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Crustal deformation studies of the Nile Valley area using GPS Observations techniques

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Abstract-The aim of this paper is to study the recent crustal movements for the Nile valley area using the GPS data and calculating the velocity field referenced to the ITRF2008. Study of recent crustal movements means the determination of the magnitude, direction and the rate of these movements. Monitoring of crustal movement (velocities in mm/year) can be determined according to the spatial and time density of measurements in addition to their degree of accuracy. A set of observations for eight points from the Egyptian Permanent GPS Network (EPGN) along the Nile Valley are used. This network was observed five times in different campaigns throughout the period 2010 – 2016. The observed data were analyzed using Trimble Business Center (TBC 3.5) software and online services are used to determine velocity vectors along the Nile Valley area. Three different methods of GPS-data processing were adopted and a comprehensive analysis study of the horizontal velocities and coordinates time series are presented.

Index Terms—crustal movements, deformation, monitoring, GPS technique, IGS stations, velocity

1. INTRODUCTION

Crustal movement studies are very important in the geodynamical research tools which help in understanding the properties of the earth. The worldwide tools for these studies are chiefly the repeated measurements of geodetic stations fixed on the Earth's surface. Space techniques have become increasingly prominent in studying deformations of plate boundaries and have approached the level of precision of global plate models. Nowadays, Global Positioning System (GPS) has been used effectively in Crustal movement studies by multiple disciplines. Web-based online services developed by several organizations; which are user friendly, unlimited and most of them are free; have become a significant alternative against the high-cost scientific and commercial software on achievement of post processing and analyzing the GPS data **(Mewafi, at el. 2017).** When high level accuracies are desired, that can be obtained easily regarding different quality engineering applications through these services. The raw data collected from anywhere around Nile valley area in Egypt by using a double frequency geodetic grade GPS receiver have been converted into Receiver Independent EXchange (RINEX) format, then they may be submitted to these web based online services and processed into them. In this paper, monitoring of the recent crustal movements is started by using a data set of observations for eight points from the Egyptian Permanent GPS

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2. FIELD DATA COLLECTION

A case study in Egypt of eight points from (EPGN) along the Nile Valle in Egypt was conducted 24-hours GPS data in static mode was collected for these points namely MNSR, SAID, BORG, ARSH, MTRH, ASWN, PHLW and ALAM along six years from 2010 to 2016 as showing in table (1)

Table (1) Available data of the GPS stations from 2010 to 2016 around the Nile Valley

Campaign	Date	Day of year (DOY)	GPS week	Sampling (s)	Mask angle
March, 2010	18.03.10	77	1575	30	13◦
	19.03.10	78	1575		
	20.03.10	79	1575		
April, 2012	17.04.12	108	1684	30	13◦
	18.04.12	109	1684		
	19.04.12	110	1684		
	20.04.12	111	1684		
February, 2014	01.02.13	32	1725	30	13◦
	02.02.13	33	1725		
	03.02.13	34	1726		
October, 2016	20.10.15	293	1867	30	13◦
	21.10.15	294	1867		
	22.10.15	295	1867		

Through the following link **http://itrf.ign.fr/** and using the **station demo's number**, the precise coordinates, velocities and their standard deviations in ITRF solutions at any day of year can be obtained. The following table shows the precise coordinates and their standard deviations of selected IGS stations in ITRF solutions in table (2).

Table (2) Available data of the GPS stations from 2010 to 2016 around the Nile Valley on IRTF 2008

DATA SET EXPRESSED IN ITRF2008 FRAME				
STATION POSITIONS AND standard deviation AT EPOCH 2015/01/01				
DOMES NB	ID	X (m)	Y (m)	Z(m)
		Ϭx (mm)	Ϭy (mm)	Ϭz (mm)
43007M001	QAQ1	2170941.923	-	5539988.45
		1	1	2
43005M002	KELY	1575558.899	-	5848076.547
		1	1	2
10202M001	REYK	2587384.096	-	5716564.087
		1	1	2
10204M002	HOFN	2679689.937	-727951.073	5722789.489
		1	1	1
1	ALAM	4742516.3575	3305688.9624	2685814.2549
		3.2	6.6	4.3
2	ARSH	4551743.456	3026108.360	3276117.451
		2.9	4.5	4.3
3	ASWN	4899061.5324	3163086.8671	2575414.1634
		4.8	7.6	10.3
4	BORG	4765954.3038	2704546.1611	3252949.1805
		3.6	3.9	9.2
5	MNSR	4671006.2086	2845893.5643	3269812.0949
		2.8	5.2	4.3
6	MTRH	4847946.8837	2494773.2994	3298721.2443
		3.4	6.2	4.8
7	PHLW	4728141.266	2879662.611	3157147.150
		5.4	4.9	5.2
8	SAID	4612664.2273	2917621.3682	3289234.9459
		1.9	4.4	6.7

3. RESULTS AND ANALYSIS

In this section, Data Processing are performed by using web-based online service for GPS relative and precise point positioning techniques:

1. **AUSPOS (relative solution approach):**

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Services using relative solution approach estimate the point coordinates with double-difference technique by using data from either global IGS network or national CORS networks. The formulation of the double-difference technique for phase measurements can be given as follows (KOUBA, 2009) :

$$\Delta\varphi\ t = r(t, t-\tau) + ds(t-\tau) - d\ iono + d\ tropo + \Delta\lambda\ N + \Delta\varepsilon\ (\varphi) \qquad (1)$$

Where;

Δ is the double difference operator at the time of receiving data

φ is the phase measurement

(t) is the time of receiving data (t-τ)is the satellite time

τ is the travel time from the satellite to the receiver r(t, t-τ) is the true geometric range

ds is the orbital prediction error

diono and dtropo are the ionospheric and tropospheric errors, respectively

λ is the wavelength

N is the integer phase ambiguity

ε is the noise components

Table (3) illustrate the coordinates of Eight monitoring GPS stations data set from (EPGN) along the Nile Valle in Egypt which was obtained from GPS-data processing on-line **AUSPOS** services which have been using the relative solution approach. This service also include the scientific software (Bernese software), which provides high accuracies at mm level, these services have been also used commonly for geodetic analyses in recent years. The coordinates of points are provided in Geocentric Datum ITRF2008 **(http://www-b.ga.gov.au/bin/gps.pl).**

Table (3): Coordinates of GPS stations in different Epochs using AUSPOS service (Bernese Software)

ST.	2010		2012		2014		2016	
	E (m)	N (m)	E (m)	N (m)	E (m)	N (m)	E (m)	N (m)
ALAM	689403.077	2773675.767	689403.079	2773675.770	689403.086	2773675.780	689403.076	2773675.773
ARSH	558824.542	3441676.863	558824.471	3441676.830	558824.552	3441676.876	558824.477	3441676.808
ASWN	484574.371	2650999.866	484574.371	2650999.86	484574.373	2650999.869	484574.374	2650999.869
BORG	746090.316	3417295.407	746090.314	3417295.408	746090.314	3417295.408	746090.320	3417295.41
MNSR	342786.849	3435314.477	342786.849	3435314.476	342786.848	3435314.475	342786.855	3435314.479
MTRH	521928.566	3467941.581	521928.564	3467941.583	521928.5658	3467941.583	521928.569	3467941.586
PHLW	339987.863	3304594.096	339987.889	3304594.129	339987.858	3304594.108	339987.886	3304594.118
SAID	434710.444	3457034.361	434710.4439	3457034.362	434710.4458	3457034.362	434710.4467	3457034.361

2. **APPS service (using PPP solution approach)**:

PPP technique becomes the most effective and novel method on GPS positioning. PPP is an absolute positioning technique, which provides high level point accuracy in static or kinematic mode depending on observation

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duration with a dual-frequency receiver. PPP uses ionospheric free both carrier-phase (Φ) and code pseudorange (P) observations collected by dual-frequency receiver for data processing. This technique provides precise positioning by using precise ephemeris and clock products provided by IGS and other organizations and by considering other corrections such as satellite effects (satellite antenna offsets and phase wind- up), site displacement effect (solid earth tides, polar tides, ocean loading, earth rotation parameters) and compatibility considerations (products formats, reference frames, receiver antenna phase center offsets, modeling/observation conventions) **(Mewafi et al., 2018).**

The ionospheric-free combinations of dual-frequency GPS pseudorange (*P*) and carrier-phase observations (*Φ*) are related to the user position, clock, troposphere and ambiguity parameters according to the following simplified observation equations **(Zumberge at al. 1997 and Kouba and Heroux 2001):**

$$P = \rho + C(dT - dt) + T_r + \varepsilon P \quad (2)$$

$$\Phi = \rho + C(dT - dt) + T_r + N\lambda + \varepsilon\Phi \quad (3)$$

where;

P is the ionosphere-free combination of P1 and P2 pseudoranges (P3)=(2.546P1-1.546P2)

Φ is the ionosphere-free combination of L1 and L2 carrier-phases (L3)=(2.546 λ_1 Φ1-1.546 λ_2 Φ2)

ρ is the geometrical range computed as a function of satellite and station coordinates

C is the vacuum speed of light

dT is the station receiver clock offset from the GPS time dt is the satellite clock offset from the GPS time.

Table (4) illustrate the all coordinates in ITRF 2008 **for** Eight monitoring GPS stations data set from (EPGN) along the Nile Valle in Egypt which was obtained from GPS-data processing on-line **APPS** services which have been using the ppp solution approach. The coordinates of points are provided in Geocentric Datum ITRF2008 **(**http://apps . gdgps . net/ /**)**

Table (4): Coordinates of GPS stations in different Epochs using APPS service(All Coordinates are in ITRF 2008)

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ST.	2010		2012		2014		2016	
	E (m)	N (m)	E (m)	N (m)	E (m)	N (m)	E (m)	N (m)
ALAM	689403.082	2773675.772	689403.088	2773675.774	689403.083	2773675.77	689403.083	2773675.77
ARSH	558824.546	3441676.871	558824.478	3441676.843	558824.499	3441676.869	558824.494	3441676.865
ASWN	484574.375	2650999.863	484574.376	2650999.865	484574.392	2650999.869	484574.394	2650999.87
BORG	746090.329	3417295.414	746090.328	3417295.416	746090.330	3417295.414	746090.327	3417295.413
MNSR	342786.852	3435314.478	342786.856	3435314.481	342786.868	3435314.482	342786.874	3435314.485
MTRH	521928.539	3467941.586	521928.558	3467941.574	521928.563	3467941.582	521928.584	3482333.585
PHLW	339987.863	3304594.103	339987.882	3304594.126	339987.899	3304594.138	339987.902	3304594.134
SAID	434710.449	3457034.361	434710.468	3457034.369	434710.468	3457034.374	434710.473	3457034.383

3.1. Horizontal velocity results from 2010 to 2016

Velocity can be described mathimatically as : velocity = distance/time, where distance is displacements (change in position from start to the end of a measurement interval) of sets of points been determined over an interval of time. It's often given in mm/yr or in cm/yr.
Table below indicates velocities of GPS stations with values indicated below.

Table (5) Horizontal and vertical velocities including the velocity of the african plate into ITRF08 from year 2010 to year 2016 (relative to AUSPOS)

Station ID	Easting (m)	Northing (m)	Height (m)	Ve (mm/year)	σ e (mm/year)	Vn (mm/year)	σ n (mm/year)	Vh (mm/year)
BORG	746090.326	3417295.414	98.147	23.55	0.66	18.71	0.75	-3.22
ALAM	689403.079	2773675.772	48.860	20.25	0.83	20.52	0.67	-2.85
ARSH	558824.508	3441676.876	27.370	21.36	3.42	19.69	2.76	-5.32
ASWN	484574.381	2650999.873	215.546	21.83	1.30	19.08	0.86	-4.70
MNSR	342786.858	3435314.482	39.626	24.56	0.72	21.62	0.88	-6.93
MTRH	521928.574	3467941.589	58.677	23.38	0.62	17.59	0.36	-4.84
PHLW	339987.858	3304594.130	148.769	22.05	0.36	18.92	0.29	-3.90
SAID	434710.452	3457034.365	41.952	22.11	2.10	19.31	1.51	-7.42

Table (6) Horizontal and vertical velocities including the velocity of the african plate into ITRF08 from year 2010 to year 2016 (relative to APPS)

Station ID	Easting (m)	Northing (m)	Height (m)	Ve (mm/year)	σ e (mm/year)	Vn (mm/year)	σ n (mm/year)	Vh (mm/year)
BORG	746090.329	3417295.414	98.142	21.25	0.64	17.90	0.72	-2.82
ALAM	689403.082	2773675.772	48.851	21.15	0.79	19.12	0.64	-1.25
ARSH	558824.499	3441676.869	27.377	18.12	3.31	16.90	2.65	-4.20
ASWN	484574.375	2650999.863	215.492	19.23	1.23	17.88	0.80	-3.90
MNSR	342786.852	3435314.478	39.561	22.36	0.65	19.12	0.85	-7.13
MTRH	521928.539	3467941.586	58.672	20.78	0.58	18.29	0.32	-3.34
PHLW	339987.849	3304594.138	148.761	19.91	0.30	17.23	0.25	-4.58
SAID	434710.449	3457034.361	41.948	20.19	2.13	18.79	1.46	-8.22

For AUSPOS service, Easting velocity here

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ranges between 20.25 mm/year to 23.55 mm/year for all stations, where northing velocity ranges between 17.59 mm/year and 21.62 mm/year for all stations and vertical velocity ranges between -7.42 mm/year and -2.85 mm/year.

For APPS service, Easting velocity ranges between 18.12 mm/year to 22.36 mm/year for all stations, where northing velocity ranges between 17.23 mm/year and 19.12 mm/year for all stations and vertical velocity ranges between -8.22 mm/year and -1.25 mm/year.

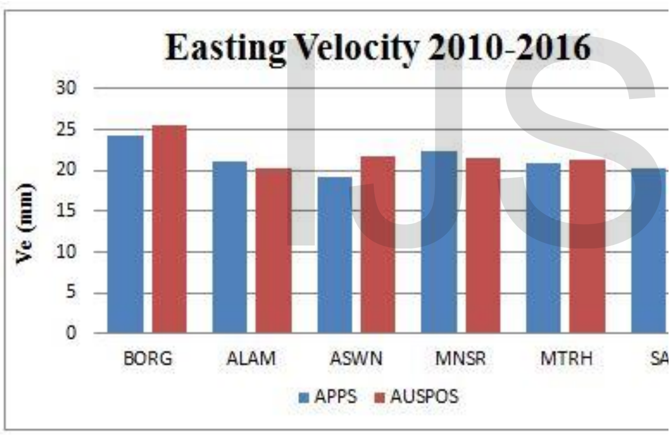
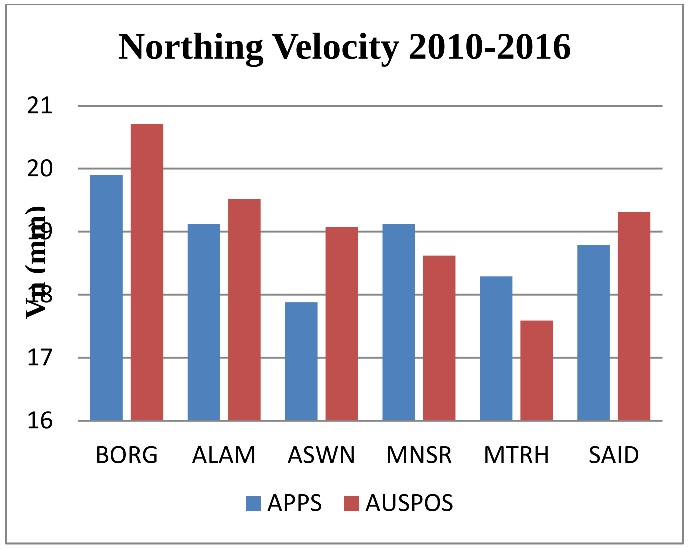
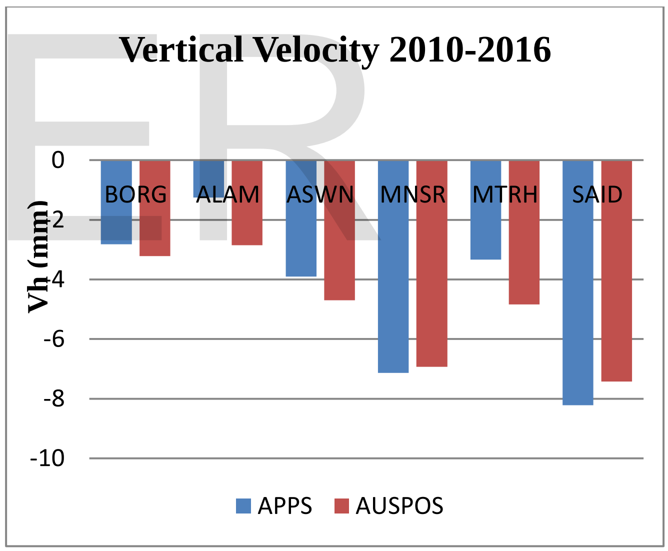


Figure (3): Easting velocity component for EPGN stations in comparison between APPS and AUSPOS



Figure(4): Northing velocity component for EPGN stations in comparison between APPS and AUSPOS



Figure(5): vertical velocity component for EPGN stations in comparison between APPS and AUSPOS

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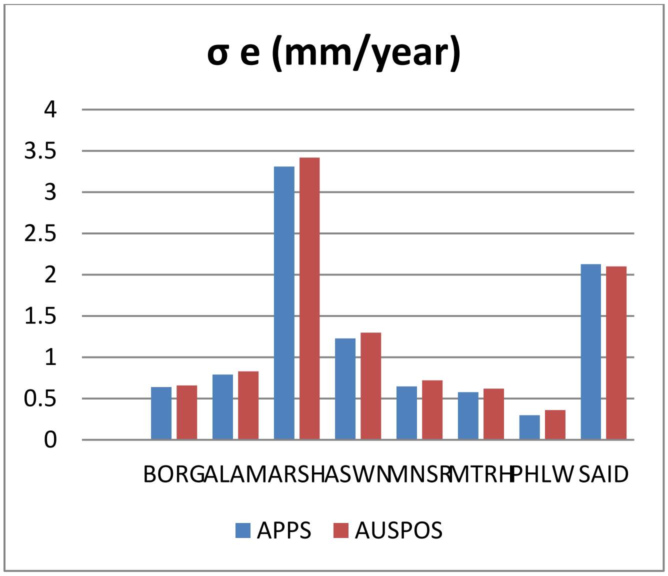
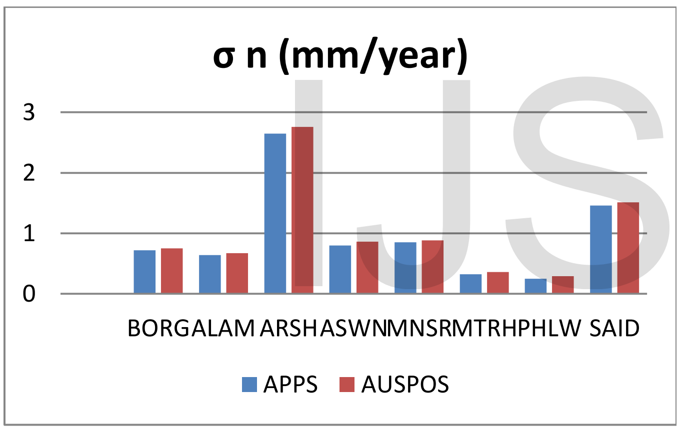


Figure(6): Standard deviation values for EPGN stations in Easting direction



Figure(7): Standard deviation values for EPGN stations in Northing direction

- From figures we can see that annual velocity and standard deviatin values is near for both services, but it is better using APPS service than using AUSPOS service, so APPS is the best service to represent data.
- We can also see that point ARSH has the maximum standard deviation value.

The residual annual horizontal velocity of the geodetic network of our area in table (7)was obtained by reducing the values in table (5) from the horizontal velocity estimated for the african plate from NUVEL 1A (**DeMets et al. 1990),** which depends on the position of station in the plate . the stations velocity within the plate were estimated using the online service at **https://www.unavco.org/software/geodetic-utilities/plate-motion-calculator/plate**

Table (7): Geodetic stations and the residual annual horizontal velocity of the area of study

Station ID	NUVEL 1A		Residual Velocity		
	Ve (mm/year)	Vn (mm/year)	Ve (mm/year)	Vn (mm/year)	Vh (mm/year)
BORG	23.93	19.95	-0.47	-3.89	-2.21
ALAM	23.18	19.65	-0.65	-3.70	-4.22
ASWN	24.03	20.07	-0.52	-4.20	-6.12
MNSR	24.22	19.80	0.43	-3.03	-9.42
MTRH	23.44	20.14	-0.94	-4.25	-1.78
SAID	24.36	19.71	-2.01	-3.57	-7.68

It can be noticed that all stations move to the northeast direction which agrees quite well with the direction of the African plate motion as shown in figure (8).

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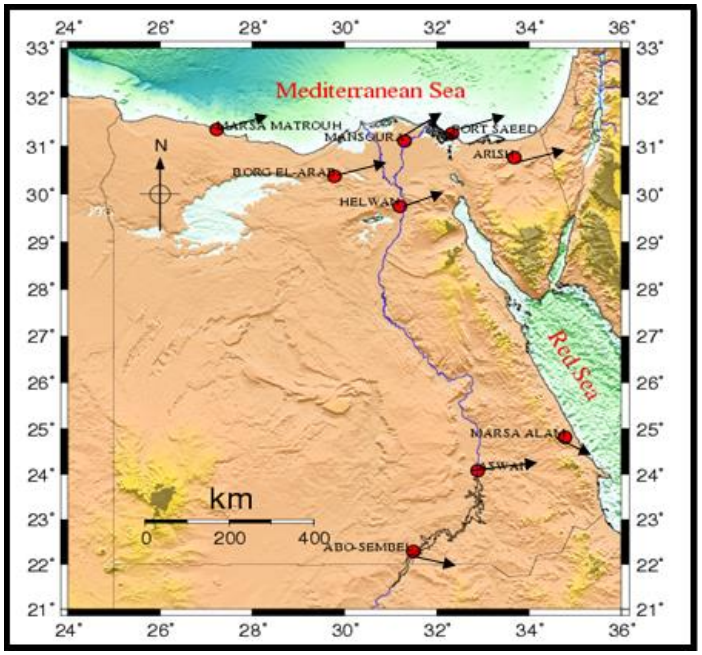

Figure (8): The Hz. Velocities of the Nile Valley network relative to PPP solution from 2010-2016.

4. CONCLUSIONS

Egypt occupies the northeastern corner of the African plate and it is not a major seismic zone, but earthquakes represent a significant hazard. Analysis of GPS campaigns of the Nile Valley network was carried out from March 2010 to October 2016. Trimble Business Center version 3.5 software package has been used to analyze our GPS measurements. In this chapter, crustal movements were processed into a relative solution using AUSPOS service and PPP solution using APPS service and from processing results, we can conclude that:

1. Velocity vector gives better accuracy with APPS service than it is with AUSPOS service.
2. Point Borg AL-Arab is under great subsidence
3. Easting velocity ranges between 18.12 mm/year to 22.36 mm/year for all stations, where northing velocity ranges between 17.23 mm/year and 19.12 mm/year for all stations .
4. vertical velocity ranges between -8.22 mm/year and -1.25 mm/yearVertical Velocity using APPS from 2010-2016 ranges between -4.76 and 7.44 mm/year.
5. Point AL-ARISH has the maximum standard deviation value.

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