Full waveform inversion of multimode surface wave data: numerical insights

Raul Cova and Kris Innanen

Banff, December 2019

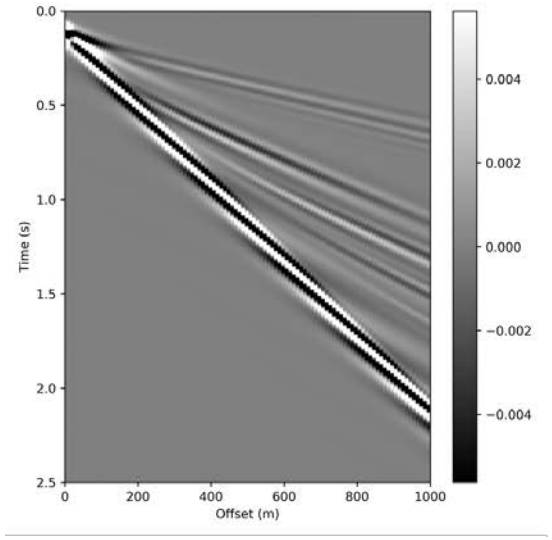
NSERC CRSNG
UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
Department of Geoscience

Introduction

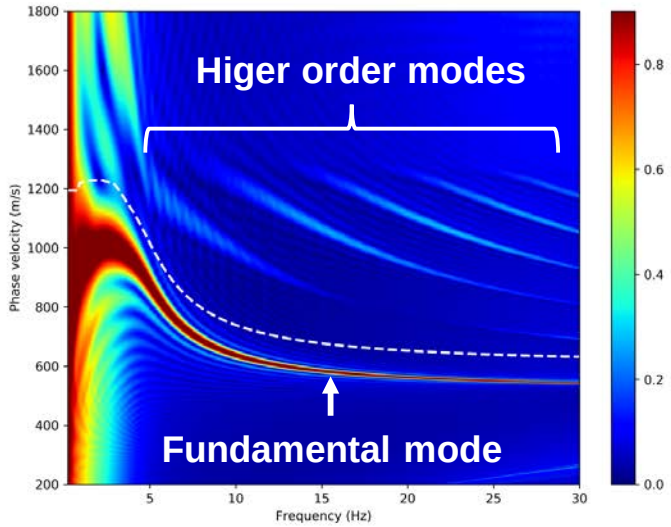
- The dispersive nature of surface waves enhances FWI cycle skipping problems.
- Hierarchical strategies have shown to be very effective in mitigating cycle skipping.
- In contrast to body waves FWI, to implement a layer stripping strategy higher frequencies must be inverted first.
- We propose a hierarchical multimode surface wave FWI, where:
  - Fundamental mode energy is used in a first FWI pass, exploiting the long wavelength components present in this mode.
  - Higher order modes are used during a second FWI pass, adding extra short wavelength information, particularly at the deeper parts of the model.

Multimode surface wave data

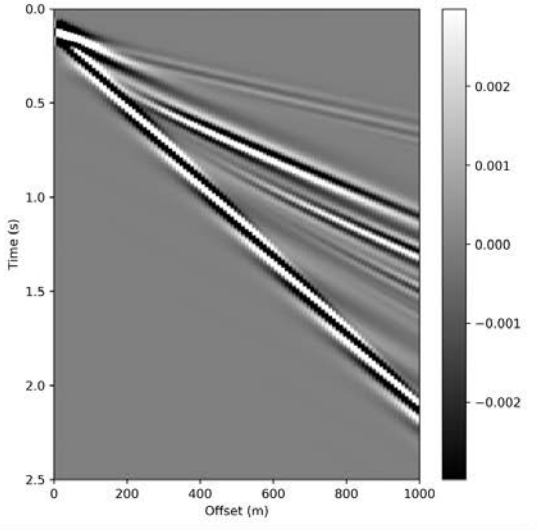
Uz



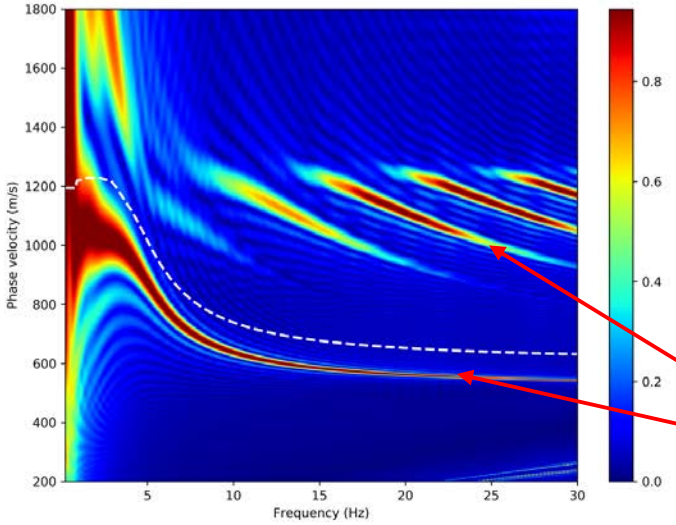
Dispersion spectrum



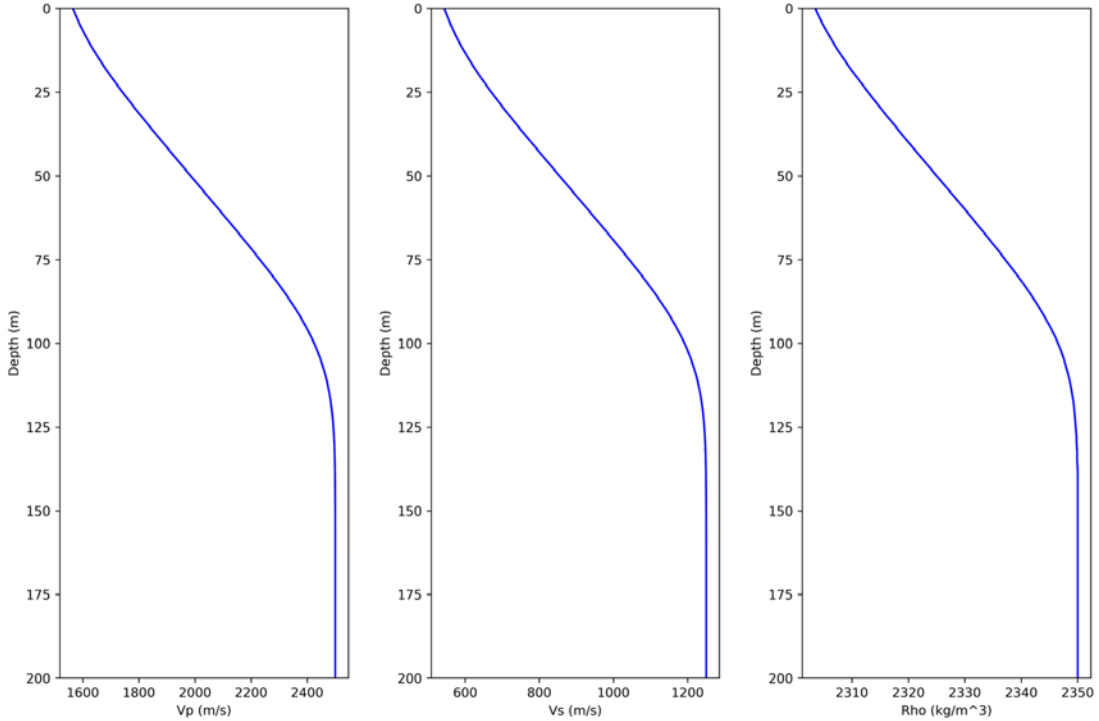
Ux



Dispersion spectrum



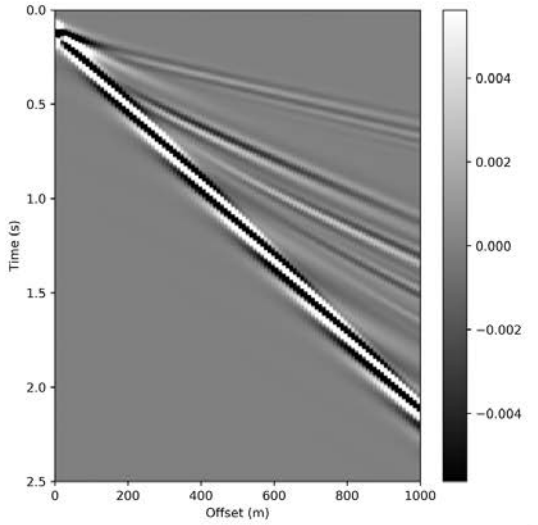
In a layered medium surface-wave propagation is a dispersive and multimode phenomenon.



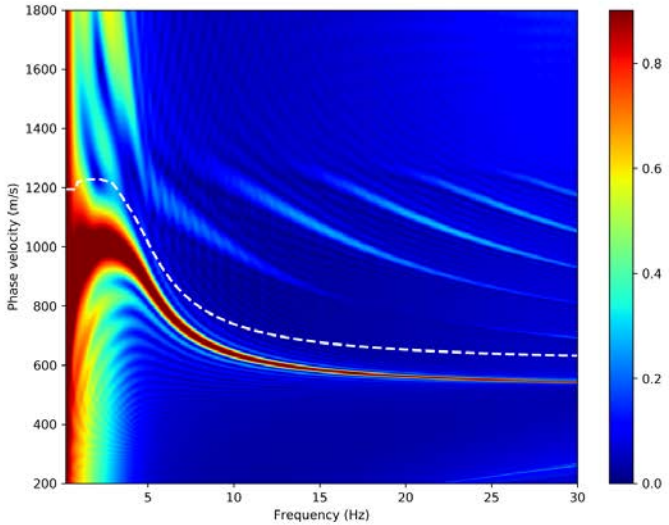
Fundamental and higher order modes have similar levels of energy on the horizontal component

Multimode surface-wave decomposition

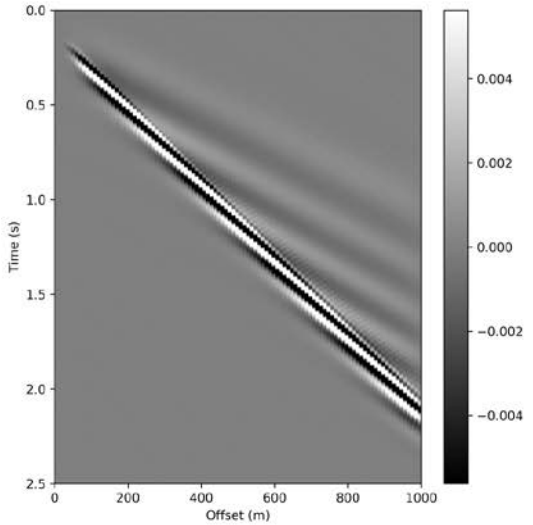
Uz



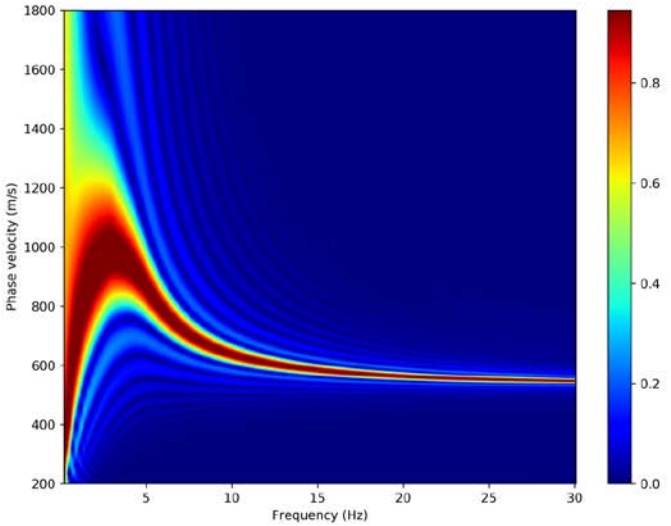
Dispersion spectrum



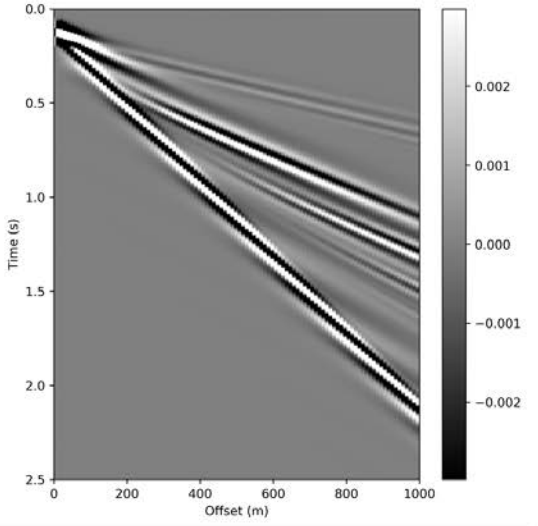
Uz: Fundamental mode



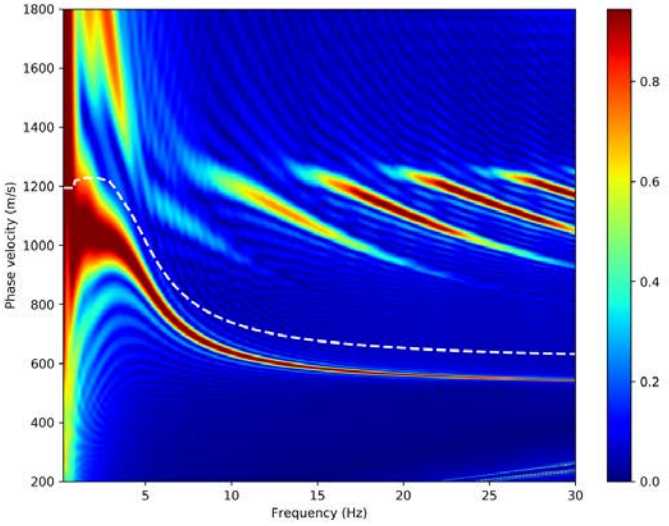
Dispersion spectrum



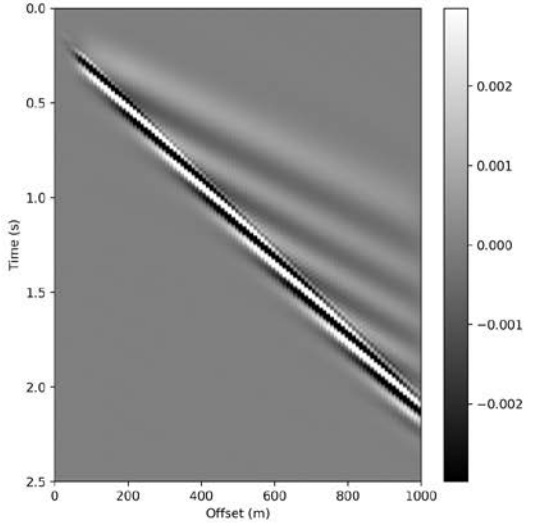
Ux



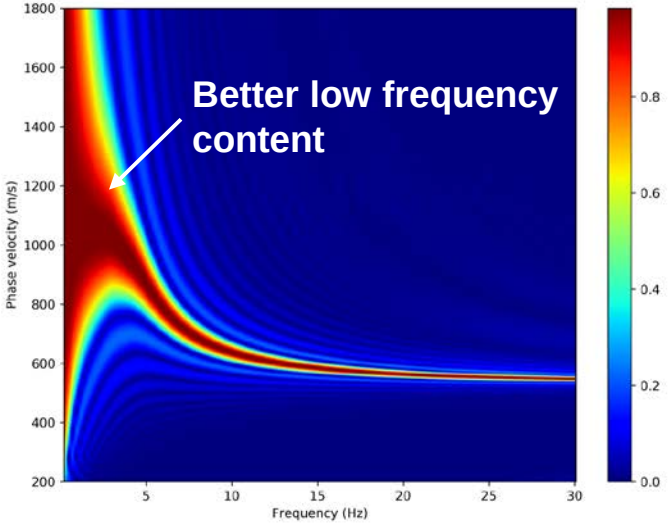
Dispersion spectrum



Ux: Fundamental mode

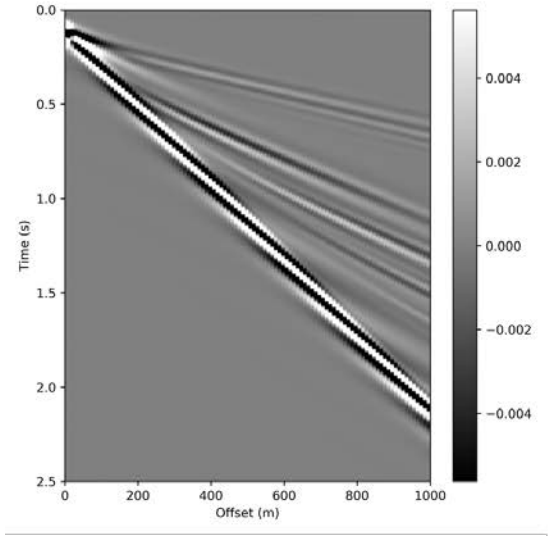


Dispersion spectrum

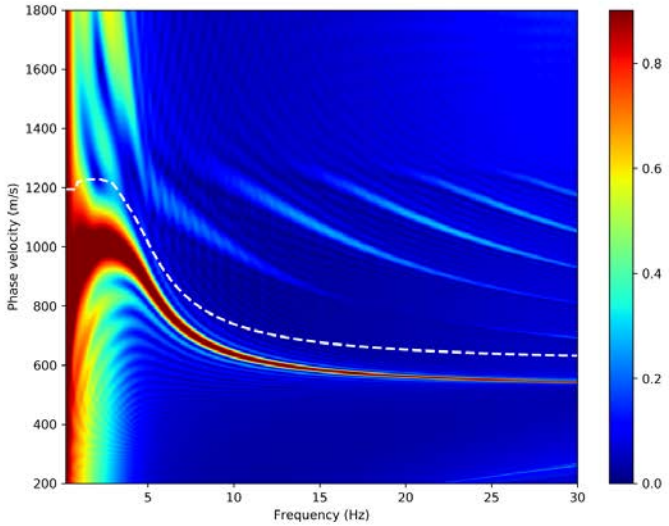


Multimode surface-wave decomposition

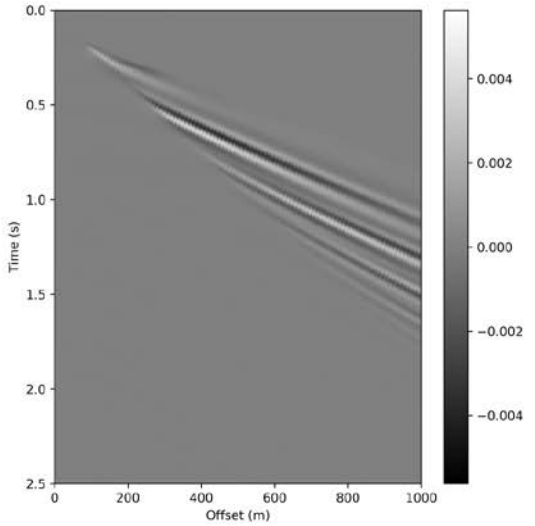
Uz



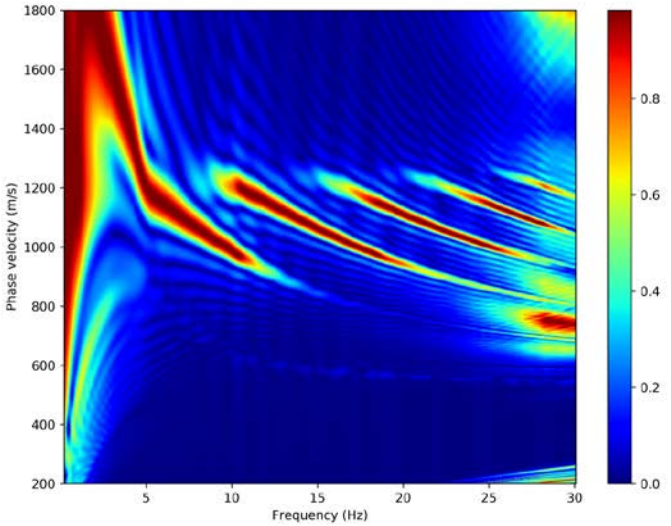
Dispersion spectrum



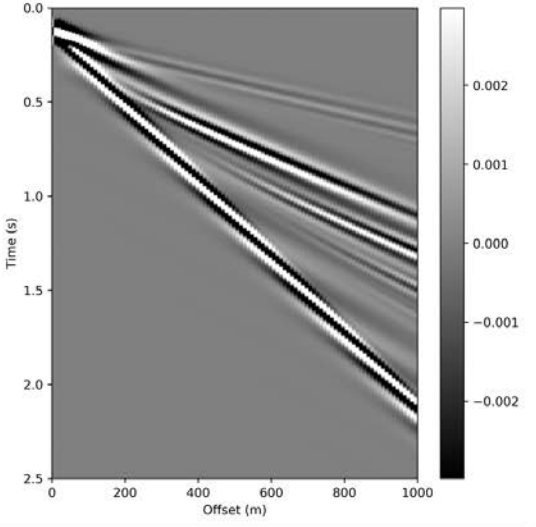
Uz: Higher order modes



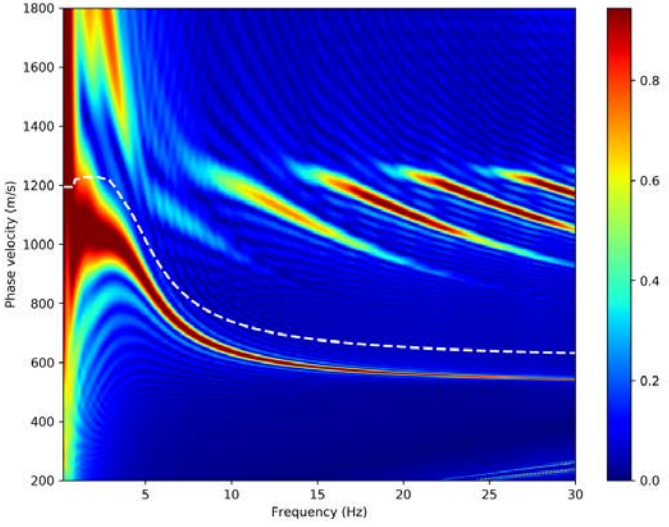
Dispersion spectrum



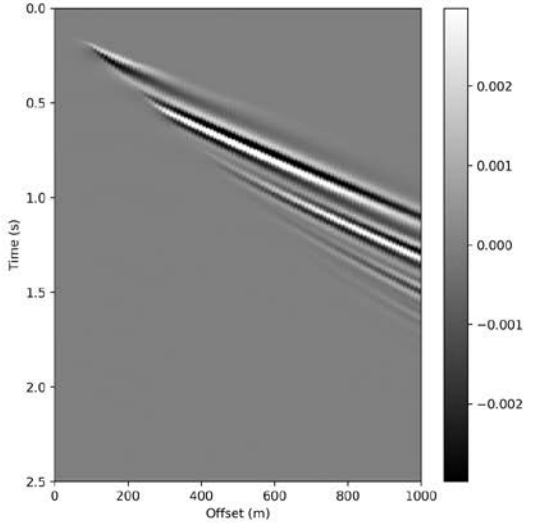
Ux



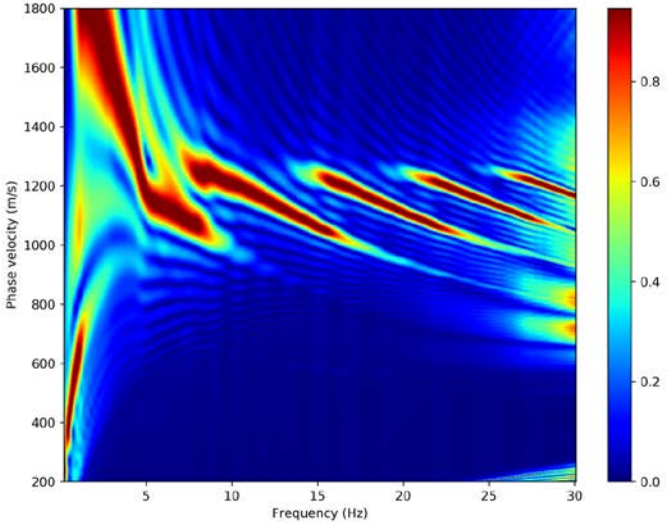
Dispersion spectrum



Ux: Higher order modes

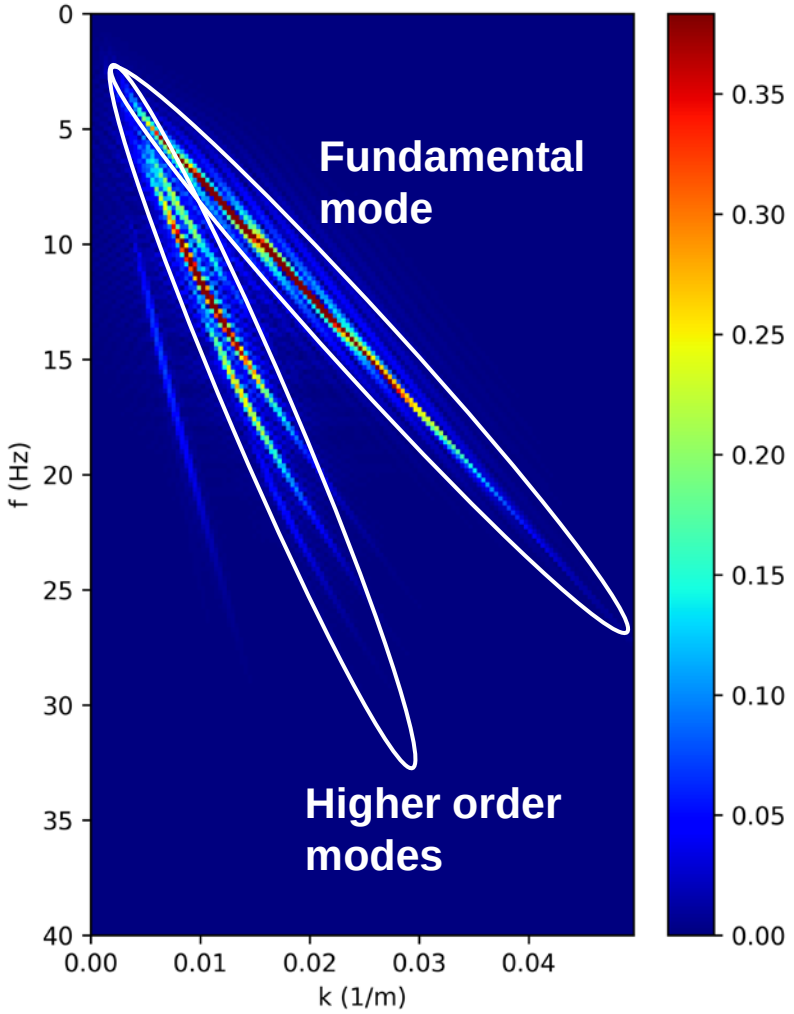


Dispersion spectrum

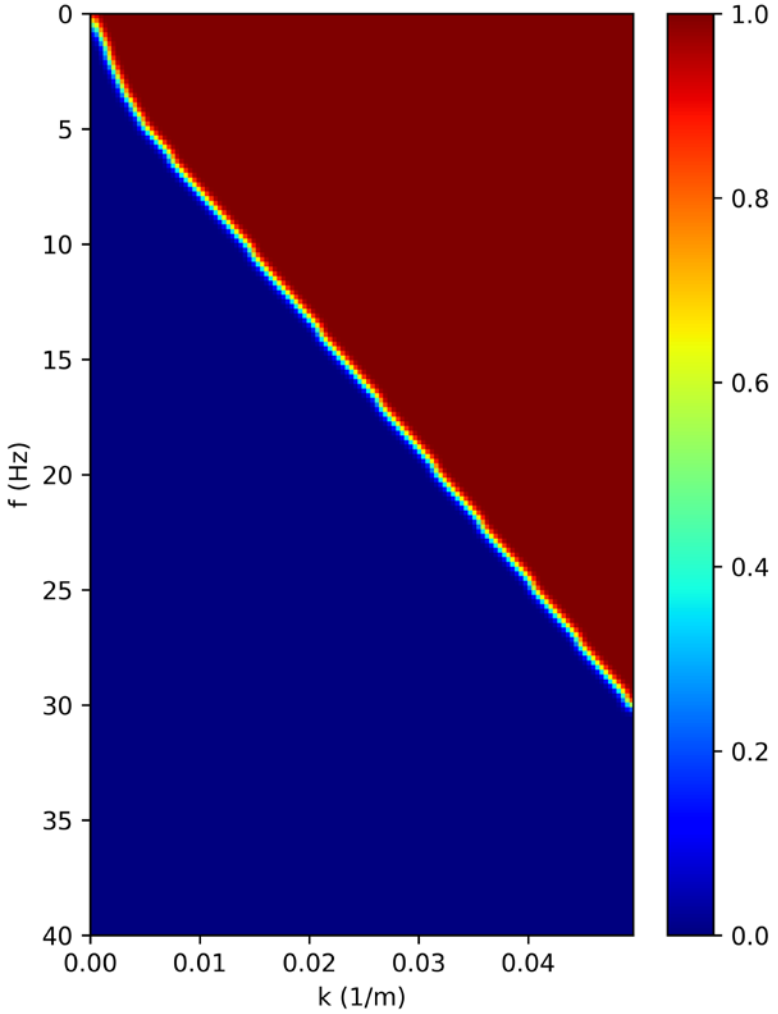


Multimode decomposition in F-K domain

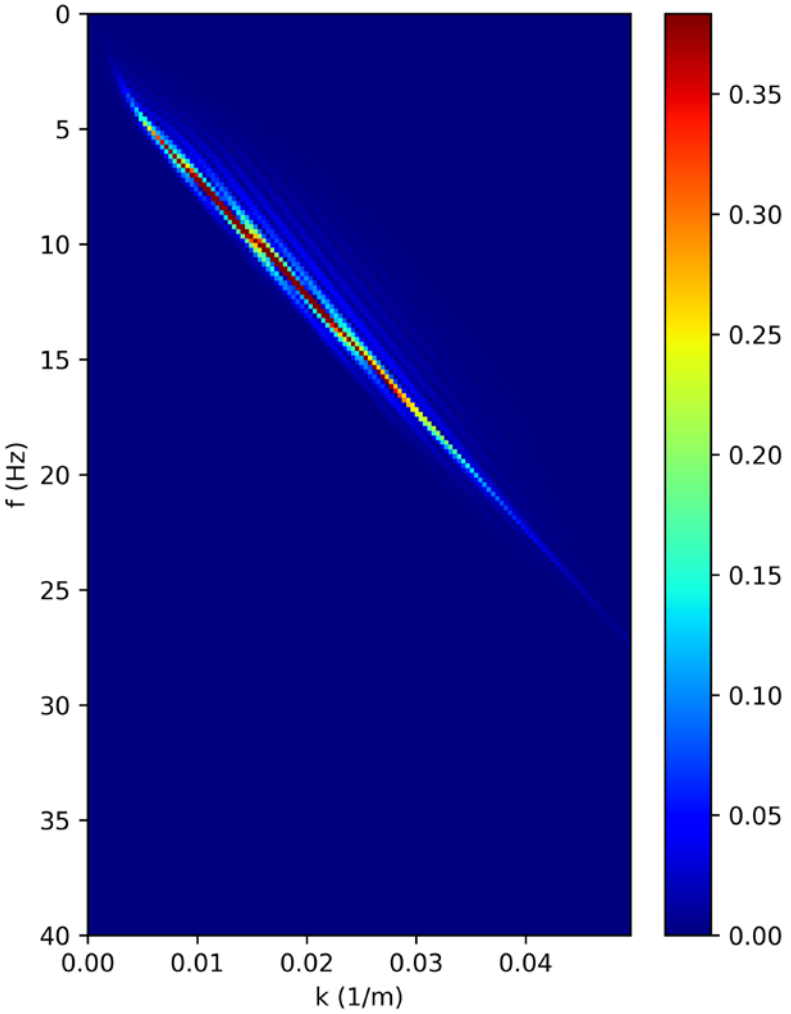
Surface wave F-K spectrum



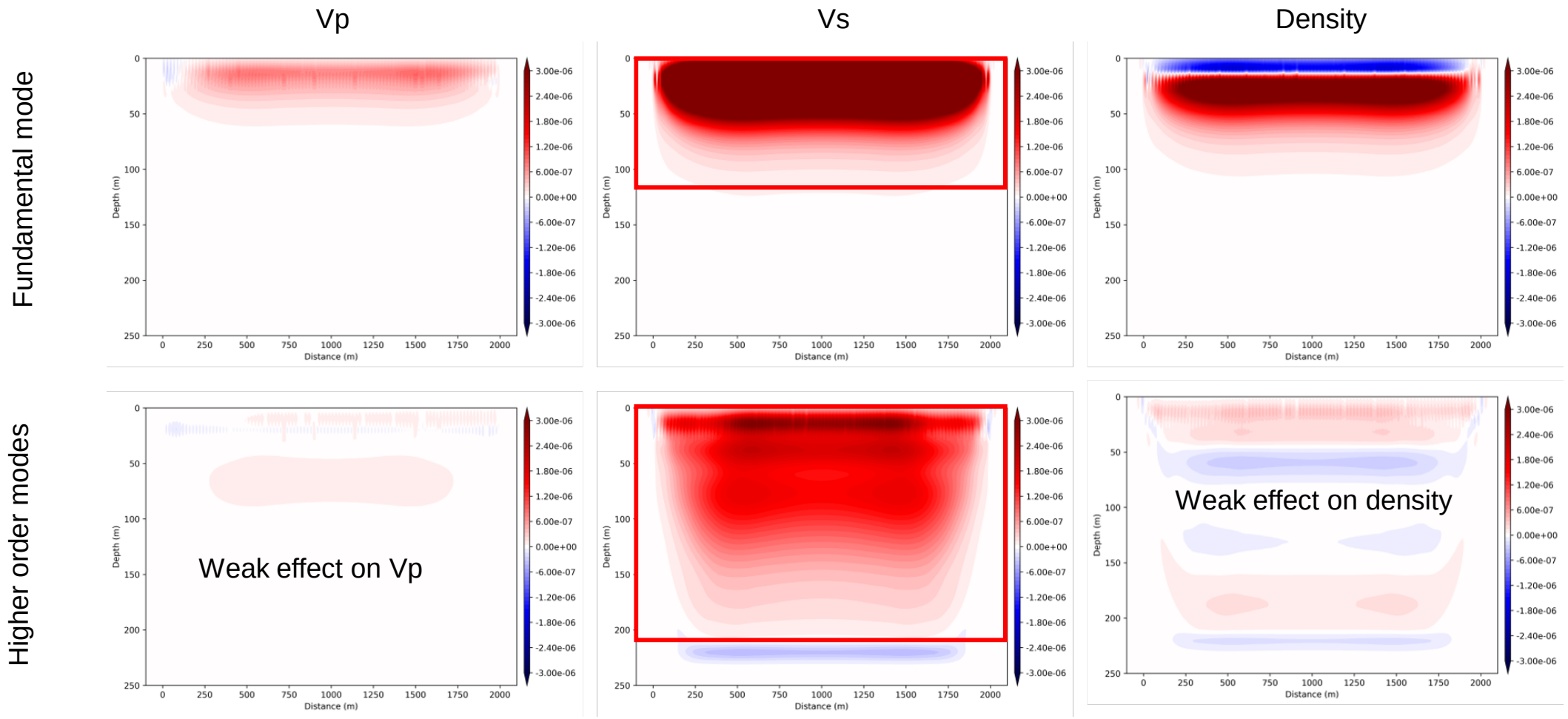
F-K mask



Fundamental mode energy

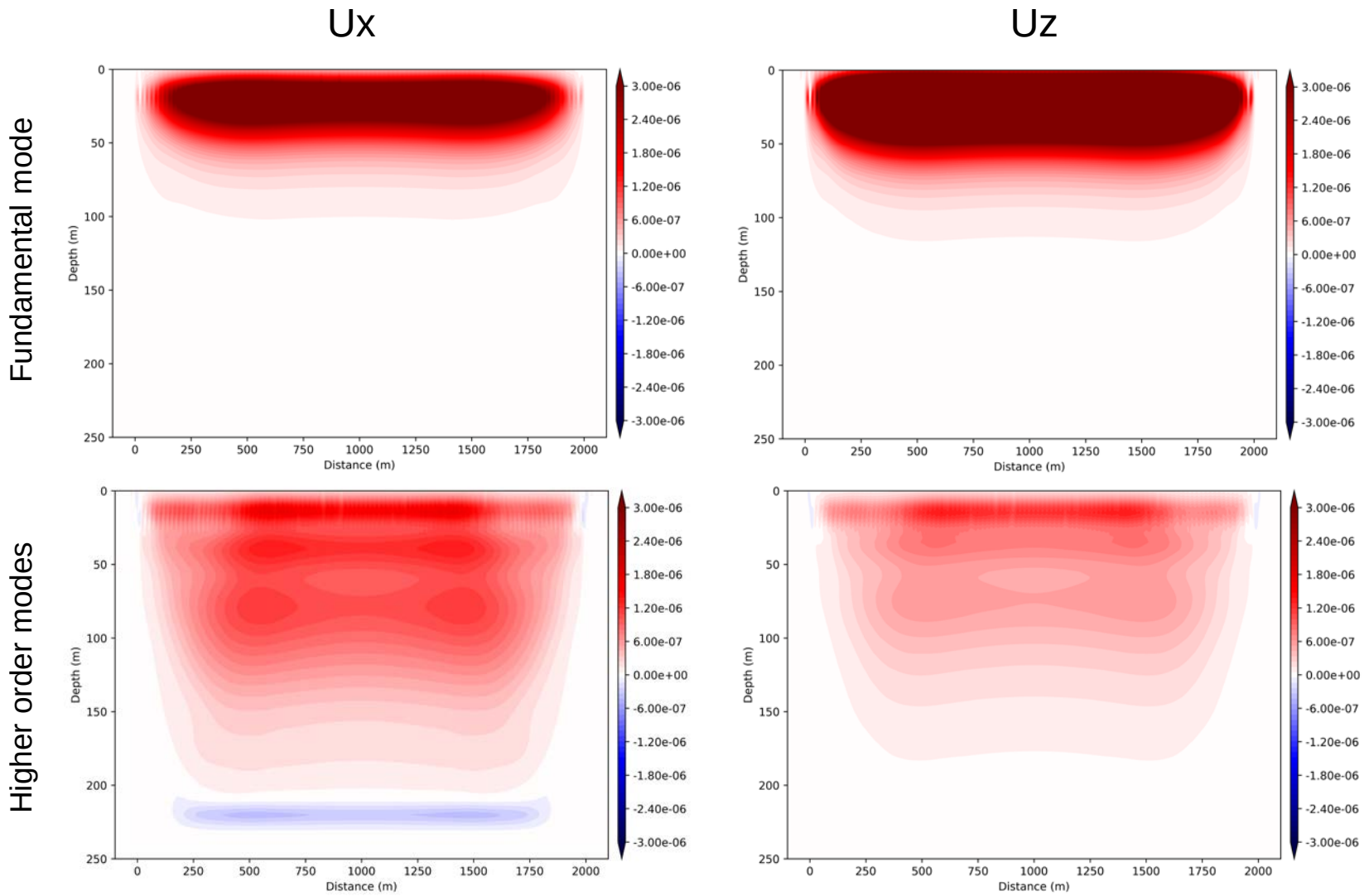


Unscaled gradients



- Fundamental mode Vs update decays exponentially with depth.
- Update provided by higher order modes reaches larger depths and decays gradually.

Unscaled Vs gradients by displacement component

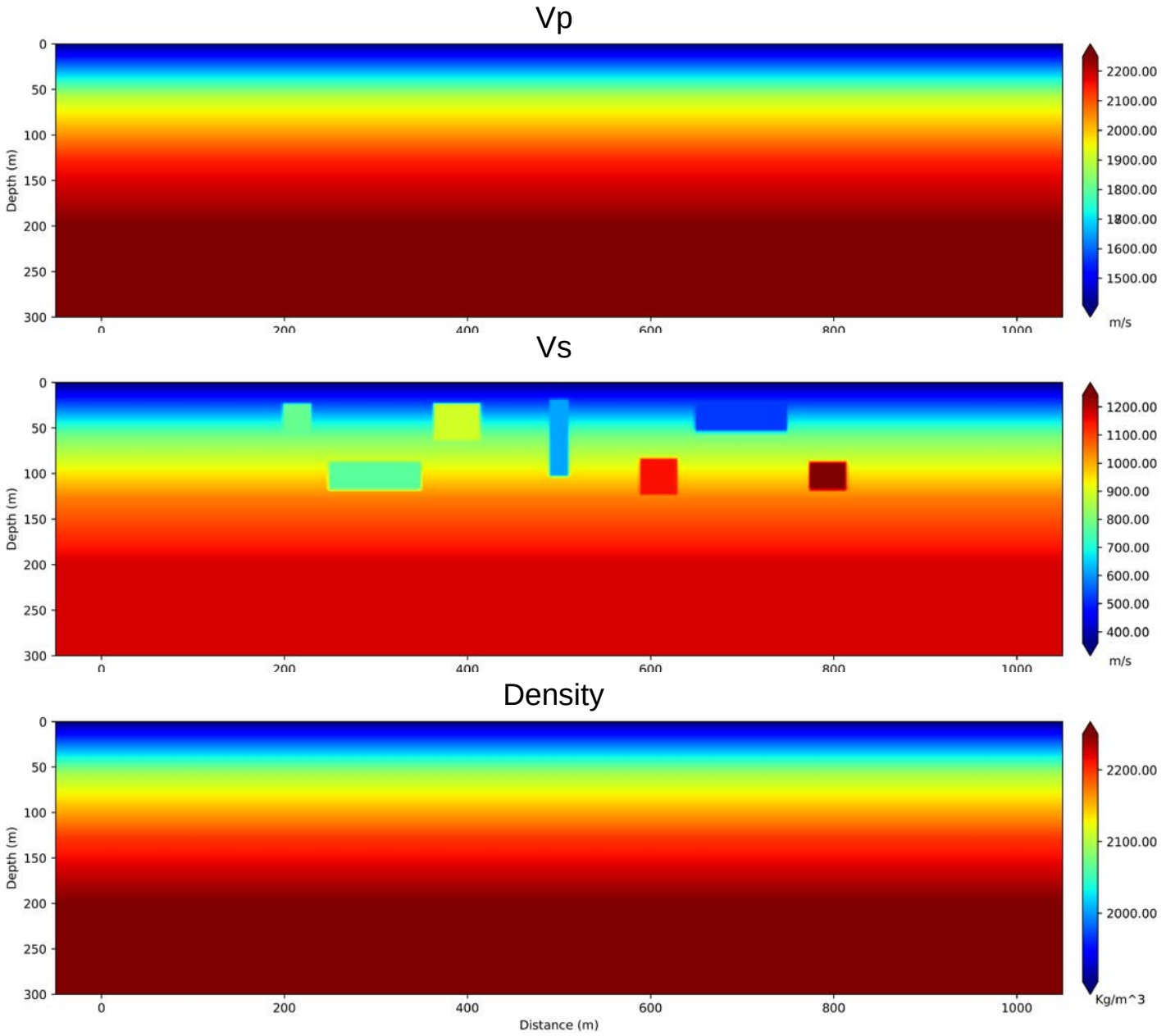


Ux contribution to model update using higher order modes is larger than Uz

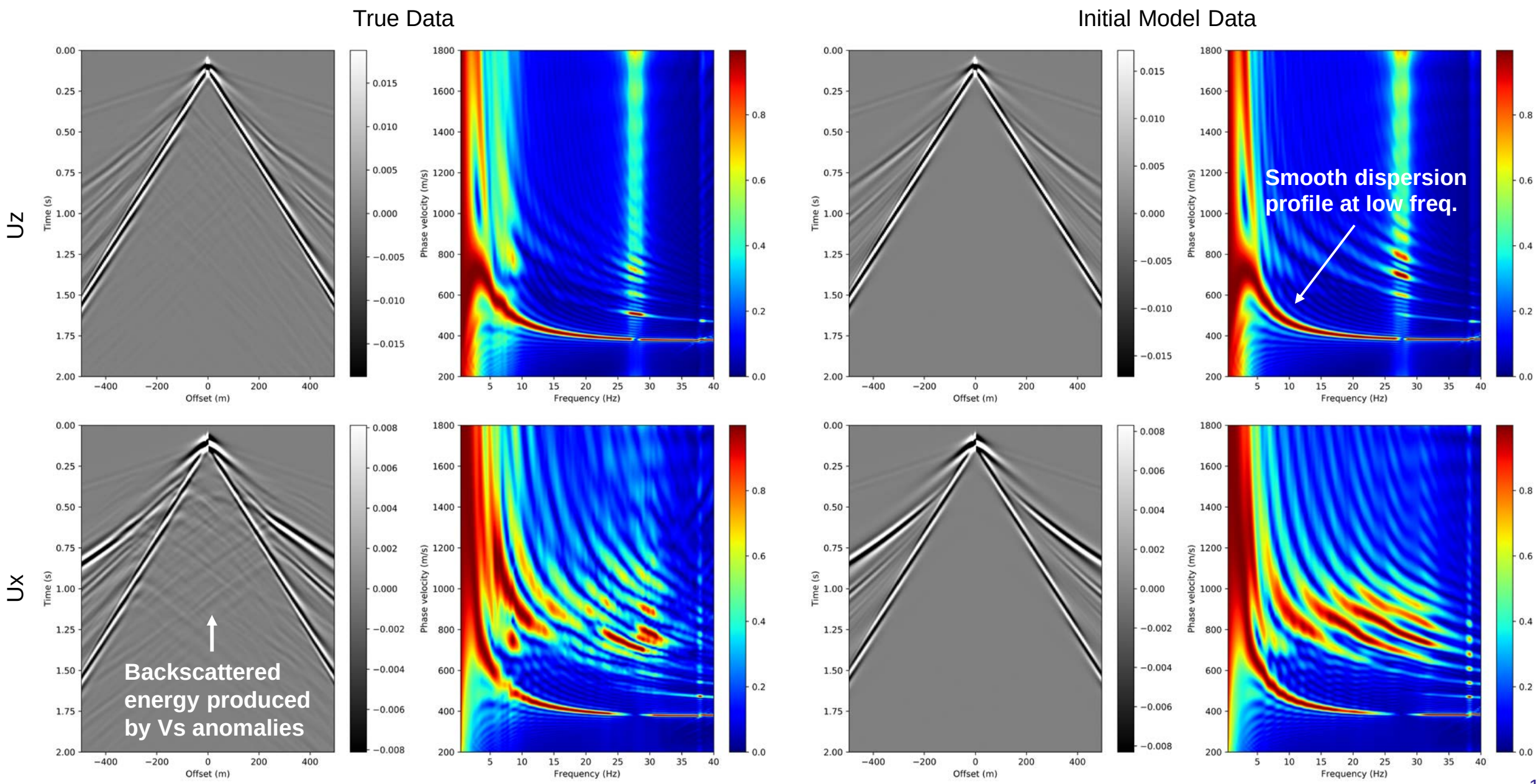
Multimode Surface Wave FWI: True models

Survey details:

- Source spacing: 20 m
- Receiver spacing: 5 m
- Source wavelet: 10 Hz Ricker wavelet



Multimode Surface Wave FWI

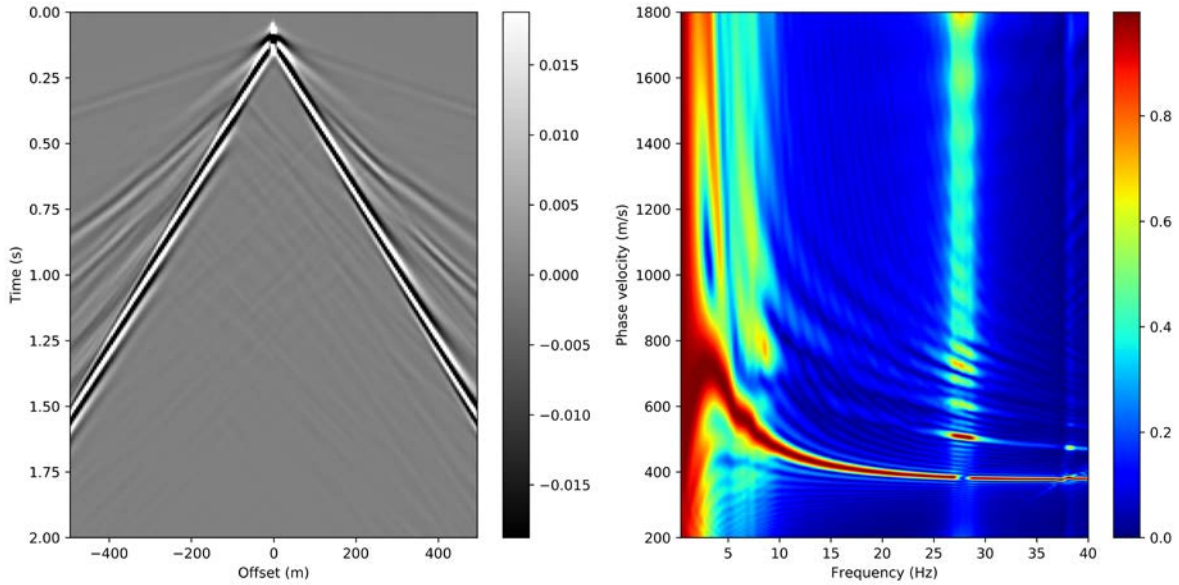


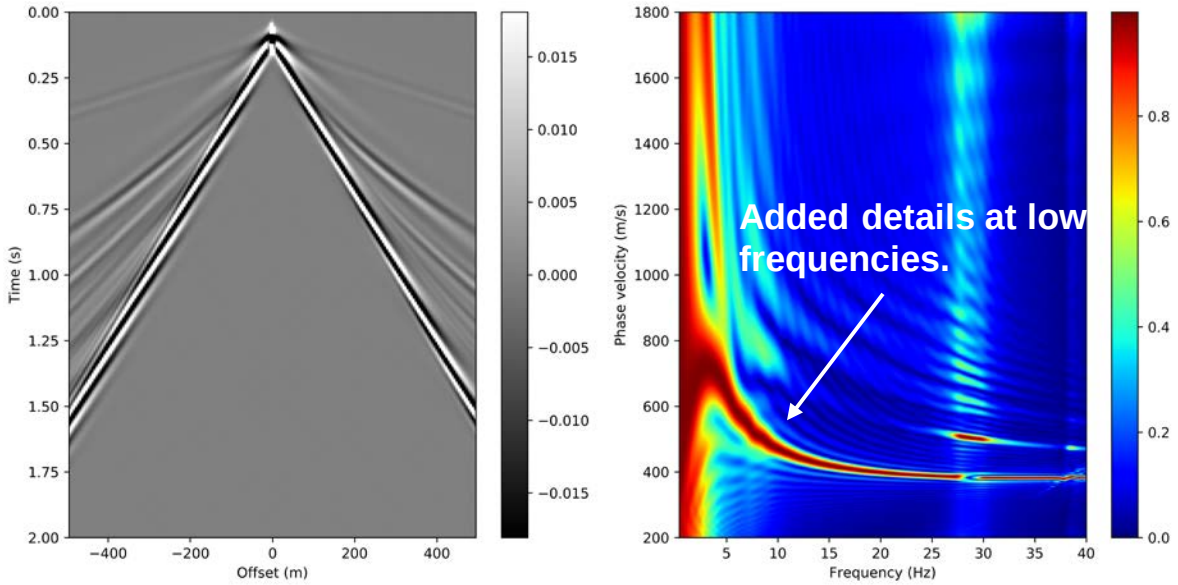
Multimode Surface Wave FWI

True Data

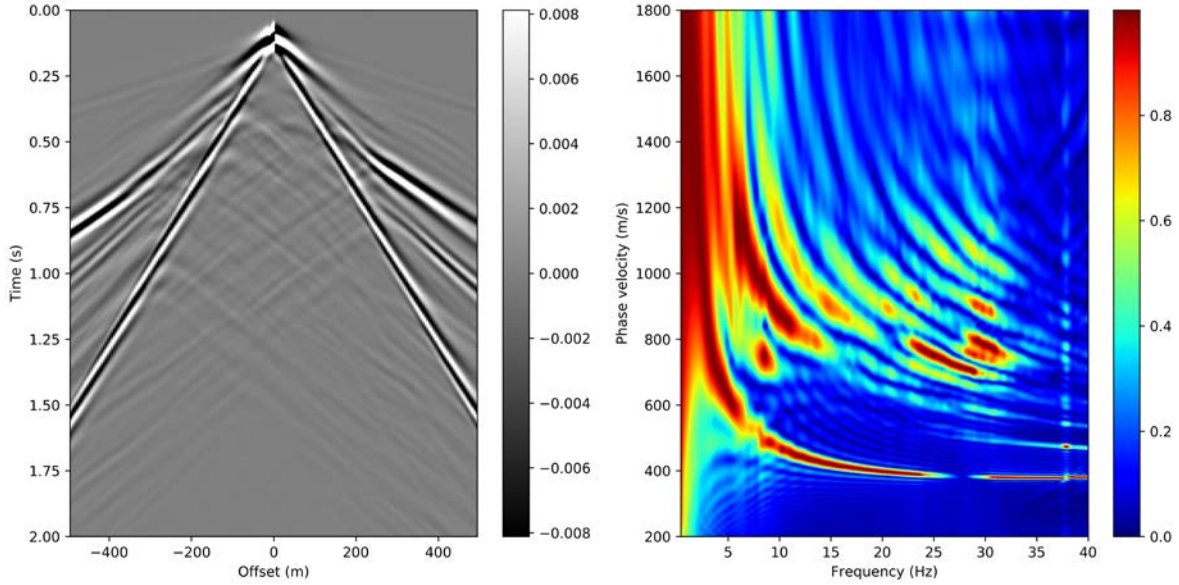
Fundamental Mode FWI Data

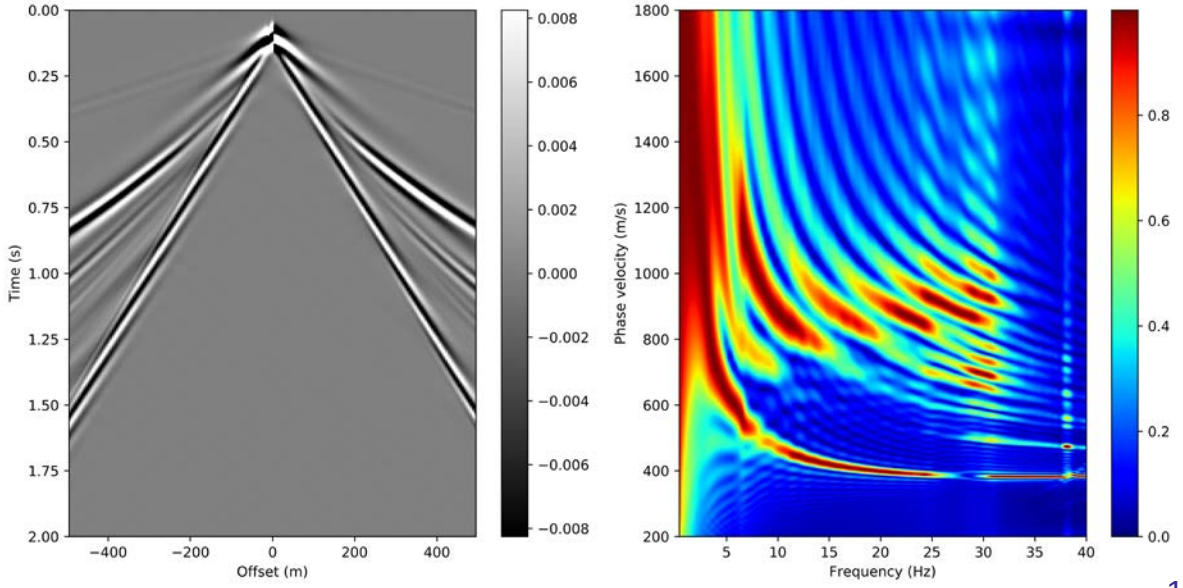
Uz





Ux

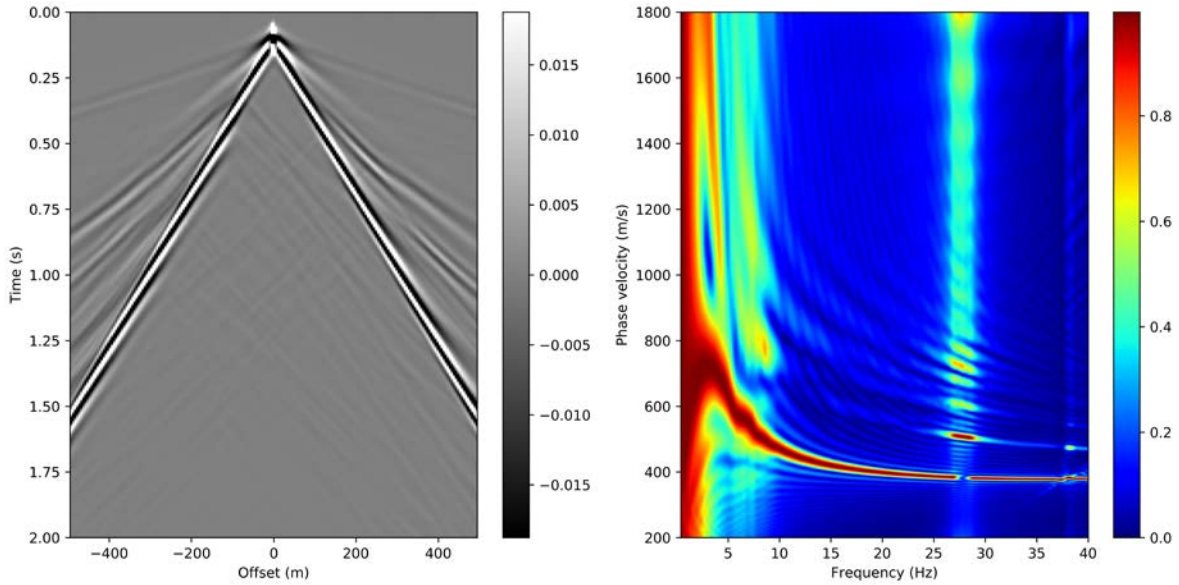


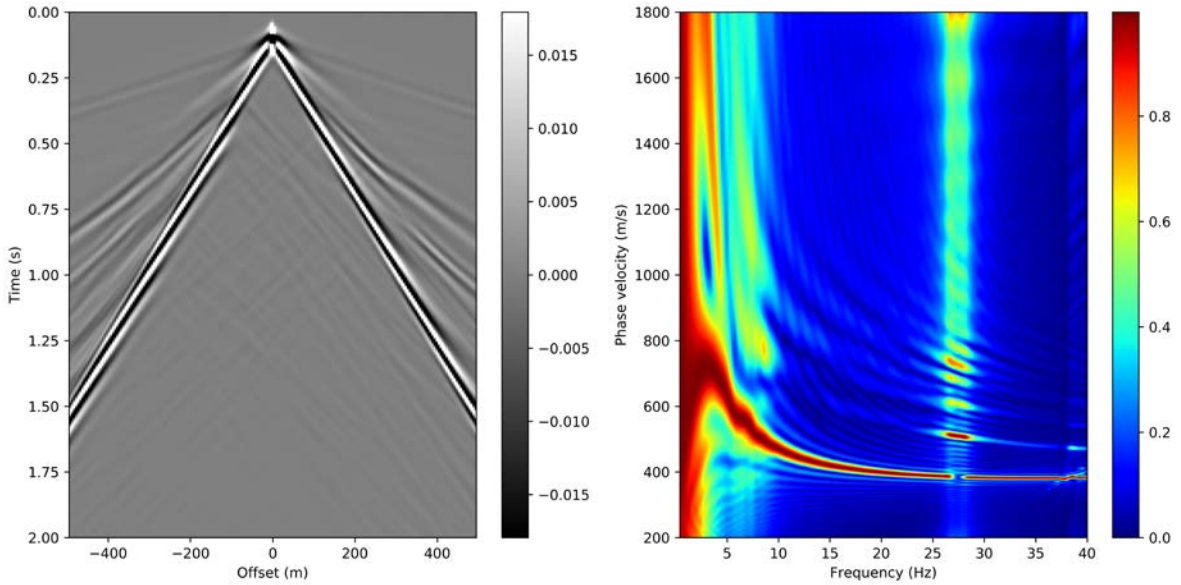


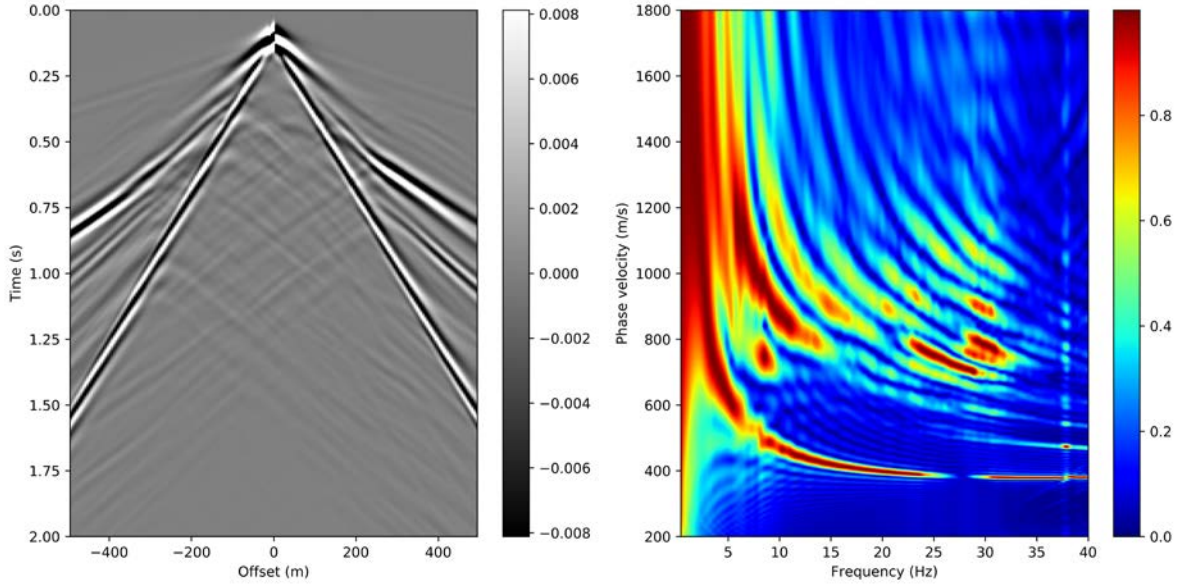
Multimode Surface Wave FWI

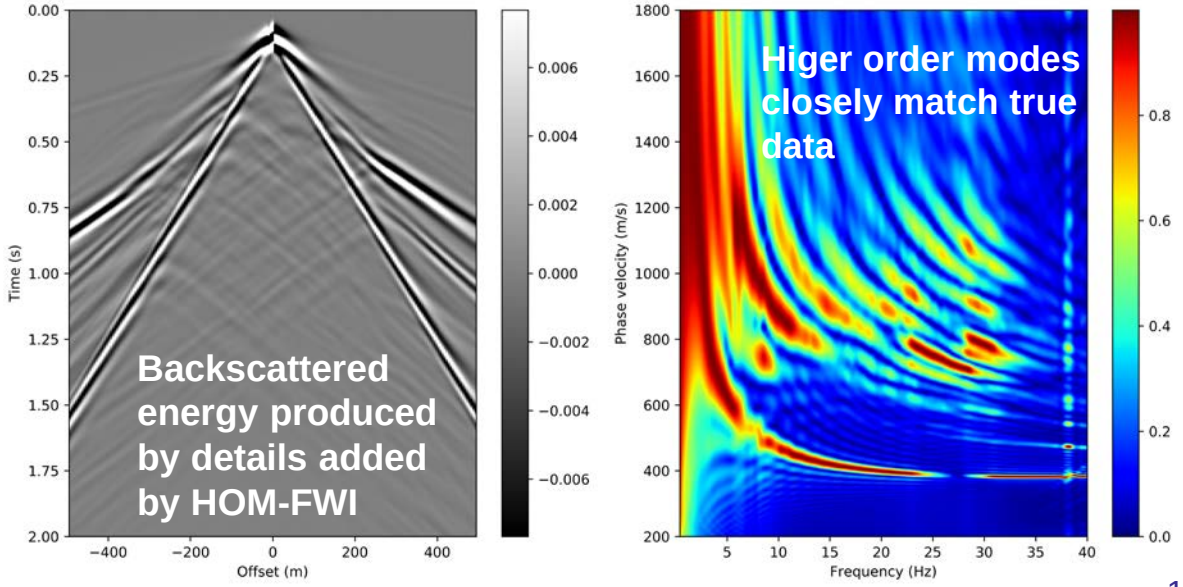
True Data

Higher Order Modes FWI Data

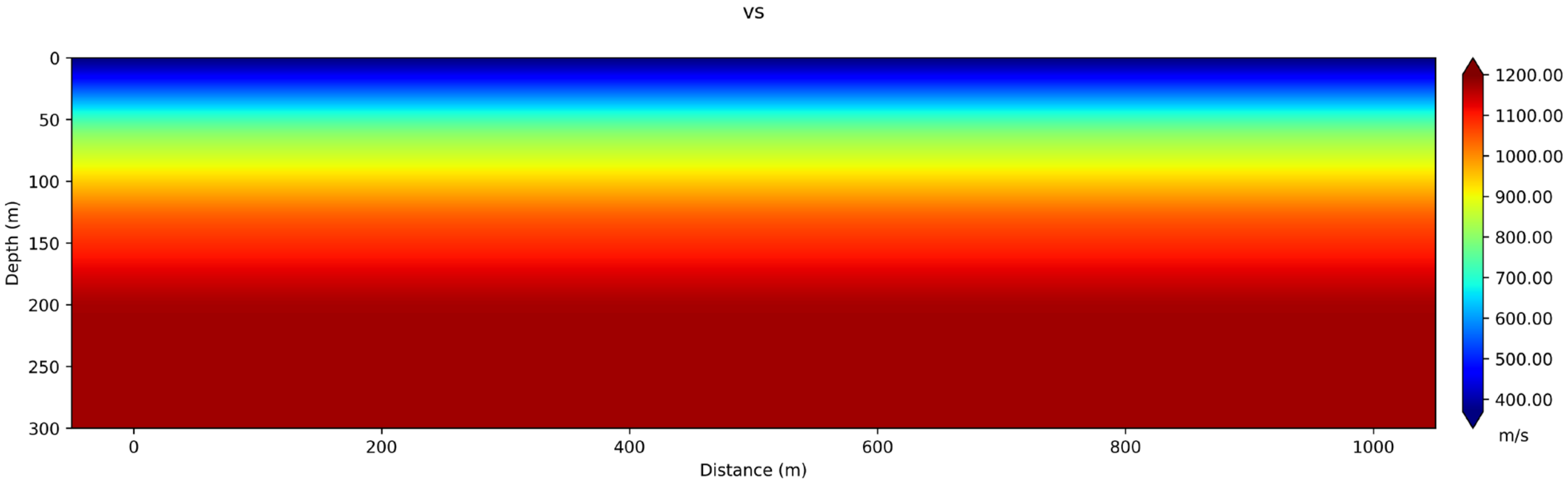




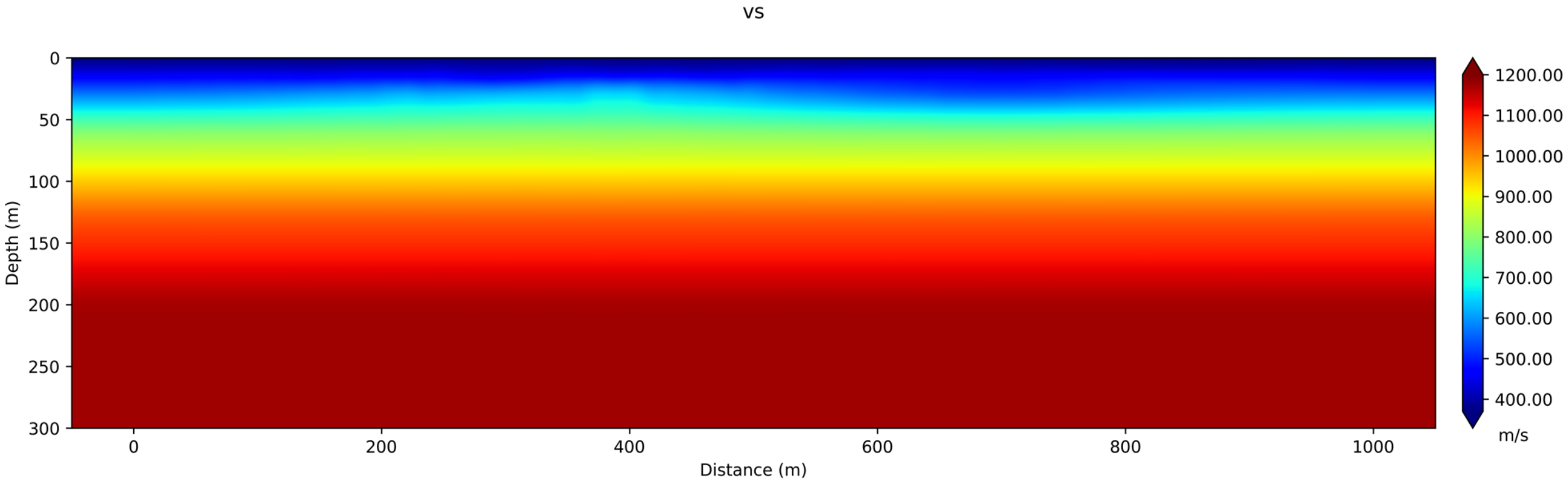




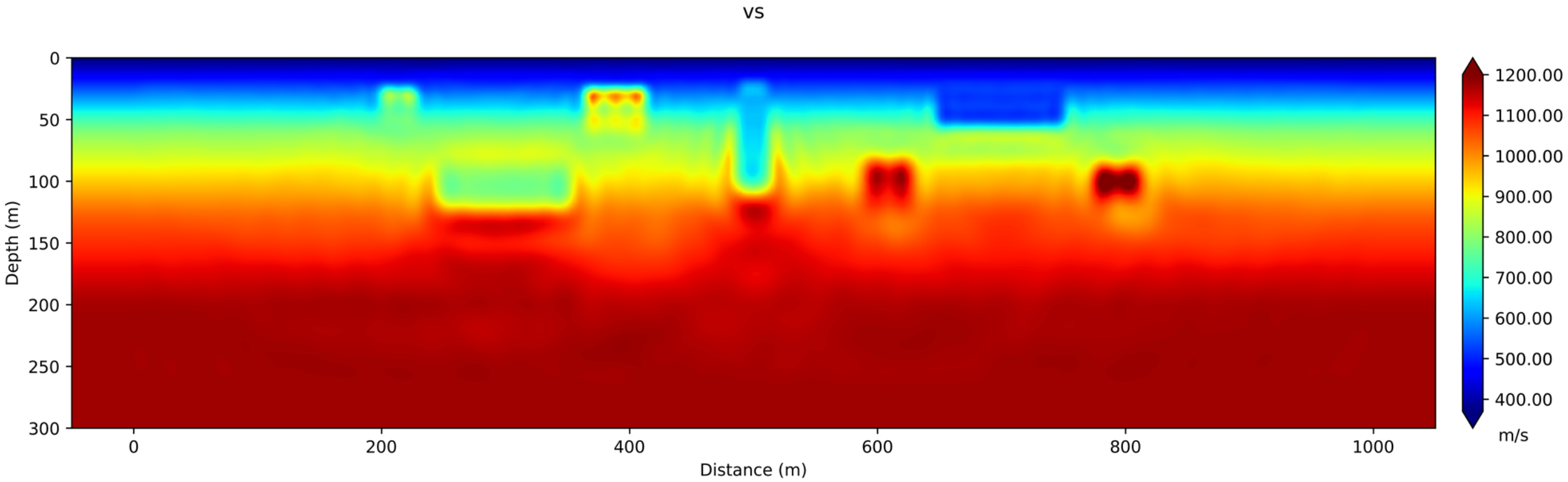
Initial Vs model



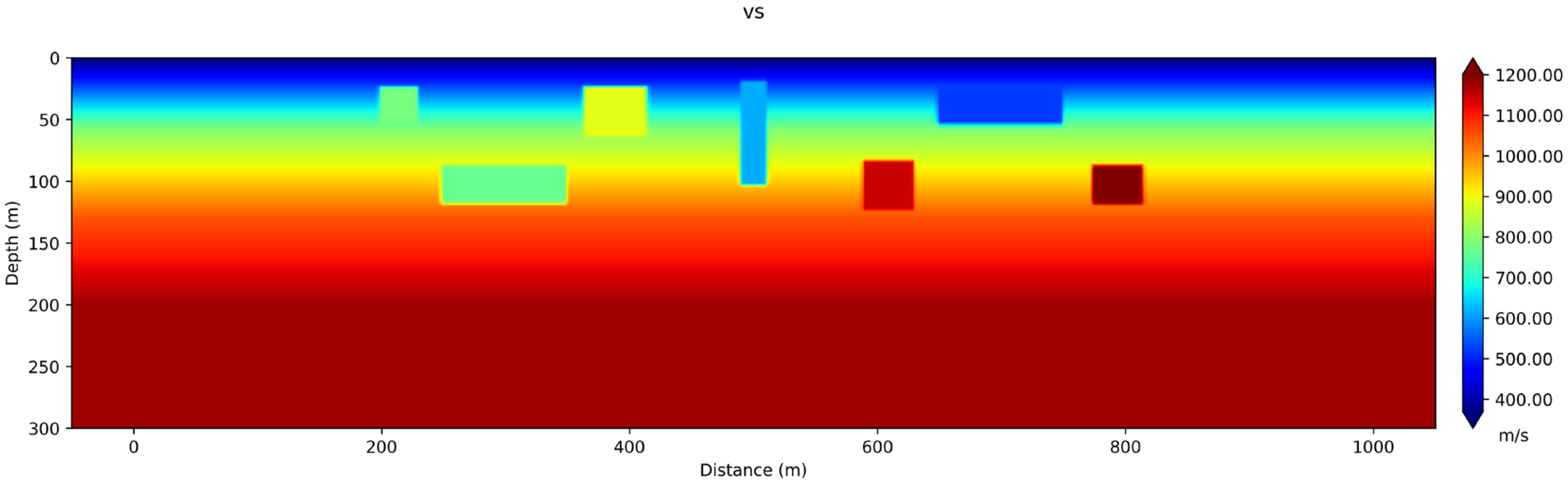
Fundamental mode FWI



Higher order modes FWI



True Model


vs
Depth (m)
0
50
100
150
200
250
300
0
200
400
600
800
1000
Distance (m)
1200.00
1100.00
1000.00
900.00
800.00
700.00
600.00
500.00
400.00
m/s

Conclusions

- Multimode surface-wave FWI provides a robust framework for near-surface characterization.
- Layer stripping is implicit in the process.
- Frequency increasing multiscale bands can still be used in this case, since layer stripping is achieved by mode separation and not by frequency band selection.
- Horizontal component data is critical for this approach since it provides a more balanced measurement of fundamental and higher order modes energy. This might benefit SW-FWI using DAS data.
- Application of this approach on real data remains to be seen.

Acknowledgements

- Dr. Wenyong Pan
- Compute Canada
- NSERC (Grant CRDPJ 461179-13)
- Canada First Research Excellence Fund (CFREF)
- CREWES sponsors
- CREWES faculty, staff and students.