# Recent East Mediterranean shallow earthquakes seen by space geodesy. The cases of Gulpinar, Lesvos, Kos and Zakynthos earthquakes


Panagiotis Elias[1], Athanassios Ganas[2], Pierre Briole[3], Sotirios Valkaniotis[2], Penelope Kourkouli[4], Varvara Tsironi[2], Isaak Parcharidis[5], Vasilios Kapetanidis[6], Ioannis Kassaras[6], Panagiotis Argyrakis[2], Alexandra Moshou[2] and Aggeliki Barberopoulou[7]

1) National Observatory of Athens, Institute of Astronomy, Astrophysics, Space Applications and Remote Sensing, Athens, Greece
2) National Observatory of Athens, Institute of Geodynamics, Athens, Greece 3) CNRS / Ecole Normale Superieure / PSL Research University, Paris, France
4) ETHZ, Department of Earth Sciences – Engineering Geology, Rämistrasse 101, 8092 Zürich, Switzerland – 5) Harokopio University of Athens, Athens, Greece
6) National and Kapodistrian University of Athens, Faculty of Geology and Geoenvironment, Athens GR 157 84, Greece –
7) AIR Worldwide, Research Department, 131 Dartmouth St, Boston MA 02116, USA


Scan me

## Summary


•On 2017 and 2018 four strong/moderate earthquakes occurred at shallow focal depths in the East Mediterranean. They share a common characteristic, which is that a large part of the induced ground deformation is offshore, thus a part of the deformation footprint is missing. Assuming that the deformation source of an earthquake can be modelled by the slip on a rectangular fault buried in an elastic and homogenous halfspace and through **inversion on GNSS and multitrack InSAR (with different weight in each case) we modelled the deformation sources and calculated their fault parameters.** Seismological data as well as the geological context exploited to assist the initialization of some parameters in the inversion and validate the results. **This study demonstrate the efficiency and the contribution of the space geodesy to the seismology**, even in such adverse conditions.


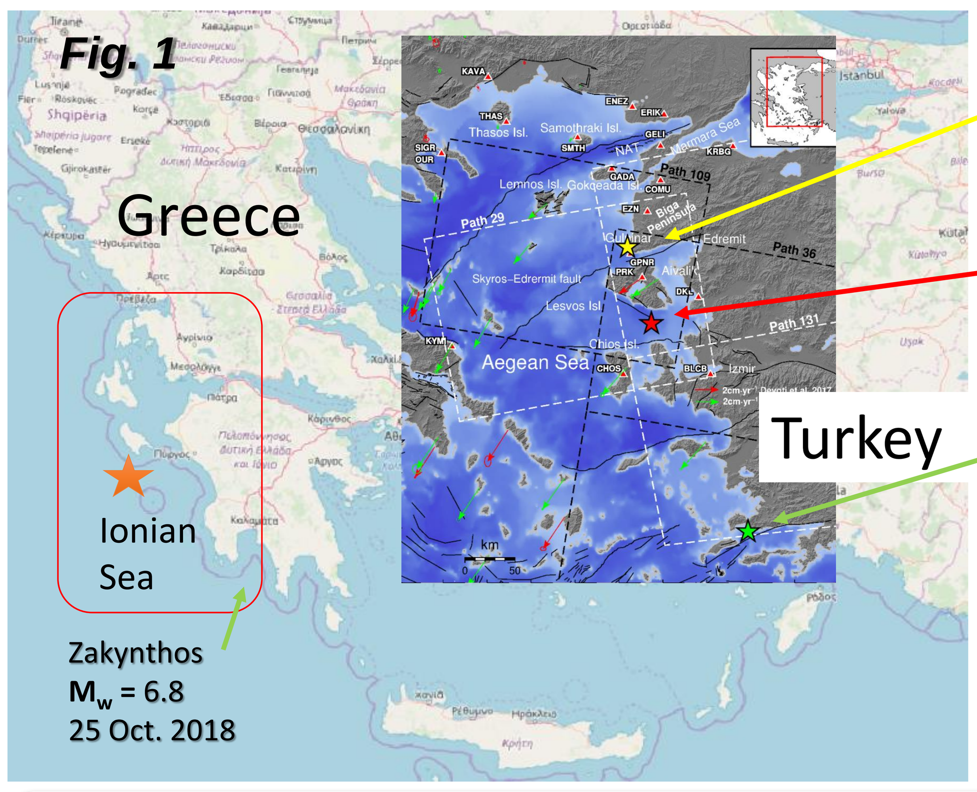


**Fig1.** The earthquakes studied in this poster are being indicated by starts. Red triangles indicate the location of the broadband seismic stations. Vectors indicate GNSS velocities to stable Europe.

## 25 Oct.18 M6.8 Zakynthos Earthquake

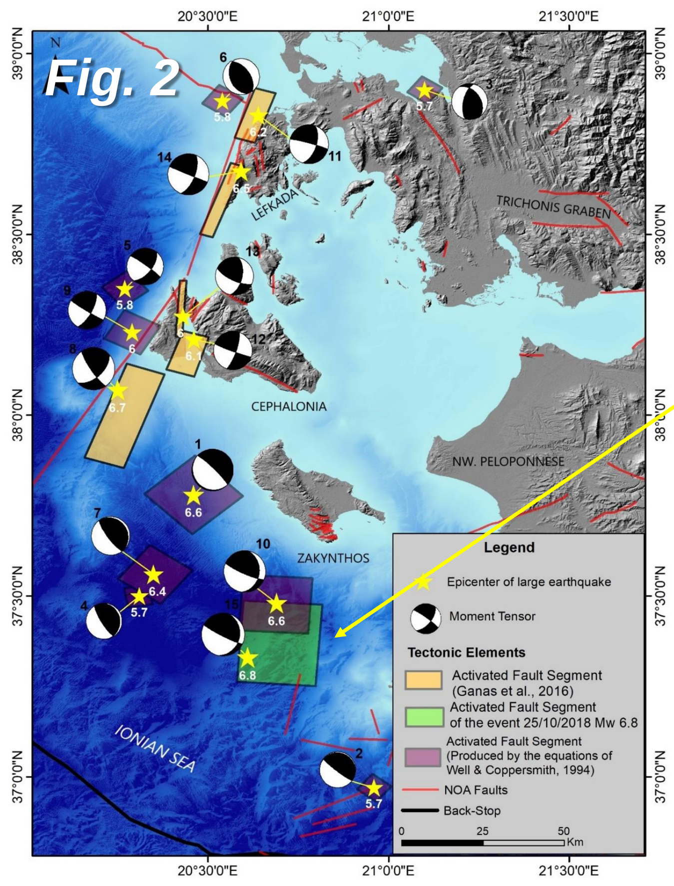


**Fig2.** Fault segments of the western Hellenic Arc and the Cephalonia Transform Fault Zone activated in the period 1959-2018 (Ganas et al., 2017). With green rectangle the projection to the surface of the fault of the earthquake of Mw=6.8, occurred on 25/10/2018 is shown.

On October 25, 2018, a strong Mw = 6.7 (NOA) earthquake occurred at shallow depth southwest of Zakynthos Island in Ionian Sea, Greece (Fig.1,2). This earthquake occurred on the west Hellenic Arc along the megathrust of the Aegean plate on top of the subducting African plate. A small tsunami was also observed at Ionian Sea tide gauges. **We derive a co-seismic fault model from inversion of permanent GNSS (Fig.3) validates by Sentinel-1 enhanced interferograms** (Fig. 5).

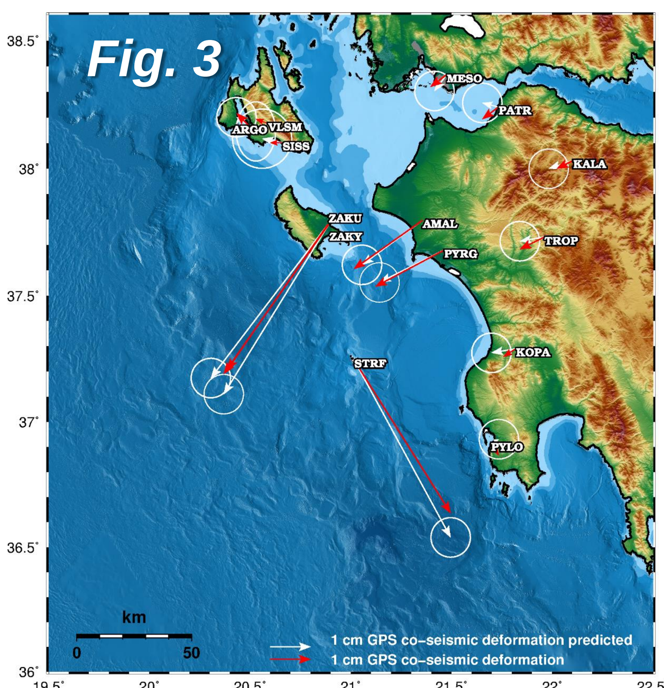


**Fig3. GNSS** co-seismic and modelled displacements.

The fault plane extends 26km along strike by 16.5km wide dipping at 25° (Fig.4). The slip vector (estimated at 2m) is dominantly right lateral with a small reverse component and a SSW-NNE direction dipping east. The hypocenter is located at 6.5 km depth.

The synthetic interferograms produced by the model predicts almost two fringes of ground deformation (at C-band) (Fig.4), throughout the island but it is not clearly visible in the single interferograms which are strongly suffering from tropospheric noise (Fig.5). The tropospheric noise currently partially minimized by applying a linear correction proportional to height (with a ratio of 22mm at 1km of altitude). So the InSAR used just to validate the result.

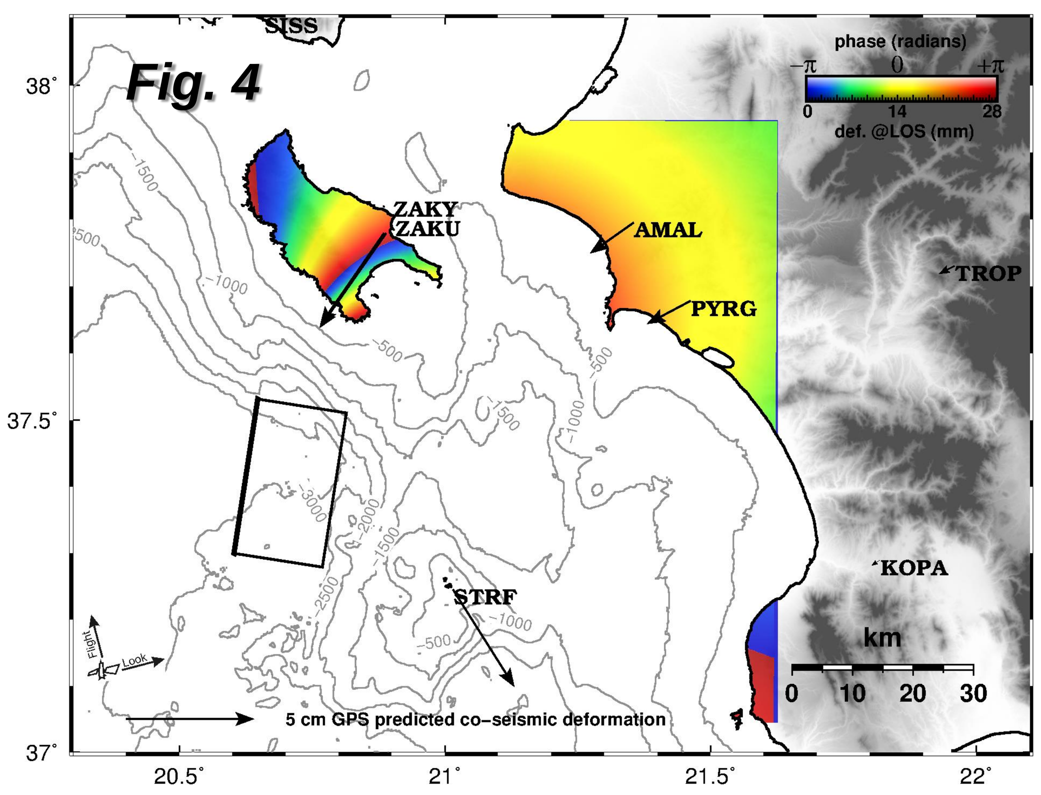


**Fig4.** The synthetic interferograms for ascending view using the fault parameters estimated from GPS inverse modelling.

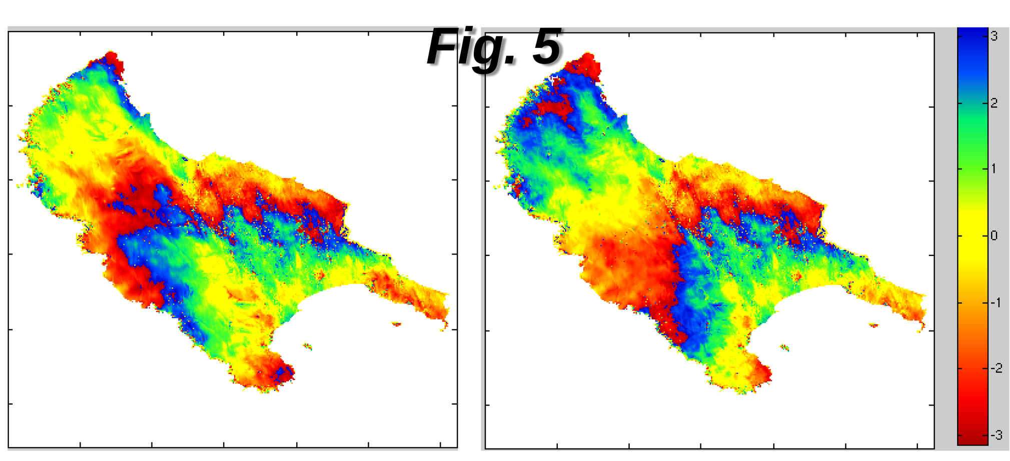


**Fig5. Left:** the initial ascending (track 175) Sentinel-1 co-seismic interferogram (14-26/10/2019) using SNAP. **Right**: the corrected for tropospheric noise. by applying a linear correction proportional to height

## February, 2017 Gulpinar M5.2 Earthquake

Between 6 and 12 February 2017, a shallow seismic sequence of moderate events with magnitudes between 5.0≤Mw≤5.2 (NOA), struck the region of Gulpinar-Babakale, onshore northwestern Anatolia, Turkey (Fig.1). **We used 49 interferograms of Sentinel-1(Fig. 6) to identify the seismic fault (striking N110° E), a minimization strategy to separate each single event and seismological data so as to refine its geometry and kinematics using inversion techniques**..

Our geodetic inversion showed that the fault has normal-slip kinematics, dimensions of 6 by 6 km (length, width), slip of 28 cm and dips at 45° (Fig.6).. The dip-direction of the fault is not retrievable from InSAR, but a south-dipping plane is clear from seismology and the aftershocks distribution. The spatial distribution of relocated events indicates the activation of one fault with a rupture zone length of about 10 km, a result of the occurrence of off-fault aftershocks along strike the main rupture (Ganas et al., 2018b).

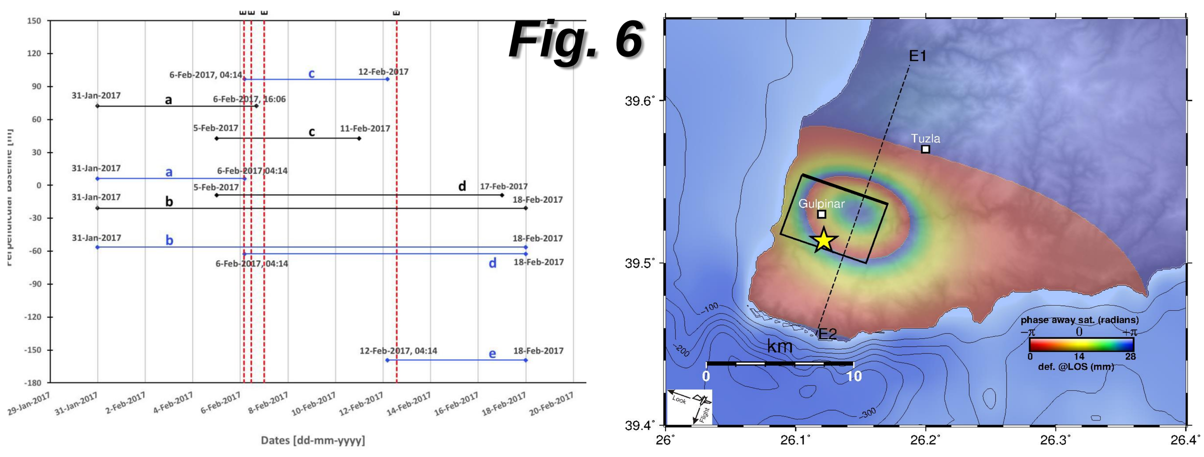


**Fig6. Left:** S1 interferograms spanning at least one event, from the descending track 36 (blue lines) and the ascending track 29 and 131 (black lines). The red dashed lines denote the four major earthquakes. **Right:** Map showing the Gulpinar forward model of LOS motion for the descending orbit 36 (with local incidence angle of 44° ), the surface projection of the modeled south-dipping fault (thin black box) is plotted. Yellow star indicates the relocated epicenter

## June 12, 2017 M6.3 Lesvos Earthquake

On June 12, 2017, a strong Mw=6.3 shallow, normal-faulting sequence offshore Lesvos (Aegean Sea, Greece) occurred, Fig.1,7. **In We use jointly geodetic and seismological data to identify the ESE-WNW striking seismic fault and to refine its geometry and kinematics using inversion techniques**. According to preliminary results the spatial distribution of relocated events shows the activation of one fault with a total length of about 20 km (Fig.8), at depths 5-15 km.

Despite the large magnitude of the mainshock, the surface deformation is not visible in Sentinel-1 interferograms without any further processing (Fig.6). The presence of a small (less than a fringe throughout the island) signal is consistent with the slip-model predictions, based on the GNSS models.

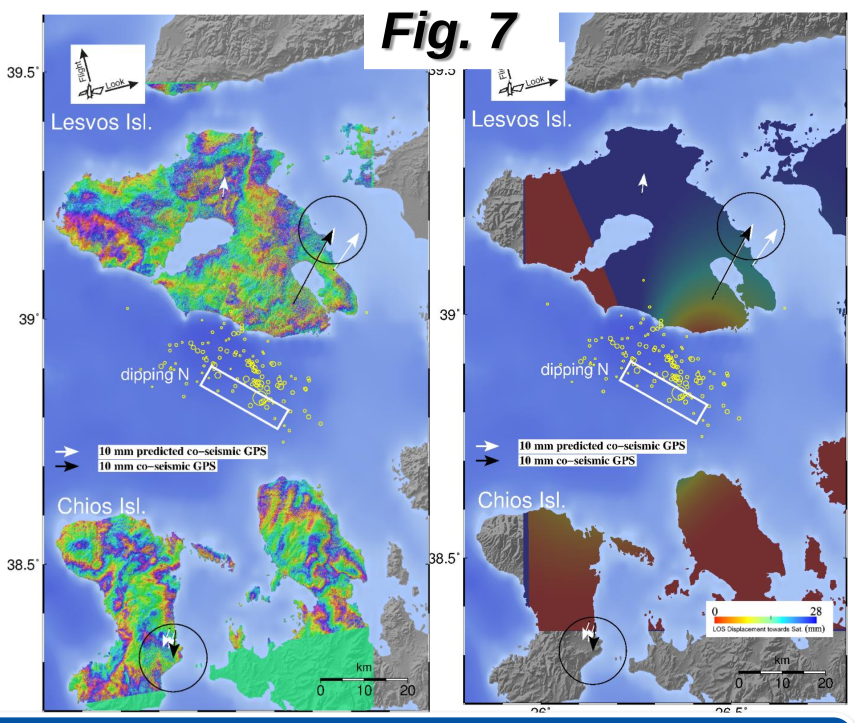


**Fig7.** Map of Lesvos and Chios Islands at the Northeast Aegean Sea and northwestern Anatolia. Vectors indicate GNSS co-seismic and modelled deformation. **Left**: Sentinel-1 co-seismic interferograms. **Right**: Synthetic co-seismic interferograms calculated considering the fault parameters inversion from GNSS data.

## July 20, 2017 M6.6 Kos Earthquake

On July 20, 2017, a strong Mw = 6.6 earthquake occurred offshore Kos (Greece) and Bodrum (Turkey) (Fig.1).

**The GNSS observations constrain well most of the model parameters (Fig.8) but the interferograms, produced from Sentinel-1, give a clear preference to the north-dipping plane (Fig.9). The geodetic model fits the pattern of the shallow, north-dipping aftershocks** (Fig.10 & 11), (Ganas et al., 2018a).

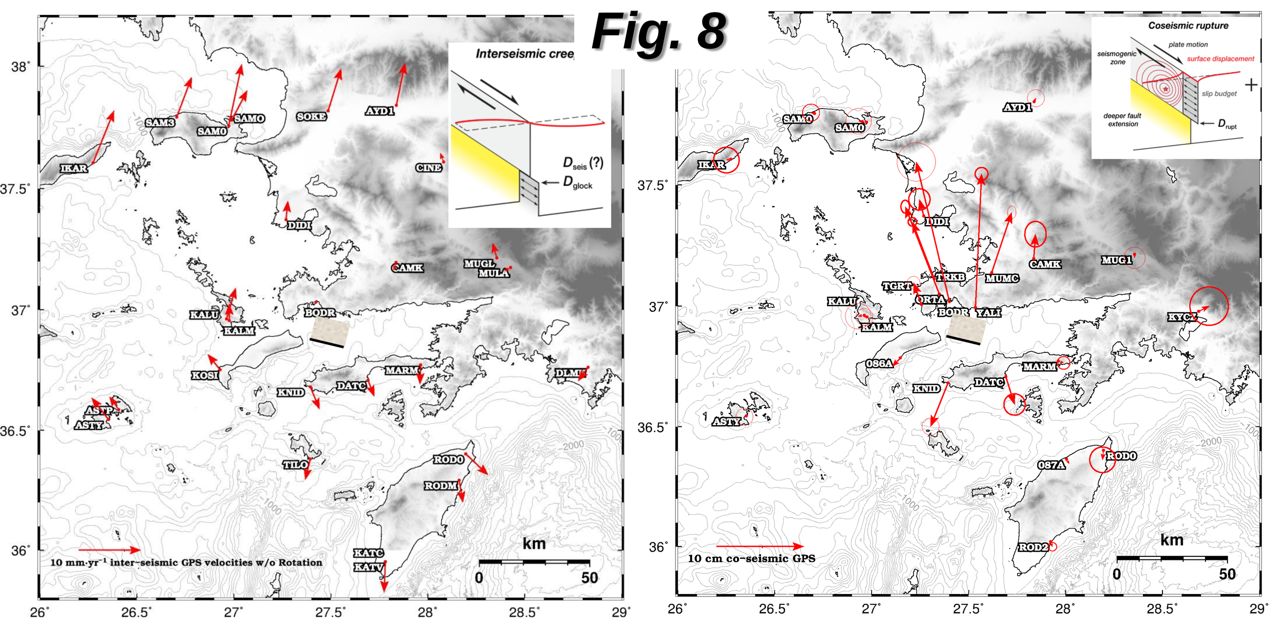


**Fig8. Left:** Map of SE Aegean showing tectonic velocities of GNSS stations. Vectors are plotted after removing the rotation effect. An extension of 3.2 mm/year across the Gokova is obtained. **Right:** Horizontal co-seismic offsets due to the 2017 Kos earthquake

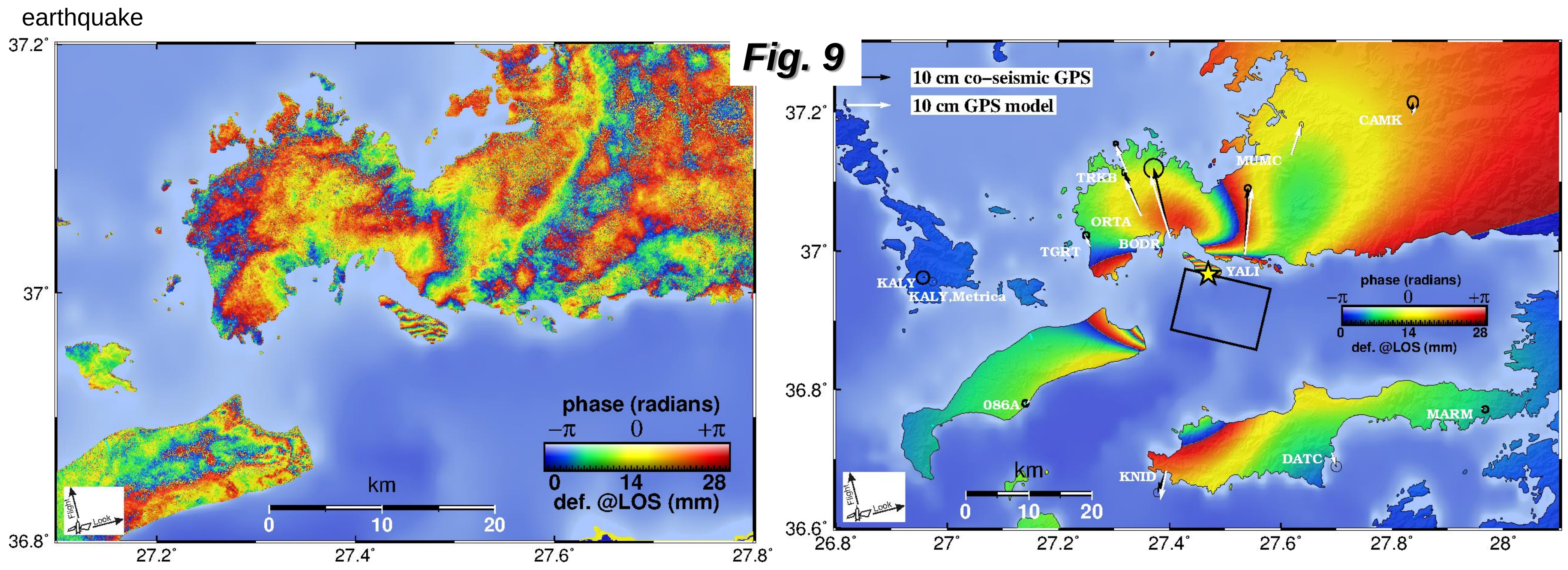


**Fig9. Left:** Sentinel 1 interferogram ascending orbit Track 131 acquisition dates: 12-24/7/2017. **Right:** Synthetic interferogram from the north-dipping fault model. The inferred source for the mainshock is shown by the black rectangle. Yellow star indicates the earthquake epicentre (relocated in this study). GNSS vectors of observed and modelled co-seismic displacements are shown.

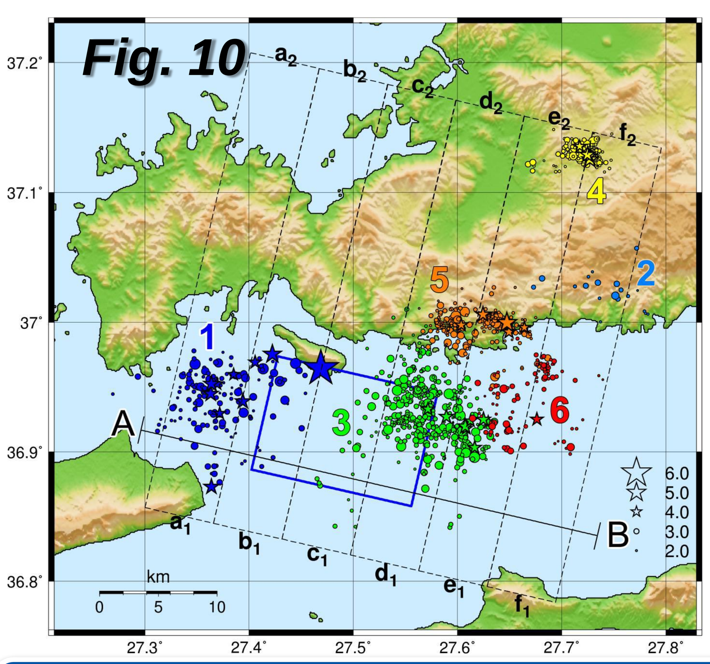


**Fig10.** Relocated epicentres separated in six spatial groups. Dashed rectangles mark the bounds of the parallel N13° cross-sections of Fig. 11.. The blue rectangle represents the projection of the fault plane that was constrained by **geodetic data**

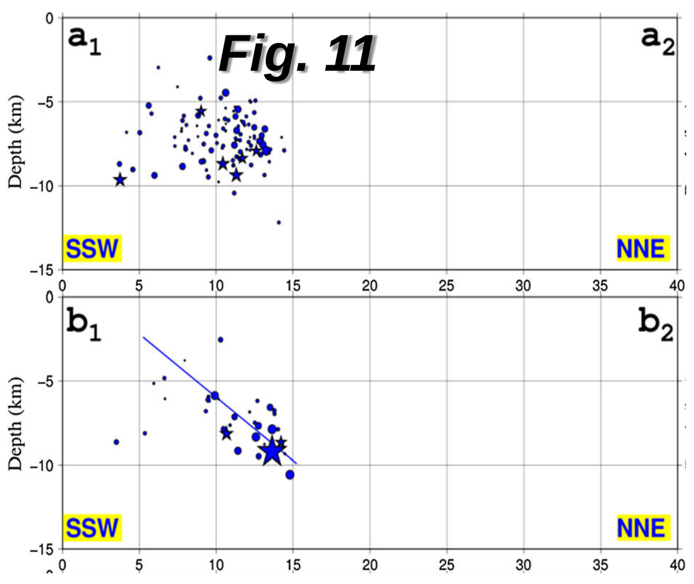


**Fig11.** Series of N13° E-oriented, 6 km-wide parallel cross-sections for the relocated hypocentres of the clusters a and b. The 37° N-dipping blue line corresponds to the projected rupture plane, as determined by **geodetic data**

## References


- Ganas, A., Elias, P., Kapetanidis, V., Valkaniotis, S., Briole, P., Kassaras, I., Argyrakis P., Barberopoulou A. and Moshou A., (2018a). The July 20, 2017 M6. 6 Kos Earthquake: Seismic and Geodetic Evidence for an Active North-Dipping Normal Fault at the Western End of the Gulf of Gökova (SE Aegean Sea). Pure and Applied Geophysics, 1-35.
- Ganas A., Kourkouli P., Briole P., Moshou A., Elias P. and Parcharidis I., (2018b). Coseismic displacements from moderate-size earthquakes mapped by Sentinel-1 differential interferometry: the case of February 2017 Gulpinar earthquake sequence (Biga penins., Turkey). Remote Sensing.
- Ganas A., Elias P., Bozionelos G., Papathanassiou G., Avallone A.., Papastergios A., Valkaniotis S., Parcharidis I and Briole P, 2016. Coseismic deformation, geo-environmental effects and seismic fault of the 17 November 2015 M=6.5, Lefkada Island, Greece earthquake. Tectonophysics, Vol. 687, 26 September 2016, pp 210–222.



*ESA Living Planet Symposium, Milano, Italy, 2019*