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DEFORMATION STUDIES IN THE CORINTHIAN GULF VIA MULTI-EPOCH ANALYSIS OF GEODETIC DATA

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Abstract

The area of the Corinthian Gulf, in Greece, being one of the densely populated, seismically active parts of Greece, is considered suitable for monitoring deformations. Thus, since 1990, the Higher Geodesy Laboratory of the NTUA and the Seismology Department of the Institut de Physique du Globe de Paris, within the frame of European multi-disciplinary research programmes concerning the evaluation of the tectonic behaviour of the Gulf, have carried out nine geodetic campaigns. A geodetic GPS control network of about 200 points, spread over an area of 10000 km^2 on both sides of the Gulf, was established piecewise. As the study of the long period deformation was of interest, more than half of the network points were chosen to belong to the Hellenic triangulation network.

In the present study, since the GPS data acquired are sparse both in space and time, statistically acceptable strain parameters are evaluated via a multi-epoch deformation model.

1. Introduction

During the last decade, deformation studies combining geodetic, seismic and geotectonic observations are being carried out on a systematic basis in various areas of Greece, since Greece is one of the most seismically active parts of Europe (Jackson J., McKenzie D., 1988).

The Gulf of Corinth is an asymmetric extending rift with recurrent seismic activity, due to an active system of en echelon normal faults, dipping north at 40^o to 55^o, situated mostly in the Southern coast of the gulf which is subject to uplift.

The earthquake magnitudes of the seismic events occurring in the region are occasionally as high as M ~5.5) 6.5. During the last decade, while the geodetic observation campaigns were taking place, two such earthquakes occurred in the vicinity: the Galaxidi earthquake (18/11/1992, M=5.9) and the Aigion one (15/06/1995, M=6.2).

2. Geodetic Measurements

Within the frame of a European multi-disciplinary research program a dense network was established in the area of the Corinthian Gulf, in order to monitor its tectonic behaviour. Nine campaigns of GPS measurements were carried out during the interval 1990-2001 (Table 1).

GPS Campaigns	1990	1991	1992	1993	1994	1995.5	1995.8	1997**	2001
Starting date	08/05	30/08	27/11	10/05	20/09	16/06	03/10	29/09	18/09
Ending date	18/05	10/09	05/12	22/05	02/10	24/06	14/10	10/10	29/09
Number of 1 st order points	7	23	9	43	16	23	51	12	35
Number of 2 st order points	-	9	-	34	24	22	84	10	23

Recent earthquakes	*φ (°)	*λ(°)	Length (km)	Strike (°)	Dip (°)	Slip (m)
18/11/1992 Galaxidi	38.30	22.45	14	270	30	.21
15/06/1995 Aigion	38.36	22.20	14	277	35	.87

Table 1. Overview of the GPS campaigns and parameters of the recent earthquakes for the Gulf of Corinth.

* The positions (φ, λ) refer to the projection on the surface of the centre of the upper edge of the fault.

** The data were acquired within the frame of a project in the vicinity of Euboea

This network of about 200 points, spread over an extended area (~10000 km^2) on both sides of the Gulf, was established in a piecewise manner. About 150 of these points are pillars of the Hellenic triangulation network while the rest comprise the first order GPS network. For all the pillars, positions in the ***H**ellenic **G**eodetic **R**eference **S**ystem* (HGRS 87) were available, based on field work that took place during the period 1966 - 1973. The coordinates of these Hellenic network points were considered as referring to the fictitious mid-epoch of 1970, since no detailed information concerning the temporal distribution of the old geodetic observations was available.

Nowadays, a rather large amount of observations has been accumulated. Nevertheless, since not all of the points were reoccupied during each campaign, the GPS data acquired, are sparse both in space and time (Figure 1).

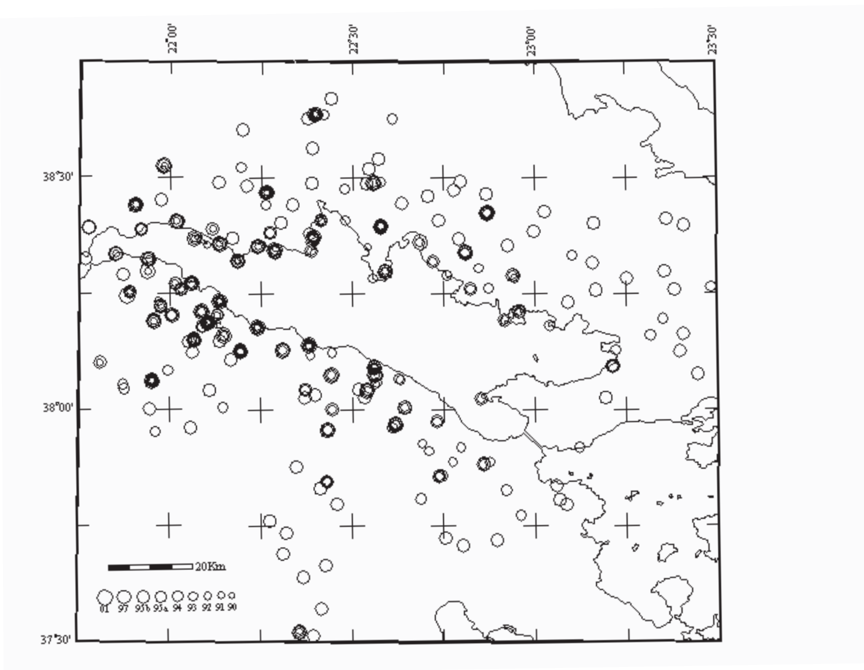

Figure 1. Repeatability of the observed network points for all epochs

3. Data Analysis

All data were processed using the same version 10.0 of the GAMIT software and the same processing strategies. IGS precise orbits were used together with the GPS data from 3 to 11 surrounding permanent IGS stations in order to constrain the absolute coordinates of the network in the ITRF2000 (A. Avallone et al., 2003).

Software was developed for the least squares estimation of the parameters of a two-dimensional linear deformation model assuming homogeneous deformation.

The software provides for breaking up the region into several blocks and may accept simultaneously as many input files as the epochs of observations (multi-epoch model). Thus, it utilizes positional information sparse both in space and time, and solves for the deformation rate inside each block as well as for the translation components.

The multi-epoch model used, deals only with the secular deformation rate. The additional parameters for episodic motion were not considered, as the so far accumulated GPS data do not allow for their reliable estimation.

Two blocks (one in Sterea Hellas and one in Peloponessos), were considered as best describing the tectonic behavior of the area (Table 2).

Deformation parameters for both blocks were estimated:

a. By the multi-epoch model, using the 11 years GPS data referring to an initial epoch of 1990. In order to detect, if possible, the influence of the co-seismic motion the epochs were grouped appropriately.

b. Using a smoothed velocity field (after the elimination of the average co-seismic motion) (Figure 2).

c. By the multi-epoch model, using the 11 years GPS data as in (**a.**) as well as the old triangulation data referring to the fictitious epoch 1970. In Figure 3 the velocity vectors are depicted between the mid GPS epoch of 1995.8 and the old 1970 data.

In the two first cases the coordinates of all points refer to ITRF2000, while in the last one the coordinates were expressed in the ***H***ellenic ***G***eodetic ***R***eference ***S***ystem 87 (HGRS 87) and point E in the south block was arbitrarily held fixed (A.M.Agatza-Balodimou et al., 2002).

4. Results-Conclusions

The most characteristic of the cases considered are presented in *Table 2.* One can notice an almost N-S opening direction of the Gulf in all cases. The same conclusion is drawn from the two velocity fields (Fig. 2 and 3), although they refer to different geodetic reference frames.

In all cases examined the strain parameters had high values, indicating significant deformation not adequately documented from the data. In the case with the smoothed velocity field (Table 2, column 3), which seems to fit better the model (σ_o ~2-3mm), the strain parameters appeared even more significant for both blocks (Figure 4).
In the case of the old data, where the long term continuous (secular) tectonic behavior was sought after, the strain parameters had lower values (Table 2, column 4). Comparing these results with the ones from previous work (A.M.Agatza-Balodimou et al., 2002), it appears that the recent GPS data have contributed to the better fitting of the model for the long term behaviour (the rms of the model is improved by more than 30%).

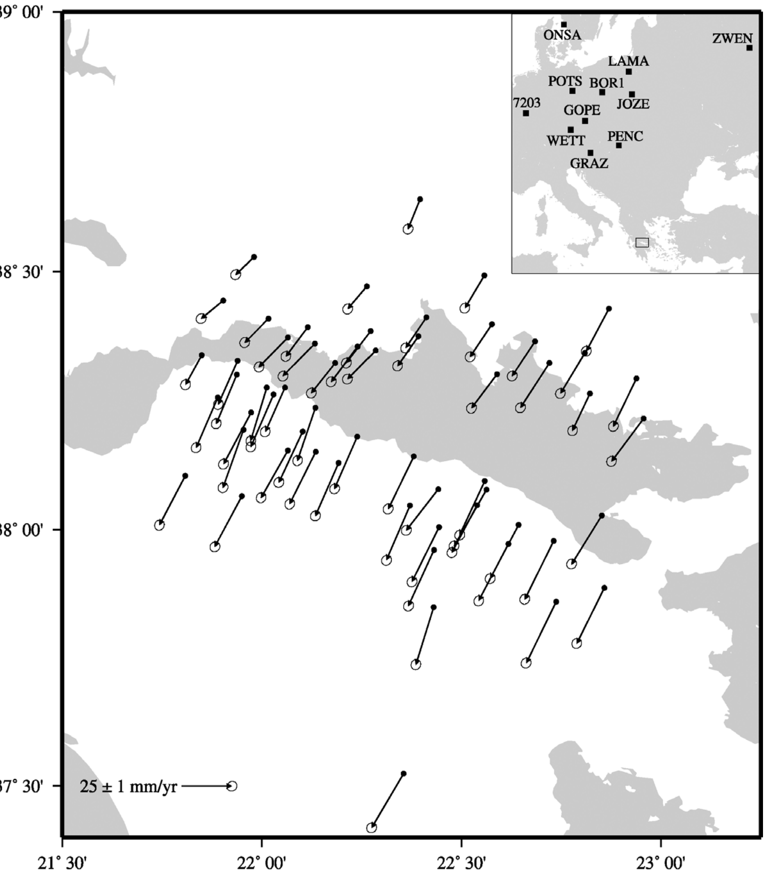

Figure 2. Smoothed velocity field

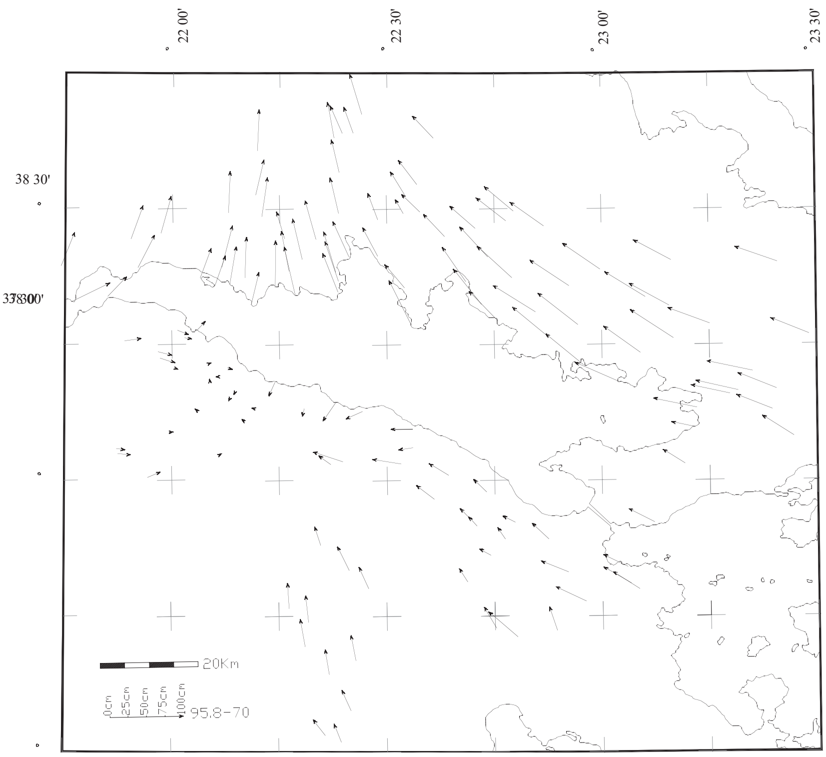

Figure 3. Velocities between conventional epochs 1970 and 1995.8

		Epochs 1990 1995.8	All Epochs	Smoothed Data	Old Data + GPS
North block	d_E (mm/yr)	1±1	2±1	0±1	0±1
	d_N (mm/yr)	20±1	16±1	8±1	9±1
	ρ (Bstr/yr)	-.06±.04	.04±.03	.11±.03	.00±.05
	ω (Bstr/yr)	.11±.04	.10±.06	.10±.03	.09±.05
	γ (Bstr/yr)	.11±.04	.19±.03	.22±.03	.08±.05
	A (degrees)	*58°.2*	*28°.1*	*13°.6*	*163°.6*
	e_{max} (Bstr/yr)	-.00±.05	.13±.04	.21±.04	.04±.06
	e_{min} (Bstr/yr)	-.11±.05	-.06±.03	-.00±.02	-.05±.04
	σ_o (mm/yr)	**25**	**29**	**3**	**24**
South block	d_E (mm/yr)	-3±1	-2±1	-2±1	-2±1
	d_N (mm/yr)	6±1	5±1	-1±1	3±1
	ρ (Bstr/yr)	-.06±.03	.04±.02	.08±.02	.03±.02
	ω (Bstr/yr)	.03±.03	.02±.02	.01±.02	.02±.02
	γ (Bstr/yr)	.19±.03	.19±.02	.21±.02	.12±.02
	A (degrees)	*55°.6*	*25°.2*	*5°.3*	*19°.9*
	e_{max} (Bstr/yr)	.04±.04	.13±.03	.18±.03	.09±.03
	e_{min} (Bstr/yr)	-.15±.03	-.05±.02	-.03±.02	-.03±.02
	σ_o (mm/yr)	**18**	**17**	**2**	**12**

Table 2. Comparisons of the strain parameters as derived of the available data for the "North -South" case. The parameter A represents the Azimuth of the maximum strain rate.

It should be mentioned that the rotation rate of the north block remains almost the same, of the order of 0.10μstr/yr (5.7°/ Myr) for all the cases. This value is in good agreement with previous geophysical and other geodetic estimations. The south block seems to rotate only by 1°/ Myr. A small discrepancy from (A. Avallone et al., 2003) may be due to the different model considered.

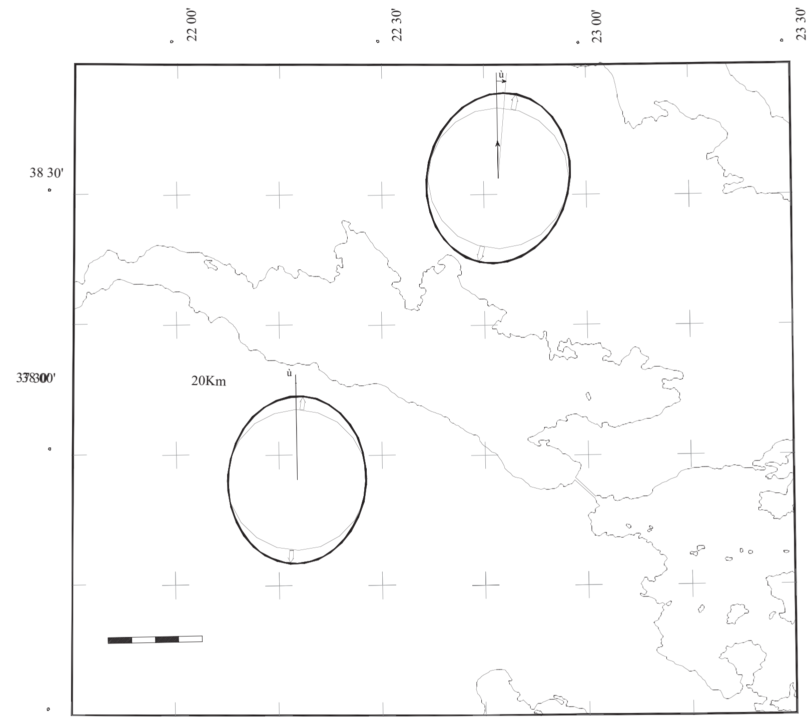

Figure 4. Strain ellipses, translation vectors and rotations corresponding to 1Myr drawn to the map scale, according to the multi-epoch model for all GPS data (Table2, Col. 2).

This consistency of the rotation rates′ values was the reason for trying a simplified model with only rotation and translation parameters.
In the multi-epoch cases, using the 11 years GPS data, this model appeared inappropriate (σo ~5-7cm), while when using the smoothed velocity field the fitting of the model proved satisfactory (σo ~2-3mm). In the latter case the rotation of the south block is in agreement with the value provided through a different approach (A. Avallone et al., 2003).

Geodetic data offer very useful information for monitoring crustal deformations, provided that a good spatial and temporal coverage is available.
It is believed that for a better understanding of the behaviour of the south block, which is of geophysical interest, existing points in central Peloponessos should be reoccupied, as there is a relative lack of data in its interior.

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