Reconciling phase velocities from ambient noise and earthquake-generated surface waves by accounting for arrival-angle effects

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two stations method: the possible approaches

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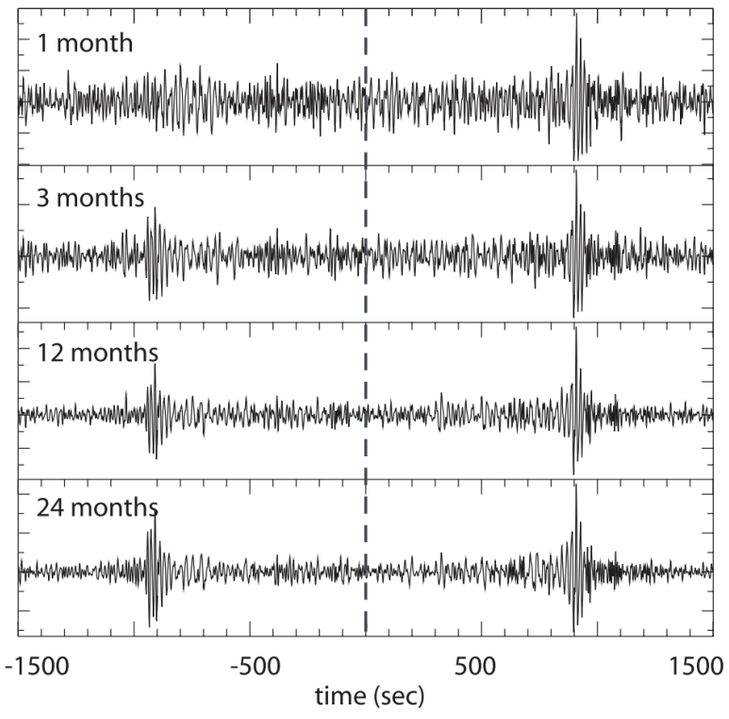
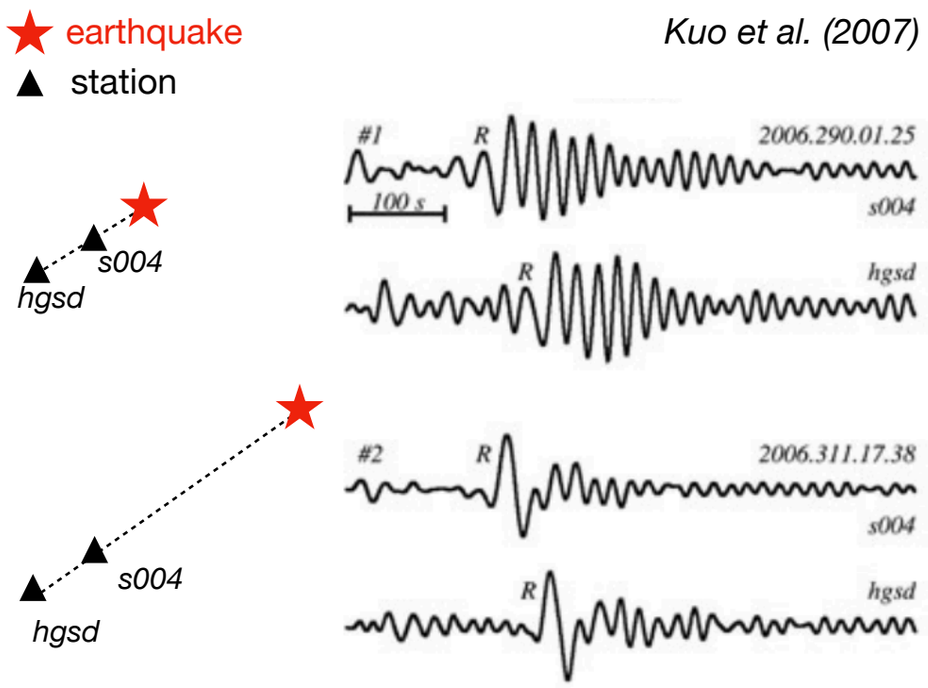
Bensen et al. (2007)





Kuo et al. (2007)

DATA

AMBIENT NOISE

or

EARTHQUAKE-GENERATED SURFACE WAVES

Rayleigh wave phase-velocities

S-wave velocity structure

Thermal structure

ΔT

Density anomalies

$\Delta \rho$

Chemical composition, water content

ΔC, %wt. H_2O

INTERPRETATION

two stations method: the possible approaches

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AMBIENT NOISE

- higher frequency content
- optimal period range: <50 s
- sensitive to **shallow structure**

EARTHQUAKE-GENERATED SURFACE WAVES

- Lower frequency content
- optimal for period > 20 s
- sensitive to **deep structure**

These approaches **overlaps** in the **20-50 s period range**

- Do the two methods retrieve the same phase velocities?

Several examples in literature report (e.g. *Yao et al*. 2006; *Kästle et al*. 2016) velocities from **ambient noise** that are **systematically lower** than those from EQs surface waves

- Do we know why?

There is no clear consensus on the the cause of such discrepancy. Possible causes:

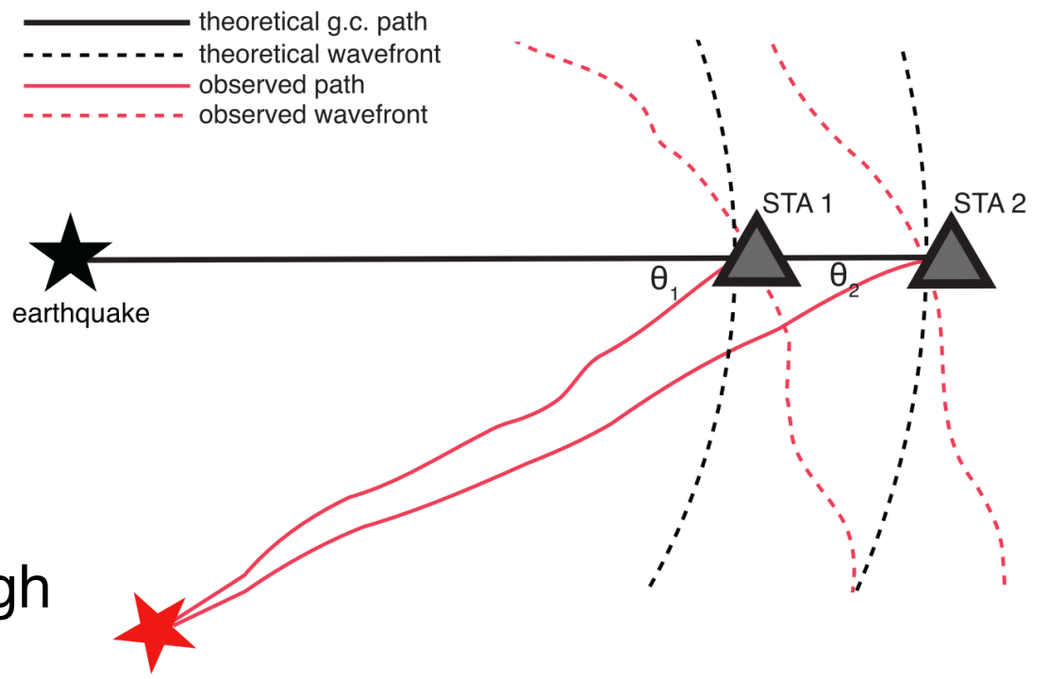
- difference in sensitivity kernel (*Fichtner et al*. 2016)
- overtone contamination (*Soomro et al*. 2016)
- **off-path propagation** of the EQ-generated wavefield (*Kästle et al.* 2016)

- Are such difference negligible?

Differences amount to **~1%** in phase velocities, which is the order of the velocity anomalies that can be caused by **thermo-chemical changes** or **variations in water content.**

reconciling the two methods…

- **Our assumption:** EQs surface waves, Rayleigh phase velocities are **overestimated** due to possible **misalignment** of stations pairs and incoming wavefield, caused by **lateral heterogeneities** of seismic velocities.



- Owing to the retrograde particle motion of Rayleigh wave, **vertical component** is π/2 shifted w.r.t the **horizontal one**.

- Phase shift can be compensated applying **Hilbert Transform** to the radial component.

- We can search the **optimal angle (θ), maximizing** resemblance of the vertical and Hilbert-transformed radial component → True direction of the incoming wavefield

NO ANGULAR CORRECTION

$$c_{12}(\omega) = \frac{\omega\,(x_2 - x_1)}{\phi_2(\omega) - \phi_1(\omega) + 2n\pi}$$

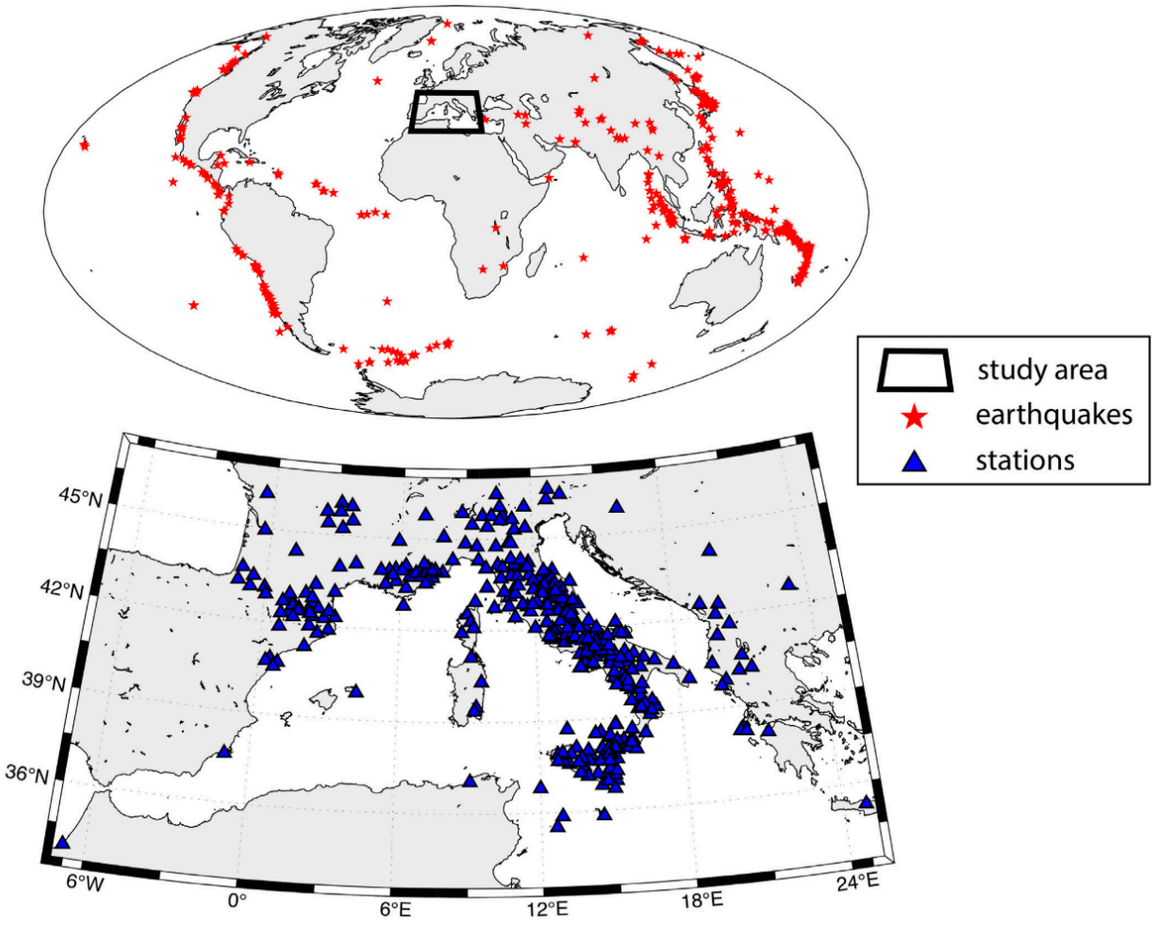
WITH ANGULAR CORRECTION

$$c_{12}(\omega) = \frac{\omega\, x \cos\left(\theta(\omega)\right)}{\phi_2(\omega) - \phi_1(\omega) + 2n\pi}$$

…some details

Area: Central Western Mediterranean

- 443 events (2005-2019)
- 361 stations
- +16.000 stations pairs for comparing ambient noise and EQs data



Cost function to determine the optimal angle of arrival

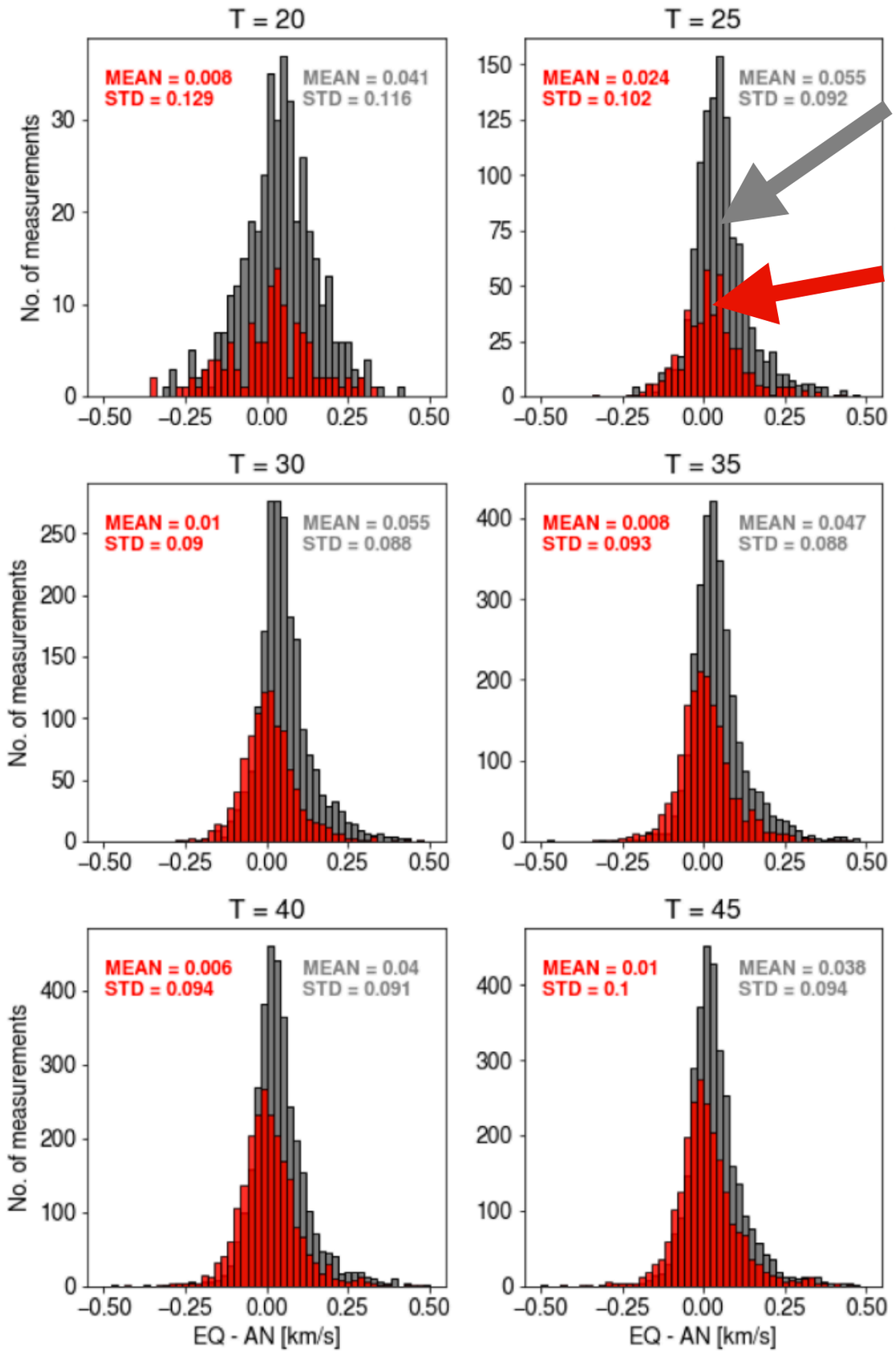
vertical component

radial component

i= i-th time sample

$$C(\theta) = \sum_{i}^{n} \left| \frac{z_i(t)}{|z(t)|_{\max}} - \frac{H_i\{r_\theta(t)\}}{|H\{r_\theta(t)\}|_{\max}} \right|^2$$

results

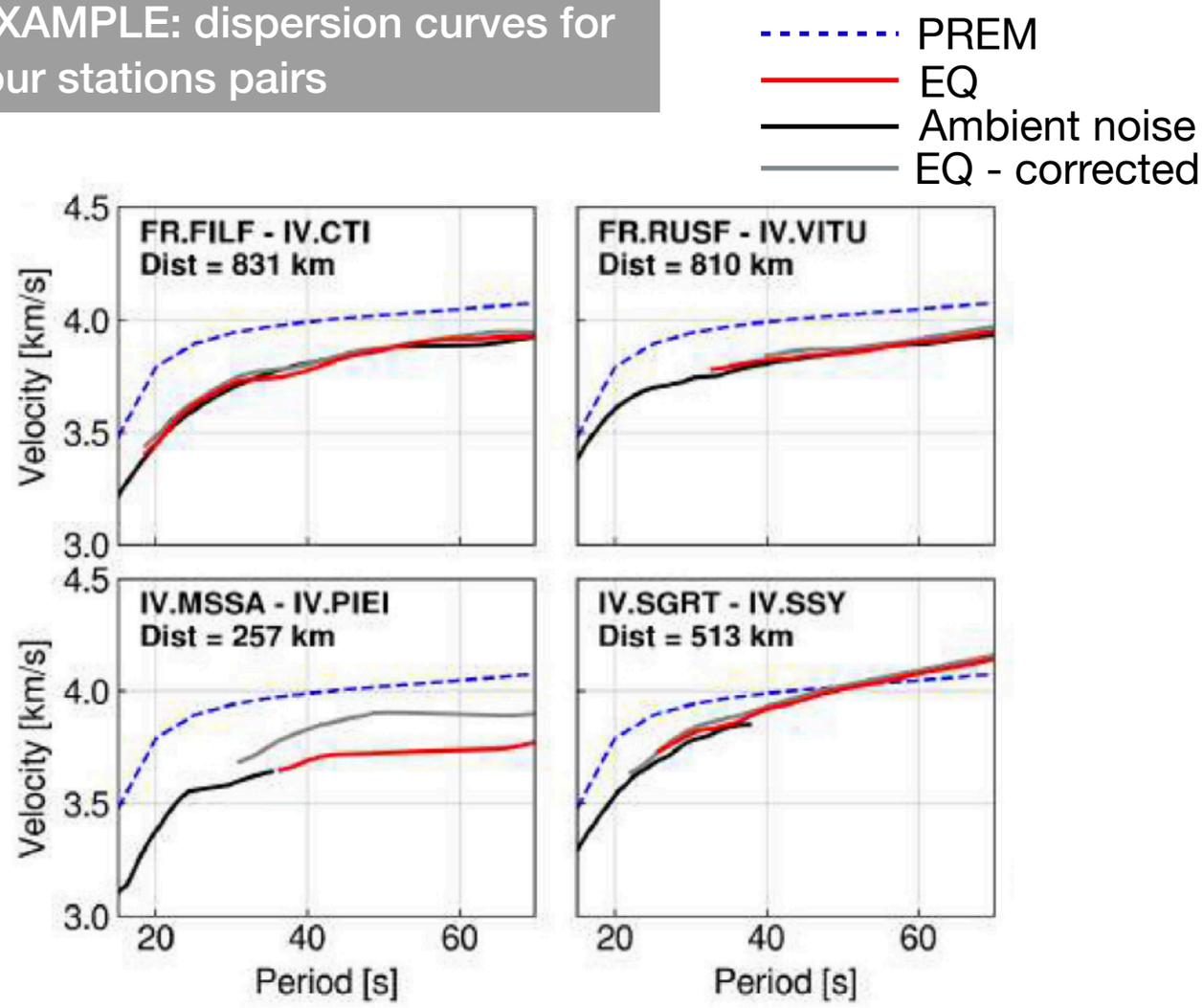


no correction

with angular correction

- Accounting for the true angle of arrival, up to **3-fold decrease** of difference between EQs data and ambient noise.
- Improvement is **statistically significant** (according to *Kolmogorov–Smirnoff* test)

EXAMPLE: dispersion curves for four stations pairs



take home message

- A **substantial discrepancy** of phase velocities from **ambient noise** and those from **earthquake-generated surface waves** is reported using two-stations method, with no clear consensus on the origin of such discordance.

- We explore the possibility that this discrepancy is mainly due to **off-path propagation** of surface wave wavefield.

- The true angle of arrival at stations (for Rayleigh wave) is estimated by rotating the **Hilbert-transformed** radial component and maximizing its resemblance with the vertical one.

- Discrepancies are **largely reduced**, proving the **major role of off-path propagation** of the wavefield in overestimating phase velocities with earthquake arrivals.

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