Toward robust multicomponent FWI on land data: handling topography and data conditioning

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Outline

- Introduction
- Finite difference vs spectral element modelling from the topography
  - Gridding and smoothing
  - Surface-wave spectral analysis
  - Computational cost comparison
- Hussar benchmark dataset
- Remarks

Introduction

Goal: to understand the impact of multicomponent land data conditioning on the FWI output.

Multicomponent land data challenges:

Strong elastic effects	→	Surface-waves
Highly heterogeneous near-surface velocities and irregular topography	→	P and S-wave Statics
Varying source and receiver spectral responses	→	Deconvolution operators
Varying source and receiver coupling conditions to the ground	→	Amplitude balancing

In general, how do we condition the data to account for the missing physics/acquisition effects in the FWI?

FD modelling

Hussar 2D-3C elevation change: 83.9 m
CMP distance 5 m
Air layer: V_p=310 m/s, V_s=0 m/s, ρ=1.25 Kg/m^3

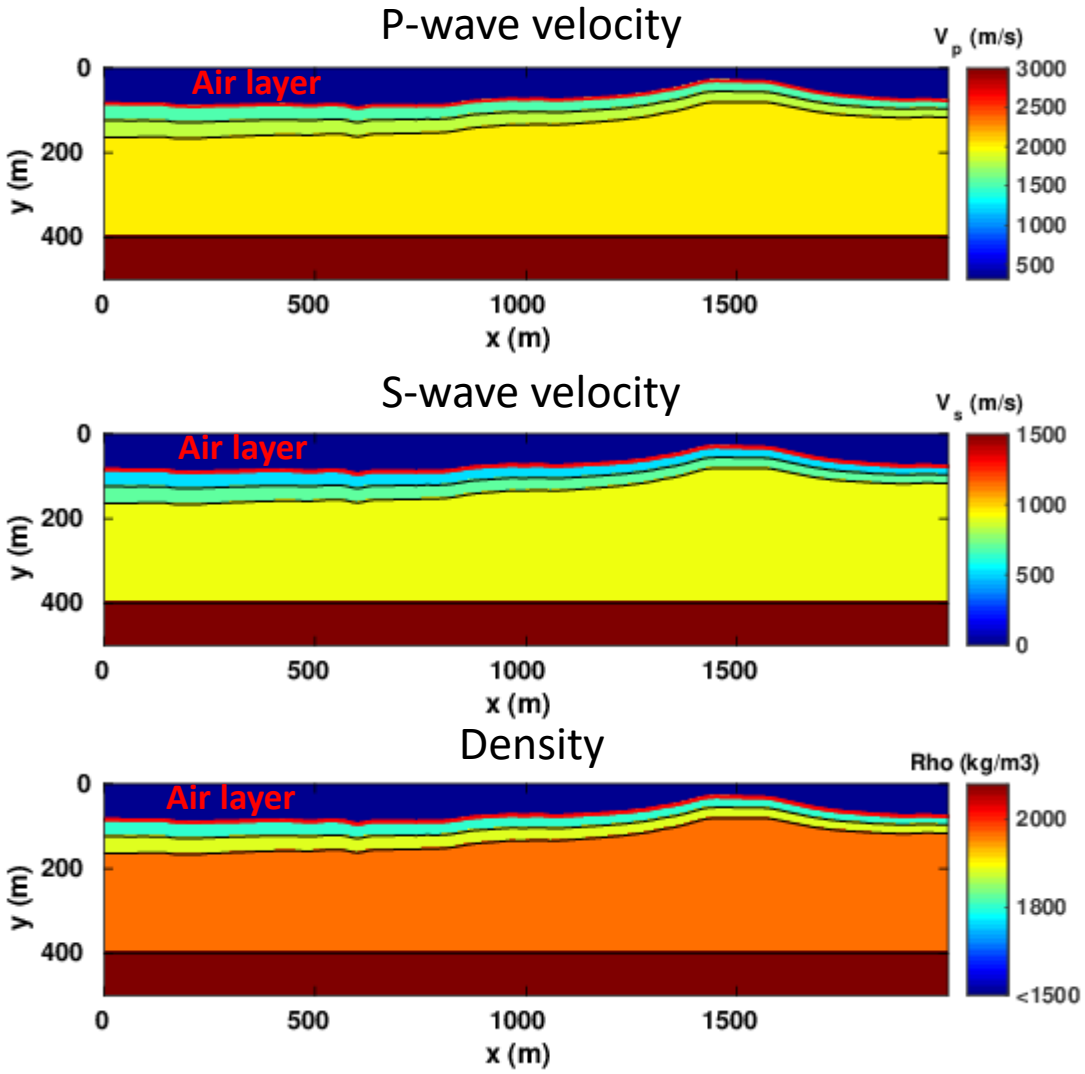
Grid dispersion

$$dh \leq \frac{V_{min}}{n f_{max}}$$

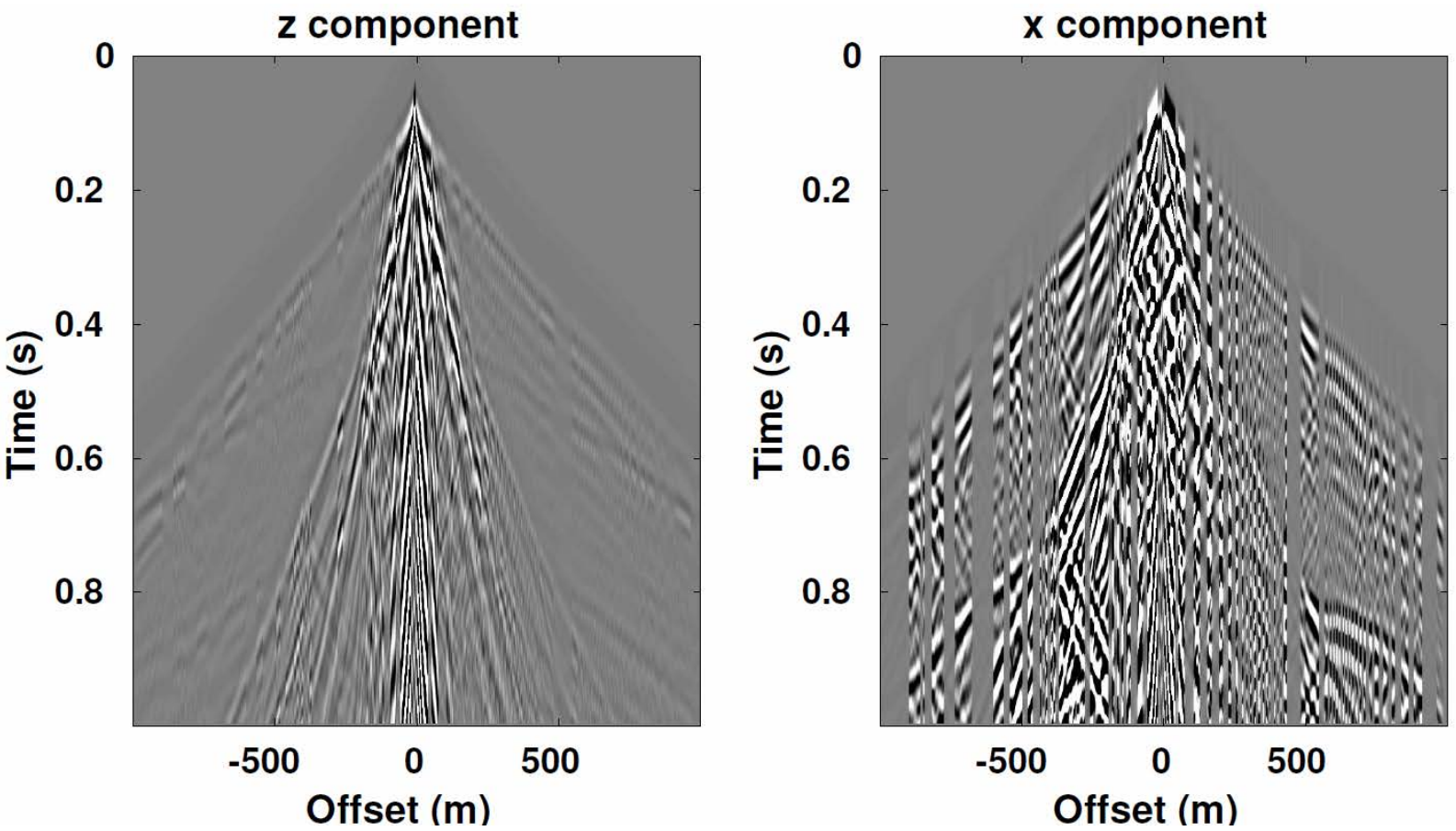
CFL (Courant–Friedrichs–Lewy) condition

$$dt \leq \frac{dh}{h\sqrt{2}V_{max}}$$

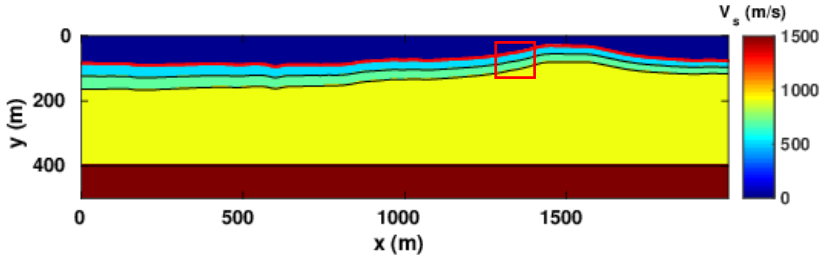
For a 12-th order space FD algorithm n=4 and h=1.34
Algorithm is 2nd order in time



FD Modelling: cell size 2.5m

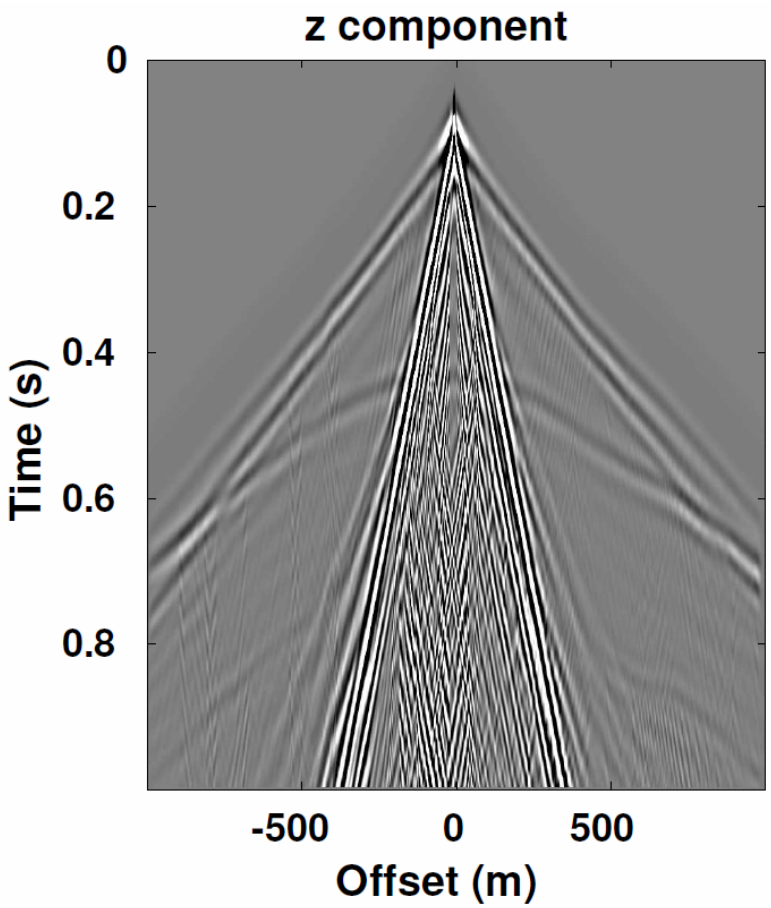


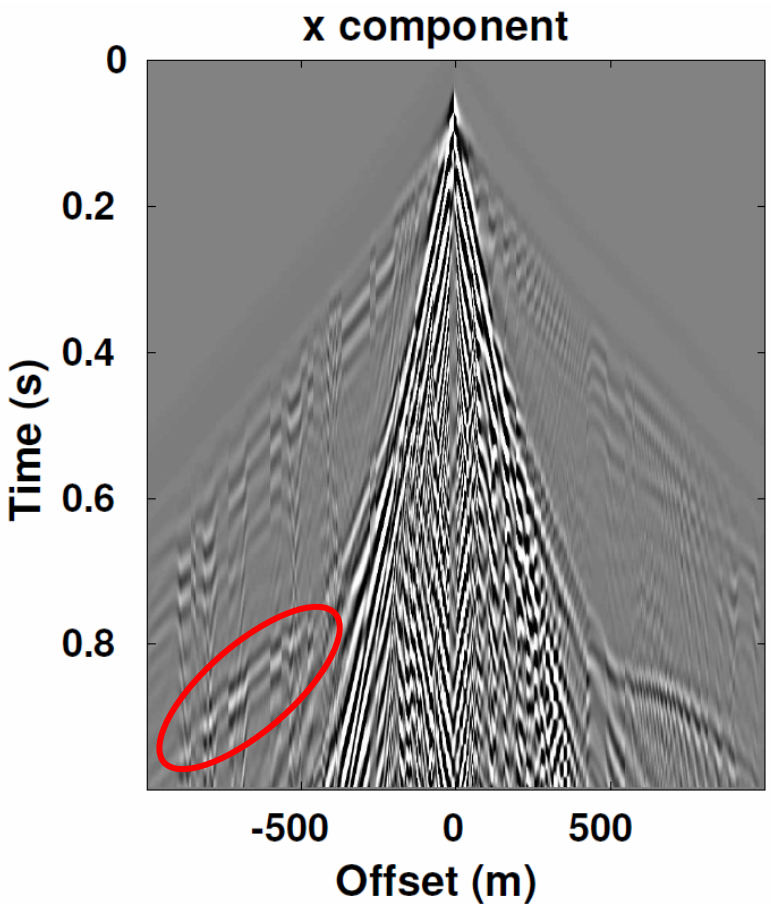
Air layer



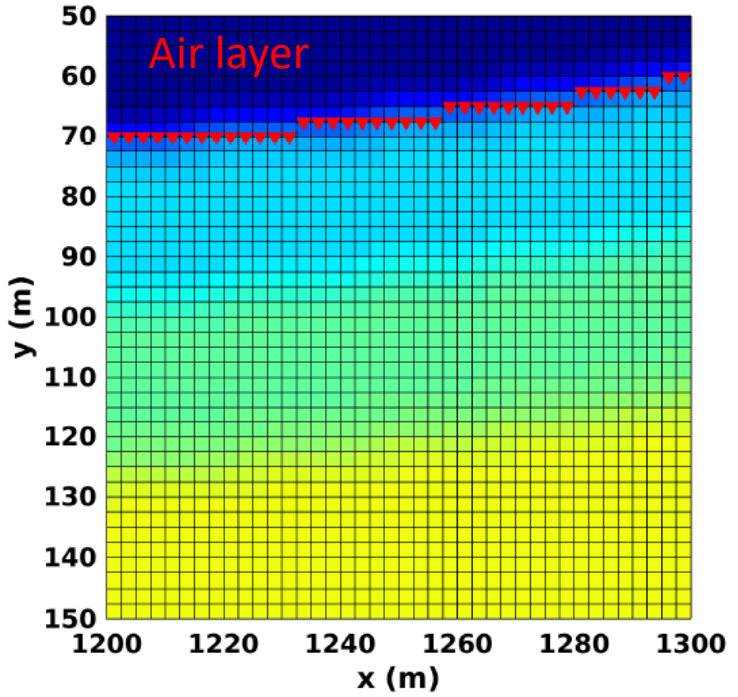
Very large lateral parameter contrasts result in distorted amplitudes

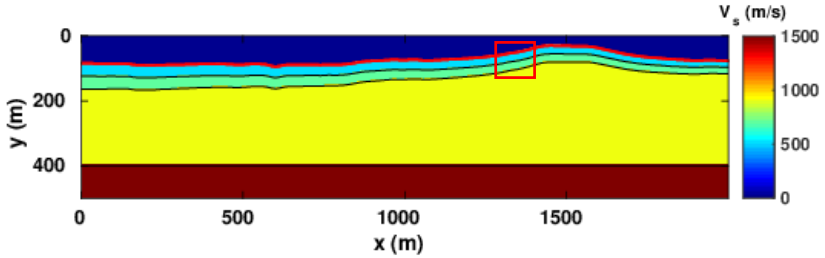
FD Modelling: cell size 2.5m + 5m smoothing



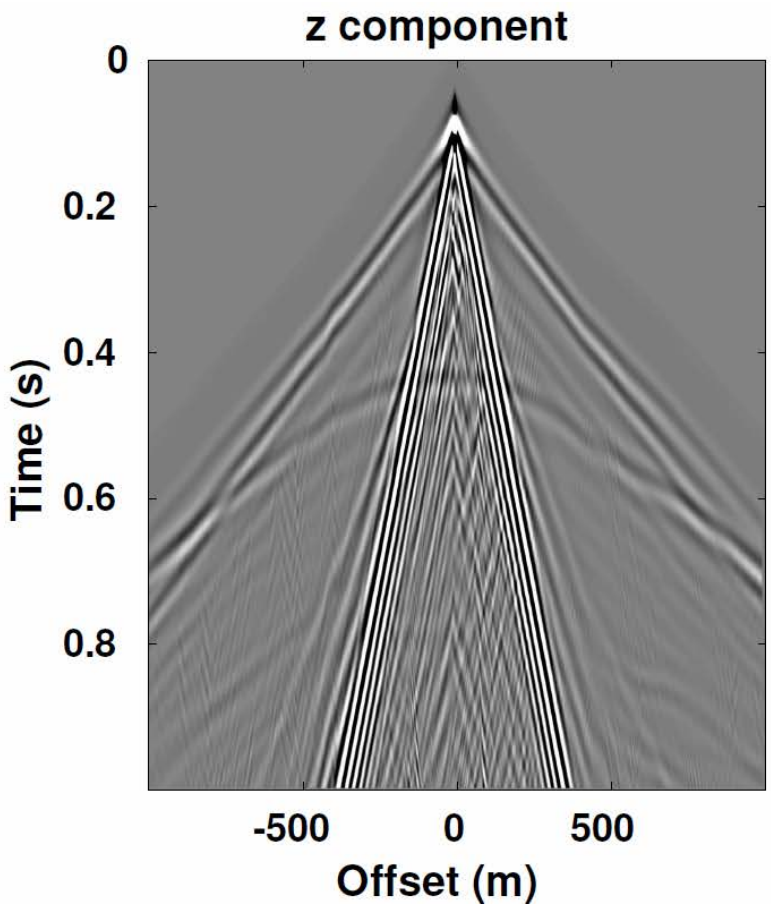


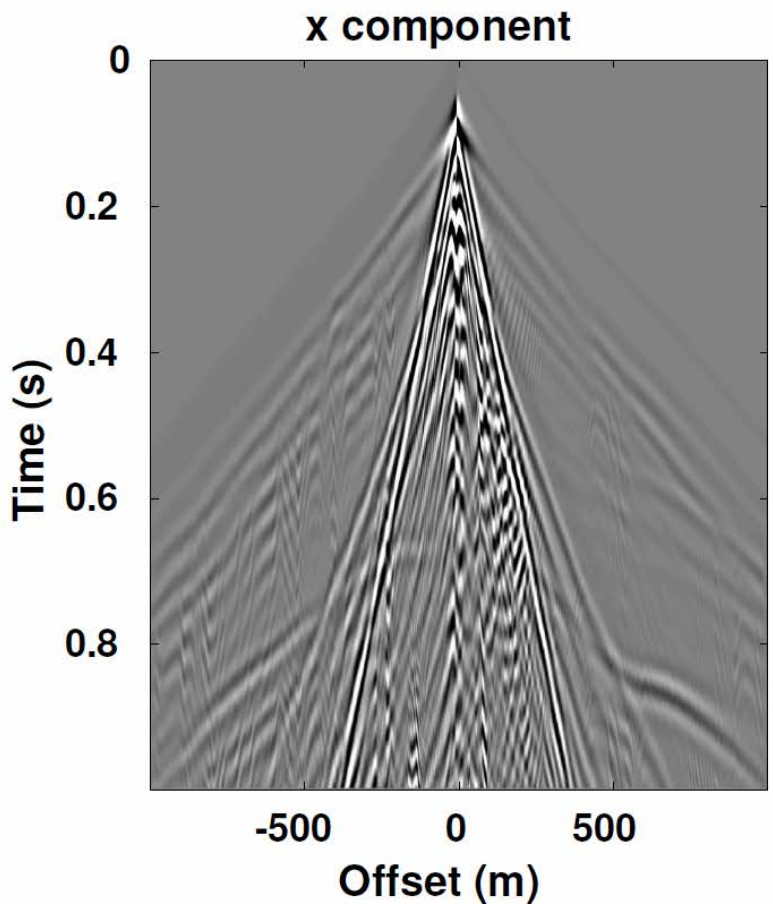
$$S_{static} = \frac{2.5m}{250m/s} = 10ms$$

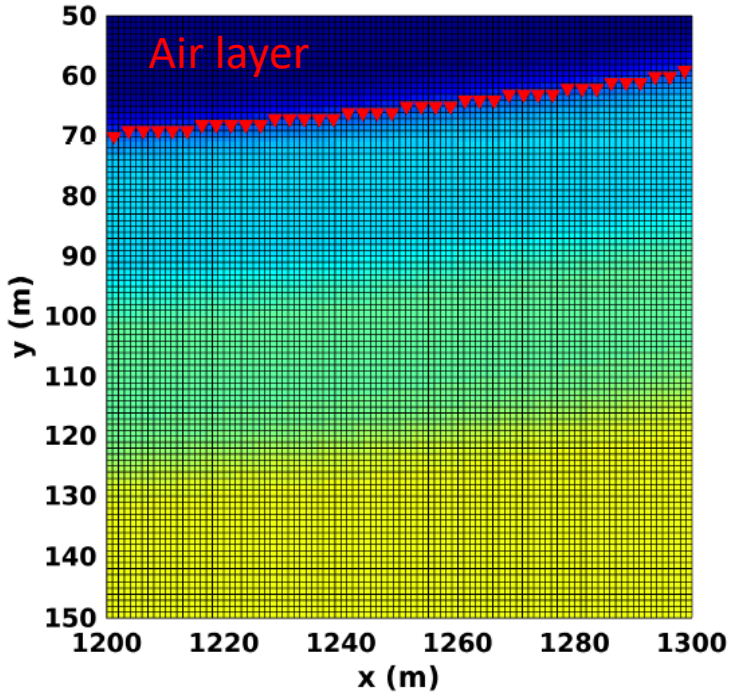


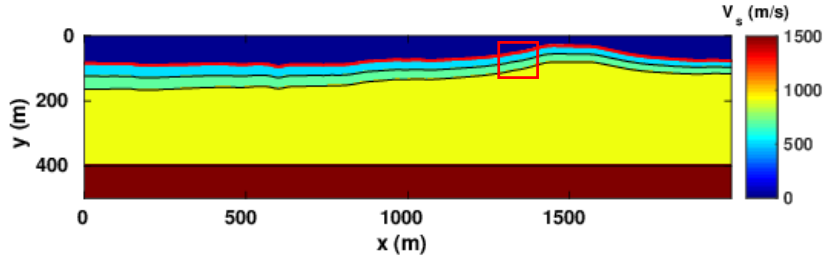


FD Modelling: cell size 1m + 5m smoothing







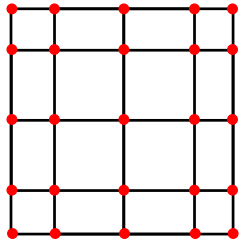


- Numerical statics have been reduced
- Fewer backscattered surface-wave energy is present

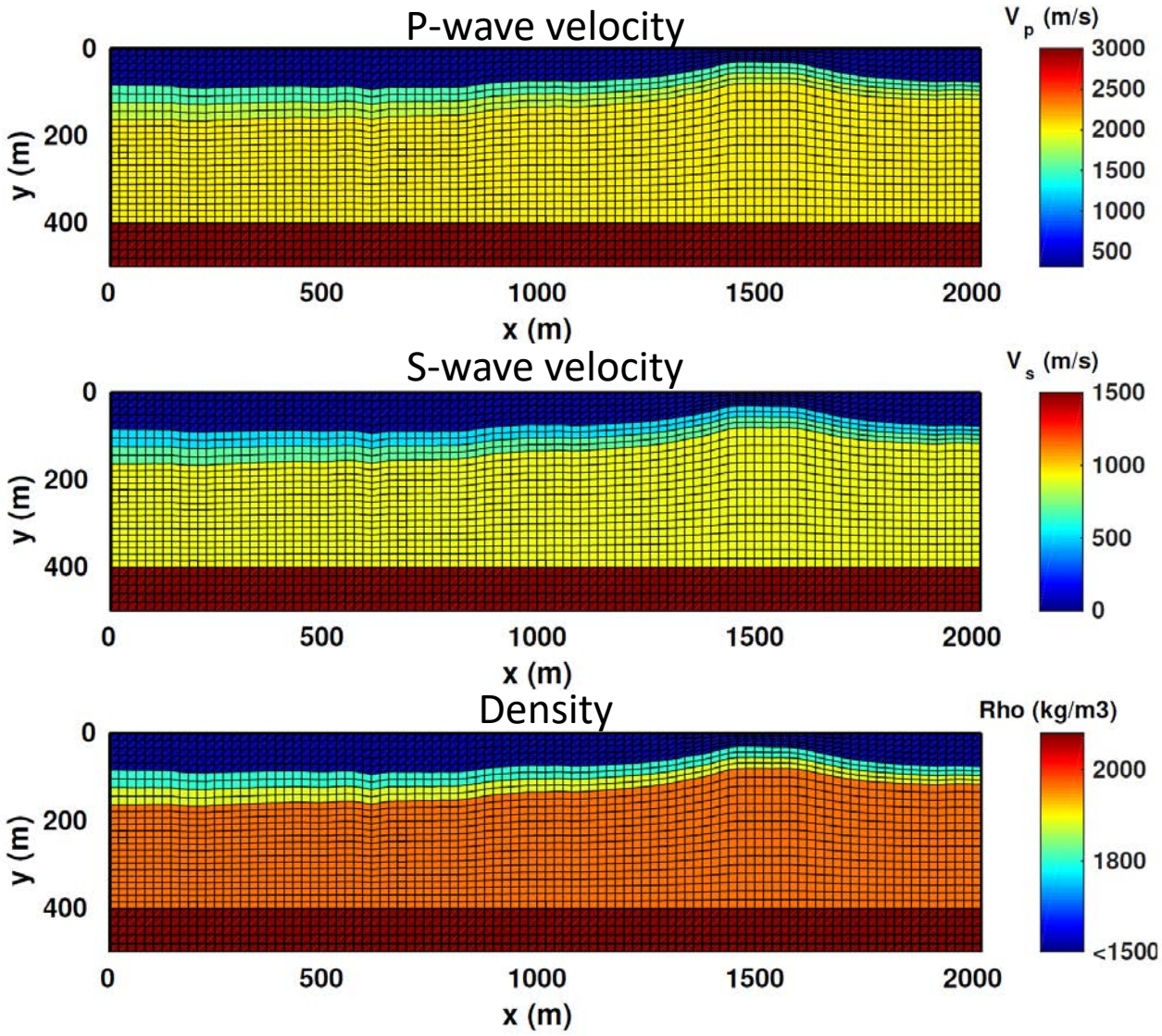
Spectral Element Modelling

SEMPACK2D (Ampuero, 2012)

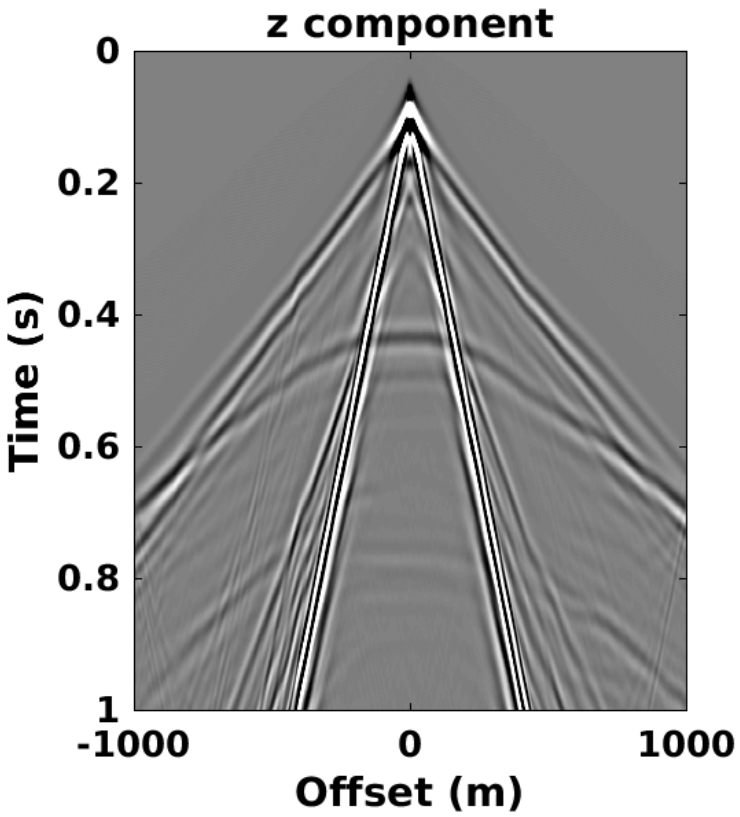
- High order spatial differentiation scheme
- Grid boundaries coincide with major interfaces
- Each element is subdivided onto a non-regular grid of N^2 nodes clustered near the edges of the elements

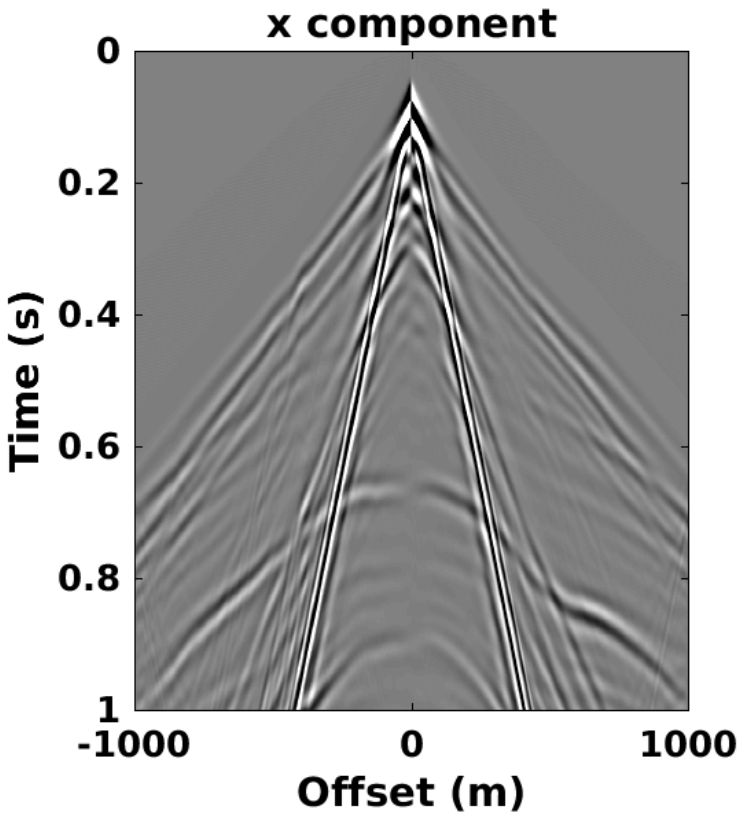


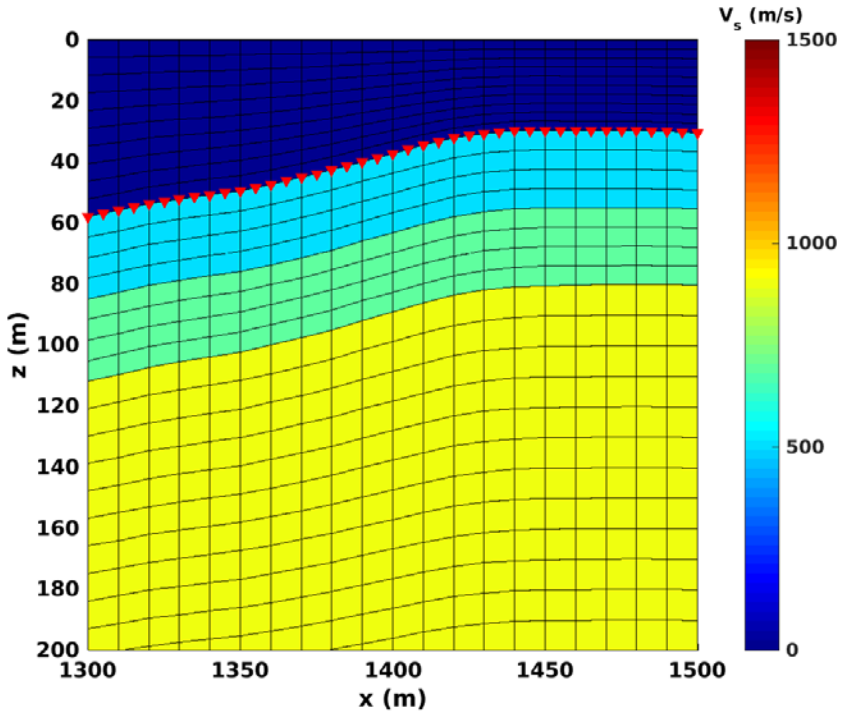
- Max element size: 10 m
- Minimum node distance: 0.51 m
- Maximum node distance: 3.42 m



Spectral Elements Modelling







- The adaptive mesh allows for more accurate vertical placement of receivers.
- No significant numerical statics are introduced.

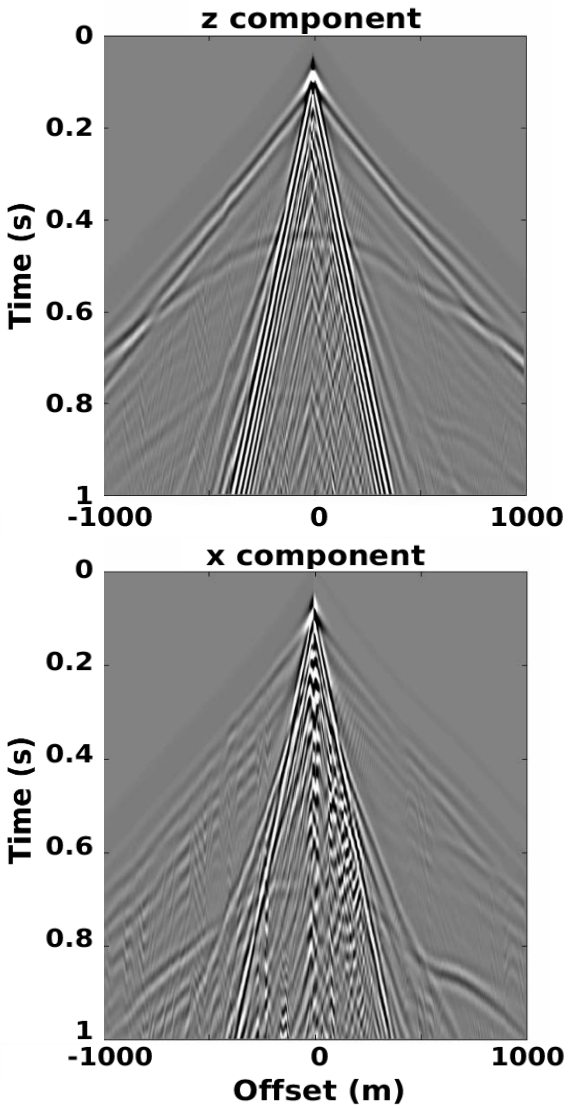
Model used for FD

- Cell size: 1 m
- Smoothing: 5 m

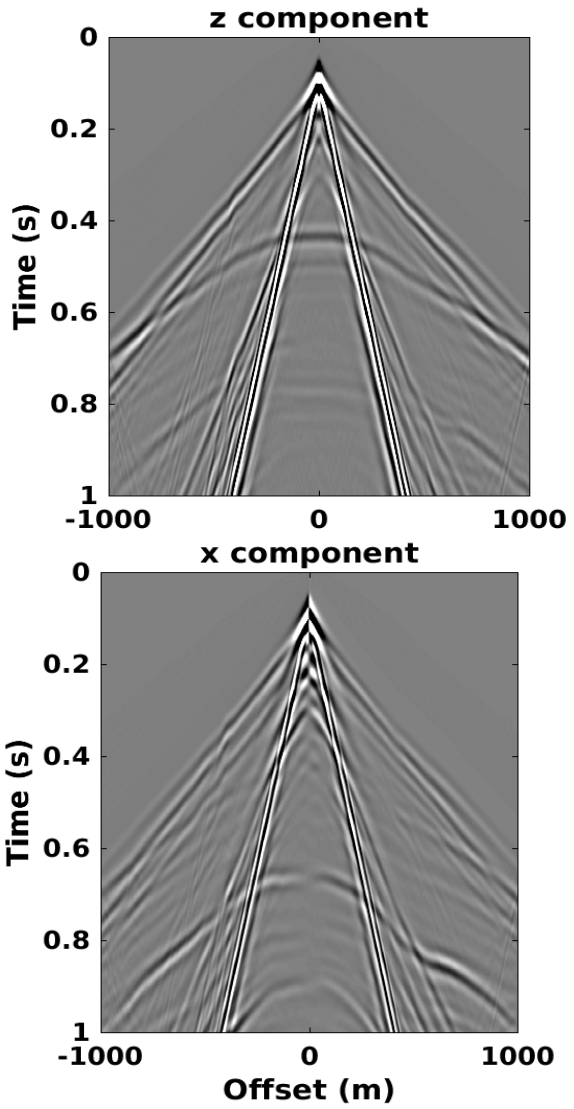
Vertical component

Horizontal component

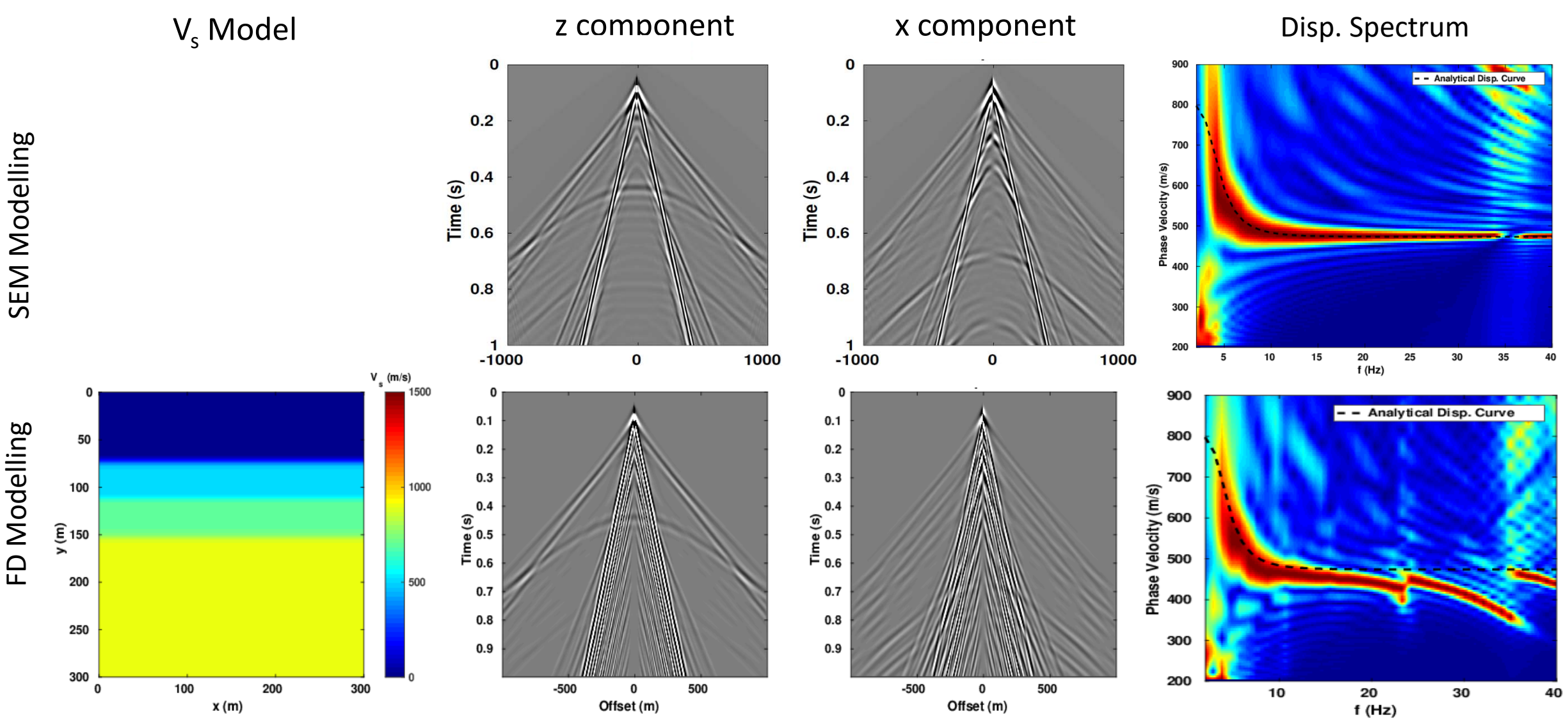
Finite difference modelling



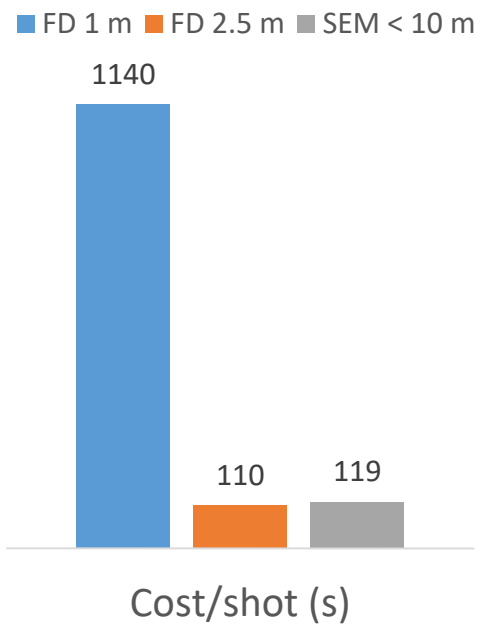
Spectral element modelling

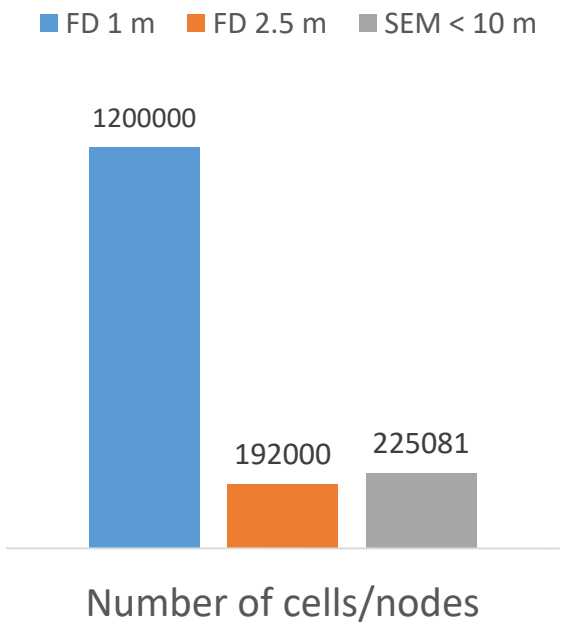


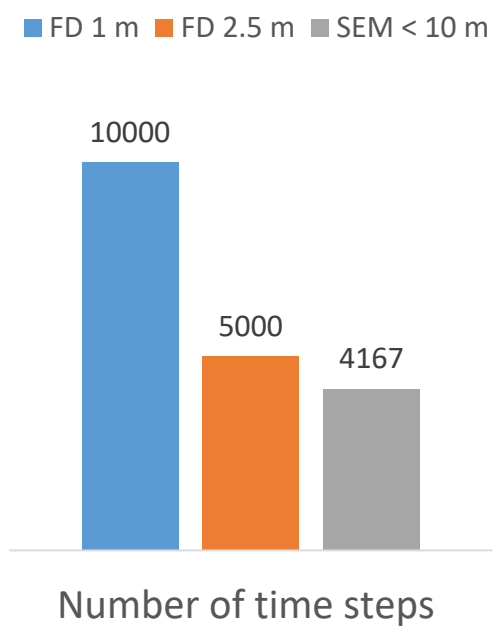
Surface-waves spectral analysis



Computational cost



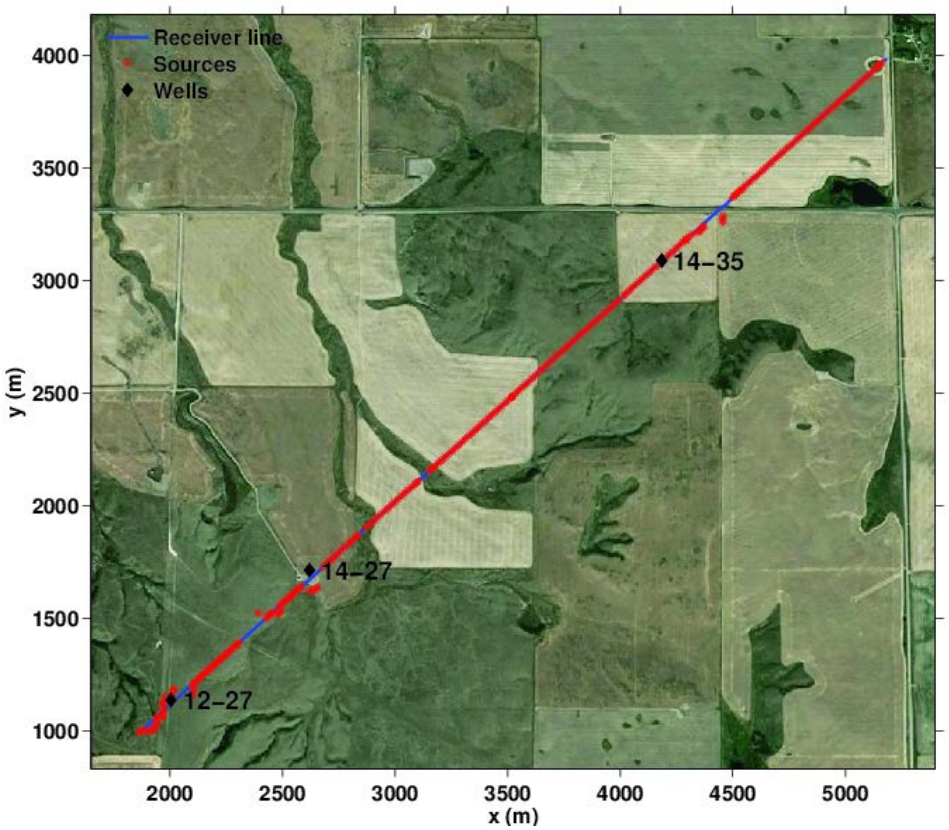




The spectral element modelling provided cleaner results at a cost 9.6 times cheaper (per shot) than our “best” FD modelling

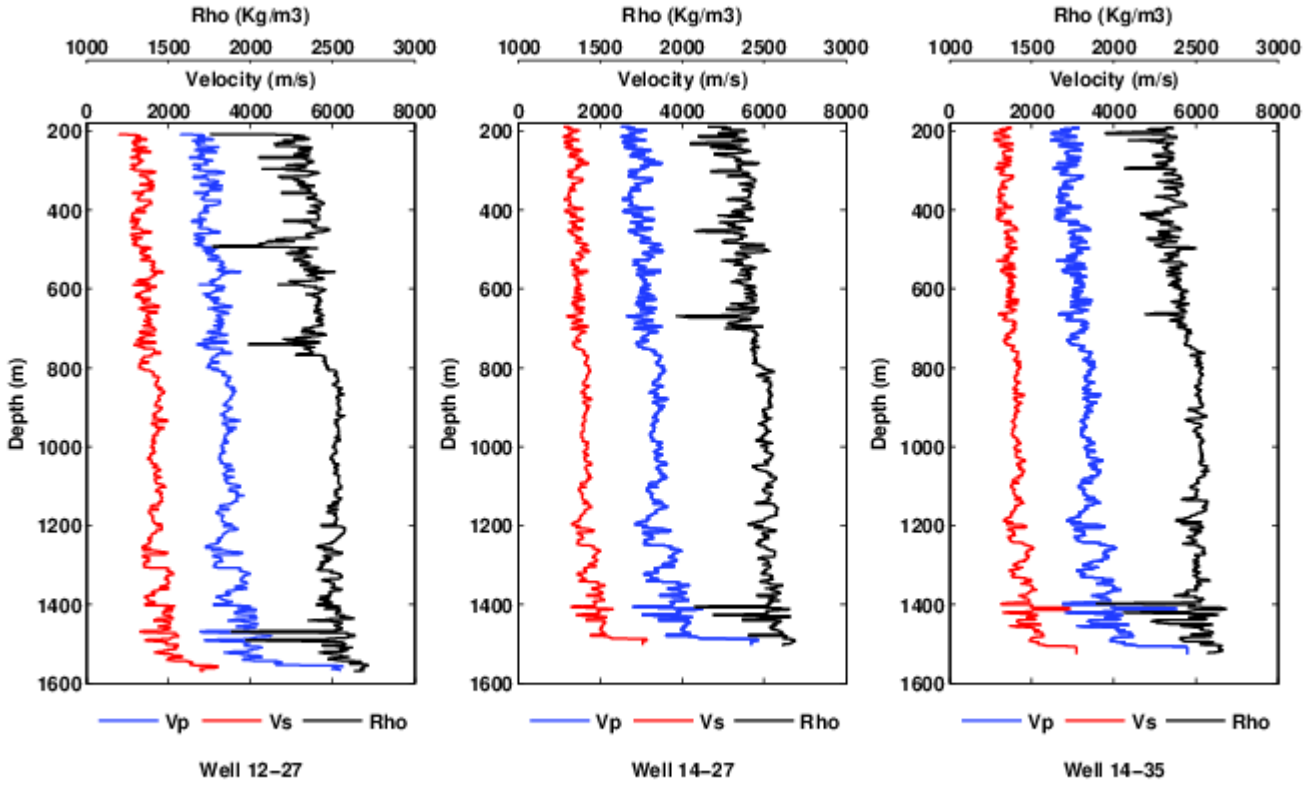
Hussar 2D-3C dataset

Survey map



- Total length 4400 m
- Receiver spacing 10 m
- Source spacing 20 m

Well log data



In wells 14-27 and 14-35 $\longrightarrow V_s = 0.6074V_p - 420.43$

(according to data from well 12-27)

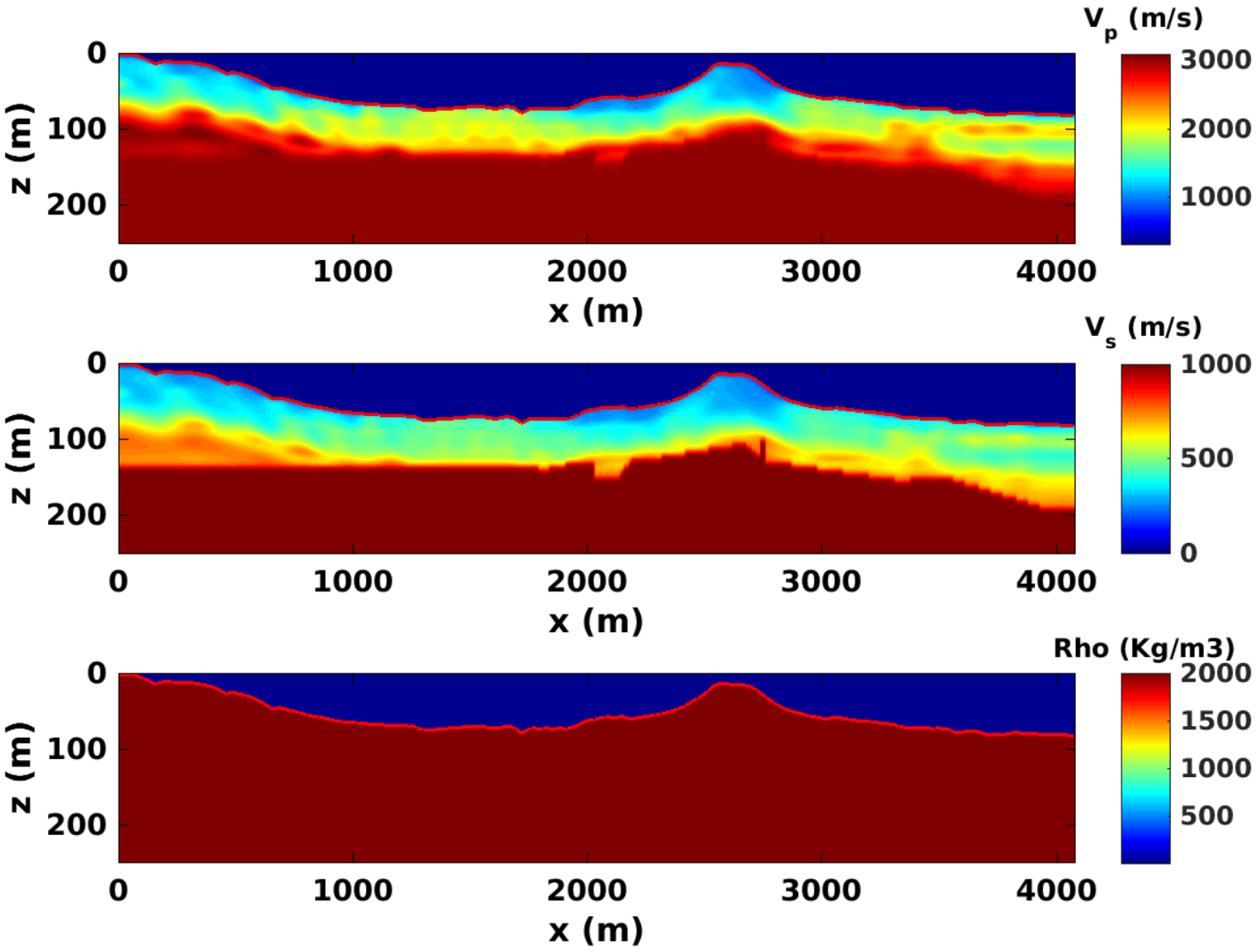
Near-surface models

P-wave first arrivals tomography

Near surface S-wave velocity model

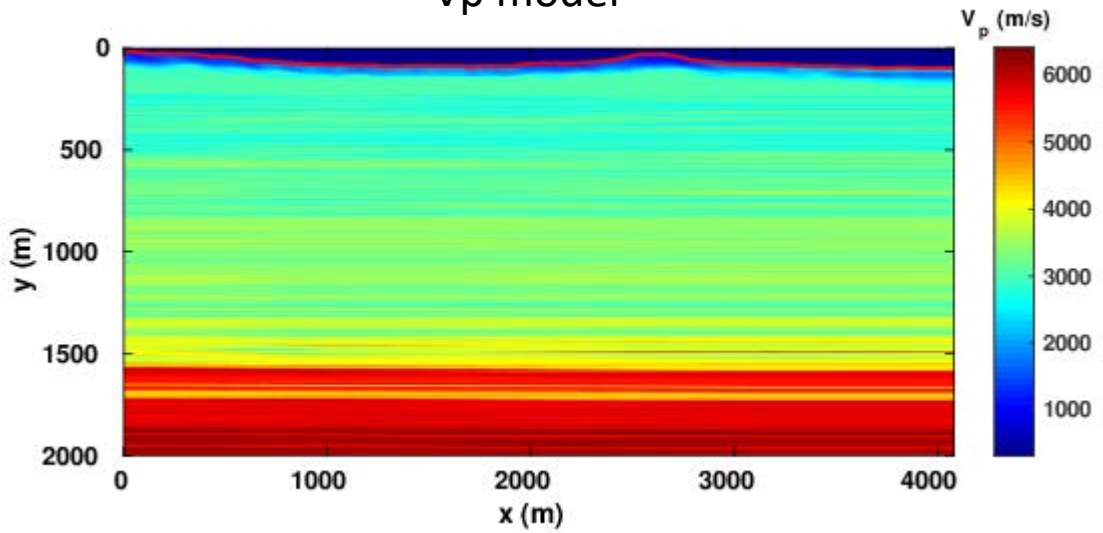
$$V_s = \frac{V_p}{4}$$

Constant density at the near-surface (2000 Kg/m^3)

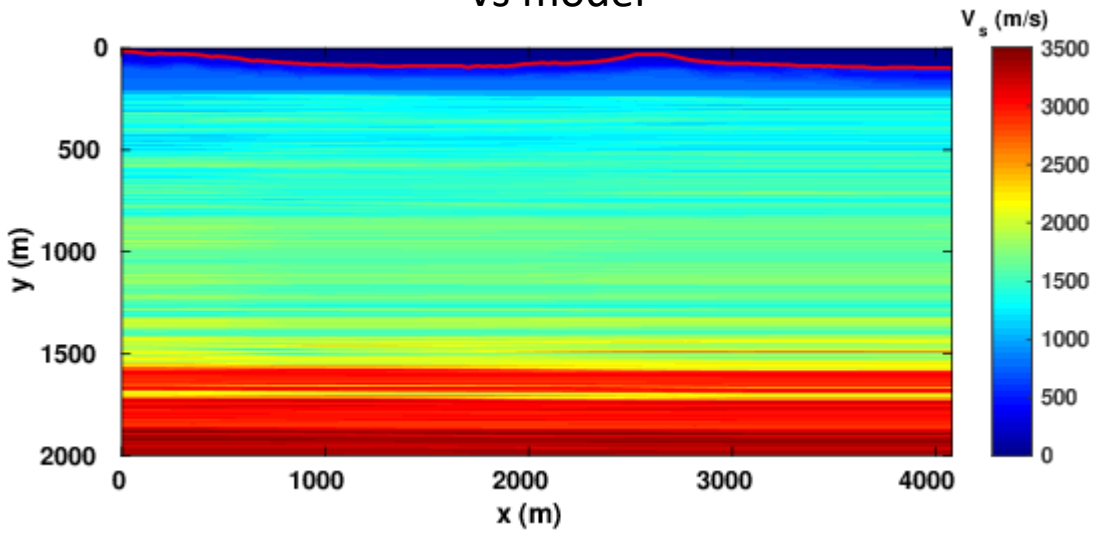


FD models

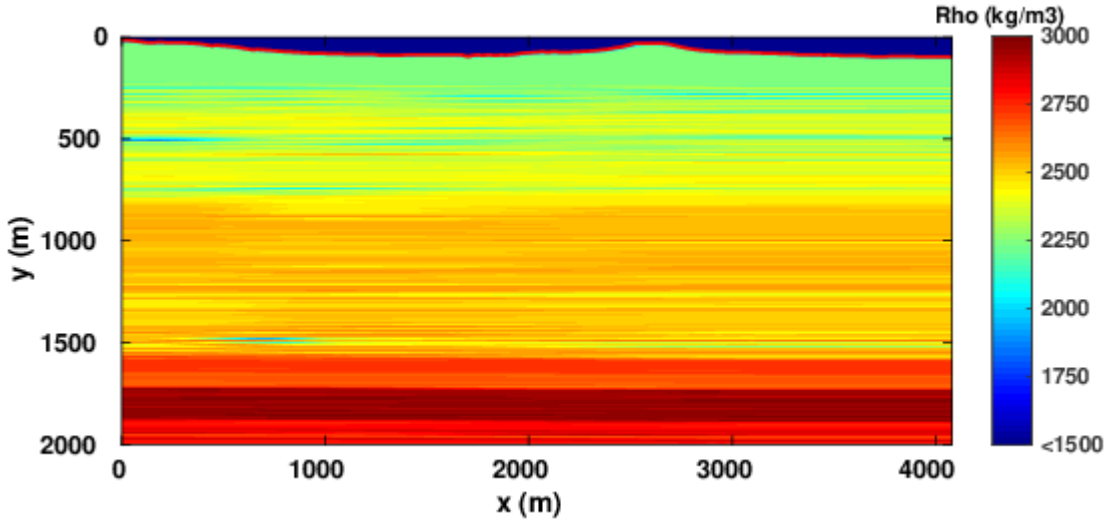
Vp model



Vs model



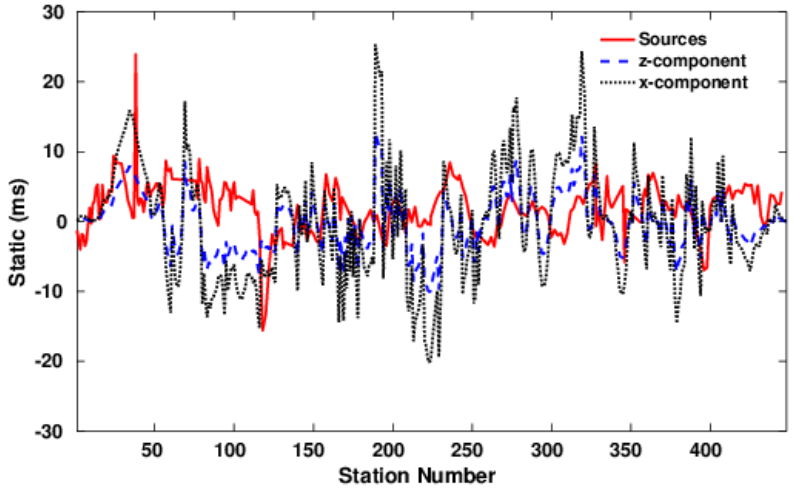
Density model



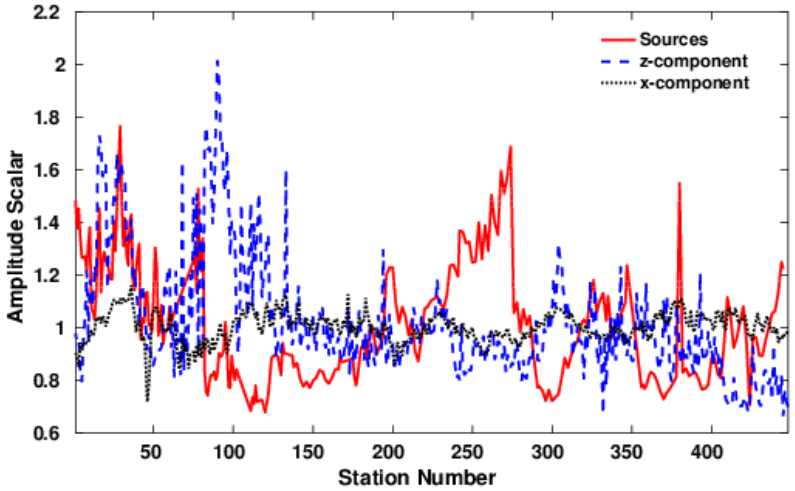
- Horizon-guided interpolation
- Horizons were created from formation tops
- Model extended from 1600 m to 2000 m using logs from a well at 7.8 Km from the line

Field data corrections

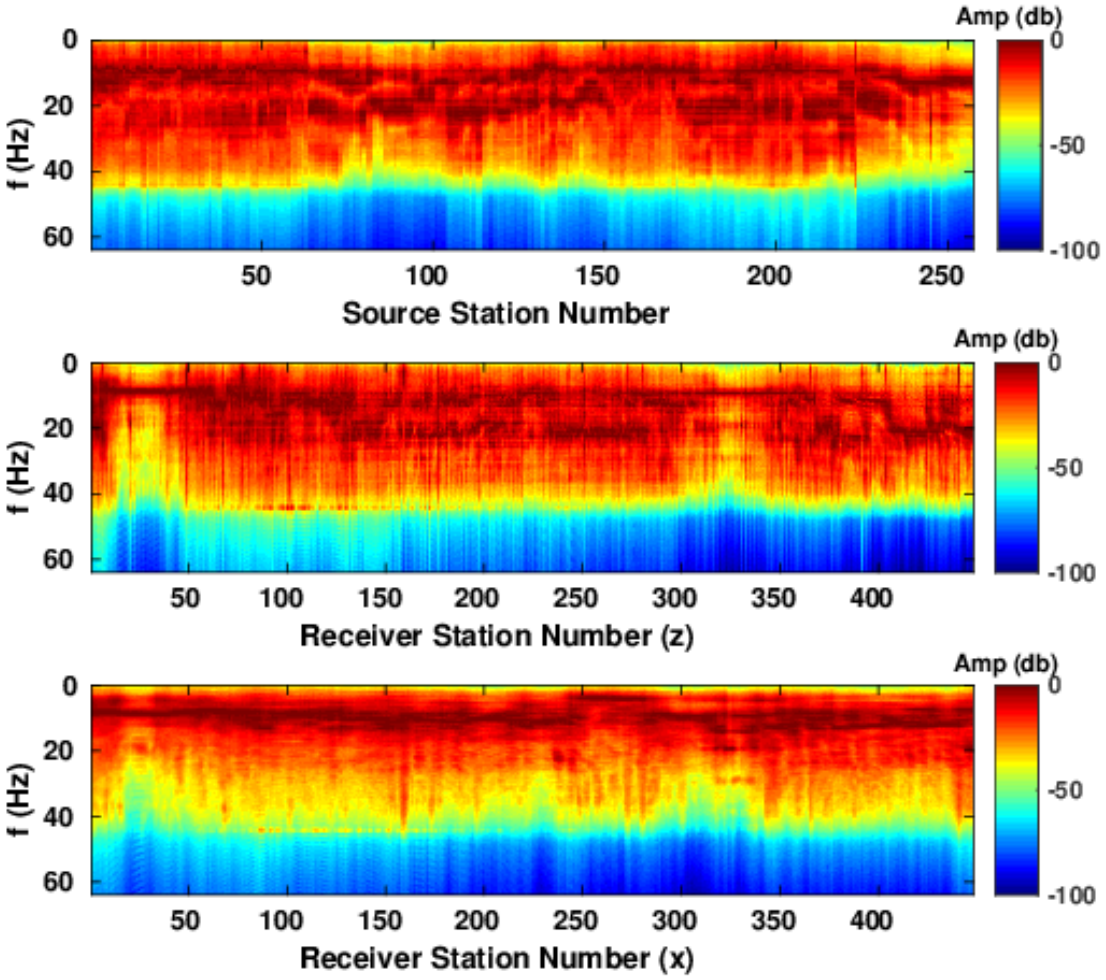
Short-wavelength surface-consistent statics



Surface-consistent amplitude scalars

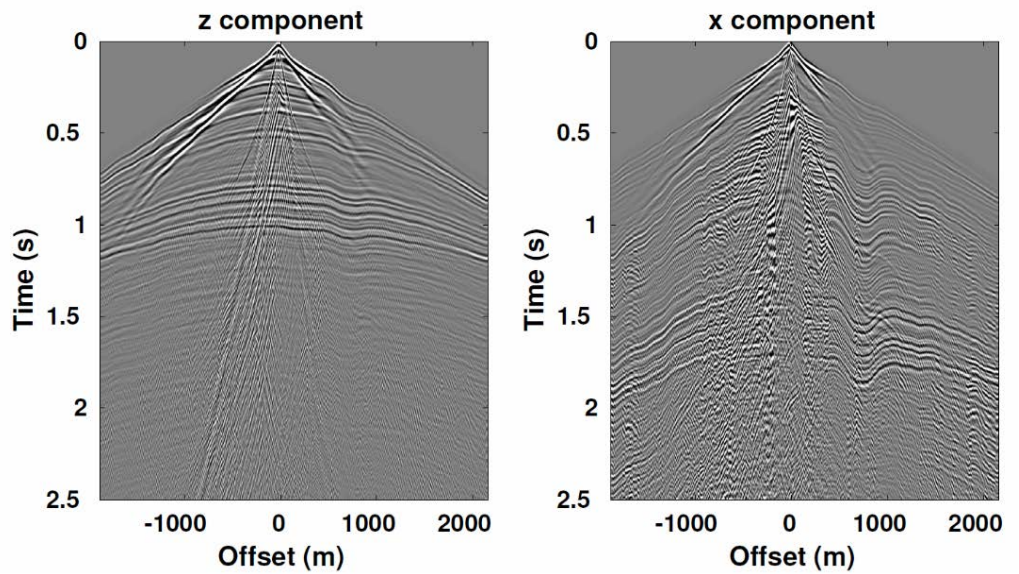


Surface-consistent decon operators amplitude spectrum

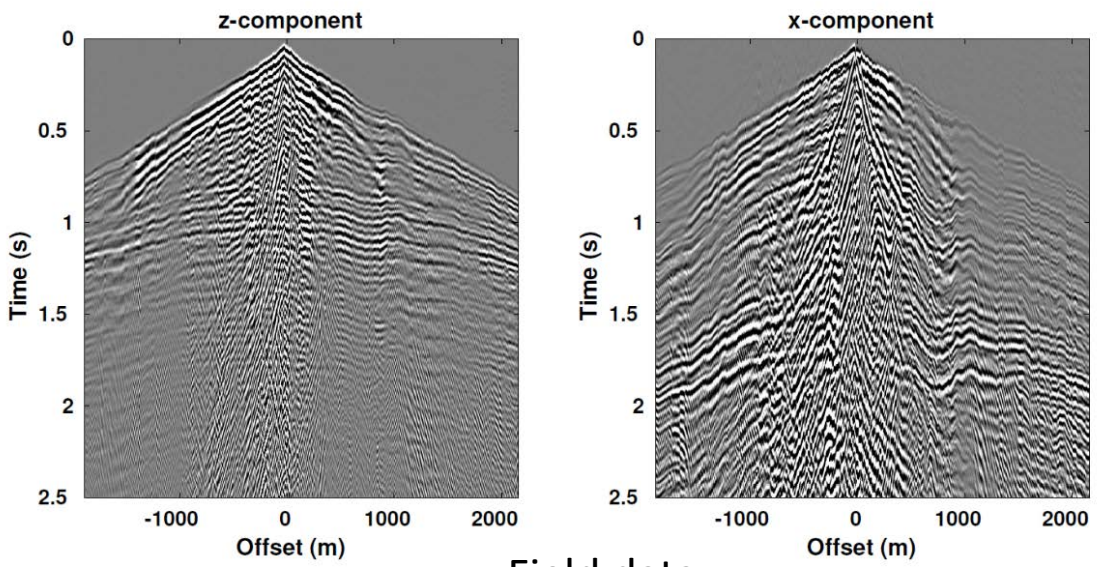


Data comparison

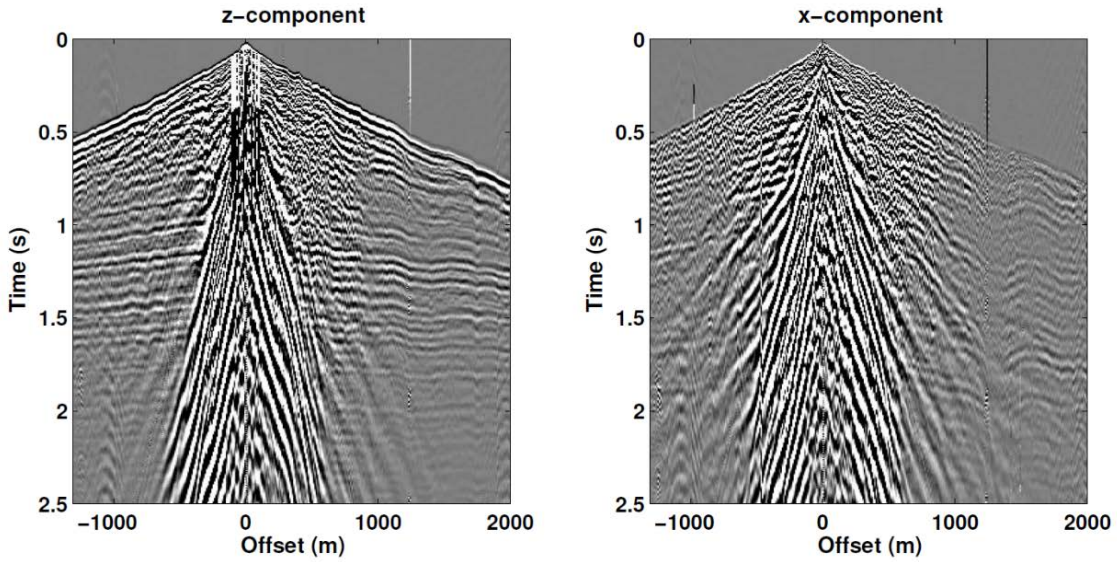
Fully synthetic data



"Field-like" synthetic data



Field data



- A more accurate near-surface S-wave velocity model is needed to properly reproduce surface-wave data
- Physics are still incomplete but the "field-like" data now contains some of the features observed on the actual multicomponent field data

Remarks

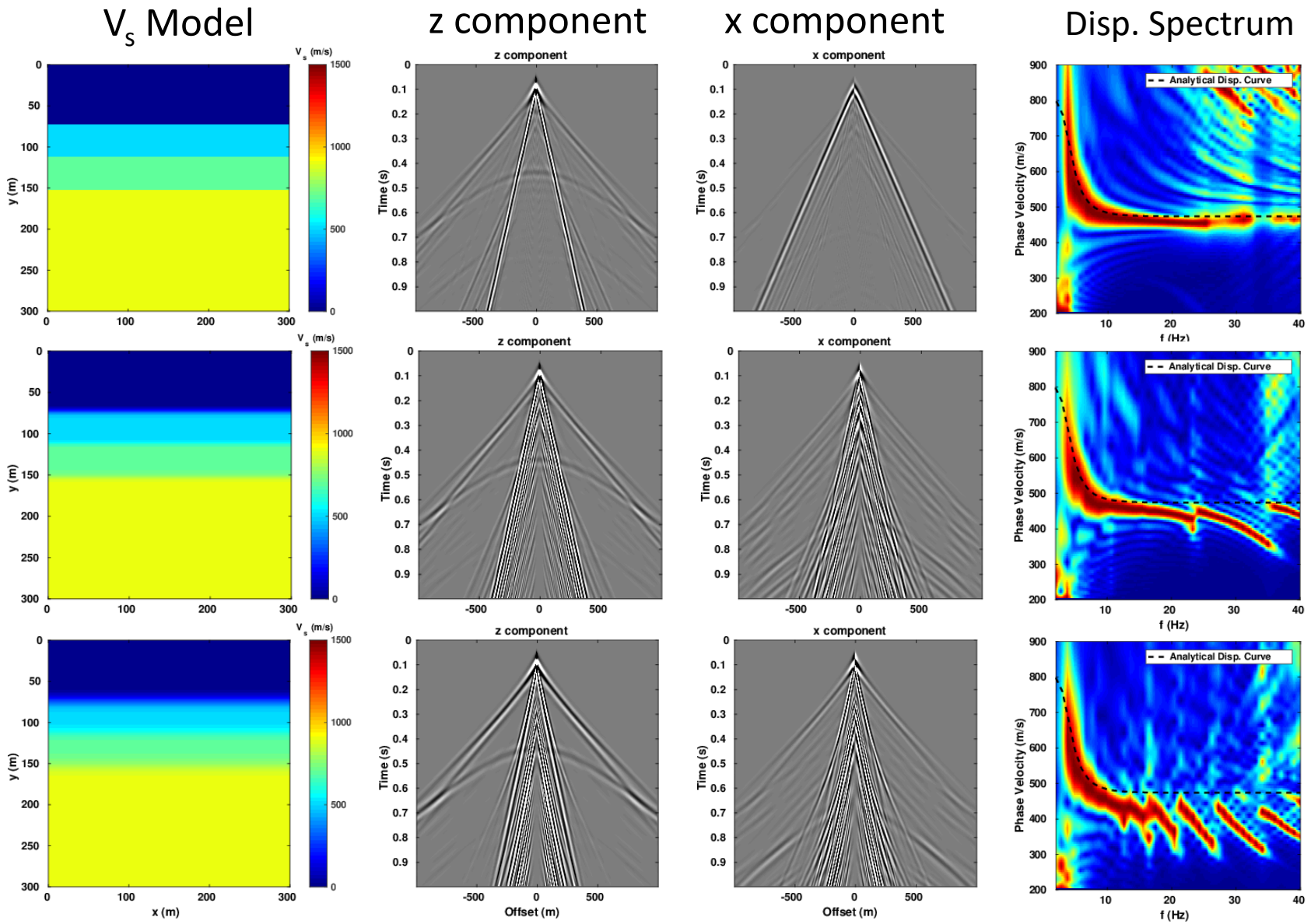
- When modelling data from the topography, the spectral element method provided “cleaner” and more accurate data than FD at a reasonable computational cost.
- A controlled dataset that resembles multicomponent land data has been produced.
- These data can be used as a benchmark not only for inversion algorithms but also for designing conditioning workflows and inversion strategies that account for acquisition-related problems present on multicomponent land data.
- Ultimately, we seek to provide a robust framework for FWI than can be used for reservoir characterization and monitoring projects using multicomponent land data.

Acknowledgements

- Canada First Research Excellence Fund
- CREWES sponsors
- CREWES faculty, staff and students.

Thanks!!!

Surface-waves spectral analysis



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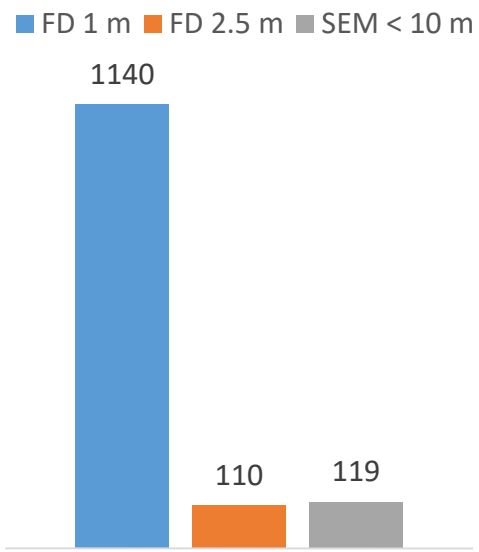

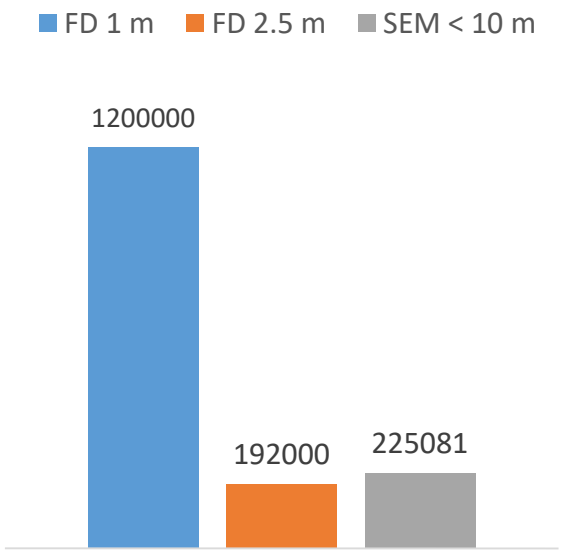

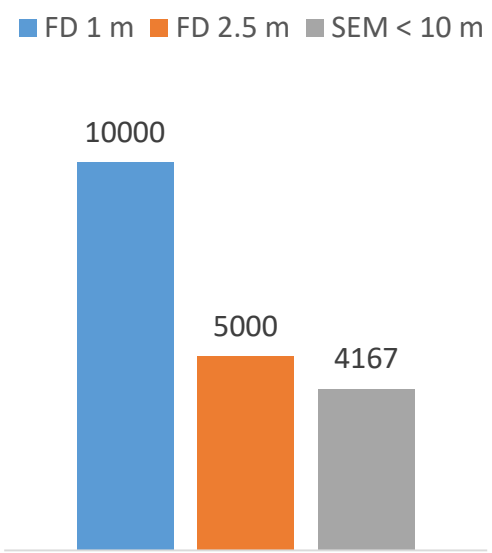

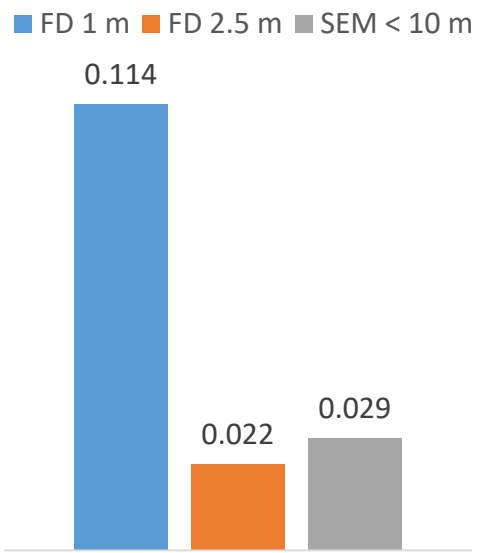

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