
OZ89	4739315.089	2828743.36	3186026.976
OZ18	4657082.606	2807149.887	3322369.803
OZ20	4796794.204	2651830.557	3250924.750

Three days campaigns were conducted in June 2015 from 3 to 6, to convert this part of HARN & NACN network in the most recent ITRF available frame at the epoch of observation campaigns, namely ITRF 2008 epoch 2015.422. However, we use the aforementioned approach, equation (7) in transferring the PPP solution of the specified part of HARN to the ITRF 2000 epoch 2000, utilizing the three parameters of Nubian plate as defined by ITRF2005-PMM [3].,

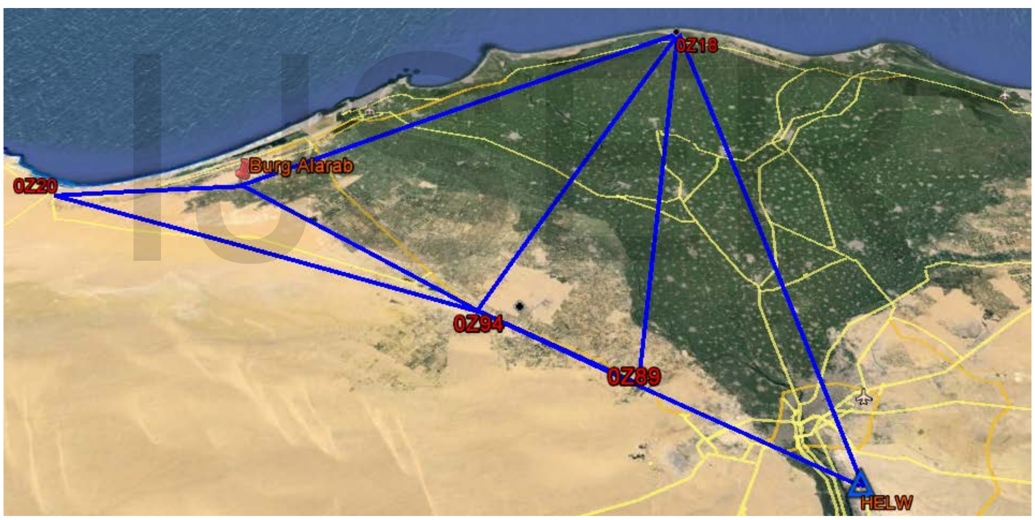

Figure (2): The location of the used part of Egypt HARN & NACN

Table (7): The Part of HARN & NACN network updated in ITRF2000

ST.	PPP Results Coordinate at Epoch 2015.422			Transformed PPP Coordinates at ITRF2008 Epoch 2005		
	X	Y	Z	X	Y	Z
PHLW	2879662.632	2879662.632	3157147.186	2879662.851	2879662.483	3157147.019
0Z18	4657081.784	2807150.059	3322370.156	4657082.003	2807149.91	3322369.989
0Z20	4796793.697	2651830.738	3250924.970	4796793.916	2651830.589	3250924.803
0Z89	4745737.246	2795140.341	3205858.797	4745737.465	2795140.192	3205858.63
0Z94	4739314.553	2828743.544	3186027.199	4739314.772	2828743.395	3186027.032
Burg	4765954.269	2704546.174	3252949.193	4765954.488	2704546.025	3252949.026
O1	4728219.033	2879743.402	3156930.676	4728219.252	2879743.253	3156930.509

The evaluation strategy is based upon:

A. Evaluating the IGS stations that were used in transferring the ITRF to HARN, by using their published ITRF2008 Epoch2015.422 coordinates values and the related transformation parameter to ITRF1994 Epoch1996 and compares the transferred values by the reported values of [7].

B. Transferring the values of HARN & NACN networks that were defined in ITRF2008 epoch 2005 to the original ITRF frame of HARN, namely ITRF1994 epoch 1996 and compare the resulted values with the original coordinate's values given by [8]. The aforementioned transformation is performed by exploiting the published 14 transformation parameters between different ITRF's Frames by IGS [9]. However, the transformation process from ITRF 2008 epoch 2015.422 to ITRF 1994 epoch 1996 will be performed in the following steps:
   1. Transforming the PPP values of HARN & NACN networks that defined in ITRF2008 epoch 2015.422 to ITRF2008 Epoch2005 using the published Absolute Pole Cartesian angular Velocity for Nubian Plate, as outlined before.
   2. Transferring the ITRF2008 Epoch2005 to ITRF1994 Epoch 2000 using the published parameters in table (8).
   3. Updating the values specified in the table (8) to be in Epoch 1996 instead of Epoch2000.
   4. Compute the differences

4.1 Evaluating the IGS Stations that was Used in Transferring the ITRF to HARN

Before digging into applying the above procedures, a check for the published transformation parameters are done. This step is so necessary to check the quality of the published data by IGS as well as to see the size of errors embedded in the stations that were used by [8] in transferring the ITRF1994 frame to Egypt's HARN, namely MATE (Italy), KIT3 (Uzbekistan), HART (South Africa) and MASP in (Canary Island). Table (9) depicts the coordinates of the four IGS stations defined in ITRF1994 Epoch 1996 as given by [8] and the published by IGS in ITRF2008, Epoch2005.

It was stated in http://itrf.ign.fr/rel_trs.php that the standerd relation of transformation between two reference systems is an Euclidian similarity of seven parameters : three translation components , one scale factor , and three rotation angles , designated respectively ,T_1, T_2, T_3, D, R_1, R_2, R_3, and their first times derivations : $\dot{T_1}$, $\dot{T_2}$, $\dot{T_3}$, $\dot{D}$, $\dot{R_1}$, $\dot{R_2}$, $\dot{R_3}$ .The transformation of coordinate vector X_1, expressed in a reference system (1), into a coordinate vector X_2, expressed in a reference system (2), is given by the following equation:

$$\boldsymbol{X_2 = X_1 + T + DX_1 + R\,X_1} \qquad (8)$$

With: $T = \begin{pmatrix} T_1 \\ T_2 \\ T_3 \end{pmatrix}$ and $R = \begin{pmatrix} 0 & -R_3 & R_2 \\ R_3 & 0 & -R_1 \\ -R_2 & R_1 & 0 \end{pmatrix}$

It is assumed that equation (7) is linear for sets of station coordinates provided by space geodetic technique (origin difference is about a few hundred meters, and differences in scale and orientation are of 10-5 level). Generally, X_1, X_2, T, D, R are function of time. Differentiating equation (7) with respect to time gives:

$$\boldsymbol{\dot{X_2} = \dot{X_1} + \dot{T} + \dot{D}\,X_1 + D\,\dot{X_1} + \dot{R}\,X_1 + R\,\dot{X_1}} \qquad (9)$$

D and R are of 10-5 level and $\dot{D}$ is about 10 cm per year, the terms $D\,\dot{X_1}$ and $R\,\dot{X_1}$ are negligible which represent about 0.0 mm over years. Therefore equation (9) could be written as:

$$\boldsymbol{\dot{X_2} = \dot{X_1} + \dot{T} + \dot{D}\,X_1 + \dot{R}\,X_1} \qquad (10)$$

Table (8): Transformation parameters Between ITRF2008 Epoch 2005 to ITRF 1994 Epoch 2000

SOLUTION UNITS……	T1 mm	T2 mm	T3 mm	D Ppb	R1 .001″	R1 .001″	R1 .001″	EPOCH
RATES UNITS……	**T1·** mm/y	**T2·** mm/y	**T3·** mm/Y	**D·** Ppb/Y	**R1·** .001″/Y	**R2·** .001″/Y	**R3·** .001″/Y	
ITRF94 rates	4.8 0.1	2.6 -0.05	-33.2 -3.2	2.92 0.09	0.00 0.00	0.00 0.00	0.06 0.02	2000

Table (9): The coordinate values of the IGS four stations in ITRF1994, Epoch 1996 and the published coordinate values for the nominated IGS stations in ITRF2008 Epoch2005

Station	ITRF2008 Epoch2005			ITRF1994 Epoch 1996 (as given by Scott, 1997)		
MATE	4641949.557	1393045.422	4133287.465	4641949.737	1393045.262	4133287.317
KIT3	1944945.139	4556652.244	4004326.007	1944945.390	4556652.199	4004325.973
HART	5084625.288	2670366.383	-2768494.401	5084625.460	2670366.404	-2768494.470
MAS1	5439192.215	-1522055.484	2953454.847	5439192.277	-1522055.641	2953454.694

The four stations in table (7) were transferred from ITRF2008 Epoch2005 to ITRF1994 Epoch2000 using the transformation parameters given in table (8) and equation (8). The results were demonstrated in table (10). Also the velocities of the specified IGS stations in ITRF1994 were also depicted in table (10).

To transfer the computed IGS coordinates from Epoch2000, as: t_0= 2000, to the epoch of the HARN solutions, ITRF 1994 Epoch1996 as t, equation (7) was used. The results of the transformation were given in table (11). To see the differences between the original coordinate values of the used IGS four stations as given by Scott (1997), defined in ITRF1994 Epoch1996, as outlined in table (7), the differences between the two ITRFs were computed and recorded in table (11). As it is shown in table (11), in spite of we have already used only in the previous processing the published values and models as specified by IGS, one can see a tolerance ranged between -8.6 cm to 14.6 cm. The reasons behind these differences are mostly returning to the limited number of stations, only 13 stations - see figure (3)-, that were used in realizing the ITRF94 that leads to sub-optimal stations distribution and small discontinuities between IGS realizations of ITRF, as clarified by [10].

4.2 Transferring the Solved PPP Part of HARN Network to the ITRF 1994 Epoch 1996

Firstly, transfer the tested part of HARN and NACN from ITRF2008 epoch2005, specified in table (5), to HARN ITRF1994 epoch 2000, with the aforementioned steps by using equation (8) and table (8). The computation results are given in table (11).

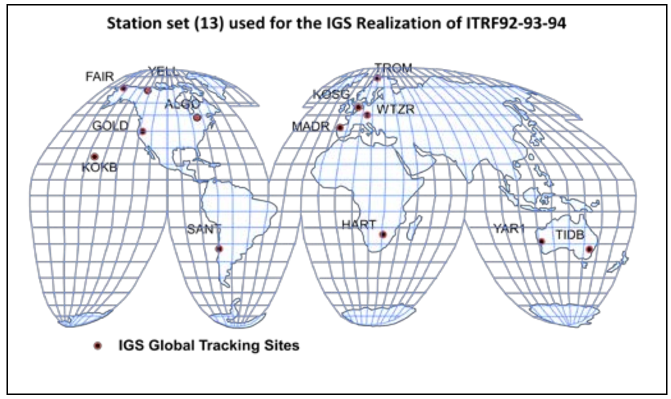

Figure (3): Station set (13) used for IGS Realization of ITRF 92-93-94

Table (10): The transferred coordinate values of the four stations to ITRF1994 Epoch2000

Station	ITRF1994 Epoch2000			Velocity m/y		
MATE	4641949.557	1393045.429	4133287.444	-0.019	0.020	0.012
KIT3	1944945.149	4556652.260	4004325.985	-0.028	0.016	0.006
HART	5084625.308	2670366.394	-2768494.442	-0.002	0.016	0.018
MAS1	5439192.236	-1522055.486	2953454.822	0.001	0.015	0.015

Table (11): The differences between the published coordinate values of the four IGS stations & the reported values by (Scott, 1997) in ITRF1994 Epoch1996

St.	ITRF1994 Epoch1996 transferred from IGS published values in ITRF2008 Epoch2005			ITRF1994 Epoch1996 as reported by Scott (1997)			Differences		
	X	Y	Z	X	Y	Z	dX	dY	dZ
MATE	4641949.633	1393045.348	4133287.396	4641949.737	1393045.262	4133287.317	0.104	-0.086	-0.079
KIT3	1944945.261	4556652.195	4004325.959	1944945.390	4556652.199	4004325.973	0.129	0.004	0.014
HART	5084625.314	2670366.328	-2768494.514	5084625.460	2670366.404	-2768494.470	0.146	0.076	0.044
MAS1	5439192.236	-1522055.548	2953454.761	5439192.277	-1522055.641	2953454.694	0.041	-0.093	-0.067

Table (11): The Results of Transformation the HARN to ITRF 1994 Epoch 1997

St.	PPP at ITRF2008 Epoch 2005			PPP at ITRF1994Epoch 2000		
	X	Y	Z	X	Y	Z
PHLW	4728141.399	2879662.459	3157146.992	4728141.418	2879662.470	3157146.968
0Z18	4657082.003	2807149.910	3322369.989	4657082.021	2807149.921	3322369.966
0Z20	4796793.916	2651830.589	3250924.803	4796793.935	2651830.599	3250924.779
0Z94	4745737.465	2795140.192	3205858.630	4745737.484	2795140.203	3205858.606
0Z89	4739314.772	2828743.395	3186027.032	4739314.791	2828743.406	3186027.008
Burg	4765954.488	2704546.025	3252949.026	4765954.507	2704546.036	3252949.002
O1	4728219.252	2879743.253	3156930.509	4728219.271	2879743.264	3156930.485

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To transfer the resulted coordinate's values of the tested part of HARN from ITRF1994 Epoch2000 to ITRF1994 Epoch 1996, there is a need to define the Nubian Plate Velocity in the same ITRF1994. Equation (10) can be used in computing the velocities of the Egyptian stations in ITRF1994, provided that the stations velocities should be defined in ITRF2008. This can be performed by applying equation (4) and table (4). The resulted velocities are represented in table (12). So the HARN stations can be converted to ITRF1994 Epoch1996, by using equation (7) and considering Epoch2000 as: t_0= 2000, and Epoch1996 as t = 1996. The results are depicted also in table (12). The differences between the reported part of HARN by Scott (1997) and the computed part based on PPP techniques and the IGS related transformation parameters and velocities defined in IREF1994 Epoch 1996 is displayed in table (13).

As it is shown in the table, the differences in X-component ranged from 34 to 37 cm, except 0Z18 that was partially destroyed, and Y-component ranged from -8 cm to -11 cm and for Z-component, the differences were ranged between -7 cm and -8 cm, except 0Z18. Finally, one can see that size of error budget that affects the original processing of Egyptian HARN network which stem from connecting parts of Egyptian HARN with four stations of IGS that were far away from EGYPT, namely HART, KIT3, MAS1 and MAT, forming very long baselines as depicted in figure (4). Also the errors in the definition of ITRF1994 itself, that was reached 7 to14 cm as computed in chapter 4.1. Additionally, within the plate boundary regions (e.g. in the vicinity of the African Rift and in the northern coastal areas) there will be inter-seismic deformation of up to a 3-4 mm/year which will not be modeled using a rigid plate transformation model [2].

5. Conclusions

To evaluate the performance of the PPP processing engine, several PPP tests on several African IGS station were performed to transfer them to ITRF2005 Epoch 2000 using three parameters kinematic rigid plate model and comprising the results of the IGS stations published IERS values in the same Epoch. The differences were just a few centimeters. The results confirm the usability of PPP with the kinematic rigid plate model in updating the frame.

By the aforementioned transformation parameters, the difference between the computed and the given original values computed by [8], in X-component ranged from 34 to 37 cm, and Y-component ranged from -8 to -11 cm and Z-component, the differences were ranged between -7 and -8 cm. As a closing conclusion for the overall results, one can say that PPP is the most feasible factor in performing datum maintenance by time and cost. The Egyptian HARN & NACN Networks need to update their frame, to be the most recent one either by PPP or traditional approach.

Table (12): The computed velocities and the transferred coordinate values to ITRF 94 Epoch 96 of the specified part of the Egyptian HARN

St.	Velocities at ITRF1994 m/y			PPP at ITRF1994Epoch 1996		
	VX	VY	VZ	X	Y	Z
PHLW	-0.0187	0.0149	0.0121	4728141.343	2879662.53	3157147.016
0Z18	-0.0190	0.0146	0.0119	4657081.945	2807149.979	3322370.013
0Z20	-0.0182	0.0151	0.0122	4796793.862	2651830.66	3250924.828
0Z94	-0.0186	0.0150	0.0121	4745737.409	2795140.263	3205858.655
0Z89	-0.0187	0.0149	0.0121	4739314.716	2828743.466	3186027.057
Burg	-0.0184	0.0150	0.0122	4765954.433	2704546.096	3252949.051
O1	-0.0187	0.0149	0.0121	4728219.196	2879743.324	3156930.533

Table (13): The Difference between the computed PPP HARN transferred to ITRF 94 Epoch 96 and the given values at the same epoch as computed by Scott (1997)

St.	**PPP Sol transferred to ITRF1994Epoch 1996**			**ITRF 1994, epoch 1996 (Scott, 1997).**			**Differences**		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**dX**	**dY**	**dZ**
0Z18	4657081.945	2807149.979	3322370.013	4657082.606	2807149.887	3322369.803	0.661	-0.092	-0.210
0Z20	4796793.862	2651830.660	3250924.828	4796794.204	2651830.557	3250924.75	0.342	-0.103	-0.078
0Z94	4745737.409	2795140.263	3205858.655	4745737.755	2795140.173	3205858.575	0.346	-0.090	-0.080
0Z89	4739314.716	2828743.466	3186027.057	4739315.089	2828743.36	3186026.976	0.373	-0.106	-0.081

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