Tutorial 2:
Station orientation on the seafloor

OBS training workshop, VUW, April 14-16, 2025

https://github.com/nfsi-canada

Software for calculating station orientation from earthquake data:

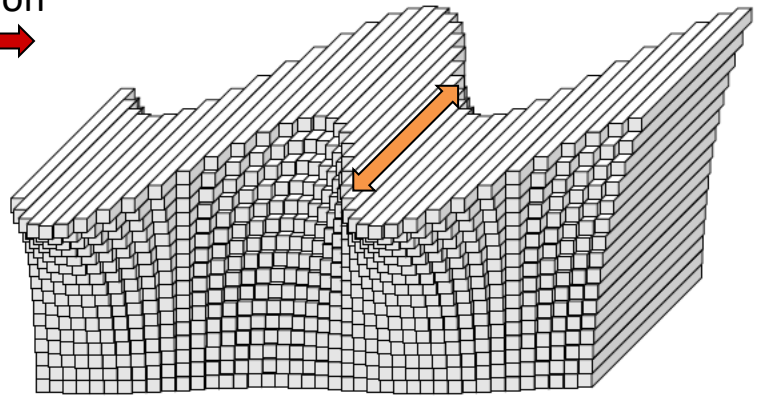
1. Polarization of (regional/teleseismic) P-waves
2. Polarization of Rayleigh waves

Seismic-wave polarizations

Propagation direction

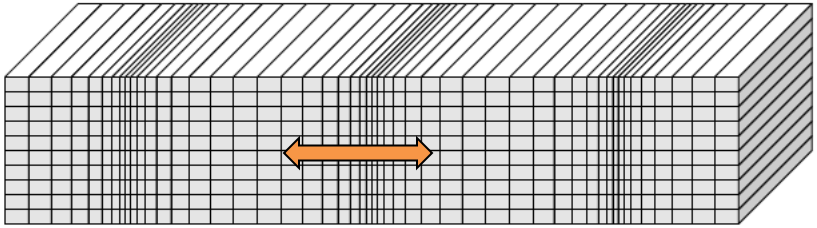
Love-wave polarization

T plane



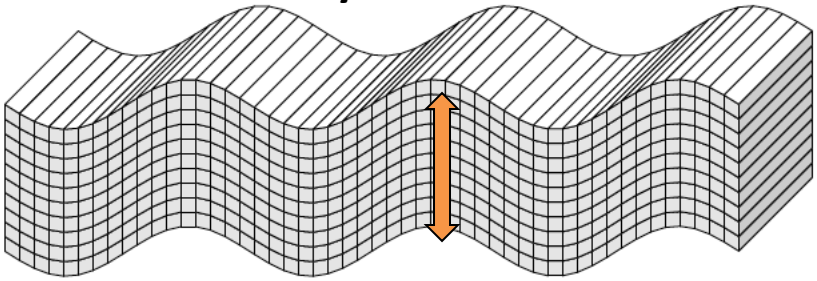
P-wave polarization

Z – R plane



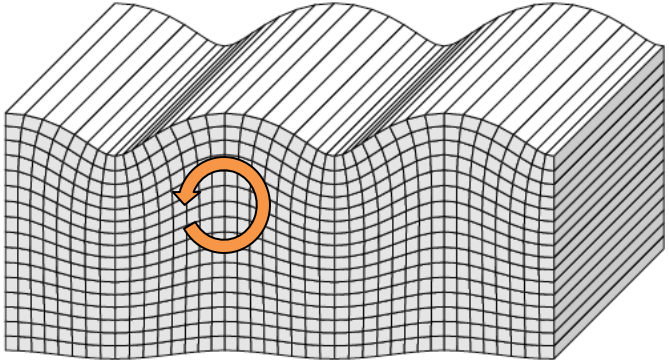
Surface waves

Body waves



S-wave polarization

Z – **R** (**– T**) plane



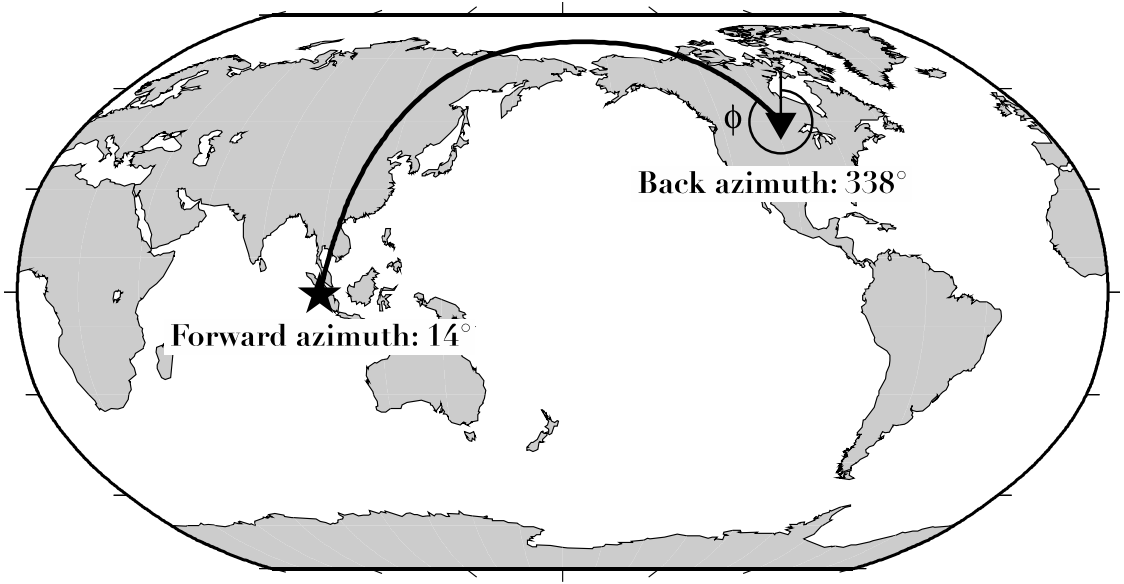
Rayleigh-wave polarization

Z – R plane

Shearer (2009)

Polarization convention

Seismic waves follow a great-circle path along the surface – or, rather, they propagate in a **ray plane** that passes through the source, the receiver, and the Earth's centre.



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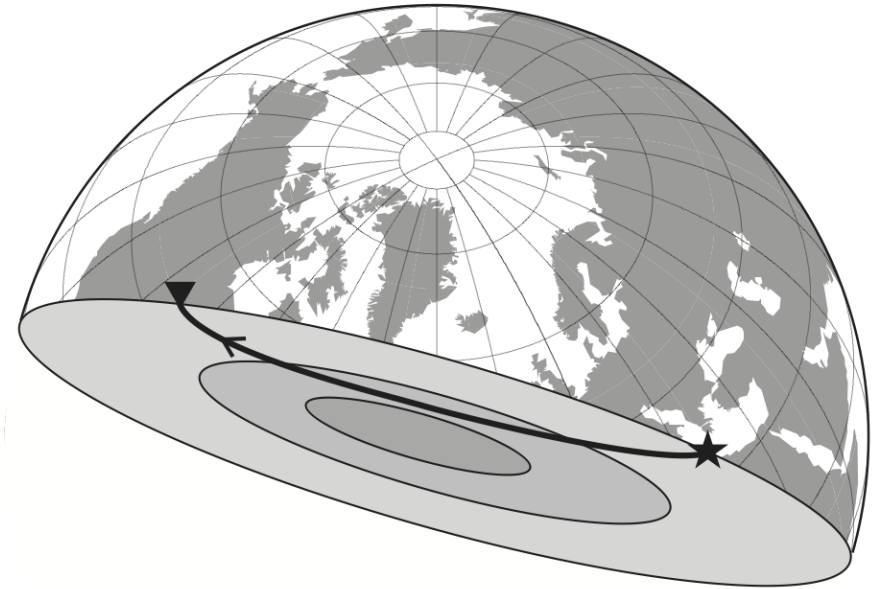
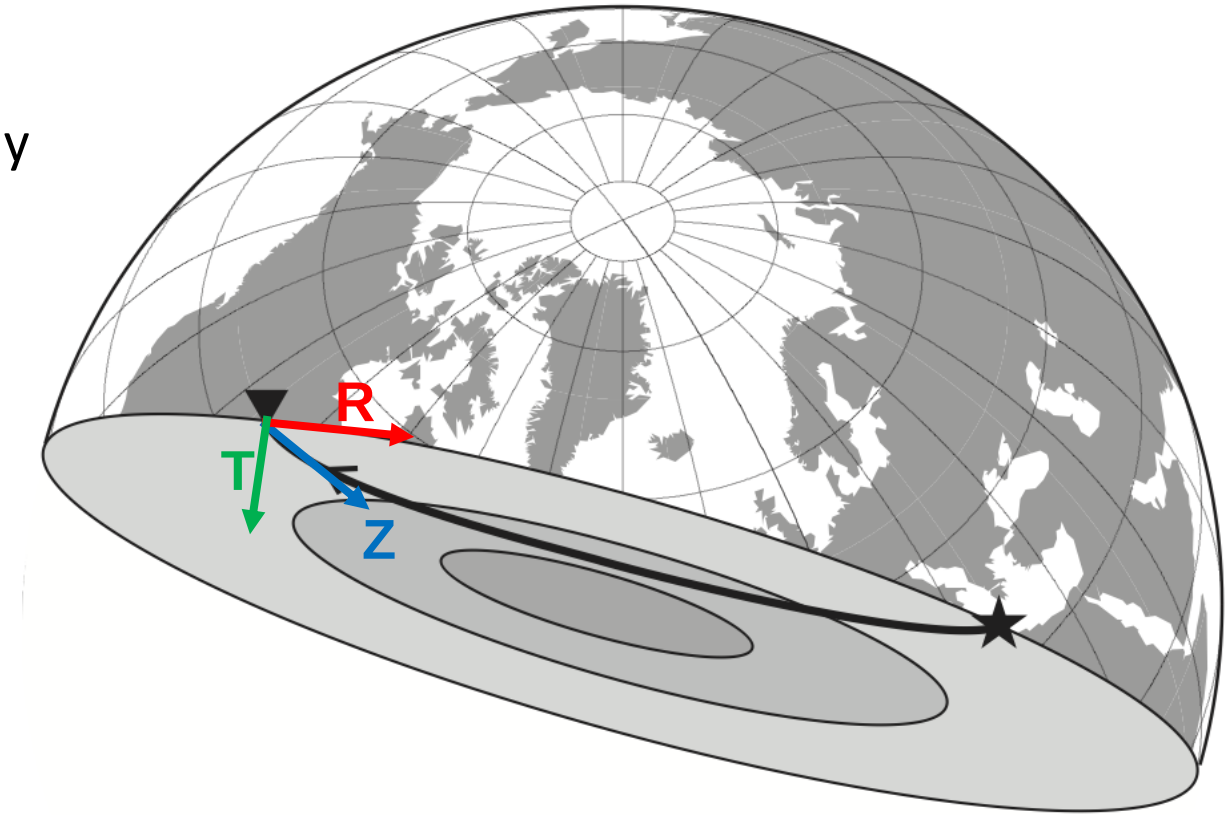


Polarization convention

Radial: horizontal, in ray plane

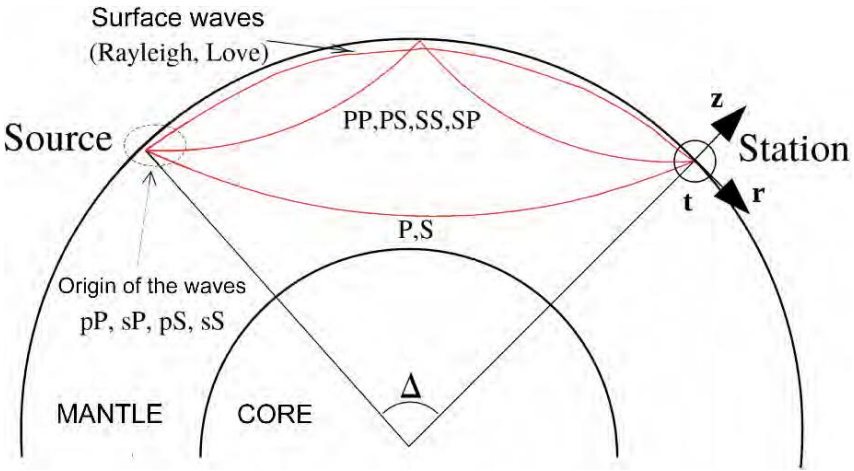
Transverse: horizontal, perpendicular to ray plane

Vertical: in ray plane



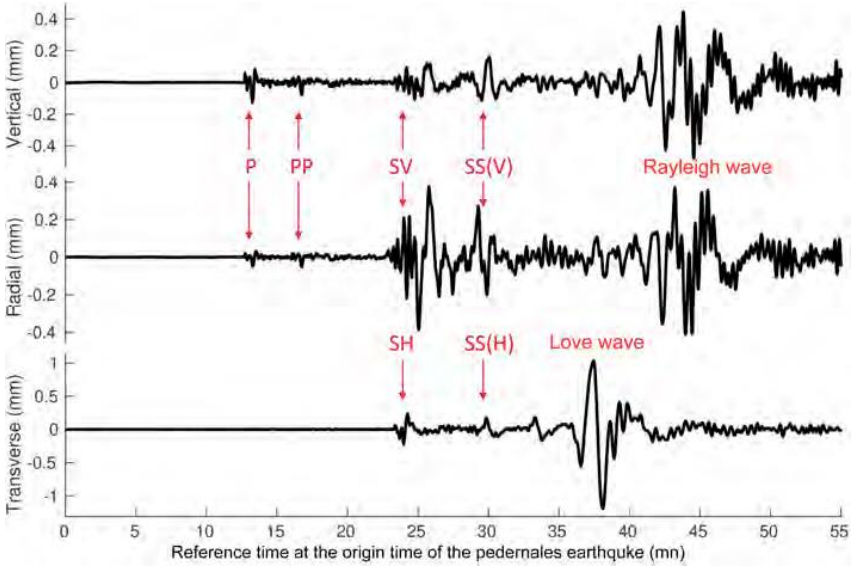
Seismic-wave polarizations

Teleseismic ray paths (shallow source)



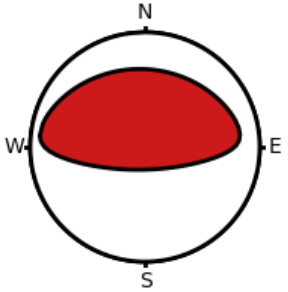
Vallée (2022)

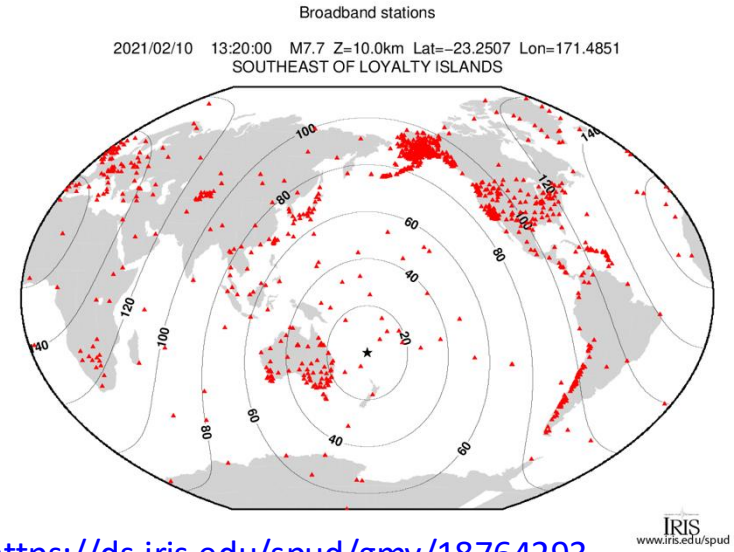
3-component seismograms

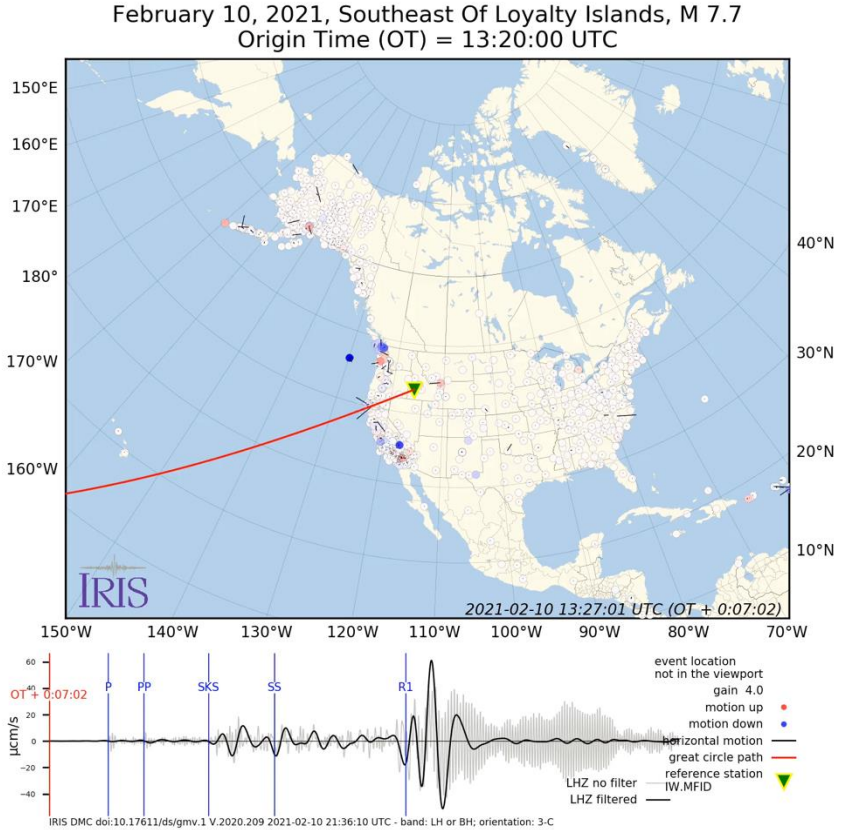


Pedernales earthquake (Ecuador, 16 April 2016, magnitude 7.8) observed in France at the SSB station from the Geoscope network

Seismic wave visualizations

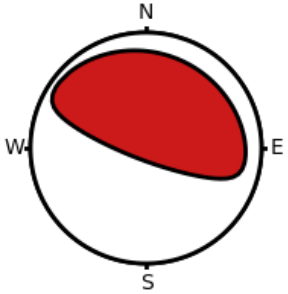


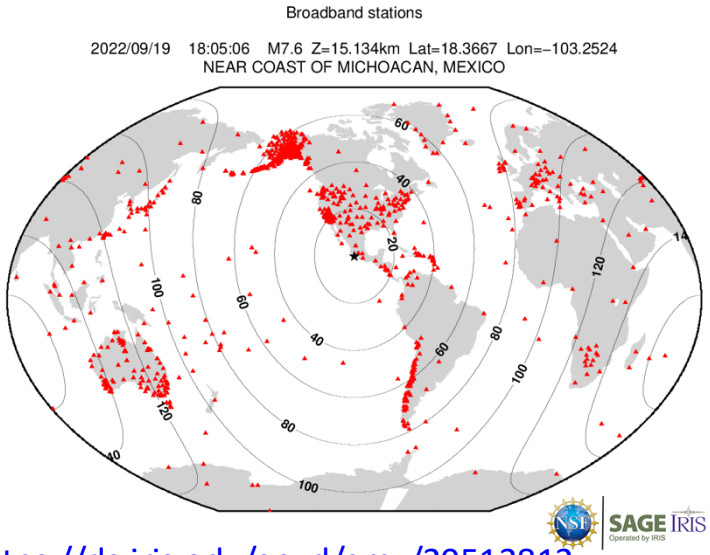


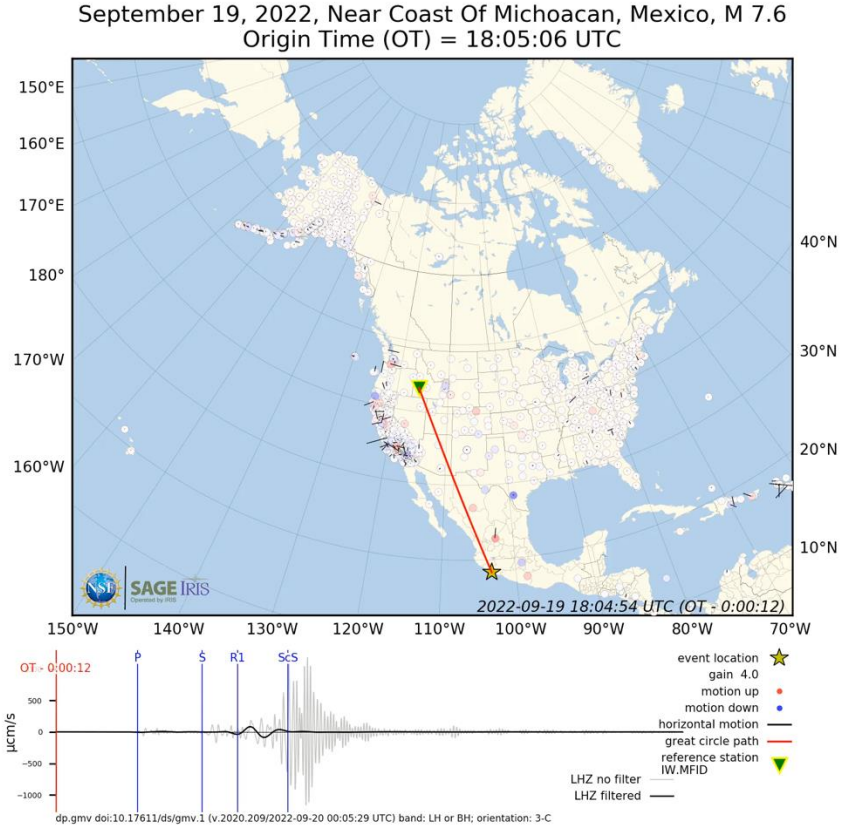


https://ds.iris.edu/spud/gmv/18764293

Seismic wave visualizations



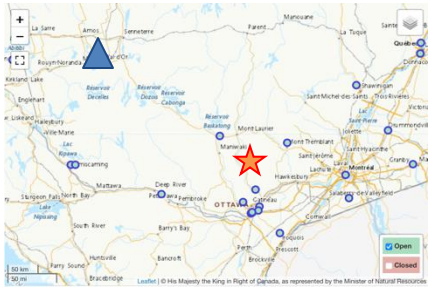


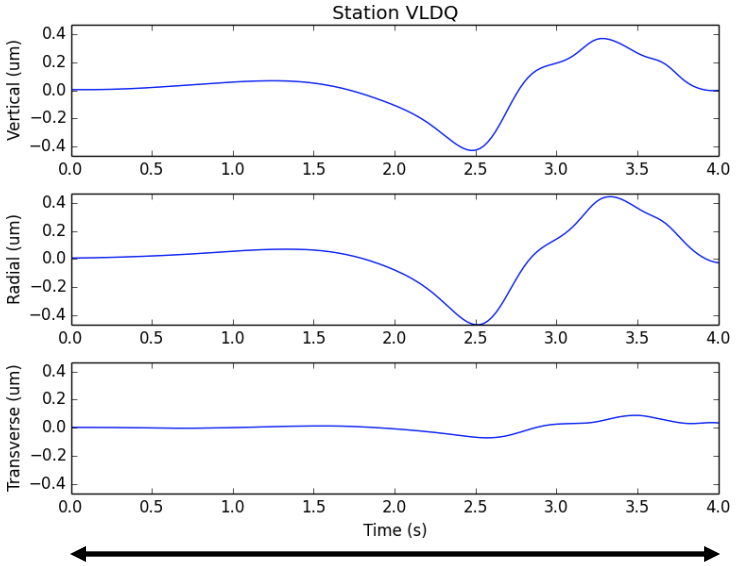


SAGE IRIS Operated by IRIS

https://ds.iris.edu/spud/gmv/20513812

P-wave particle motion

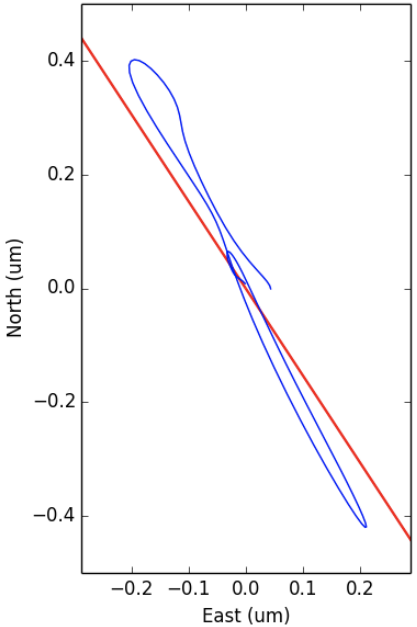


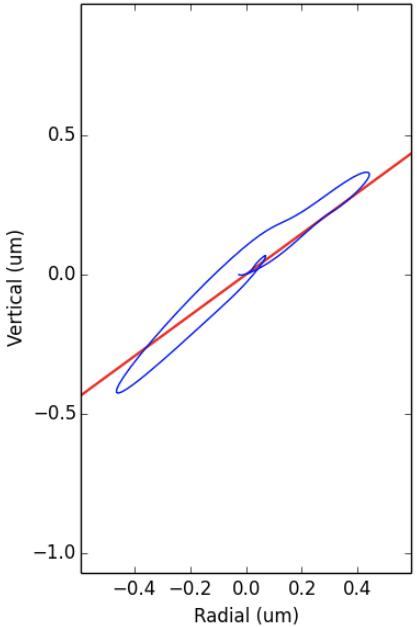


P-wave arrival window

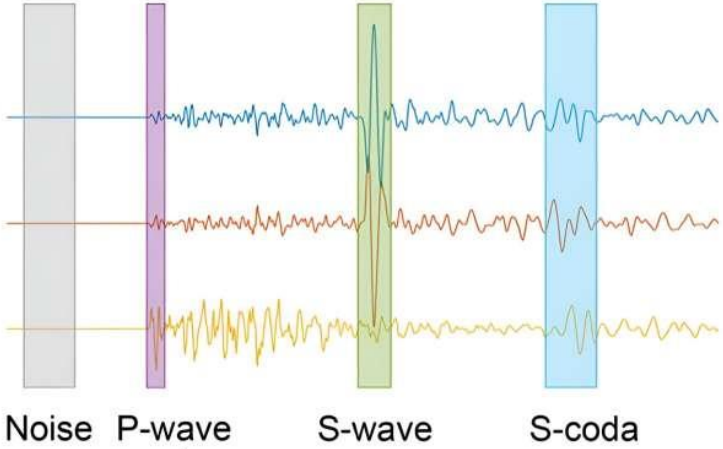
Direct P wave is polarized in longitudinal direction:

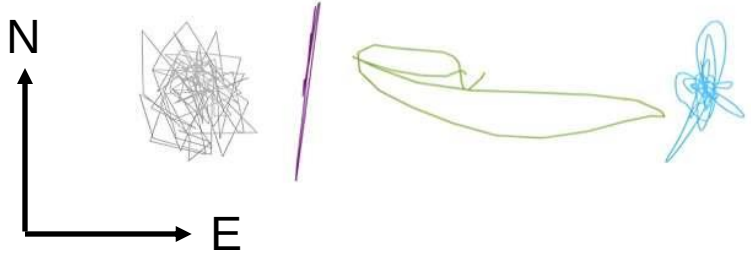
- Z – R seismograms are correlated
- Z – R particle motion is linear
- T seismogram has negligible motion
- N – E particle motion points to back-azimuth

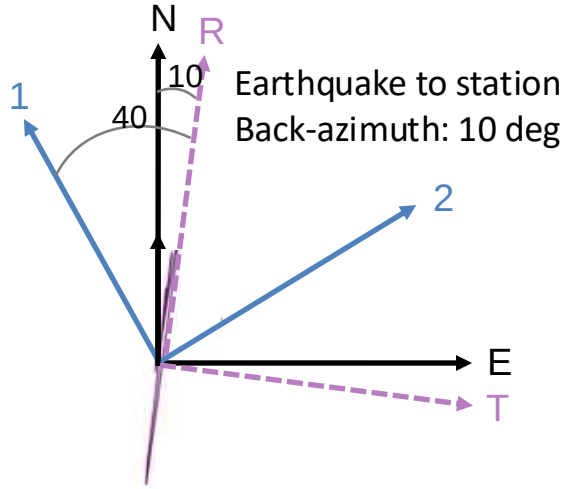




P-wave polarization





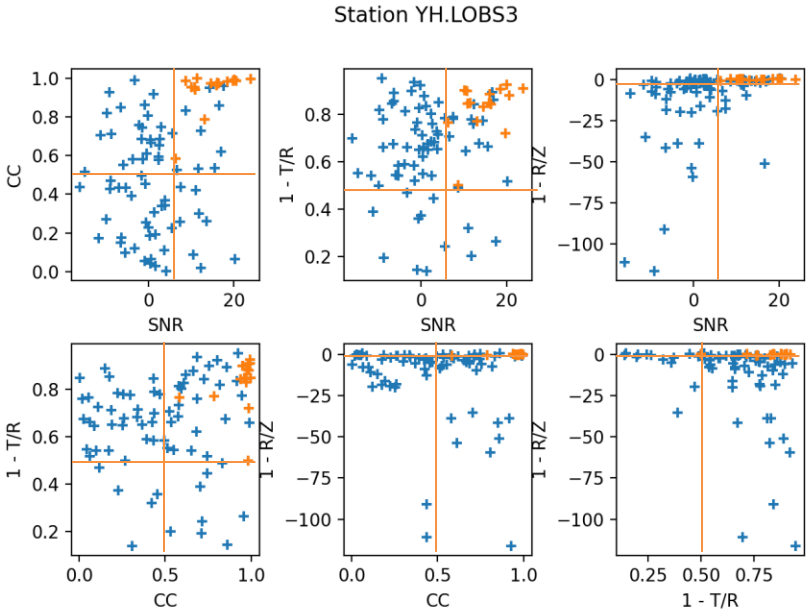


Algorithm:

- Extract P-wave arrival time window from velocity model
- Rotate component 1 until you find max correlation with Z (or minimum energy on T): obsBAZ
- Take difference between BAZ and obsBAZ as component 1 orientation

OrientPy implementation

- Based on Braunmiller, Nabelek and Ghods (2020)
- Flexibility to use regional or teleseismic P-waves (also PP)
- Downloads all data and calculates quality control criteria between rotated components with default thresholds

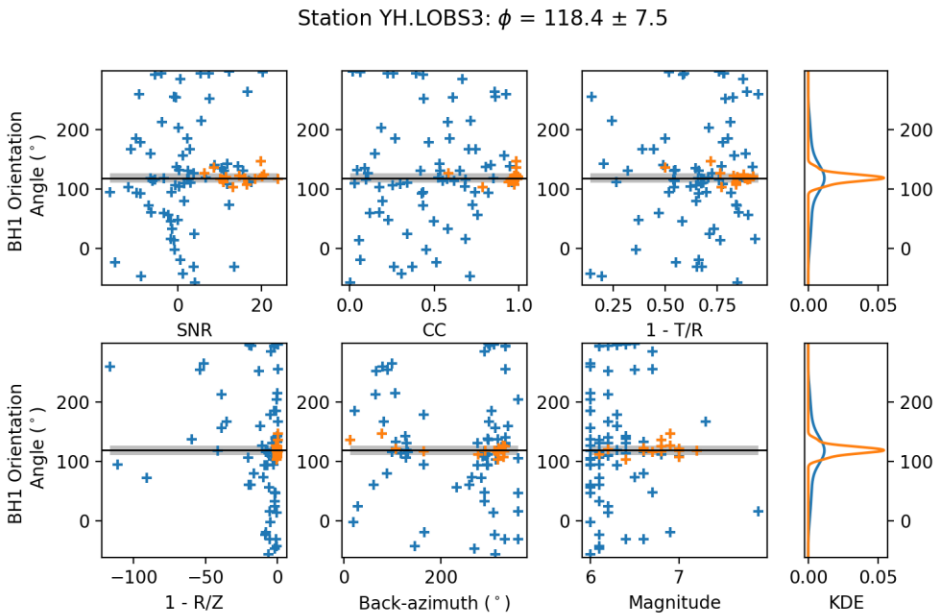


Quality control criteria:

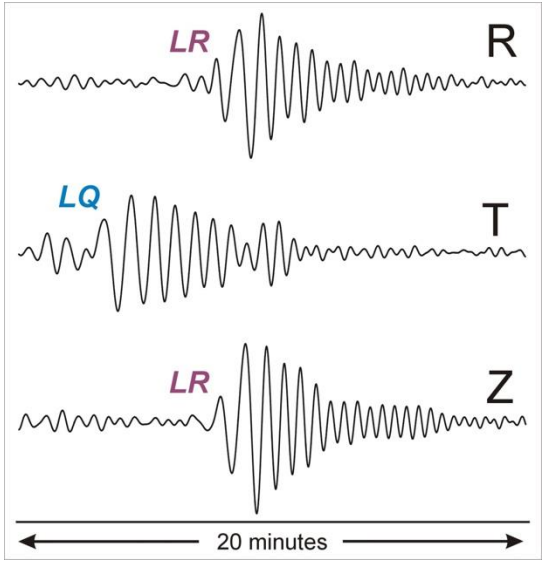
- CC: Cross-correlation between Z and R (0.5)
- SNR: Signal-to-noise ratio measured on Z component (5 dB)
- 1-R/Z: proportion of signal isolated on R vs Z (-1)
- 1-T/R: proportion of signal isolated on T vs R (0.5)

OrientPy implementation

- Average orientation for QC values that pass threshold values
- Calculate uncertainty

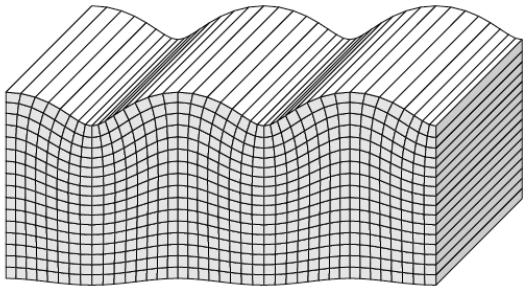


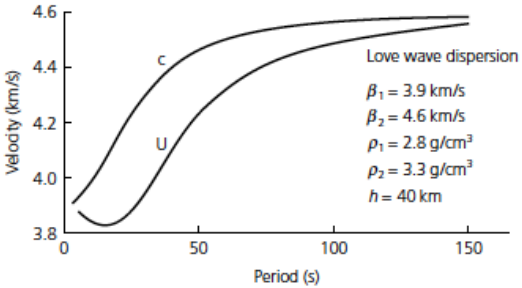
Rayleigh-wave particle motion

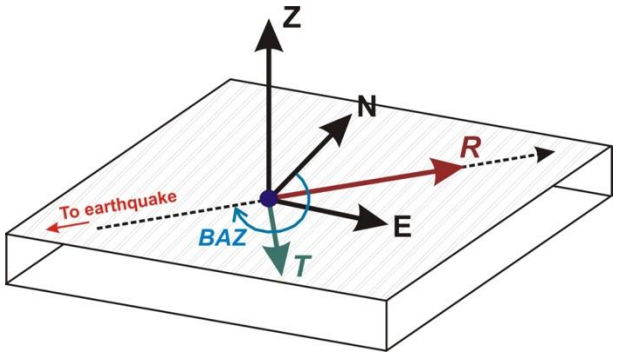


Rayleigh waves produce elliptical, retrograde motion in Z – R plane:

- R component is rotated 90 degrees from Z
- Z & rotated R seismograms are strongly correlated
- T seismogram has negligible motion
- This holds at multiple periods due to dispersion

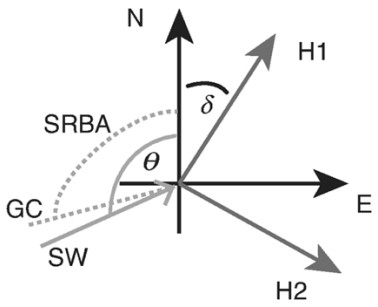


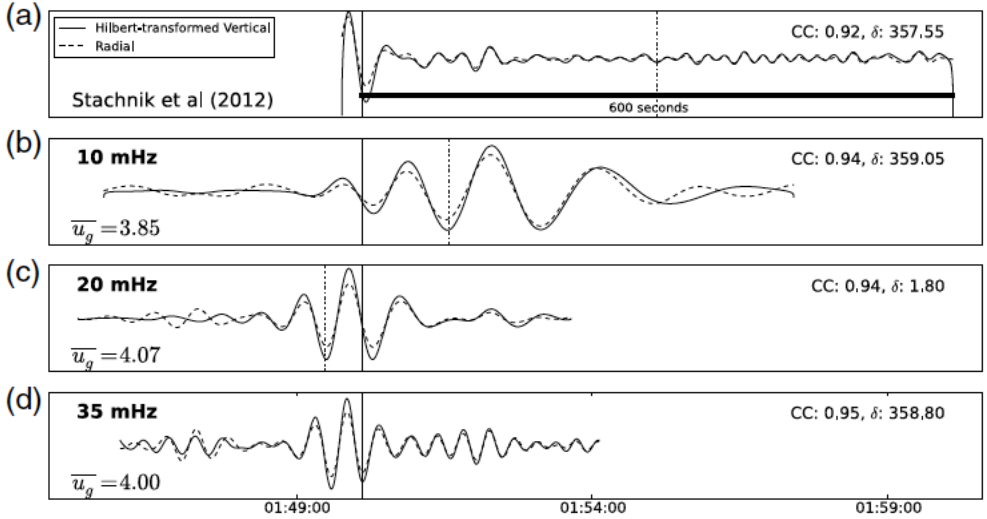




Shearer (2009), Stein & Wysession (2003)

OrientPy implementation (DLOPy)





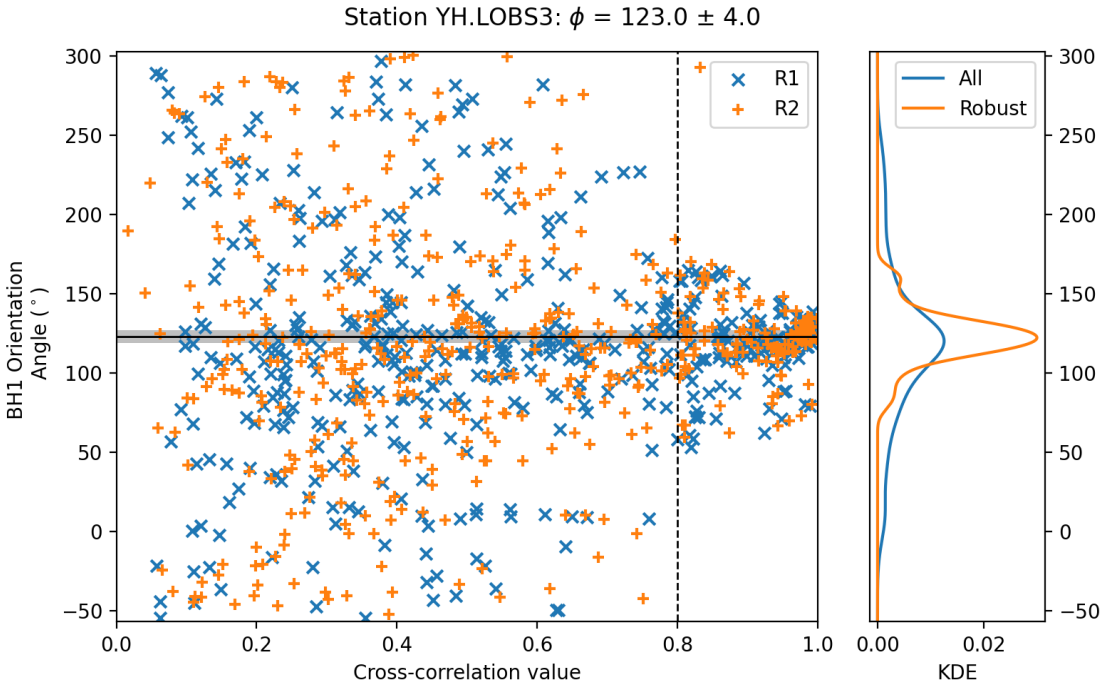
Algorithm:

- For *R* in *R1* (minor arc) and *R2* (major arc):
  - For each period *P* in default range:
    - For each angle $\alpha = \theta + \delta$ increment :
      - Rotate component 1
      - Calculate Hilbert transform of rotated 1
      - Correlate with Z
    - Determine α from maximum cross-correlation

Doran and Laske (2017)

OrientPy implementation (DLOPy)

- Only 1 quality control criterion: cross-correlation value
- Average all orientations for CC > 0.8
- Calculate uncertainty



References

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