A ten years analysis of deformation in the Corinthian Gulf via GPS and SAR Interferometry

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Abtract

The Corinthian Gulf in Greece, is the most active of a series of extending grabens which accomodate the deformation in the highly seismic Aegean region.

The geodetic network established in the region has about 200 points: 50 1st order points and ~150 2nd order points. The network covers an area of about 100 x 80 km^2, which correspond to an average density of 1 point every 5 km^2. This dense network allows to study the main active faults in the region. Eleven field surveys were organized in 1990, 1991, 1992, 1993, 1994, June 1995, October 1995, 1997, and 2001. Two earthquakes occurred in the vicinity during the ten years period: the 1992, 18 November Ms=5.9 Galaxidi earthquake and the 1995, 15 June 1995 Ms=6.2 Aigion one.

With respect to the stable Europe, we find for Peloponnessos an average displacement rate of 30 mm/yr in the N215° direction, similar to that found in previous studies. Our results show that most of the deformation in the Corinthian Gulf is localizes off-shore, in a narrow band, in the central part of the Gulf. The extension rate measured over 10 years is 11 mm/yr in the N185° direction in the middle of the Gulf (Xiloxastro) and 16 mm/yr in the N185° direction in its western part (Aigion). The southern block appears un-deformed, except the region of Aigion event.

Using CNES DIAPASON software, we derived 85 interferograms of the Corinthian Gulf from 38 raw ERS SAR images acquired between 1992 and 1999. The interferograms sampling the 1995 earthquake show a clear coseismic signal reaching 250 +/- 15 mm at Psaromita cape, a value consistent with the GPS measurements. No post-seismic motion, within the error bars of SAR interferometry (+/- 15 mm), is observed during the 1995-1999 period.

Gulf of Corinth network

In Greece, one of the most seismically active regions in Europe, the deformation is accommodated by a series of extending grabens, as the North Aegean trough, the Evvia Graben and the Gulf of Corinth. The complex geodynamic context, the high deformation rate across the grabens, especially the rift of Corinth and the frequent occurrence of M=5 to 6 earthquakes (typically one M=5 per year in the Gulf of Corinth) make this region an important zone to investigate. The area is characterized by the presence of different geodetic networks (**Fig. 1**), with baselines ranging from some tens of kilometers to hundreds of kilometres.

The Gulf of Corinth network (black stars) is a densification of the whole Greece network (red stars), which spatially covers a region 650 km long by 500 km large. The Hellenic Arc geodetic network (white stars) (Kahle et al., 1995) and some points of the Ionian Sea network (grey stars) (Anzidei et al., 1996) complete the GPS coverage of the area to the west.

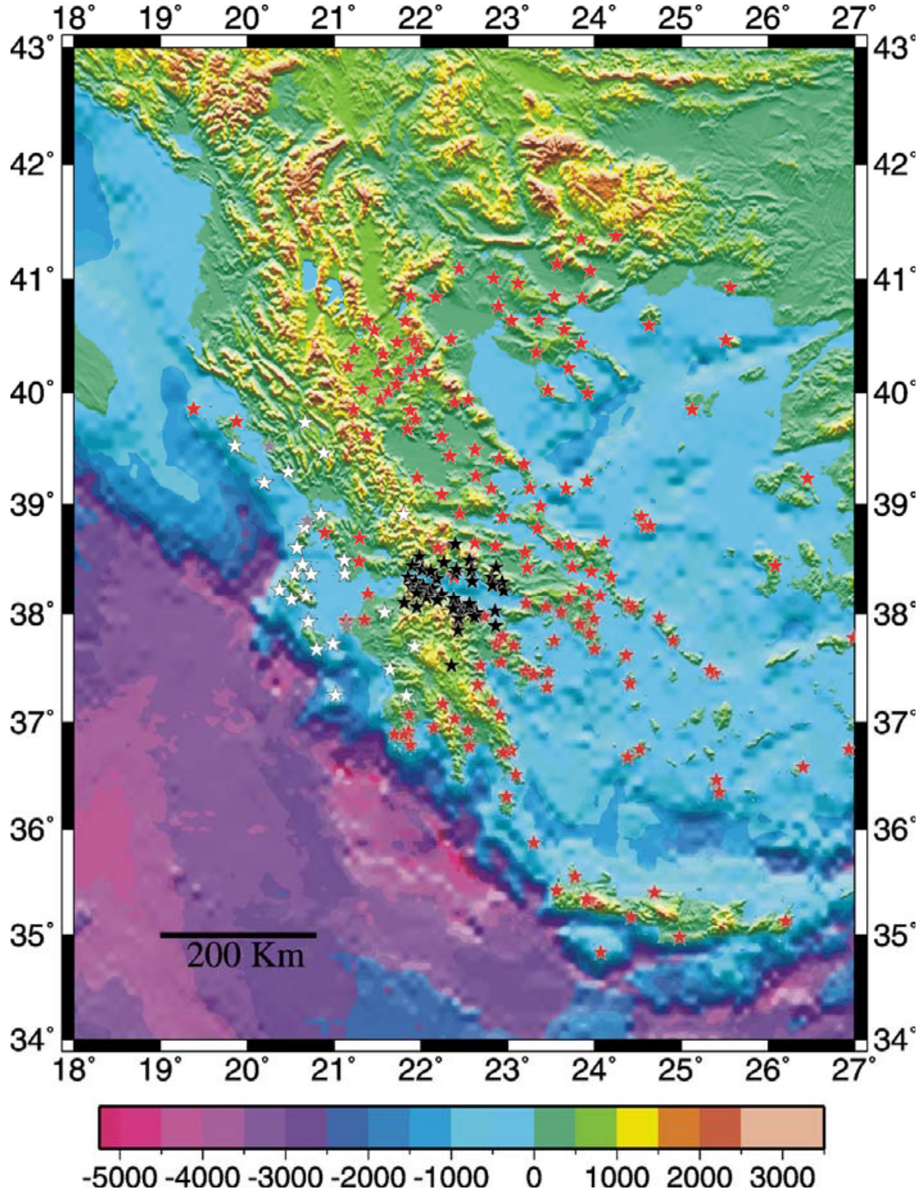

Fig. 1: The picture shows the Gulf of Corinth network (black stars) with respect to the whole Greece network (red stars), the Hellenic Arc network (white stars) (Kahle et al., 1995) and Ionian Sea network (grey stars) (Anzidei et al., 1996).

The geodetic network deployed in the Gulf of Corinth is constituted by approximately 200 points (**Fig. 2**): 50 1st order points, known with a 3 mm horizontal accuracy for each survey, and about 150 2nd order points, known with a 1-2 cm accuracy. Located in not masked places, the 1st order points are measured with 8-24-hours sessions for 3-4 days, whereas the benchmarks of 2nd order points are more masked and, in average, they are measured with shorter sessions (2-6 hours for 1-2 days). The whole network covers a surface of about 100 x 80 km, which corresponds, including sea surface, to 1 point every 5 km. This dense network allows us to have a satisfactory sampling of the main active faults in the region.

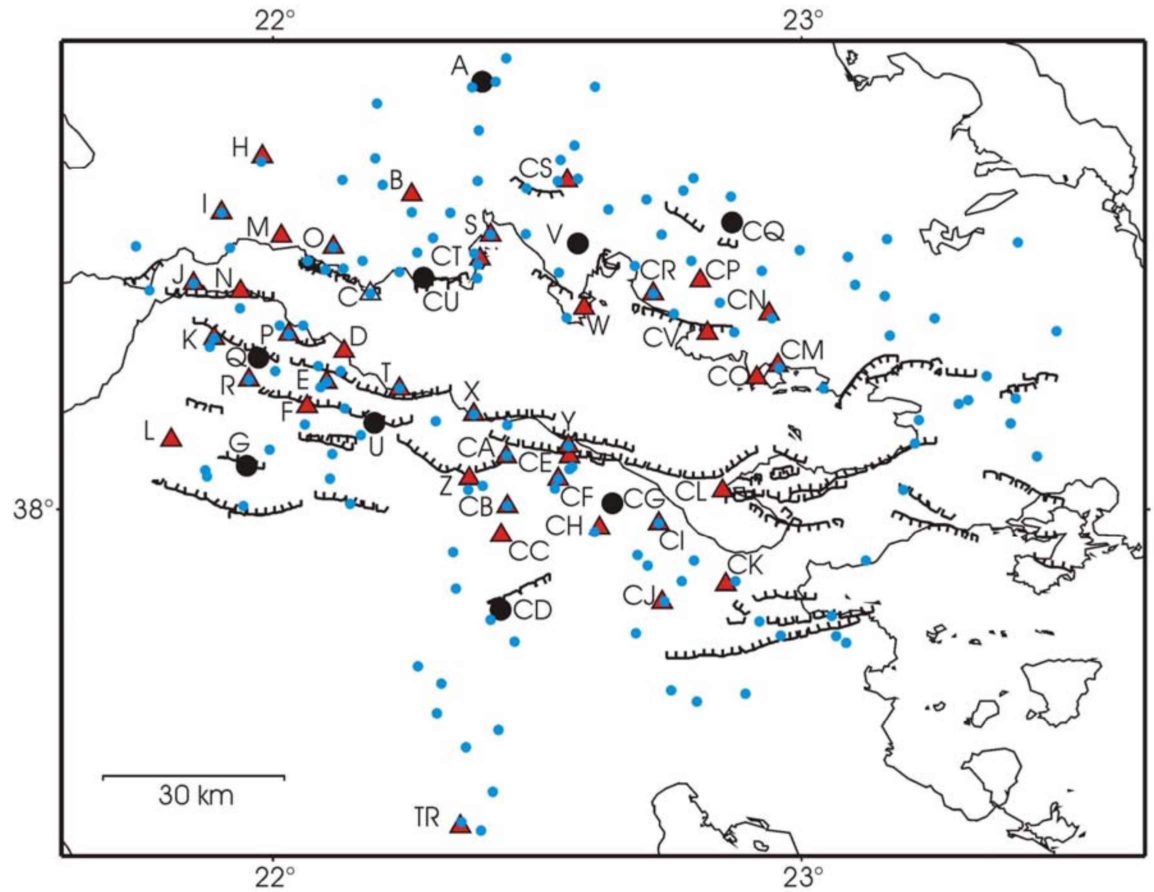

***Fig. 2**: The picture shows the positions of the Gulf of Corinth network GPS points: red triangles, blue dots and black dots correspond respectively to the 1st order points, 2nd order points (also old triangulation points) and to the points common with the Central Greece network. Dented segments show the localisation of the main active faults in the area.*

Eleven field surveys on this network were already organized in 1990, 1991, 1992, 1993, 1994, June 1995, October 1995, 1997, 1999, 2000 and 2001. Two of them (1992 and june 1995) were performed for a post-seismic scope after the 1992 Galaxidi (Ms=5.9) and the 1995 Aigion (Ms=6.2) earthquakes. The 1993 and October 1995 field surveys interested the whole 1st order network points, whereas the 1990, 1991, 1994, 1997, 1999, 2000 and 2001 surveys interested only a part of them.

The last field survey in the Gulf of Corinth was organized in the framework of the CORSEIS project. The interest and aim of this survey was, first of all, to carry on with the monitoring of the deformation in the area, and, secondly, to detect the displacements occurred in the area in the last 11 years. For this survey, which spanned 12 days (from 18 to 29 September 2001), three points of the network (CT, CH and DIAK) plus the Dyonisos point (in Central Greece) (**Fig. 3**) were maintained as fixed to acquire permanently for the entire campaign. In order to ensure the maximum accuracy of the network, 33 1st order points of the 1991-1993 networks were observed three to four times (to have a certain redundancy and repeatability). 19 of the 2nd order points were also observed for a single four-hours session.

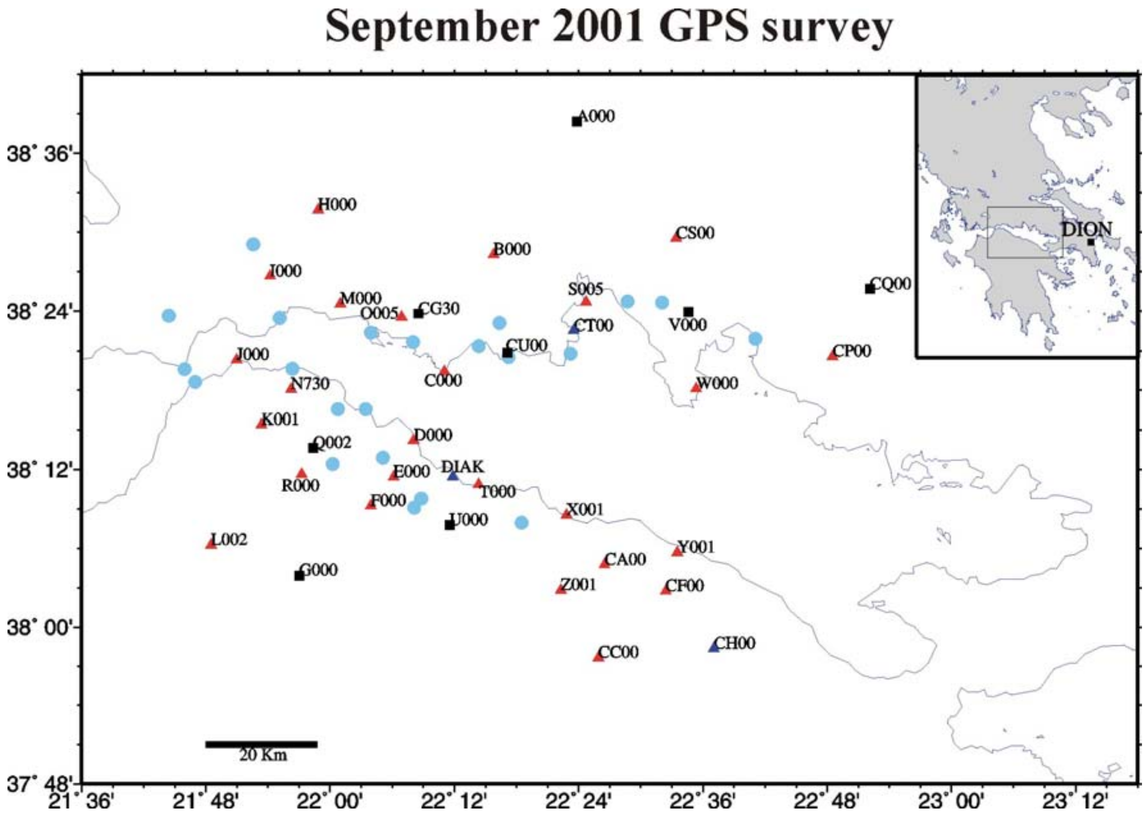

Fig. 3*: The figure shows the points measured during the 2001 survey. Red triangles, blue dots and black squares indicate respectively the 1st order points, the 2nd order points and the points common to the Central Greece network. CH00, CT00 and DIAK points (blue triangles) plus the Dionysos benchmark (in the box on the upper right of the figure) were used as reference points during the survey.*

GPS processing and results

The GPS data of all the surveys carried out in the region since 1990, were processed with GAMIT/GLOBK software (King & Bock, 1998; Herring, 1998). We set 15 degrees elevation angle cut off to reduce perturbations due to multipaths of the signals. Moreover, we used all the available IGS stations (further than 100 km) to anchor our network and to constrain the zenithal delays.

The velocity field obtained from the GPS data analysis, calculated with respect to the Peloponnisos, is represented in **Fig. 4**. This velocity field indicates an almost N-S opening direction and puts in evidence two main features: firstly, an important gradient of deformation localized off-shore, on a very narrow band, in the central part of the gulf and quickly decreasing moving away through the interior; secondly, an increase of the opening rate from east to west ranging between 11 mm/year in its central part and 16 mm/year in the west.

These rate values do not take into account the earthquakes contribution. Horizontal co-seismic displacements observed for the Ms=6.2 June 15, 1995 event reach 15 cm in correspondence of the northern coast and quickly decrease moving away towards the North.

GPS observations do not show any important variations in the southern block, except in the Aigion area. However, the area located immediately east of Patras, close to the Psatopyrgos fault, is discordant with the behavior of the southern block (Peloponnisos) and it shows a deformation which is concordant with the northern side of the Gulf.

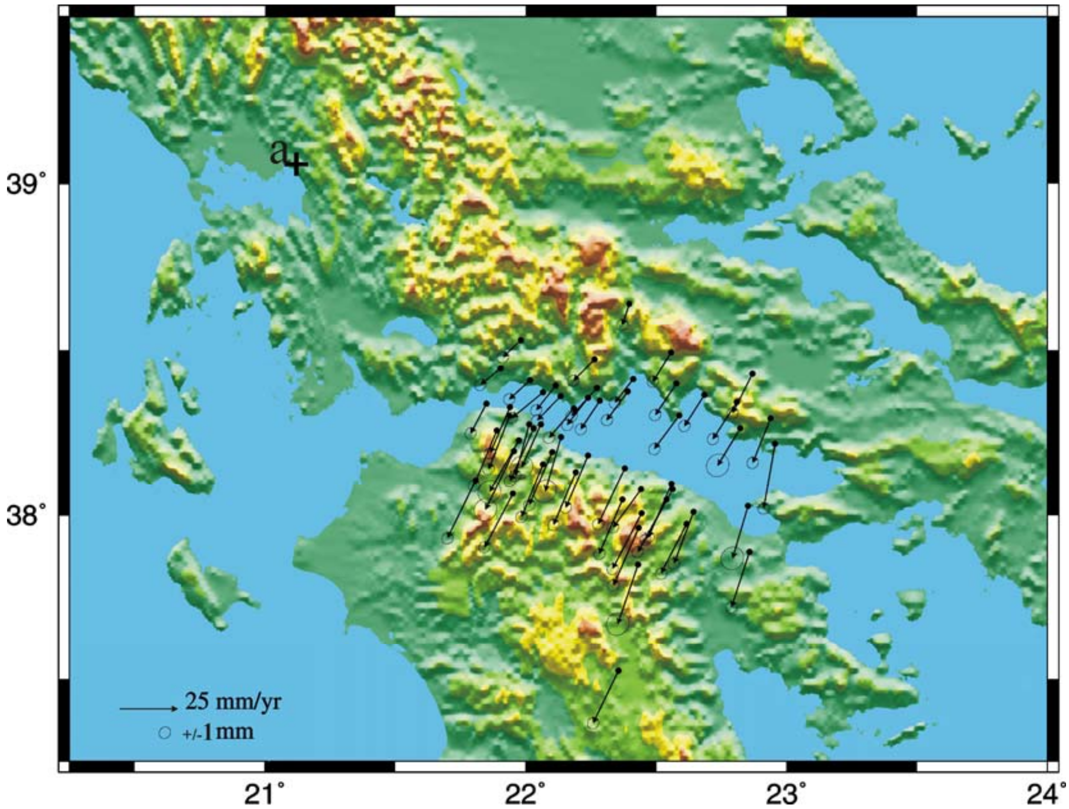

Fig. 4: The picture shows the velocity field in the Gulf of Corinth obtained from the comparison of the GPS field surveys data between 1990 and 2001. The velocity vectors are plotted with respect to the stable Europe. The cross a indicates the localisation of the rotation pole determined by the modeling of the northern side velocity field.

Interpretation and modelling

The velocity field, drawn in **Fig. 4**, clearly shows a different behaviour between the northern and southern sides of the Gulf of Corinth. The north of Peloponnessos does not show any evident internal deformation. This means that the accumulation rate of deformation on the major faults of the southern part of the Gulf is slow, not larger than 1 to 2 mm/year, but still difficult to estimate precisely. Such a rate is compatible with long recurrence periods for large earthquakes (Ms=7) on these major faults of the southern coast of the Gulf of Corinth. The southwesterly displacement rates for Peloponnessos are consistent with the rates at Dionissos point, to the east, and some other GPS points to the south (**Fig. 5**). These velocity values are compatible with previous GPS studies (McClusky et al., 2000) and could be explained by the combination of two driving forces: the pushing of Anatolia plate (McKenzie, 1978) and the african slab retreat (Meijer & Wortel, 1996; Jolivet & Faccenna, 2000).

Conversely, an important gradient of deformation is localised off-shore, in the central part of the Gulf of Corinth (**Fig. 5**), on a very narrow band, and quickly decreases moving away through the interior. On the other hand, the eastern end of the Gulf of Corinth can be traced as a diffuse zone through the Thiva basin and the South Gulf of Evia (Goldsworthy et al., 2002). Furthermore, the velocity field of the northern side of the gulf reveals that the Gulf opens more rapidly in the west than in the east. This means that the eastern side of the Corinthian Gulf tends to follow the southwesterly movement of Evia and Peloponnessos, whereas its western part is stopped to the west by the collision between Apulia-Adria plate and the Northern Greece (Taymaz et al., 1991; Cianetti et al., 2001). This geodynamical context results in a clockwise rotation of the northern side of the Gulf of Corinth.

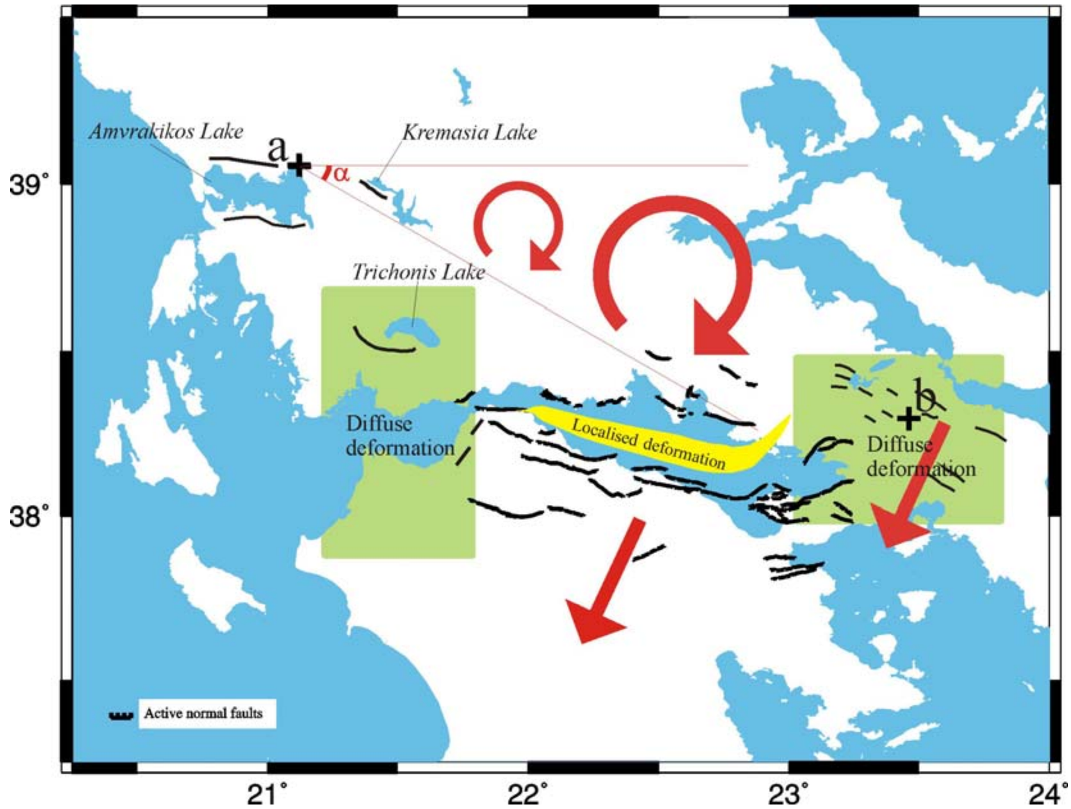

Fig. 5: Interpretative sketch map of the GPS velocity field shown in Fig. 4. The two red arrows indicate the sense of movement of Dionissos region and of Peloponnessos with respect to Europe. Rotating arrows show the clockwise rotation of the northern side of the Gulf of Corinth with respect to a pole (cross a, see text). In yellow and in light green it is indicated respectively the localised deformation deduced by this study and the distributed deofrmation regions as described by Goldsworthy et al. (2002).

We determined a rigid-body rotation that minimized the difference between the velocity field vectors in this area and we obtained a pole located at 39.09°N 21.12°E and a rate of 6°/Myr (cross a in **Fig. 5**). Conversely, with respect to Peloponnessos, we obtained the same rate and a pole located at 38.30°N 23.46°E (cross b). The stress present in the area is confirmed by a series of basins, to the north of the Gulf of Patras, as the Trikhonis lake, the Kremasia lake and Amvrakikos Gulf, where some extensional structures appear.

One of the features enhanced by the coverage of the Gulf of Corinth GPS network is the total absence of GPS benchmarks to the west, whereas the eastern end of the Gulf has already been investigating by the Central Greece network (**Fig. 1**, and Clarke et al., 1998). Aim of our future works is to extend the present network to the west in order to monitor the deformation occurring in the region around Gulf of Patras and to improve our knowledge about the distributed deformation existing in this area.

Sar Interferometry results

Using CNES DIAPASON software, we derived 85 interferograms of the Corinthian Gulf from 38 raw ERS SAR images acquired between 1992 and 1999. After a tropospheric contribution correction at both global and local scales (Chaabane et al., 2003), the interferograms sampling the 1995 earthquake (**Fig. 6**) show a clear coseismic signal reaching 250 +/- 15 mm at Psaromita cape, a value consistent with the GPS measurements.

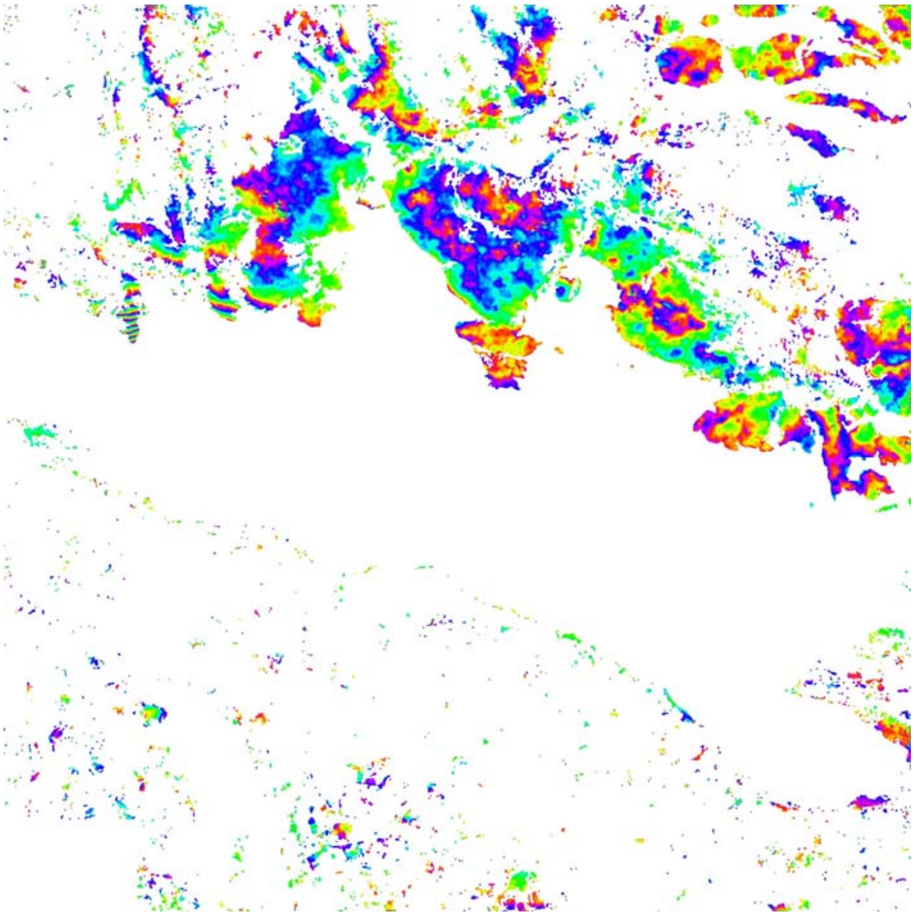

Fig. 6*: Interferograms of the Gulf of Corinth area covering the period 19 September 1992 – 2 September 1997. The areas with low coherence have been masked (white). The sampled period includes the 18 November 1992 and 15 June 1995 earthquakes. The fringe pattern produced by the latter is well visible near the "Psaromita" cape. There are no apparent fringes associated with the former.*

The fringe uncertainty here includes either the noise resulting by the temporal and spatial decorrelation between the images or the presence of a residual tropospheric effect. No post-seismic motion, within the error bars of SAR interferometry (+/- 15 mm), is observed during the 1995-1999 period.

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