Positive isotropic components of the 2025 Santorini-Amorgos earthquakes

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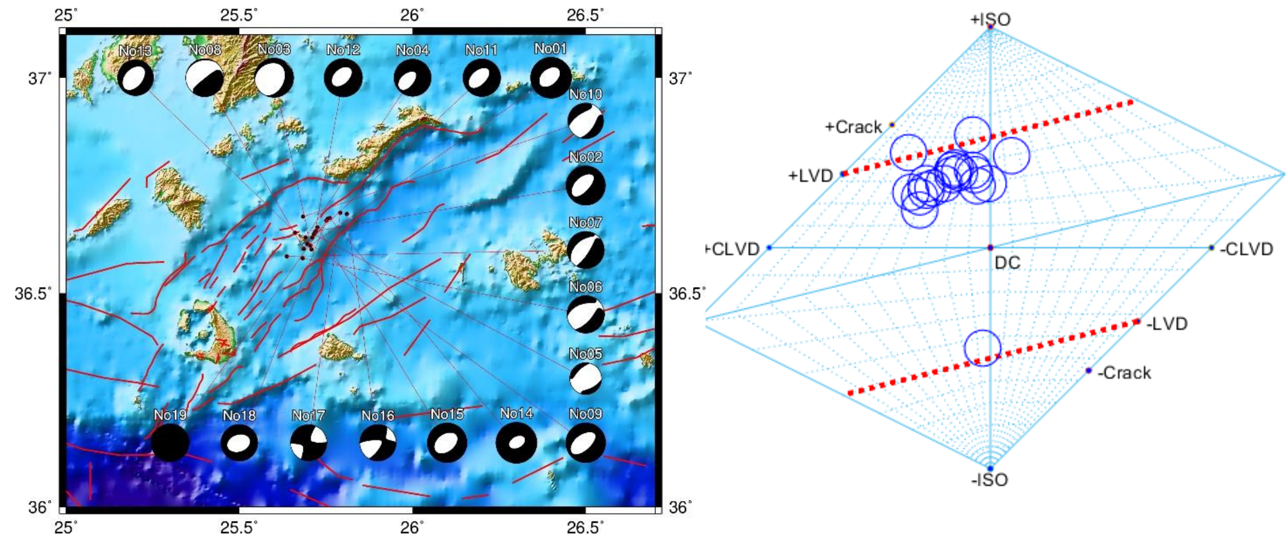
Abstract. We used full waveforms of the Hellenic Unified Seismic Network (HUSN) regional stations and a frequency range of 0.03-0.06 Hz. We calculated full moment tensors (MTs) and focused on their ISO and CLVD components. In the tested depth range of 1-20 km, the medians of ISO (=VOL) and CLVD are positive, but their 68% confidence intervals are broad due to the tradeoff of the non-DC with depth. When constraining source depths to ≥ 7 km, indicated by relocations, MTs have unambiguously positive ISO and positive CLVD, pointing to a shear-opening source process.

Introduction. The current seismic activity near Amorgos Island may contribute to understanding the relative roles of tectonic and volcanic processes in the region (e.g. Andinisari et al., 2021). Here we report on non-double-couple (non-DC) components of the full moment tensor (MT) of 19 events analyzed so far.

Method. We use semi-automatic station selection, starting from the deviatoric moment-tensor calculation of NOA with GISOLA (Triantafyllis et al., 2016 and 2022), http://orfeus.gein.noa.gr/gisola/realtime/2025/, and we adopt their pre-processed instrumentally corrected full waveforms. A typical set consists of ~ 8-15 stations of HUSN (Evangelidis et al. 2021) at epicentral distances from ~50 to ~250 km. Further, we use the manually revised epicenter location by NOA and set the trial source positions below the epicenter. Four 1D velocity models were tested, i.e., Brüstle, et al. (2012), Dimitriadis et al. (2010), Novotný et al. (2001), and Fountoulakis (personal communication). Results for the latter velocity model are presented below. All the tested models provide qualitatively the same results in the frequency range of 0.03-0.06 Hz. Full moment tensor is calculated with ISOLA2024 software (Zahradník and Sokos, 2018 and 2025) and its newer Bayesian bootstrap version enabling quantification of confidence intervals of the ISO and CLVD components. An example of the processing for the event of 2025-02-04 (13:04 UTC) is shown in Attachment, Figs. A1-A4.

Results. The full MTs with the best waveform fit are presented in Fig. 1a. Their waveform-preferred depths vary from 3 to 12 km. The results from the Bayesian bootstrap are presented in Table 1. First, we use trial source depths of 1-20 km (step 1 km). The table shows that the ISO median values of all events (except one low-quality inversion) are positive. However, the 68% confidence intervals of ISO and CLVD are relatively large. This effect is due to the tradeoff between non-DC components and depth. The zero-valued ISO and CLVD would be possible if the depth is shallower than ~7 km. In this light, fundamental improvement of the resolution of the non-DC components is provided using relocated hypocenters. We calculate them by hypoDD code (Waldhauser, 2000; Waldhauser and Ellsworth, 2000), see Table 1. Based on the relocations we performed the second set of inversions with depth constrained to 7-20 km. Then, as demonstrated in Fig. 1b, the waveform inversion unambiguously provides full MTs with ISO > 0 and CLVD > 0 (highlighted in bold in Table 1) thus pointing to a shear-tensile (opening) source process. Interpretation will be provided elsewhere.



a) b)

Fig. 1. (a) Full MTs from best-fit Isola solutions, topography and bathymetry from GEBCO (https://www.gebco.net/) and fault lines from NOA FAULTS 6.0 (Ganas, 2023). (b) The source-type plot of 19 events based on median ISO and CLVD values obtained with depth constrained to 7-20 km. The isolated circle in panel (b) is an outlier, related to an event with poor data fit (No 8 of Table 1).

Table 1. ISO and CLVD are given with their 15.87%, 50% (median), and 84.13% percentiles. No. is an internal numbering of events in this study.

Date - Time	Mw	ISO (%) Depth 1-20 km	CLVD (%) Depth 1-20 km	ISO (%) Depth ≥ 7 km	CLVD (%) Depth ≥ 7 km	Relocated depths (km) (dependent on the model of initial picks)
No01_2025/02/04_13:04:14.56	5.3	23 35 45	-2 15 27	24 **36** 46	-1 **16** 27	13.9
No02_2025/02/05_19:09:38.62	5.0	-21 24 40	-23 26 39	18 **29** 42	9 **29** 39	12.6
No03_2025/02/03_09:29:42.49	5.1	-24 16 53	-56 -21 16	19 **39** 58	-41 **-3** 19	14.2
No04_2025/02/03_20:19:39.39	4.8	-15 21 39	-27 15 40	15 **29** 42	3 **21** 42	13.9
No05_2025/02/08_16:30:00.76	4.1	-32 2 41	-34 -2 28	19 **35** 51	-6 **17** 35	12.4
No06_2025/02/08_09:00:41.37	4.8	-15 14 39	-5 17 29	15 **27** 42	13 **26** 37	14.0
No07_2025/02/07_07:16:13.66	4.8	-5 20 42	3 30 48	12 **25** 44	16 **36** 50	12.2
No08_2025/02/02_23:54:41.58	4.9	-39 -23 -4	-32 -8 41	-43 **-26** -1	-38 **6** 56	12.0
No09_2025/02/09_19:05:39.41	5.1	0 22 31	9 25 35	16 **26** 34	22 **29** 37	11.6
No10_2025/02/05_17:47:28.04	4.6	-14 26 49	-19 5 30	43 **51** 60	-4 **8** 28	17.8
No11_2025/02/04_02:46:06.98	4.8	17 32 44	-4 16 32	18 **33** 45	-1 **17** 32	12.7
No12_2025/02/03_12:17:40.53	4.9	13 32 44	-7 13 28	18 **34** 46	-5 **14** 27	12.3
No13_2025/02/02_17:45:44.99	4.6	-15 25 44	-34 0 21	19 **35** 49	-12 **8** 24	13.2
No14_2025/02/10_20:16:29.37	5.3	-30 30 44	-35 3 20	16 **33** 45	-10 **7** 21	13.7
No15_2025/02/10_22:37:25.55	5.1	2 26 40	-18 5 19	13 **28** 43	-13 **6** 20	12.4
No16_2025/02/10_11:23:17.71	4.7	6 17 26	19 31 42	8 **17** 26	19 **32** 42	16.9
No17_2025/02/11_05:58:44.81	4.7	17 23 32	18 32 45	17 **23** 32	18 **32** 45	14.9
No18_2025/02/11_07:17:19.00	4.7	-19 25 45	-32 -3 13	8 **29** 45	-19 **0** 15	15.3
No19_2025/02/11_11:43:54.22	4.9	29 42 53	17 36 47	34 **43** 54	22 **37** 48	12.0

Attachment

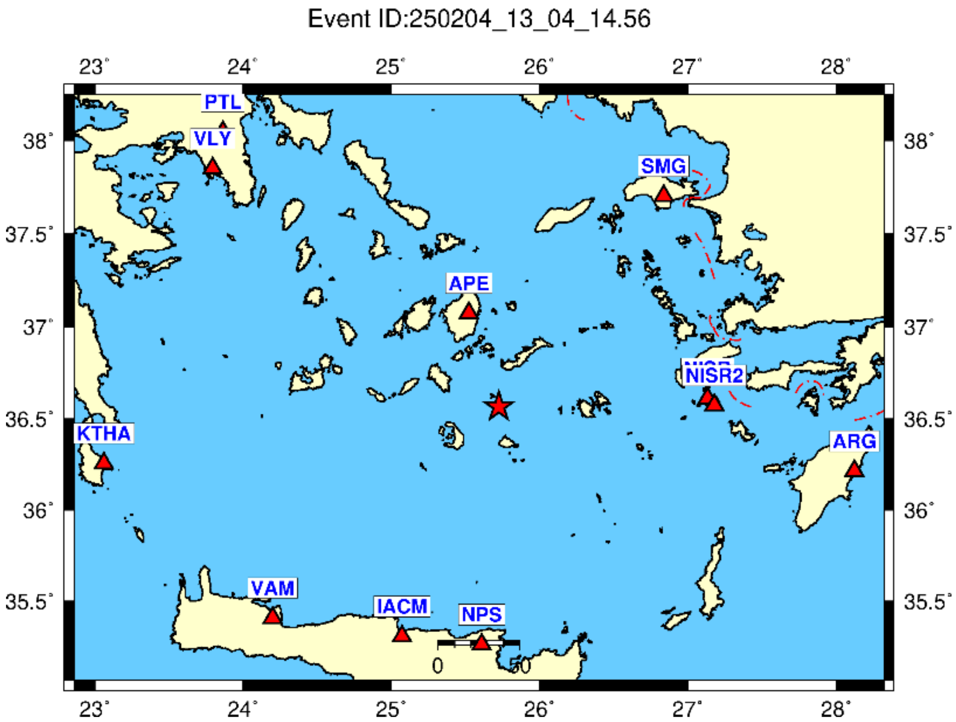


Fig. A1. Epicenter (star) of one of the events, No. 1, and used HUSN stations (triangles).

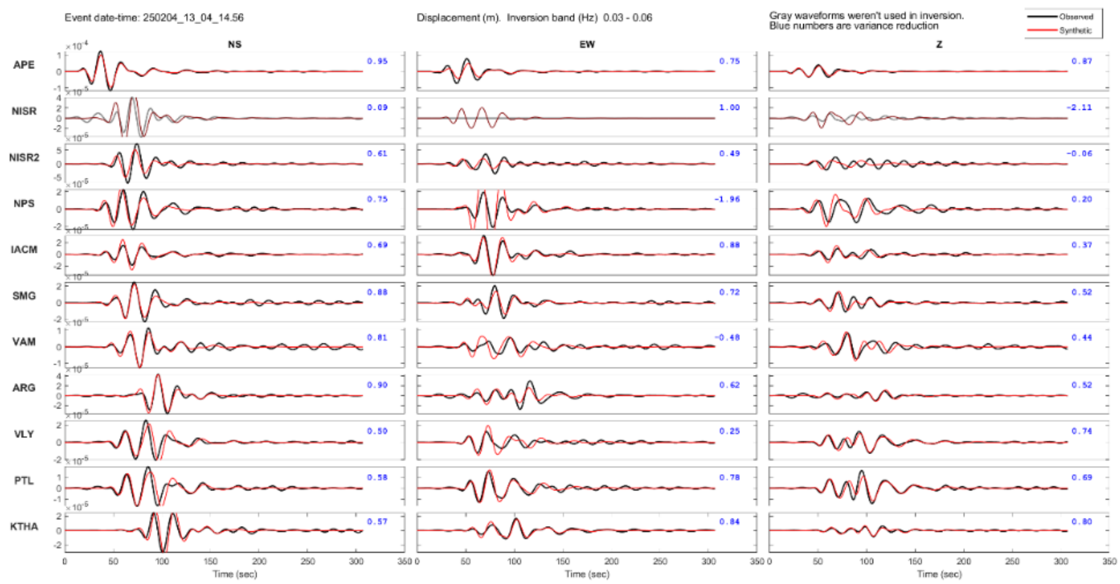


Fig. A2. Waveform fit.

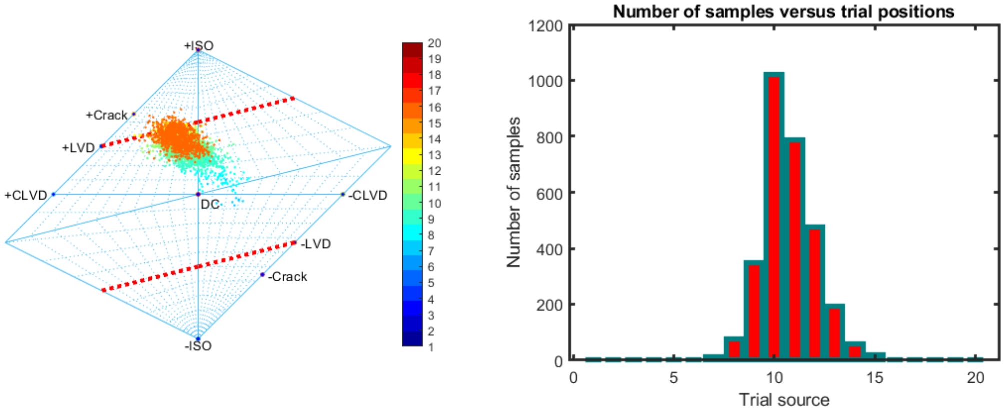
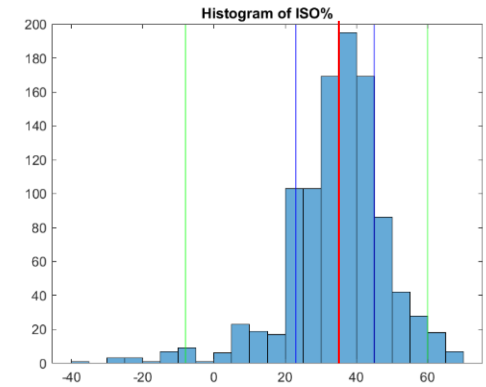
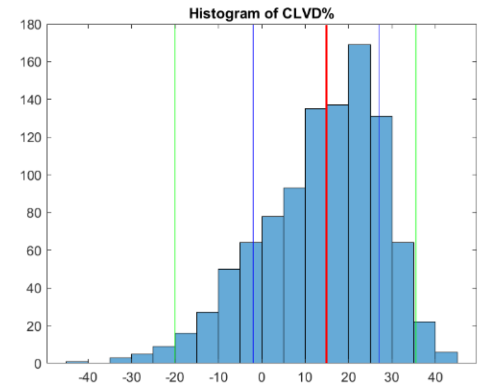


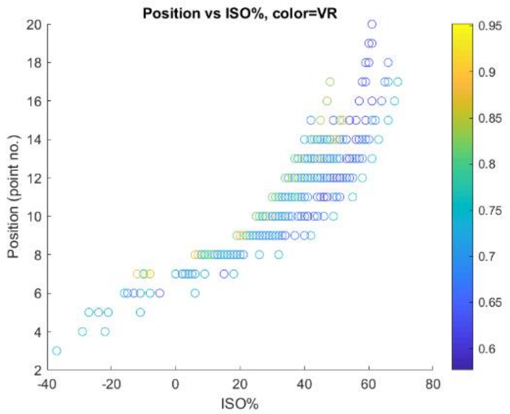
Fig. A3. Source type plot and depth preference from Isola2024 (positions 1-20 refer to depth 1-20 km). Dots in the source type plot, color-coded with trial depth, are random MT samples demonstrating uncertainty.



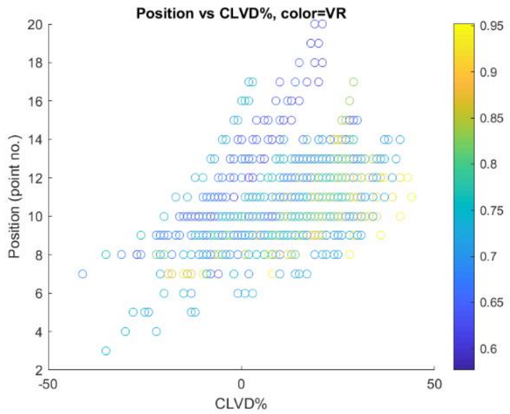
a)



b)



c)



d)

Fig. A4. Non-DC components (ISO and CLVD)) and their uncertainty estimate from the bootstrap version of Isola (positions 1-20 refer to depth 1-20 km). Vertical lines in panels (a) and (b) are the percentiles, median is shown in red. Note ISO > 0 for depths > 7 km in panel (c). VR is variance reduction.

Data and Resources. Regional waveform data used in this study were obtained from the Hellenic Unified Seismic Network (HUSN) networks, HL, DOI:10.7914/SN/HL, HC, DOI:10.7914/SN/HC, HP, DOI:10.7914/SN/HP and HA, DOI:10.7914/SN/HA. Data from the HL, HC, HP, and HA networks can be accessed through the National Observatory of Athens (NOA) EIDA node https://eida.gein.noa.gr/ (Evangelidis et al., 2021). ISOLA software can be downloaded from https://geo.mff.cuni.cz/~jz/for_ISOLAnews/. The maps were generated using the Generic Mapping Tools v.6, https://www.generic-mapping-tools.org/download/.

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