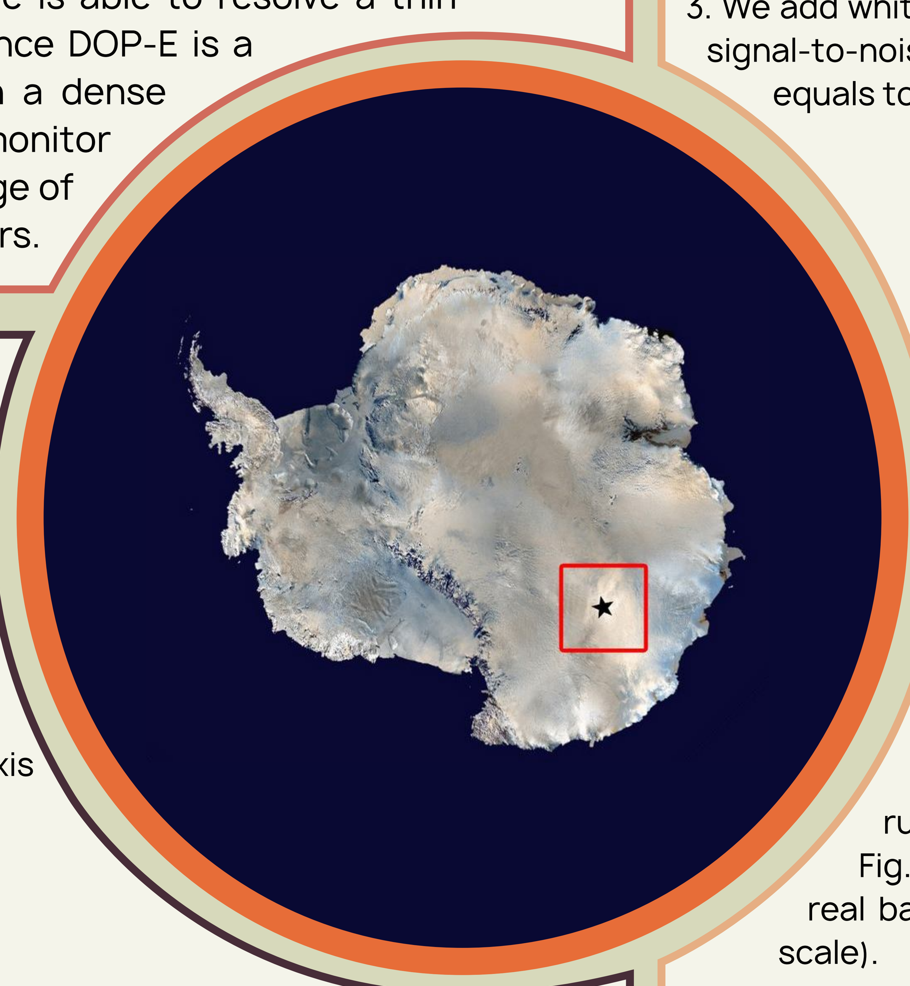
# Investigating the Antarctic subglacial liquid water layer

## using the ellipticity of Rayleigh waves from polarization analysis of seismic noise

A. Berbellini[1,3], M. Schimmel[2], A.M.G. Ferreira[3], A. Morelli[1]

## SUMMARY

We investigate the seismic structure of the uppermost ice and crustal layers beneath the Concordia station (Antarctica) using a new method based on the inversion of ellipticity of Rayleigh waves from ambient noise by degree-of-polarization analysis (DOP-E). We apply this technique to 1 month of continuous noise recordings in the period band 2 - 10 s, and complement such analysis with measurement of Rayleigh-wave ellipticity on earthquake data (in the period band 10 – 60 s). Results show no evidence of a liquid water layer beneath the ice directly beneath the station confirming the results from previous studies. To further validate this result we perform a synthetic test demonstrating that this technique is able to resolve a thin (>100m) liquid water layer at the baseof the ice (3.5km). Since DOP-E is a completely single-station technique, it can be used when a dense seismic array is not available. It can also be used to monitor possible transients in the shear-waves velocity in a wide range of geological settings such as volcanoes, fault zones and glaciers.



## METHOD

1. Identification at each time and frequency of the ellipse which best fits the ground motion (fig. 1a)

2. Separation of the portions of waveform where the polarization is stable along the ellipse -> higher Degree-of-Polarization (fig. 1b)

3. Selection of the ellipses polarized on a vertical plane with axis orthogonal to the Earth surface (fig. 2)

4. Measurement of the ratio between horizontal and vertical axis

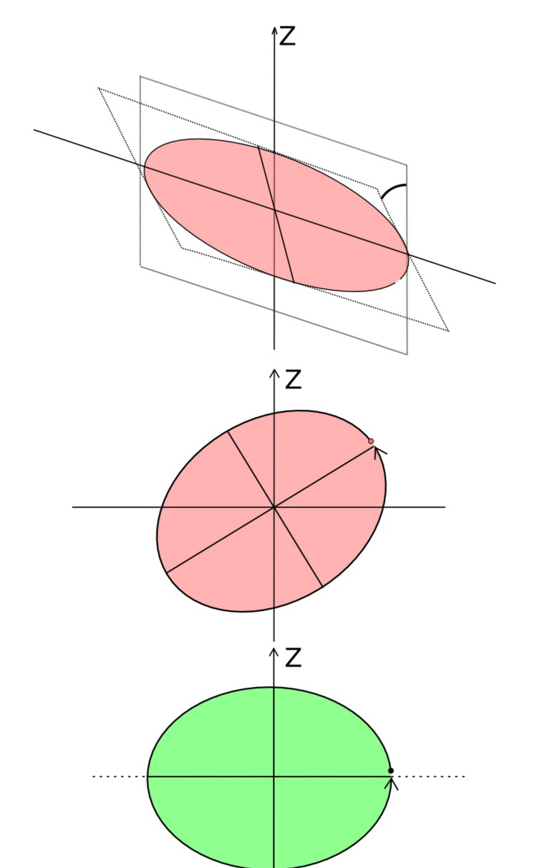


Fig. 1

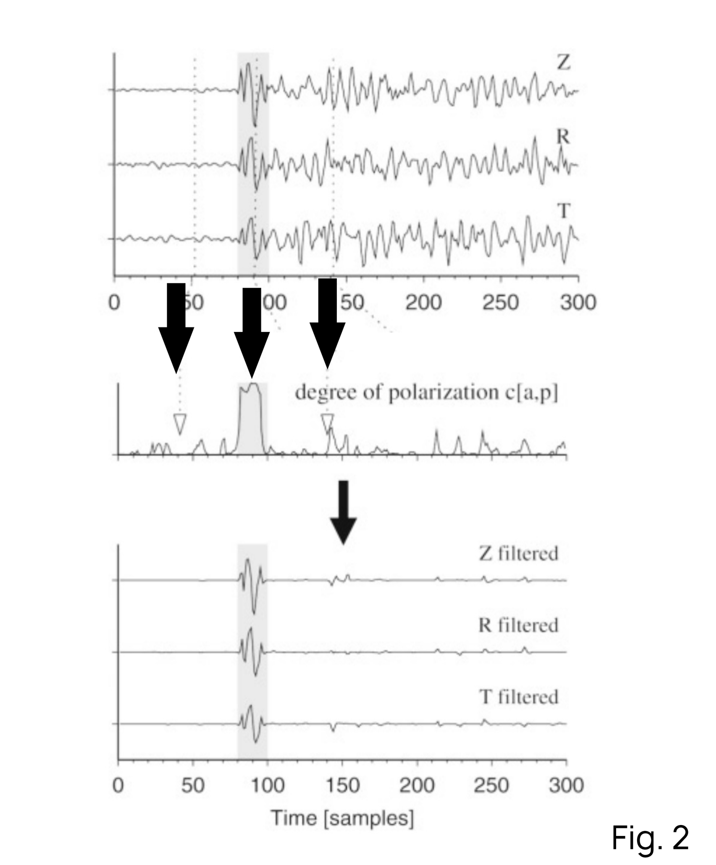



Fig. 2

## VALIDATION

We simulate synthetic ambient noise generated by a storm in Northern Atlantic:

1. We stack synthetics computed at Parma station (Northern Italy) from 300 random, vertical, instantaneous sources on model Prem (Fig 3)
2. We add synthetic Love waves generated by 200 horizontal, random, double-couple sources at the same location
3. We add white noise with a signal-to-noise ratio equals to 7.5

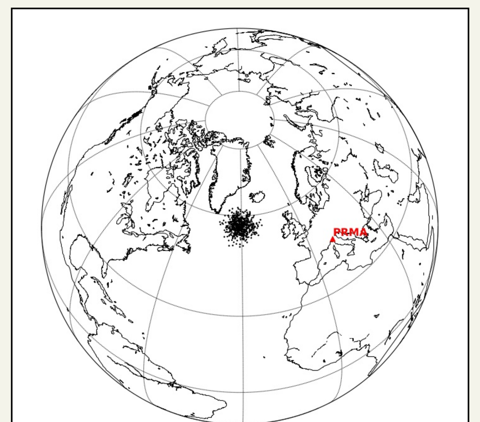


Fig. 3

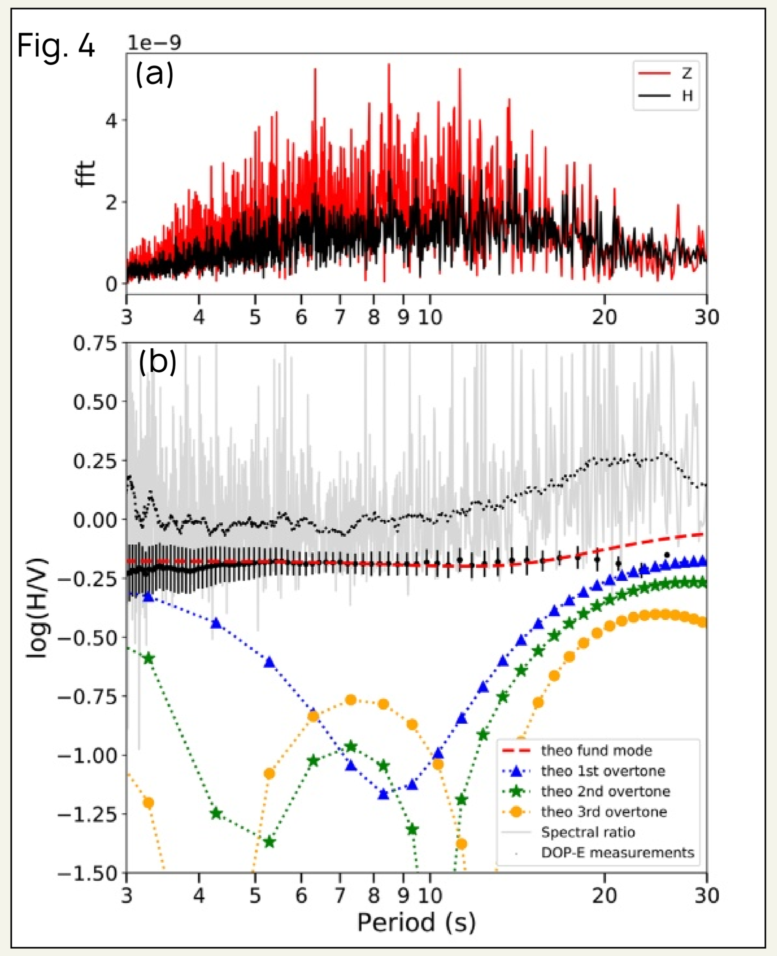



Fig. 4a: Horizontal (black) and vertical (red) power spectra of synthetic ambient noise.

Fig. 4b: Ellipticity measured using the DOP-E approach (black); theoretical ellipticity curve of fundamental model computed on Prem model (red); spectral ratio between vertical and horizontal components (gray) and running average (black dotted line).

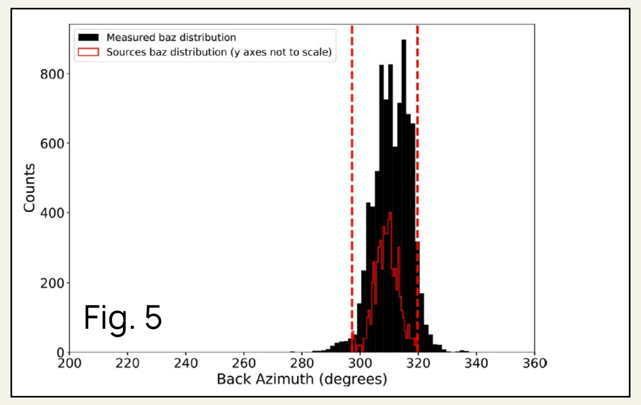



Fig. 5: back azimuth measured by DOP-E (black) and real back azimuth of the sources (red) (y axis not to scale).

## SENSITIVITY TEST

We test the capability to resolve an hypothetical liquid layer beneath the ice using ellipticity. We select 5 different models with fixed thickness and different Vs (fig. 6a). We then compute the theoretical curves from each model (fig. 6b).

We then assume that a liquid water layer is present, we choose 5 different thickness (fig. 6c) and compute the theoretical ellipticity curves (fig. 6d).

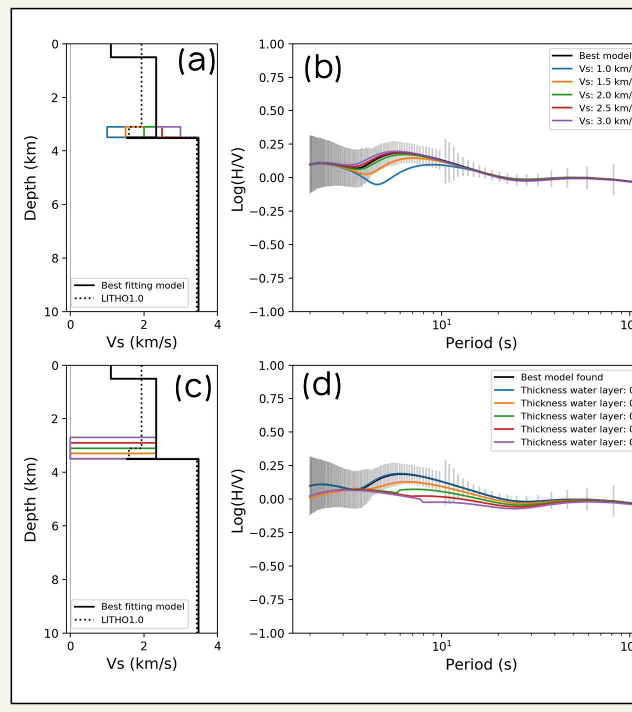



Fig. 6

## RESULTS

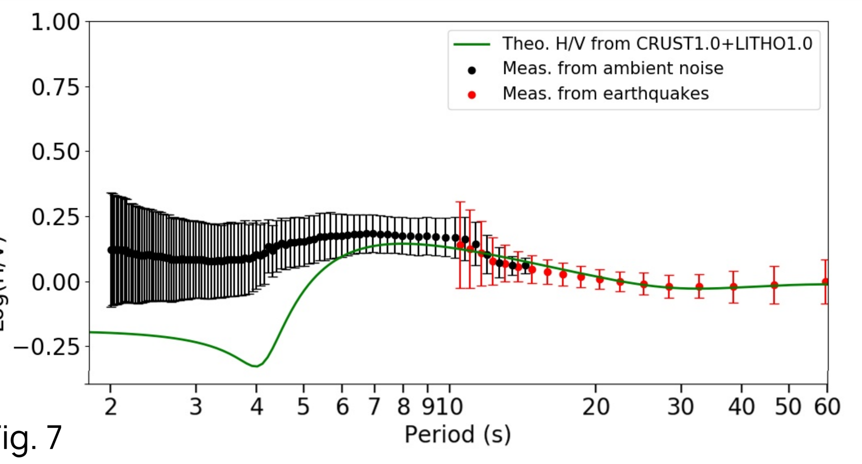



Fig. 7

Fig. 7: ellipticity measurements from both ambient noise (black) and earthquakes data (red) and theoretical ellipticity from CRUST1.0 (Laske et al. 2013) (green).

Fig. 8a: measured ellipticity (black) and theoretical ellipticity from best fitting model (red)

Fig 8b: best fitting $v_s$ profile (red) compared to $v_s$ profile from model CRUST1.0. Fig. 8c: zoom of the top 6 km

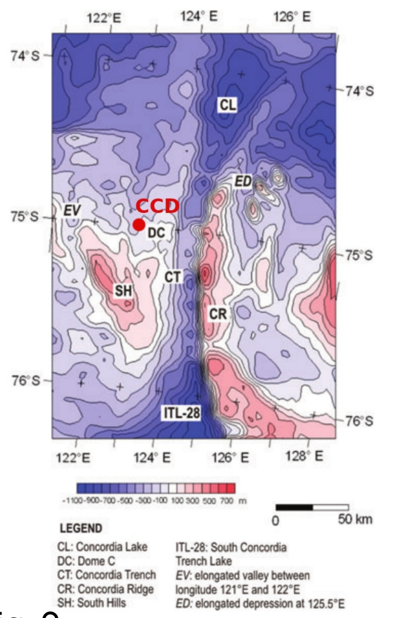



Fig. 9

Fig. 9: 3 km gridded map of the Concordia Trench-Lake system and the main physiographic features of the investigated area (Cianfarra et al. 2009)

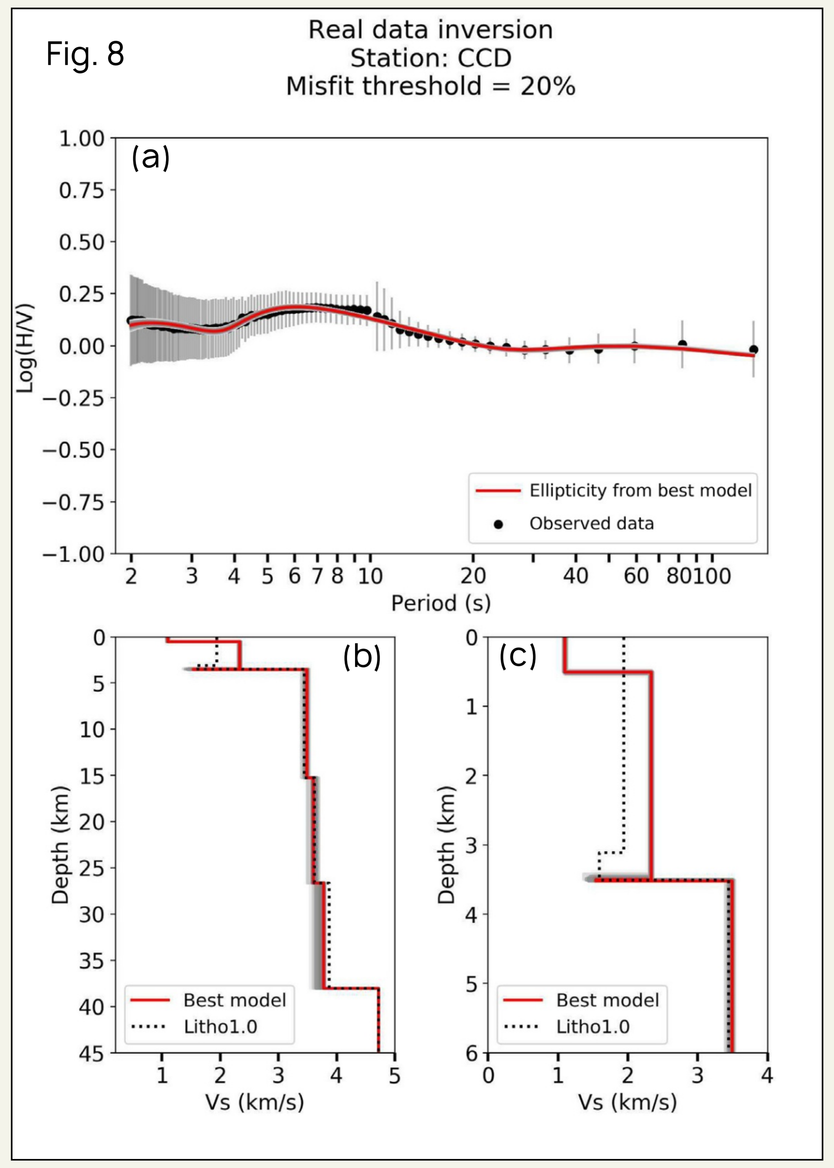



Fig. 8

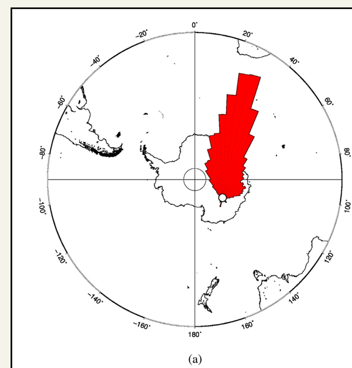


Fig. 10

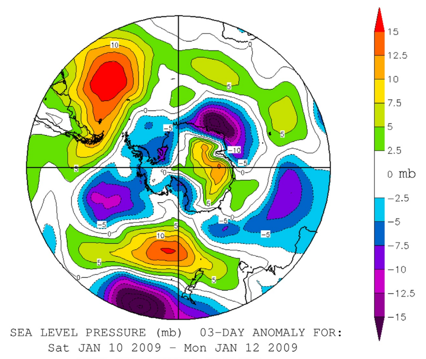


Fig. 11

Fig. 10 back azimuth measured from ambient noise by DOP-E analysis

Fig. 11: air pressure anomaly (data from NOAA

## NEXT PROJECT

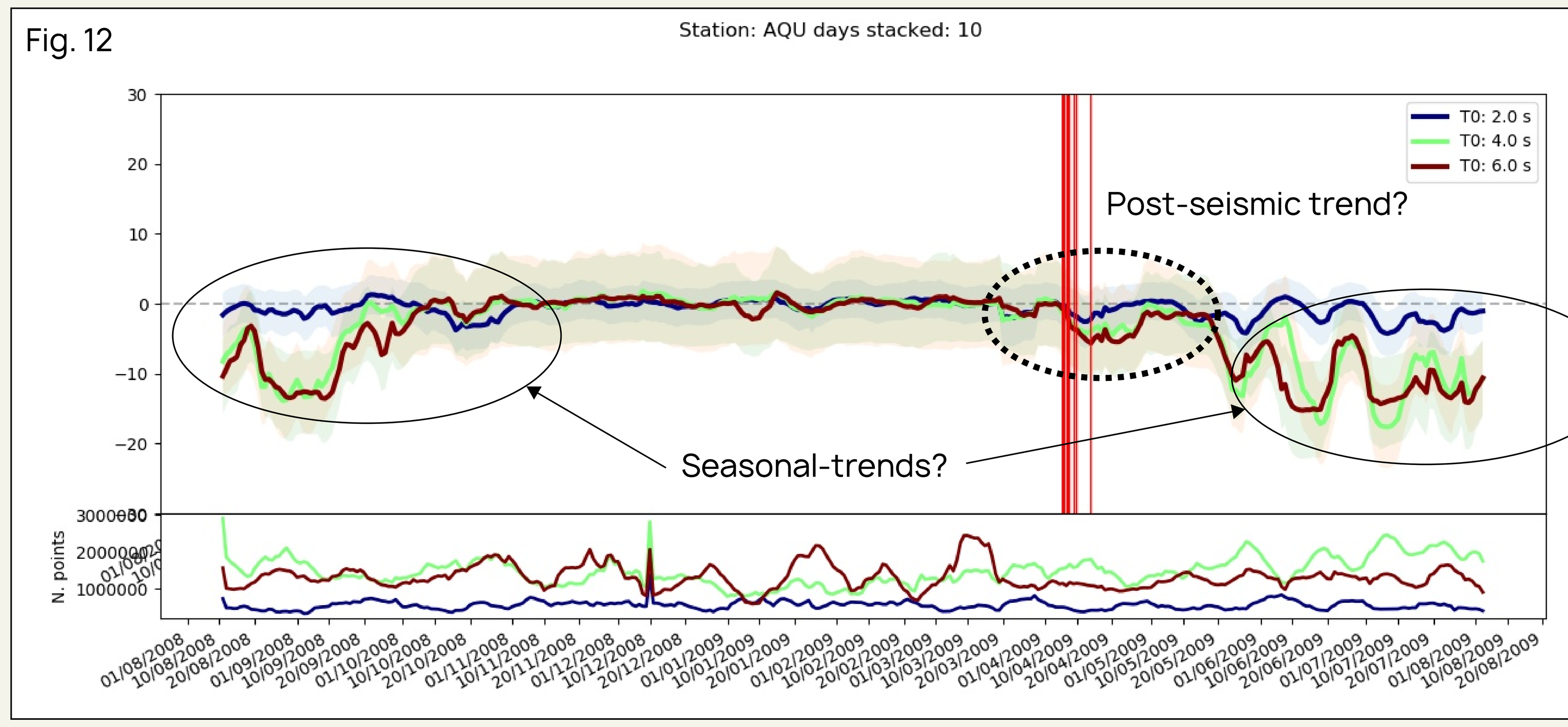



Fig. 12

Fig. 12 top: Ellipticity variations at different periodsmeasured from ambient noise using DOP-E on 1 year of data before and after the L'Aquila earthquake Mw 6.3 (Italy) (red vertical lines).
Bottom: number of measurements available

## DOWNLOAD!

The DOP-E code to measure ellipticity from ambient noise is free to download here: **https://github.com/berbellini/DOP-E** (QR code on the left)

Please cite us: Berbellini, A., M. Schimmel, A.M.G. Ferreira and A. Morelli (2018). Constraining S-wave velocity using Rayleigh wave ellipticity from polarization analysis of seismic noise, Geophysical Journal International (QR code on the right)

QR code for the method

QR code for the paper

1 INGV
2 ICTJA INSTITUT DE CIÈNCIES DE LA TERRA JAUME ALMERA
3 UCL
NERC SCIENCE OF THE ENVIRONMENT
TIDES

Contact: andrea.berbellini@ingv.it

Berbellini, A., M. Schimmel, A.M.G. Ferreira and A. Morelli (2018). Constraining S-wave velocity using Rayleigh wave ellipticity from polarization analysis of seismic noise, Geophysical Journal International, ggy512, https://doi.org/10.1093/gji/ggy512. • Cianfarra, P., Forieri, A., Salvini, F., Tabacco, I.E. & Zirizotti, A., 2009. Geological setting of the Concordia Trench-Lake system in East Antarctica, Geophys. J. Int., 177(3), 1305–1314. • Laske, G., Masters., G., Ma, Z. and Pasyanos, M., Update on CRUST1.0 - A 1-degree Global Model of Earth's Crust, Geophys. Res. Abstracts, 15, Abstract EGU2013-2658, 2013. • Schimmel, M. & Gallart, J., 2003. The use of instantaneous polarization attributes for seismic signal detection and image enhancement, Geophys. J. Int., 155(2), 653–668