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MONITORING CRUSTAL MOVEMENTS WITH GPS IN THE EAST MEDITERRANEAN AREA

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ABSTRACT

The East Mediterranean Area is one of the most tectonically active area on the earth. Therefore monitoring the current crustal movements is important and is one of the main aspects of Geodetic research.GPS observations used in this paper taken during the East Mediterranean GPS Geodynamic (EASTMED) Project. There are two GPS campaigns held in the project namely, one in October 1995 and one immediately after strong earthquake occurred in the Gulf of Eilat/Aqaba, November 1995.This paper details the GPS processing and preliminary results from two GPS campaign.

Key Words: GPS, GPS Processing, Crustal Movements, EASTMED Project.

DOĞU AKDENİZ BÖLGESİNDE GPS İLE YER KABUĞU HAREKETLERİNİN İZLENMESİ

ÖZET

Doğu Akdeniz Bölgesi, yer yuvarında tektonik olarak en aktif bölgelerden biridir. Bu nedenle güncel yerkabuğu hareketlerinin izlenmesi önemlidir ve Jeodezik araştırmaların hedeflerinden biri dir. Bu makaledeki GPS gözlemleri, Doğu Akdeniz GPS Jeodinamik Projesi (EASTMED) kapsamında ölçülmüştür. Bu projede iki GPS ölçü kampanyası; Ekim 1995 te ve Eilat/Aqaba Körfezinde meydana gelen depremden hemen sonra Kasın 1995 gerçekleştirilmiştir.

Bu makalede,belirlenen bu iki kampanyada ölçülen GPS gözlemlerinin prosesindeki ayrıntıları ve ön sonuçları sunulmuştur.

Anahtar Kelimeler: GPS, GPS Prosesleri, Yer Kabuğu Hareketleri. EASTMED Projesi.

1. INTRODUCTION

Monitoring the Earth deformation is important in order to understand geodynamics. East Mediterranean Region is one of the active area on the earth, due to probability of three tectonic plates meet in the area. Classical and space geodesy play important role in determining crustal deformation parameters, due to the fact that deformation, in general, means a change in geometric configurations. GPS is a powerful tool for monitoring crustal deformations.

One of the main aims of the East Mediterranean GPS Geodynamic Project (EASTMED) organised by the Institute of Engineering Surveying and Space Geodesy at the University of Nottingham is monitoring the crustal movements in the region by means of regional GPS network. The author involved in this project.The EASTMED project consists of two measuring Campaigns, one in October 1995 and one immediately after strong earthquake (M=7.1) occurred in the Gulf of Eilat/Aqaba, in November 1995[16].

In this paper, the EASTMED project, measuring GPS campaigns, processing strategies and the preliminary results will be presented.

2. EAST MEDITERRANEAN GPS GEODYNAMICS PROJECT (EASTMED)

The East Mediterranean GPS Geodynamics project involves representatives from a number of countries namely Egypt, Israel, Jordan, Turkey. and the UK. On 19 May 1995. The project should aim at defining a **Zero Order Network,** based on the ITRF, which could be used as

a) A base framework for monitoring crustal dynamics in a region of high interest in tectono-physics and geodynamics,
b) A network for monitoring high precision vertical displacements of major tide gauges, and hence mean sea level, for a region stretching from the Black Sea to the Red Sea, and including the Eastern Mediterranean, and
c) A common high precision horizontal and (especially) vertical datum for large engineering projects in the region, e.g. hydro-dynamic projects where high precision heighting control is essential.

The Zero Order Network could also be used as a framework for national GPS networks of the individual countries in the region, to help them define

d) A common mapping datum, compatible with the ETRF89, the European mapping datum,
e) A common coordinate reference framework for sea, land and air navigation, compatible with WGS84,
f) A framework for future DGPS and Wide-Area-DGPS regional networks, and
g) A geo-referencing system for continuous environmental monitoring in the region, in terms of water and land resources, and general ecological purposes.

The project would be carried out in two phases, starting as soon as possible. For Phase I, it was agreed that a First-Epoch GPS Campaign would be carried out from Monday 23 October to Friday 27 October 1995. The reconnaissance, station monumentation and GPS observations would be the responsibility of the organisations from the East Mediterranean countries, with some assistance from the UK Military Survey, if requested. The University of Nottingham would act as coordinators of Phase I, and would collect and distribute all of the GPS data to all of the participants, along with the following information.

a) IGS Precise ephemerides.
b) GPS data from the IGS stations.
c) Fiducial station coordinates in the ITRF for the IGS stations.

Following the meeting in Nottingham in May 1995, a network of seventeen survey stations was established within the region. A preliminary GPS campaign was carried out at these survey stations from 23 to 27 October 1995, with five days of 24 hour observation at each survey station. Shortly after the campaign ended, the 22 November 1995 Earthquake (M_w = 7.1) took place in the Gulf of Eilat/Aqaba, with reports of ground fractures, damage and collapse of buildings in Eilat in Israel, Aqaba in Jordan and the Sinai Peninsula in Egypt [6]. A repeat GPS campaign was quickly organised, and five of the fifteen survey stations were re-observed from 29 November to 2 December 1995, with five days of 24 hour observations at each survey station.

3. TECTONIC SETTING OF THE EAST MEDITERRANEAN

The Mediterranean province is one of the areas where adequate explanation of plate boundaries is expected due to the belief among geologists that a large ocean, *Tethys*, once existed between Eurasia and Africa during the Cretaceous and early Tertiary periods. Therefore, the present tectonic setting of the area is believed to be the remnant of this ocean.

The tectonic setting of the East Mediterranean region is largely governed by three major plates together with some small plates [8]. These plates are the African, Eurasian and Arabian plates (Figure 1). Present day tectonic deformation of the area is closely related to the northerly motion of the African-Arabian plate relative to Eurasia and to the medial to late Eocene events (23-50 ma) in the Red Sea. During this period, Africa and Arabia combined as a single plate closing the back arc basin of the Tethys [4]. Then the process of combination continued forming subduction of Africa underneath Eurasia. As this continued, the extension in the Red Sea and Gulf of Aden formed by the separation of Arabia from Africa, caused a convergence of the Arabian plate against Eurasia. The stresses by the convergent motion were relieved by the extrusion of continental wedges along transform faults. Consequently, Anatolion strike slip faults formed [2]. Westward lateral motion of the Anatolian plate is due to the forces concerned with the Eurasia/ Arabia collision. The Anatolian Fault that extends from East to West defines the Northern boundary of the block. In the Marmara Sea, the boundary spread out series of parallel fault systems extending into the Northern Aegean Sea. The westerly motion of Anatolia relative to Eurasia, continental collision by the Adriatic plate against Northwest Greece and Albania, and by Arabia against Eurasia, and the subduction at the Hellenic arc control the present-day kinematics of deformation in the eastern Mediterranean [11].

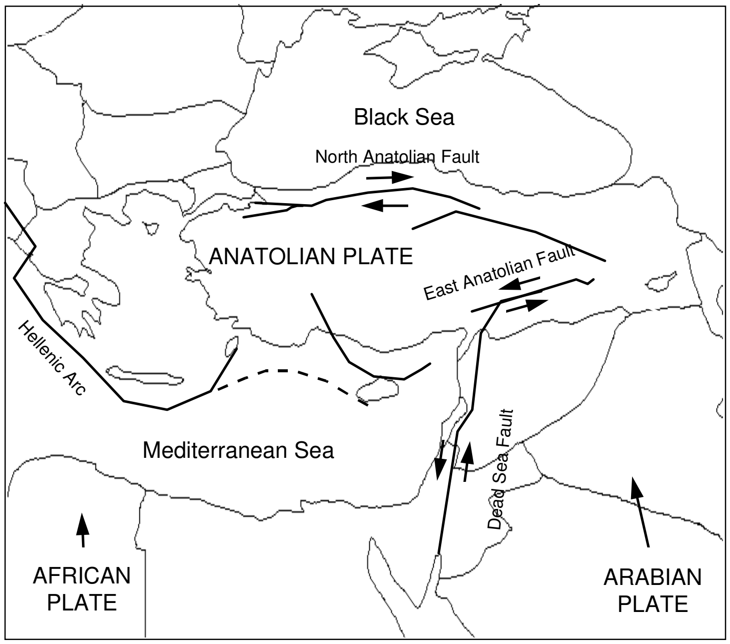

Figure 1 Simplified Tectonic Framework of East Mediterranean

According to a study by Nooman et al, [9] of the episodic crustal motions in the geologicaly active Mediterranean region using satellite laser ranging (SLR) techniques supports the hypothesis that the obliquely convergent motion between the Arabian and Eurasian plates is largely partitioned into right-lateral strike slip faulting in eastern Turkey and shortening farther North. Another study done by Noomen et al., [10] showed the deformation taking place in the area as: the Northward motion of Arabia, the lateral escape to the West of Anatolia, the NE-SW expansion in the Aegean Basin and the Northward motion of Africa being transduced into the central part of the Mediterranean.

The Arabian plate appears moving Northward and pushing Turkey (Figure 1). The motion of Eastern Turkey is characterised by distributed deformation while the motion of Central/ Western Turkey by coherent plate motion involving Westward displacement and counterclockwise rotation of the Anatolian plate. This difference in Eastern and Western Turkey to collision of Arabia may result from the different boundary conditions, the Hellenic arc forming a free boundary to the West and the Asian continent and oceanic lithosphere of the Black and Caspian Seas forming a resistant boundary to the North and the East [12].

The East Mediterranean Region has undergone several destractive earthquakes most of which are now close to modern population centers [1]. Most of these earthquakes resulted from the realtive motions between the African, Arabian and Eurasian plates.

The motion of the Arabian plate is constrained from several plate boundaries in the region [5]. These boundaries are the Gulf of Aden, the Dead Sea Transform Fault, the Red Sea, the Suez Rift and East African

Rift.The seismic slip rate calculated for the Dead Sea Transform Fault is 1-2mm per year, which is an order of magnitude smaller than Arabia-African motion [14]. Spatial distribution of earthquakes along the Israel-Jordan section of the Dead Sea Transform Fault is also non-uniform (Figure 2). Activity is mostly localised at large basins along its strike, ie the Kinneret-Hula, the Dead Sea and the Gulf of Eilat/Aqaba, whereas the inter-basin segments are quiet. This non-uniform strain release may indicate non-uniform slip rates and strain accumulation along various sections of the Dead Sea Transform Fault.The Gulf of Eilat/Aqaba is currently the most active segment of the Dead Sea Transform Fault [17] and produced the Mw=7.1 Nuweiba earthquake in November 1995 with a mean dislocation of 3m [16]. This level of activity implies that large strains are accumulating along the Arava Valley segment of the Dead Sea Transform Fault (Figure 2).The Nuweiba earthquake in 1995 is important for this study since we have two campaigns of GPS data (October 1995, and just after the earthquake, November 1995) from the East Mediterranean GPS Geodynamics Project(EASTMED).

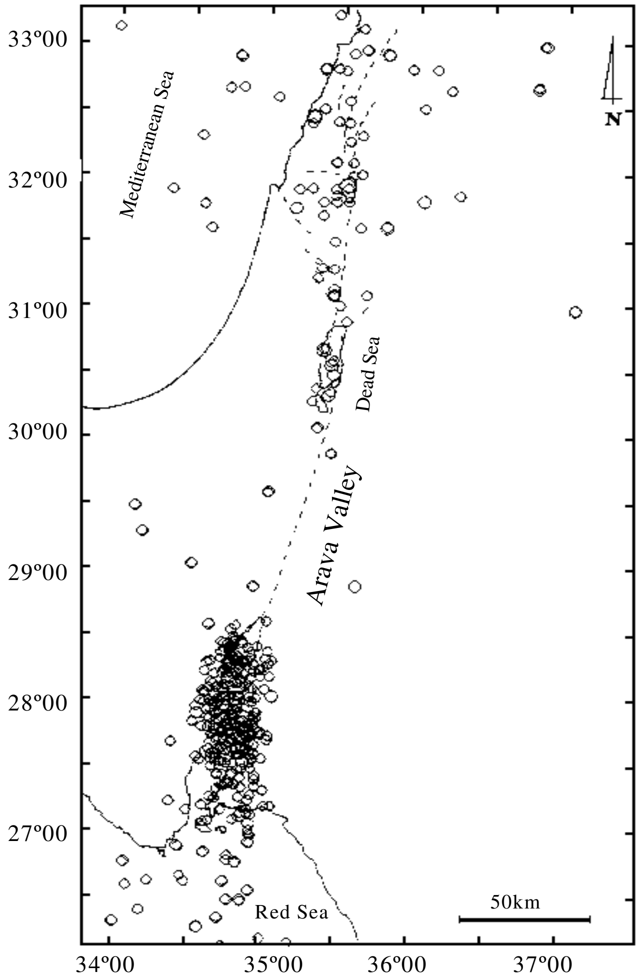

Figure 2 Seismicty Along the Dead Sea Transform Fault: 1900-1996

4. FIELD CAMPAIGNS SUMMARY

The October 1995 Campaign measurements were carried out at a total of seventeen stations being five in Turkey, one in Cyprus, seven in Israel, three in Jordan and one in Egypt. A summary of the stations is given in Table 1. In the November 1995 Campaign, measurements were carried out at a total of seven stations being four in Israel, two in Jordan and one in Egypt. A summary of the stations is given in Table 2.

Station Information

Station Name	Station Type	Station Code	Approx Coordinates Latitude	 Longitude
Samsun	Tide Gauge	SAMS	41 20 N	36 20 E
Ankara IGS	Other	ANKR	39 41 N	32 44 E
Mentes	Tide Gauge	IZMI		
Melengicik SLR	Other	MELE	37 12 N	33 11 E
Antalya	Tide Gauge	ANTG	36 49 N	30 36 E
Cyprus	Other	CYPR	34 42 N	32 51 E
Haifa	Tide Gauge	HAIF	32 50 N	34 57 E
Haifa Technion)	Other	TECH	32 47 N	35 01 E
Tel Aviv	Other	TARD	32 04 N	34 47 E
Bar Giy SLR	Other	BARG	31 43 N	35 05 E
Beer Sheva	Other	BEER	31 16 N	34 48 E
Mizpe Roman	Other	MIZP	30 36 N	34 46 E
Eilat	Tide Gauge	ELAT	29 31 N	34 55 E
Dala	Other	DALA	32 08 N	35 37 E
Shobak	Other	SHOB	30 33 N	35 32 E
Aqaba Area	Tide Gauge	AQAB	29 31 N	35 00 E
Helwan SLR	Other	HELW	29 52 N	31 21 E

Observation Information

Date	Day of the week	Julian day & Session	START Time (UT)	STOP Time (UT)
23.10.1995	Monday	296-1	0000	1200
		296-2	1230	2359
24.10.1995	Tuesday	297-1	0000	1200
		297-2	1230	2359
25.10.1995	Wednesday	298-1	0000	1200
		298-2	1230	2359
26.10.1995	Thursday	299-1	0000	1200
		299-2	1230	2359
27.10.1995	Friday	300-1	0000	1200
		300-2	1230	2359

Table 1 Satiation and Observation Information in October 95 Campaign

Station Information

Station Name	Station Type	Station Code	Approx Coordinates Latitude	Longitude
KATZ	Other	KATZ	33 00 N	35 41 E
Tel Aviv	Other	TARD	32 04 N	34 47 E
Bar Giyorra SLR	Other	BARG	31 43 N	35 05 E
Eilat	Tide Gauge	ELAT	29 31 N	34 55 E
Dala	Other	DALA	32 08 N	35 37 E
Aqaba	Tide Gauge	AQAB	29 31 N	35 00 E
Helwan SLR	Other	HELW	29 52 N	31 21 E

Observation Information

Date	Day of the week	Julian day & Session	START Time (UT)	STOP Time (UT)
29.11.1995	Wednesday	333-1	0000	1200
		333-2	1230	2359
30.11.1995	Thursday	334-1	0000	1200
		334-2	1230	2359
01.12.1995	Friday	335-1	0000	1200
		335-2	1230	2359
02.12.1995	Saturday	336-1	0000	1200
		336-2	1230	2359

Table 2 Station and Observation Information in November 95 Campaign

5. GPS PROCESSING STRATEGY

The EASTMED data have been processed by using the software GAS (GPS Analysis Software developed by the IESSG)[19]. In processing, the IGS precise ephemeris [20]and ionospshericly free observable[3] were used, and corrections were applied for tropospheric delay (using the Magnet standard model and solving for tropospheric scale foctors as a stepwise function per station)[18] and a model for antenna phase centre variations[13,15]. The estimation of the coordinates of the stations were computed with respect to the ITRF93 (epoch 1995.82). Details of the whole strategy are given in the following.

The available data were collected in floppy discs form the observing agencies along with their booking sheets. The conversion of the observation data files from the manufacturers raw format to RINEX format is carried out using the Bernese Programes TRRINEXO for Trimble receivers and ASRINEXO for Ashtech receivers. Any 24 hour observation data files in RINEX Format were edited using WS (Wordstar) to produce two separate 12 hour observed data files in RINEX format. Then all of the 12 hour observation data files were edited using WS (Word Star) in order to input the L1/L2 phase centre, antenna heights used in GAS.

From the RINEX format observation data file headers, the coordinates were collected for the station from all sessions. Then the collected coordinates were averaged to improve the approximate station positions. The conversion of observation data files from RINEX format to the GAS NOTT2 format was then carried out using the IESSG Program FILTER, with the pseudo-range option used to check the approximate station positions. FILTER was also used to correct large cycle slips and delete any unwanted data, such as satellites which fall and then rise again in the same processing session.

When using GAS in the cleaning stage, cycle slips are detected using double and triple differences for a specified baseline. The station TARD was accepted as the origin station with good approximate coordinates. The source coordinates computed in the ITRF93 (epoch 1995.82) with respect to the IGS station in Wettzell, and with TARD being assumed to be clean from cycle slips.

The baselines relative to TARD were then cleaned using the IESSG Program PANIC in single baseline mode. In this mode, six base satellites were defined providing whole 12 hours cover without a break. If any slips detected on a particular baseline, the slips are cleaned using the IESSG Program SLIPCOR.

This procedures was repeated for all stations and all the sessions. Once all of the baselines in the regional network were cleaned, a network solution was computed for each session using the IESSG Program PANIC, in network adjustment mode. The baseline used in the cycle slip cleaning and network solution are shown in Figure 3. After computations of these session solutions, a campaign solution was then computed using the IESSG Program CARNET[7]. Once a campaign solution had been obtained, repeatabilities of the coordinates and baselines were computed using the IESSG Program REPDIF in order to obtain precision estimates.

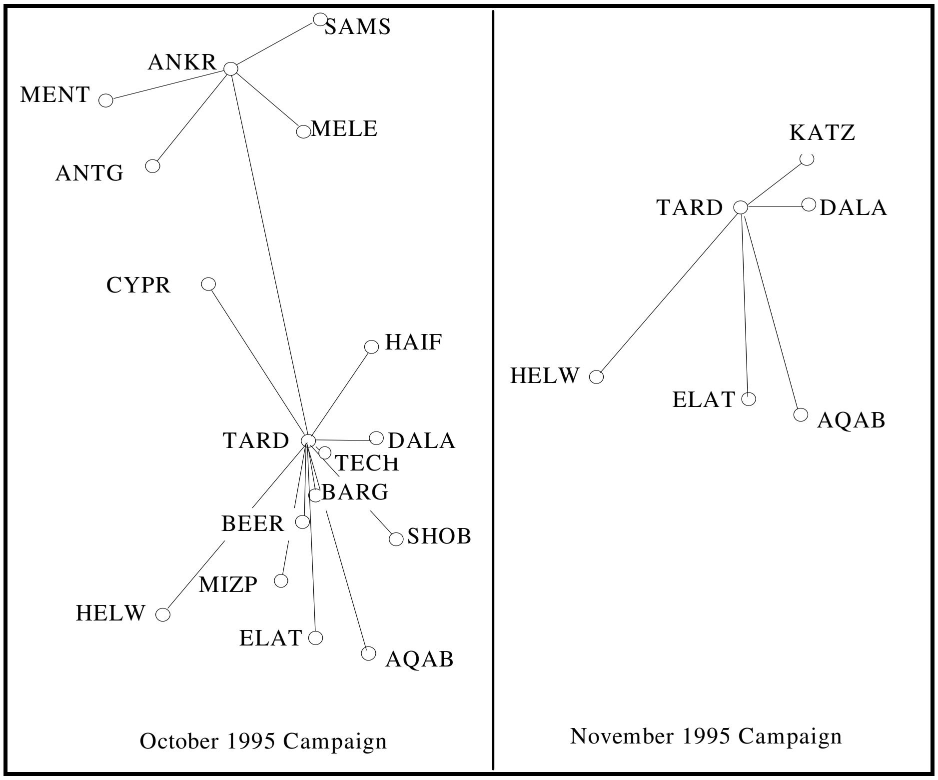

Figure 3 Baselines Used in the Cycle Slip Cleaning and Network Solution

6. RESULTS

The repeatabilities of station coordinates are given in Figure 4 for the October 1995 Campaign and and Figure 5 for the November 1995 Campaign. In these figures only the five stations common to both campaigns are illustrated.

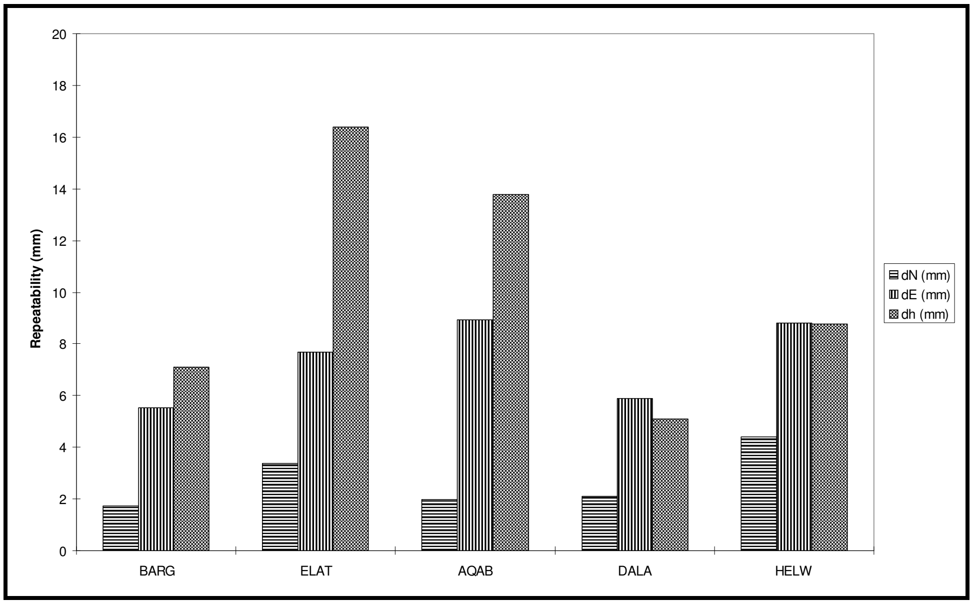

Figure 4 Coordinate Repeatabilities in October 95 Campaign

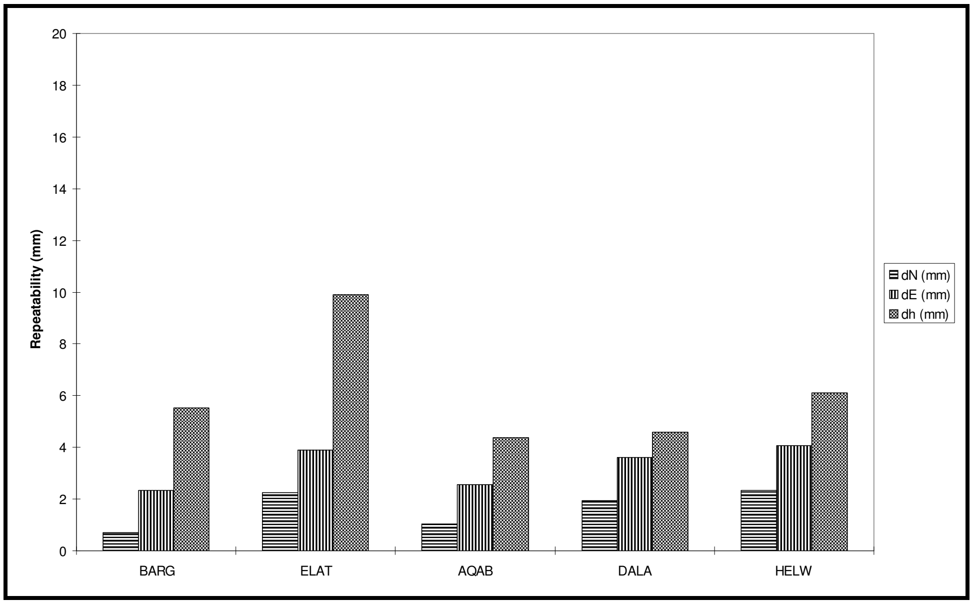

Figure 5 Coordinate Repeatabilities in November 95 Campaign

These results demonstrate that the coordinate precisions were slightly better in the November 95 compaign. The plan coordinate precisions being 2 to 9 mm and 1 to 4 mm in the two campaigns. The height precisions being 7 to 16 and 4 to 10 mm in the two campaigns. Here it should be noted that these values are based on the deviations of a single sessional solution from the weighted mean campaign solution, and do not involve any transformations between sessional and campaign solutions.

A comparison of the baseline components determined for the two campaigns (October and November 1995) is presented in Table 3. These baseline differences are also divided by the baseline length to give the equivalent ppm value from which a significant movement can be detected.

From	To	dx (mm)	ppm	dy (mm)	ppm	Dz (mm)	ppm	db (mm)	ppm
TARD	BARG	-2.20	-0.04	12.0	0.24	-7.30	-0.15	13.79	0.28
TARD	ELAT	7.50	0.02	17.0	0.06	-23.7	-0.08	28.91	0.10
TARD	AQAB	-11.3	-0.4	19.3	0.068	-2.80	-0.01	4.93	0.01
TARD	DALA	-3.9	-0.04	2.3	0.02	0.1	0.0	4.22	0.05
TARD	HELW	4.9	0.01	-1.8	-0.0	-0.50	-0.0	4.57	0.01
BARG	ELAT	9.7	0.03	5.0	0.02	-16.4	-0.06	19.67	0.08
BARG	AQAB	-9.1	-0.03	7.3	0.03	4.50	0.01	-5.93	-0.02
BARG	DALA	-1.7	-0.02	-9.7	-0.14	7.4	0.10	1.73	0.02
BARG	HELW	7.1	0.01	-13.8	-0.03	6.8	0.01	10.04	0.02
ELAT	**AQAB**	**-18.8**	**-2.5**	**2.3**	**0.3**	**20.9**	**2.79**	**14.87**	**1.99**
ELAT	DALA	-11.4	-0.3	-14.7	-0.049	23.8	0.08	27.62	0.09
ELAT	HELW	-2.6	-0.0	-18.8	-0.05	23.2	0.06	17.19	0.04
AQAB	DALA	7.4	0.02	-17.0	-0.05	2.90	0.01	0.73	0.00
AQAB	HELW	16.2	0.04	-21.1	-0.05	2.3	0.0	26.48	0.07
DALA	HELW	8.8	0.01	-4.1	-0.0	-0.6	0.0	8.68	0.01

Table 3 Baseline Vector Differences (mm & ppm) (Oct 95 minus Nov 95)

It was anticipated that the three survey stations which were not close to the Earthquake epicentre, ie Helwan (HELW) in Egypt, Bar Giyorra (BARG) in Israel, and Dala (DALA) in Jordan, would not have been affected by the Earthquake and would not have moved over the short period of 5 weeks between the two preliminary GPS campaigns. However, we did expect that the two survey stations at Eilat (ELAT) in Israel and Aqaba (AQAB) in Jordan, which are located on either side of the Dead Sea Transform Fault (DSTF) to the North of the Gulf of Eilat/Aqaba, could have been affected by the Earthquake some 120 km to the South.

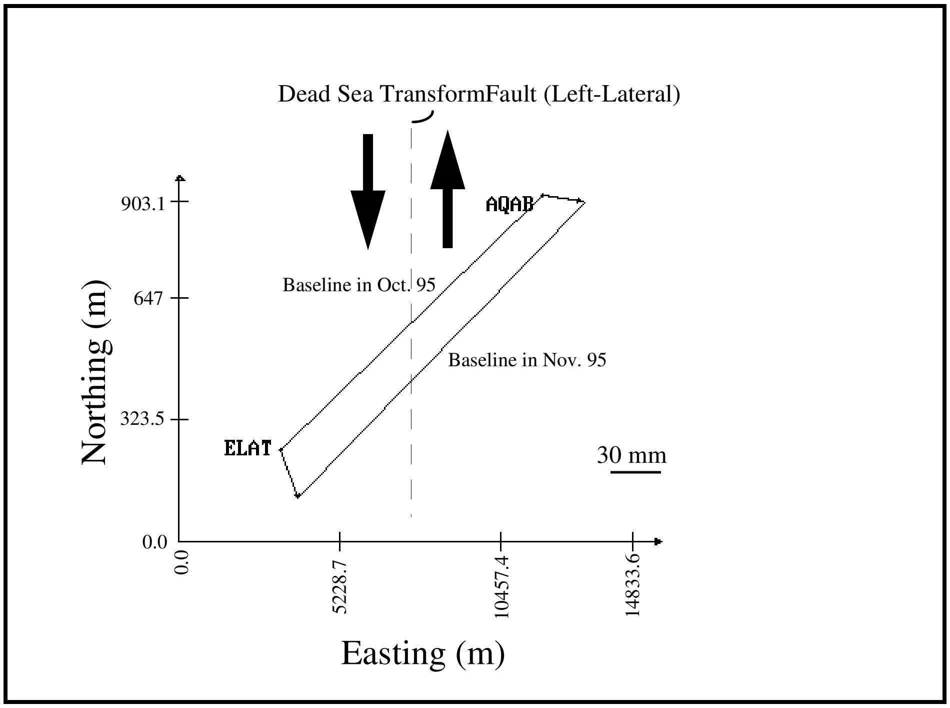

Figure 6 Baseline Extension Between Eilat/Aqab

From Table 3 it can be seen that the baseline Elat-Aqab shows the largest proportional difference which can be attributed to ground movement occurring within the 37 days between the two campaigns. In Figure 6, the ELAT/AQAB baseline is illustrated in both October and November 1995 campaigns.

According to the DSTF, it is clear that the station Elat moved in an anticipated direction. The baseline experienced 15mm (or 2 ppm) extension and 0″.68 seconds of arc anticlockwise rotation.

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