Coupled earthquakes and resonance processes during the uplift of Campi Flegrei caldera

Supplementary material

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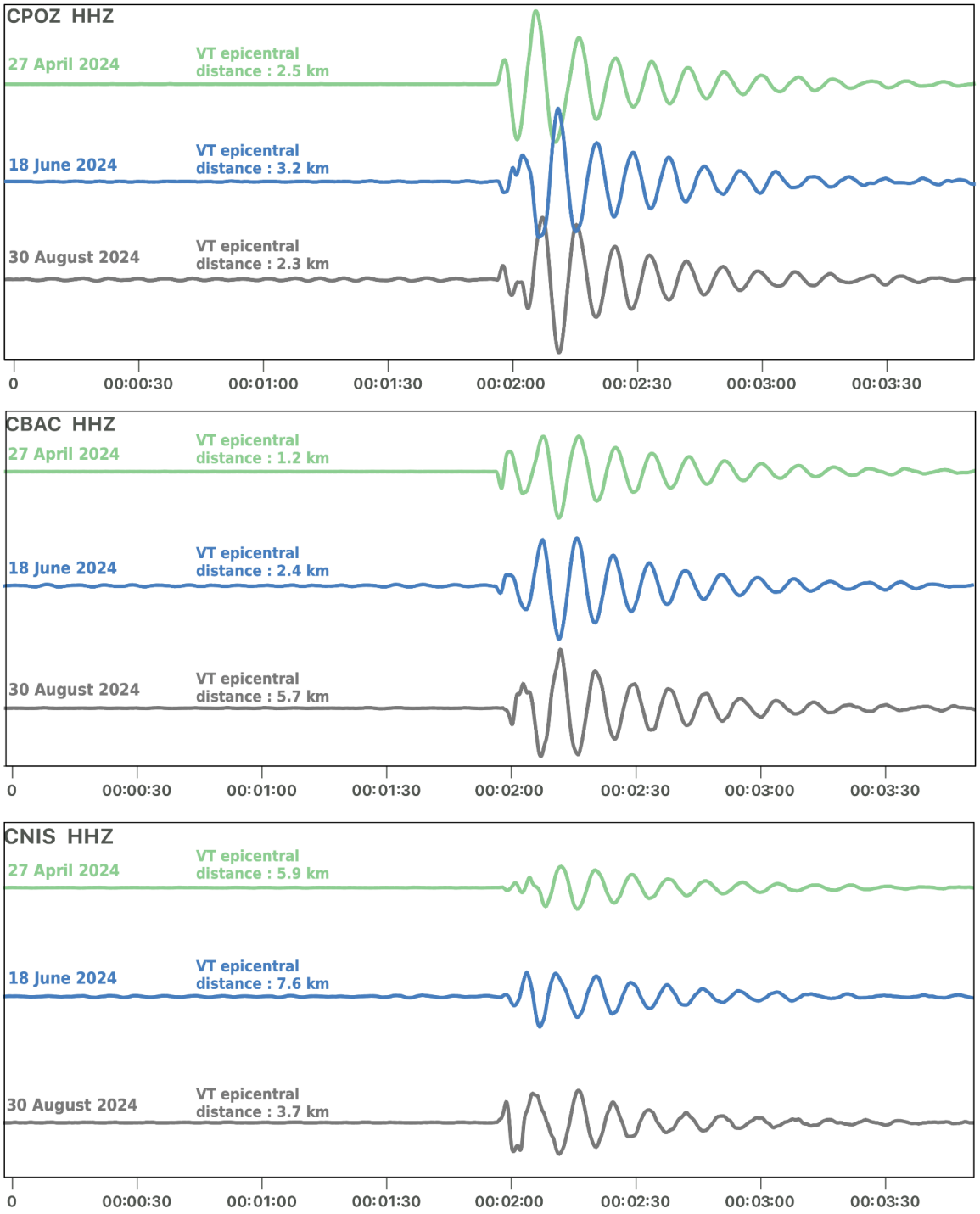
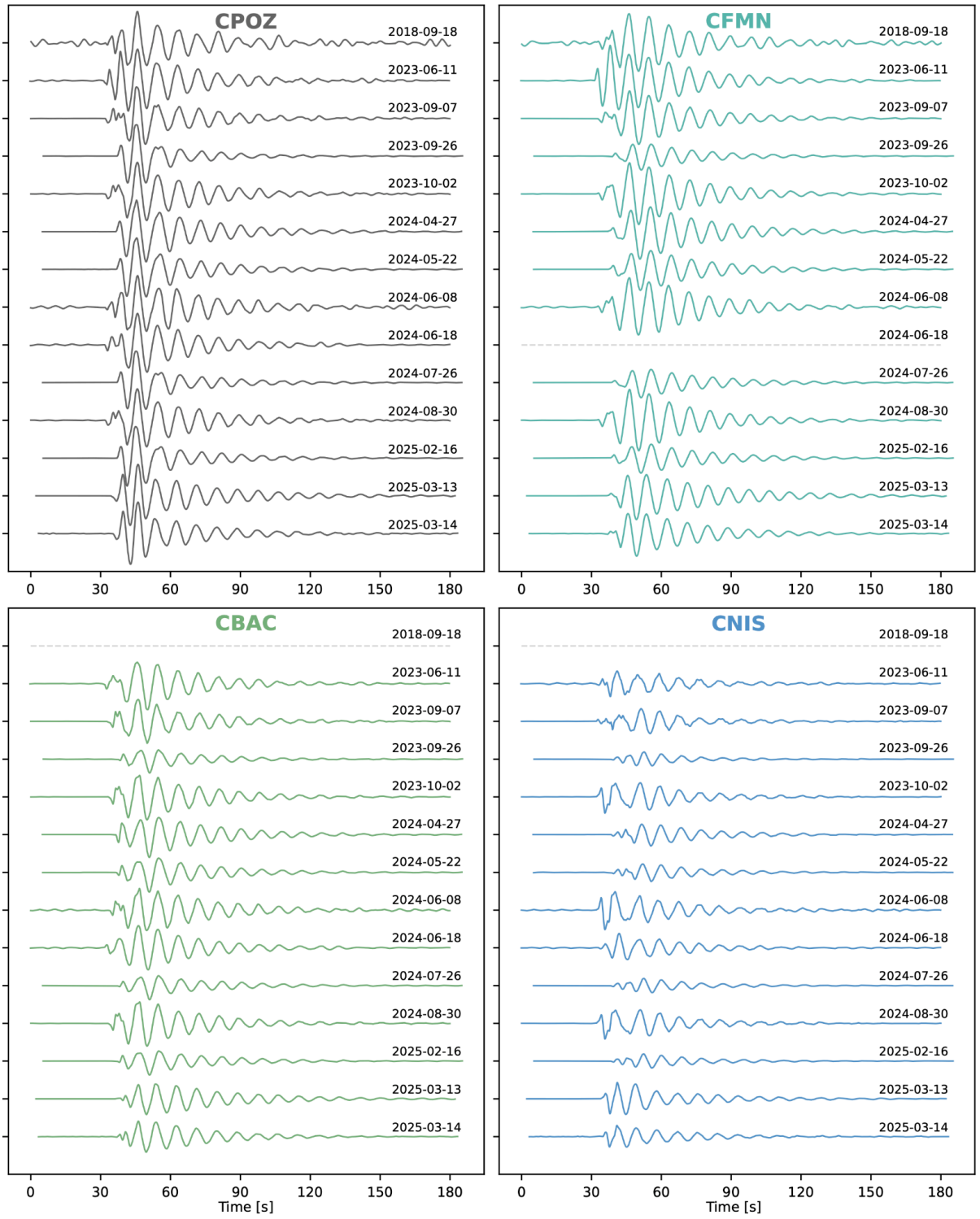
Network	Station	Latitude	Longitude	Elevation
IV	CAAM	40.820065	14.142049	170.0
IV	CBAC	40.810901	14.08057	77.0
IV	CFMN	40.832942	14.090403	92.0
IV	CMIS	40.778154	14.089047	134.0
IV	CMSN	40.8382	14.1818	20.0
IV	CMTS	40.8314	14.1972	40.0
IV	CNIS	40.79817	14.163176	50.0
IV	COLB	40.819016	14.144606	56.0
IV	CPIS	40.829224	14.146981	117.0
IV	CPOZ	40.821072	14.11911	52.0
IV	CQUE	40.885355	14.155414	109.0
IV	CSFT	40.829168	14.139635	151.0
IV	CSOB	40.826469	14.143963	223.0
IV	CSTH	40.829447	14.149329	108.0
IV	IOCA	40.746797	13.90142	166.0
IV	MODR	41.1459	13.8779	345.0
IV	OVO	40.8275	14.39667	584.0
IV	PAOL	41.031206	14.567486	715.0
IV	PIGN	41.200001	14.17989	398.0
IV	SORR	40.58256	14.335709	537.0

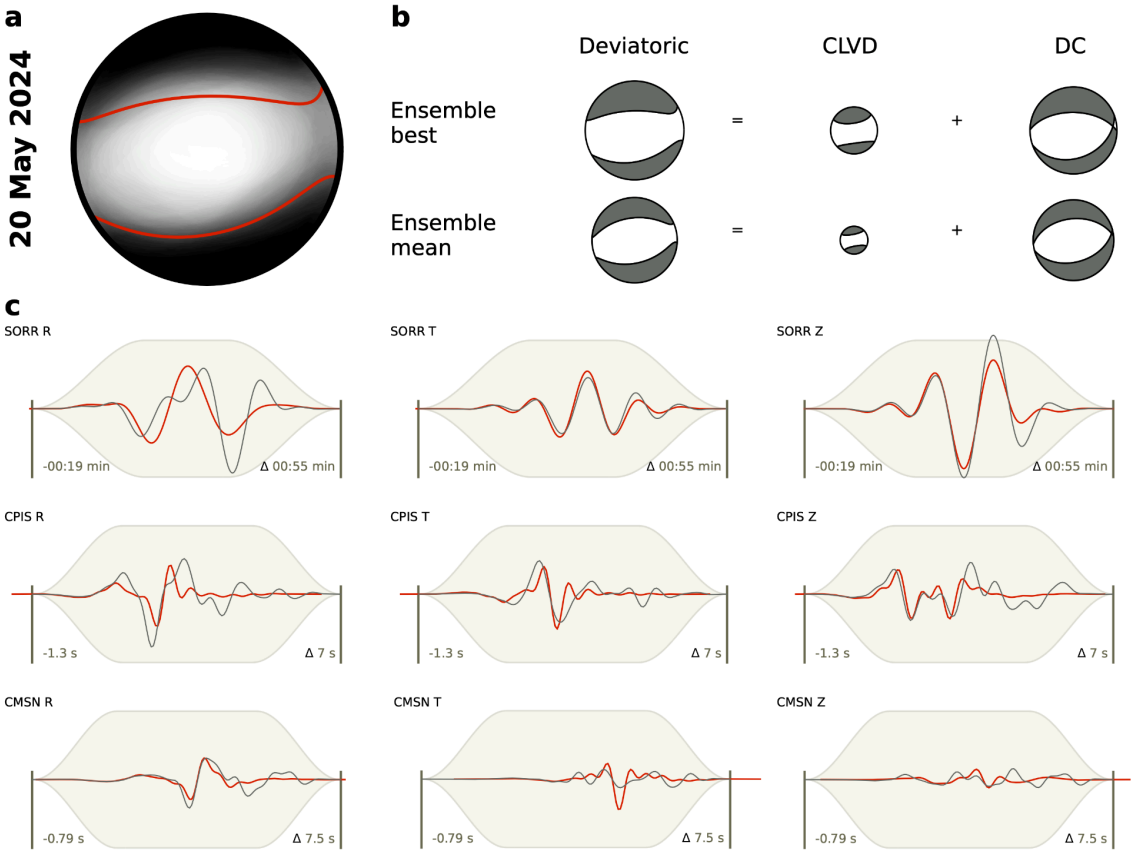
Supplementary Table 1: Network of stations used in the analysis.



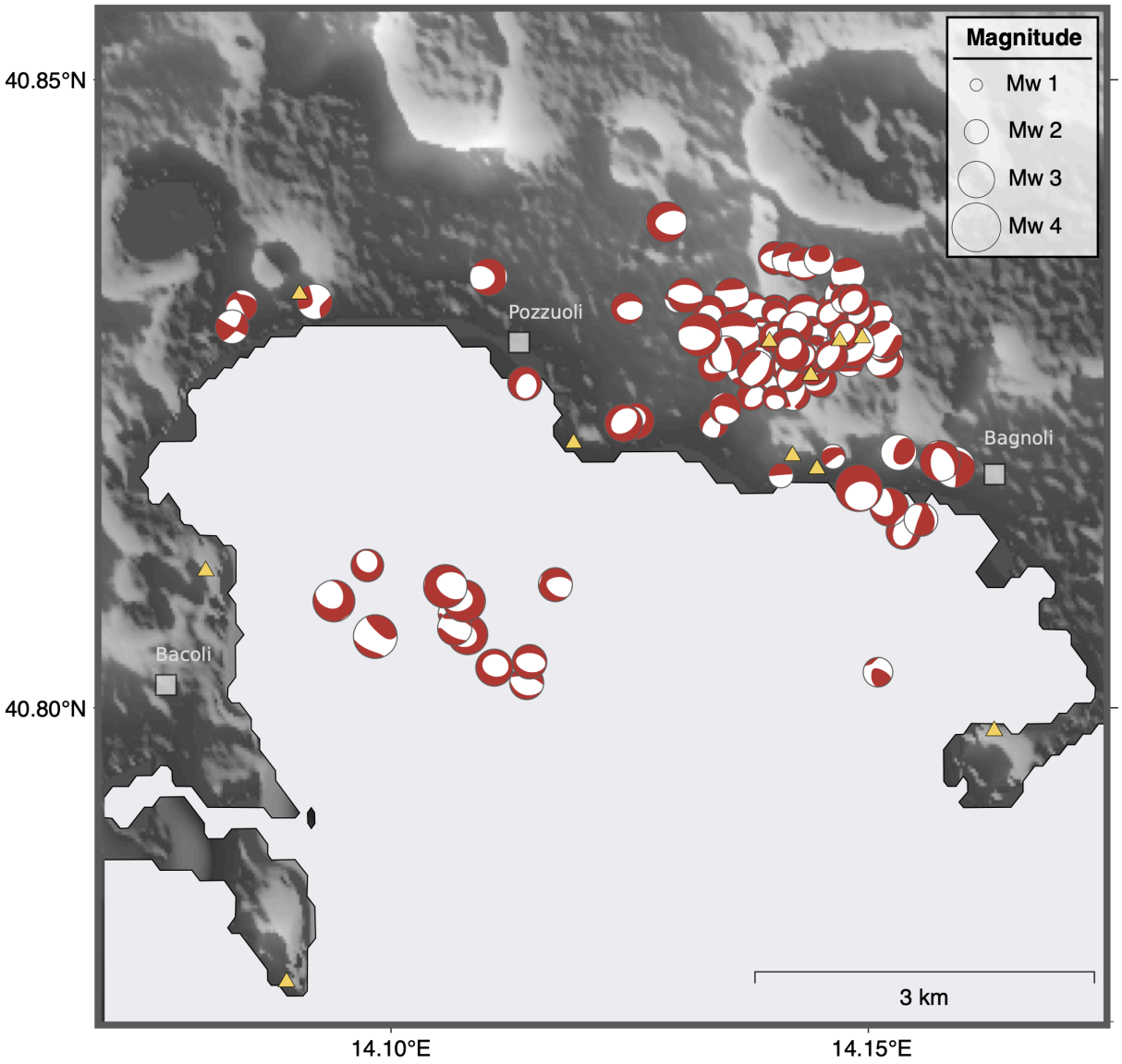
Supplementary Figure 1: VLP amplitude decay. Traces *amplitude comparison, recorded at three stations (CPOZ, CBAC, CNIS) for three events (27 April 2024, 18 June 2024, and 30 August 2024). Amplitudes normalised per event. Regardless of the VT's event localization, the station with the highest VLP signal amplitude is CPOZ, located in Pozzuoli. Traces filtered in the frequency range 0.075-0.125 Hz.*



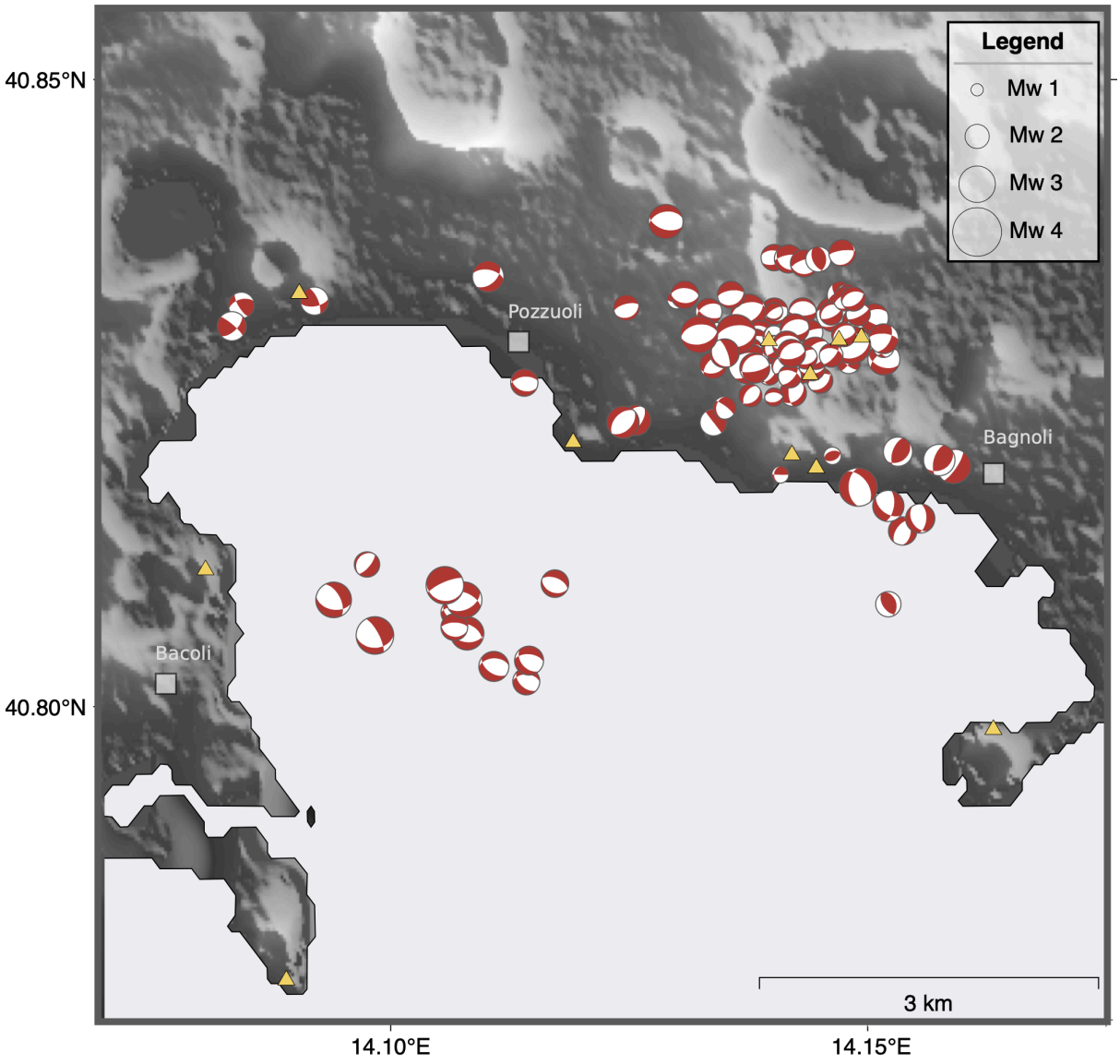
Supplementary Figure 2: Waveform similarity. *Waveform similarity for all the VLPs events, recorded on the vertical component (HHZ), at four stations: CPOZ, CFMN, CBAC, and CNIS. Traces normalised per event and filtered in the frequency range 0.09-0.13 Hz.*



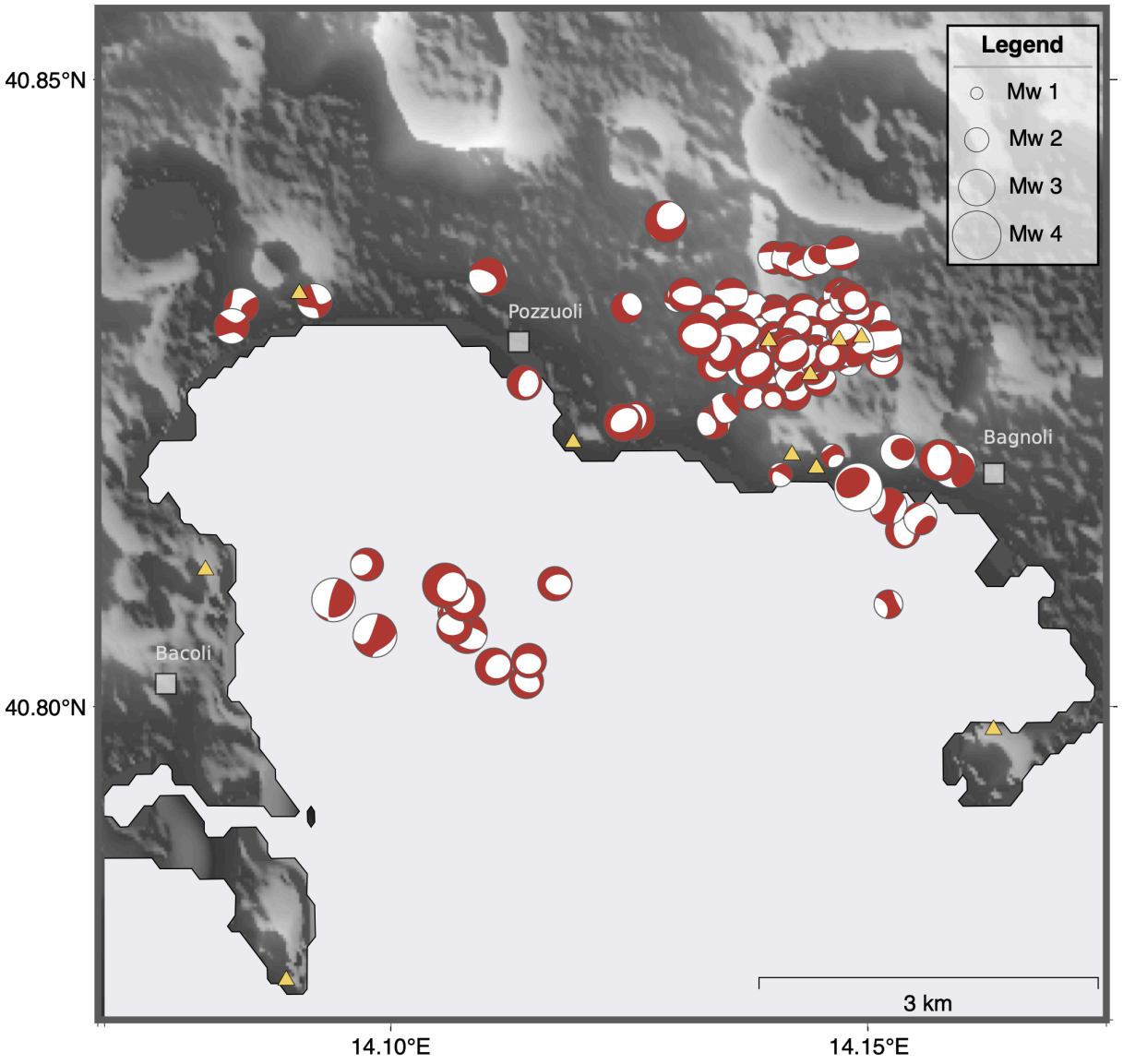
Supplementary Figure 3: MT inversion results for the VT event of 20 May 2024. a, *fuzzy moment tensor: superposition of all the solutions extracted with the bootstrap method, the red line shows the best solution.* ***b:*** *deviatoric moment tensor decomposition for the best and the mean moment tensor solutions, where the mean solution is obtained from the population of solutions extracted with the data bootstrap approach.* ***c:*** *fit between observed waveform (red lines) and synthetic waveform (black lines) generated using the best solution parameters. Full waveforms are shown for regional (top row) and local (bottom two rows) stations in all three components, radial (R), transversal (T), and vertical (Z).*



Supplementary Figure 4: VTs deviatoric moment tensor solution. *The double couple components are shown in Fig. 3.*



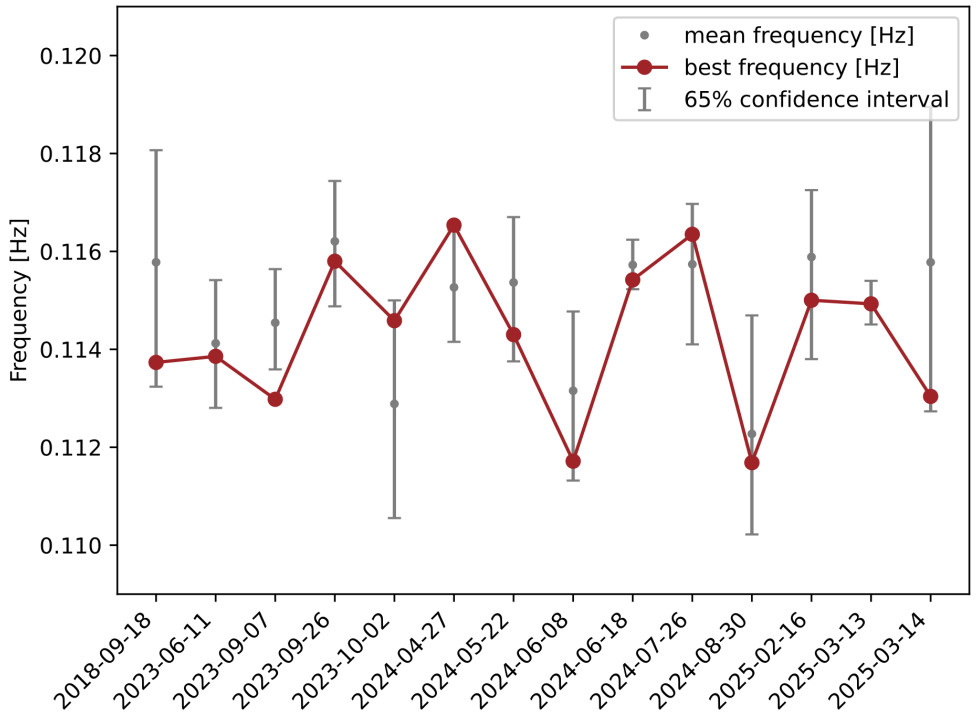
Supplementary Figure 5: VTs double couple moment tensor solution.



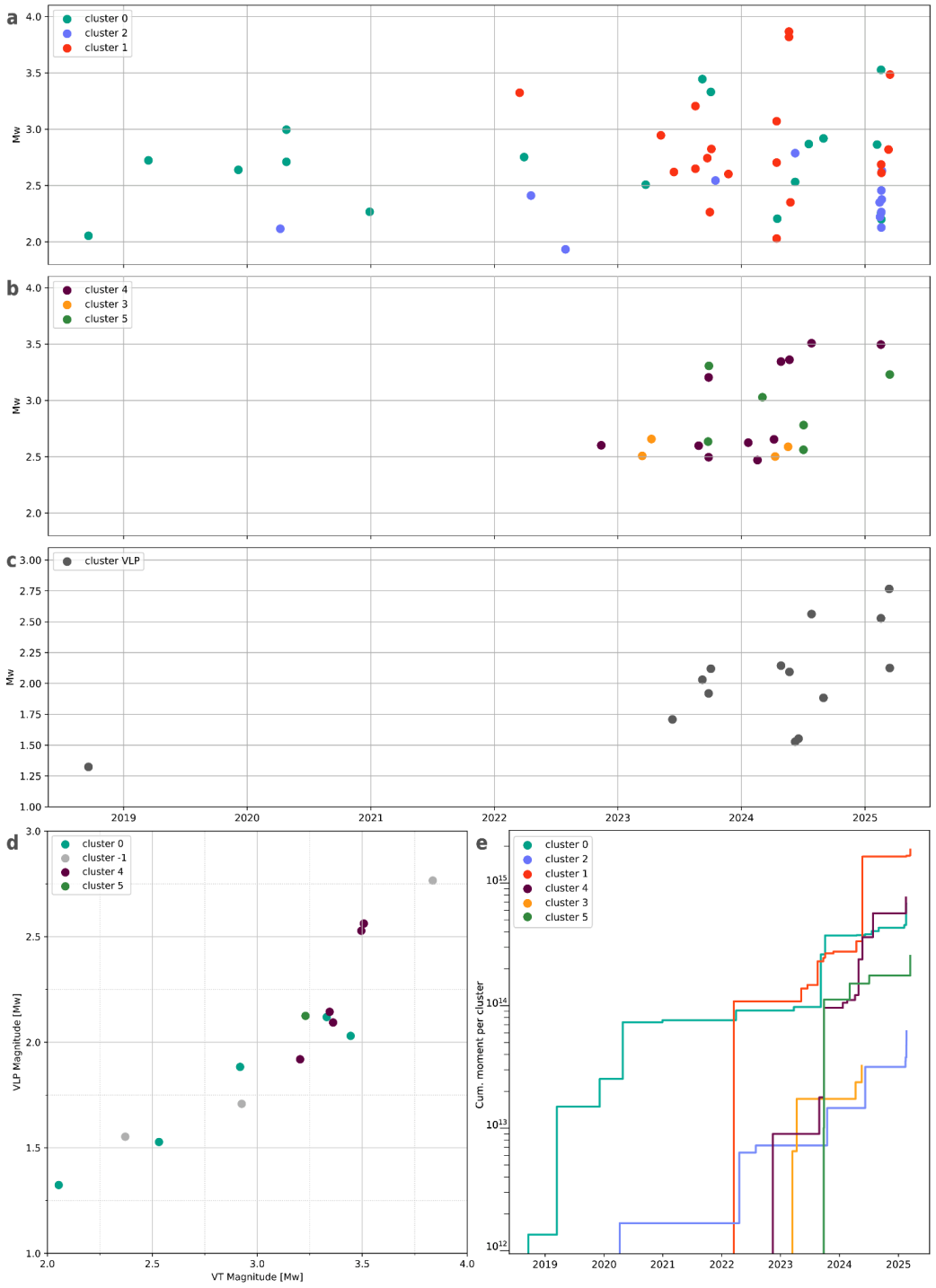
Supplementary Figure 6: VTs deviatoric components of the full moment tensor solution.

Cluster	Mean depth [km]	Max Magnitude [Mw]
0	2.6 ± 0.8	3.53
1	2.7 ± 0.6	3.87
2	1.6 ± 0.3	2.79
3	3.0 ± 0.3	2.66
4	3.7 ± 0.3	3.51
5	3.4 ± 0.5	3.31
VLP	3.6 ± 0.6	2.77

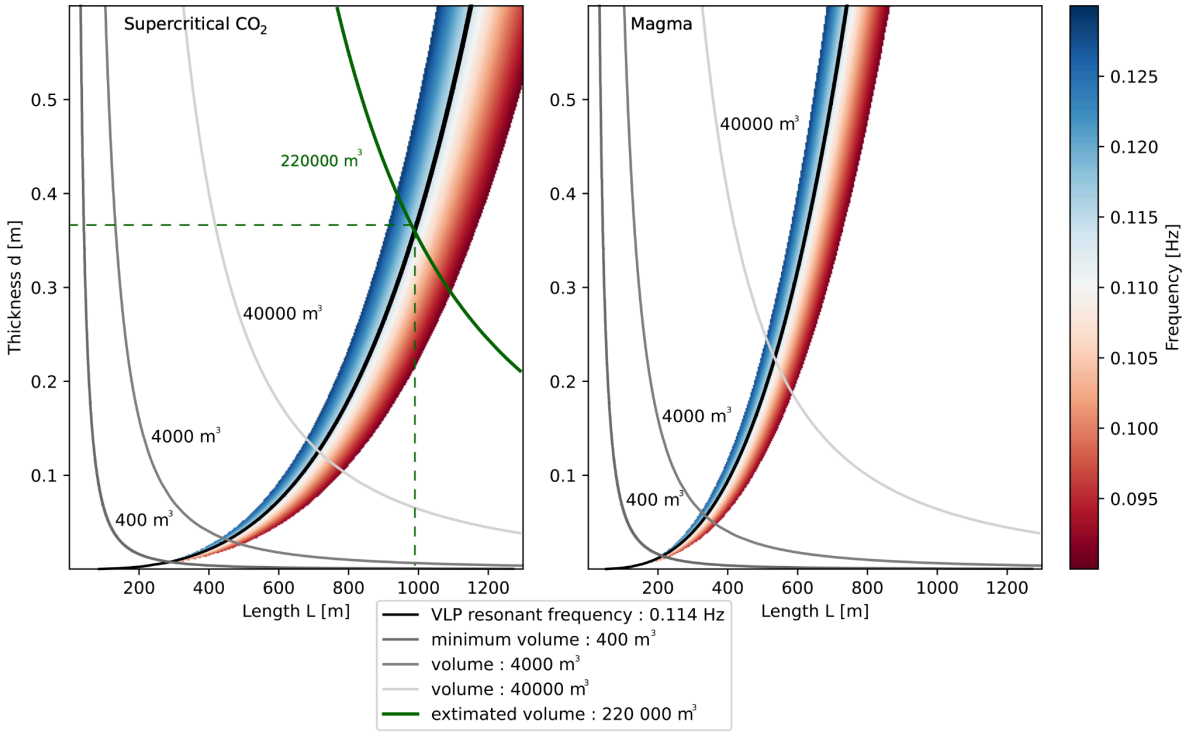
Supplementary Table 2: Mean depth and maximum moment magnitude values for each cluster, obtained by centroid MT inversion. *Depth values were obtained by computing the mean and the standard deviation of the events' best solutions, for every cluster.*



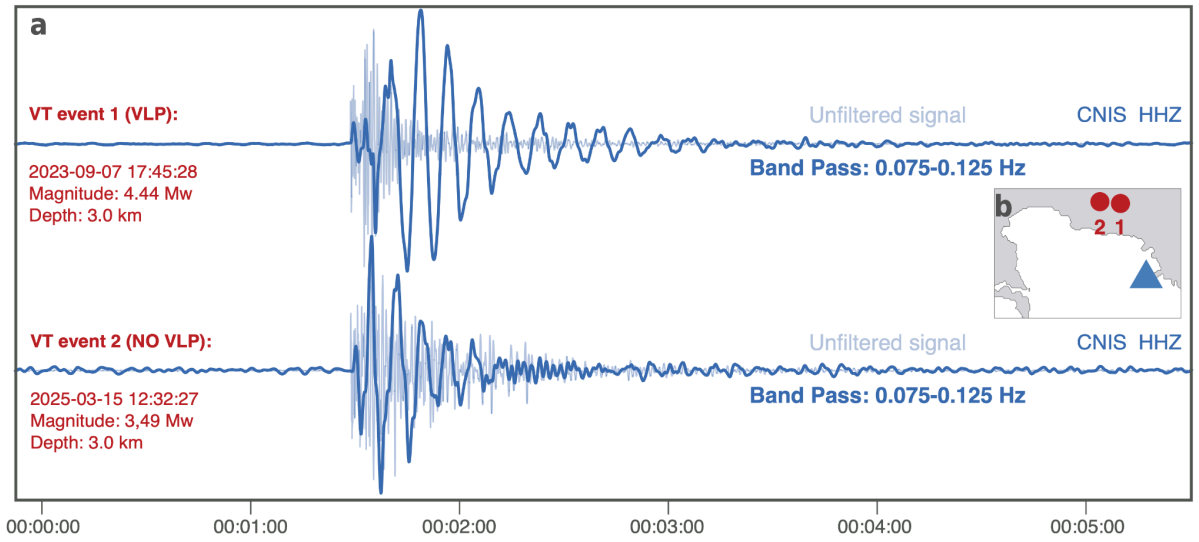
Supplementary Figure 7: Resonant frequencies for VLP events: *In red, the resolved resonant frequency for each best MT solution of the VLP events, in grey, the error bar showing the 65th percentile distribution of the MT solutions, generated with the bootstrap method, and their mean value (grey dot).*



Supplementary Figure 8: Magnitude evolution in time for different clusters. a, b, *Moment magnitude results plotted as a function of time for the 6 VT clusters. Clusters 0-2, located within the caldera, have been active since 2018, while clusters 3-5, located in the outer part of the caldera, became active afterwards, in late 2022 and early 2023.* ***c,*** *VLP moment magnitude results plotted as a function of time.* ***d,*** *Correlation between the calculated Mw for the VT earthquake and the corresponding VLP event. Light grey points (cluster -1) refer to unclustered VTs.* ***e,*** *Cumulative moment for VT clusters.*



Supplementary Figure 9: Relation between resonance period, material and size estimates of resonator source. *Curve showing the length (L) and thickness (d) ratios of the VLP source given the resonance frequency (black line)*[36,37]*. The dark grey line represents the minimum volume of the source, calculated from the seismic moment, the other two lighter-coloured lines are multiples of the minimum volume. The green line represents the estimated volume for the crack, the dotted green lines indicate the corresponding length and thickness.* ***a,*** *resonance model for a supercritical CO_2 filled crack.* ***b,*** *resonance model for a magma filled crack.*



Supplementary Figure 10: VLP signal comparison in two different VT events. a, *Light blue curves show the unfiltered traces recorded at the same station (CNIS) during two earthquakes with similar magnitude, depth, location and epicentral distance from the station. Dark blue curves show the same two traces filtered between 0.075-0.125 Hz. Traces are individually normalised to enhance the relative duration of the VLP signals. Event 1 has a clear VLP signal: although initially the energy from the VT is present in the same frequency band, after a few periods the long-lasting resonance of the crack-like structure dominates the signal. Event 2 shows a much shorter low frequency signal, which we attribute to the VT event itself; in this case, the resonator was not triggered or it oscillated with a small amplitude, comparable to the noise.* ***b,*** *Schematic map showing the epicentral position of the two earthquakes (red dots) and the station recording the waveforms (blue triangle)*