Workshop on Observatory Synergies for Astroparticle physics and Geoscience
11-12 February 2019 IPGP - Paris

From signal detection to passive subsoil imaging

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This talk:

General: a short summary of the topics currently object of the INGV – EGO collaboration.

1. INGV earthquake monitoring program, and the issues of common interest with GW antennas

2. The Signal vs Noise dilemma

3. Exploiting noise properties

4. **It's not noise, but it's isotropic**: 2D and 3D subsoil imaging @ VIRGO from multichannel recordings of strong regional earthquakes

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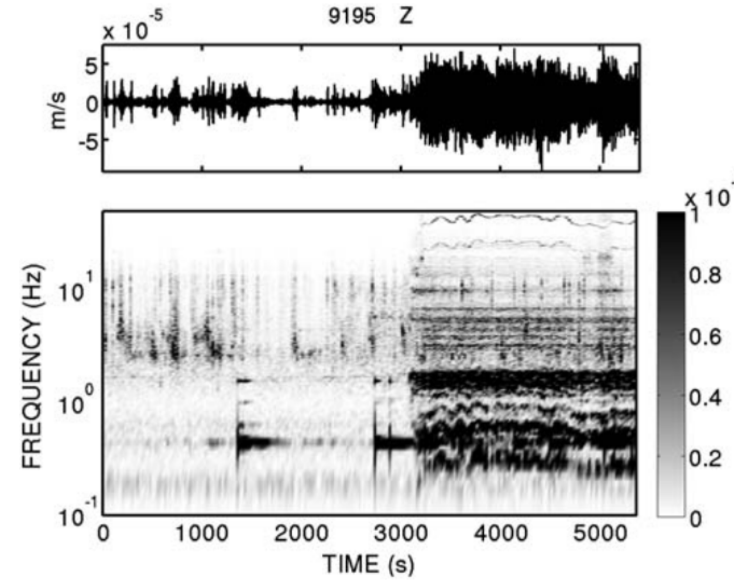
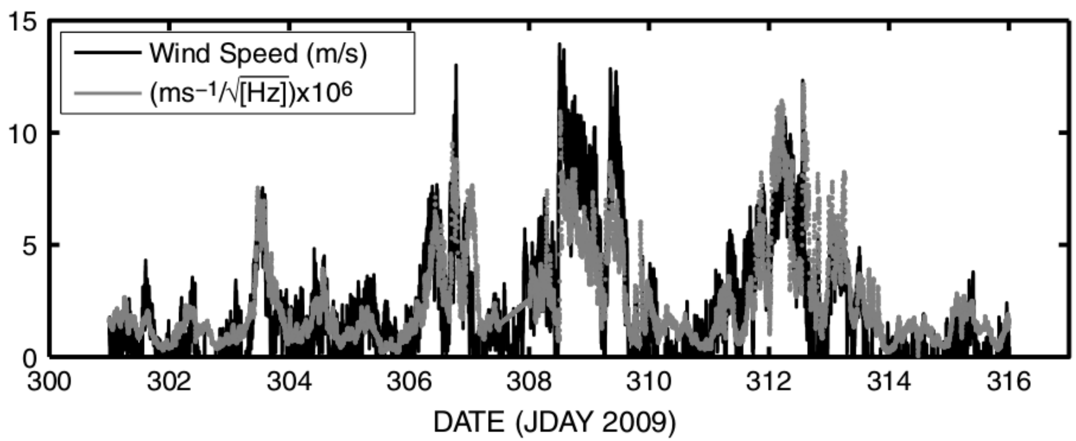
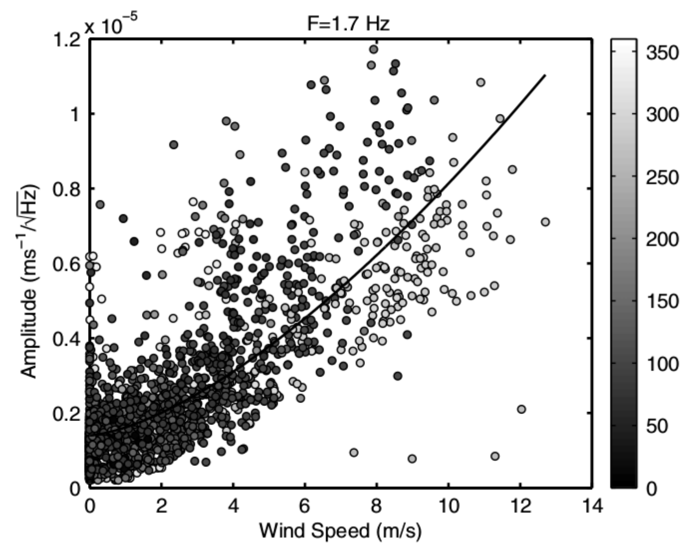
The beginning

2008-2009: Assessing the impact of existent and project wind farms in terms of measured and predicted ground vibrations @ Virgo.







Bulletin of the Seismological Society of America, Vol. 101, No. 2, pp. 568–578, April 2011, doi: 10.1785/0120100203

Seismic Noise by Wind Farms: A Case Study from the Virgo Gravitational Wave Observatory, Italy

by Gilberto Saccorotti, Davide Piccinini, Léna Cauchie,* and Irene Fiori

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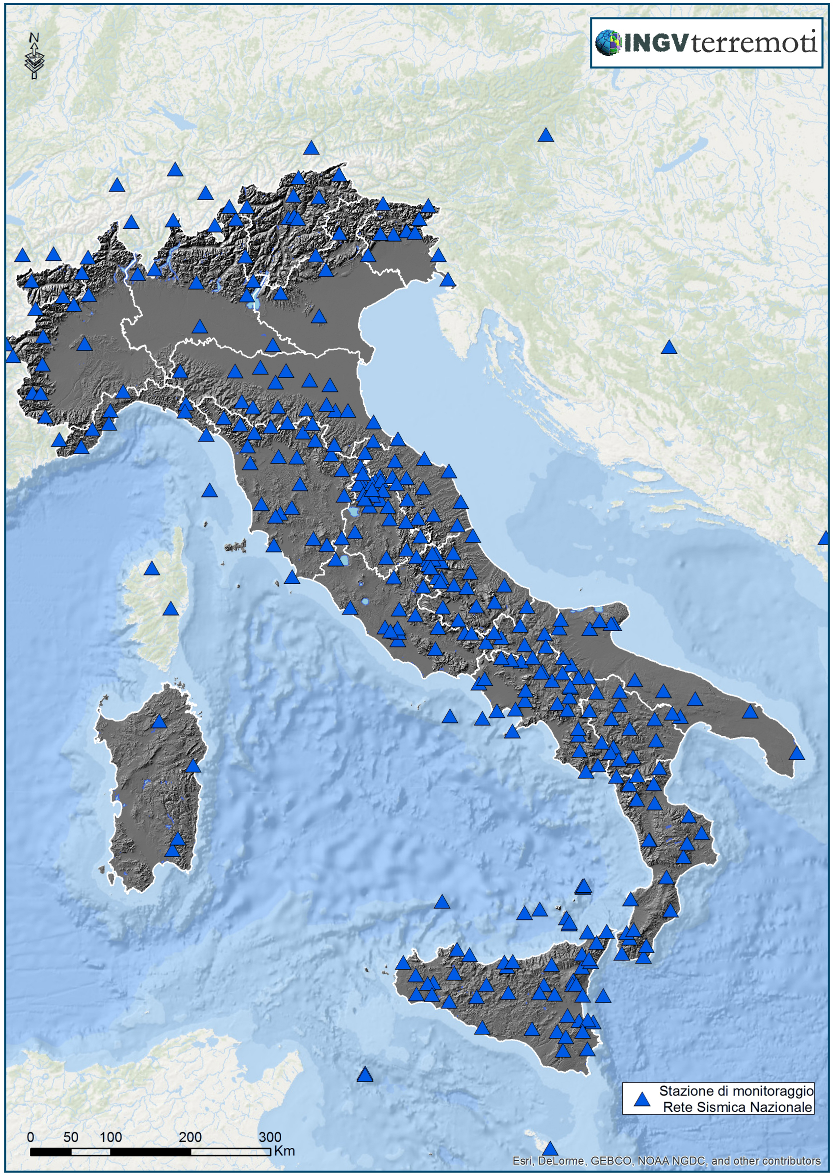
INGV’s Earthquake monitoring program

INGV is in charge of the earthquake and volcanic monitoring and surveillance for the whole national territory.

- ~ **400** seismic stations transmitting in real-time;
- **3** operative centers 24/7
- Prompt (**2’-5’-30’**) dispatch to Civil Protection and local authorities for the timely activation of emergency responses.



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Metrics

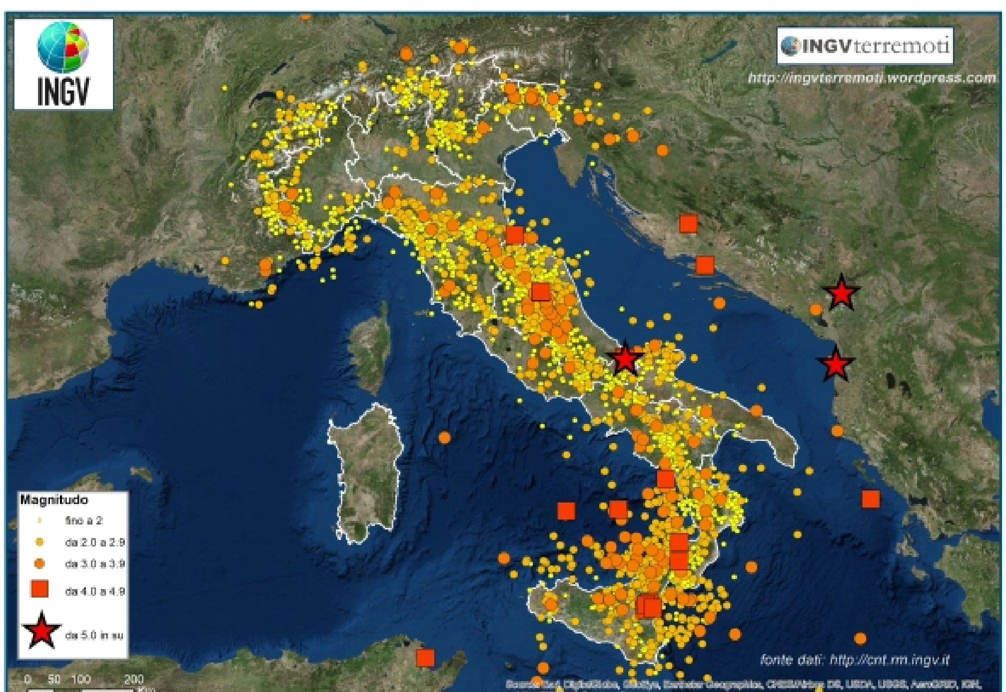
Yearly number of locations (2012-2018):

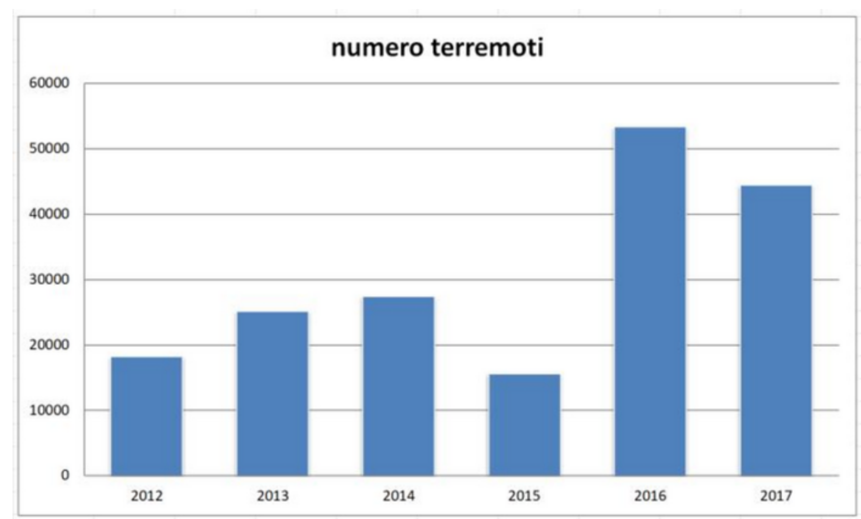
20000-55000 (~50-150/ day)

Automatic Detection
→ **Automatic Phase picking (prone to errors)**
Automatic Location
Manual revision (time-consuming)
Revised Location

Perspectives for an Earthquake Early Warning system @ Virgo:

See Poster Session, *C. Giunchi et al.*





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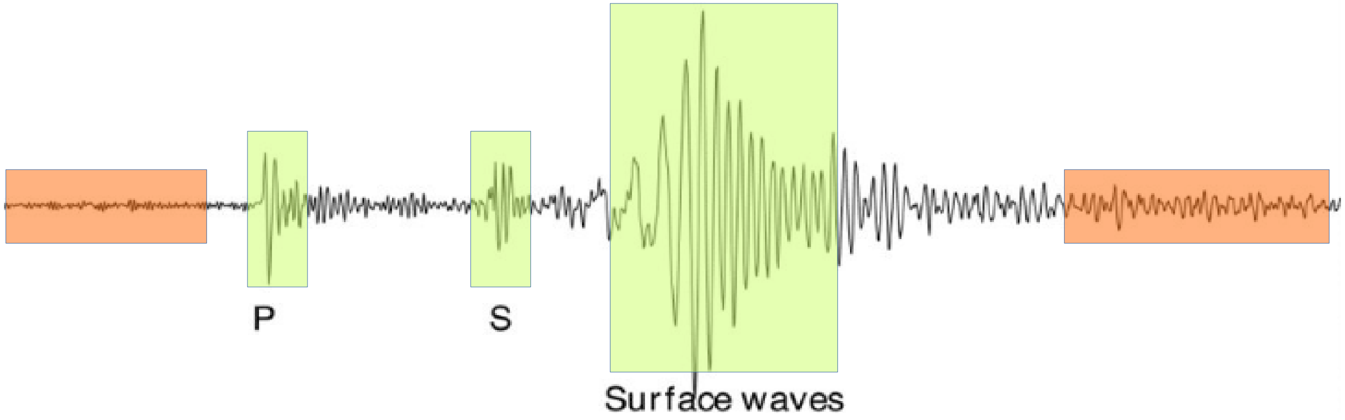
Some relevant issues



* **Signal**: every phase which may be associated with a distinct path

* **Noise:** all the rest, that we must get rid of **(really?).**

* **Detection:** to discern a signal from the background noise

* **Measurement**: the arrival times of the phase of interest

* **Source Location:** Inversion of the arrival times

* **Classification:** To obtain quick glimpses on the driving source mechanism

Current Arguments

DETECTION:

- Thresholding on Characteristic Functions: STA/LTA, Kurtosis, Energy, Envelope,….
- Polarisation Filtering

DETECTION & CLASSIFICATION

- Template Matching
- Feature extraction

ARRIVAL TIME ESTIMATES

- AIC
- AI, ML….

LOCATION

- Full-waveform locations, back-projection, etc.

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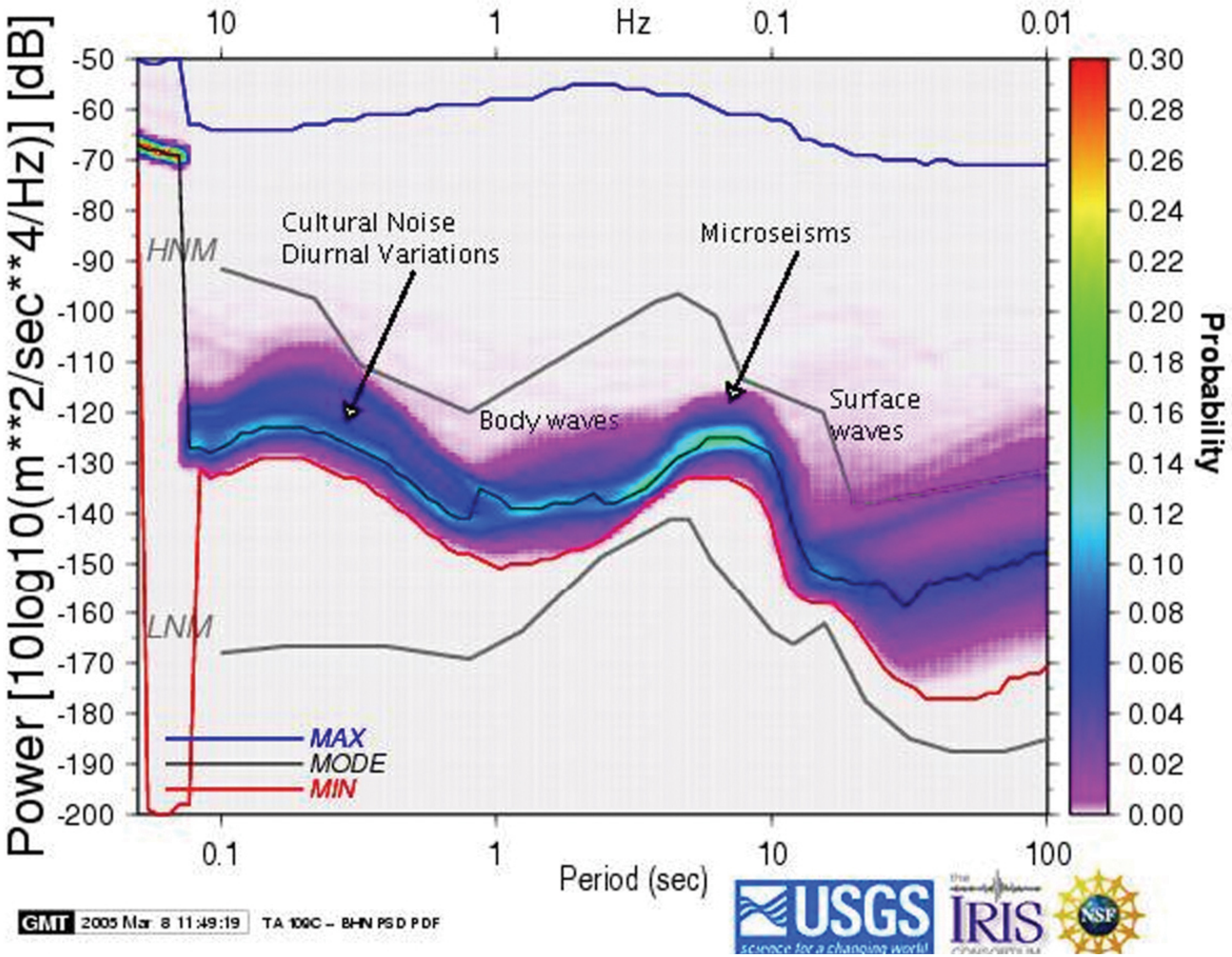
The Noise spectrum



Regional / Local EQs

Tremor - LP

Very Long Period

Teleseismic

SUGGESTED TALKS:

Irene Fiori - Geophysical noise in the Virgo gravitational wave antenna. 12.2.2019 9:40-9.55

S. Koley - Seismic characterization of GW detector sites using an array of wireless geophones 12.2.2019 09:55 - 10:10

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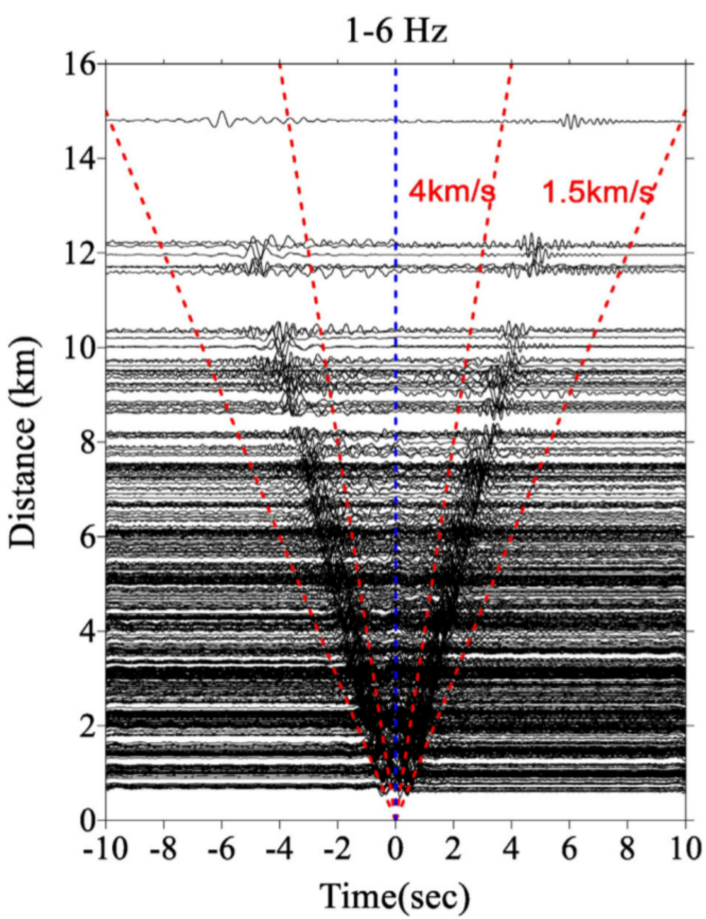
Beyond seismic sources: the NCF ($r > \lambda$)

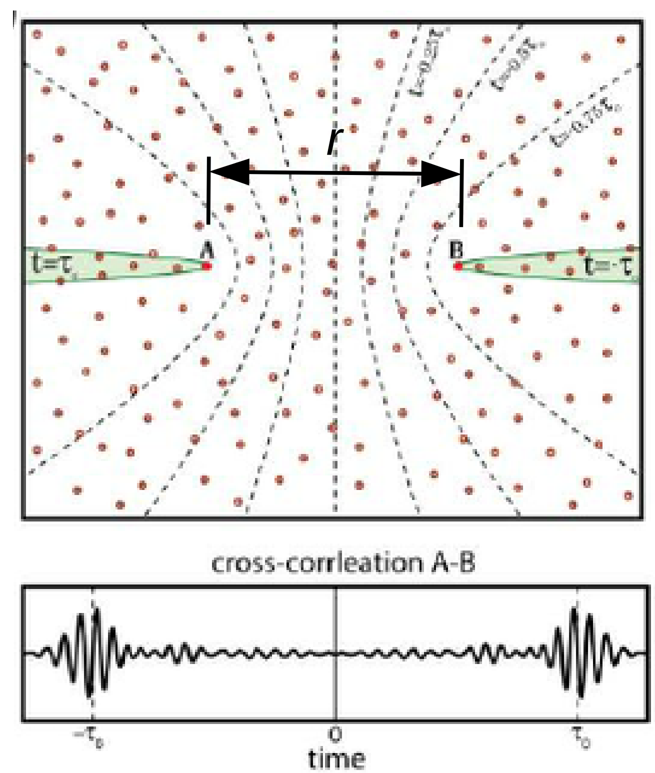
High-Resolution Surface-Wave Tomography from Ambient Seismic Noise

Nikolai M. Shapiro,[1*] Michel Campillo,[2] Laurent Stehly,[2] Michael H. Ritzwoller[1]

www.sciencemag.org SCIENCE VOL 307 11 MARCH 2005

For an **isotropic** distribution of noise sources, the Green's function of waves that propagate between two receivers can be found by cross-correlating noise waves recorded at these receivers; this technique obviates the need for a source at one of the two locations.





From *Seismic imaging using ambient noise*, by Nikolai M. Shapiro, Michel Campillo, Philippe Roux. *Enciclopedia of Solid Earth Geophysics*, DOI: 10.1007/978-90-481-8702-7_218

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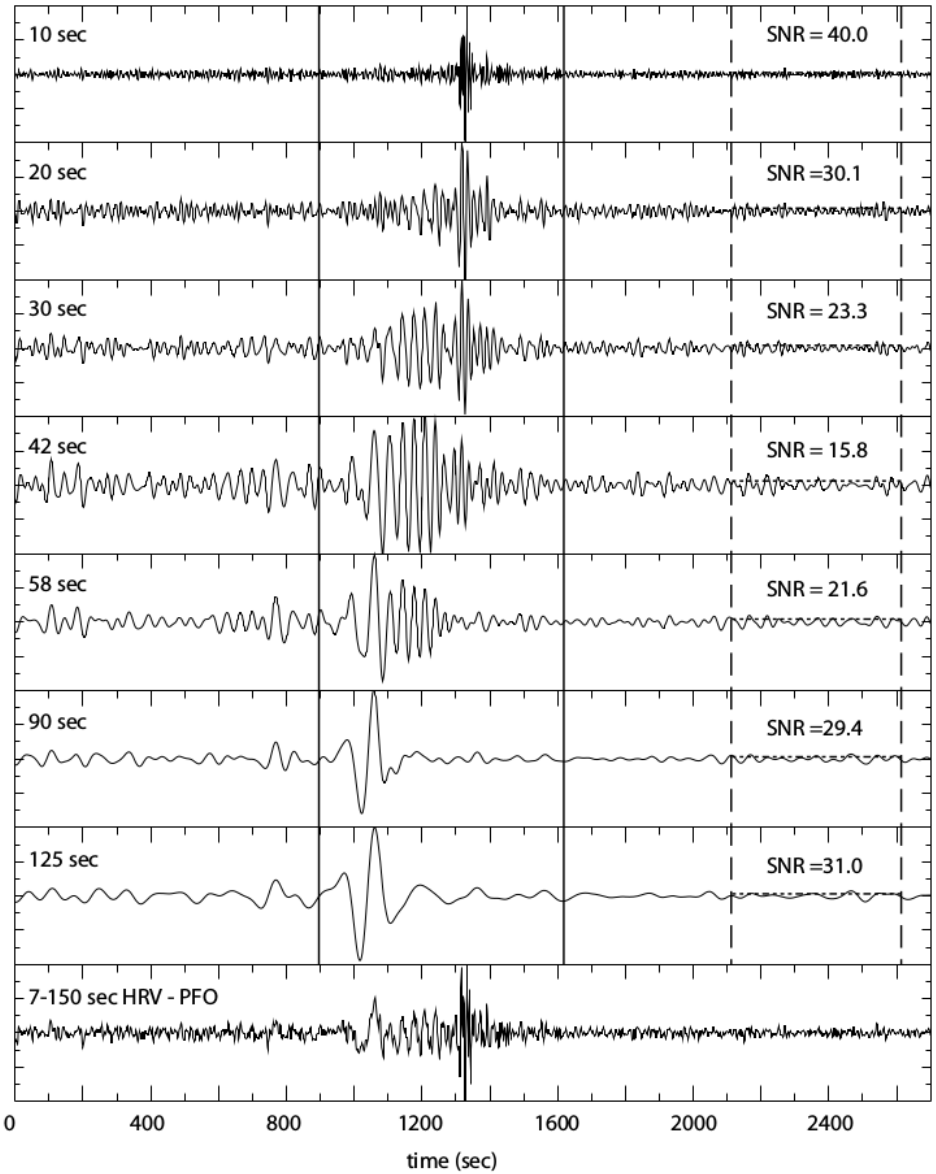
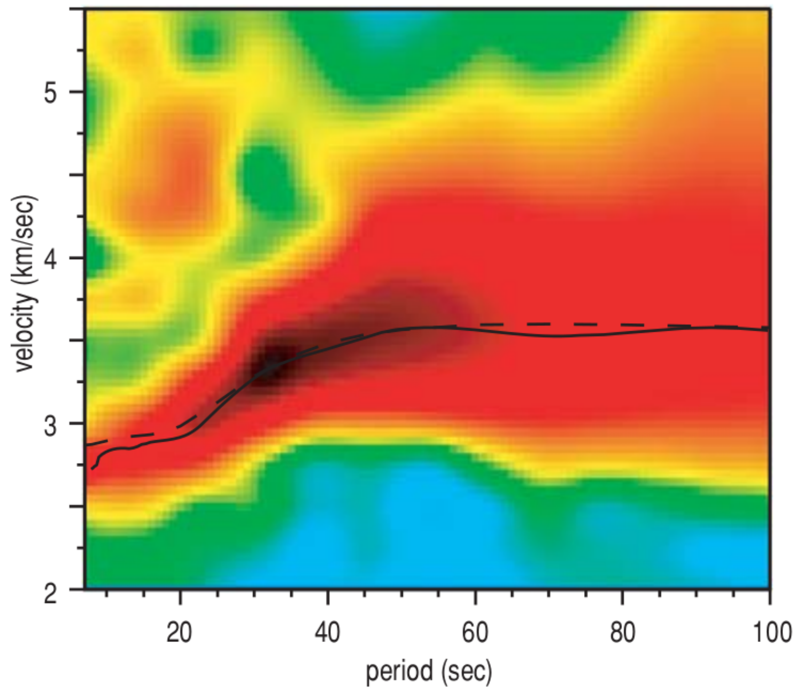
From the NCF to dispersion



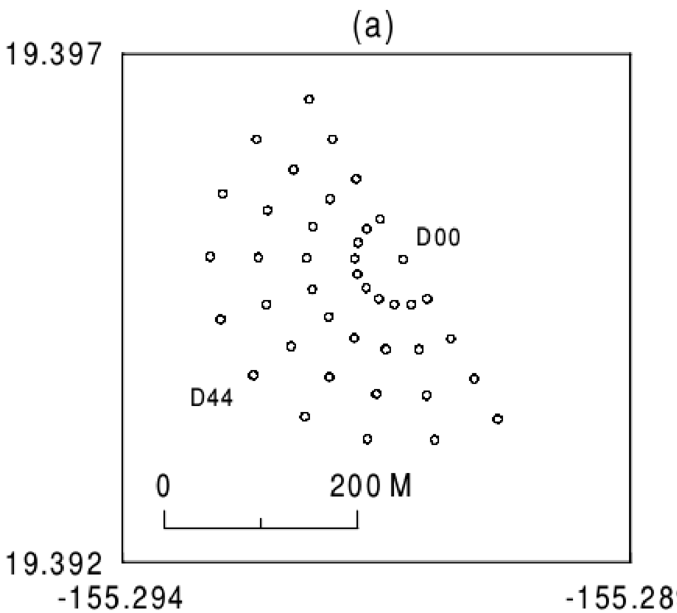


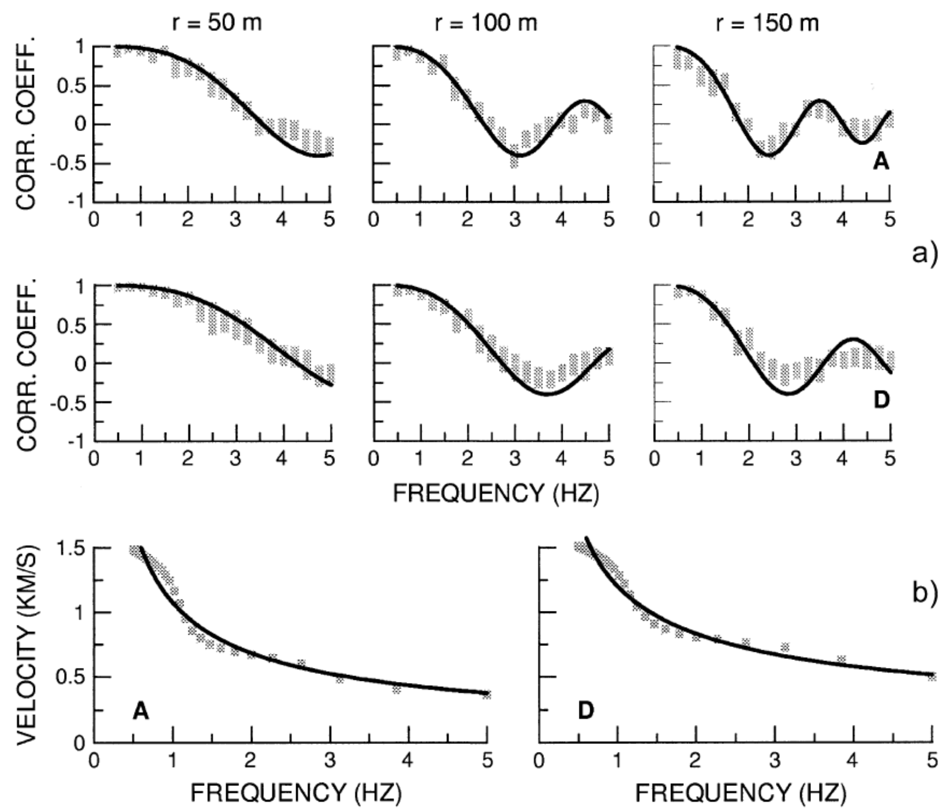
From Bensen et al., *Geophys. J. Int.* (2007) **169**, 1239–1260

Beyond seismic sources: SPAC ($r < \lambda$)

$$\overline{\rho}(r,\omega_0) = J_0\left(\frac{\omega_0 r}{c(\omega_0)}\right)$$

Aki (1957): The azimuthal average of the zero-lag correlation between 2 recorders is directly related to phase velocity $c(\omega)$.





The correlation curves are then inverted to derive a phase velocity dispersion function $c(\omega)$ representative of the medium in between the two sites.

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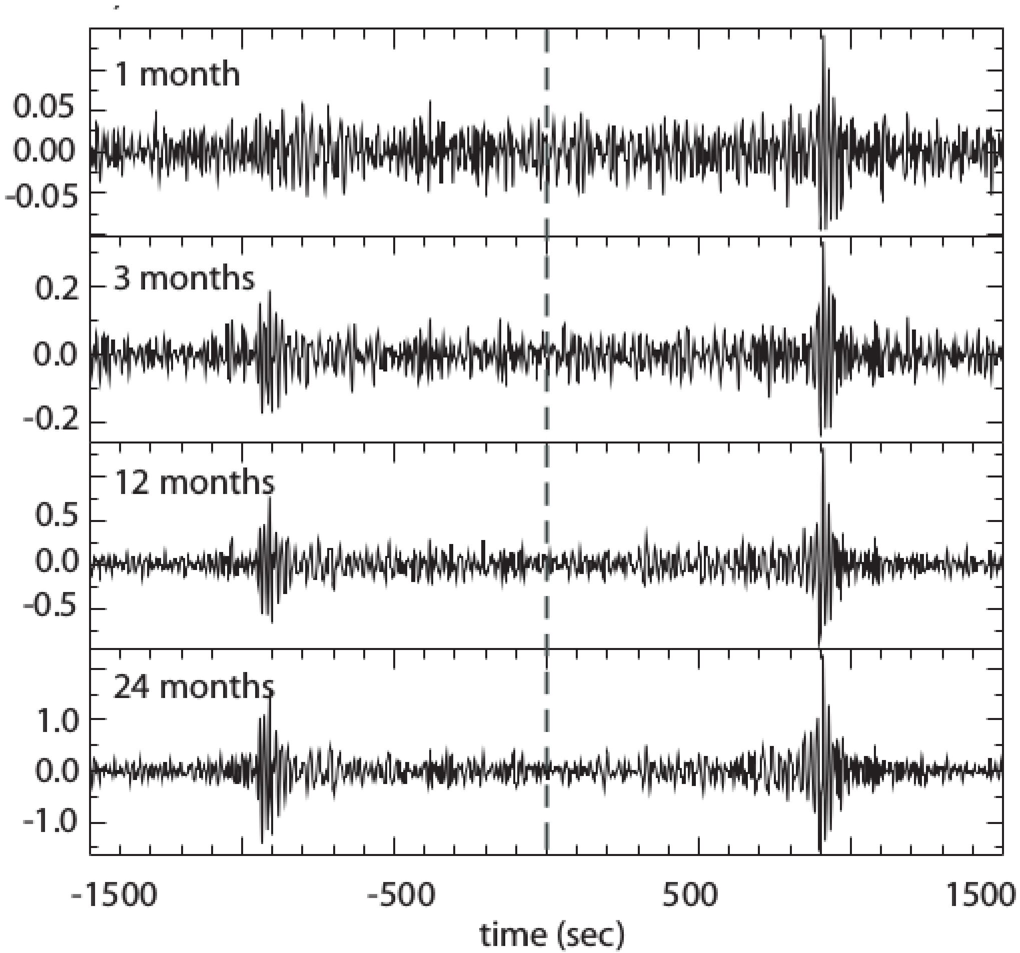
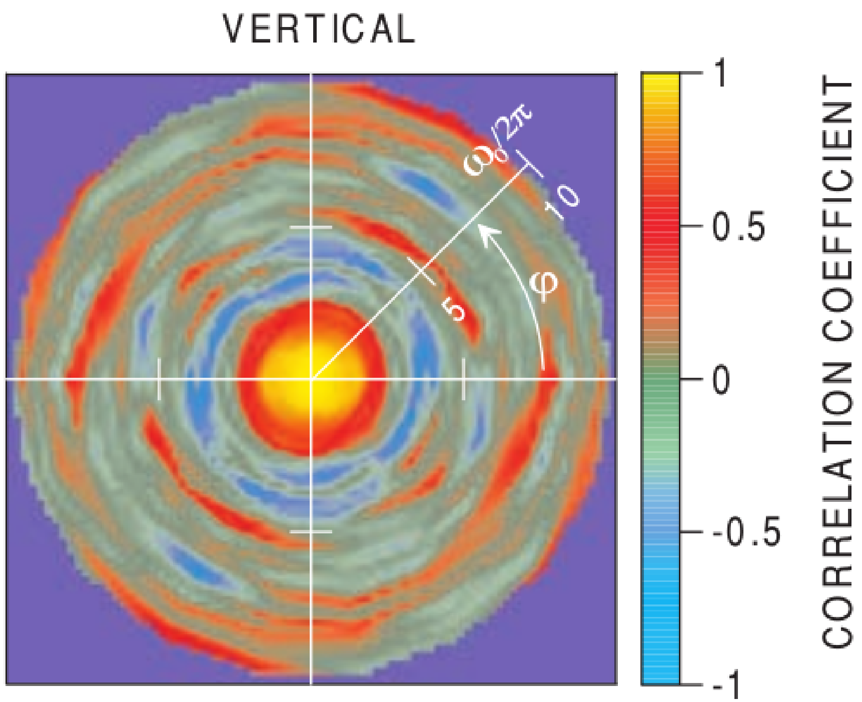
Going isotropic

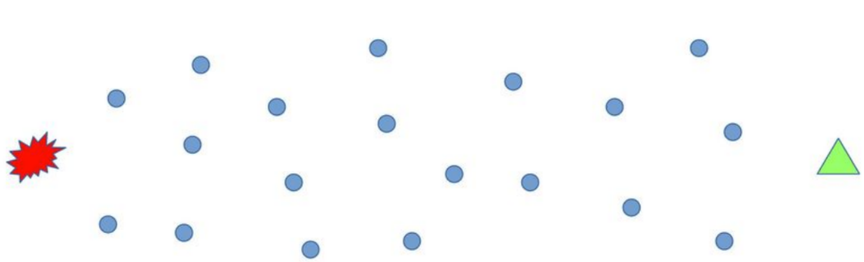


From Bensen et al., *Geophys. J. Int.* (2007) **169**, 1239–1260

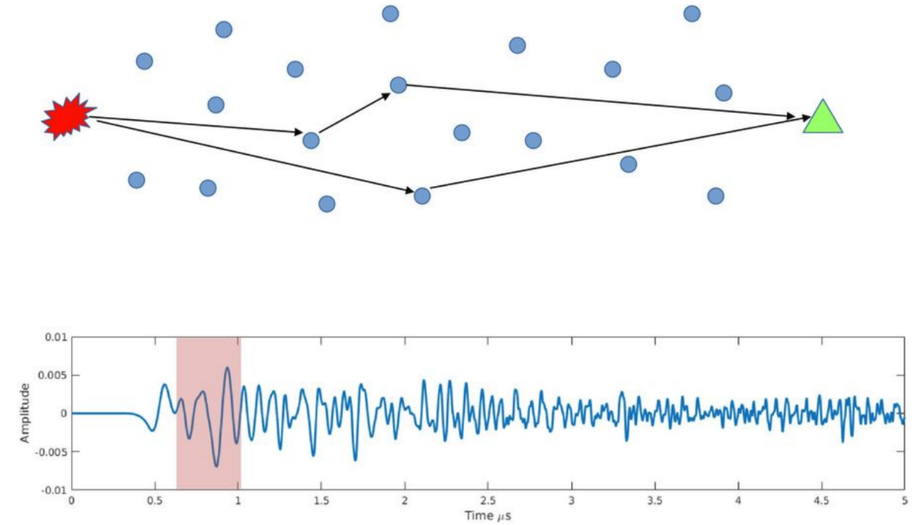
Noise wavefields rarely are completely equi-partitioned. The **isotropy requirement** can be fullfilled by azimuthal averaging (need lots of measurement sites) or by extensive **temporal** averaging .



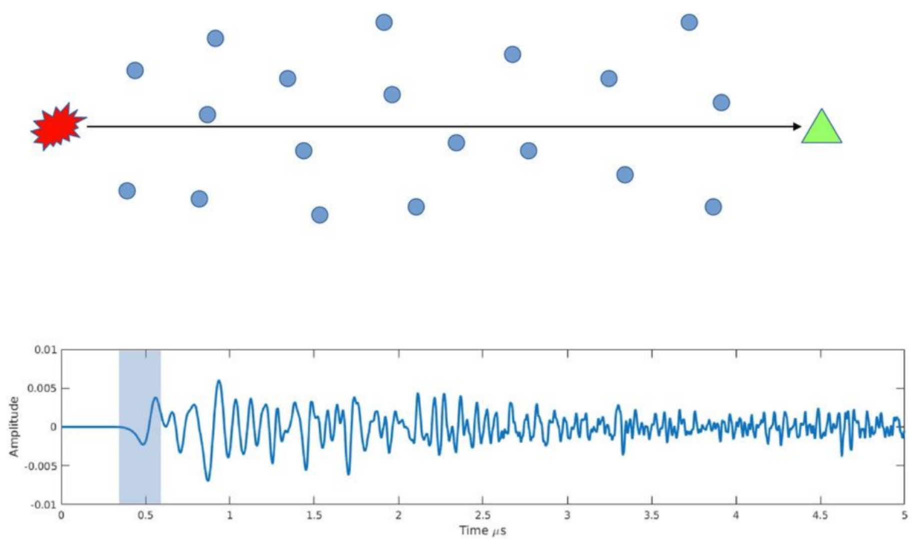
The earthquake coda



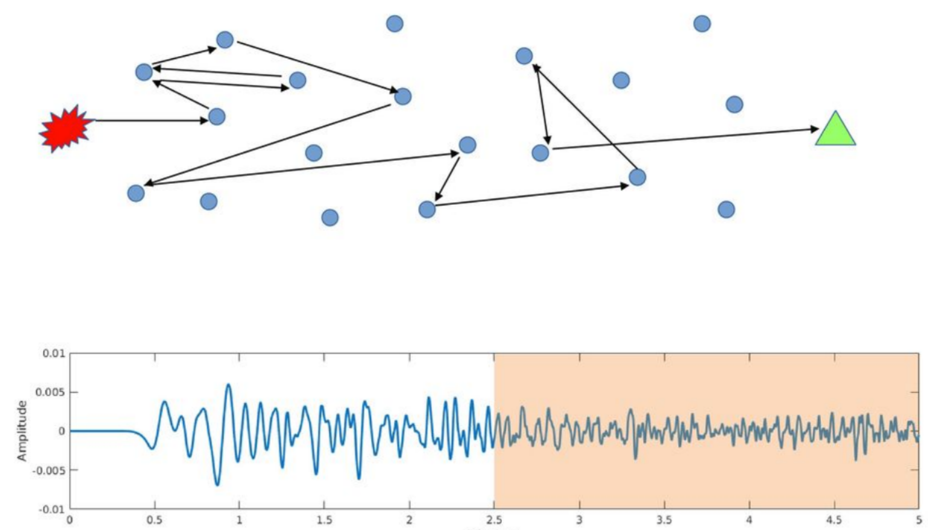
A medium with scatterers



Single-scattering arrivals



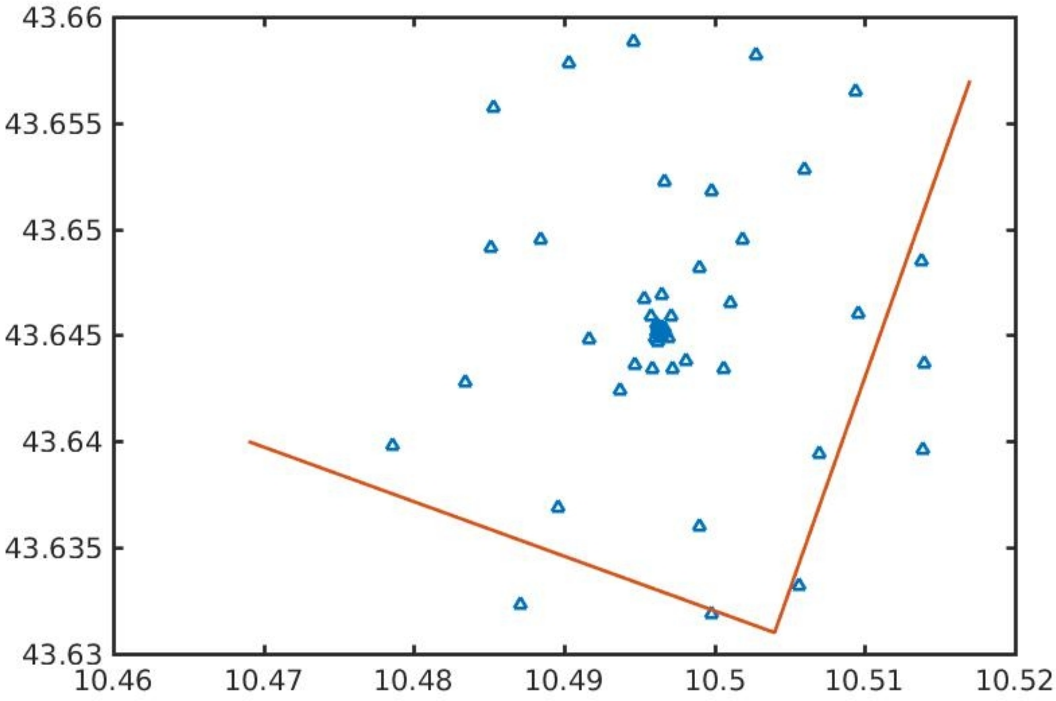
The ballistic arrival



Multiple-scattering arrivals

Taken from Singh et al., *Coda Wave Interferometry (CWI) for Time-Lapse Monitoring*.

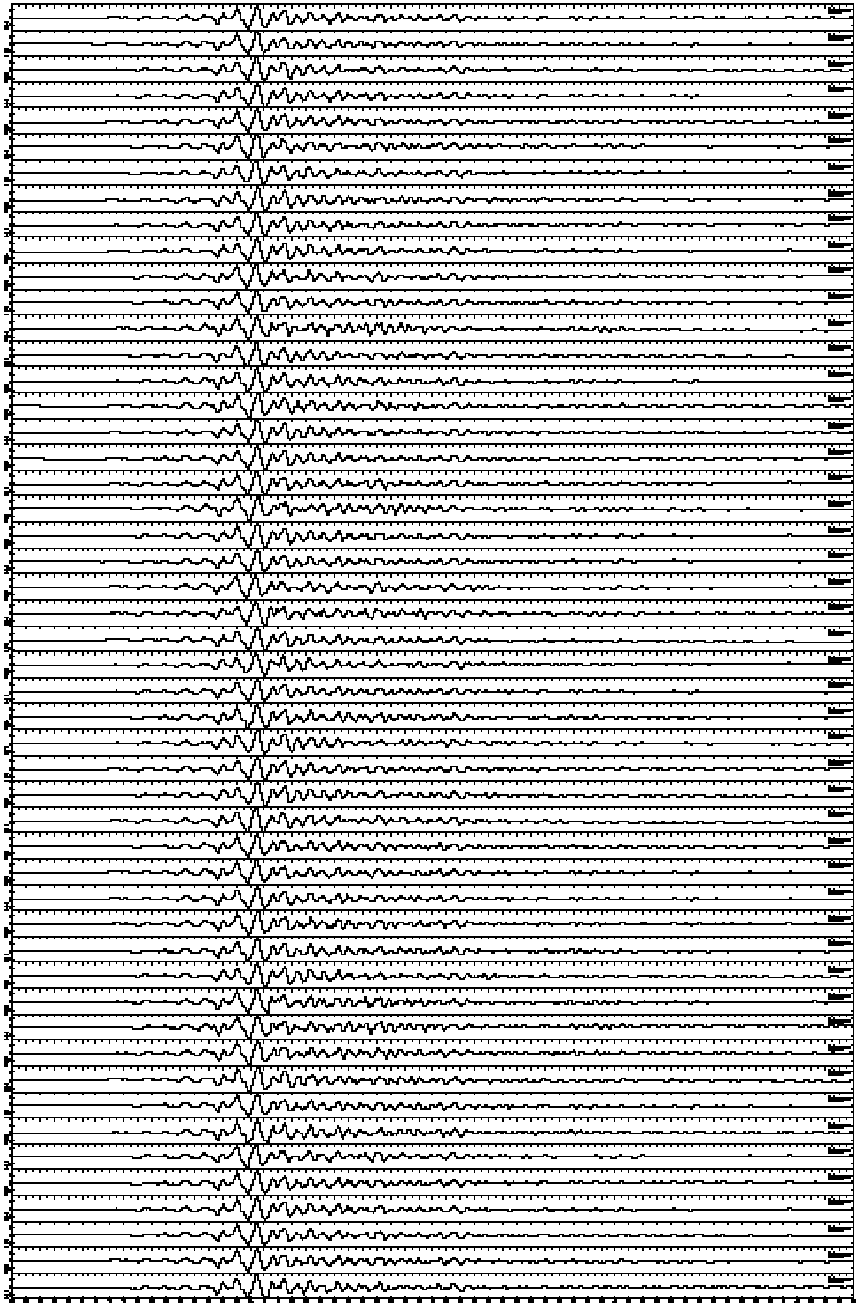
Earthquakes @ Virgo

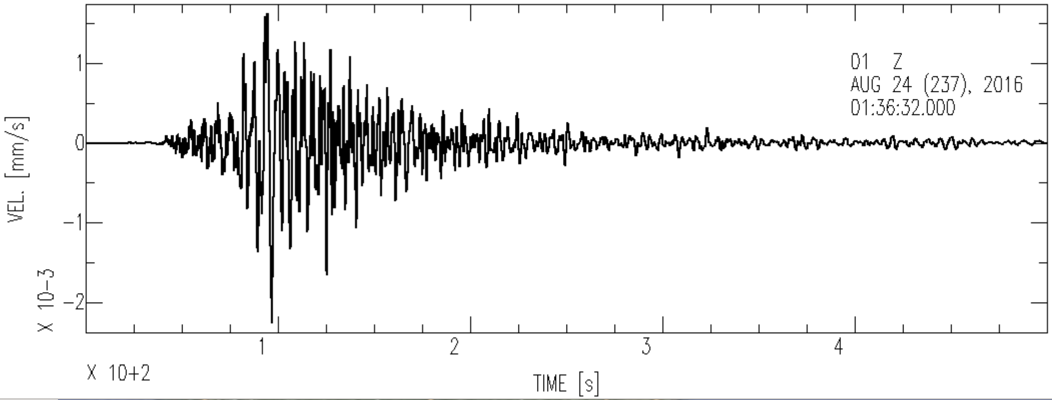


- Array of 50 INNOSEIS geophones

Timing accuracy < 20µs
Sensitivity σ = 76.4636V /m/s
Damping = 0.69
Resonance frequency = 5Hz
Sampling rate = 250Hz
Interstation distances between **11m** and **2880m**

Earthquakes @ Virgo





01:36:32 Aug 24, 2016 Mw=6.2

D=245 km

Vertical Component

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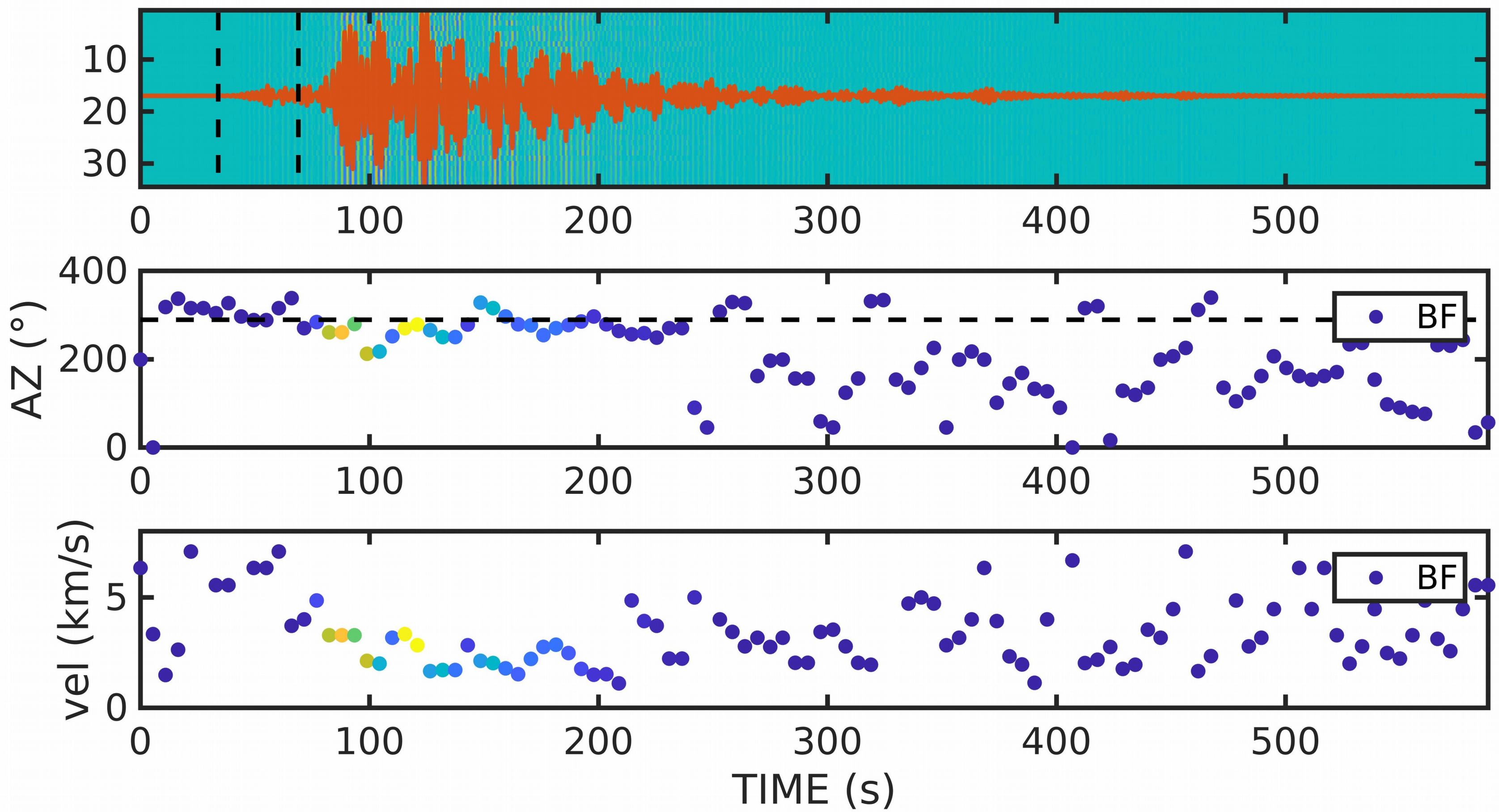
Earthquakes @ Virgo



P- and S-waves are correctly recovered. The coda manifests itself as a scattered wavefield, with a quasi-homogeneous distribution of propagation directions

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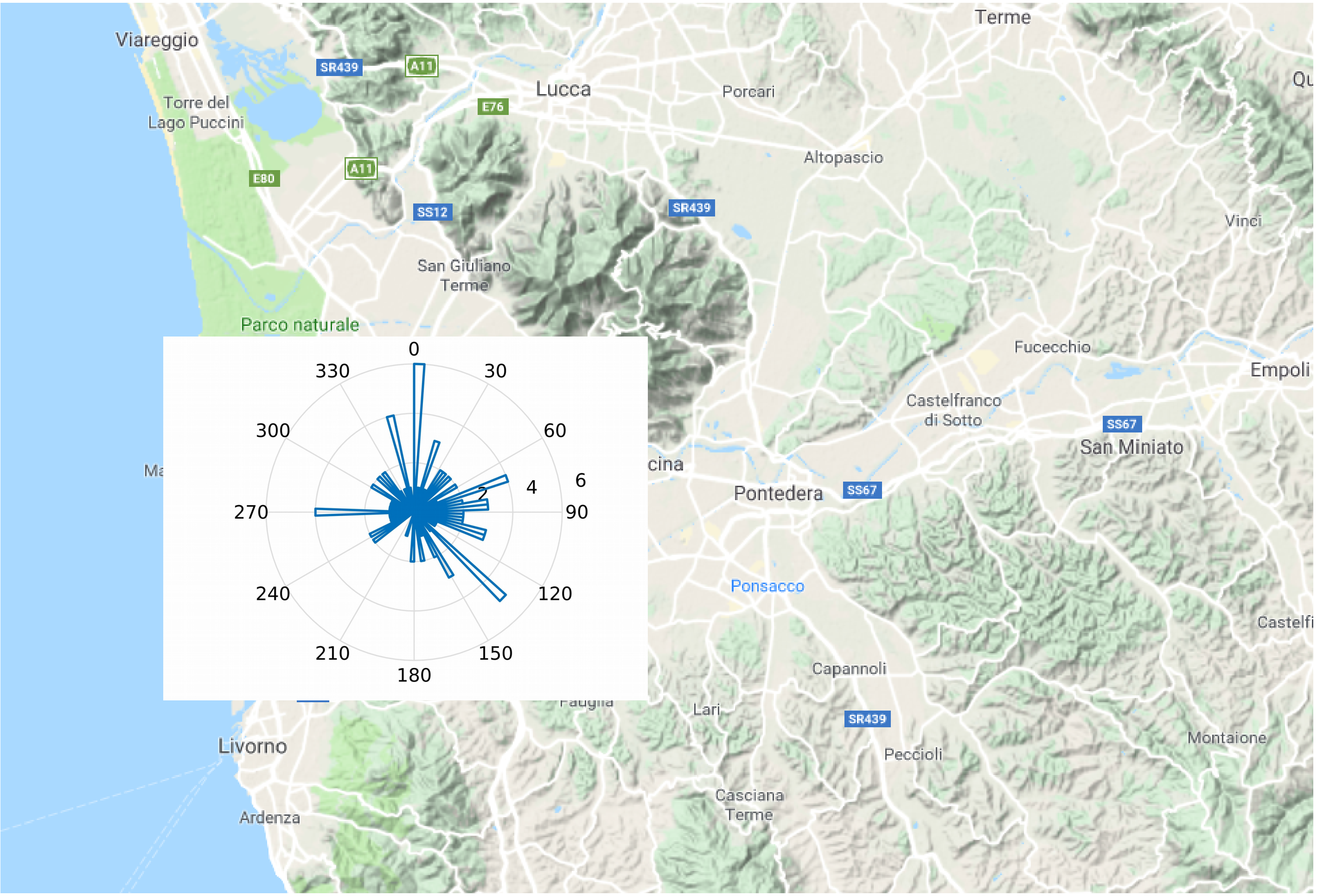
Earthquakes @ Virgo



Main scatterers associated with marked topographic features.

We can use coda waves for correlation studies.

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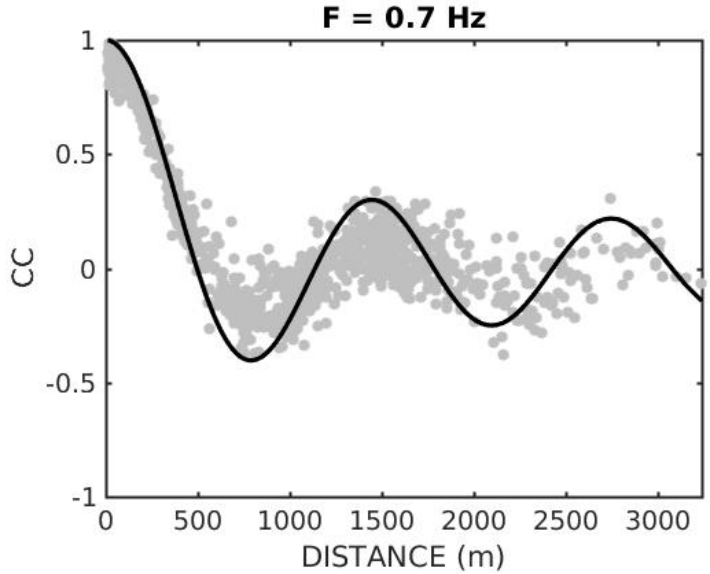
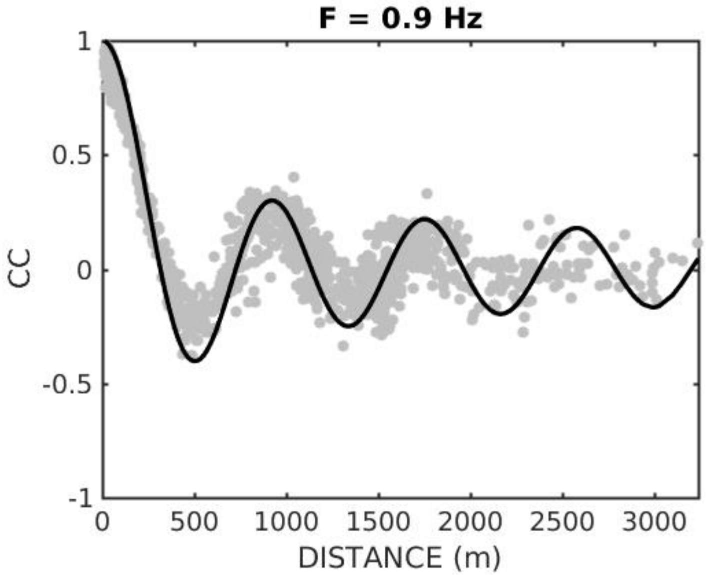
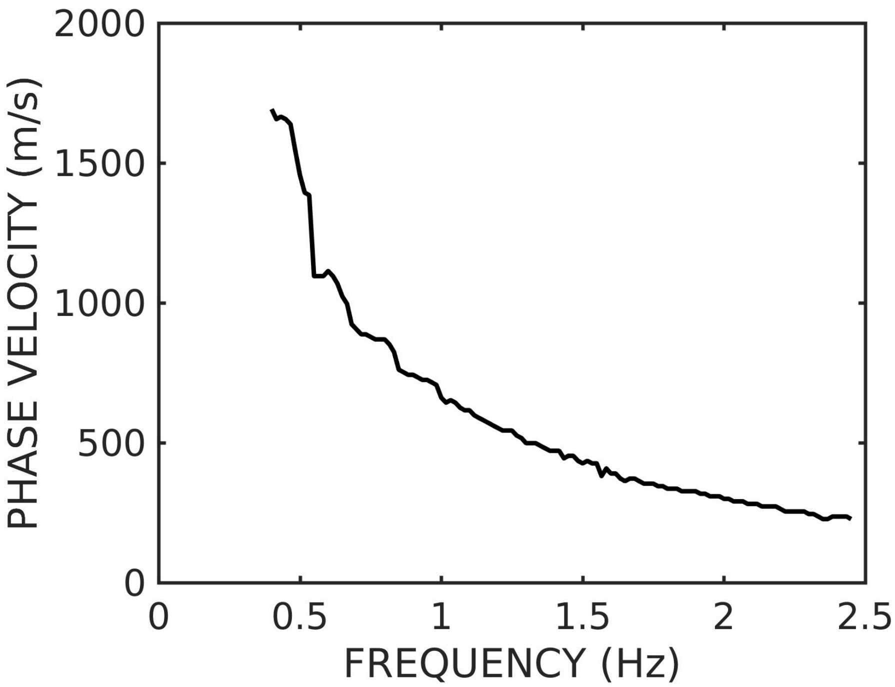
Rayleigh wave dispersion @ Virgo







Array-averaged dispersion curve from coda correlations obtained for all the station pairs, at different target frequencies

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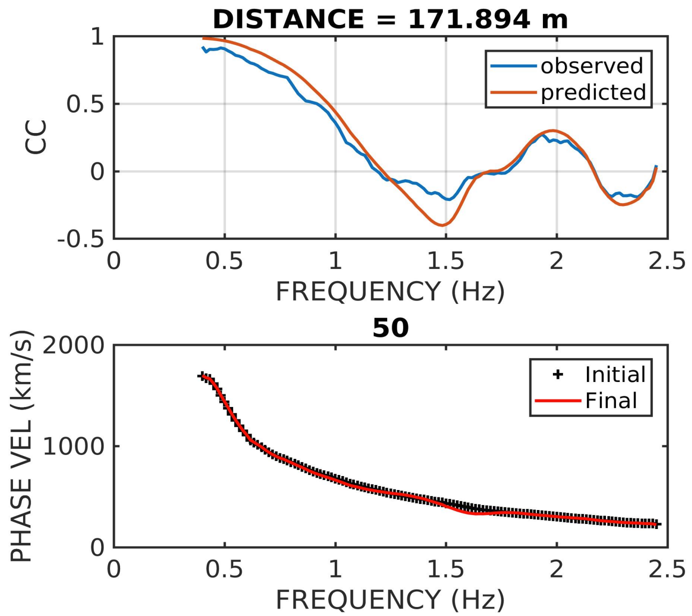
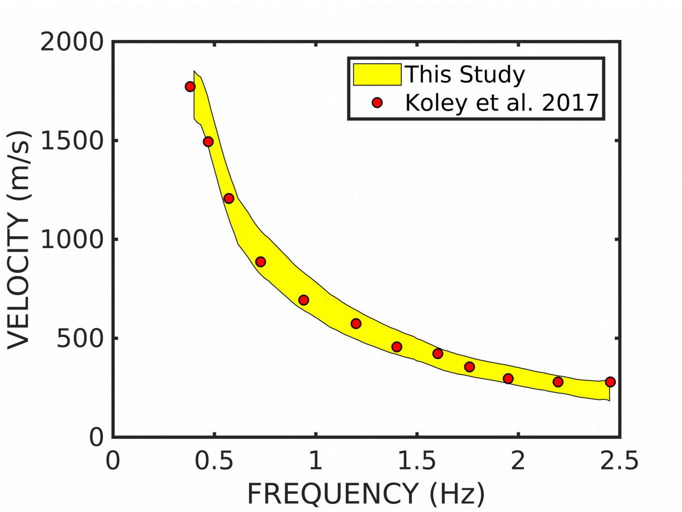
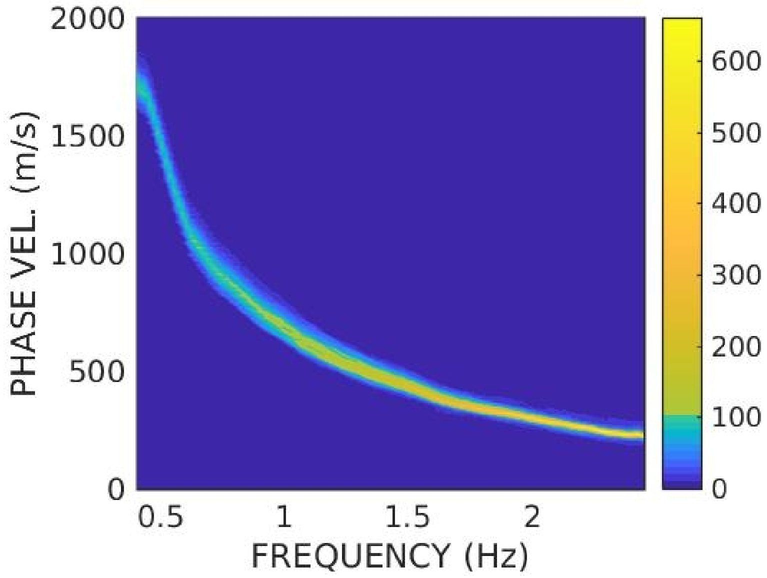
Rayleigh wave dispersion @ Virgo



Direct search of best-fitting dispersion curve → starting model for refined, iterative non-linear inversion.

Consistent w/ noise !





Dispersion curves obtained at individual station pairs, for a given frequency span.

- 1225 station pairs (dispersion)
- 0.4-2.5 Hz frequency band, 0.1 step
- 1225 travel times at each ref. frequency

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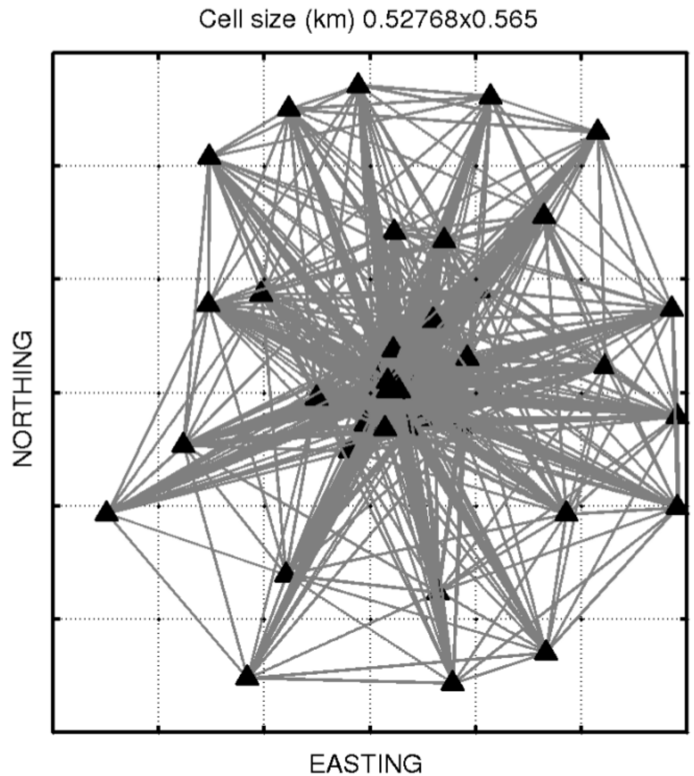
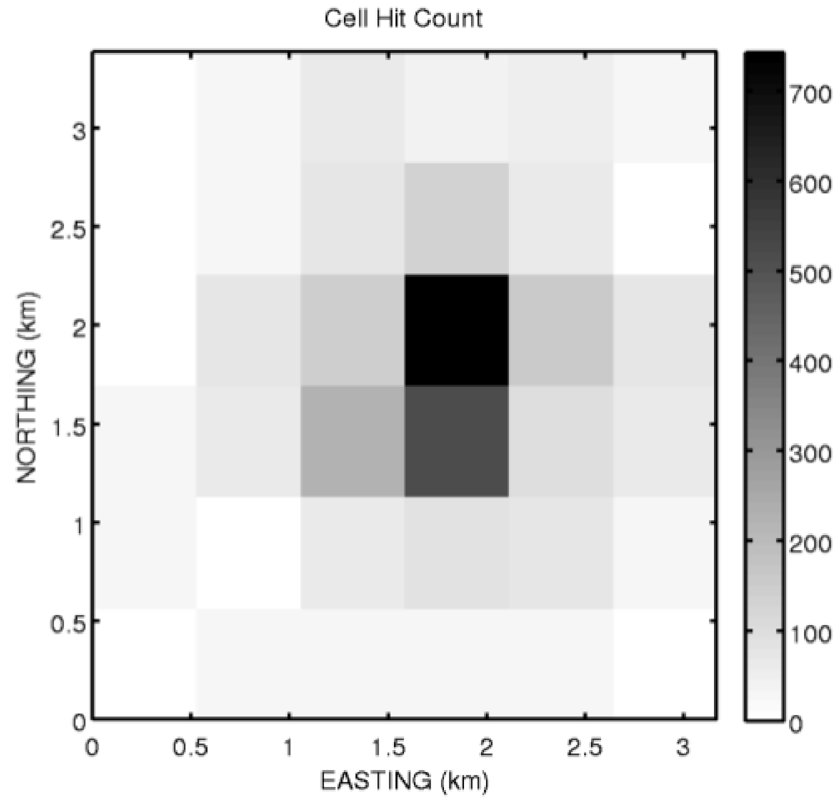
Phase velocity maps @ Virgo





At each reference frequency:

From phase velocity to inter-station travel time

$$T_{ij} = \frac{r_{ij}}{c_{ij}(\omega)}$$

Travel times as a linear combination of ray segments lengths and slowness of cells

$$T_{ij} = \sum_{j=1}^{M} l_{ij} s_j$$

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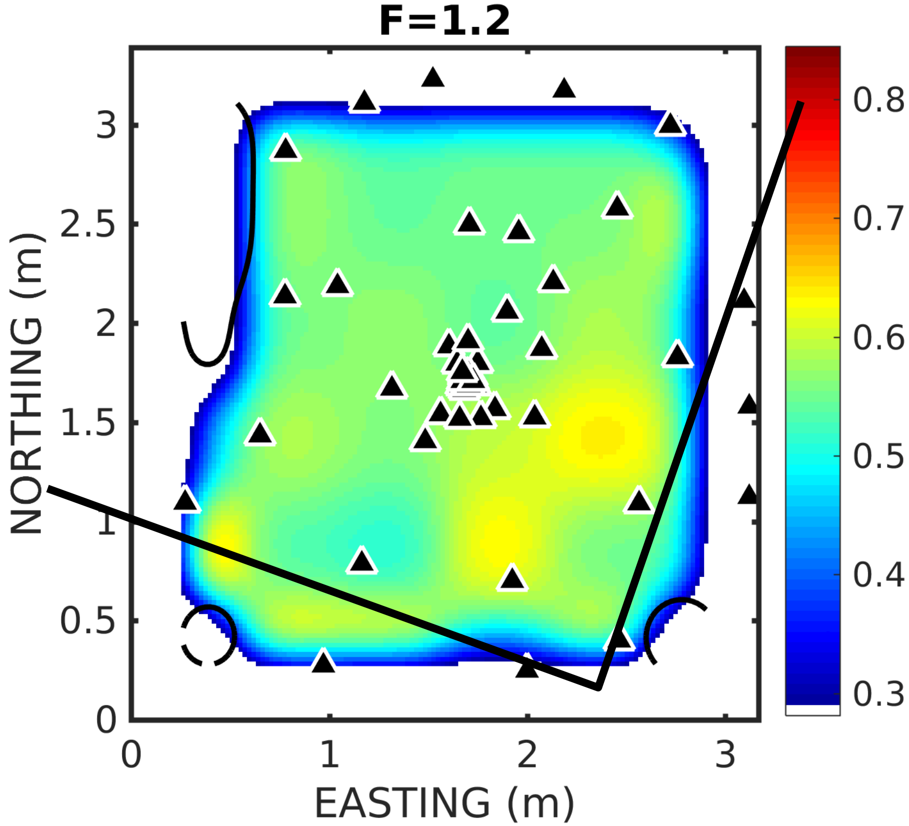
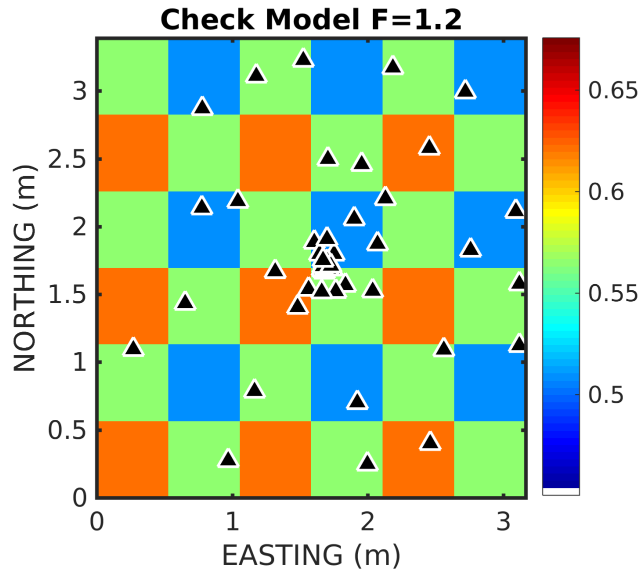
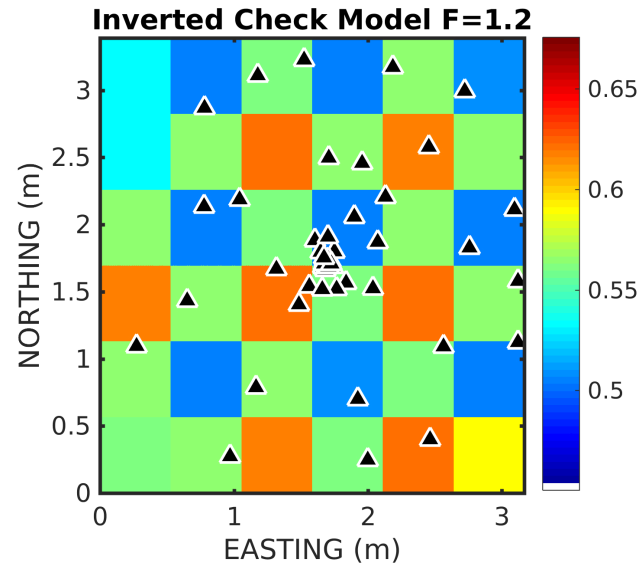
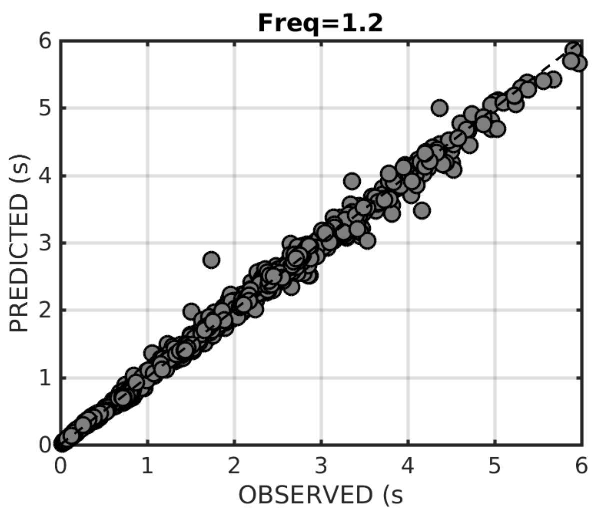
Phase velocity maps @ Virgo







Phase velocity map @ f=1.2 Hz (z~100-200m)



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On Line!

International Federation of Digital Seismograph Networks

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VR: Virgo Interferometric Antenna for Gravitational Waves Detection

FDSN Network Information

Are you the operator of this network? Update this information.

FDSN code	VR	**Operated by**	European Gravitational Observatory (ego)
Network name	Virgo Interferometric Antenna for Gravitational Waves Detection (virgo)	**Deployment region**	Italy
Start date	March 1, 2019	**End date**	-
Short description	The Virgo antenna is a 3 km long interferometer for gravitational waves detection. It is located in Cascina, near Pisa (Italy), and it is hosted by the European Gravitational Observatory (EGO). The interferometer is equipped with 3 broadband seimometers, located in its main experimental buildings.		

Citation Information

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Thanks for your attention