Note on the analysis and modelling of the GPS time-series available around the location of the October 25, 2018 Zakynthos earthquake

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GNSS

We analysed the time series (Table 1, Plate 1) of fourteen permanent GNSS stations located around the epicentre, two of them (ZAKU, ZAKY) being located on the island of Zakynthos and one (STRF) on the small island of Strofades. The GNSS data are processed using the GIPSY 6.4 software. Tab. 1 (Fig. 1) gives the velocities of the stations in the ITRF2014 and Tab. 2 (Fig. 2) the velocities with respect to the African plate and to Kalavrita in the north central Peloponnese.

Code	Location	Owner	Start	Lat	Long	v_E	v_N	v_U
				°	°	mm/yr	mm/yr	mm/yr
AMAL	Amaliada	TreeComp	01/2016	21.355	37.796	8.0 ± 0.4	-8.0 ± 0.4	2.4 ± 0.7
ARGO	Argostoli	Metrica	03/2016	20.492	38.169	16.6 ± 0.4	5.0 ± 0.4	-0.5 ± 0.7
KALA	Kalavrita	CRL/CNRS	10/2014	22.102	38.030	9.3 ± 0.3	-10.4 ± 0.3	-0.4 ± 0.5
KOPA		Metrica	06/2018	21.818	37.289			
MESO	Messologhi	CRL/CNRS	10/2014	21.475	38.366	13.4 ± 0.3	2.3 ± 0.3	-0.5 ± 0.5
PATR	Patras	Metrica	01/2011	21.733	38.241	8.2 ± 0.2	-7.4 ± 0.2	-0.4 ± 0.4
PYLO	Pylos	NOA	08/2011	21.695	36.914	2.4 ± 0.2	-12.7 ± 0.2	-1.4 ± 0.4
PYRG	Pyrgos	Metrica	09/2011	21.462	37.679	5.4 ± 0.2	-12.4 ± 0.2	-0.9 ± 0.4
SISS	Sission	NOA	03/2014	20.659	38.101	17.9 ± 0.5	-1.3 ± 0.5	-1.3 ± 0.8
STRF	Strofades	INGV/NOA	10/2016	21.014	37.250	3.4 ± 0.5	-4.9 ± 0.5	1.2 ± 0.8
TROP	Tropaia	TreeComp	01/2016	21.959	37.730	7.1 ± 0.4	-9.5 ± 0.4	0.4 ± 0.7
VLSM	Valsamata	NOA	09/2006	20.589	38.177	17.4 ± 0.2	4.4 ± 0.2	-1.0 ± 0.4
ZAKU	Zakynthos	TreeComp	01/2016	20.889	37.779	12.5 ± 0.5	-0.7 ± 0.5	1.5 ± 0.8
ZAKY	Zakynthos	Metrica	08/2013	20.878	37.781	13.4 ± 0.3	-2.3 ± 0.3	1.8 ± 0.5

Table 1. GNSS stations and their absolute velocities in ITF2014

Code	v_E % Africa (mm/yr)	v_N % Africa (mm/yr)	v_E % Kalavrita (mm/yr)	v_N % Kalavrita (mm/yr)
AMAL	-10.2	-28.1	-1.3	2.4
ARGO	-1.6	-15.1	7.3	15.4
KALA	-8.9	-30.5		
MESO	-4.8	-17.8	4.1	12.7
PATR	-10.0	-27.5	-1.1	3.0
PYLO	-15.8	-32.8	-6.9	-2.3
PYRG	-12.8	-32.5	-3.9	-2.0
SISS	-0.3	-21.4	8.6	9.1
STRF	-14.8	-25.0	-5.9	5.5
TROP	-11.1	-29.6	-2.2	0.9
VLSM	-0.8	-15.7	8.1	14.8
ZAKU	-5.7	-20.8	3.2	9.7
ZAKY	-4.8	-22.4	4.1	8.1

Table 2. Velocities of the stations points with respect to the African plate, assuming an ITRF2014 velocity of the plate of 18.2 and 20.1 mm/yr towards east and north respectively at a virtual point located on the seafloor at 20°E and 37°N on the African plate. Velocities of the GNSS stations with respect to Kalavrita.

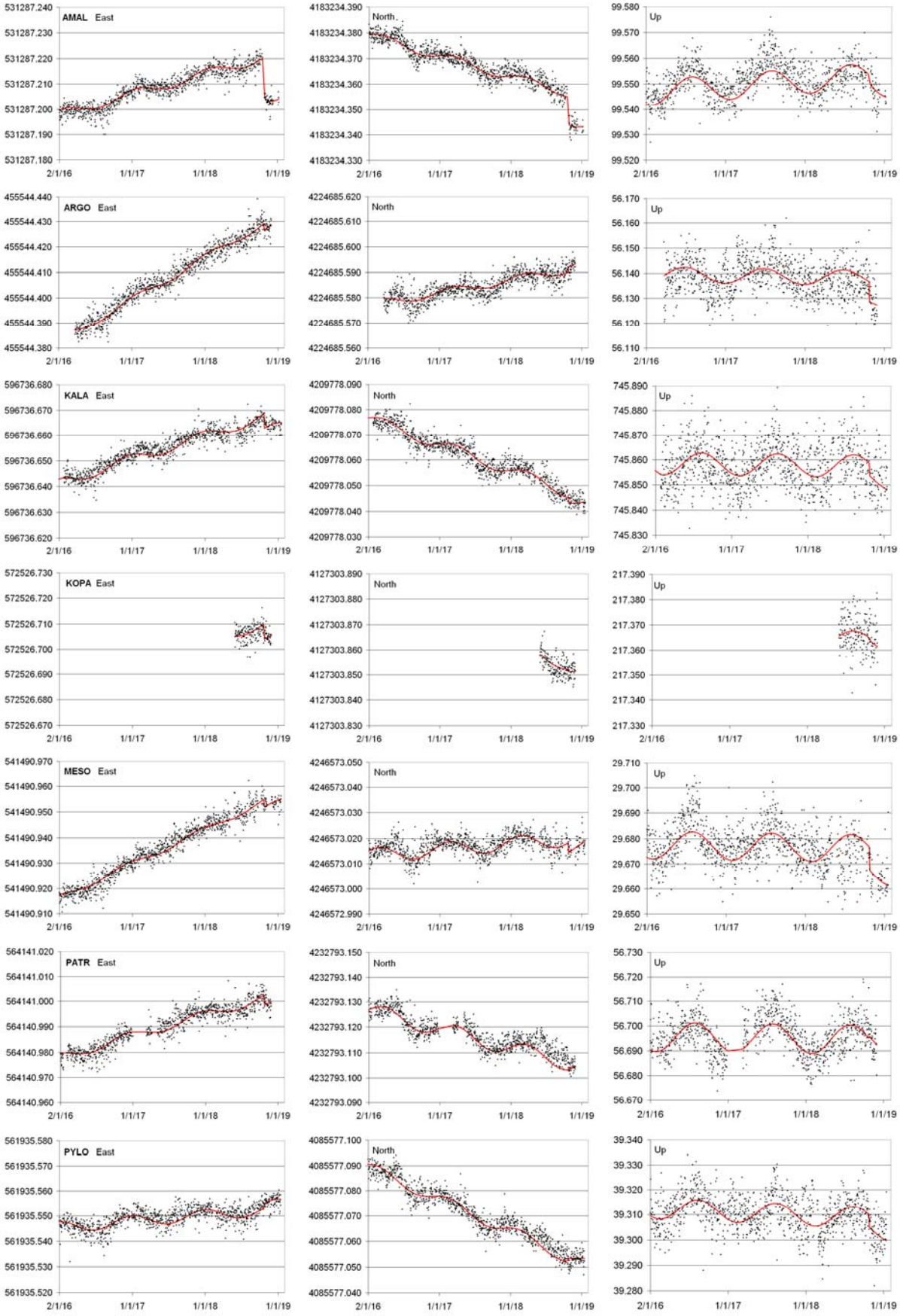

Plate 1a. Times series of coordinates of the GNSS stations AMAL, ARGO, KALA, KOPA, MESO, PATR, PYLO

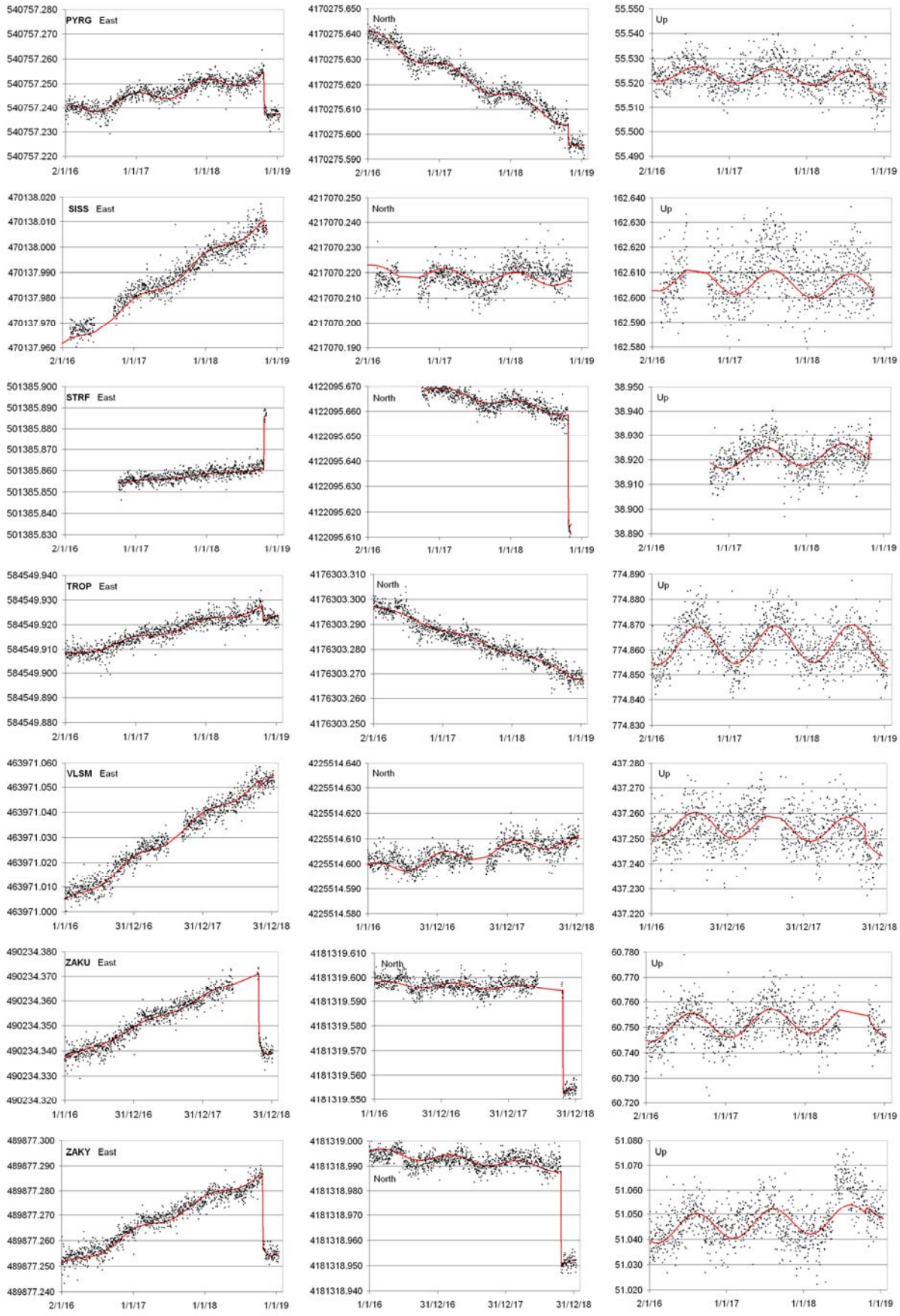

Plate 1b. Times series of coordinates of the GNSS stations PYRG, SISS, STRF; TROP, VLSM, ZAKU, ZAKY

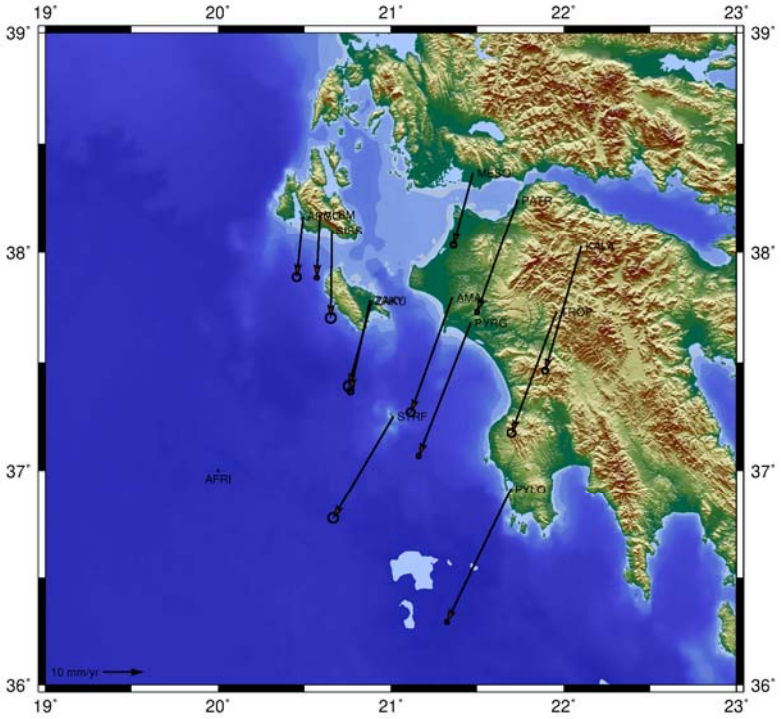

Figure 1. Velocities of the GNSS stations with respect to a virtual point AFRI located on the African plate on the slab. The absolute velocity of that point was inferred using the pole of rotation of Altamimi et al. 2012. The figure shows that the coupling is low at the plates interface but increases around the island of Zakynthos

Figure 2. Velocities of the GNSS stations with respect to Kalavrita. The line (fault-zone) Patras – Movri- Katalolon cape – Stofades is a transition between a region with very little coupling (to the south) and a region with significant coupling and the transition to right-lateral strike slip faulting in the upper crust (e.g. the Cephalonia fault).

The co-seismic displacements are listed in Tab. 3 and plotted in Fig. 4. We noticed that a small component of pos-seismic motion (Tab. 4) is visible, especially in the east components, at the stations closest to the epicentre, ZAKU, ZAKY (Fig. 3), STRF, AMAL, PYRG.

	East	North	Co-seismic displacements			Model 7		
Code	UTM34	UTM 34	d_E	d_N	d_U	m_E	m_N	m_U
	km	km	mm	mm	mm	mm	mm	mm
AMAL	531.29	4183.23	-15 ± 2	-11 ± 2	-3 ± 4	-17	-12	2
ARGO	455.54	4224.69	-3 ± 2	2 ± 2	-8 ± 5	-3	3	-2
KALA	596.74	4209.78	-6 ± 2	-2 ± 2	-5 ± 7	-4	-2	1
KOPA	572.53	4127.30	-6 ± 2	-1 ± 2	-1 ± 5	-3	-2	0
MESO	541.49	4246.57	-3 ± 2	-4 ± 2	-9 ± 6	-4	-3	1
PATR	564.14	4232.79	-4 ± 2	1 ± 2	1 ± 5	-4	-3	1
PYLO	561.94	4085.58	2 ± 2	1 ± 2	-5 ± 5	2	-3	-1
PYRG	540.76	4170.28	-16 ± 2	-8 ± 2	-4 ± 4	-17	-9	2
SISS	470.14	4217.07	-5 ± 3	1 ± 3	-1 ± 8	-3	0	-2
STRF	501.39	4122.10	24 ± 2	-44 ± 2	9 ± 4	24	-38	1
TROP	584.55	4176.30	-6 ± 2	-1 ± 2	-3 ± 5	-6	-3	1
VLSM	463.97	4225.51	-3 ± 2	-2 ± 3	-5 ± 6	-3	1	-2
ZAKU	490.23	4181.32	-26 ± 2	-42 ± 2	-1 ± 5	-26	-37	-4
ZAKY	489.88	4181.32	-29 ± 2	-38 ± 2	2 ± 6	-25	-36	-4

Table 3. Co-seismic displacement and displacements predicted by the model7. Average scatters are 1.1, 2.3 and 4.5 mm in east, north and up respectively, thus comparable to the average scatters of the uncertainties. This indicates that the model fits well the data.

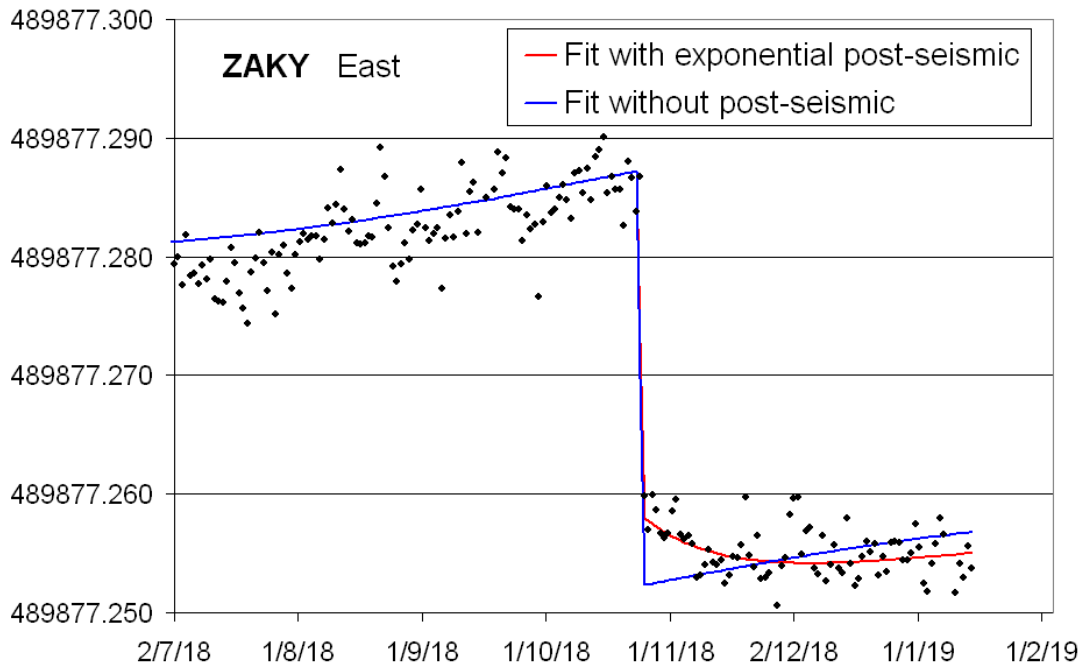

Figure 3. Detail of the eastern component of the coordinates time series of the GNSS station ZAKY showing the better fit obtained when considering the existence of a component of post-seismic slip, here modelled using en decreasing exponential function.

Code	d_E	d_N	d_U	decay	mE	mN	mU
	mm	mm	mm	days	mm	mm	mm
AMAL	-5 ± 3	-1 ± 3	-1 ± 7	20	-4	-3	2
PYRG	-4 ± 3	0 ± 3	0 ± 7	21	-3	-2	1
STRF	4 ± 3	-7 ± 3	0 ± 7	21	7	-10	-3
ZAKU	-10 ± 3	1 ± 3	-2 ± 7	22	-9	-7	3
ZAKY	-8 ± 3	1 ± 3	2 ± 7	23	-9	-7	3

Table 4. Post-seismic displacements. Average scatters are 1.4, 4.6 and 2.6 mm in east, north and up respectively. The fit is significantly less good in the north-south direction, i.e. along strike. This might be due partly to simplicity of our model that assumes homogenous slip along the fault plane.

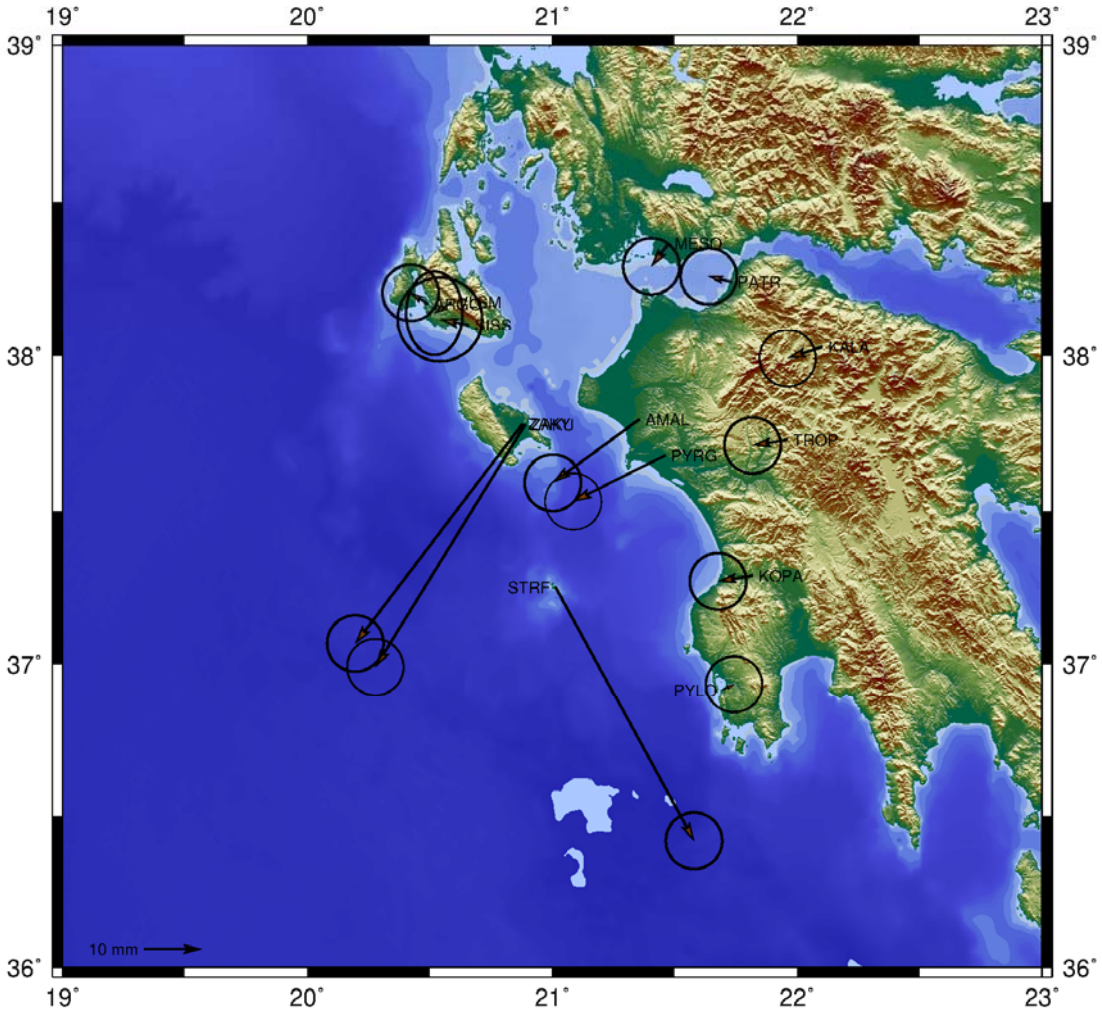

Figure 4. Co-seismic displacements

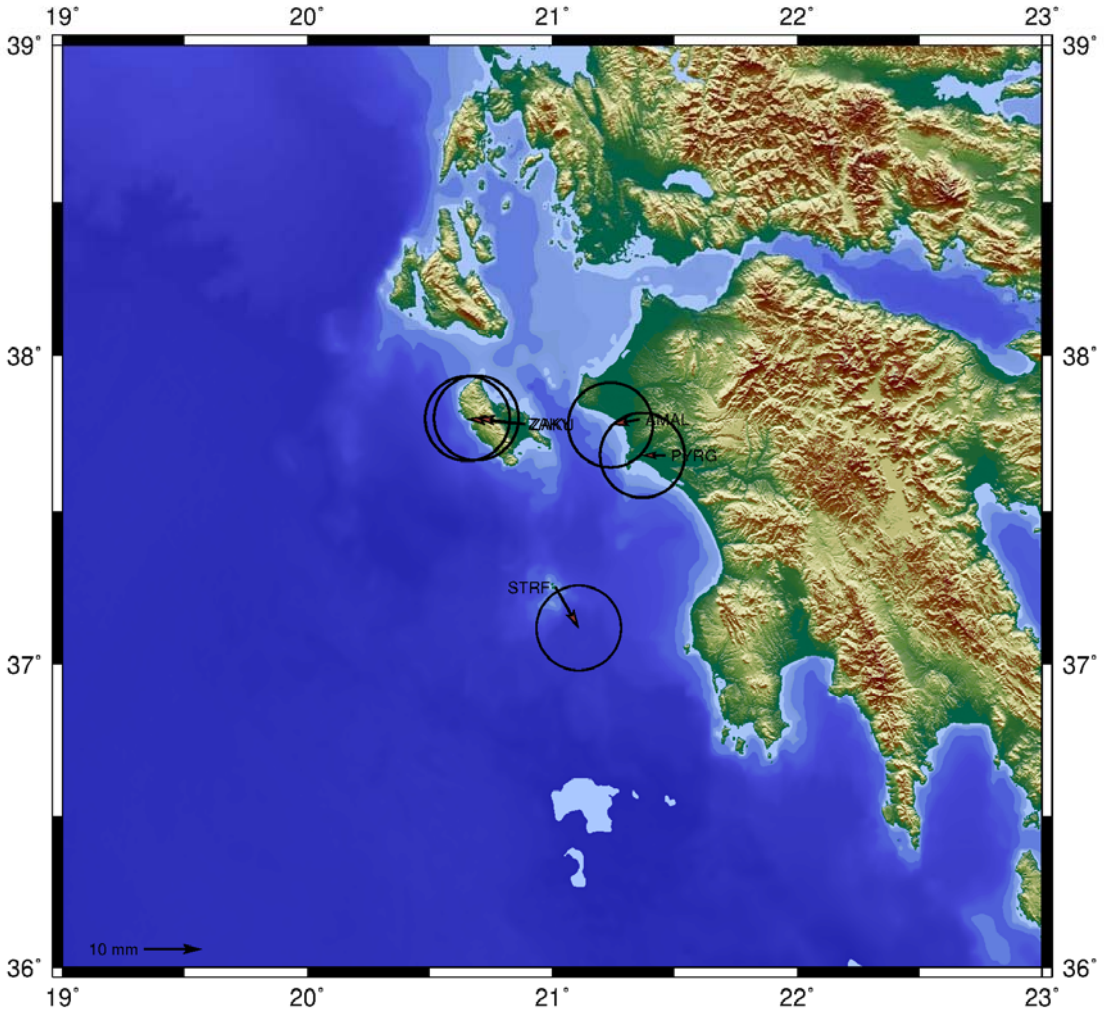

Figure 5. Post-seismic displacements

Model

We model the co-seismic displacements by assuming that the earthquake corresponds to a homogenous slip on a rectangular fault buried in a elastic half space, and we use the formalisms of Okada (1985). We constrain the angle of our models to be consistent with those from the focal mechanism (Tab. 5). We use the value 3.3 10^{10} N m^{-2} for the medium rigidity.

Source	**Strike**	**Dip**	**Rake**	**Depth**	**Moment**
	°	°	°	km	x 10^{19} N m
GEOSCOPE	10	24	158	15	3.41
CGMT	13	24	165	12	2.31
INGV	17	27	168		2.5
NOA	14	49	174		1.45
UPAT	12	41	165		1.7

Table 5. Moment tensors from various sources

The best fitting model parameters are listed in Tab. 6. The upper edge of the co-seismic fault is at a depth of 3 km and the lower edge at a depth of 10 km.

Parameter	Unit	Co-seismic	Post-seismic
Long(1)	°	20.625 ± 0.01	20.625 ± 0.02
Lat(1)	°	37.415 ± 0.01	37.415 ± 0.02
Depth	km	3 ± 1	0 ± 1
Length	km	26 ± 3	26 ± 6
Width	km	16.5 ± 2	3 ± 2
Strike	°	9 ± 6	9 ± 25
Dip	°	25 ± 5	90 ± 40
Rake	°	170 ± 6	180 ± 25
Slip	m	1.93 ± 0.1	1.9 ± 0.5
Moment	N m	$2.73\ 10^{19}$	$0.44\ 10^{19}$
Centroid	km	6.5	1.5

Table 6. Parameters of the models. (1) Longitude and latitude of the centre of the upper edge of the fault. The modelled post-seismic fault is a vertical fault located on top of the co-seismic fault between depths 0 and -3 km.

Stofades earthquake

Source	**Strike**	**Dip**	**Rake**	**Depth**	**Moment**
	°	°	°	km	x 10^{19} N m
CGMT	8	31	162	23	0.90

Table 7. CGMT parameters of the M_w = 6.5 1997 November 18 Strofades earthquake

	East	North	Co-seismic displacements			Model		
Code	Long	Lat	d_E	d_N	d_U	m_E	m_N	m_U
	°	°	mm	mm	mm	mm	mm	mm
STRF	37.247	21.010	11 ± 6	-118 ± 6	91 ± 15	13	-118	77
KERI	37.645	20.836	-9 ± 6	-17 ± 6	-1 ± 15	-1	-12	-11

Table 8. Co-seismic displacements at the GPS stations KERI and STRF

Parameter	Unit	Co-seismic
Long(1)	°	20.854 ± 0.03
Lat(1)	°	37.316 ± 0.03
Depth	km	9 ± 3
Length	km	29 ± 5
Width	km	17 ± 5
Strike	°	8 ± 15
Dip	°	31 ± 10
Rake	°	162 ± 10
Slip	m	1.16 ± 0.3
Moment	N m	$1.89\ 10^{19}$
Centroid	km	13.4

Table 9. Best fitting parameters of the 1997 Strofades earthquake