Rotational sensor on a volcano: New insights from Etna, Italy

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1. Abstract

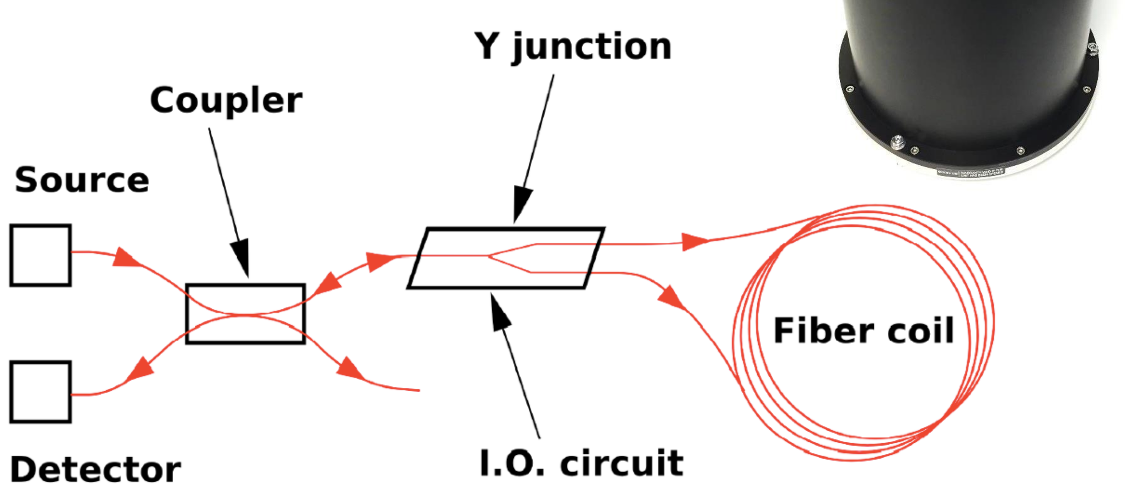
- 294 local earthquakes on Etna from 24.8–23.9.2019 (INGV catalog, Gruppo Analisi Dati Sismici, 2020) recorded by rotational sensor & seismometer
- Record of the full wavefield: 3 translational & 3 rotational motions
- Earthquake location using (i) only horizontal rotational components and (ii) vertical rotation rate & transverse acceleration
- Location codes using the horizontal rotational component (Wassermann et al. 2020, Yuan et al. 2020) yield consistent result
- SH phase velocities derived from (ii) in the range of a few 100 m/s for local earthquakes at a few kilometres distance
- Moving tremor source detected
- Measuring the full wave field is better than measuring only translation → More accurate understanding of processes
- Earthquake & tremor location possible using recordings from one site → Fewer sensors → easier to maintain & install
  → array-like results without frequency constraint

2. The sensor: blueSeis-3A

- Fiberoptic gyroscope
- First portable, broadband, low noise sensor
- High dynamic range for measuring rotational ground motion in 3 components
- detailed sensor performance characterization crucial for reliable seismic observations
- Available sensors need to be tested
- Challenges: large weight, large size, high power consumption

Pros:
- Based on Sagnac effect, no inertia, no moving parts
- flat response over a large frequency range (DC - ~ kHz)
- no sensitivity to translational motion
- closed loop sensor (larger dynamic range)

Cons:
- closed loop sensor (higher noise)
- high power consumption
- high sensor self noise

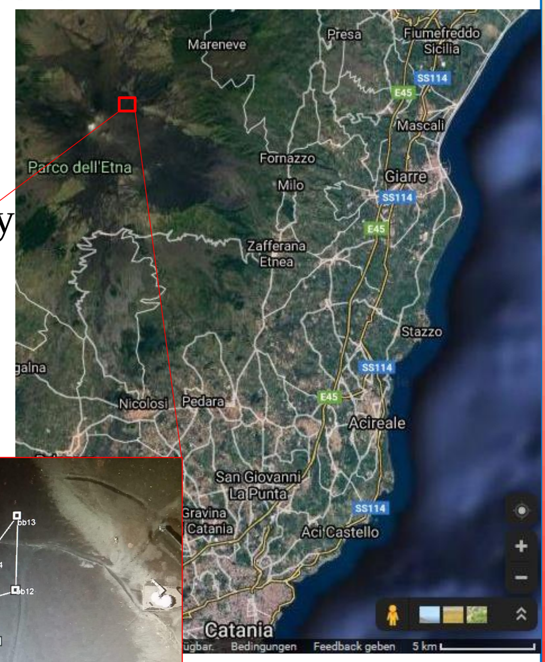


modified from Lefevre, 2014

3. Field site & experiment on Etna

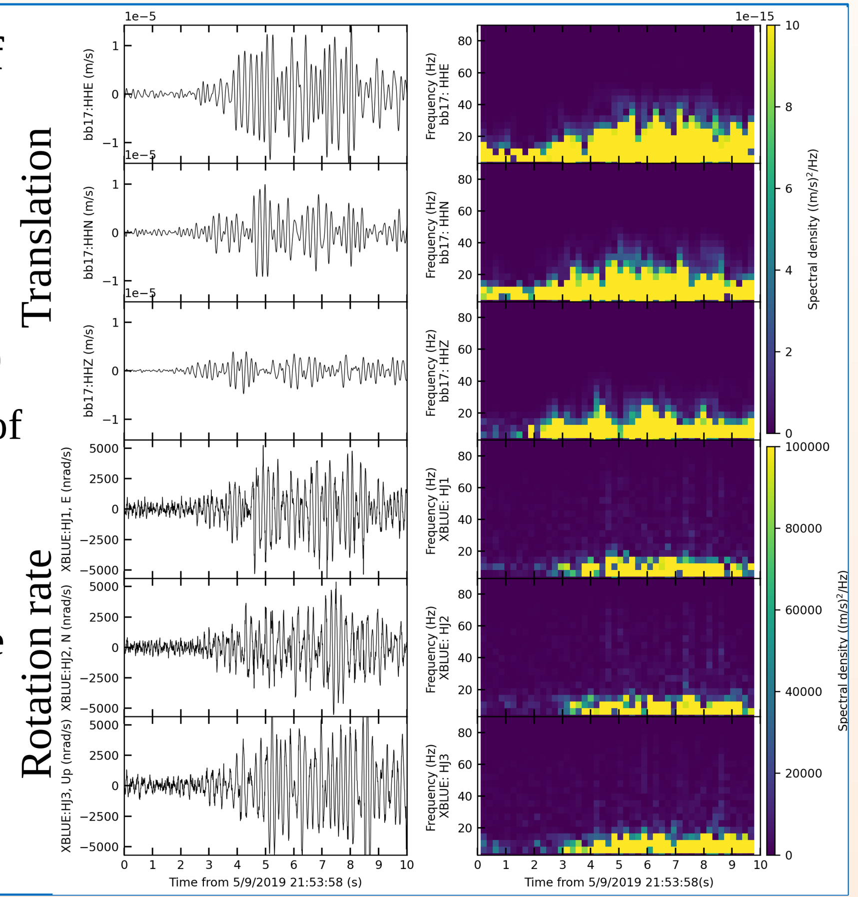
- Pizzi Deneri, INGV Observatory
- 23 August - 23 September 2019
- 1 rotational sensor in the middle of:
  - 26 station broadband seismic array
  - 1 fibre-optic cable for Distributed Acoustic Sensing (DAS)

  PI: P. Jousset
- Power:
  - 3 solar panels, 140 W each
  - 3 batteries, 70 Ah each



4. Full wavefield recording of an earthquake

- 294 earthquakes in INGV earthquake catalog from 24.8- 23.9.2019
- VT event on 5.9.2019 21:53:59
- Seismograms & spectrograms of translation (Trillium Compact) & rotation (blueSeis-3A)
- Rotational motion caused by Rayleigh waves, SH or SV type waves, scattered energy of linearly polarised waves



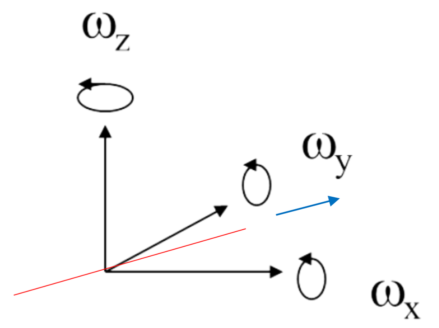
5. Methods: Back azimuth and phase velocity calculation

1) back azimuth calculation using only rotational sensor:

Extracting the principle polarization component from E & N rotation rates

Wassermann et al. (2020):
- orthogonal distance regression focussed on SV-type or Rayleigh waves
- direction estimations using the horizontal rotational motion components only
- 180° ambiguity resolved: corresponding acceleration & rotational seismograms are in phase for correct quadrant

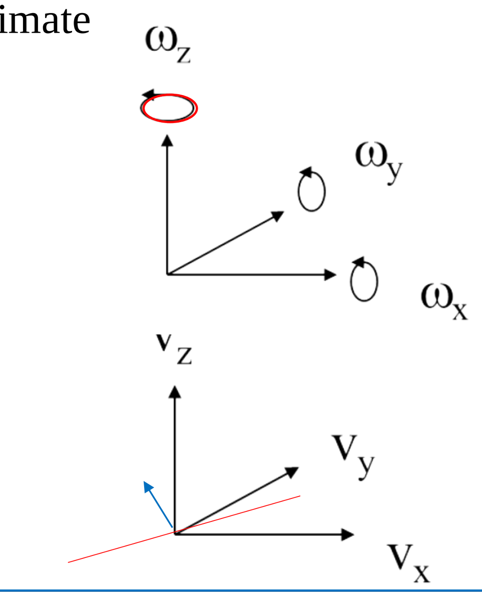
Yuan et al. (2020):
- singular value decomposition
- covariance matrix of horizontal rotational components
- 2 components of eigenvector of largest eigenvalue used to calculate direction



Rayleigh waves:
- Rotation rate $\omega_z = 0$
- Linear particle motion in horizontal plane (red line)
- Arc tangent or orthogonal distance regression of ω_x and ω_y to find direction (blue arrow)

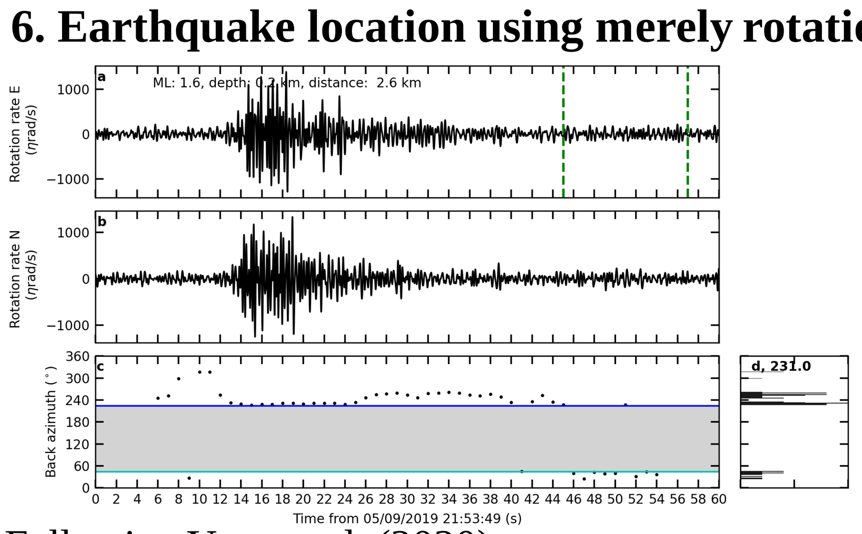
2) back azimuth calculation using 6C:

Wassermann et al. 2016:
- orthogonal distance regression technique focussed on SH-type waves
- rotation of the horizontal components of the translational motion
- regression on transverse acceleration & vertical rotation rate for direction estimate

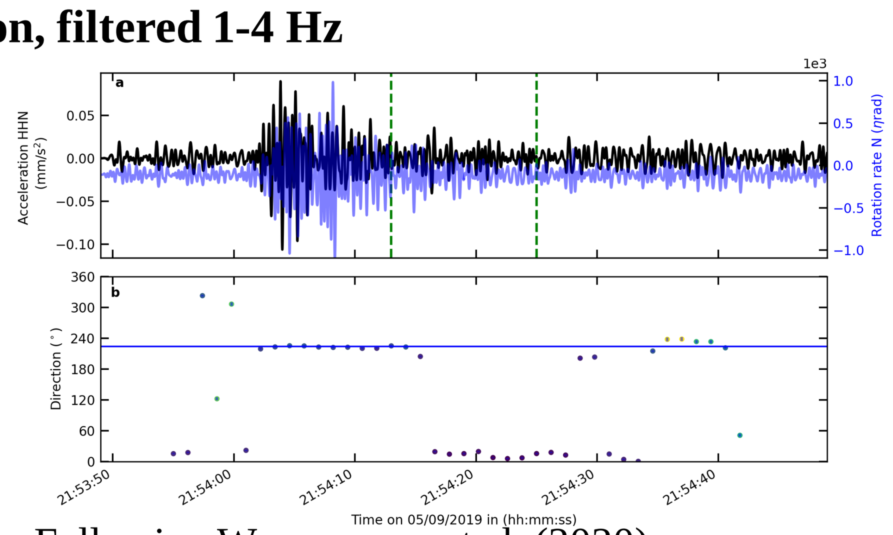


Love waves:
- Rotation rate $\omega_x = \omega_y = 0$
- Rotation rate $\omega_z = v_{Transverse} / -2c$
- Particle motion (red line) perpendicular to direction (blue arrow)
- Orthogonal distance regression of ω_z and $v_{Transverse}$ to find direction

6. Earthquake location using merely rotation, filtered 1-4 Hz



Following Yuan et al. (2020)
(a) E & (b) N rotation rate
(c) Back azimuth assuming Rayleigh waves, grey area cannot be resolved



Following Wassermann et al. (2020)
(a) E & N rotation rate
(b) Back azimuth assuming Rayleigh waves

green lines = moving window length
blue line = expected direction based on INGV catalog

7. Earthquake location using vertical rotation & transverse accelerat.

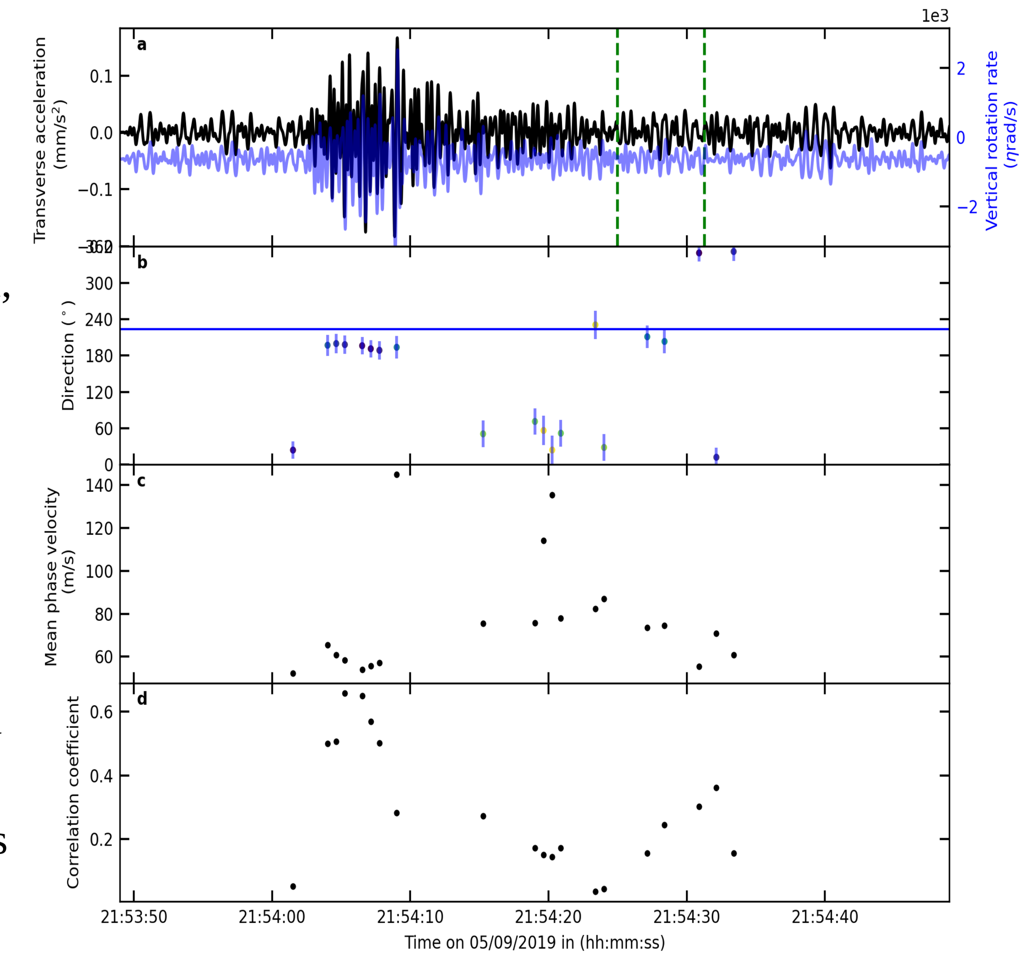
Output: Direction & Phase velocity
Filtered 1-4 Hz

(a) Seismogram of translation & rotation, green lines = moving window

(b) Back azimuth, blue line = expected direction based on INGV catalog

(c) SH phase velocity

(d) Correlation values



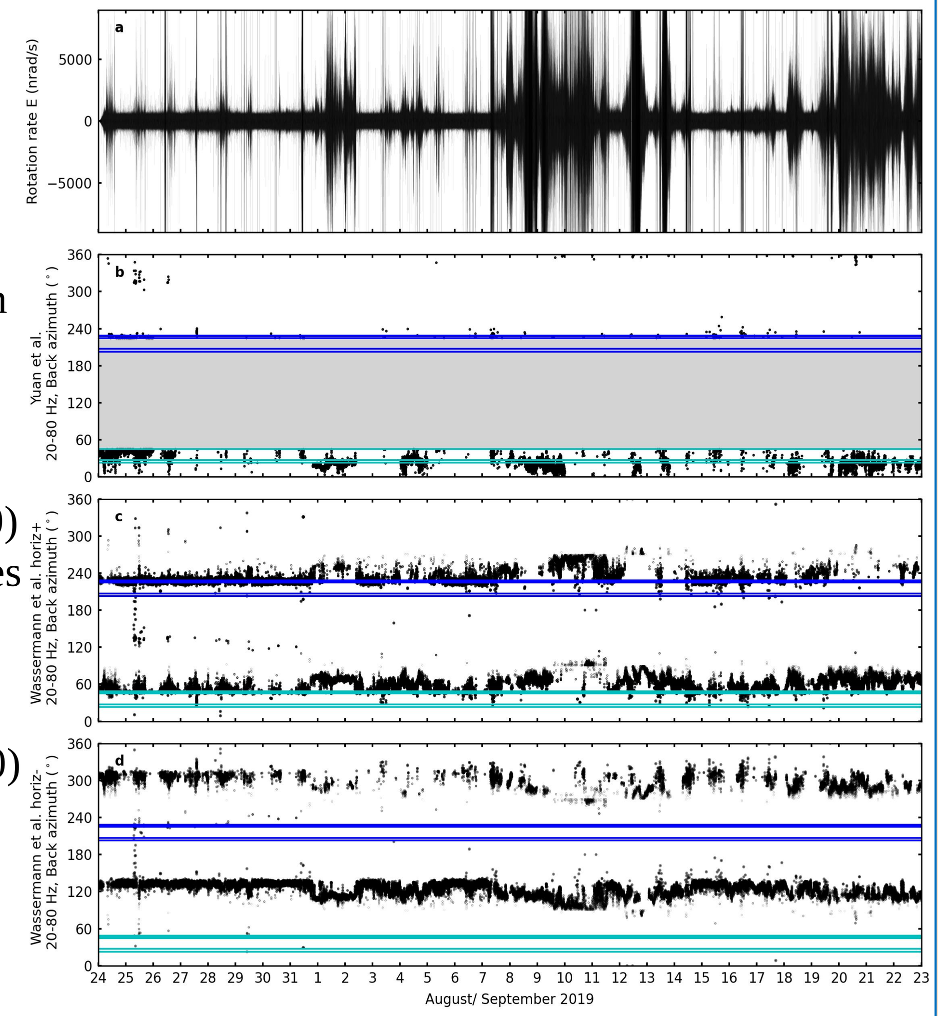
8. Outlook: 30 days of moving tremor location

(a) Seismogram of explosions & tremor

(b-d) Tremor back azimuth using the method from
(b) Yuan et al. (2020)
Moving window: 90 s
Overlap: 0%

(c) Wassermann et al. (2020) assuming Rayleigh waves
Moving window: 90 s
Overlap: 50%

(d) Wassermann et al. (2020) assuming SV waves
Moving window: 90 s
Overlap: 50%



9. Future work

- Compare & test different codes for back azimuth & phase velocity calculation using active sources
- Compare with back azimuth calculation from 3C of seismometer
- Compare rotation derived from broadband array to rotational sensor output
- Compare rotation derived from broadband array and DAS record
- Determine Rayleigh wave velocities from the rotation rate
- Perform a simple inversion for the shallow velocity structure below the station
- Tilt correction of seismic translational signals

10. References: https://tinyurl.com/mab6pen

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