Estimating the Cartesian Rotation Vector of Nubian Plate-ITRF08 by Using the Egyptian GPS Permanent Network

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ملخص البحث

حساب سرعات حركة النقاط على سطح الأرض يمثل اهمية كبرى فى معرفة الأحداثيات الصحيحة للنقاط الثابتة فى اى وقت حيث يتم حساب السرعات من خلال الرصد المتكرر للنقاط او باستخدام نماذج حساب السرعات التى تحسب للرقائق التكتونية المكونة للقشرة الأرضية. فى هذا البحث تم حساب نموذج السرعة للرقيقة التكتونية النوبية باستخدام عدد من النقاط الدائمة التى تمثل جزء من شبكة المعهد القومى للبحوث الفلكية والجيوفزيقية بمصر بحيث نحصل على نموذج سرعة يكون اكثر تمثيلا لمصر. قمنا فى هذا البحث بحساب نموذج السرعة لسنة 2011 و2013 على ITRF08 . تم عمل اختبار لهذة النماذج على نقاط الـ HARN ولكن بعد تحويل هذة النقاط من 1996.0 ITRF94 epochالى 1996.0 ITRF08 epoch حيث قمنا بحساب السرعات لهذة النقاط وكان اكبرفرق فى النتائج لهذين النموذجين فى حدود 0.2 cm ± وللحصول على نموذج سرعة افضل قمنا بأخذ متوسط النموذجين وتخليق نموذج السرعة المحلى لمصر وقمنا بحساب السرعات لنقاط الـ HARN وايضا النقاط الدائمة ومقارنة ذلك بالسرعات التى تم حسابها من نموذج السرعة للرقيقة المحسوب من IGS stations حيث كان اقصى اختلاف فى حدود 0.14cm±. من خلال النتائج يظهر لنا ان السرعة التى حصلنا عليها من معالجة ارصاد الـ GPS لأى نقطة من النقاط الدائمة تختلف من عام الى اخر بينما سرعة نفس النقاط التى حصلنا عليها من نموذج السرعة المحلى ثابتة لاتتغير وبالرغم من ذلك فأن قيمة متجة السرعة الناتج من معالجة ارصاد الـ GPS يقترب من القيمة الناتجة من نموذج السرعة المحلى كلما ذاد الفرق بين سنوات الرصد وهذا يظهر بوضوح فى نقطة الـ HARN (0Z17) حيث كان الفرق بين متجة السرعة المحسوب من معالجة ارصاد الـ GPS والمحسوب من نموذج السرعة فى فترة زمنية 17.14 عام هو 0.5 mm. لذلك قمنا بعمل برنامج يحتوى على نموذج السرعة المحلى مع معاملات التحويل بين ITRF94 and ITRF08 فى ايجاد احداثيات نقاط شبكة الـ HARN لأى epoch على ITRF 08.

Abstract

The fixed stations of a geodetic network are continuously changing, due to the change of its tectonic plate. When the instantaneous coordinates of the stations at any epoch are needed, the velocity of the stations should be known. The velocity of any station is determined by two techniques, firstly by using the time series of GPS observation and secondly by using the created velocity model of plate which obtained from the plate Cartesian rotation vector. In this research, using the available number of the permanent GPS stations made by the Egyptian National Research Institute of Astronomy and Geophysics (ENRIAG) to obtain the two velocity models of Nubian-plate ITRF2008 for year 2011 and 2013.

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Using the High Accuracy Reference Network (HARN) stations after transforming them from ITRF94 epoch 1996.0 into ITRF08 epoch 1996.0 to check the two local models by determining the velocities at all stations. The maximum difference in velocities between these models is found within ±0.2 cm. Therefore we took the mean of the two local models to create the best fit local velocity model. Additionally we used the HARN network and permanent GPS stations to assess the local velocity model with the velocity model of Nubian-plate ITRF08 which created by the IGS stations, the maximum difference between them is found within ±0.14cm.

From the results, the velocities obtained at all permanent stations by processing the time series of GPS observations are changing yearly while the velocity model gives constant velocity for each station yearly. Nevertheless, the velocity vector length which obtained by the local velocity model is closest to the velocity vector length which obtained by GPS processing when increasing the time difference between the GPS sessions , this is appear in HARN station (0Z17) where the difference in velocity vector length is 0.5 mm at 17.14 years. Finally we created a computer program to compute the HARN stations at any epoch on ITRF08 by using the local velocity model and the transformation parameters between ITRF94 and ITRF08.

Key words

Bernese GPS software version 5.0, Cartesian Rotation Vector of Nubian Plate-ITRF08, Precise Ephemeris (PE), International Terrestrial Reference Frame (ITRF), High Accuracy Reference Network (HARN), Velocity Model, and MATLAB software.

1. Introduction

Geodetic coordinates of points on the surface of tectonic plates change with time due to plate motion, and thus become dependent of the epoch in which the coordinates were obtained. If these elements (direction and magnitude) are known, it is possible to determine the change of the point coordinates as a function of time. Since the 1980's, GPS has provided an ideal technique for supporting this type of research, either for regional or global applications, because of the low cost equipment and high precision. The contribution of GPS to geodynamics was further developed with the implementation of the IGS (International GNSS Service) network, in 1994. Nowadays, there are more than 400 stations composing the IGS network, providing very important coordinate and monitoring information **[3].**

The main object of this research is monitoring the number of GPS permanent network stations made by the Egyptian National Research Institute of Astronomy and Geophysics by processing the observations of available GPS permanent stations on years (2011, 2012, 2013, 2014) and estimating the velocity for this network stations and computing the best fit angular velocity of the Nubian plate for Egypt to create the local velocity model which used to determine the velocity (Vx, Vy, Vz) at any fixed station inside Egyptian territory. To check the local velocity model, we compute the velocity of the HARN network and compare it with the velocity determined by the velocity model created by the published angular velocity of ITRF 2008 of Nubian plate. The velocity of stations is used in updating the static coordinates at reference epoch from any epoch when required on the same reference frame. Additionally we were using the velocities obtained by the time series of the Egyptian GPS permanent stations to assess the accuracy of the local velocity model.

The Egyptian High Accuracy Reference Network (HARN) was established in 1995 by the Egyptian Survey Authority (ESA) used for surveying and mapping activities. The HARN of Egypt is a static coordinates defined on International Terrestrial Reference Frame 1994 (ITRF94) at the reference epoch of 1 January1996 and consists of 30 stations with approximate separation of 200 km see figure (1) **[4].** The coordinates of the HARN stations are obtained from the published report prepared by **[16].** In this research we use the created local velocity model and the transformation parameters between the two reference frames to transform the HARN stations of Egypt from ITRF 94 epoch 1996.0 to ITRF08 at any epoch.

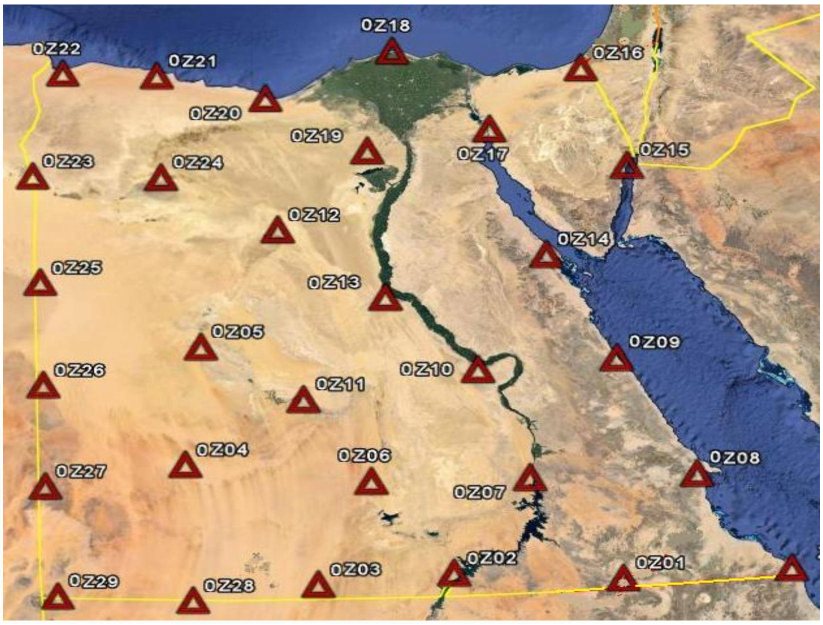

Figure (1): The Distribution of the HARN Stations in Egypt.

2. Study Area, and Data Sources

In this research, the local Cartesian rotation vector of Nubian Plate-ITRF2008 ($\omega x,\omega y,\omega z$) was accomplished by using the velocities data from six stations of the ENRIAG network of Egypt, see figure (2). This local Cartesian rotation vector ($\omega x,\omega y,\omega z$) is used to create the local velocity model, which used to compute the velocity of any reference station in Egypt.

Figure (2): Six GPS Stations of the Egyptian National Earthquakes Network.

The following data were collected for the computations:

- Precise satellite ephemeris (final orbits) data for GPS at all observation sessions.
- The published Cartesian rotation vector of Nubian Plate-ITRF2008 (ωx,ωy,ωz).

For all the following GPS observations days, we obtained the twenty-four hours GPS data in RINEX format for ELAT station (fixed station) and ELAT station coordinates by using the station velocity from International GNSS Service

- Twenty-four hours GPS data in RINEX format for the five stations PHLW, ASUT, MNSR, MARS and SAFG were obtained from ENRIAG at 20 January 2011 and 20 January 2012.
- Twenty-four hours GPS data in RINEX format for the SLUM station, obtained from ENRIAG at 01 January 2011 and 20 January 2012.
- Twenty-four hours GPS data in RINEX format for the three stations PHLW, MNSR and SLUM were obtained from ENRIAG at 20 January 2013 and 20 January 2014.
- Twenty-four hours GPS data in RINEX format for ASUT station, obtained from ENRIAG at 20 January 2013 and 01 January 2014.
- Twenty-four hours GPS data in RINEX format for the three stations PHLW, ASUT and SAFG were obtained from ENRIAG at 20 January 2007.
- GPS data in RINEX format for HARN station (0Z17) at 21 February 2013.

3. Crustal Motion

Station coordinates vary both continuously and episodically due to gradual plate tectonic motion, earthquakes, volcanos, landslides and other geodynamic processes. These motions are quantified by global plate tectonic models and local/regional crustal deformation or velocity models. To maintain centimeter or better accuracy station positions must be updated for the effects of crustal motion **[7].**

3.1 Plate Motions on a Sphere

- Euler theorem: the motion of a rigid body can be described by a translation + a rotation,
- On the Earth surface: translation = 0 => (rigid) plate motions are rotations about axis passing through the center of the Earth figure (3),
- Rotation fully described by:

– The location of the intersection of the plate rotation axis with the Earth's surface = rotation pole, or Euler pole [latitude, longitude]

– The angular velocity of the rotation about the pole **[10].**

Cartesian Rotation Vector Ω (ωx,ωy,ωz) is equivalent to Euler parameters (latitude λ, longitude φ, angular velocity a). The following two items illustrate how to obtain one from the other **[11].**

A- Euler to Rotation

$$\omega_x = a\cos(\lambda)\cos(\varphi) \quad (1)$$

$$\omega_y = a\cos(\lambda)\sin(\varphi) \quad (2)$$

$$\omega_z = a\sin(\lambda) \quad (3)$$

B- Rotation to Euler

$$\lambda = \tan^{-1}\left(\frac{\omega_z}{\sqrt{\omega_x^2 + \omega_y^2}}\right) \quad (4)$$

$$\varphi = \tan^{-1}\left(\frac{\omega_y}{\omega_x}\right) \quad (5)$$

$$a = \sqrt{\omega_x^2 + \omega_y^2 + \omega_z^2} \quad (6)$$

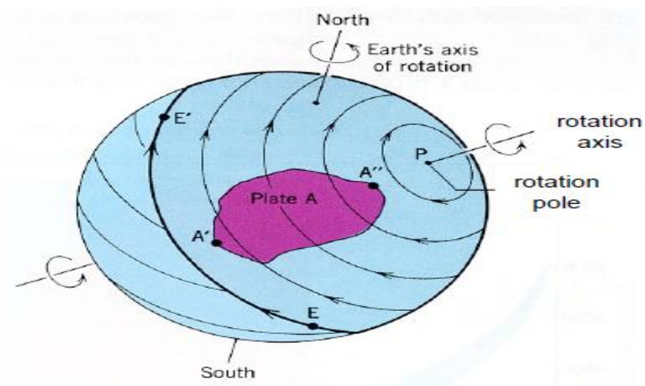

Figure (3): The Motion of a rigid Body (plate) on the Earth Surface ***[After, 10].***

3.2 Estimating Site Velocities

It is easiest to compute the site velocities if you have the plate's angular velocity vector, because the site velocity is just the cross product of the site location vector with the plate angular velocity **[13].**

GPS velocities, in a Cartesian geocentric frame, can be modeled as:

$$\vec{V} = \vec{\Omega} \times \vec{P} \qquad (7)$$

Where P(X,Y,Z) is the unit vector defining the position of the GPS site, V(Vx,Vy,Vz) is the velocity vector at that site, and Ω (ωx, ωy, ωz) is the rotation vector defining the motion of the plate carrying the site **[2].** The equation (7) can be written as the following equation (8) **[8].**

$$\begin{bmatrix} Vx \\ Vy \\ Vz \end{bmatrix} = \begin{bmatrix} \omega_y \cdot Z - \omega_z \cdot Y \\ \omega_z \cdot X - \omega_x \cdot Z \\ \omega_x \cdot Y - \omega_y \cdot X \end{bmatrix} \qquad (8)$$

3.3 Estimating Plate Angular Velocity

To get the angular velocity from site velocities, we need to invert the equation (7) **[13].** This cross product can be written in matrix form (9).

$$\begin{bmatrix} Vx_1 \\ Vy_1 \\ Vz_1 \\ \ldots\ldots \end{bmatrix} = \begin{bmatrix} 0 & Z_1 & -Y_1 \\ -Z_1 & 0 & X_1 \\ Y_1 & -X_1 & 0 \\ \ldots\ldots & & \end{bmatrix} \begin{bmatrix} \omega_x \\ \omega_y \\ \omega_z \end{bmatrix} \quad \text{OR} \quad V = A.\Omega \qquad (9)$$

Where V is the vector of observations, A is the model matrix, and Ω the vector of unknowns. The least-squares solution is then given by equation (10) **[2]**.

$$\Omega = (A^T A)^{-1} A^T V \qquad (10)$$

4. International Terrestrial Reference Frame (ITRF)

ITRF is a physical realization of the International Terrestrial Reference System (ITRS); it consists of number of physical points with precisely determined coordinates and velocities. It is realized by means of 4 space geodetic techniques GPS, Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR) and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). The 12 realizations have been produced by International Earth Rotation and Reference Systems Service (IERS) since 1988. One of the realized ITRF is ITRF 2008. ITRF2008 is based on reprocessed solutions from all 4 mentioned techniques. Data span of each technique used for ITRF2008 realization is given in table below **[14].**

Table (1): The Techniques Used for ITRF2008 Realization and Data Span ***[After, 14].***

Technique	Data Span	Solutions
VLBI	1980.0 - 2009.0	daily
SLR	1983.0 - 2009.0	weekly
GPS	1997.0 - 2009.5	weekly
DORIS	1993.0 - 2009.5	weekly

4.1 ITRF2008 Plate Motion Models

The ITRF2008 velocity field is demonstrated to be of higher quality and more precise than past ITRF solutions. The estimated an absolute tectonic plate motion model made up of 14 major plates, using velocities of 206 sites of high geodetic quality (far from plate boundaries, deformation zones and Glacial Isostatic Adjustment (GIA) regions), derived from and consistent with ITRF2008 see figure (4) and figure (5) **[12]**. The main criteria selection are (1) the velocity formal error is less than 0.5 mm/yr and (2) the post fit residuals should not exceed the threshold of 1.5 mm/yr for each site **[15]**.

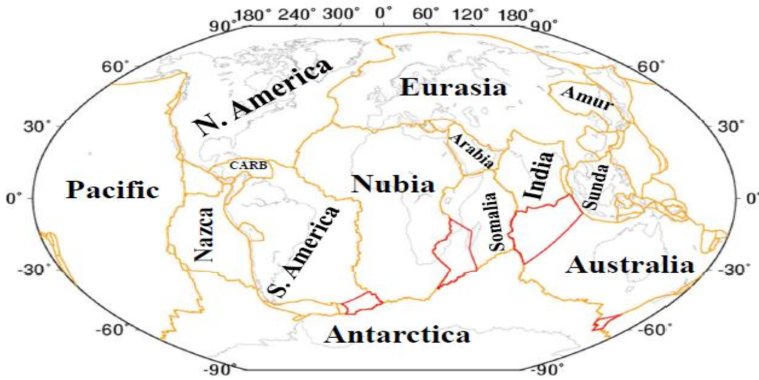

Figure (4): Plate Motion Model Estimated From ITRF 2008 ***[After, 1].***

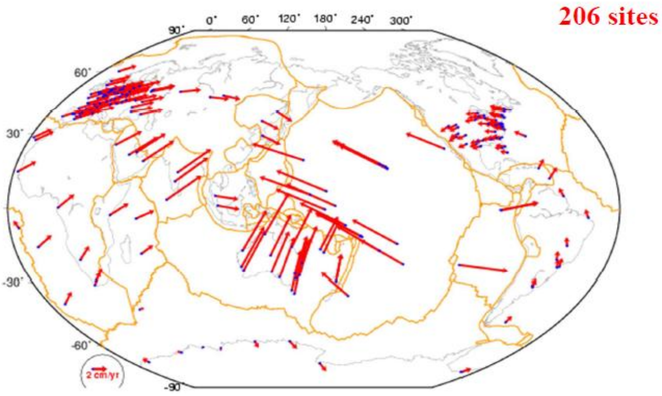

Figure (5): Site Velocities for ITRF2008 Plate Motion Model (ITRF2008-PMM) ***[After, 1].***

5. Coordinate Transformation Equations

There are two most common transformation equations used to transform between the two reference frames. These equations are illustrated in the following section.

5.1 7- Parameters Transformation Equations

Using the 7- Parameters transformation if both datum's in the transformation process are static, i.e. there is no change in point coordinates over time, then the 7 rate parameters would equal zero and the transformation would be the same at any epoch. The general form of the 7-parameters transformation model can be expressed in equation (11) **[5]**.

$$\begin{bmatrix} x_B \\ y_B \\ z_B \end{bmatrix} = \begin{bmatrix} d_x \\ d_y \\ d_z \end{bmatrix} + (1+s_c) \times \begin{bmatrix} 1 & r_z & -r_y \\ -r_z & 1 & r_x \\ r_y & -r_x & 1 \end{bmatrix} \times \begin{bmatrix} x_A \\ y_A \\ z_A \end{bmatrix} \qquad (11)$$

5.2 14- Parameters Transformation Equation

14-parameters, 7 parameters (three translations d_x,d_y,d_z, three rotations r_x, r_y, r_z, and one scale change s_c) define the relationship between two datums at a certain point in time, known as the reference epoch. The additional 7 parameters define the rate of change of these translations, rotations and scale change **[5]**. In this research, the equation (12) to transform between ITRF94 epoch 1996.0 and ITRF08 epoch 1996.0 is used because the two datums are dynamic or kinematic. Where [X_{ITRF08}, Y_{ITRF08}, Z_{ITRF08}] are the transformed ITRF2008 earth centered Cartesian coordinates (meters), [X_{ITR94}, Y_{ITRF94}, Z_{ITRF94}] are the input ITRF94 earth centered Cartesian coordinates (meters),d_x,d_y,d_z, $\dot{d}_x$, $\dot{d}_y$, $\dot{d}_z$ are translations and their rates (meters, meters/year), r_x, r_y, r_z, $\dot{r}_x$, $\dot{r}_y$, $\dot{r}_z$ are rotations and their rates (radians, radians/year) and s_c, $\dot{s}_c$, is a scale and its rate (scale, scale/year). The parameter $\mathbf{t_0}$ is 2000.0 it's refer to the reference epoch of 14-Parameter transformation published between two datums and **t** is the reference epoch of the input ITRF coordinates which is 1996.0. **[9].**

$$\begin{bmatrix} x_{ITRF08} \\ y_{ITRF08} \\ z_{ITRF08} \end{bmatrix} = \begin{bmatrix} d_x + \dot{d}_x \times (t - t_0) \\ d_y + \dot{d}_y \times (t - t_0) \\ d_z + \dot{d}_z \times (t - t_0) \end{bmatrix} + \{1 + s_c + \dot{s}_c \times (t - t_0)\} \times \tilde{R} \times \begin{bmatrix} x_{ITRF94} \\ y_{ITRF94} \\ z_{ITRF94} \end{bmatrix} \quad (12)$$

$$\tilde{R} = \begin{bmatrix} 1 & \{r_z + \dot{r}_z \times (t - t_0)\} & -\{r_y + \dot{r}_y \times (t - t_0)\} \\ -\{r_z + \dot{r}_z \times (t - t_0)\} & 1 & \{r_x + \dot{r}_x \times (t - t_0)\} \\ \{r_y + \dot{r}_y \times (t - t_0)\} & -\{r_x + \dot{r}_x \times (t - t_0)\} & 1 \end{bmatrix}$$

Table (2) represents the 14-transformation parameters between ITRF 2008 to ITRF 1994 at epoch 2000.0. We used the 7-rates for the transformation parameters between ITRF 2008 and ITRF 1994 to obtain the 7-transformation parameters at the epoch of the input ITRF94 coordinates, which is 1996.0 see table (3) and using these parameters to transform the input coordinates to ITRF08 at the same epoch of input coordinates.

Table (2): Illustrates the 14-Transformation Parameters between ITRF 2008 To ITRF 1994 at Epoch 2000.0 ***[After, 6]***.

t (year)	**d_x (meter)**	**d_y (meter)**	**d_z (meter)**	**r_x (as)**	**r_y (as)**	**r_z (as)**	**s_c (ppm)**
2000.0	-0.0048	-0.0026	0.0332	0	0	-0.06	-0.00292
Rate/year	-0.0001	0.0005	0.0032	0	0	-0.02	-0.00009

Table (3): Illustrates the 7-Transformation Parameters between ITRF 2008 To ITRF 1994 at epoch 1996.0.

t (year)	**d_x (meter)**	**d_y (meter)**	**d_z (meter)**	**r_x (as)**	**r_y (as)**	**r_z (as)**	**s_c (ppm)**
1996.0	-0.0044	-0.0046	0.0204	0	0	0.02	-0.00256

6. Practical Work

- ELAT fixed station is used for processing the observations of six GPS stations (PHLW, ASUT, MNSR, MARS, SAFG and SLUM) which we obtained in two years 2011 and 2012 by using Bernese software. The differences in coordinates (X,Y,Z) between the two years at all stations represent the velocities of these stations on 2011.

- ELAT fixed station is used for processing the observations of four GPS stations (PHLW, ASUT, MNSR and SLUM) which we obtained in two years 2013 and 2014 by using Bernese software. The differences in coordinates (X,Y,Z) between the two years at all stations represent the velocities of these stations on 2013.

- We used the least squares solution, see equation (10) by MATLAB software to compute the first local Cartesian rotation vector of Nubian Plate-ITRF2008 ($\omega x, \omega y, \omega z$) from using the velocities of the stations which obtained at years 2011 and compute the second local Cartesian rotation vector of Nubian Plate-ITRF2008 ($\omega x, \omega y, \omega z$) from using the velocities of the stations which obtained at 2013.

- Created the two local velocity models at 2011 and 2013 by using equation (8), from using the two local Cartesian rotation vector of Nubian Plate-ITRF2008 computed at 2011 and 2013.

- Using equation (11) to calculate HARN coordinates on ITRF08 at epoch 1996.0 which is the reference epoch for HARN on ITRF94. The 7-transformation parameters between two datums ITRF08 and ITRF94 are given in table (3).

- Compute the velocities (Vx, Vy, Vz) of HARN stations by using the two local velocity models to know the compatibility and proximity of the results.

- To obtain the best of the local Cartesian rotation vector in Egypt as more representative for the Cartesian rotation vector of Nubian Plate-ITRF2008 we need the velocities on long time series for the GPS stations. In this research, we took the mean of the local Cartesian rotation vector at year 2011 and year 2013 to obtain the best local Cartesian rotation vector and we created the mean local velocity model. The published Cartesian rotation vector of Nubian Plate-ITRF2008 is computed based on the number of years and different data as we mentioned earlier.

- We created the velocity model by using equation (8), from using the published Cartesian rotation vector of Nubian Plate-ITRF2008.

- We computed the velocities (Vx, Vy, Vz) for HARN stations and the Egyptian GPS stations by using the two velocity models (which created by mean local Cartesian rotation vector of Nubian Plate-ITRF2008 and created by the published Cartesian rotation vector of Nubian Plate-ITRF2008).

- To check the mean local velocity model, we subtracted the velocities of HARN stations and the Egyptian GPS stations which we obtained by using the velocity model created by using the published Cartesian rotation vector of Nubian Plate-ITRF2008 from the velocities of the same stations which obtained by the mean local velocity model.

- ELAT fixed station is used for processing the observations of three GPS stations (PHLW, ASUT and SAFG) which we obtained in year 2007 by using Bernese software.

- We compared between the velocities vector lengths computed at each Egyptian GPS station by subtracting the coordinates at each two years in the time series of GPS observations and the same velocities vector lengths computed by using the mean local velocity model.

- Using ELAT fixed station to process the station (0Z17) at 21 February 2013, this station is one of HARN network. The station name on the Old Egyptian Datum 1930 (OED -30) is A6.

- Determine the velocity of the station (0Z17) at each year by subtracting the transformed coordinate (X,Y,Z) obtained on ITRF 1994 at epoch 1996 to ITRF2008 epoch 1996 from the processing coordinate station on ITRF 2008 at epoch 2013.14 and divided this result on the difference of epoch.

- Finally, we created a computer program by the MATLAB software from using the transformation parameters between the two datums ITRF08 and ITRF94 on reference epoch 1996.0 see table (3) and the mean local velocity model to obtain the HARN stations coordinates at any epoch on ITRF 2008. The following is a computer program which created by the MATLAB software

```
Coord = Load ('c:/XYZ.txt');
X94 = Coord (:, 1);
Y94 = Coord (:, 2);
Z94 = Coord (:, 3);
%Transformation Parameters between ITRF 1994 and ITRF 2008 Epoch 1996
Tx=-0.0044;
Ty=-0.0046;
Tz=0.0204;
Sc=-2.56*10^-9;
Rx=0;
Ry=0;
Rz=9.696*10^-11;
%the Equation Which Using to Transformation
n= length(X94);
For i=1: n
X08 (i) = Tx + [(1+Sc) * X94(i)] + [Rz * Y94 (i)];
Y08 (i) = Ty - [Rz * X94(i)] + [(1+Sc) * Y94 (i)];
Z08 (i) = Tz + [(1+Sc) * Z94 (i)];
End
Coord08=[X08; Y08; Z08];
Coord08=coord08';
%the Nubian plate angular velocity of Egypt at itrf 2008
Wx = 2.308 * 10^-9;
Wy = -1.8345 * 10^-9;
Wz = 4.8365 * 10^-9;
For i=1: n
Vx(i)=[Wy *Z08(i)] - [Wz * Y08(i)];
Vy(i)=[Wz *X08(i)] - [Wx * Z08(i)];
Vz(i)=[Wx *Y08(i)] - [Wy * X08(i)];
End
Reference epoch=1996;
Observational epoch=2014;
Diff= Observational epoch - Reference epoch;
For i=1: n
X observational epoch (i) = X08 (i) + [Vx (i) * Diff];
Y observational epoch (i) = Y08 (i) + [Vy (i) * Diff];
Z observational epoch (i) = Z08 (i) + [Vz (i) * Diff];
End
Coordinates of observational epoch =[X observational epoch; Y observational epoch; Z
observational epoch];
Coordinates of observational epoch = Coordinates of observational epoch ';
Sprintf( ' %10.3f ' , Coordinates of observational epoch)
```

7. Results and Analysis

Analysing the practical work which illustrated above, and its obtained results, the following points could be introduced:

- The range difference between the two local velocity created are from 0.198 cm to -0.221cm, when using the two local velocity models which obtained by the Cartesian angular vector at two years 2013 and 2011 for computed velocities (Vx,Vy,Vz) at all HARN stations, see table (4).

- We compute the mean of two local velocity models to get the best representation of the velocities and compared this mean local velocity model with the created velocity model which obtained by using the published Cartesian rotation vector of Nubian Plate-ITRF2008. The ranges difference in velocities (Vx,Vy,Vz) for HARN stations and the Egyptian GPS stations obtained by using the two models are from 0.148 cm to -0.14 cm see table (5). This results refer to the compatibility between the two velocity models, despite the mean local velocity model is created by using the velocities of stations at two years and GPS data only compared with the other velocity model which created by the time series of stations velocities and a variety of data.

- The velocities (Vx, Vy, Vz) of six GPS stations in Egypt obtained from the time series of GPS observations are changed in the values at each year see tables (6) and (7), but the velocities vector lengths obtained at the same stations at the different observational years, not changed in the direction see figures (6) and (7).

- The velocities (Vx, Vy, Vz) of six GPS stations in Egypt obtained by the mean local velocity model are constant in values at each year and changed about the velocities obtained by time series of GPS observations see table (8), but the velocities vector lengths at the same station at different years not changed in the direction compared to direction of the velocities vector lengths by time series of GPS observations see figure (8).

- The computed difference between the velocities vector lengths at each station obtained by time series of GPS observations and the velocities vector lengths computed by mean local velocity model are irregular values, the maximum difference is 2.26 cm at ASUT station and the minimum difference is -0.01cm at SLUM and MNSR stations see Tables (9) to (14).

- The tables (10) and (11) of the stations PHLW, ASUT illustrate, the velocity vector length which obtained from the time series of GPS observations is closest with the velocity vector length which computed by the mean local velocity model when we used the larger time period between two years for examples (2014-2007).
- Depending on the analysis obtained above for all stations and to check the accuracy for the created mean local velocity model at long time periods. The velocities (Vx,Vy,Vz) at each year for station (0Z17) determined by using the mean local velocity model coincide with the velocities (Vx, Vy, Vz) computed at each year by processing the GPS observations at long time periods which obtained from subtracting the coordinate computed by processing GPS observation at epoch 1996.0 from the coordinate computed by processing GPS observation at epoch 2013.14 on ITRF 2008 and divided the result on 17.14. The difference in vector length between them is 0.50 mm, see table (15).

Table (4): The Difference in Velocities between the Two Local Velocity Models

station	Diff in Vx (cm)	Diff in Vy (cm)	Diff in Vz (cm)
0Z00	-0.145	0.087	0.158
0Z01	-0.110	0.110	0.072
0Z02	-0.070	0.125	-0.012
0Z03	-0.044	0.146	-0.082
0Z04	0.027	0.089	-0.145
0Z05	0.065	0.017	-0.132
0Z06	-0.020	0.078	-0.050
0Z07	-0.054	0.059	0.029
0Z08	-0.090	0.037	0.116
0Z09	-0.031	-0.019	0.076
0Z10	-0.004	0.001	0.007
0Z11	0.023	0.037	-0.082
0Z12	0.089	-0.060	-0.089
0Z13	0.040	-0.031	-0.036
0Z14	0.020	-0.073	0.045
0Z15	0.033	-0.134	0.088
0Z16	0.078	-0.188	0.068
0Z17	0.076	-0.142	0.020
0Z18	0.127	-0.179	-0.026
0Z19	0.096	-0.116	-0.041
0Z20	0.139	-0.138	-0.092
0Z21	0.173	-0.141	-0.148
0Z22	0.198	-0.134	-0.199
0Z23	0.167	-0.068	-0.217
0Z24	0.135	-0.080	-0.148
0Z25	0.126	-0.004	-0.216
0Z26	0.089	0.057	-0.218
0Z27	0.052	0.119	-0.221
0Z28	-0.022	0.171	-0.148
0Z29	0.010	0.186	-0.220

Table (5): The Difference in Velocities between the Mean Local Velocity Model and the Published Velocity Model

station	Diff in Vx (cm)	Diff in Vy (cm)	Diff in Vz (cm)
0Z00	-0.121	0.077	0.125
0Z01	-0.096	0.094	0.066
0Z02	-0.068	0.104	0.007
0Z03	-0.049	0.120	-0.040
0Z04	0.001	0.080	-0.084
0Z05	0.026	0.029	-0.075
0Z06	-0.032	0.072	-0.018
0Z07	-0.057	0.058	0.036
0Z08	-0.083	0.042	0.096
0Z09	-0.042	0.003	0.069
0Z10	-0.023	0.018	0.020
0Z11	-0.002	0.043	-0.040
0Z12	0.042	-0.024	-0.046
0Z13	0.008	-0.004	-0.009
0Z14	-0.006	-0.034	0.046
0Z15	0.001	-0.077	0.076
0Z16	0.032	-0.115	0.062
0Z17	0.032	-0.082	0.029
0Z18	0.067	-0.108	-0.002
0Z19	0.046	-0.064	-0.013
0Z20	0.076	-0.079	-0.048
0Z21	0.101	-0.081	-0.087
0Z22	0.118	-0.076	-0.122
0Z23	0.097	-0.029	-0.134
0Z24	0.074	-0.038	-0.087
0Z25	0.069	0.015	-0.133
0Z26	0.044	0.058	-0.134
0Z27	0.019	0.101	-0.136
0Z28	-0.032	0.137	-0.085
0Z29	-0.009	0.148	-0.135
MNSR	0.057	-0.097	0.002
PHLW	0.040	-0.069	0.002
ASUT	0.003	-0.012	0.007
MARS	-0.061	0.021	0.082
SAFG	-0.031	-0.007	0.060
SLUM	0.121	-0.076	-0.126

Table (6): The Velocities of the Stations Computed by Using the GPS Observations at (2011 and 2012)

Station	Vx (cm)	Vy (cm)	Vz (cm)	Vector velocity length (cm)
MNSR	-3.960	1.070	0.620	4.140
PHLW	- 2.050	1.710	1.510	3.060
ASUT	-0.870	3.040	2.685	4.148
MARS	-2.480	0.800	0.940	2.770
SAFG	-1.240	2.330	2.020	3.324
SLUM	-1.790	0.750	1.160	2.261

Table (7): The Velocities of the Stations Computed by Using the GPS Observations at (2013 and 2014)

Station	Vx (cm)	Vy (cm)	Vz (cm)	Vector velocity length (cm)
MNSR	-1.34	2.26	1.63	3.092
PHLW	0.04	2.03	2.54	3.252
ASUT	-4.37	0.916	1.063	4.588
MARS	---	---	---	---
SAFG	---	---	---	---
SLUM	-1.09	1.263	1.813	2.466

Table (8): The Velocities of the Stations Computed by Using the Mean Local Velocity Model

Station	Vx (cm)	Vy (cm)	Vz (cm)	Vector velocity length (cm)
MNSR	-2.032	1.586	1.523	2.994
PHLW	-2.016	1.620	1.541	3.010
ASUT	-1.986	1.683	1.576	3.044
MARS	-2.062	1.670	1.585	3.091
SAFG	-2.054	1.654	1.572	3.070
SLUM	-1.830	1.685	1.541	2.927

--- Not available in this years

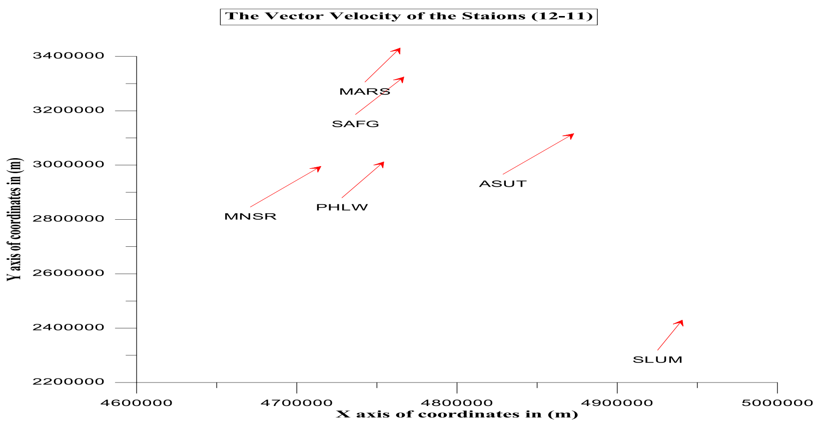

Figure (6): The Velocities Vector Length of the Stations Computed by Using the GPS Observations at (2011 and 2012).

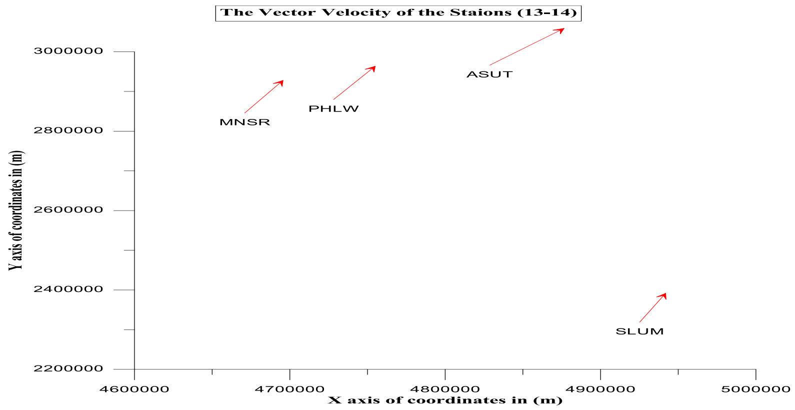

Figure (7): The Velocities Vector Length of the Stations Computed by Using the GPS Observations at (2013 and 2014).

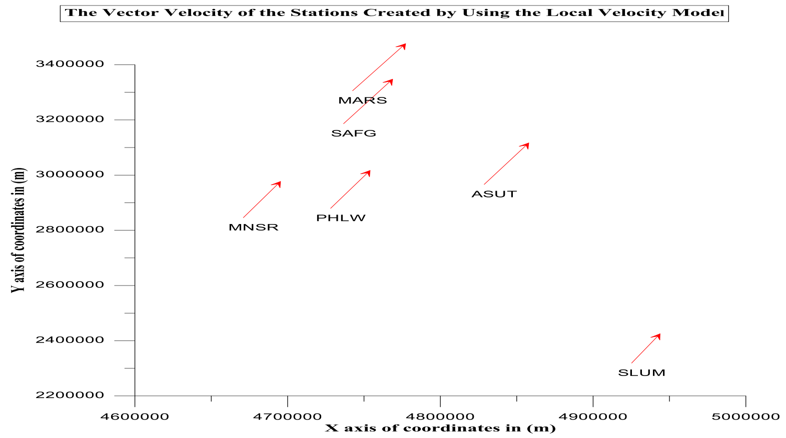

Figure (8): The Velocities Vector Length of the Stations Computed by Using the Mean Local Velocity Model.

Table (9): The Difference in Velocities Vector Lengths Obtained by the GPS Observations and the Mean Local Velocity Model for MNSR Station at Different Observation Times

Station / Years	Velocity Vector length (Observed and Computed by model)					
	14-13	13-12	12-11	14-12	14-11	13-11
MNSR (GPS)	0.0309	0.0344	0.0415	0.0581	0.0982	0.0754
MNSR (model)	0.0291	0.0291	0.0291	0.0582	0.0873	0.0582
Diff in cm	0.18	0.53	1.24	-0. 01	1.09	1.72

Table (10): The Difference in Velocities Vector Lengths Obtained by the GPS Observations and the Mean Local Velocity Model for PHLW Station at Different Observation Times

Station / Years	Vector of Velocity (Observed and Computed by model)						
	14-13	13-12	12-11	11-07	12-07	13-07	14-07
PHLW (GPS)	0.0325	0.0277	0.0307	0.1308	0.1614	0.1881	0.2124
PHLW (model)	0.0251	0.0251	0.0251	0.1177	0.1472	0.1766	0.2060
Diff in cm	0.74	0.26	0.56	1. 31	1.42	1. 15	0. 64

Table (11): The Difference in Velocities Vector Lengths Obtained by the GPS Observations and the Mean Local Velocity Model for ASUT Station at Different Observation Times

Station / Years	Vector of Velocity (Observed and Computed by model)						
	14-13	13-12	13-11	11-07	13-07	14-07	14-07
ASUT (GPS)	0.0436	---	0.0830	0.1048	0.1761	0.2122	---
ASUT (model)	0.0302	---	0.0604	0.1031	0.1811	0.2113	---
Diff in cm	1.34	---	2.26	0.17	-0.5	0.09	---

Table (12): The Difference in Velocities Vector Lengths Obtained by the GPS Observations and the Mean Local Velocity Model for SAFG Station at Different Observation Times

Station / Years	Vector of Velocity (Observed and Computed by model)						
	14-13	13-12	12-11	11-07	12-07	13-07	12-07
SAFG (GPS)	---	---	0.0332	0.1125	0.1430	---	---
SAFG (model)	---	---	0.0308	0.1233	0.1541	---	---
Diff in cm	---	---	0.24	-1.08	-1.11	---	---

Table (13): The Difference in Velocities Vector Lengths Obtained by the GPS Observations and the Mean Local Velocity Model for SLUM Station at Different Observation Times

Station / Years	Vector of Velocity (Observed and Computed by model)						
	14-13	13-12	12-11	13-11	14-11	14-12	14-07
SLUM (GPS)	0.0276	0.0284	0.0226	0.0500	0.0740	0.0546	---
SLUM (model)	0.0277	0.0277	0.0277	0.0554	0.0831	0.0554	---
Diff in cm	-0.01	0.07	-0.51	-0.54	-0.91	-0.08	---

Table (14): The Difference in Velocities Vector Lengths Obtained by the GPS Observations and the Mean Local Velocity Model for MARS Station at Different Observation Times

Station / Years	Vector of Velocity (Observed and Computed by model)						
	12-11	12-13	13-11	14-11	14-12	13-07	12-07
MARS (GPS)	0.0277	0.0383	0.0638	---	---	---	---
MARS (model)	0.0314	0.0314	0.0627	---	---	---	---
Diff in cm	-0.37	0.69	0.11	---	---	---	---

Table (15): The Velocity for Station 0Z17 at each Year Obtained by the GPS Observations which the Difference in Time between the Two Observations Sessions Equal 17.14 Years and by the Mean Local Velocity Model

Station	Vx (cm)	Vy (cm)	Vz (cm)	Vector velocity length (cm)
0Z17 (GPS)	-2.04	1.55	1.574	3.006
0Z17 (model)	-2.02	1.52	1.540	2.960
Diff in cm	-0.02	0.03	0.034	0.05

--- Not available in this years

8. Conclusions

- The velocities (Vx, Vy, Vz) of GPS stations obtained by processing the time series of GPS observations are not constant but changing in values at each year.
- The mean local velocity model created by using the velocities of the GPS stations is best fitting with the model created by using the published Cartesian rotation vector of Nubian Plate-ITRF2008.
- When the time period between the two GPS observations sessions increases, the velocities vector lengths obtained by the mean local velocity model and the processing GPS observations nearly coincides.
- From the results, the velocities (Vx, Vy, Vz) obtained at any station which computed by using the two velocity models (local and other) do not give the actual velocities at each year but give the velocities as the mean of velocities (Vx, Vy, Vz) taken a long time period.
- The important job for creating the velocity model is to update the network stations on fixed epoch to any epochs at the same datum or different datum but we use the transformation parameters between the two datums.

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