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Optimised workflows for high-frequency seismic interferometry using dense arrays

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Questions to answer

What is the optimal workflow for high-frequency ambient noise imaging?

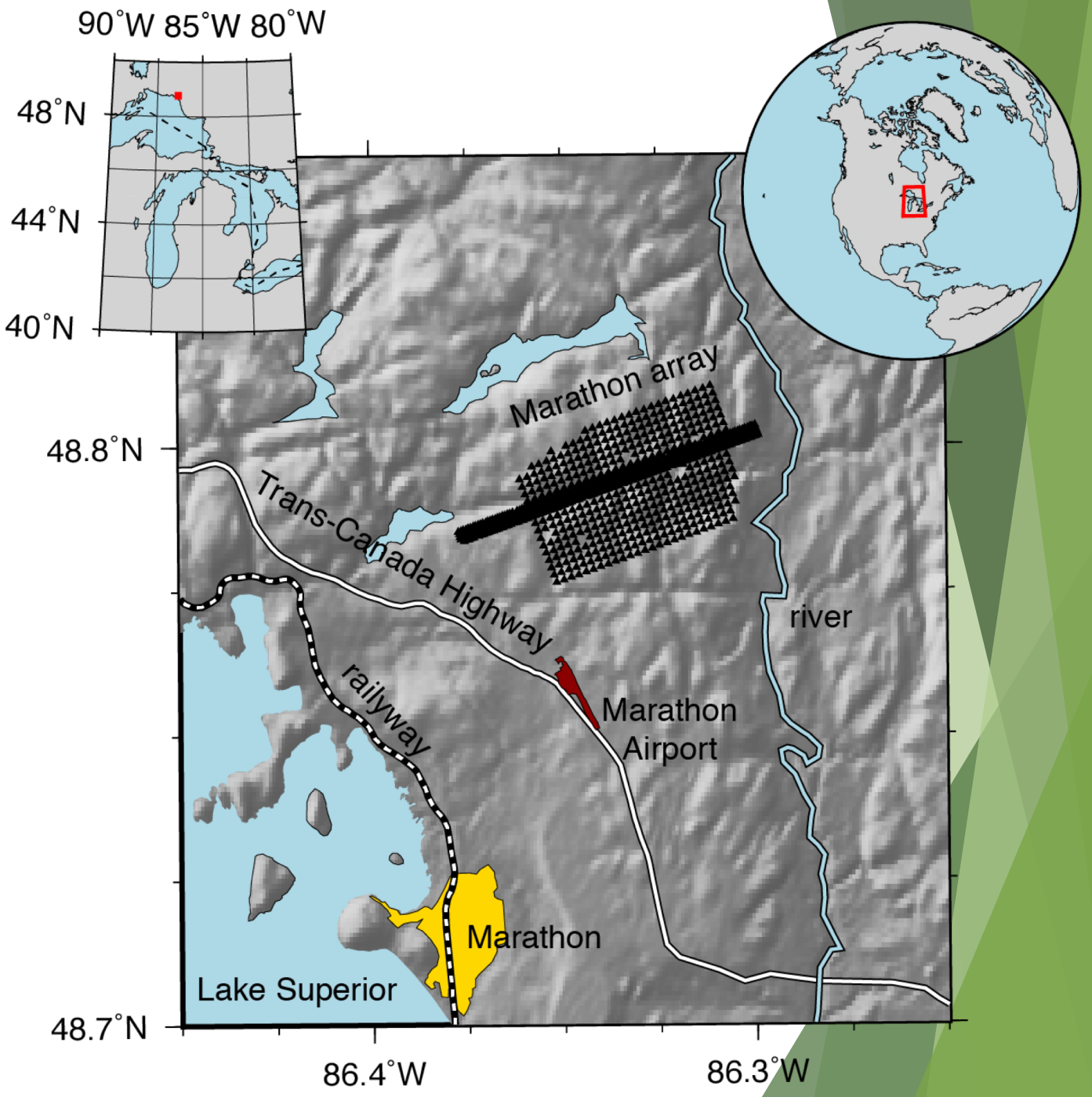
Using the Marathon dataset from a ”Large-N” array in Canada, we assessed the following aspects

- Noise cross-correlation
- Phase velocity measurement
- Quality control

Marathon array

- 1024 nodes
- **Rectangular array**
  - **414 nodes**
  - **150 m spacing**
- Fat line array (not used in this study)
  - 610 nodes
  - 50 m spacing

We use the rectangular array for all the following experiments



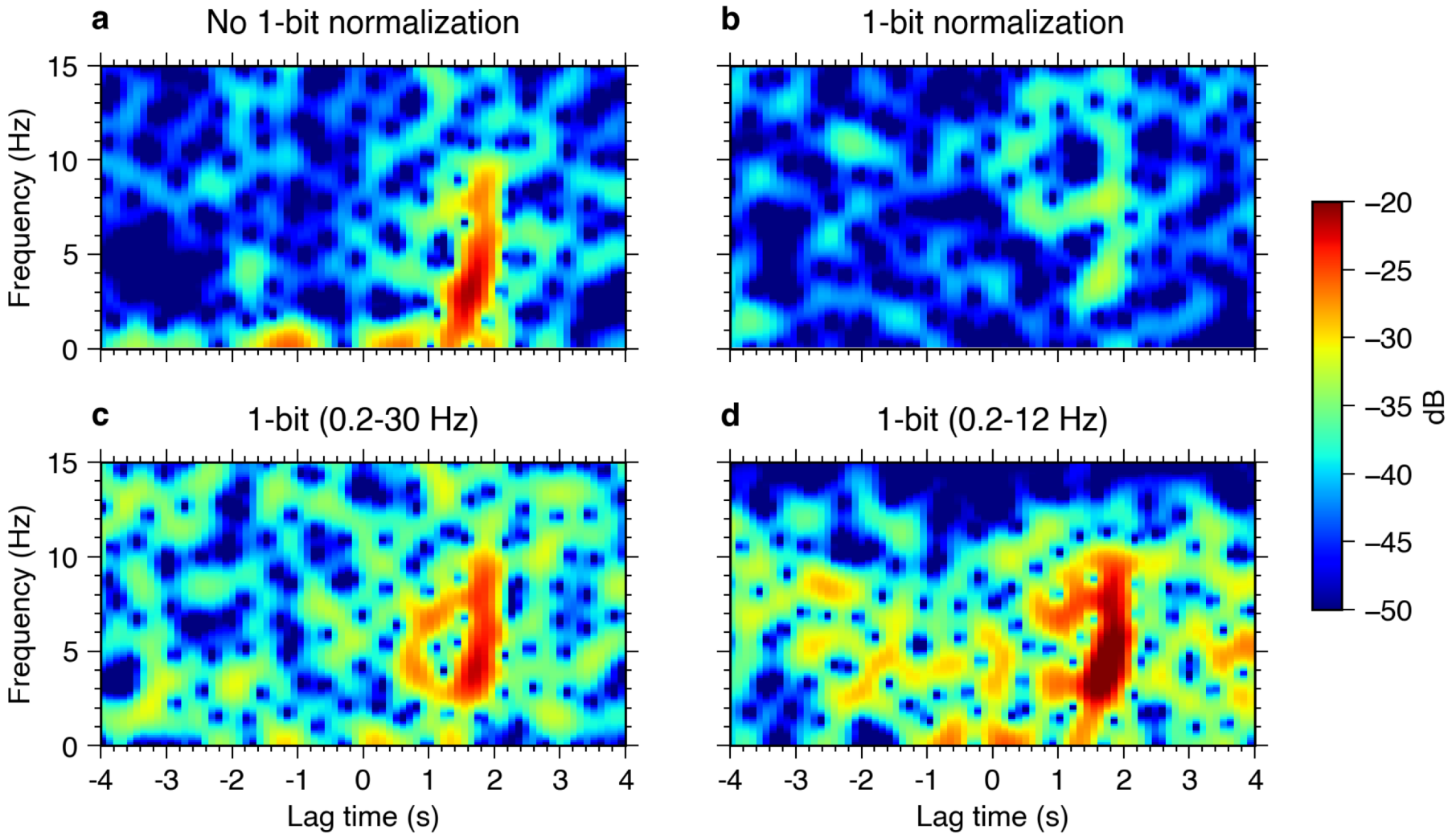
Noise cross-correlation

1-bit normalization

->

short segment stacking

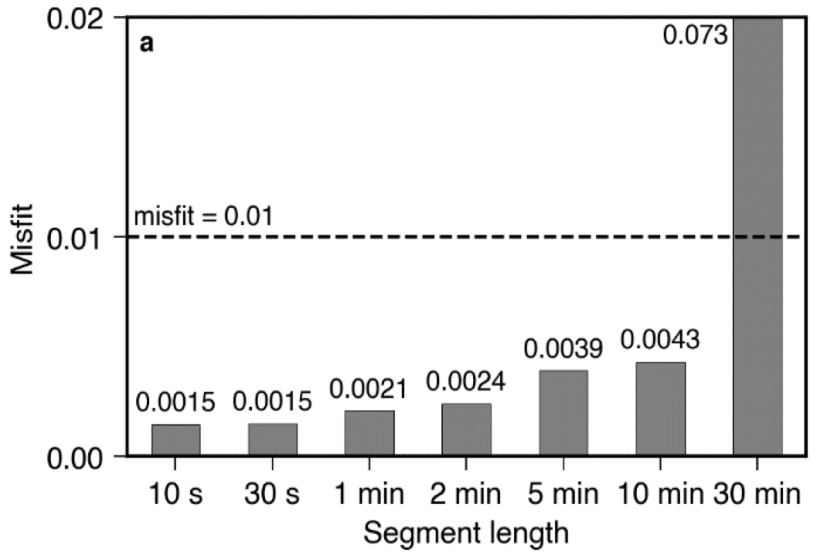
Cross-correlations without one-bit normalization is better than those with one-bit normalization (no matter if bandpass filters are applied or not)

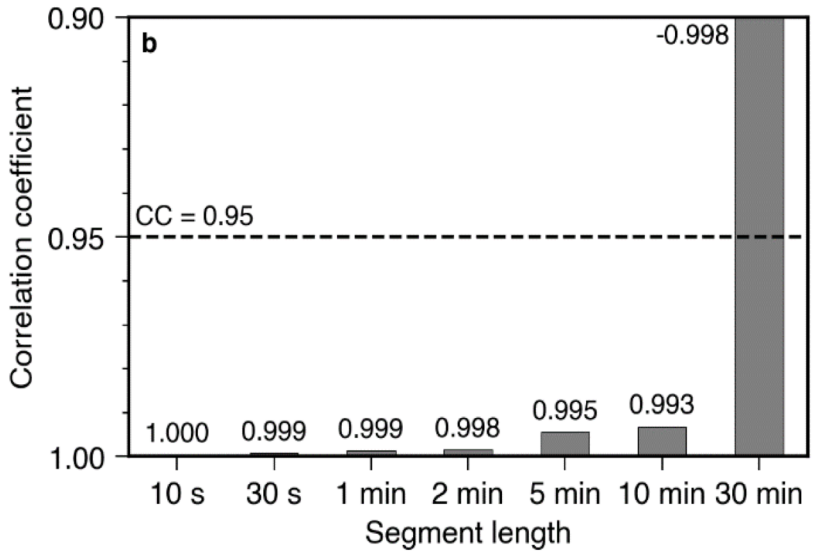


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optimal segment length

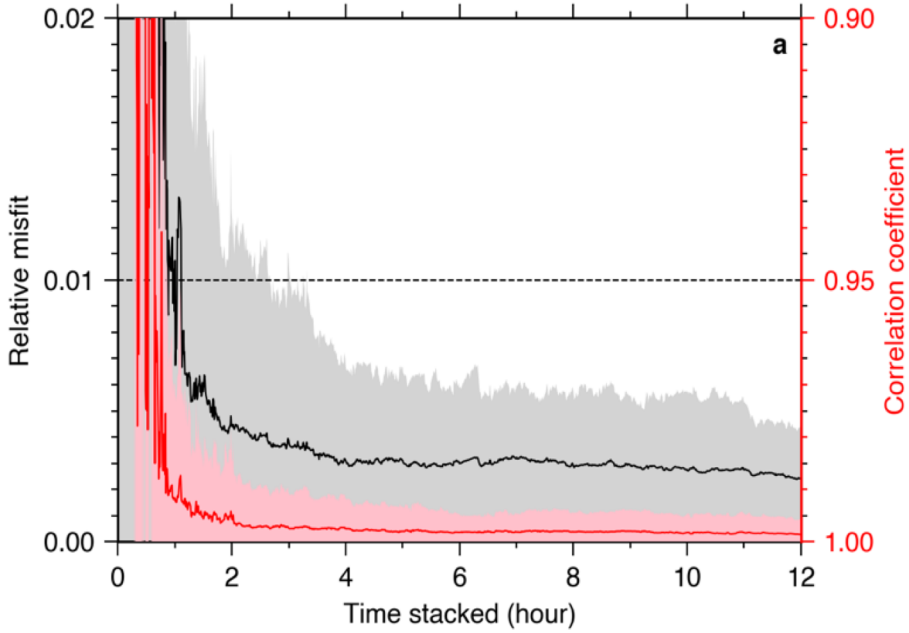
1. *Shorter segments give better dispersion curves**
2. *Fortunately, a wide range is acceptable (10 s-10 min)*

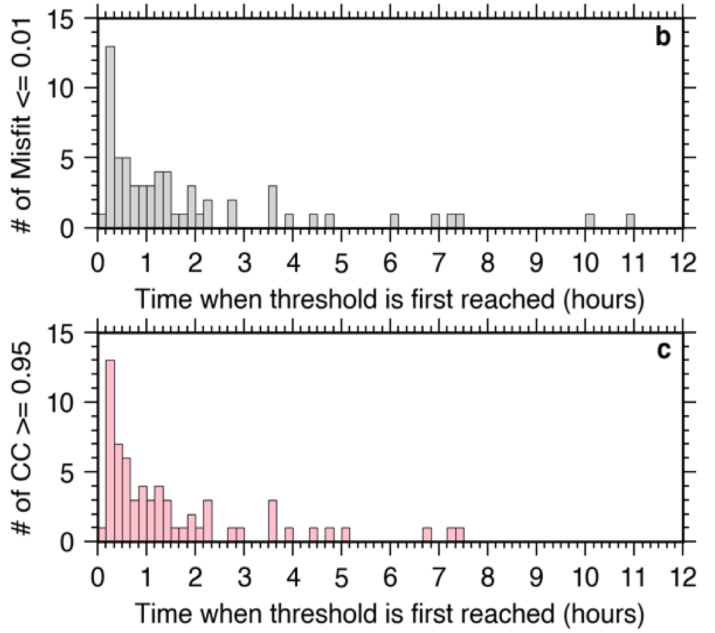




Convergence of NCFs

1. *Convergence varies greatly (from 10 min to 11 hours)*
2. *In general, 1-3 hours are sufficient for obtaining high-quality dispersion curves.*

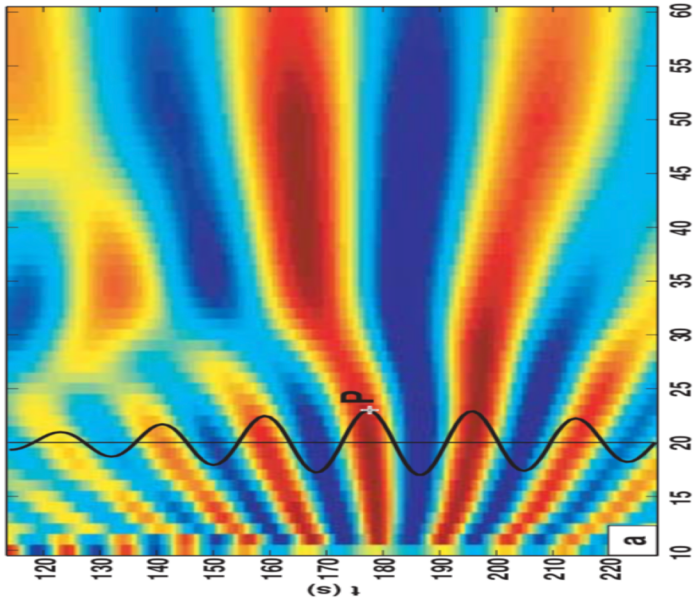




* *The quality of dispersion curves are measured against a reference curve from the one-month stack NCF.*

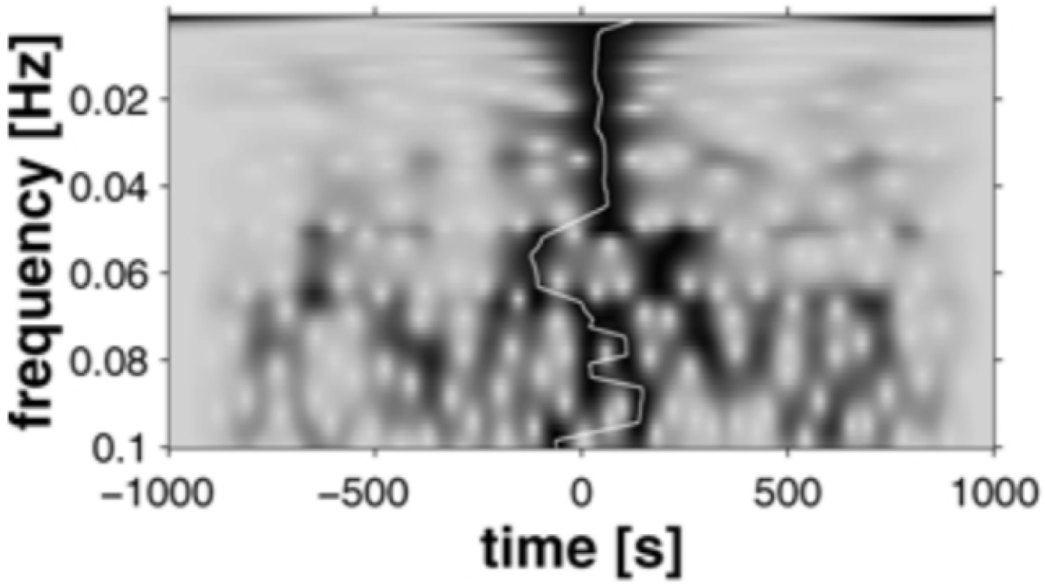
2π ambiguity problem and its solutions

One continuous peak



Modified from Yao et al. (2006)

Multiple peaks



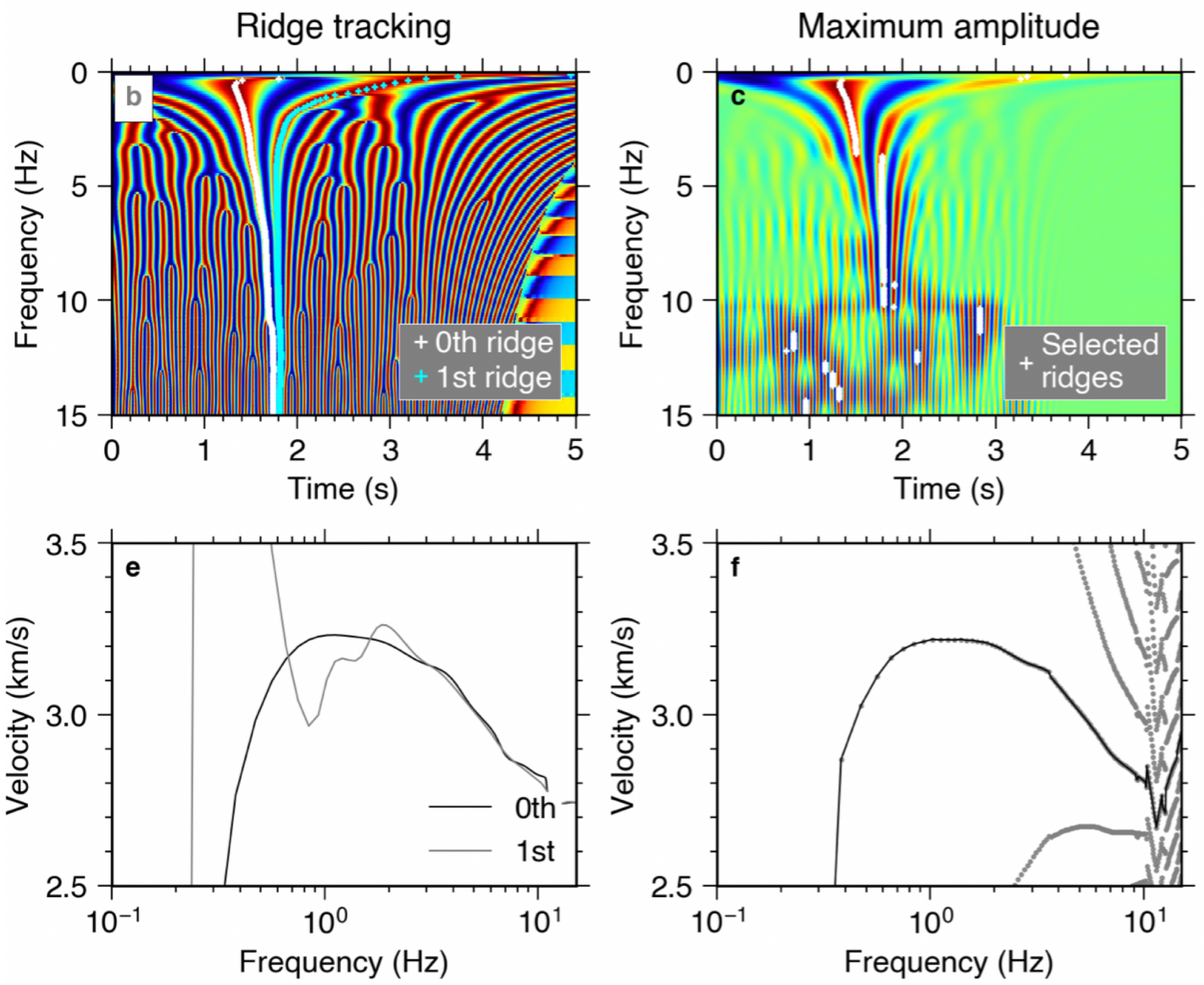
Meier et al. 2004

The 2π ambiguity problem refers to the multiple options in waveform peaks, whose arrival time is then converted to phase velocity
One common solution is to select the peak associated with correct phase travel time.
Another solution is to combine measurements from multiple peaks.

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Multiple measurements from 2π ambiguity

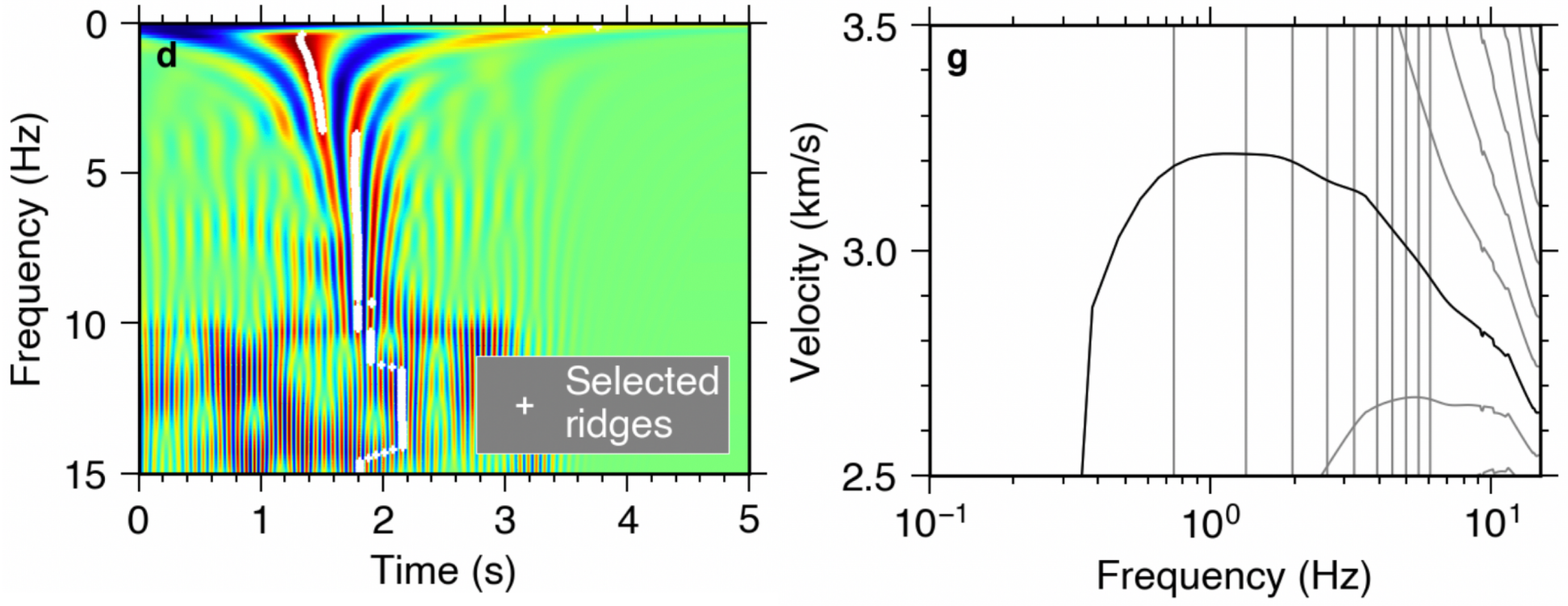
- Not only the correct ridge can yield correct phase velocities if
- High amplitude ridges tend to have better accuracy.



Amplitude-guided ridge tracking

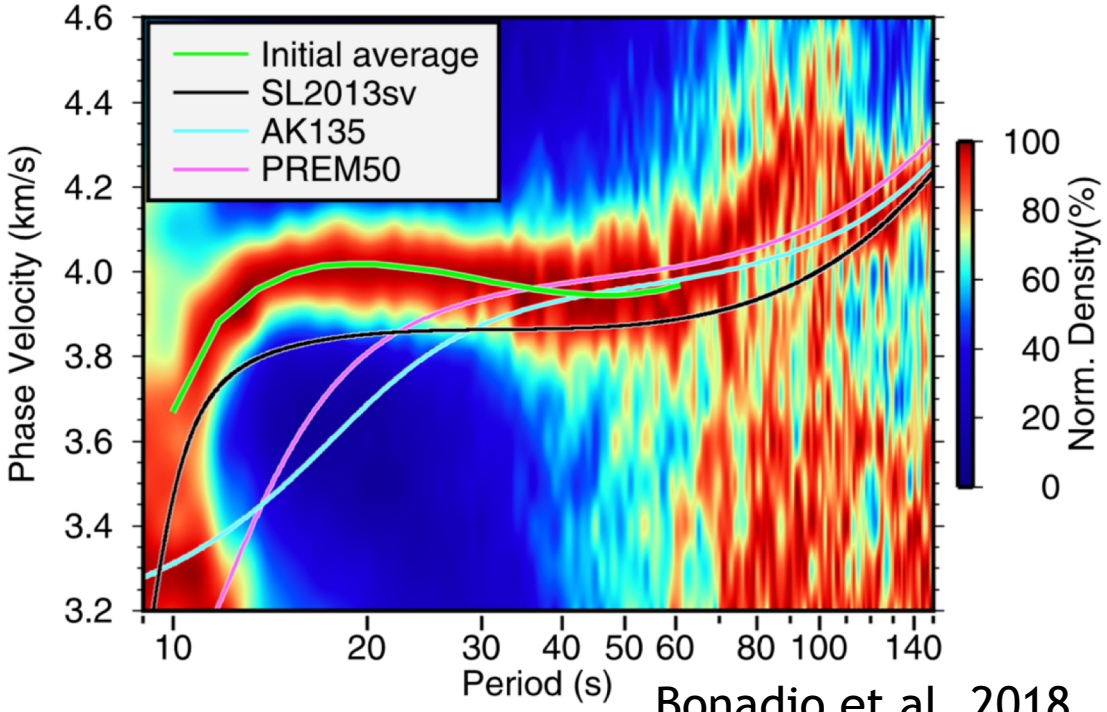
Advantages:

1. Allow ridge tracking to switch ridges (to use measurements from multiple ridges)
2. Keep records of the number of jumps (to correct the 2pi ambiguity)



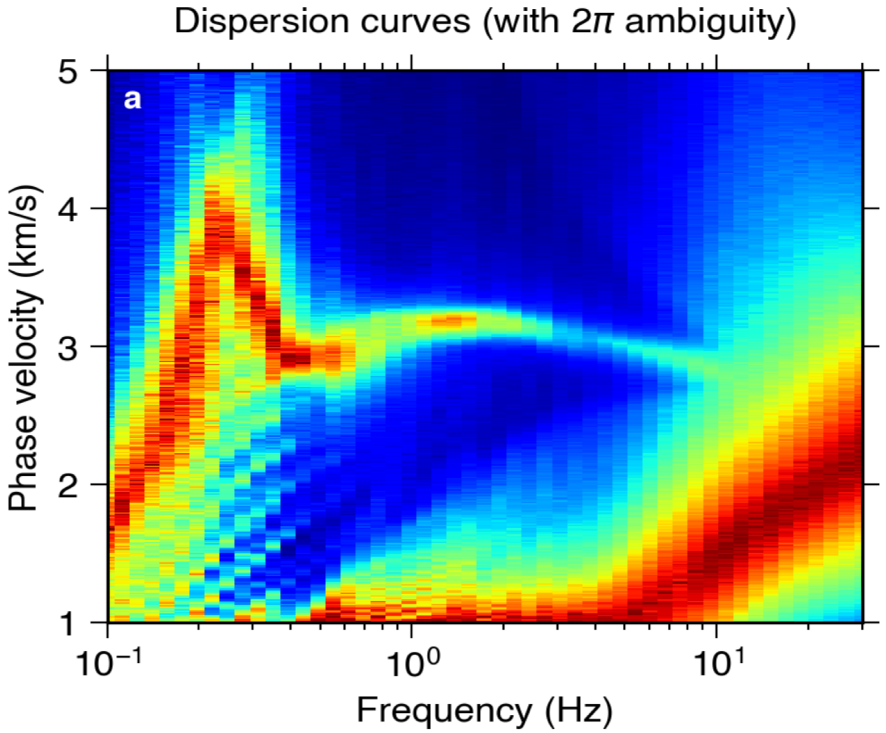
Solving the 2π ambiguity (option 1):
Obtain reference dispersion curves without a model

Two-station method



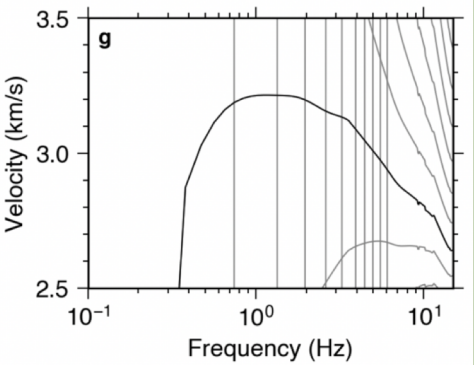
Bonadio et al. 2018

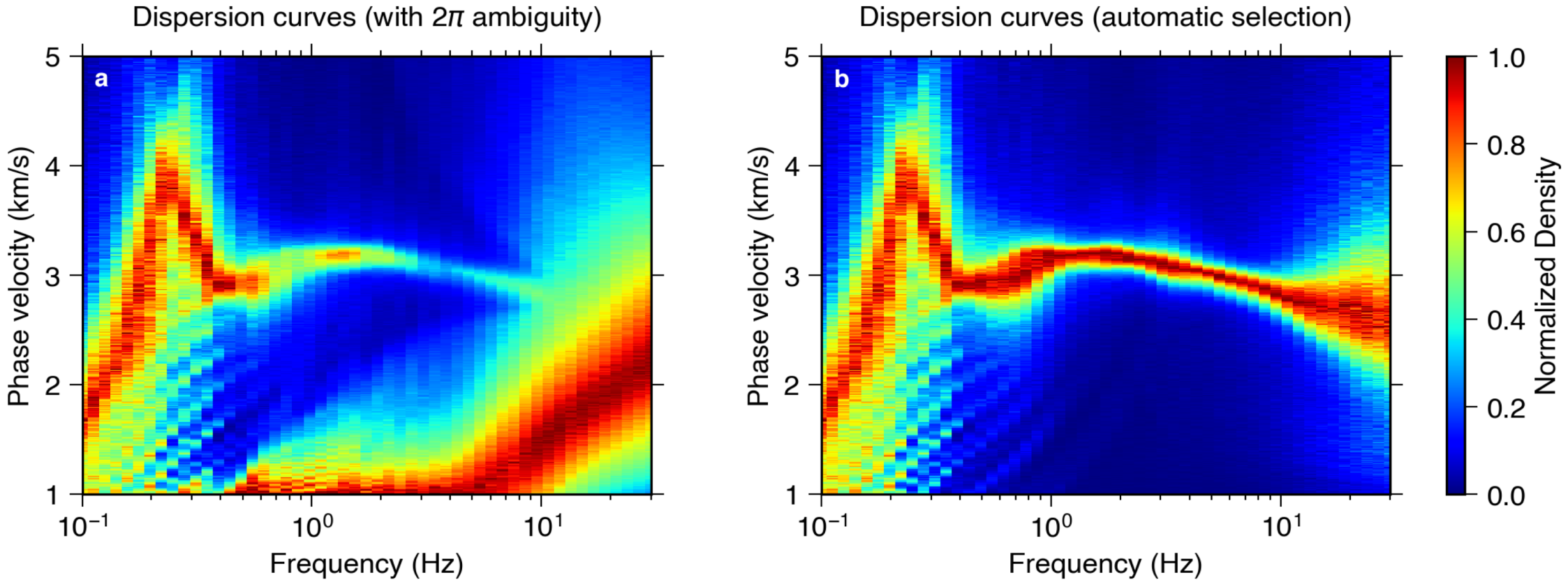
Noise cross-correlation



A Correct reference dispersion curve can be obtained from the density plot of all the dispersion curves, even some of them are not corrected for the 2π ambiguity.

Solving the 2π ambiguity (option 2): Without reference dispersion curves

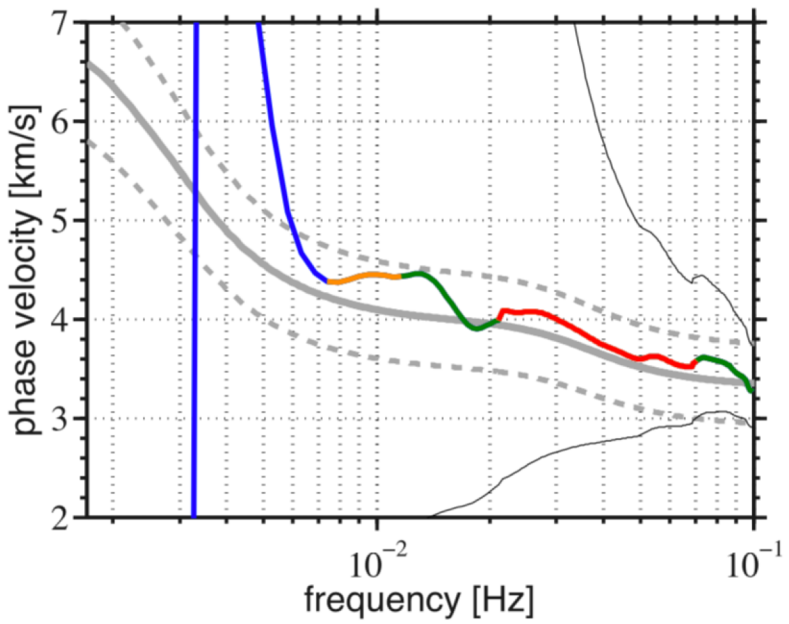




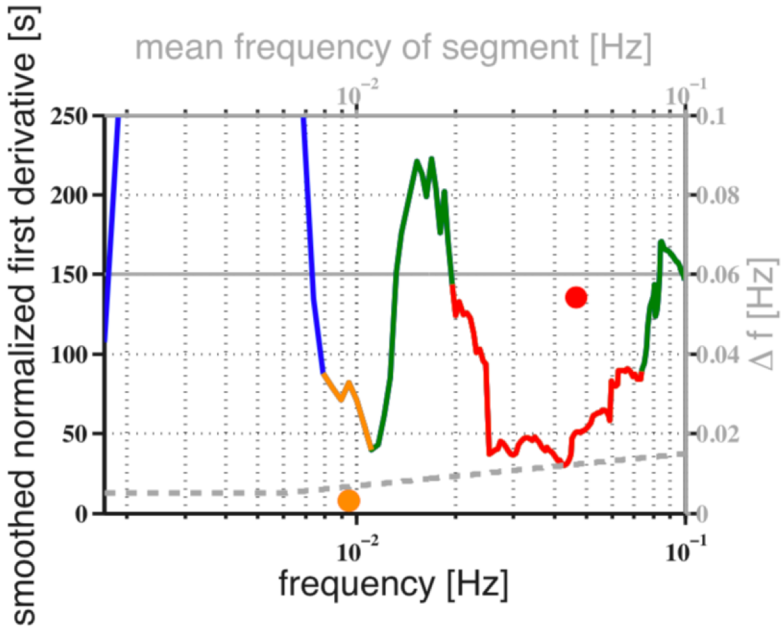
The correct ridge tend to have maximum amplitude at low frequencies.

Quality control

1. Slope; 2. Probability; 3. Median absolute deviation



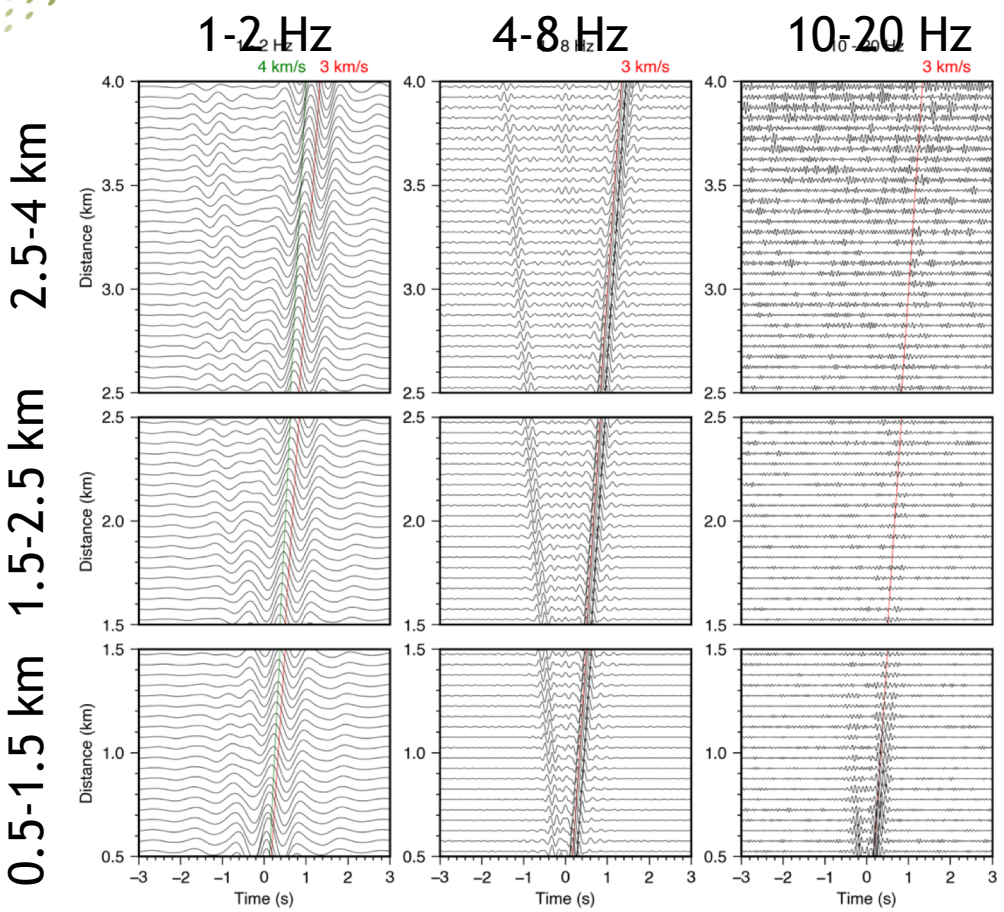
(a) Background model criterion



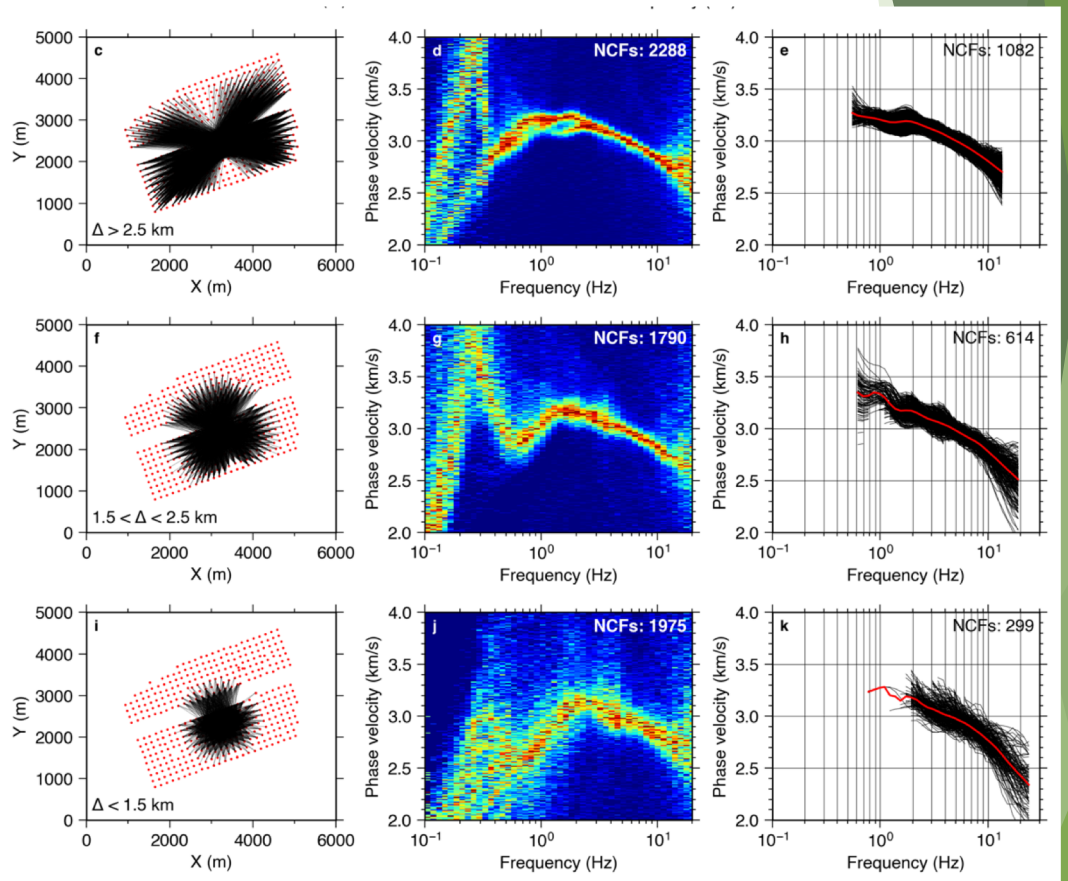
(b) Smoothness and length criterion

Soomro et al. 2016

Distance-dependent quality control

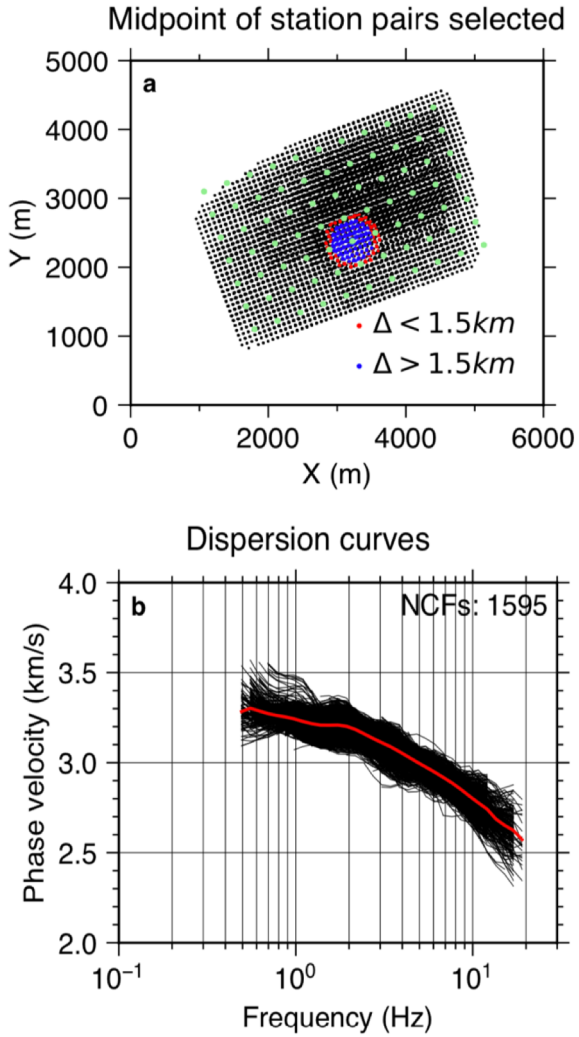


Before After quality control

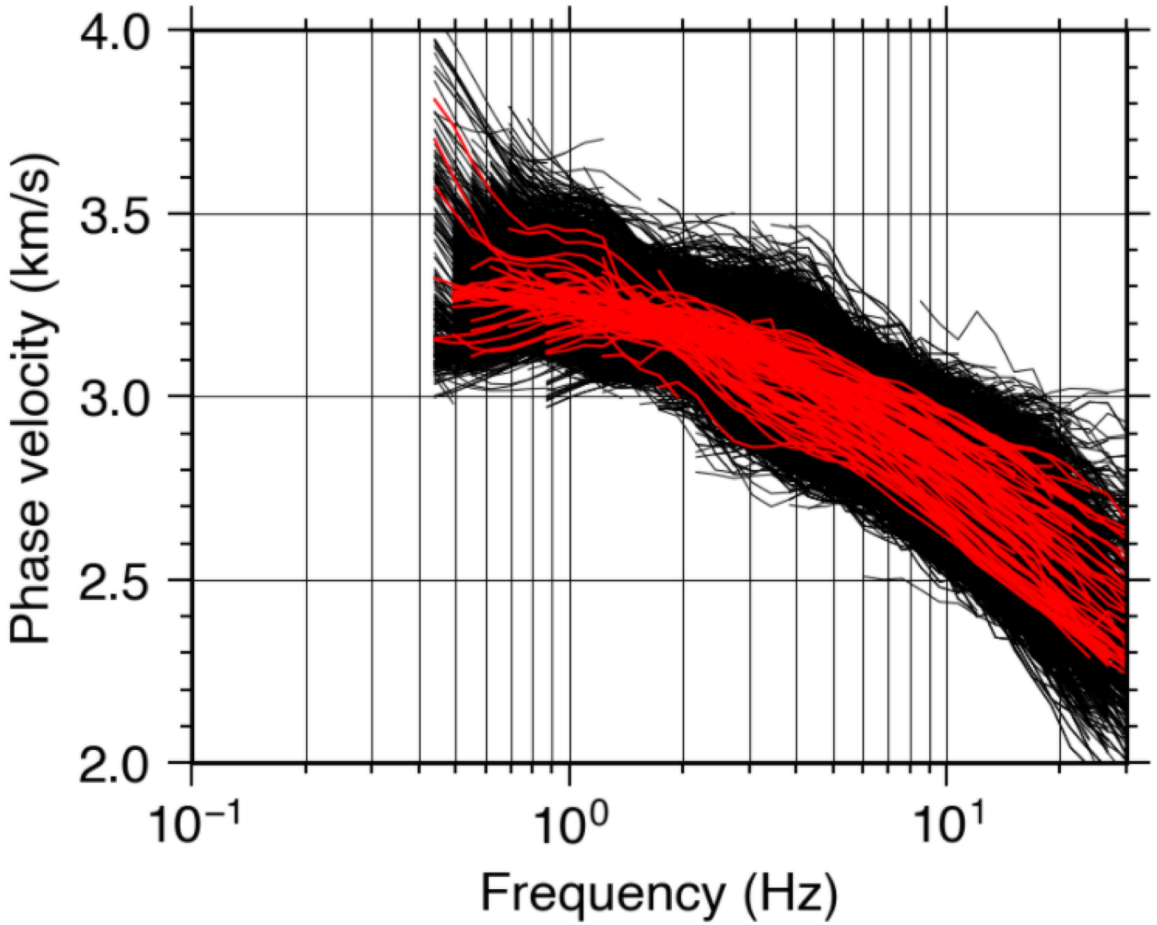


The frequency range with reliable dispersion measurements changes with interstation distance. When using quality control based on mutual similarity, split the dispersion curves in distance groups.

Dispersion curves

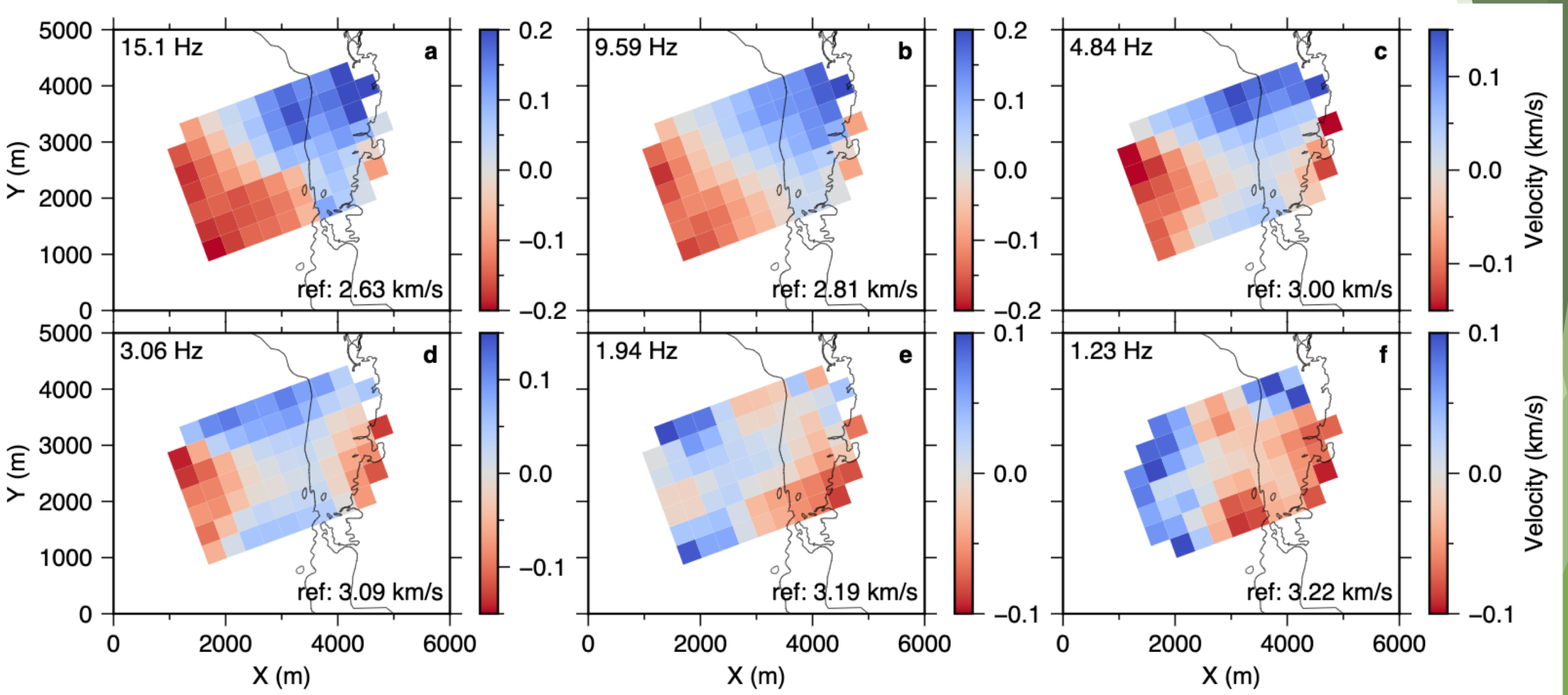


All dispersion curves (black) and average dispersion curves (red)



Phase velocity maps

High velocity anomaly = Gabbro intrusions ?



Conclusions

- Noise cross-correlation
  - Short segment stacking
  - Cross-coherence
  - No 1-bit normalization; No bandpass filters
  - Fastest convergence can happen within 10 minutes; slowest as long as 11 hours
- Phase velocity measurement
  - Amplitude-guided ridge tracking
  - Correct branches can be selected without reference dispersion curves
- Quality control
  - Dispersion curves should be divided into groups according to the interstation distance, if mutual consistency is used for quality control

If you have any questions, please feel free to contact me (xuyh@cp.dias.ie)