DEFORMATION STUDIES IN THE WESTERN PART OF THE GULF OF CORINTH (GREECE): FIRST RESULTS FROM GPS CAMPAIGNS, ACCURACY AND COMPARISON WITH TRIANGULATION DATA

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ABSTRACT

As part of a seismotectonic study of the Gulf of Corinth, we carried out two GPS campaigns in 1990 and 1991. We occupied 34 sites, including 22 pillars of the 1966-72 greek triangulation network, in the Patras-Aigion region on both sides of the Gulf. The network was designed to quantify the extension of the gulf and give the possibility to measure the coseismic deformation in case of large earthquake. Three software packages were used to process the GPS data (GPPS-Ashtech, GAMIT, BERNESE). The average repeatability of the baseline length using GAMIT is 3-4 mm, almost independent of the baseline's length. The average and maximum scatter between GAMIT and BERNESE are 2 mm and 10 mm. The accuracy of the triangulation previously estimated to be in the 5-10 cm range, is emphasized by the consistency of the two sets of coordinates of points in the northern part of the Gulf supposed to remain undeformed. A 30 cm average displacement is found between points located on opposite sides of the Gulf. We conclude that N-S extension is occuring across the Gulf of Corinth at a rate of 1.5 +/- 0.5 cm/yr, over a width of at most 25 km. A GPS campaign is planned in 1993 to reoccupy some old stations and extend the network eastward.

ΜΕΛΕΤΕΣ ΠΑΡΑΜΟΡΦΩΣΗΣ ΣΤΟ ΔΥΤΙΚΟ ΤΜΗΜΑ ΤΟΥ ΚΟΡΙΝΘΙΑΚΟΥ ΚΟΛΠΟΥ: ΠΡΩΤΑ ΑΠΟΤΕΛΕΣΜΑΤΑ ΑΠΟ ΤΙΣ ΜΕΤΡΗΣΕΙΣ GPS,ΑΚΡΙΒΕΙΑ ΚΑΙ ΣΥΓΚΡΙΣΗ ΜΕ ΔΕΔΟΜΕΝΑ ΤΡΙΓΩΝΙΣΜΟΥ

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ΠΕΡΙΛΗΨΗ

Η σεισμοτεκτονική μελέτη του Κορινθιακού κόλπου έγινε κατά την διάρκεια 2 ετών (1990-1991). Σαν μέρος αυτής της μελέτης έγιναν μετρήσεις GPS στην περιοχή. Η μελέτη έγινε σε 34 θέσεις,

εκ των οποίων στις 22 υπήρχαν ενδεικτικές στήλες από το Ελληνικό δίκτυο (1966-1972) του συστήματος τριγωνισμού, τόσο στην Πάτρα όσο και στο Αίγιο, δηλ.και στις δύο πλευρές του κόλπου. Το δίκτυο έχει σχεδιασθεί για να μετράει την επέκταση του κόλπου και δίνει την δυνατότητα να μετράται η σεισμική παραμόρφωση σε περίπτωση μεγάλου σεισμού. Τρία πακέτα (GPPS-Ashtech, GAMIT,BERNESSE) προγραμμάτων H/Y χρησιμοποιήθηκαν για την επεξεργασία των GPS δεδομένων. Η μέση επαναληψιμότητα του μήκους κάθε γραμμής (χρησιμοποιώντας το GAMIT) είναι 3-4mm, σχεδόν ανεξάρτητη από το συνολικό μήκος της γραμμής. Η μέση και η μέγιστη διασπορά μεταξύ του GAMIT και του BERNEST είναι 2mm και 10mm αντίστοιχα. Η ακρίβεια του τριγωνισμού είχε εκτιμηθεί προηγουμένως μεταξύ 5-10cm, τονίζεται από την συμφωνία μεταξύ των 2 ομάδων των συντεταγμένων των σημείων στο βόρειο τμήμα του κόλπου υποθέτοντας ότι δεν έχει παραμορφωθεί το μέρος αυτό. Βρέθηκε μιά μέση μετατόπιση 30cm μεταξύ σημείων που βρίσκονται στις αντίθετες μεριές του κόλπου. Συμπεραίνουμε ότι συμβαίνει μιά επέκταση με διεύθυνση B-N στον Κορινθιακό κόλπο με ρυθμό 1.5(±0.5) cm/y σε μιά περιοχή πλάτους περίπου 25 km. Οι νέες μετρήσεις GPS θα επαναληφθούν και το 1993 αφενός παίρνοντας μετρήσεις σε μερικά παλιά σημεία και αφετέρου επεκτείνοντας το δίκτυο ανατολικότερα.

INTRODUCTION

The Gulf of Corinth is an active deforming area which is commonly described as an E-W half-graben structure. The present active deformation of the gulf is demonstrated by the presence of Holocene scarps along the fault traces and by quaternary uplifted marine terraces in the Corinth-Xylokastro area. Few large earthquakes occurred in this region during the last century, e.g.: Helike in 1861 (M=6.6-6.7; Schmidt, 1881; Papazacchos & Papazachou, 1989), Eratini in 1965 (M_s=6.4; Ambraseys & Jackson, 1990), Corinth in 1981 (M_s=6.7, 6.4, 6.4; Jackson et al, 1982; King et al., 1985), Itea in 1992 (M_s=6.0, Briole et al., same issue). The most active E-W trending normal faults are located on the southern coast of the Gulf, the normal faults on the northern coast being considered as antithetic faults. A first estimation of the rate of extension across the Gulf of about 1 cm/yr was deduced by Billiris et al., (1991) from a comparison between old triangulation data (~ 1890) and GPS measurements carried out in 1988 at the scale of the entire continental Greece.

In order to have a more precise understanding of the deformation mode of the Gulf of Corinth, we started a multidisciplinary study in the Patras-Aigion area combining seismological, tectonic and geodetic studies (see Rigo et al., same issue).

During two field campaigns in 1990 and 1991, we installed a dense geodetic (GPS) network in this area (Fig. 1). This network was designed to measure the extension rate and its spatial gradients across the gulf. These data are fundamental to assess the seismic and aseismic parts of the deformation during the seismic cycle. In case of a large earthquake, of course, the same network will be used to measure the coseismic deformation (horizontal and vertical displacements).

During both GPS campaigns, we occupied 34 sites (7 in 1990 and 32 in 1991) using 3 receivers in 1990 and 8 in 1991, all Ashtech dual-frequency codeless receivers. In this paper, we are dealing only with the results of the 1991 campaign. During this campaign, we occupied each point 4 times, 6-7 hours, at night to minimize the ionospheric and tropospheric pertrations. Among the 34 points, 5 are common to the 1988 GPS "Central Greece" campaign (Billiris et al., 1991) and 22 are pillars of the 1966-1972 Greek Triangulation Network. This link provides us with a first, relatively good, determination of the displacements and the crustal deformations across the Gulf of Corinth at the local scale.

DATA ANALYSIS

Three software packages were used to process the GPS data:
- 1, GPPS (by Ashtech inc.) to have a quick look at the quality of the data and a first set of coordinates.
- 2, GAMIT (developed at MIT, USA) as the main software.
- 3, BERNESE (developed at the University of Berne-Switzerland), to check the GAMIT solutions.

For each day, we processed all the possible combinations of baselines (i.e. 28 for the 8 receivers operated simultaneously) except with BERNESE (14 per day).

We made the tropospheric correction using the parameters (temperature, humidity, pressure) measured in the field averaged over the whole 6-7 h session. This approximation was possible due to the very stable troposphere at night.

The GPPS processing was done in L1 mode (single-frequency). This option is not accurate on long baselines because the ionospheric delay is not taken into account as in the L_1C option, but it provides a good set of coordinates to start with the other, more sophisticated softwares. Moreover, the processing in L1 allows to check the ambiguities fixing and the residuals give an interesting quick look at the quality of the data and at the ionospheric fluctuations. This quality was found to be good with small ionospheric perturbations. GPPS software fixed almost all the ambiguities in the L_1 option, even for the longer baselines (60-70 km long), or for the baselines with large elevation differences (700-1400 m).

We then processed the data with GAMIT starting with the coordinates given by GPPS. The GAMIT package includes an easy interactive graphic data editor. We used this tool to correct the data for cycle-slips and for some bad quality data encountered at low satellite elevations. Further, the same refined data files were used as input to the final calculation of GAMIT and BERNESE.

For each baseline measured more than once, figure 2 shows the rms scatter on the baseline versus its length. The average of the rms scatters, i.e. the mean repeatability of the baseline's lengths, is about 3-4 mm. This 3-4 mm level is what we estimate to be the global accuracy of our 1991 network. It corresponds to a relative accuracy of 0.05 ppm. The absence of increase of the rms scatter with increasing baseline length suggests that part of the remaining errors may be due to local errors in centering the antenna over the GPS marker.

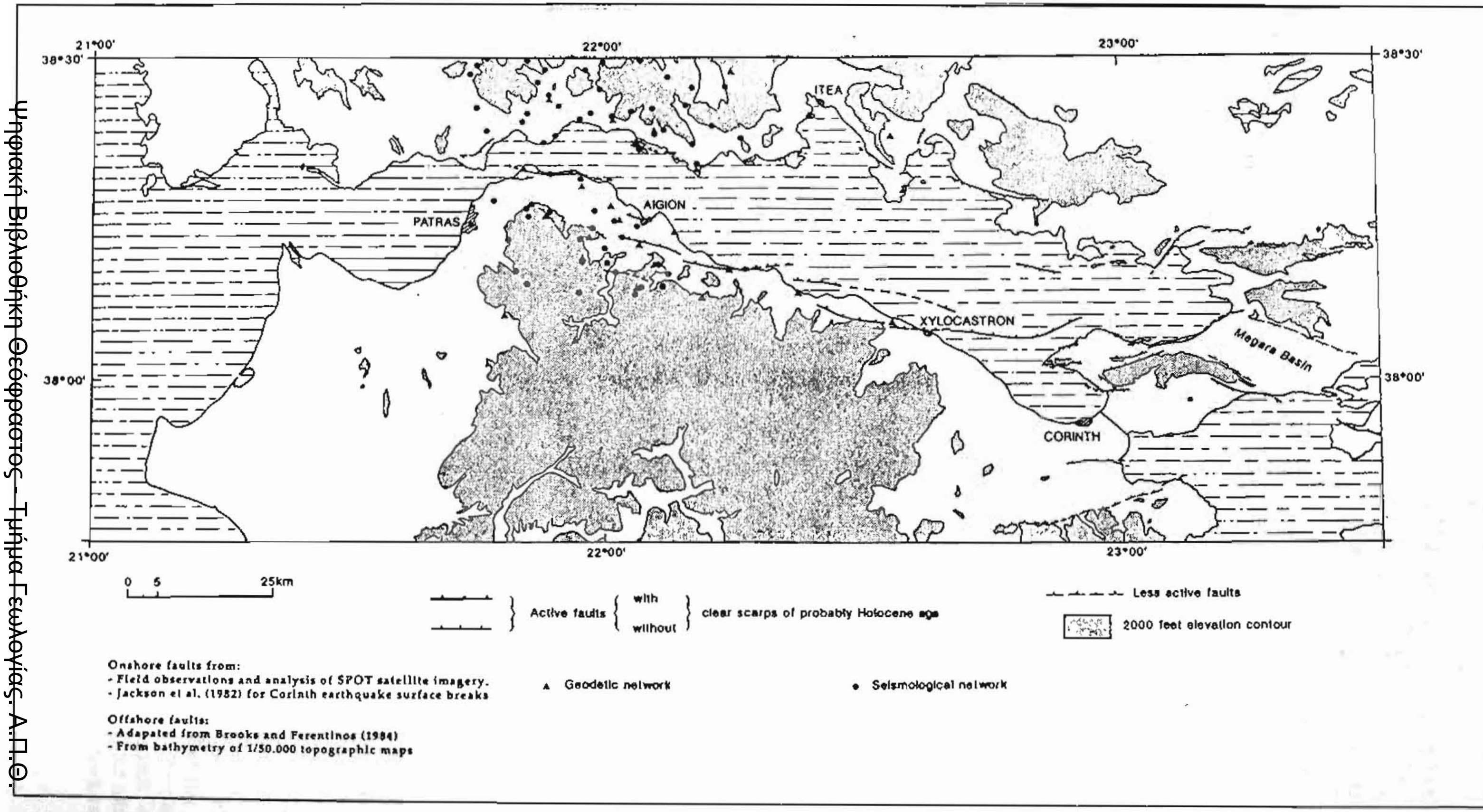

Fig.1. Tectonic map of the Gulf of Corinth.

In figure 3 we compare the baseline's lengths obtained with GPPS and BERNESE versus those obtained with GAMIT. The differences are also independent of the baseline's length. The average and maximum scatter are 7 mm and 15 mm between GAMIT and GPPS (a relatively good result as GPPS was run in L1 option) and 2 mm and 10 mm between GAMIT and BERNESE.

There are at least two causes that can explain the remaining small discrepancies between GAMIT and BERNESE: first, for the GAMIT processing we used the P.G.G.A. orbits from Scripps/MIT whereas for the BERNESE processing we used broadcast orbits; second, during the inversion of the data, GAMIT estimated a complementary tropospheric delay to be added to the one deduced from field observations, although the BERNESE software used only this last delay without additional estimated parameter (this difference in the processing mode is important for vertical determination but has little effect on distances).

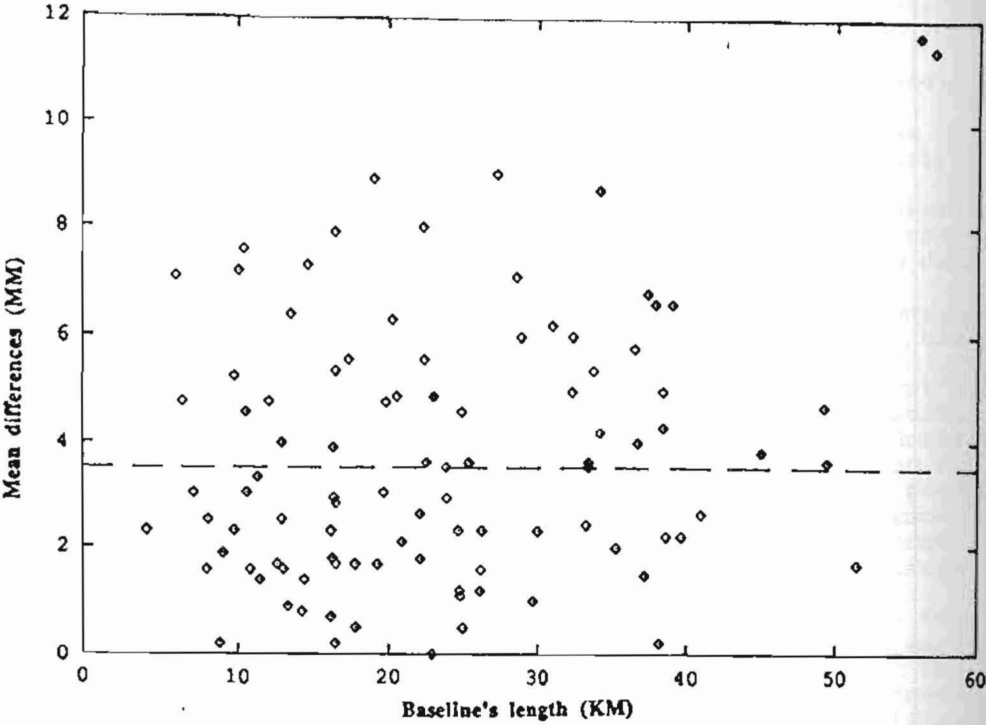

Fig.2. Repeatability of the baseline's length calculated with the GAMIT Software. The mean repeatability is around 3-4 mm.

COMPARISON WITH TRIANGULATION DATA

Among the 34 points of our network, 22 are pillars of the Greek triangulation network (3th and 4th order). This network was measured in 1967 for the southern part of the Gulf and in 1972 for the northern part, both sides having been connected together during both campaigns. The comparison of the two sets of coordinates are plotted in figure 4. The accuracy of the triangulation data has been previously estimated to be of a few centimeters + 10^{-6} ppm (Veis et al., 1992), i.e. 5-10 cm at the scale of our network. This is strongly confirmed by the coherency of the vectors found in the northern part of the Gulf. Not having been able, for the moment, to reprocess the 1967-1972 data together with the new ones, no other estimate of the errors is available. The very clear feature in this map, is the confirmation of the ~N-S extension of the Gulf of Corinth. The average displacement between points located on both sides of the Gulf is 30 ± 10 cm for an average of 21 years. This indicates a N-S extension rate of 1.5 ± 0.5 cm/yr.

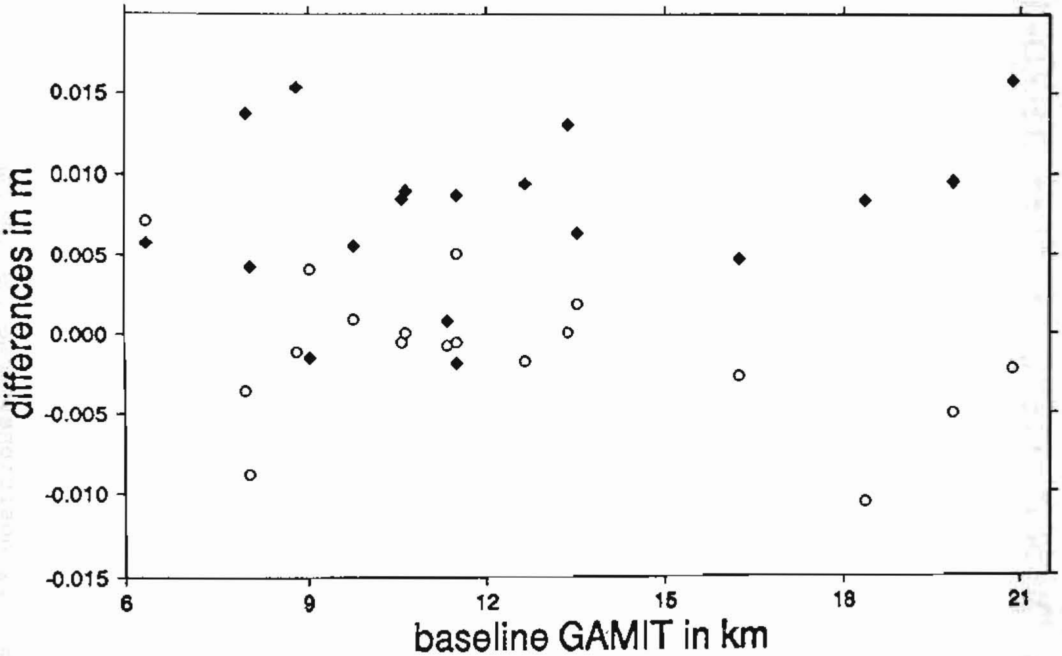

Fig.3. Comparison of the GPPS and BERNESE baseline's lengths versus the GAMIT baseline's lenths. :GPPS-O:BERNESE.

CONCLUSIONS

We compare in this paper the results and the accuracy obtained using three different software packages for the same measurement campaign in the Patras-Aigion region : GPPS, GAMIT and BERNESE softwares. To obtain the best result, we used the following procedure : GPPS was used to determine a set of "a priori" point positions, GAMIT to more accurately refine the data and to calculate the final solutions, and BERNESE to check the GAMIT results. GAMIT and BERNESE give solutions consistent at an average 2 mm level, whereas the average repeatability of the baseline's lengths calculated by GAMIT is found to be 3-4 mm.

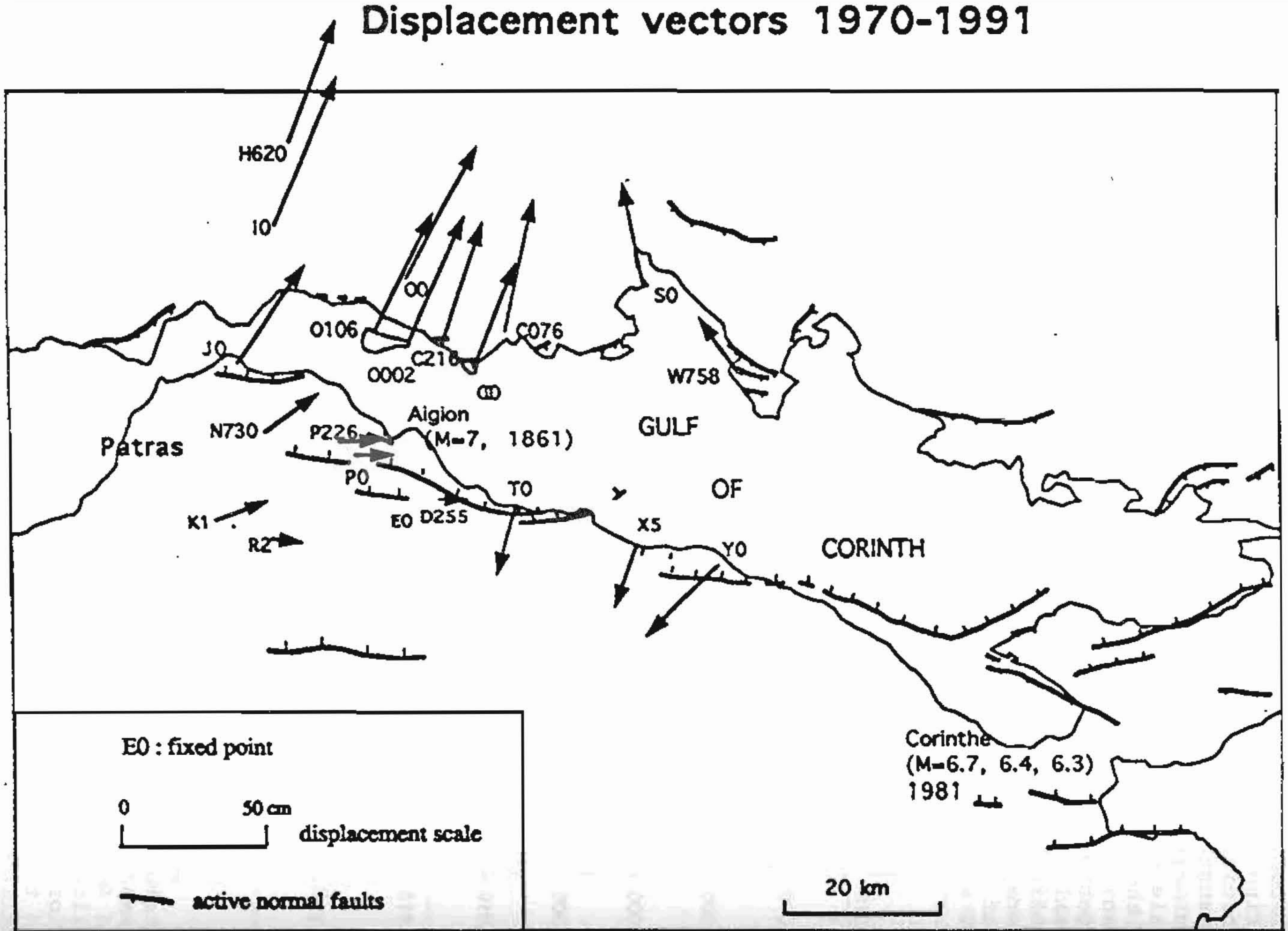

Fig.4. Displacement vectors map for the period 1970-1991 obtained by comparing the tringulation 1970 positions with the GPS 1991 positions.

The comparison between the GPS coordinates and the coordinates of 22 pillars of the Greek Geodetic Network (from triangulation data) in the Patras-Aigion region allows us to quantify the extension rate of the Gulf at 1.5 ± 0.5 cm/yr, a value 50% larger than that obtained by Billiris et al., (1991) at a larger scale. Moreover, our data show that the extension across the Gulf of Corinth is localized over a width of at most 25 km.

Extension rates determined using moment tensor summation are ranging between 4 and 7 mm/yr (Ambraseys and Jackson, 1990; Papazachos and Kiratzi, 1992). Although a large uncertainty exists for this determination mainly due to the magnitude-moment relation, there seems to be a significant discrepancy between geodetic and seismic extension rates. This suggests, as already proposed by Billiris et al., (1991) that some amount of aseismic deformation occurs in the Gulf of Corinth. Alternatively, the simple hypothesis that the observed deformation may be due to elastic accumulation cannot be ruled out since no large earthquake occured in the area after 1861 (Helike, $M\sim7$). In such hypothesis, the observed strain rate (6 10^{-7}/yr) and the estimated slip of 1-2 meters for the Helike earthquake (see Schmidt, 1881) would suggest a recurrence time of 100-150 years.

The geodetic network installed since 1990 will allow to discriminate between elastic strain accumulation and aseismic deformation through the evaluation of gradients of deformation across the area.

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