Ambient noise surface wave tomography of Mt. Etna volcano structure during 2020-2021

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1. Motivation

How can Ambient Noise Tomography (ANT) improve our knowledge of the deep structure beneath Mt. Etna within the actively debated geodynamic context of Eastern Sicily?

What?
1) Provides **V_S, radial anisotropy** models of Eastern Sicily;
2) **Petroseismical** models.

How?
1) Improved **Ambient Noise Tomography**;
2) Developement of a **Petroseismical inversion framework.**

2. ANT

- **Key components:** dispersive Rayleigh and Love waves;
- **Sensitivity:** V_S (Rayleigh → V_{SV}, Love → V_{SH});
- **Lateral Resolution:** Station network density and geometry;
- **Vertical Resolution:** Function of the analyzed frequencies (via sensivity kernels, e.g. Agius et al., 2023, G³);
- **Data Volume:** ∝ $N_S^2/2$, continuous waveforms able to storage.

Frequency domain
- Input data: **Rayleigh and Love dispersion curves** for available inter-station paths;
- **No needs for phase correction** [Kästle et al., 2016, GJI].

Main Assumption & "Saving Grace"

Assumption: Diffuse wavefield [Boschi & Weemstra, 2015, Rev. Geophys].

Why it works anyway:
- Kästle et al., 2016, GJI: Azimuthal averaging recovers true velocity;
- Mulargia and Castellaro, 2008, PRL: On-axis (Fresnel zone) waves dominate correlation;
- Weaver et al., 2009, JASA: Negligible error at short distances.

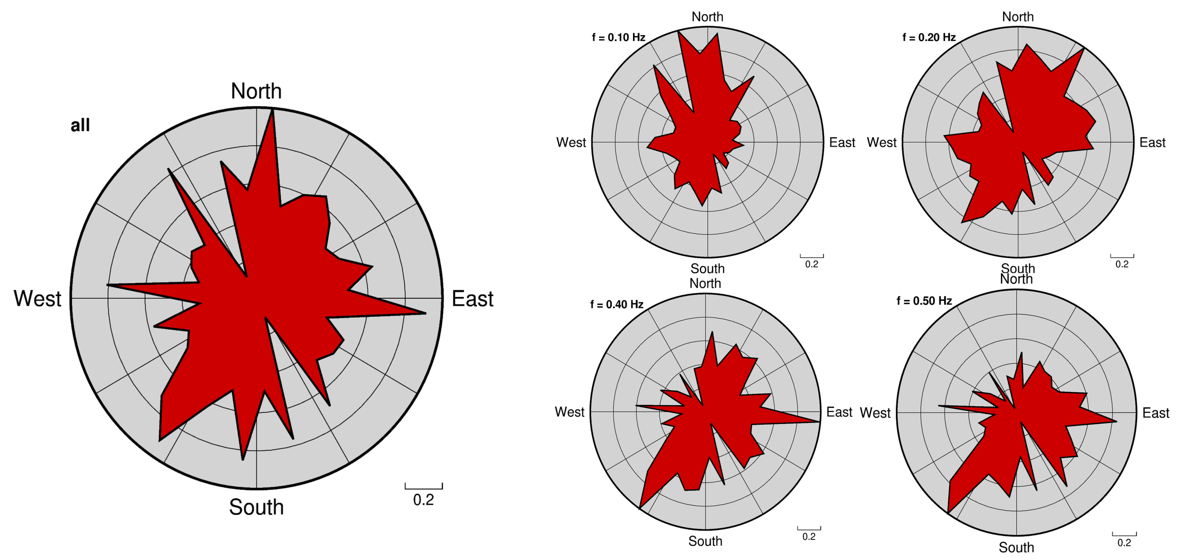


Figure 2: Wind roses as a function of frequency showing the directional power of ambient-noise sources for Rayleigh waves, derived from the coherent wavefield.

3. Data

Array configuration
30 velocimeter from INGV network
- Minimum interstation distance accepted: ~ 27 km (stability);
- 390 dispersion curves for Rayleigh, 370 for Love.

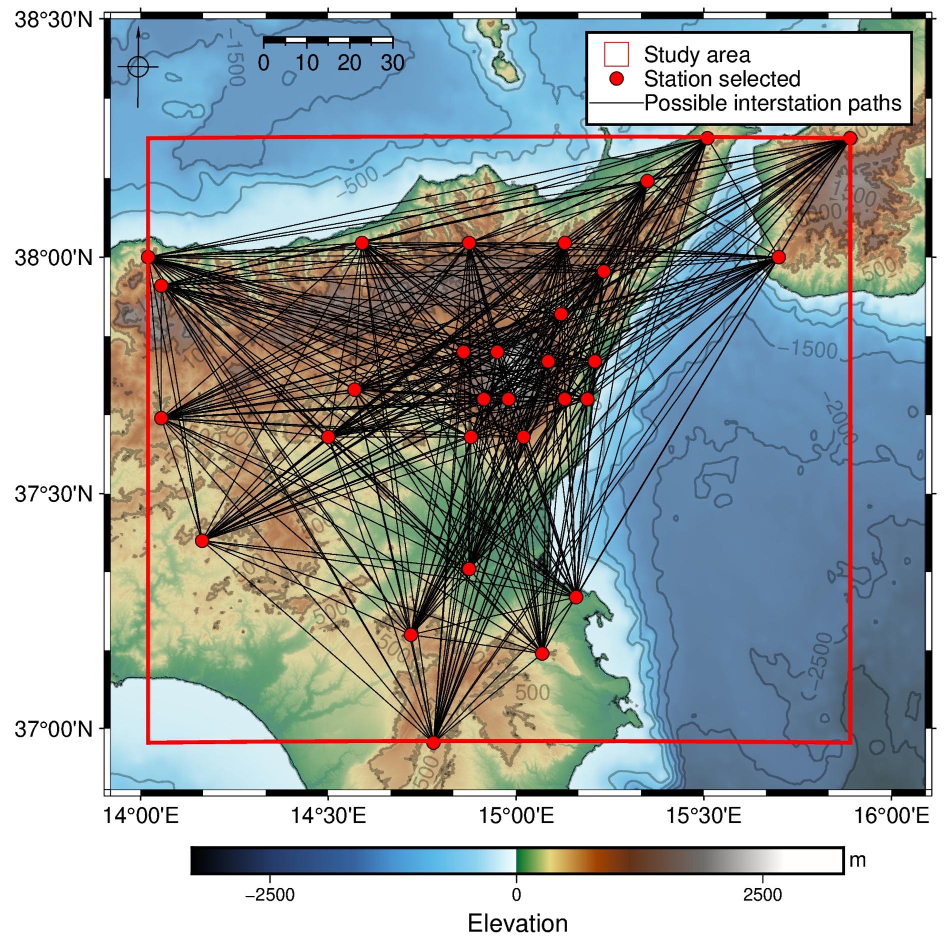


Figure 1: Study area (red square) and selected station network. Colored solid lines indicate the available interstation paths considered in the analysis.

Period Range
1st Jan 2020 → 31st Dec 2021 (2 years)
- Avoids main fissural eruptions (2018-2019);
- Seasonally balanced [Yang & Ritzwoller, 2008, G³].

Frequency range
0.08 Hz → 0.50 Hz

- Sources: ocean waves [Yang & Ritzwoller, 2008, G³, Borzì et al., 2024, GJR Solid Earth]; → Seaflor / Coast
- Avoids the characteristic 0.70 Hz volcanic tremor peak [Wegler and Seidl, 2009, GRL];
- Reduces effects of unfulfilled assumptions [Kästle et al., 2016, GJI, Tromp et al., 2010, GJI].

4. Methodology (with SeisLib [Magrini et al., 2022, GJI])

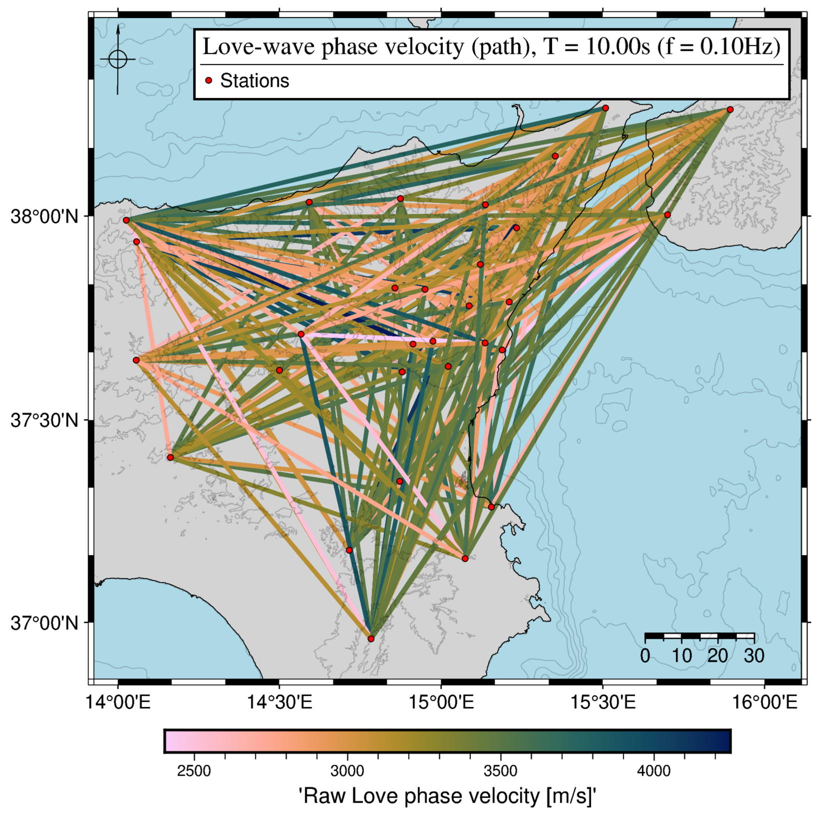
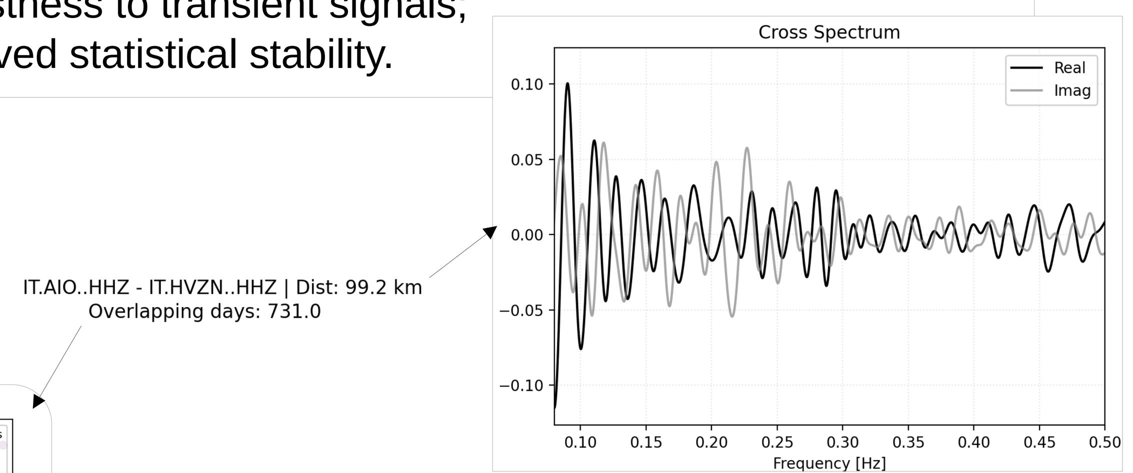


Figure 3: Inter-station paths used for inversion, each assigned its own phase-velocity value at ν = 0.10 Hz (T = 10.00 s), extracted from the corresponding dispersion curve.

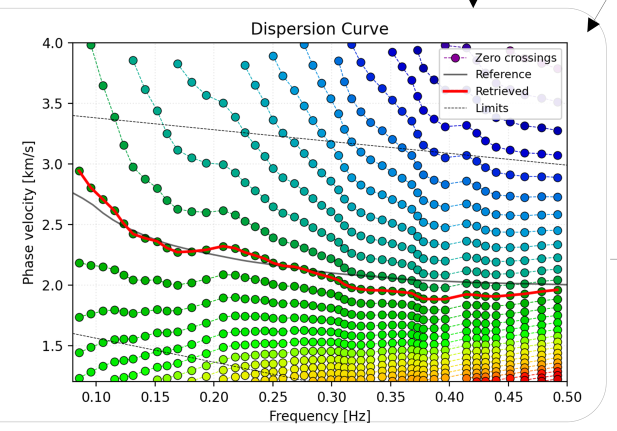
Basic Pre-Processed waveforms

Earthquake Removal
- 2500+ events systematically removed;
- Reduced incoherent signal;
- Enforced diffuse wavefield assumption;
- Stabilized dispersion curve retrieval.

Cross-spectrum via Welch's method [Seats et al., 2012, GJI]
- Improves diffuse wavefiels assumption;
- Faster Cross-spectrum convergence;
- Robustness to transient signals;
- Improved statistical stability.



Picking of the dispersion curves (multiple braches arising from spurious arrivals)



The inverse problem
Regularised Least Square
- Ray-theory approach [Boschi and Dziewoński, 1999, JGR Solid Earth];
- Handles ill-posed problems (e.g., M>D);
- Roughness regularization.

5. Preliminary results

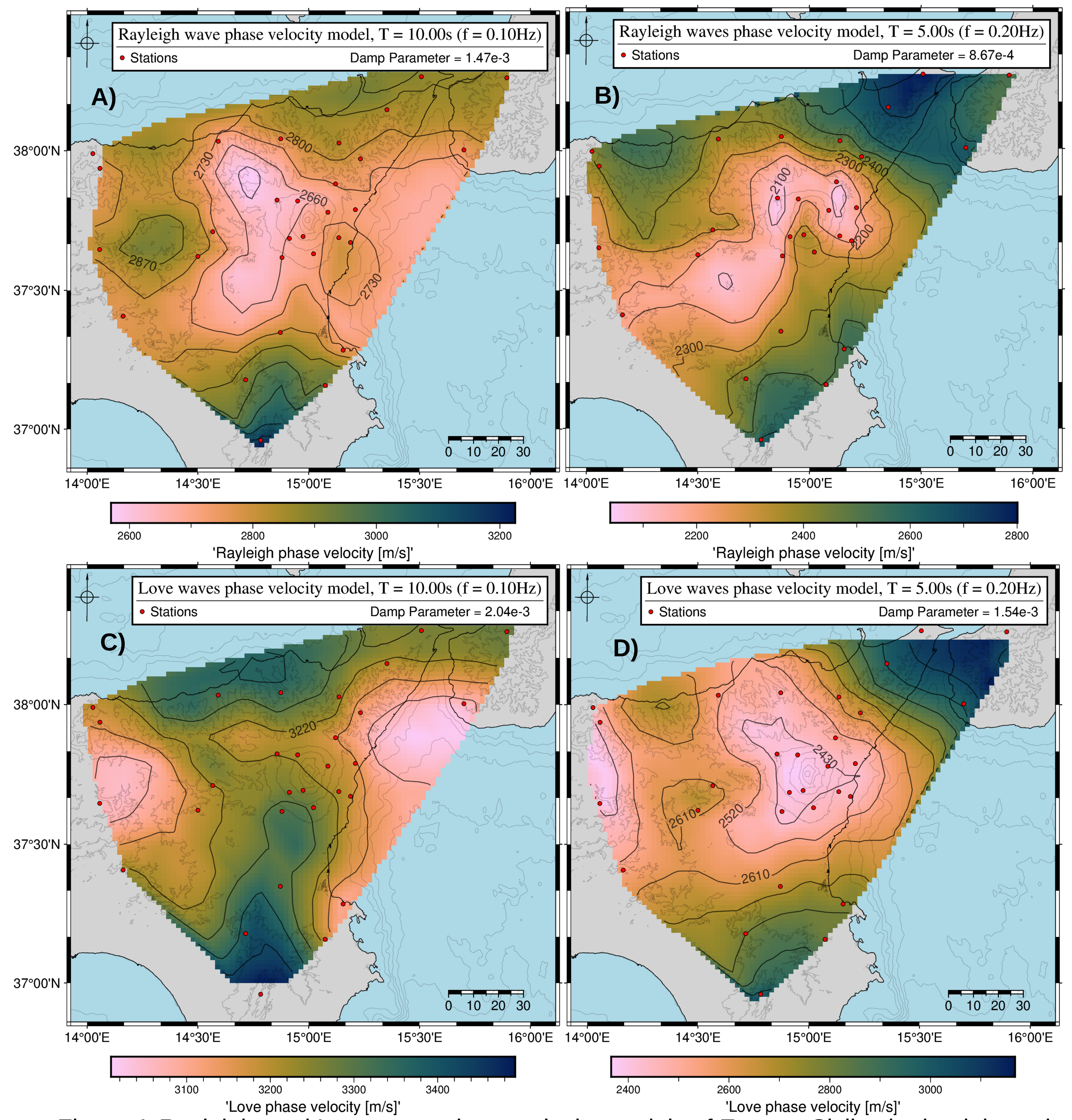


Figure 4: Rayleigh- and Love-wave phase-velocity models of Eastern Sicily obtained through inversion of interstation phase velocities derived from dispersion curves at selected frequencies using SeisLib.

6. Preliminary conclusions (pending Bayesian inversion)

- West and beneath Mt. Etna: low Rayleigh-wave velocity anomaly down to ~25 km;
- Shallow Etna: potential high-velocity body [Lo Bue et al., 2024, GRL];
- Hyblean Plateau: high-velocity, rigid/cool crust;
- East Etna: low Love and Rayleigh wave velocities;
- Madonie/Nebrodi: low Love and Rayleigh wave velocities, possibly fractured medium.

7. Future works

Bayesian Inversion (BayesBay [Magrini et al., 2025, SRL])
- **Joint Rayleigh-Love inversion:** estimation of V_S and radial anisotropy models:
  - Bias-free and data driven trans-dimensional Bayesian MCMC;
  - Uncertainty estimates based on ambient-noise power anisotropy.
- **Petroseismical framework inversion:**
  - Coupling MAGEMin [Riel et al., 2022, G³] petrological modelling with the BayesBay framework.

Wind rose and maps are generated with PyGMT (Tian et al., 2026, Zenodo, v0.18.0)