



EGU21: Gather Online

Shear wave velocity from inter-source interferometry

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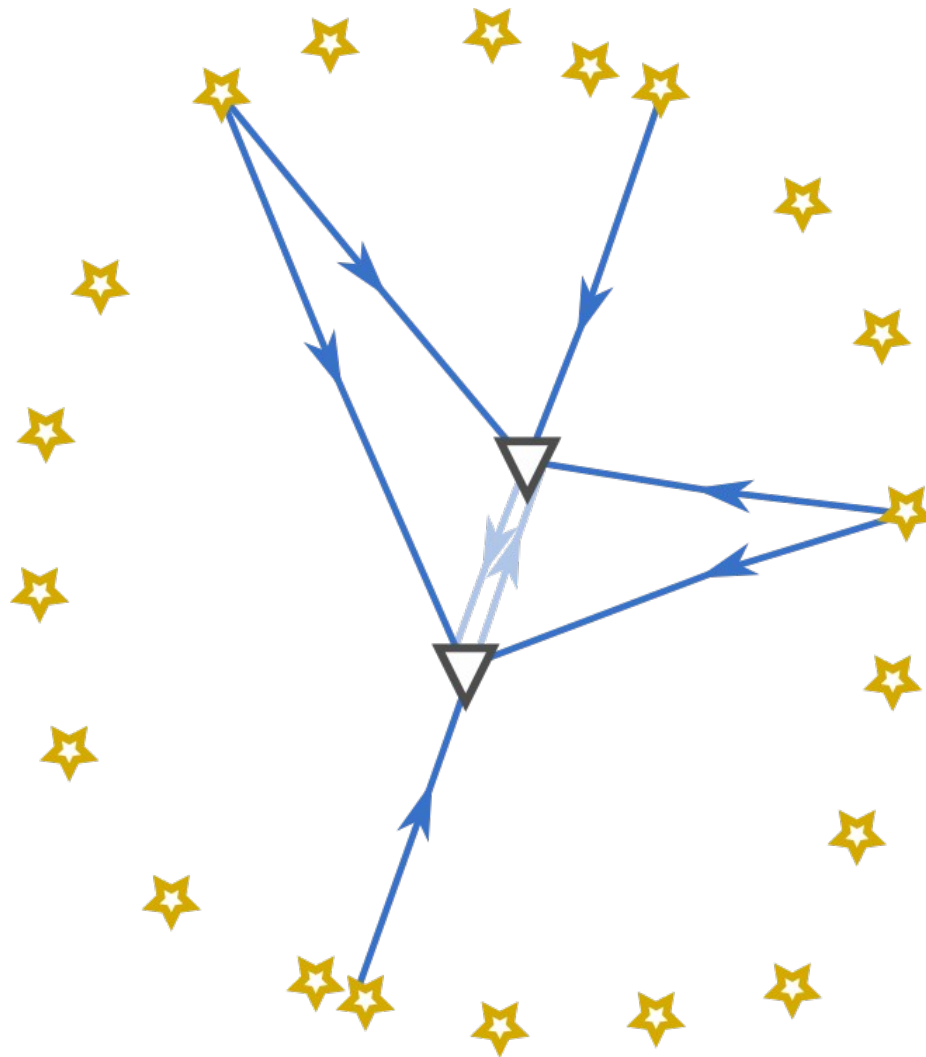
Source code on [Github](#)

Tom Eulendorf
Friedrich Schiller University Jena
Institute of Geosciences

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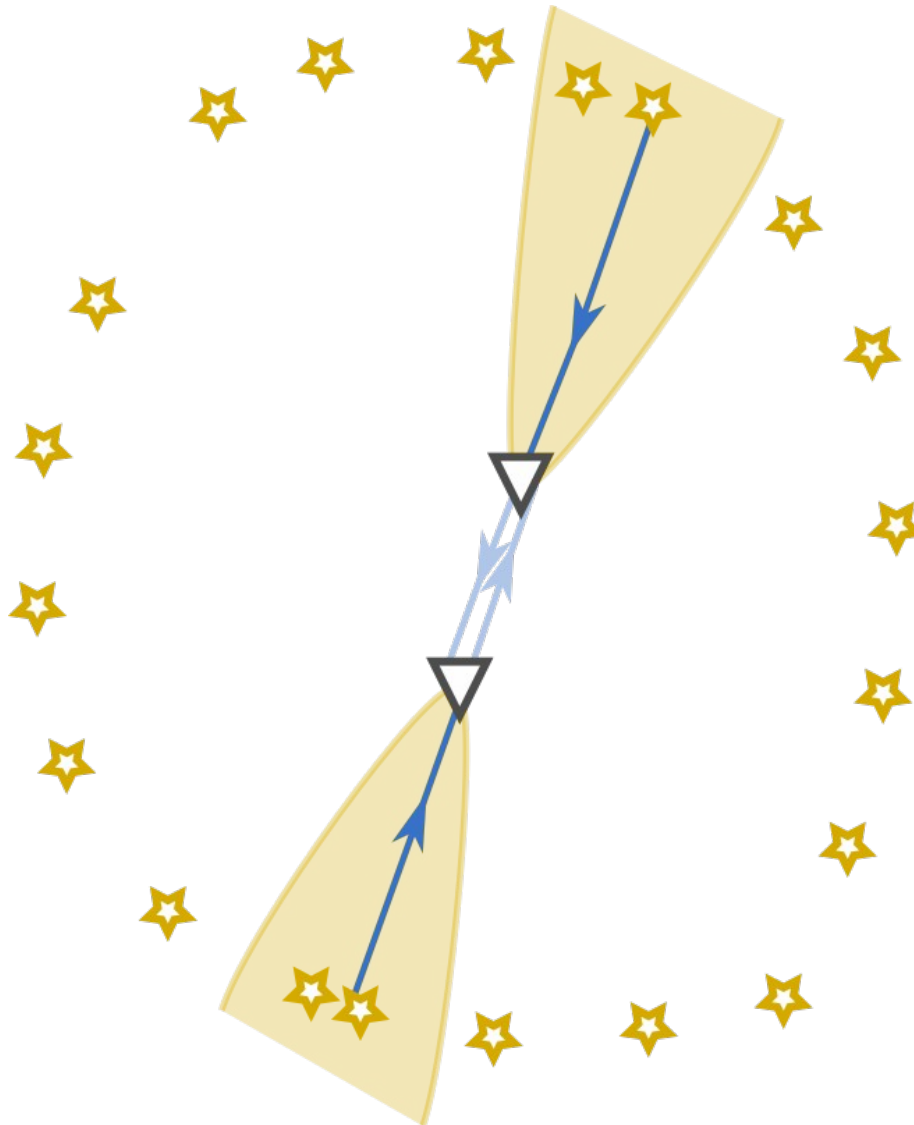
- Introduction to inter-source interferometry
- WEBNET dataset, earthquake (EQ) catalog, processing
- Discussion of different features of inter-event cross correlation (CC) functions
- Results and comparison with classical tomography

Intro: Seismic interferometry with ambient noise



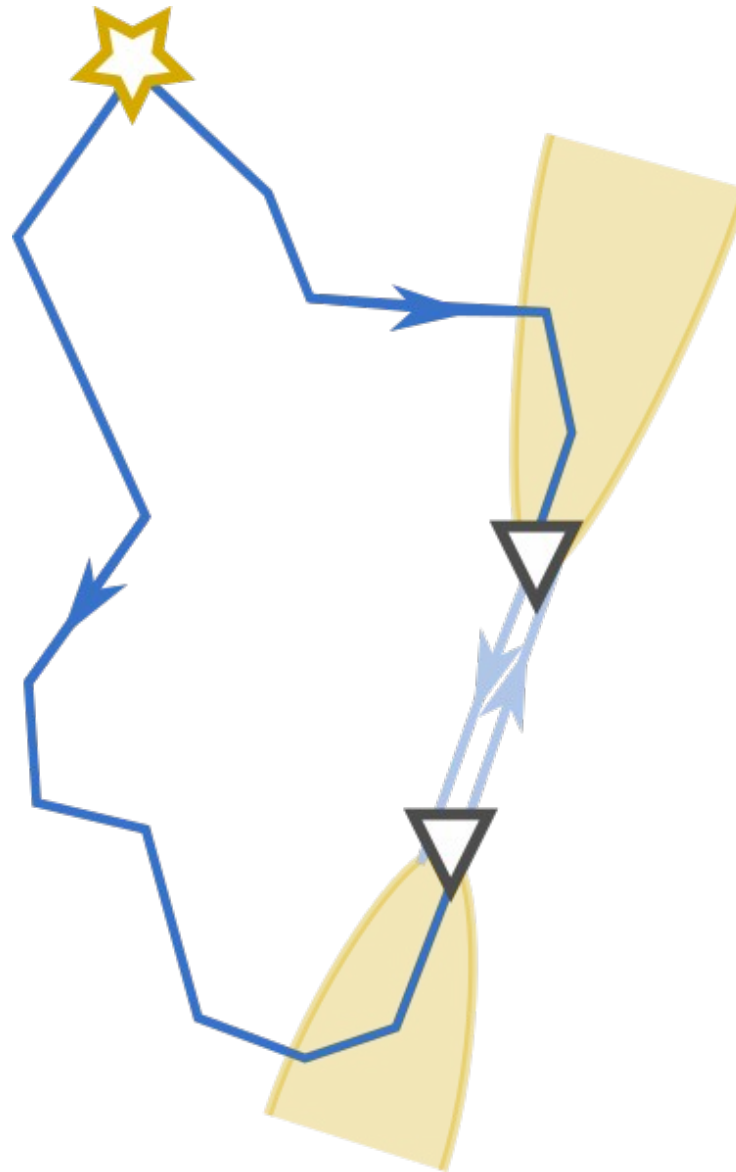
- Green's function from cross-correlation of seismic ambient noise (e.g. Snieder 2004)
- Important: isotropic wave field

Intro: Seismic interferometry with ambient noise



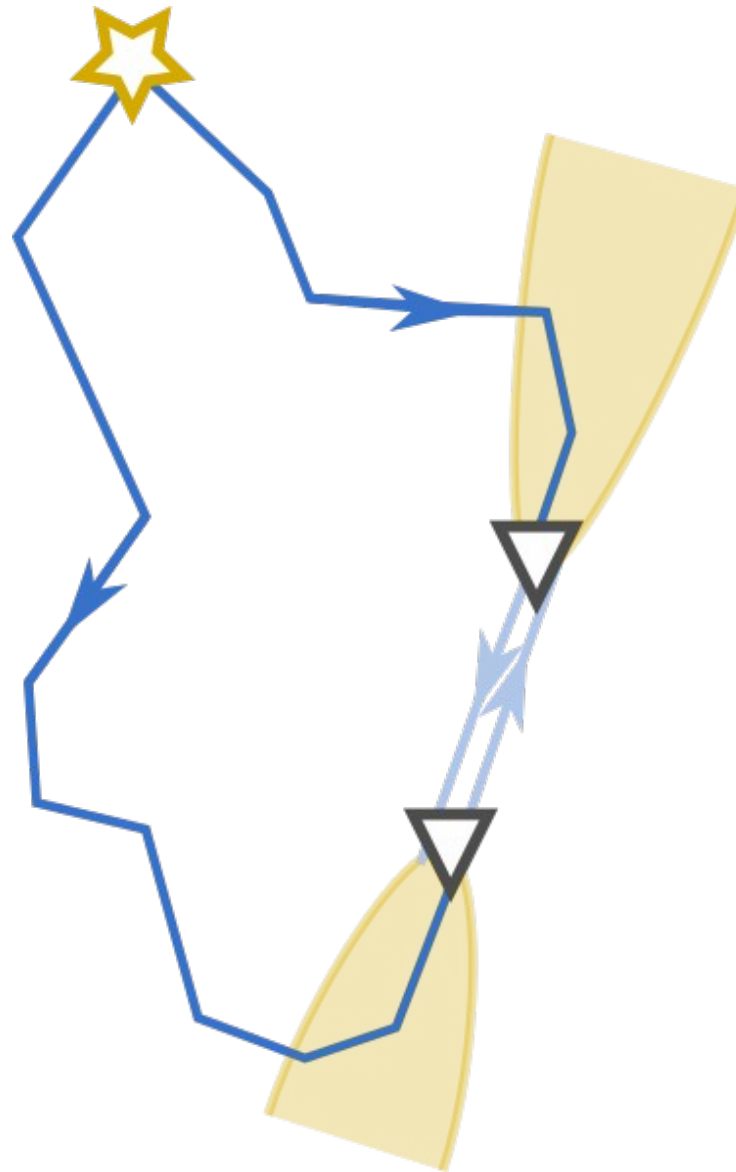
- Green's function from cross-correlation of seismic ambient noise (e.g. Snieder 2004)
- Important: isotropic wave field
- Sufficient for construction of direct wave between receivers: Sources in stationary phase zone

Intro: Seismic interferometry with coda waves



- Use coda wave field instead of ambient noise
- Sufficient for construction of direct wave between receivers: Sources Scatterers in stationary phase zone

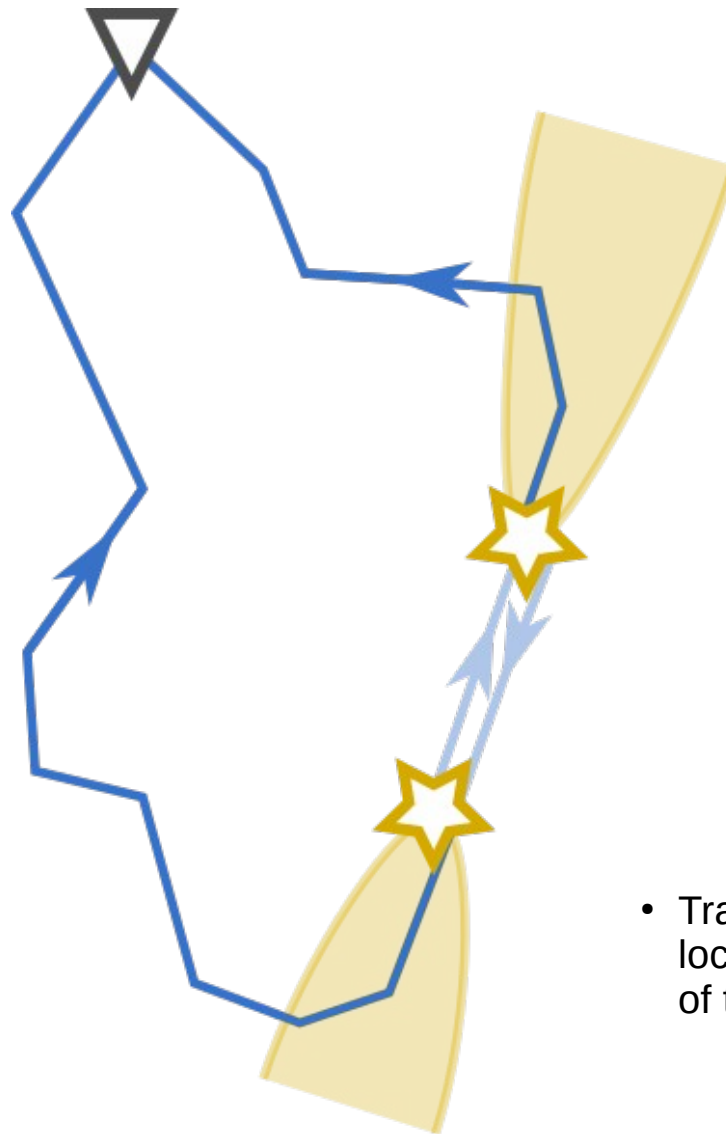
Intro: Seismic interferometry with coda waves



- Use coda wave field instead of ambient noise
- Sufficient for construction of direct wave between receivers:
~~Sources~~ Scatterers in stationary phase zone

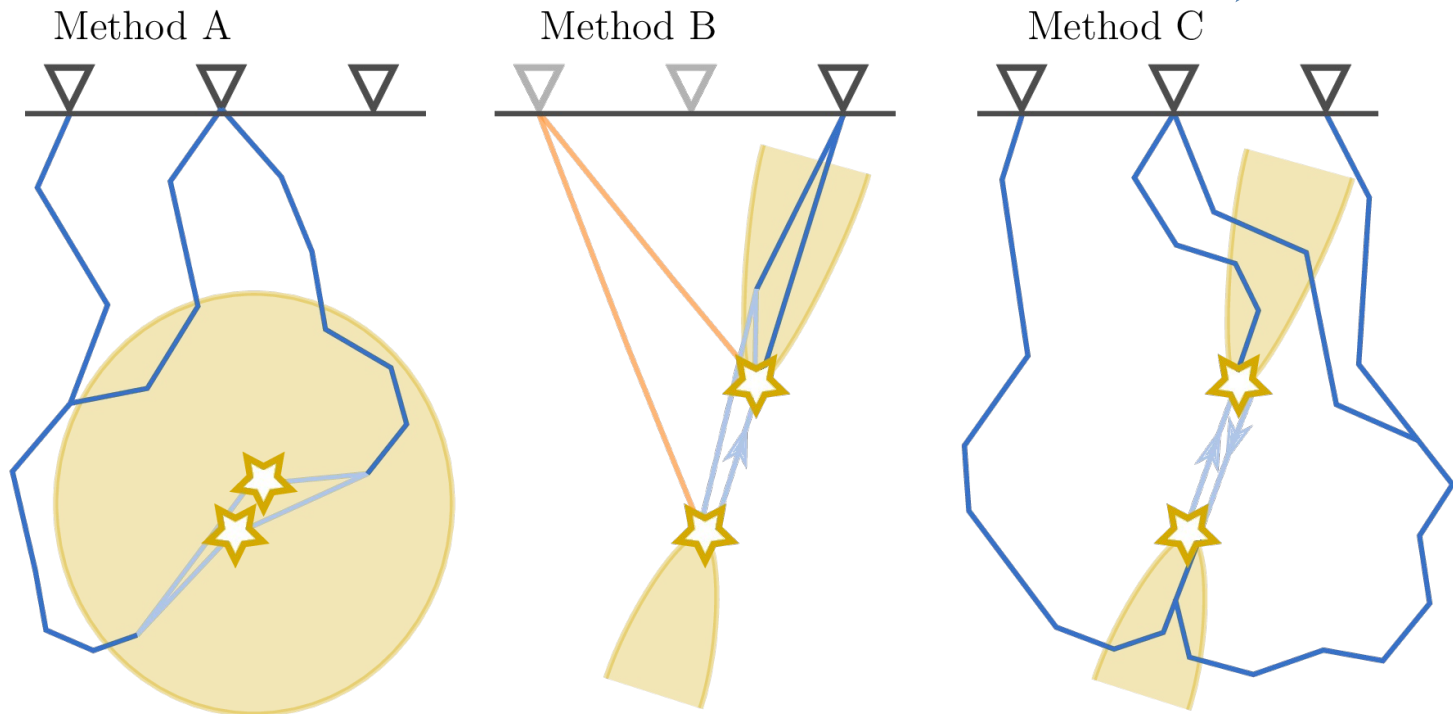
=> Apply reciprocity and exchange receivers and sources

Intro: Inter-source interferometry with coda waves



- Travel time between earthquake locations from cross-correlation of the coda wave fields

Intro: Inter-source interferometry – 3 different methods

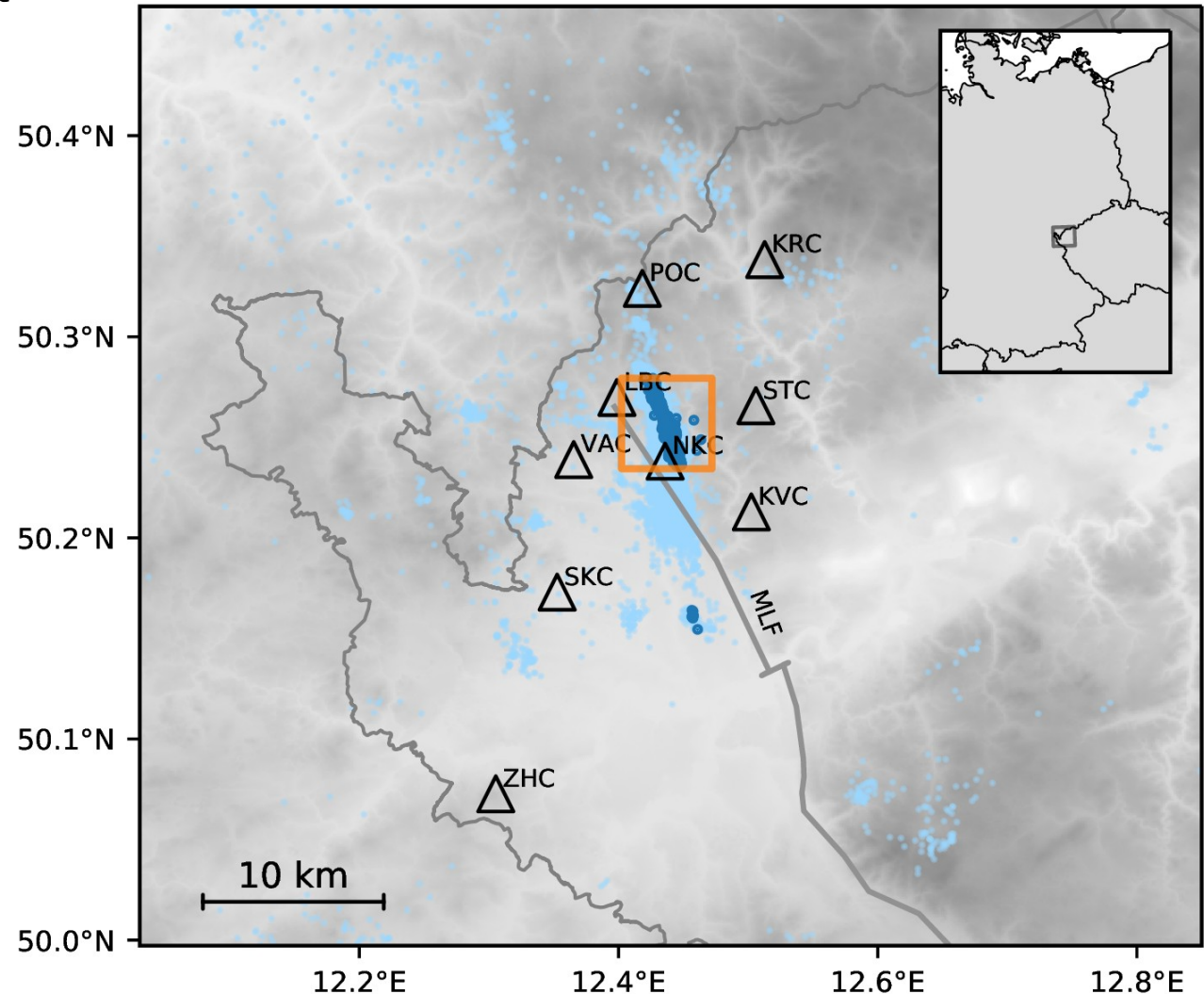


Method	Decorrelation of coda waves of nearby events	Cross-correlation of surface waves, direct P or S wavelet in stationary phase zone	Cross-correlation of inter-event coda waves
Event separation	Smaller than dominant wavelength	Larger than dominant wavelength	Larger than dominant wavelength
Station constraints	None, single channel can be used	Need to be located in stationary phase zone	None, stacking over several stations often necessary
Studies	Snieder and Vrijlandt (2005); Robinson et al. (2011, 2013); Zhao et al. (2017); Zhao and Curtis (2019)	Curtis et al. (2009); Tonegawa and Nishida (2010); Shen and Zhan (2020), this study (using all stations)	Sun et al. (2016), this study

Earthquake swarms in Czech-German border region

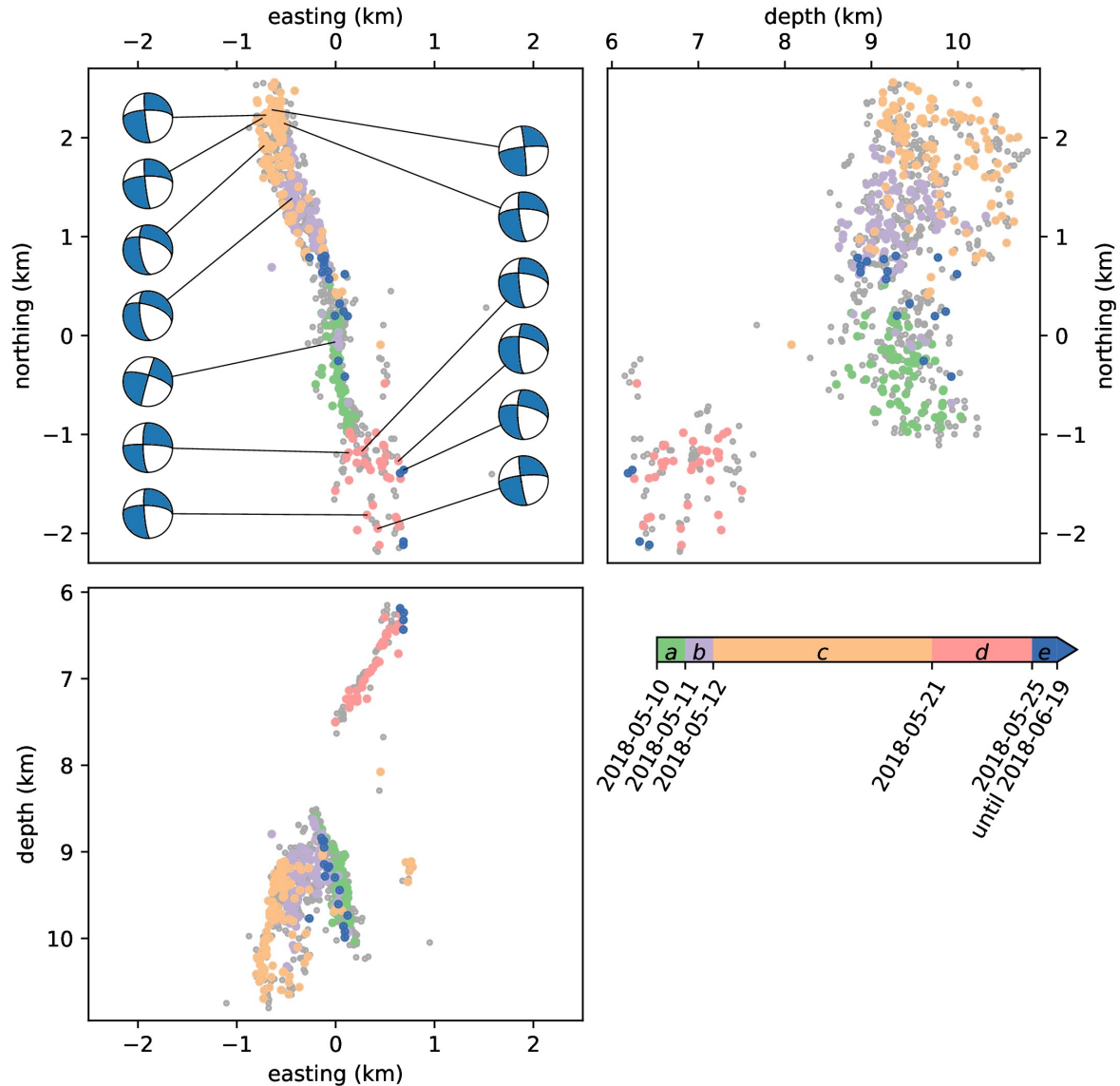
WEBNET dataset

- Light blue: WEBNET EQ catalog
- Dark blue: 2018 EQ swarm
- Data from 9 WEBNET seismic stations with 250 Hz sampling rate
- Dataset available on zenodo

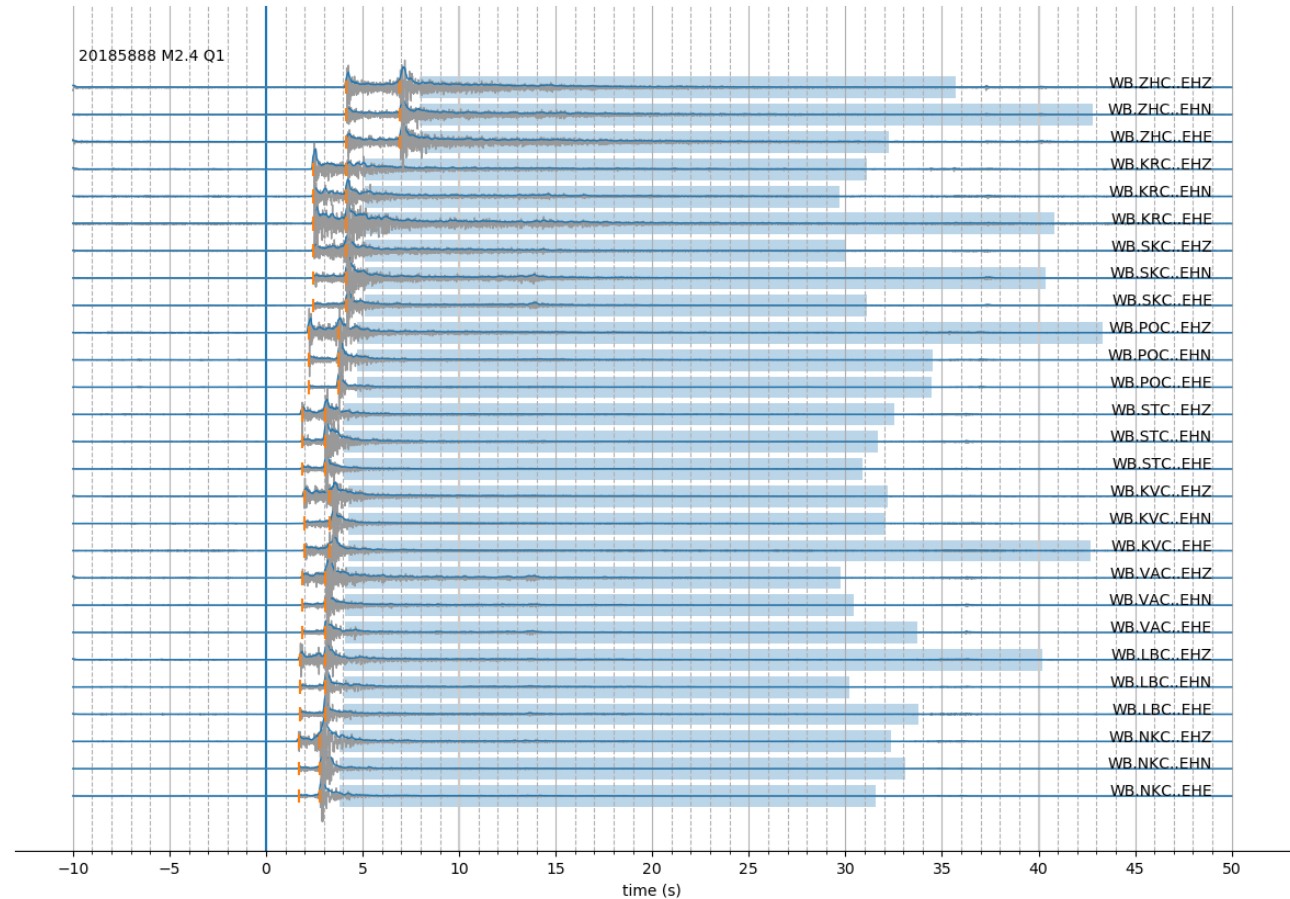
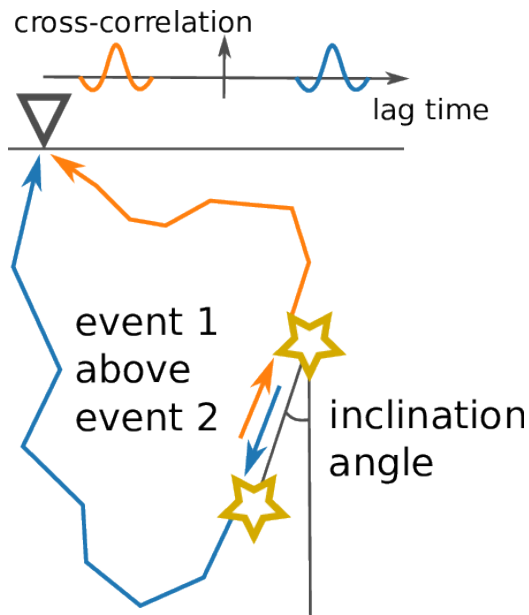


5 clusters in 2018 West Bohemia earthquake swarm

- Double difference EQ catalog from Martin Bachura
- Focal mechanisms from Laura Barth & Thomas Plenefisch
- Divide 2018 swarm into 5 temporal clusters with low spatial overlap

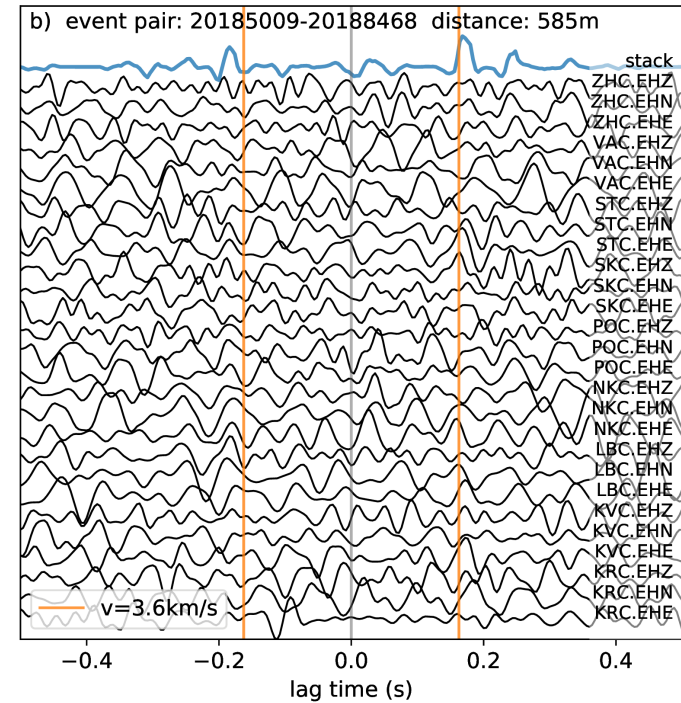
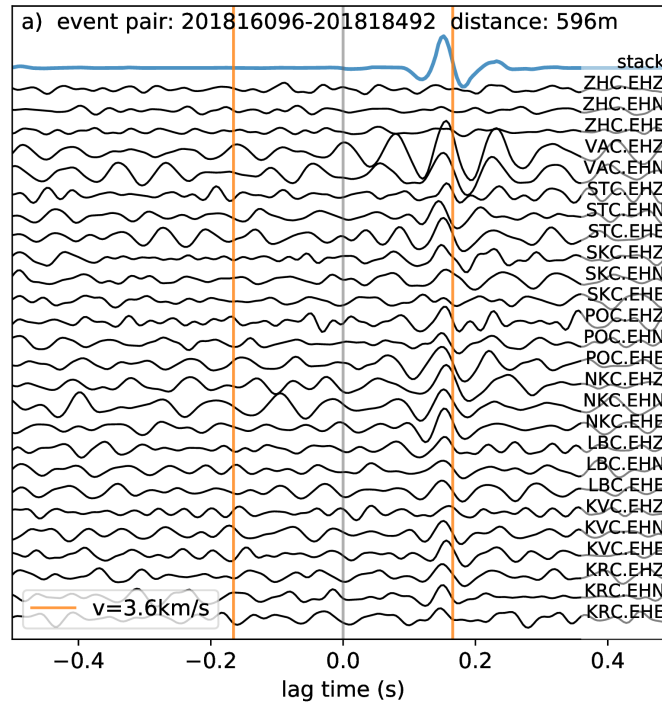
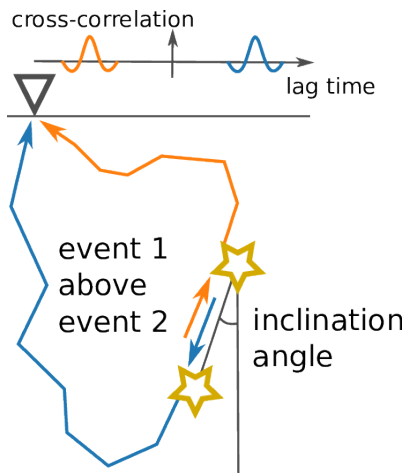


Processing



- Filter between 10 and 40 Hz
- Select coda window for different events, normalize by envelope to account for intrinsic loss
- EQ pair: align with origin times, overlap of coda window for each channel defines window for CC
- Phase weighted stack of CCs of different channels => 1 CC for each EQ pair

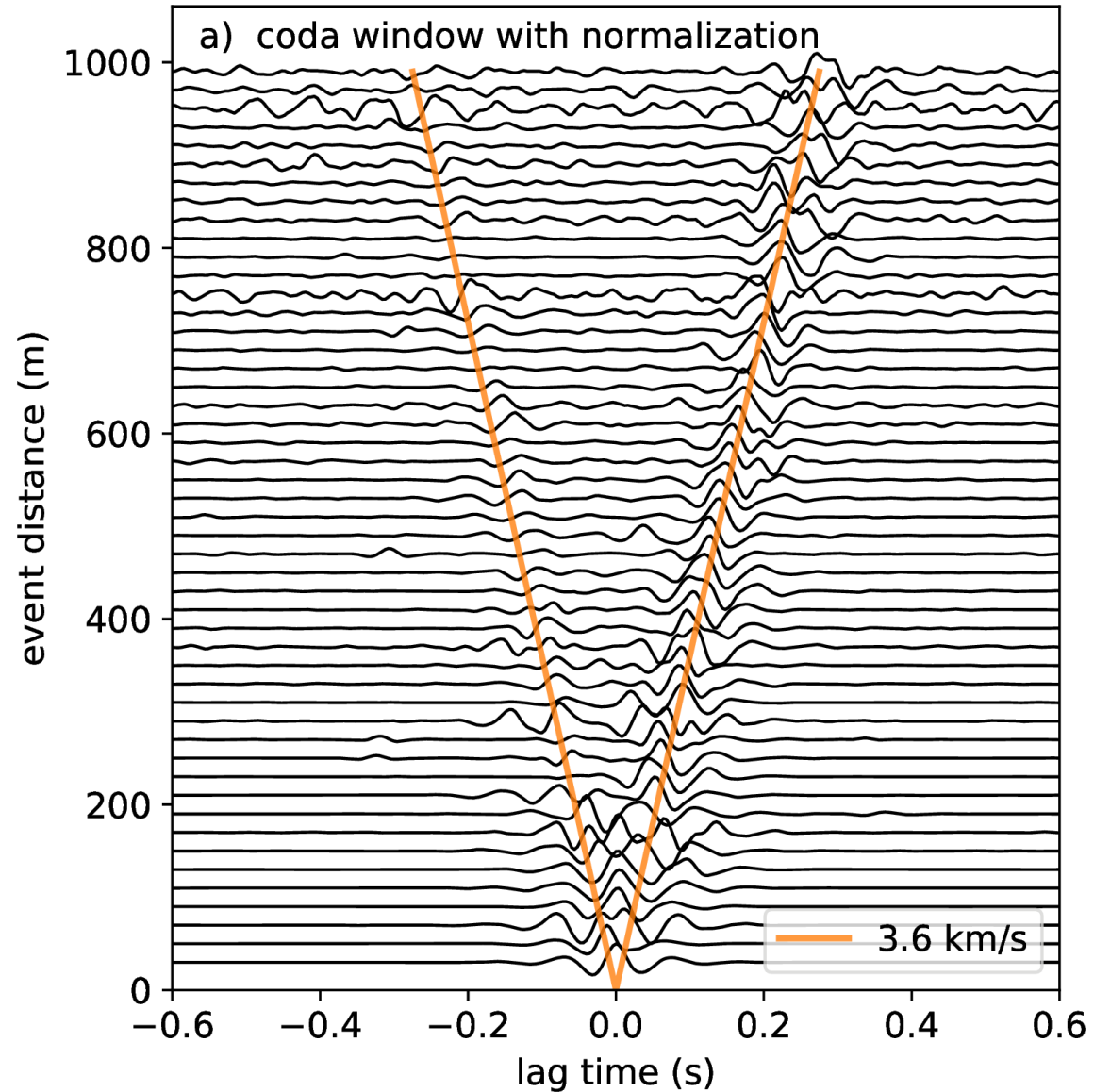
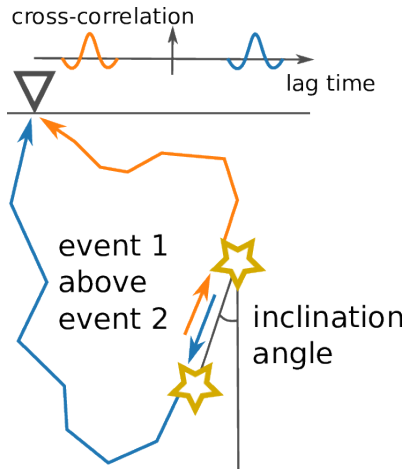
Inter-source cross-correlation for two different event pairs



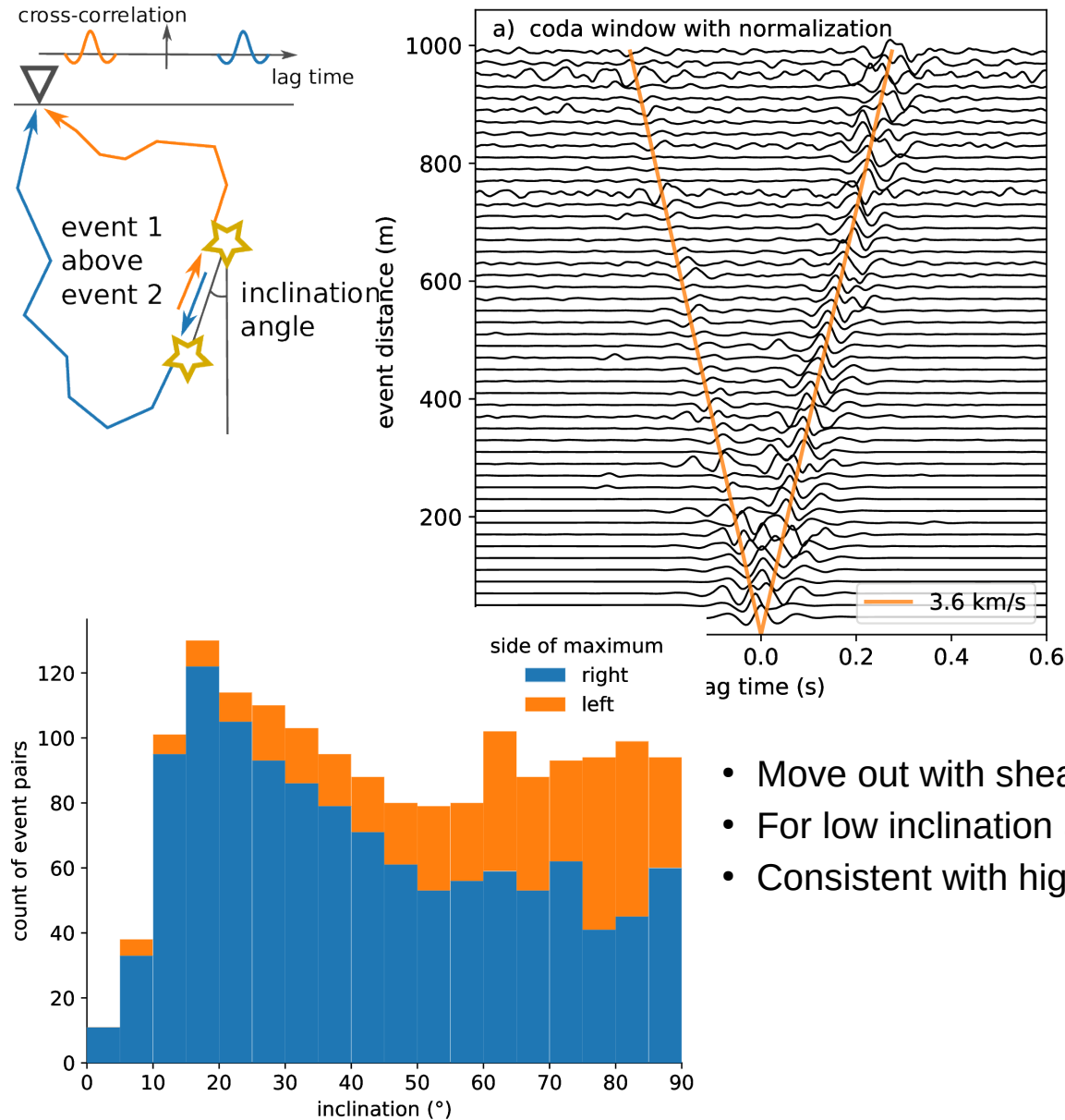
- Left example: clear inter-source arrival for each channel
- Right example: clear inter-source arrival only for phase weighted stack
- Peak in CC function at expected travel time of shear wave
- Travel time is simply the absolute time of the maximum. Errors are introduced by the difference of errors in origin time of first and second event and by a possible inhomogeneous scatterer distribution in the stationary phase zone:

$$t_{\max} = t_{\text{travel}} \operatorname{sgn}(t_{\max}) + \Delta t_{0,1} - \Delta t_{0,2} + \delta_{\text{err}}$$

Inter-source cross-correlation stacked by event distance

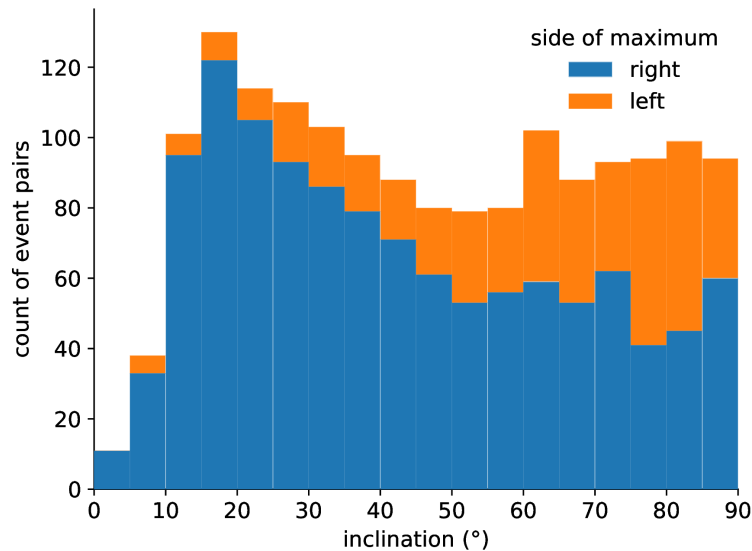
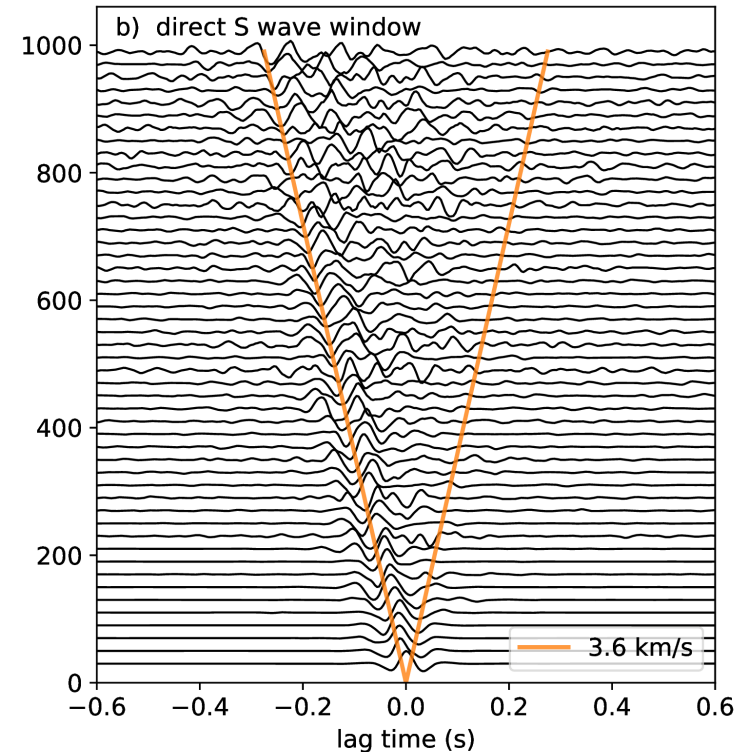
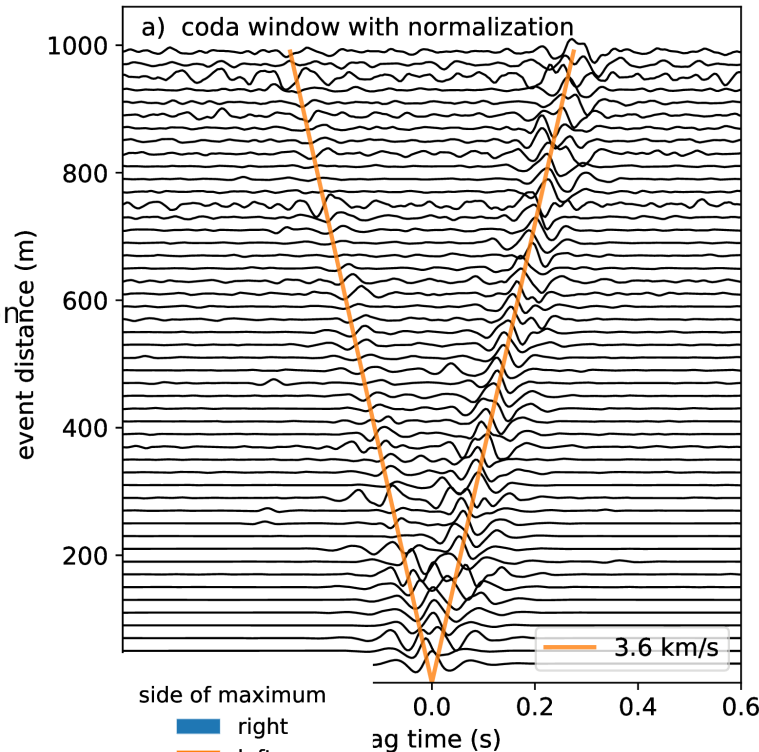
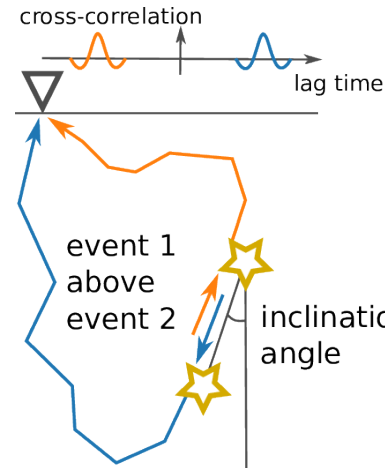


Inter-source cross-correlation stacked by event distance



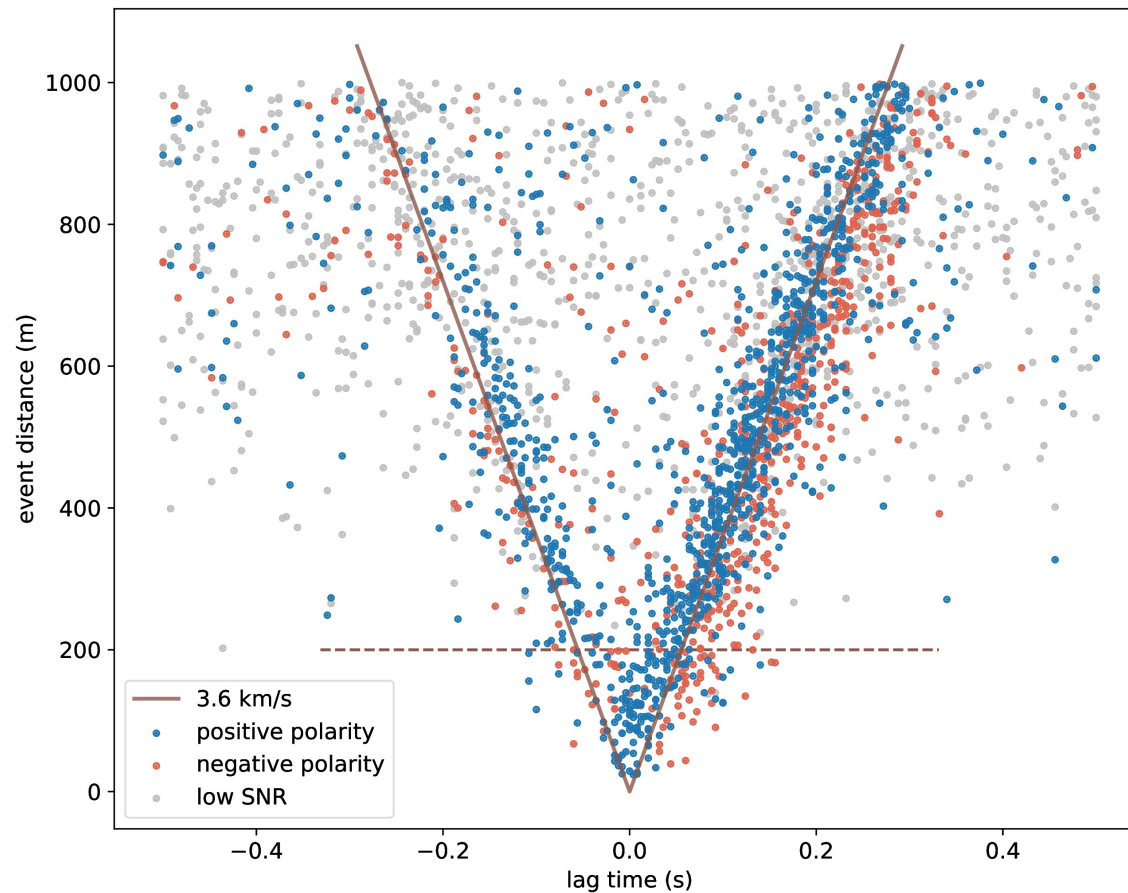
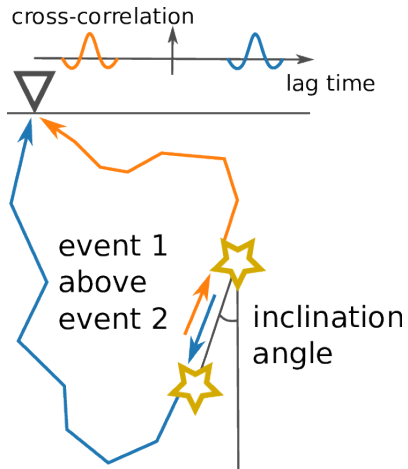
- Move out with shear wave velocity
- For low inclination angles mostly peaks on right side of CC
- Consistent with higher intrinsic attenuation in upper crust

Inter-source cross-correlation stacked by event distance



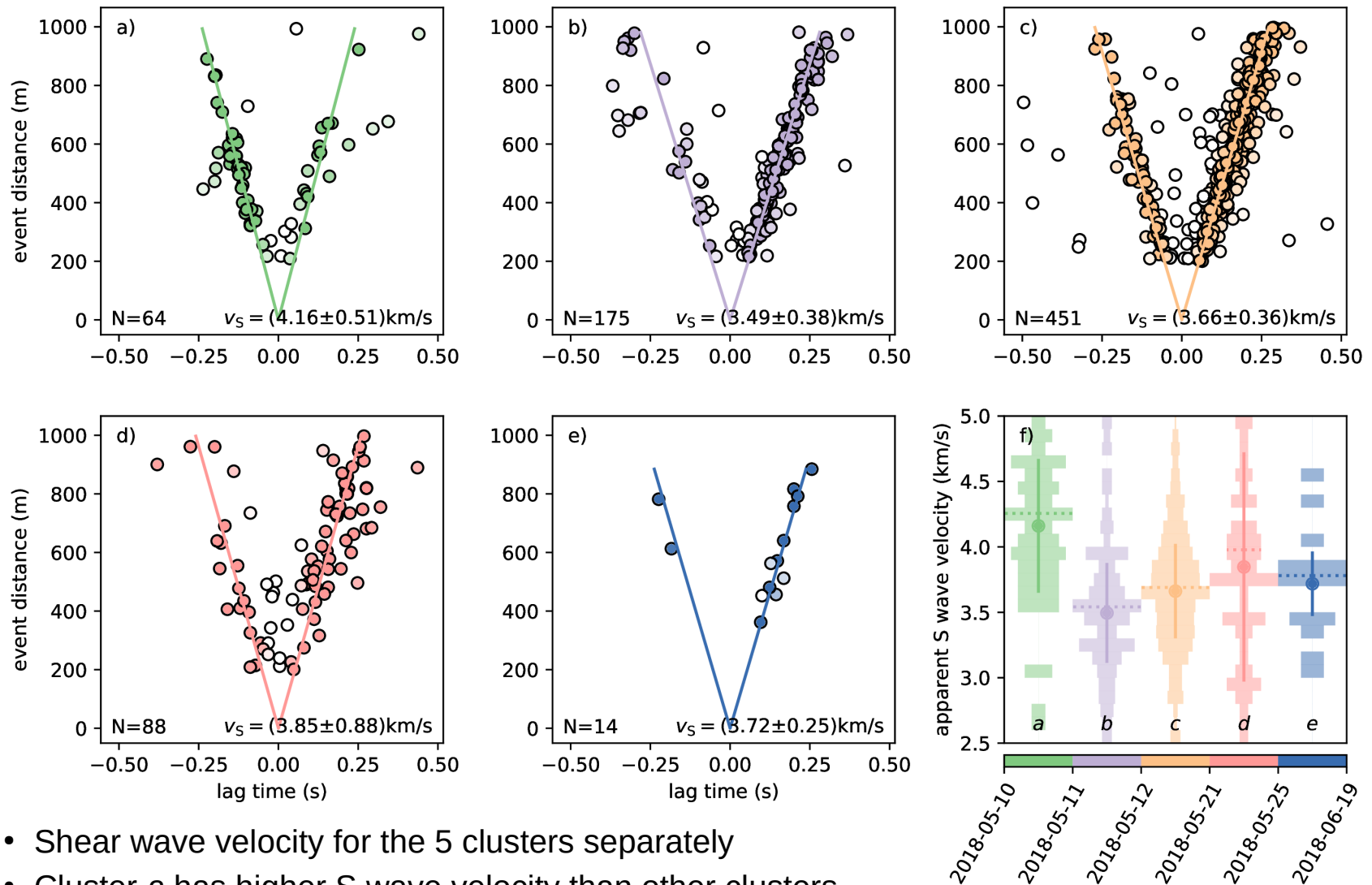
- Move out with shear wave velocity
- For low inclination angles mostly peaks on right side of CC
- Consistent with higher intrinsic attenuation in upper crust
- Comparison with inter-source interferometry of direct S wave window (method B) --> method C is superior for this data set

Maxima of inter-source cross-correlation for each event pair



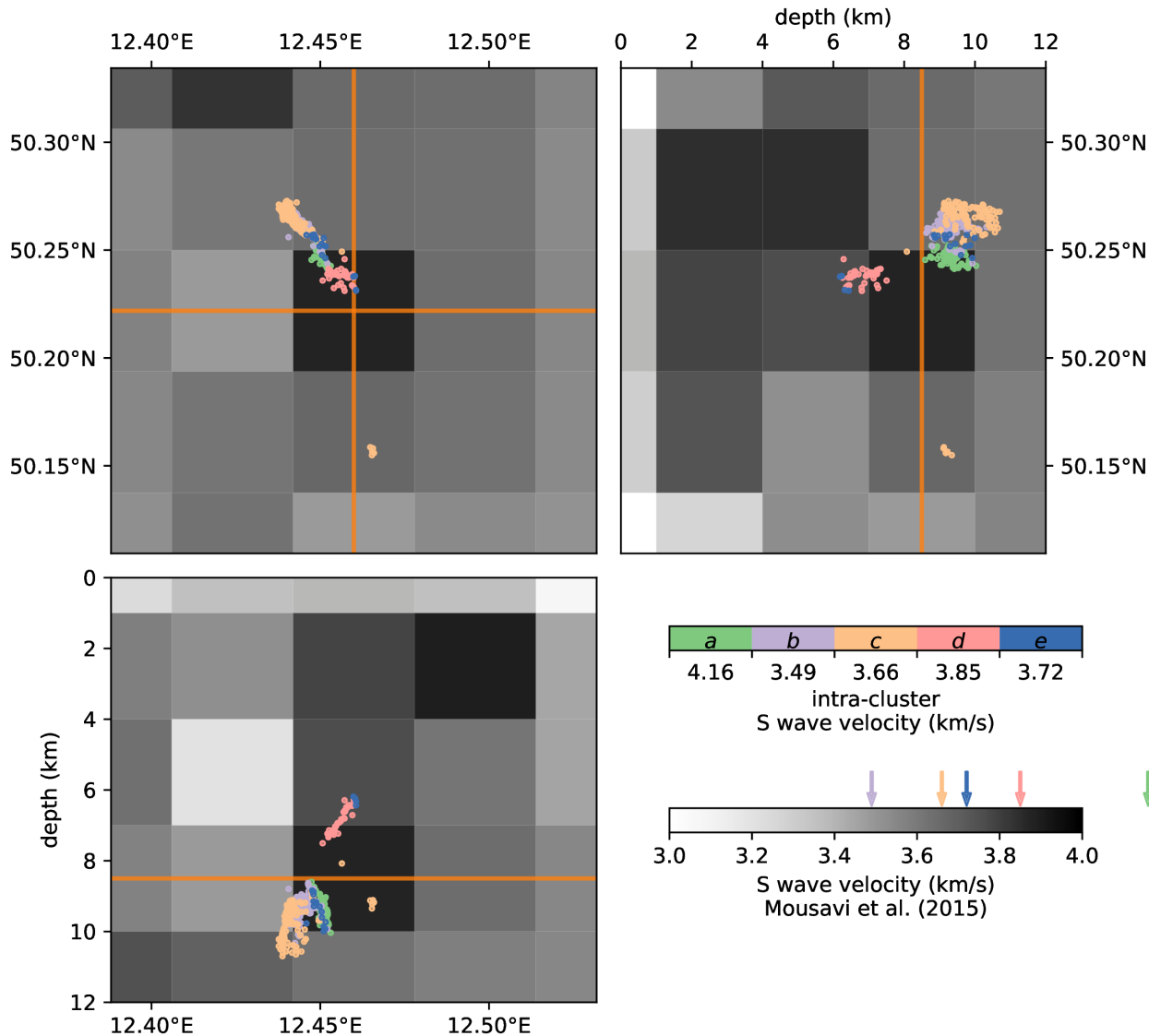
- Maxima with negative polarity (minima) often occur after expected travel time of shear wave
- Reason not completely clear, but it is desirable to only use maxima with positive polarity

Intra-source shear wave velocity for 5 clusters



- Shear wave velocity for the 5 clusters separately
- Cluster a has higher S wave velocity than other clusters
- High uncertainty, probably due to errors in catalog origin times and locations
- But: These errors are not systematic

Comparison to seismic tomography



- Comparison with tomography of Mousavi et al. (2015)
- Cluster a with high velocity consistent with high velocity box of tomography model
- Enhanced resolution (1 km) compared to classical tomography (3 km)
- Idea: Use inter-source interferometry together with direct arrivals to invert for origin times, locations and velocity grid (resolution will be further enhanced < 200m)

Summary

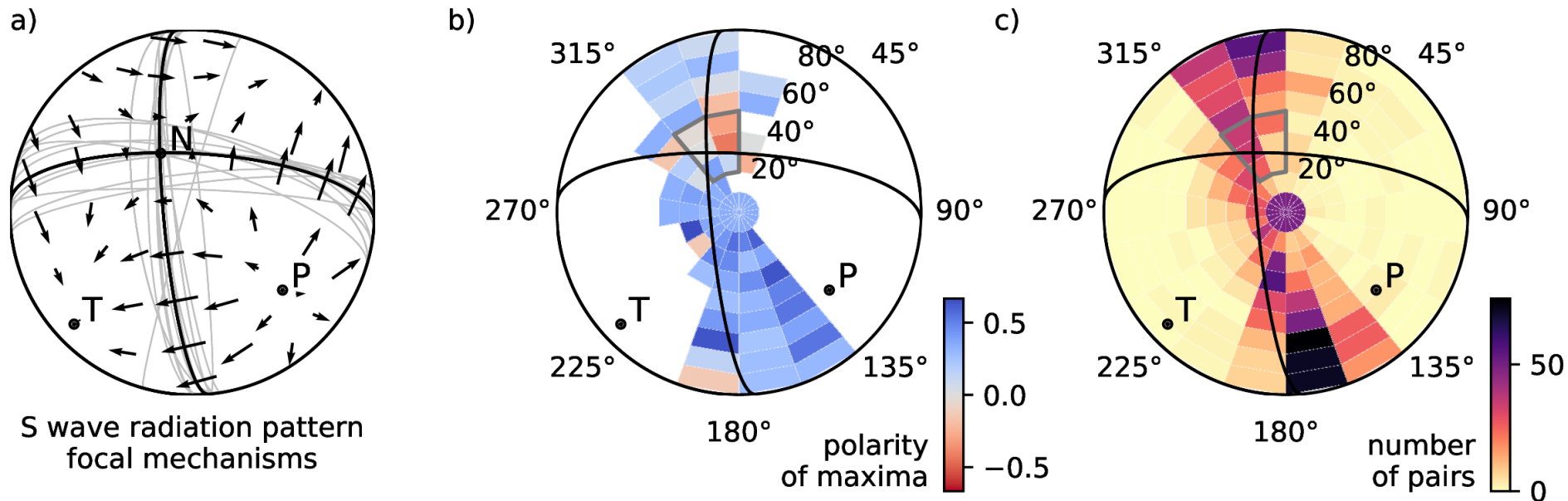
- Shear wave travel times between earthquake locations from cross-correlations of coda waves
- Spatial variability of seismic velocity at region of 2018 earthquake swarm
- Enhanced spatial resolution compared to classical tomography
- Idea: Use the method in a tomographic inversion and map the shear wave velocity in the source region with unprecedented resolution
- Influence of attenuation properties and location of the maxima in the cross-correlation functions was discussed
- Influence of focal mechanisms on the polarity of maxima was *not* yet discussed

Some references

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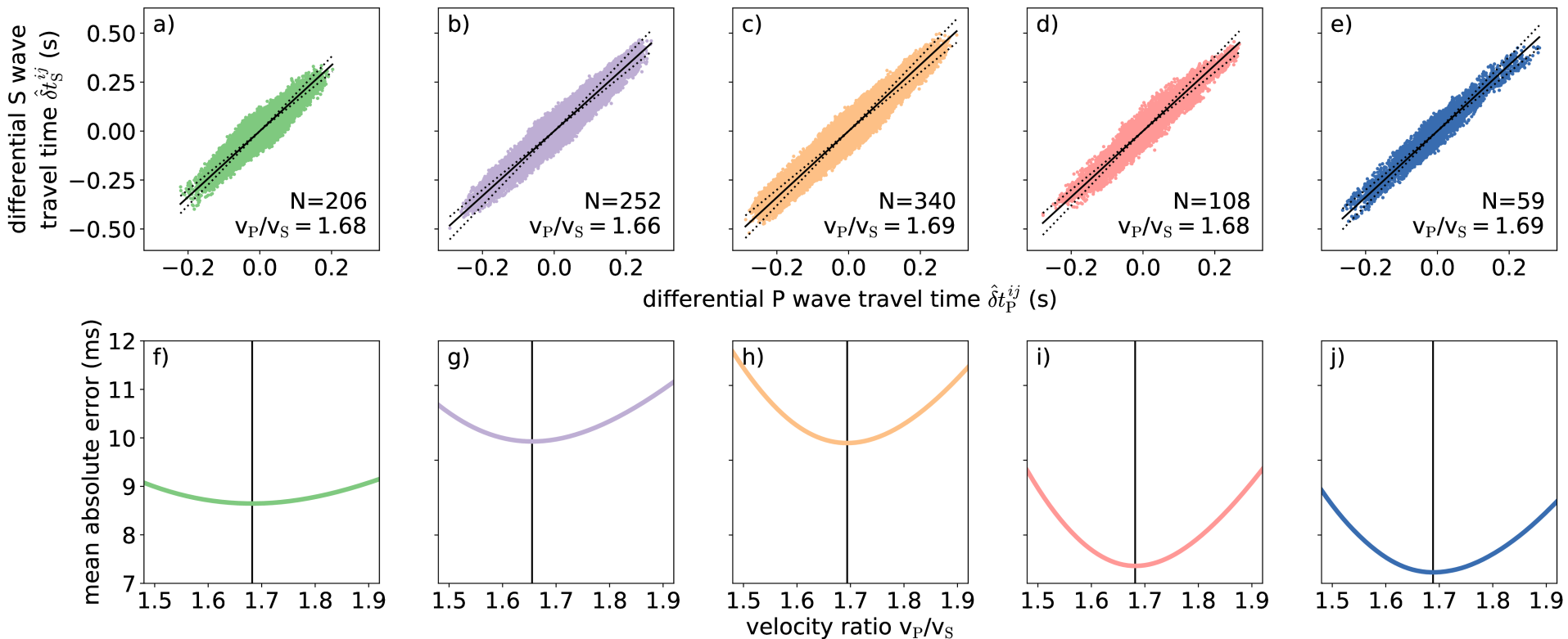
Appendix: S wave radiation pattern and polarity of maxima

Polar plots with axes: inter-event azimuth and inclination of event pairs



- When do we expect minima in the CC function? => Polarity of radiation pattern in inter-source direction can be different.
- For same focal mechanisms of the two EQ: always expect positive polarity
- For *similar* focal mechanisms of the two EQ: expect positive polarity for most situations
- Problem near P, N and T-axis: different S wave polarity even for similar focal mechanisms => exclude these situations in the analysis (gray polygon)

Appendix: Intra-source vp/vs constant for 5 clusters



- Similar v_P/v_S ratio of ~ 1.7 for 5 clusters from double difference arrivals, consistent with previous observations (Malek, 2005)
- Method of Lin & Shearer (2007), applied in Dahm & Fischer (2013) and Bachura & Fischer (2016)