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Transformation Parameters between Two ITRF Based Networks for Detection of Land Deformations in Egypt

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الملخص العربي
أنشأت هيئة المساحه مؤخرا أول شبكه تحكم قوميه جيوديسيه النشطة (المحطات المرجعيه مستمرة التشغيل CORS). و قد كشف انشاء تلك الشبكه بعض الفروق في الإحداثيات مع نقط تحكم حددت مسبقا بإستخدام شبكة التحكم القوميه الجيوديسيه السالبه (الشبكه المرجعيه ذات الدقه العاليه HARN). في هذا البحث يتم إستعراض طرق الرصد و الضبط لكلا الشبكتين وأسباب الإختلافات. كلا الشبكتين منسوبتين إلي الإطار الدولي المرجعي (ITRF) و الذي يستحدث بإستمرار لإعتبار ديناميكيه الأرض. وفي نفس الوقت فقد تم تعديل الإطار المرجعي لنظام تحديد المواقع الكوني (GPS) حتي يتوائم عن قرب مع ال ITRF . و بالتالي فإن شبكتي ال CORS و ال HARN منسوبتين الي محطات في نظم ITRF08 و ITRF96 علي الترتيب. و قد تم تحديد و عرض الفروق بين الشبكتين ثم عمل نموذج رياضي لتلك الفروق كمعاملات للتحويل بين نتائج الشبكتين لإستخدامها في المنتجات الجيوديسيه النهائيه لهيئة المساحه المصريه. و قد استنتج أن زيادة مواقع الخدمه الدوليه لل GNSS (IGS) علي الكره الأرضيه يحسن من تحقيق نظام مرجعي أرضي دولي (ITRS) من خلال الإطار الدولي المرجعي (ITRF).كذلك تم إستنتاج أن التشكلات في مصر كانت اكثر في الشرق و الشمال بين 1996 و 2008.

Abstract

Recently, the Egyptian Surveying Authority (ESA) established the first Active National Geodetic Control Network "Continuously Operating Reference Stations" (CORS). The implementation of the CORS network within Egypt has uncovered some discrepancies in the coordinates of control points previously determined using the Passive National Geodetic Control Network "High Accuracy Reference Network" (HARN). In this paper, methods of observation and adjustment for both CORS and HARN networks are introduced, and the reasons for discrepancies are discussed. Both networks; CORS and HARN are referenced to the International Terrestrial Reference Frame (ITRF), which is regularly updated to account for the dynamics of Earth. In the meantime, GPS datum (WGS84) is refined several times to be closely aligned with the ITRF. Accordingly, the CORS network was referenced to ITRF08 stations, while the HARN network was referenced to ITRF96 stations. Based on the available results of the same stations in both CORS and HARN networks, the discrepancies due to plate tectonics are determined and presented. The discrepancies are then modeled as transformation parameters between the results of both networks to be considered within ESA final geodetic products. It is concluded that increasing the International GNSS Service (IGS) sites over the Earth's crust improves the realization of International Terrestrial Reference System (ITRS) through ITRF and that crustal deformations in Egypt between 1996 and 2008 were more in the east and north directions.

1. Introduction

The ITRS is the complete conceptual definition for terrestrial coordinates to satisfy the highest possible accuracy. It defines the origin and the orientation of fundamental planes or axes of the system. The definitions of this system also include scale, physical constants, and models such as, the size, shape, and orientation of the reference ellipsoid that approximates the geoid and the Earth’s gravity field model. This reference system is a mathematical abstraction while its practical realization through geodetic observations is known as a reference frame. Accordingly, the ITRF means the practical realization of a reference system through Cartesian coordinates and linear velocities of a global set of sites equipped with various space geodetic observing systems [Boucher et al., 1990]. This frame has the center of mass of the earth as its geo-center. The parameters for such reference frame are determined by the combination of worldwide tracking sites of Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Doppler Orbitography and Radio Positioning Integrated by Satellite (DORIS), and Global Positioning System (GPS).

The ITRF changes continuously in reference to the temporal variations of reference network coordinates and their velocities. These temporal variations are caused by the effects of crustal motion, earth orientation, polar motion and other geophysical phenomena such as earthquakes and volcanic activity (Bock, 1998). Consequently, The ITRF is updated regularly in order to account for the dynamics of the earth and is now sufficiently refined to ensure that the change between successive ITRF versions is in the order of 1-2 cm. The common early versions of this frame i.e., ITRF92, ITRF93, and ITRF94 successively, were produced with the limited distribution, availability, and performance of the reference network stations known by fiducials. With the introduction of ITRF96 in March 1998, the set of fixed fiducials was greatly expanded and improved to 47 sites. The number of stations was expanded again with the introduction of ITRF97 on August 1999 to 51 sites. The following two versions of the ITRF were ITRF2000 and then ITRF 2005; in which about 800 stations at about 500 locations were included

The ITRF2008 solution was published on 31 May 2010. In that solution, the ITRF2008 consisted of sets of station positions and velocities with their variance/covariance matrices. It has been computed using solutions from four different space geodetic techniques: VLBI, SLR, DORIS, and GPS. Lately, a newer ITRF solution (ITRF2013) was published in July-August 2014 [https://confluence.qps.nl/pages/ viewpage. action? pageId=29856813 Jul 16, 2015].

On the other hand, the Global Navigation Satellite Systems (GNSS) is being used in position determination for geodetic and engineering applications. In order to ensure the integrity of any GNSS system and to precisely determine satellite orbits of its constellation, an associated and well-defined reference frame has to be maintained over time. Accordingly, the World Geodetic System 1984 (WGS84) was developed for GPS by the U.S. Defense Mapping Agency (DMA), later named National Imagery and Mapping Agency (NIMA), and is now called the National Geospatial-Intelligence Agency (NGA). This system is based on the WGS84 ellipsoid which can generally be assumed identical to the GRS80. The WGS84 datum was first introduced in 1987 based on Doppler observations and has since been refined several times to be closely aligned with the ITRF in order to prevent degradation of the GPS broadcast ephemerides due to plate tectonics (True, 2004).

The WGS84 reference frame, which is based completely on GPS observations, is WGS84 (G730) where the letter G stands for "GPS" and "730" denotes the GPS week number (starting at 0h UTC, 2 January 1994). Another WGS84 realization, called WGS84 (G873), is also based completely on GPS observations. Again, the letter G reflects this fact, and "873" refers to the GPS week number starting at 0h UTC, 29 September 1996.

The current WGS84 realization is called WGS84 (G1150). [www.uvm.edu/giv/resources/WGS84_NAD83.pdf]. The above mentioned WGS84 realizations are coincident with ITRF at about 10-centimeter level, and there are no transformation parameters between the previous ITRF realizations and WGS84. This means that ITRF coordinates are expressed in WGS84 at 10 cm level. However, the most recent G1674 of WGS84 realization adopted ITRF2008. Thus, ITRF2008 and WGS84 (G1674) are likely to agree at the centimeter level, and this yielding zero transformation parameters between ITRF2008 and WGS84 (G1674) realization [confluence.qps.nl/pages/viewpage.action?pageId=29856813Jul,16,2015].

Regional or national GNSS reference services usually tie their reference site coordinates to an almost recent ITRF at a fixed epoch to account for any tectonic plate motion. The reference stations coordinates are usually expressed referenced to stable global coordinates and national datum. Any new ITRF update can be taken into account later on. Several countries, including Egypt, already have a national network of GNSS reference stations. Such a network has usually been connected to the IGS network, and thus the coordinates of the stations are accurate in both the WGS84 and the ITRF. When establishing a new stand-alone reference station or a new network of stations, it is usually preferable to connect the new station or the new network to the national network. If there is no suitable national network, then the alternative is to connect the new station or the new network of stations to the IGS network. In Egypt, information on the national network and data from the National Stations are maintained by the Egyptian Surveying Authority (ESA).

Worldwide, there is a trend to maintain the old data that was referenced to an older datum, and establish transformation parameters to a more recent datum. Thus, data referenced to older datum can be employed in current applications. For example, the North American Datum of 1983 (NAD 83) epoch ITRF06 is a geodetic datum that provides a spatial reference for Canada and the United States. The WGS84 (G1150) ≡ ITRF2000 coordinates can be transformed to NAD83, but the two sets of coordinates must be reduced to a common epoch before the comparison is made. Provided that the velocities of the three components v_x, v_y, and v_z, are known in cm/year for a particular point, the transformation between the epochs is determined [www.uvm.edu/giv/resources/WGS84_NAD83.pdf]. Another example is the transformation in Hong Kong between the old and the new ITRF systems. Through this process, the Hong Kong reference system was transformed to the ITRF96 [www.fig.net/pub/fig2012/ppt/ts02b/ts02b_kwok_6113_ppt.pdf].

In Egypt, two national GNSS networks have recently been established. The first network was the High Accuracy Network (HARN) referenced to ITRF96, while the other network was the Continuous Operating Reference Station (CORS) referenced to ITRF08.

2. High Accuracy Reference Network (HARN)

The High Accuracy Reference Network (HARN) consisted of 30 GPS stations covering most of Egypt. HARN inter-station distances were between 150 km and 250 km with 1:10,000,000 distance accuracy. The stations were occupied by Ashtech-Z12 dual frequency receivers. Each session included 8 GPS receivers that were collecting simultaneous observations for 8-hour sessions. Temperature, pressure, and humidity were measured at the stations to model the troposphere [Geonex Inc., 1996].

The data was downloaded from GPS receivers to personal computers in the form of B (binary file), E (ephemeris file), and s (site file). The raw data were processed by a GPS Software; the resulting output file contained baseline components (dx, dy, and dz). The output file was then exported to the adjustment software (Fillnet) as input data to perform the network adjustment; in which HARN was tied to the IGS sites located in Greece, Morocco, Pakistan, and South Africa as control points. The known coordinates of the IGS sites (ITRF96) were fixed in the constrained adjustment phase of the HARN network. As a result, the adjusted final coordinates were produced. Table (1) shows baseline lengths between employed ITRF96 stations and Cairo- Egypt.

Table1: Baseline lengths between the ITRF96 stations and Cairo.

ITRF96 Stations which HARN is tied in	
ITRF Station	Baseline Length to Cairo
Pakistan	3954 km
Morocco	3563 km
Greece	1125 km
South Africa	6385 km

3. GPS National Agricultural Cadastre Network (NACN)

The NACN consists of 112 GPS stations covering the Nile valley of Egypt. NACN inter-station distances are between 40 km and 60 km with 1:1000,000 distance accuracy. The stations have been occupied by Ashtech-Z12 dual frequency receivers. Each session included eight GPS receivers collecting simultaneous observations for 4 hours-sessions. Data on the GPS receivers were downloaded to personal computers and the network was adjusted as explained in section (2) above.

4. The continuous operating reference stations network (CORS)

GPS applications in Egypt suffered several drawbacks because of difficulties in tying GPS works to the national geodetic control networks (HARN or NACN) in certain cases. Examples of such difficulties are lack of geodetic control points, difficulty to access the geodetic control points in certain areas, and long baselines that require longer sessions.

To overcome such difficulties and to provide a unified datum for the entire country, Egypt established the Continuously Operating Reference Stations Network (CORS) along the Nile valley and its Delta. The CORS stations were established between the cities of Alexandria and Aswan, it included 40 stations that are spaced by distances that range from 50 km to 70 km as shown in figure (1). The stations are mounted on top of governmental and Engineering office-buildings that belong to the Egyptian Surveying Authority (ESA) all over the country. CORS stations are equipped with dual frequency GNSS receivers (Trimble Net R5) as shown in figure 2 [Zone Technologies Co., 2011].

Figure 1: CORS distribution in Egypt

OWNER	PERMANENT CONTROL MARKER	ESTABLISHED BY	
ESA		ZoneTechnologies	
GOVERNORATE		AREA	
GIZA	CARO	ESA CAIRO	
Date : 23/10/2011		Method :	GPS (STATIC)
WGS-84 ELLIPSOID COORDINATES		WGS84 DATUM PARAMETERS	
Latitude :	N30°01'55.72157"	Horizontal Datum :	WGS84
Longitude :	E31°12'55.05207"	Ellipsoid / Spheroid :	WGS84
Ellip. Height :	75.635	Semi-Major Axis :	6378137.000m
		Flattening(1/ f) :	298.257
description of loctaion	The station is located over Survey Authority - Abdel-Salam Aref street - Giza Orman - Giza Governorate.		
Description of Station Mark:	2M fixed height mast.		
Photos			

Figure 2: Description card of a permanent station

The GNSS receivers collect the GNSS raw data and transmit it to the Control Center Server through 40 ADSL lines which are grouped in 2 Leased lines conveying the data to the Server of the CORS network control center room as shown in figure 3.

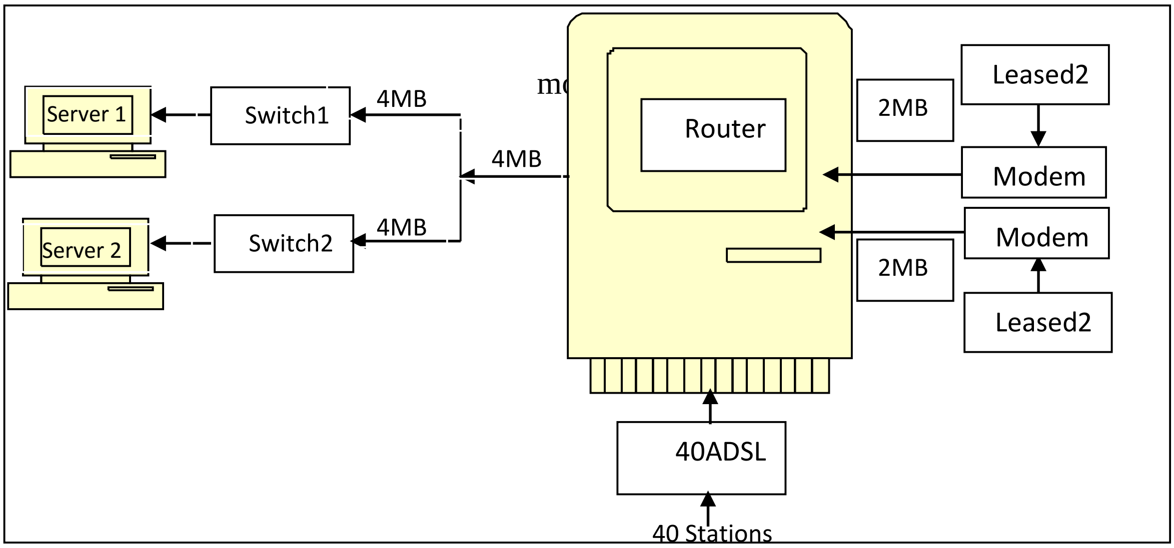

Figure 3: Control center communications

4.1 CORS Stations Referenced to (ITRF08)

Using the collected data from 40 CORS stations that track satellites for 24 hour-sessions, duration, the network is processed and adjusted using Trimble Business Center (TBC) software. The CORS network is tied to three ITRF08 stations, the baseline lengths between the ITRF08 stations and Cairo are shown in table (2). The ITRF08 stations' coordinates (precise ephemeris) are fixed in the constrained adjustment as control points for the Egyptian CORS network. The output coordinates of the CORS stations are geographic coordinates (WGS84) referenced to ITRF08.

Table 2: Baseline lengths between ITRF08 stations and Cairo.

ITRF08 Stations which CORS is Tied in		
ITRF Station (lat , long)		Baseline Length to Cairo
410738.31864N	204738.57303E	1593km
350827.55001N	332347.19643E	610km
303551.38442N	344547.30793E	357km

4.2 CORS Stations Referenced to HARN (ITRF96)

The CORS stations are also tied to the existing National passive ground geodetic control network (HARN). Using the same collected data from 40 CORS stations with 24 hours-sessions duration, and occupying 8 (HARN) geodetic control network points distributed around the CORS stations network by 8 GNSS Antennas for 8 hour-sessions duration, the CORS stations network are processed and adjusted by Trimble Business Center (TBC) software. Eight geodetic control network points (HARN) are fixed in the constrained adjustment The output coordinates of the CORS stations are called CORS-ITRF96 (HARN) WGS84 in this paper. The following is a list of adjustment statistics:

Number of Iterations for Successful Adjustment:	2
Network Reference Factor:	1.00
Chi Square Test (95%):	Passed
Precision Confidence Level:	1-sigma
Degrees of Freedom:	1115

Post Processed Vector Statistics

Reference Factor:	1.00
Redundancy Number:	1115.00
A Priori Scalar:	4.60

Where Chi Square Test (95%) = $\sigma^{2\wedge}/\sigma^{2}_{0}$

Where $\sigma^{2\wedge}$ is sigma aposteriori

Where σ^{2}_{0} is sigma apriori

Where $\sigma^{2\wedge} = v^{t}pv$

Where v is the residuals, p is the weight and t is the transpose of the matrix

If $\sigma^{2\wedge}/\sigma^{2}_{0} = 1$,it means the test is passed

If $\sigma^{2\wedge}/\sigma^{2}_{0} > 1$, ther is an over flow due to systematic errors or incorrect mathematical model

If $\sigma^{2\wedge}/\sigma^{2}_{0} < 1$,it means the 0bservations were more precise than we were expecting

1-sigma means that the probability of (x+€ > x > x-€) is 68.3%

Where x is the measurement, € is the error

5. Comparing the two coordinate systems of CORS stations

The differences in Northing (ΔN) Easting (ΔE), and (Δh) between ITRF08 and ITRF96 are calculated and shown in table (3). In table (3) the maximum and minimum values of ΔN, ΔE and Δh are highlighted. The contours of the differences are presented in Figures (4) through (8).

Table (3) Differences between ITRF08 and ITRF96 coordinates at CORS stations

Point Id	diff.(N) m	diff.(E) m	diff.(h) m
ADFO	0.270	0.306	-0.115
ADWH	0.0000	0.000	-0.215
ALEX	0.414	0.365	-0.296
ASHM	0.377	0.360	-0.220
ASOF	0.327	0.313	-0.203
AYAT	0.360	0.343	-0.188
BADR	0.388	0.364	-0.235
BLTM	0.417	0.411	-0.243
BNHA	0.377	0.363	-0.210
CARO	0.370	0.352	-0.188
DKRN	0.389	0.393	-0.203
DMNH	0.408	0.376	-0.266
DOMT	0.390	0.401	-0.197
ETSA	0.357	0.327	-0.213
FAYD	0.348	0.360	-0.150
GHNM	0.327	0.308	-0.204
HMOL	0.376	0.361	-0.210
ISML	0.357	0.374	-0.151
ISNA	0.282	0.307	-0.142
KBER	0.374	0.375	-0.191
KRKS	0.339	0.312	-0.215
LXOR	0.287	0.315	-0.150
MNSH	0.308	0.311	-0.179
MNZL	0.385	0.396	-0.184
MOUS	0.339	0.314	-0.218
MTMR	0.409	0.359	-0.278
QANA	0.292	0.325	-0.156
QANT	0.366	0.383	-0.161
RMDN	0.363	0.359	-0.174
RSHD	0.423	0.387	-0.274
SAID	0.375	0.396	-0.167
SDAT	0.387	0.351	-0.239
SHKH	0.402	0.384	-0.244
SMLT	0.345	0.319	-0.234
SUEF	0.351	0.327	-0.195
SUZE	0.339	0.364	-0.144
TANT	0.389	0.370	-0.227
THAT	0.319	0.317	-0.174
TSHT	0.302	0.314	-0.190
WAKF	0.296	0.326	-0.169
Mean	**0.348**	**0.342**	**-0.200**
ST.DEV	**0.069**	**0.064**	**0.041**

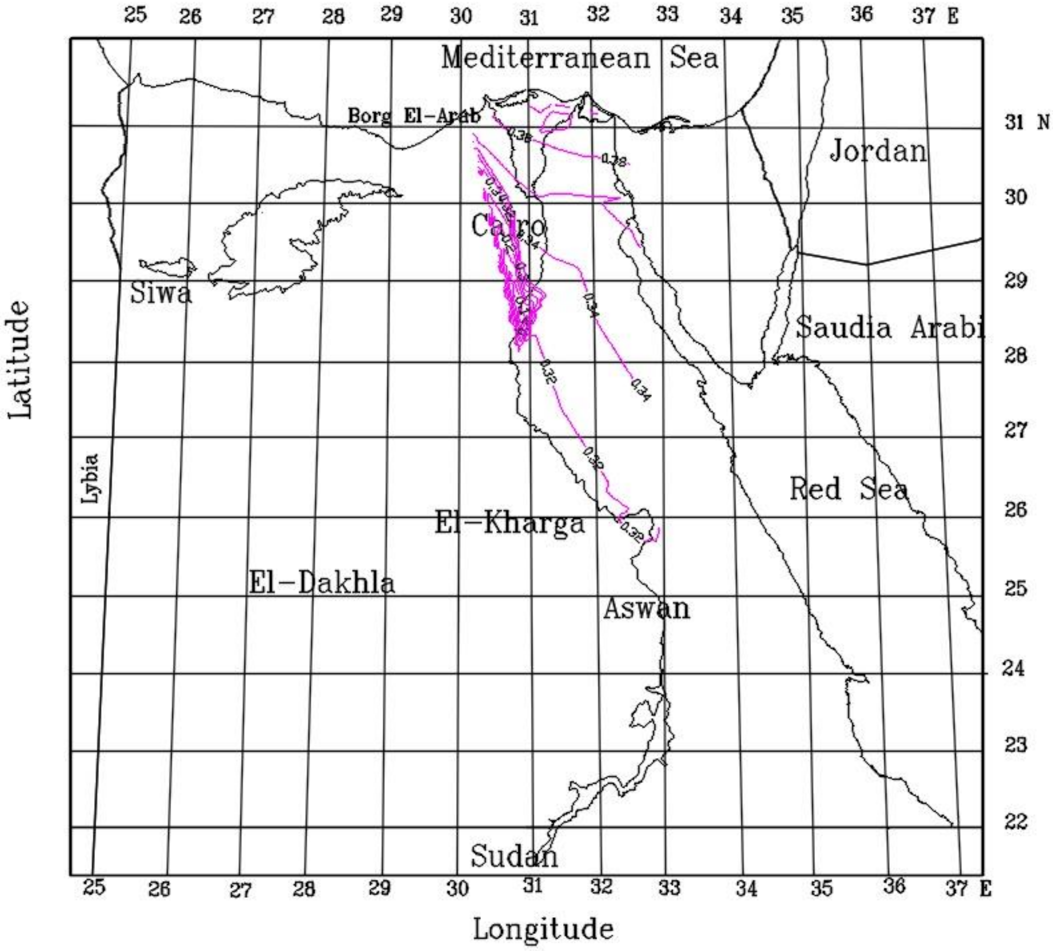

Figure4: Easting differences between ITRF08 andITRF96 with contour interval 0.02m

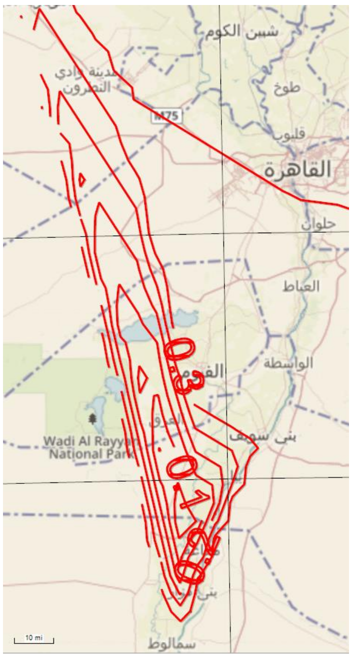

Figure 5: Easting differences between ITRF08 andITRF96 with contour interval 0.05m

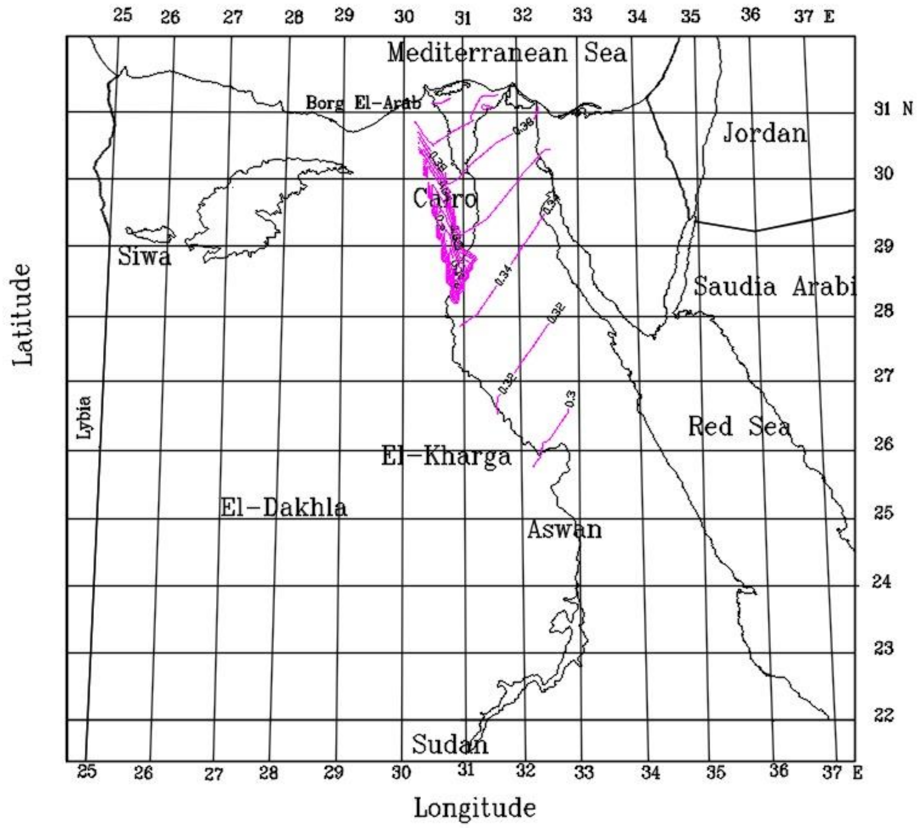

Figure 6: Northing differences between ITRF08 andITRF96 with contour interval 0.02m

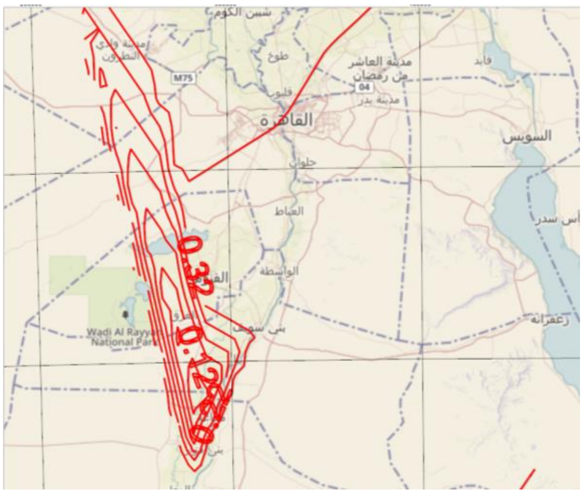

Figure 7: Northing differences between ITRF08 andITRF96 with contour interval 0.05m

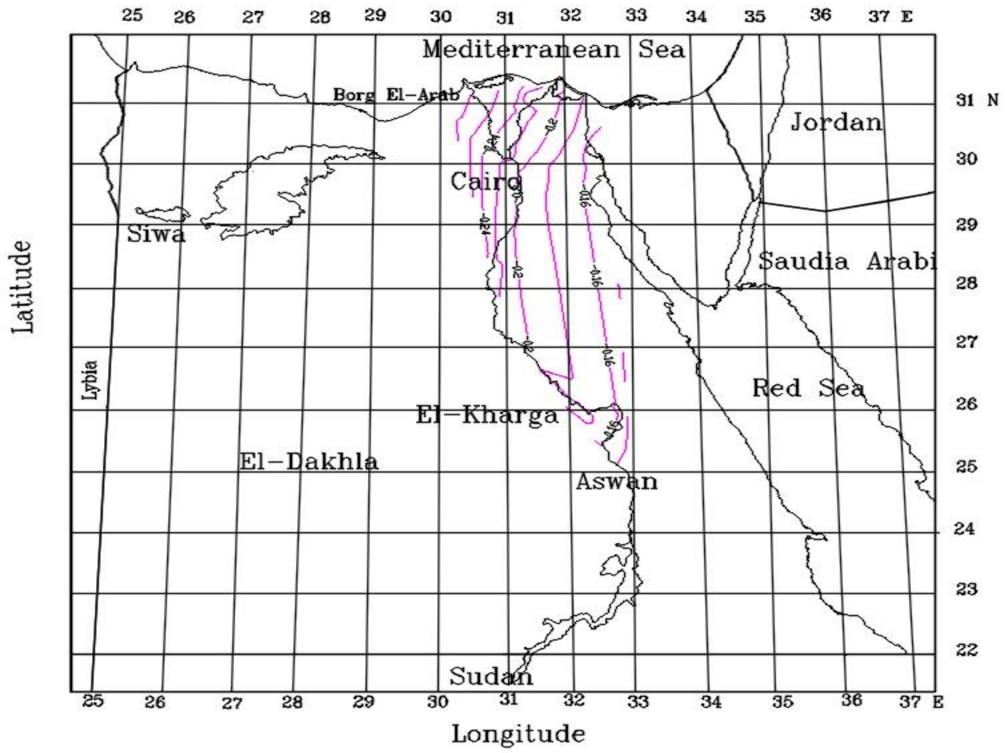

Figure 8: Height differences between ITRF08 and ITRF96 with contour interval 0.02m

6. Determination of transformation parameters

Figure (9) shows the geometry of the Bursa–Wolf transformation. the X, Y, Z axes of system 1 are rotated by very small angles εx, εy, εz from the X, Y, Z axes of system 2, and the origins of the two systems are displaced by translations tx, ty, tz in the directions of the X, Y, Z axes of system 2. I_2 and I_1 are vectors of coordinates in both systems and t is a vector of translations. The mathematical relationship between coordinates in both systems can be written in the form of a vector equation

$I_2 = t_2 + (1+ds)\, R_s\, I_1$ Seeber, G, (2003)

$$R= \begin{vmatrix} X1 \\ Y1 \\ Z1 \end{vmatrix} = \begin{vmatrix} X\Delta \\ Y\Delta` \\ Z\Delta \end{vmatrix} + (I+ds\,) * \begin{vmatrix} 1 & €z & -€y \\ -€z & 1 & €x \\ €y & -€x & 1 \end{vmatrix} * \begin{vmatrix} X2 \\ Y2 \\ Z2 \end{vmatrix}$$

Where

$I1 = [X1, Y1, Z1]^t$ t stands for transpose of the matrix,

I2 = [X2, Y2,Z2]t ,

$t2 = [X\Delta\ Y\Delta, Z\Delta]^t$

$$I = \begin{vmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

ds = Scale Factor.

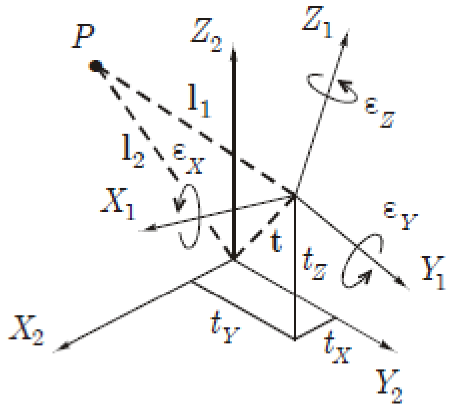

Figure 9: Geometry of Bursa-Wolf transformation

Determining the transformation parameters between ITRF08 'CORS' to ITRF96 'HARN' in Egypt is crucial for several reasons. Even though the ESA relies on the CORS network in producing Geodetic control for users, ESA has not used ITRF96 'HARN' in producing Geodetic control for users in the areas that are covered by CORS since 2012. Therefore, surveying works before 2012 are not compatible with surveying works after 2012 due to the differences in coordinates that are shown in table (3). This problem has to be taken into consideration to avoid matching problems between areas surveyed before and after 2012. To account for the differences in coordinates the transformation parameters from ITRF08 'CORS' to ITRF96 'HARN' are determined using the Bursa-Wolf model. 12 points that have coordinates in both systems were employed in determining the transformation parameters.

7. Results

The mean of the easting (ΔE) and, northing (ΔN) coordinate differences between ITRF08 and ITRF96 are 0.34 m and 0.34 m respectively. The RMS of the easting (ΔE) and, northing (ΔN) coordinate differences are 0.064 m and 0.069 m respectively. The transformation parameters are as follows:

dx = -1.7563 m
dy = 1.577 m
dz = -0.7609 m
εx =-0.716" (arc seconds)
εy = 0.0789" (arc seconds)
εz = -1.25" (arc seconds)
K = 1.5373* e-010

In other words, the shifts in X, Y, and Z direction between ITRF08 and ITRF96 are -1.7563 m, 1.577 m and, -0.7609 m respectively. The rotations about X, Y. and Z axes are -0.716", 0.0789", and -1.25" respectively. The above-mentioned transformation parameters between ITRF08 and ITRF96 imply the effect of increasing the IGS sites over the Earth's crust from 1996 to 2008. Figure (4) shows that the difference in the easting coordinate increases toward the east. therefore, CORS stations in the east along Suez Canal seem to have moved more than the others. Figure (6) shows that the difference in the northing coordinate increases toward the north. Figures (4) through (7) combined give an indication that there is an anti-clockwise rotation of Egypt, a rotation towards North-East direction. Figure (8) reflects the change of WGS84 datum as a last realization due to the increase in ITRF sites in ITRF08 than ITRF96; which makes the WGS84 ellipsoid surface closer to the terrain of Egypt at the Nile valley. This can be deduced from the negative signs of Δh.

8. Conclusion

Using the Bursa-Wolf model, the transformation parameters from ITRF08 'CORS' to ITRF96 'HARN' are determined. It was concluded that increasing the IGS sites, over the Earth's crust from 1996 to 2008, improved the realization of the ITRS through the ITRF. As for the influences of improving ITRF from 1996 to 2008 on the accuracy of the Egyptian national networks, it was found that relative to Egypt location, the baseline lengths to the ITRF stations are decreased; which resulted in decreasing the errors in those baselines, table (1) and table (2) demonstrate the improvement of ITRF by comparing the baseline lengths of the two available ITRF's sites to Egypt. To evaluate such improvement, the transformation parameters between the old ITRF based coordinates "HARN" and the recent ITRF based coordinates "CORS" are determined. The transformation parameters reflect the changes in the accuracy of the position of WGS84 as a GPS datum from the old ITRF to the recent ITRF. The transformation parameters showed that a rotation about Z-axis in Egypt; this means that there is a crustal movement toward the east. The positive sign of ΔE and ΔN as shown in table (3) are compatible with the rotation about Z-axis and X-axis respectively.

9. References

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