Full Waveform Inversion *or* Seismic velocity estimation

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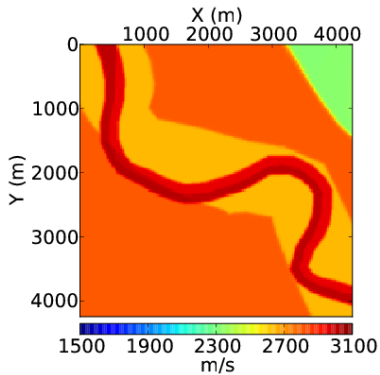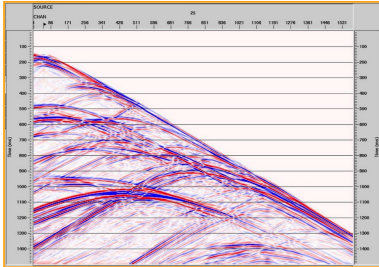NTNU
Department of Petr. Techn. and Applied Geophysics
borge.arntsen@ntnu.no
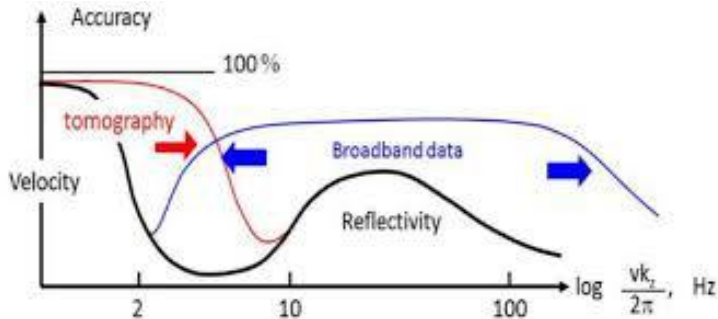
March 11, 2015

Overview

Introduction

Ultimate goal:
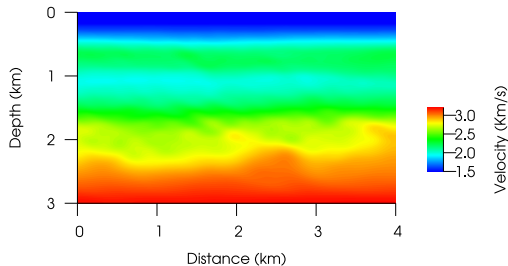Estimate seismic velocity from raw seismic data with high resolution

Introduction

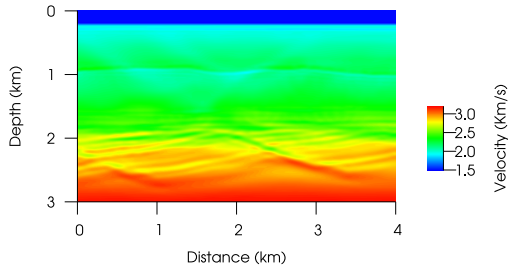Resolution of velocity models with using standard techniques
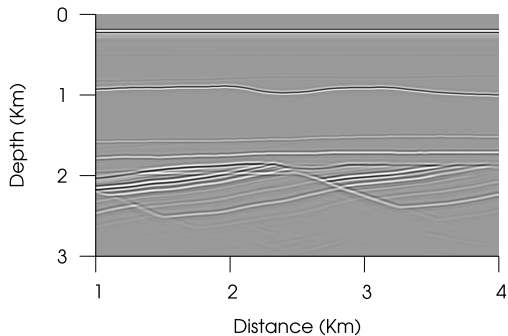
Introduction

Low resolution
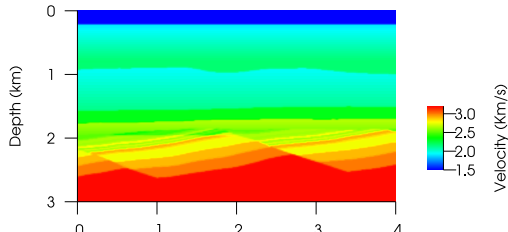

Intermediate resolution

Introduction

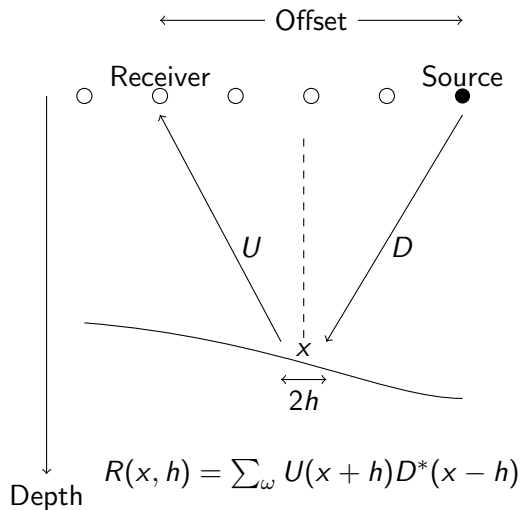## High resolution

True model

Introduction

Our approach:

1. Migration Velocity Analysis (MVA) (Low resolution)
2. Full waveform inversion (Intermediate resolution)
3. Migration (High resolution)

Seismic velocity models

Migration Velocity Analysis (MVA)

$$R(x, h) = \sum_\omega U(x+h)D^*(x-h)$$

Seismic velocity models

Minimize e_s w.r.t c

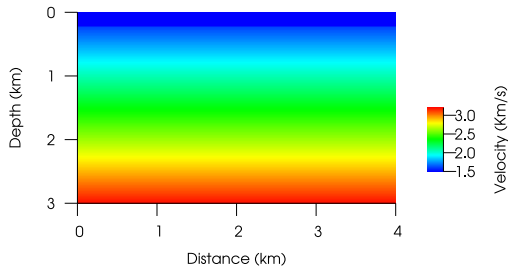$$e_s = \sum_x \sum_h h^2 \left[\frac{\partial R(x, h)}{\partial z} \right]^2, \qquad (1)$$

Iterative solution

$$c = c_0 + \Delta c$$
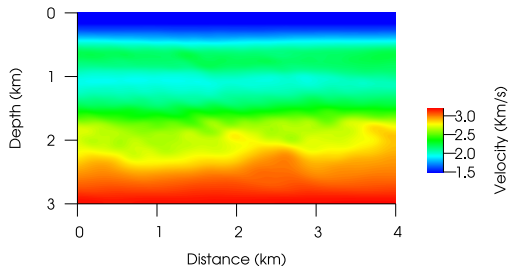$$\Delta c \approx \alpha \nabla_c e_s \qquad (2)$$

- e_s is mainly sensitive to travel-time
- Low resolution
- Relies on the Born Approximation
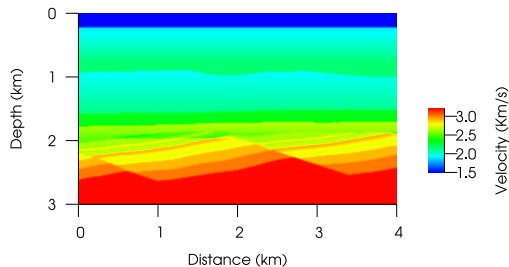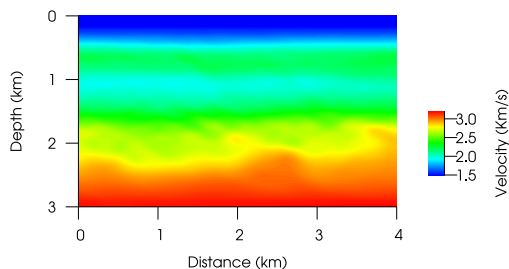
Seismic velocity models

Initial model

MVA
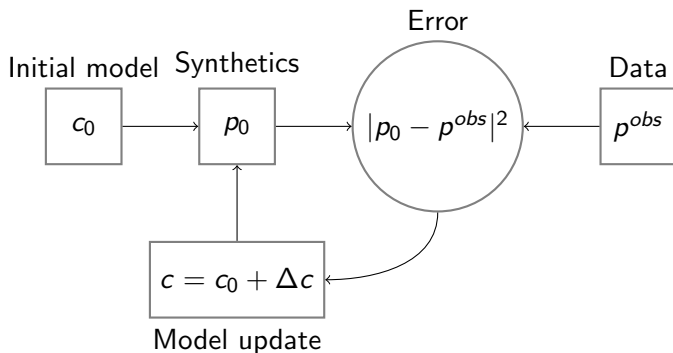
Seismic velocity models

Exact model

MVA

Seismic velocity models

Full Waveform Inversion loop

Seismic velocity models

Full Waveform Inversion (FWI) minimization the least-squares error w.r.t. velocity (Tarantola, 1984)

$$e_l = |p - p^{obs}|^2 \qquad (3)$$

Linearization leads to a Newton-Raphson Scheme where the first iteration is
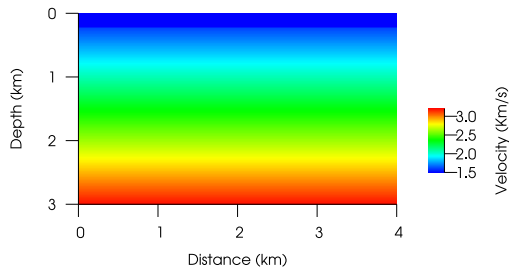
$$\mathbf{J}^T[p_0 - p^{obs}] = \mathbf{J}^T \mathbf{J} \Delta c \qquad (4)$$

where $\mathbf{J}$ is the Jacobi operator and the Born approximation is

$$\Delta p = p_0 - p^{obs} = \mathbf{J} \Delta c \qquad (5)$$

$$\Delta c \approx \alpha \nabla_c e_l = \alpha \mathbf{J}^T[p_0 - p^{obs}] \qquad (6)$$

Seismic velocity models

Initial model

FWI

Seismic velocity models
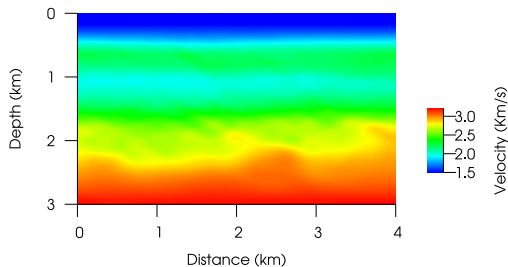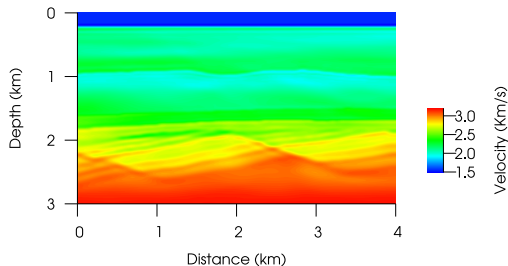
Exact model

FWI

Seismic velocity models
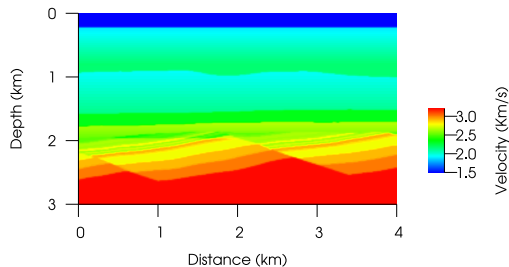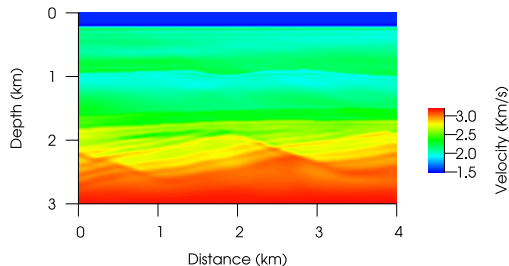

MVA Initial model
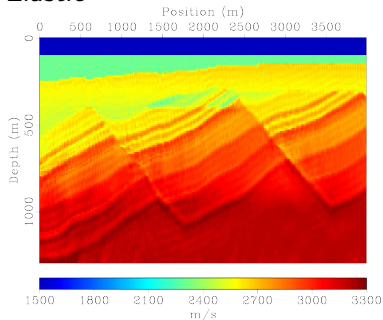
FWI

Seismic velocity models
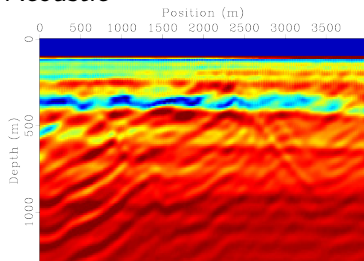
Exact model

FWI

Getting the physics right

- The Finite-difference forward model is extremely time consuming
- A common approximation is to neglect shear wave propagation
- Amplitudes of reflected compressional waves will be incorrect
- The 3D problem is treated as a 2D problem
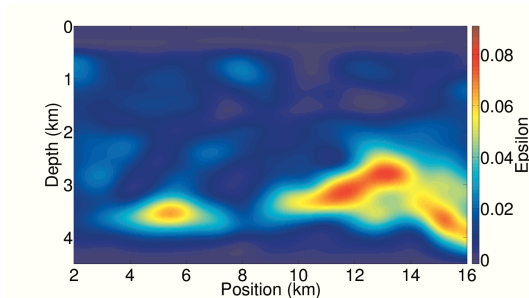
Getting the physics right
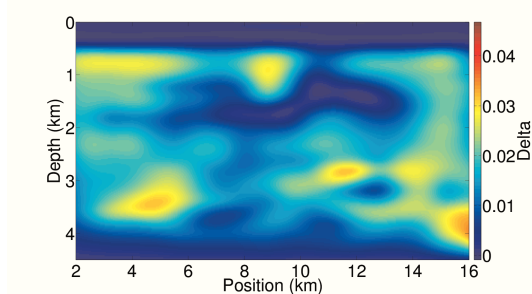
Elastic

Acoustic

OBC Synthetic Elastic FWI

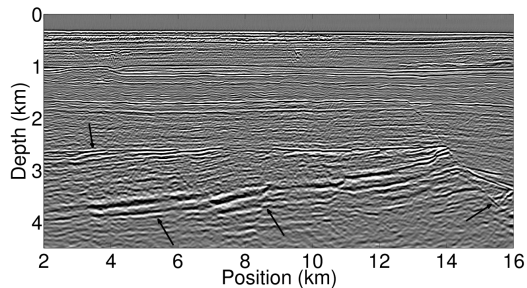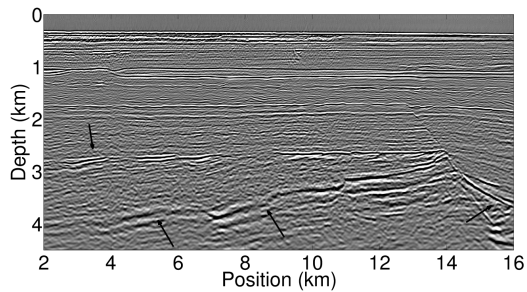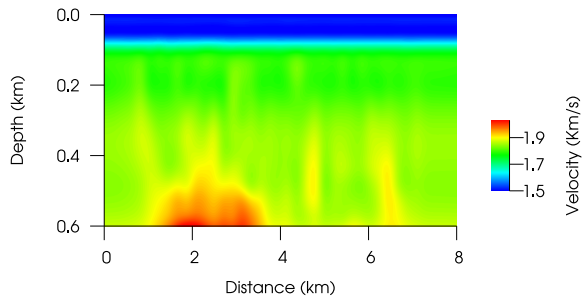# North Sea MVA

Initial

MVA
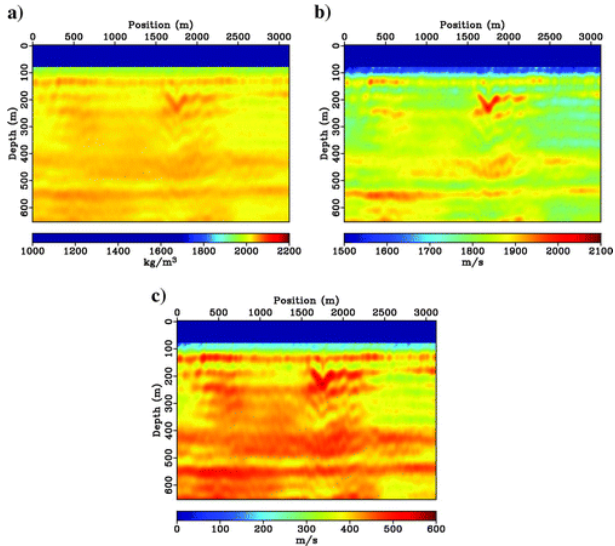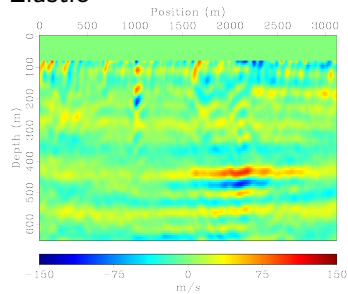
North Sea MVA

Anisotropy parameters

North Sea MVA
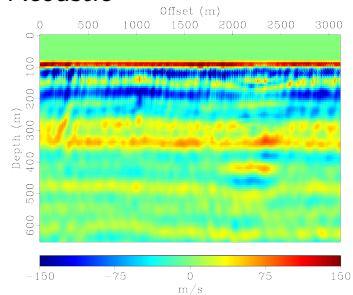
North Sea 2D Elastic FWI

North Sea 2D Elastic FWI
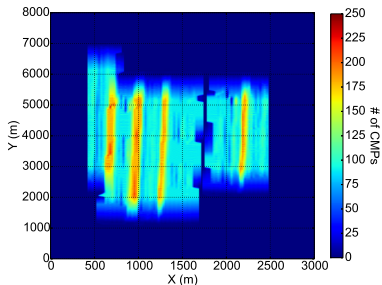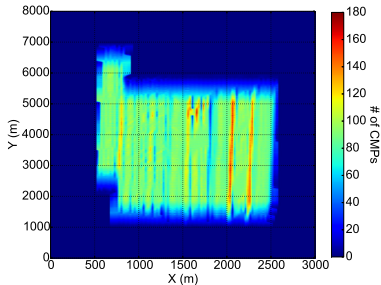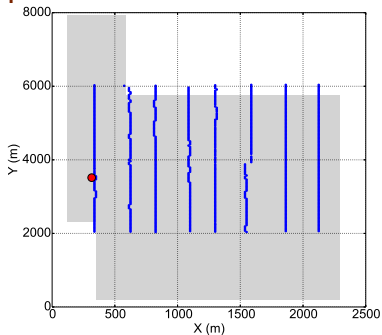
North Sea 2D Elastic FWI

Elastic

Acoustic

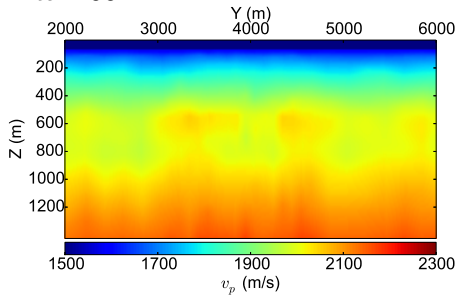# Sleipner 3D Elastic Full Waveform Inversion
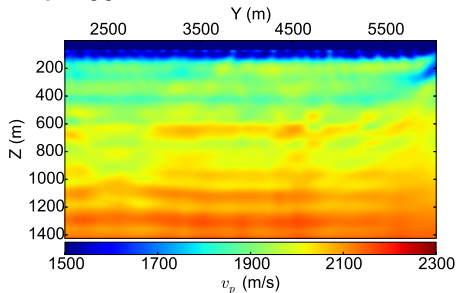

Streamer surveys from 1994 and 2006.

Sleipner 3D Elastic Full Waveform Inversion

Inital 1994

Final 1994

Sleipner 3D Elastic Full Waveform Inversion

Sleipner 3D Elastic Full Waveform Inversion

Well log

Sleipner 3D Elastic Full Waveform Inversion

Initial 1994

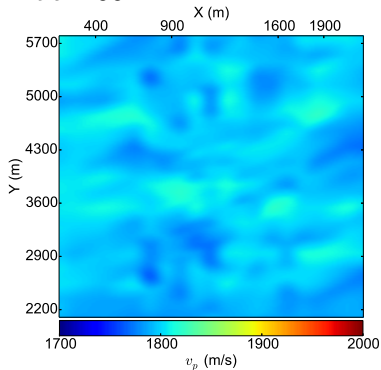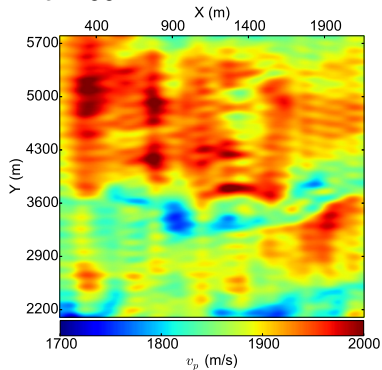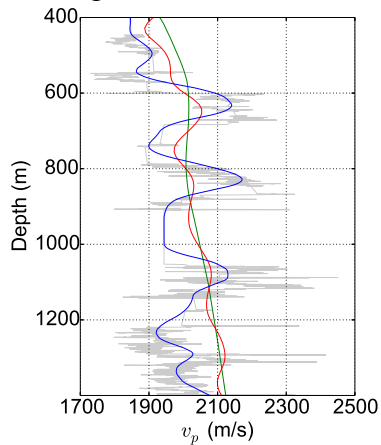# Sleipner 3D Elastic Full Waveform Inversion

Final 1994

Sleipner 3D Elastic Full Waveform Inversion

Initial 1994

Final 1994

Sleipner 3D Elastic Full Waveform Inversion
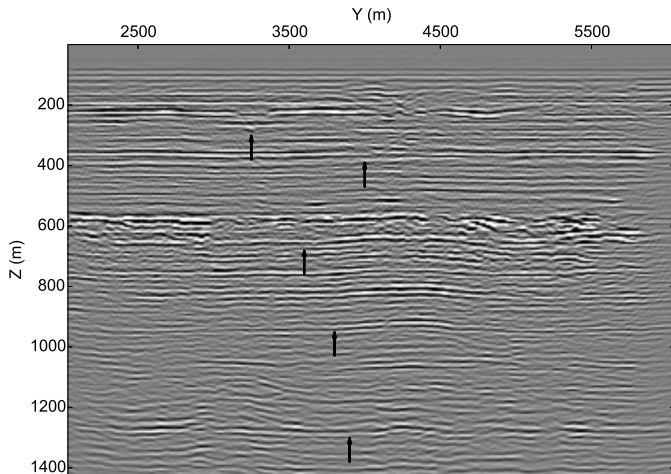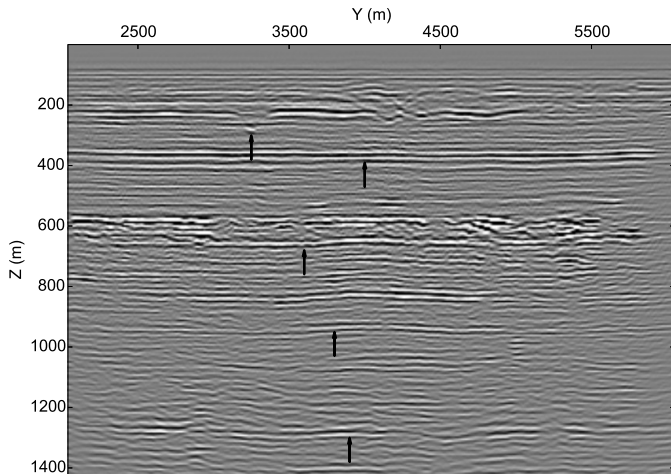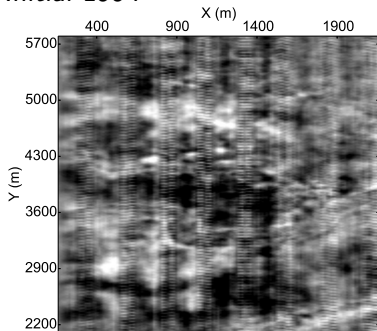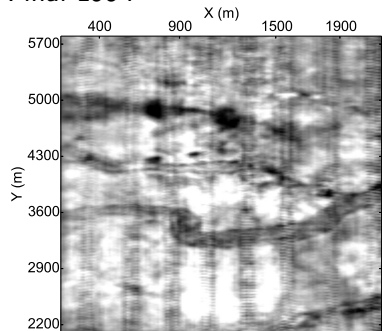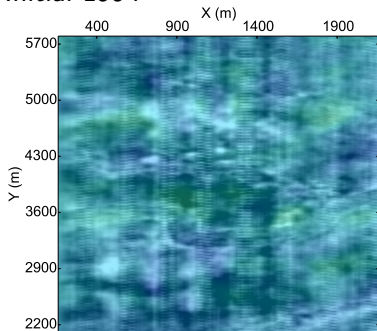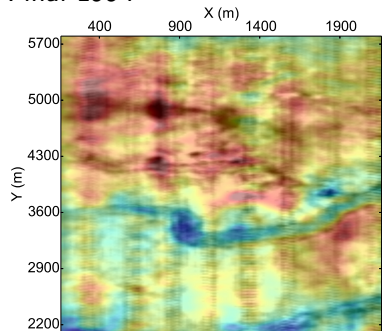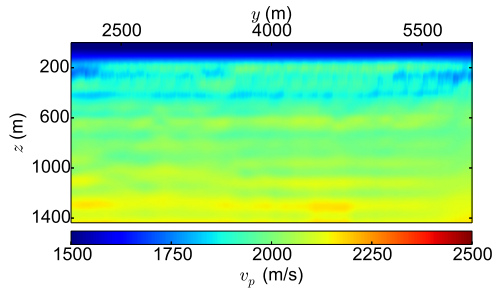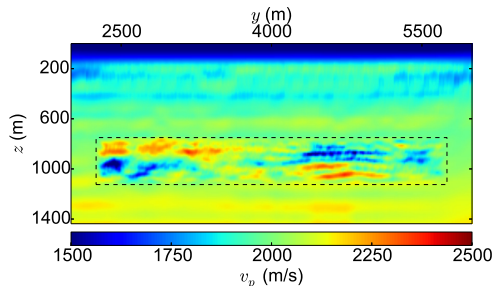
Initial 1994

Final 1994

Sleipner 3D Elastic Full Waveform Inversion
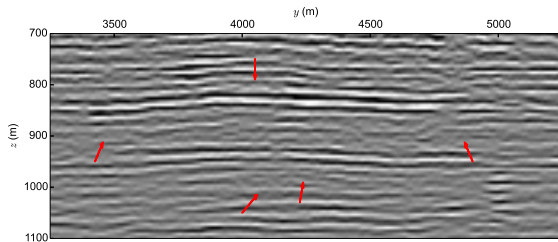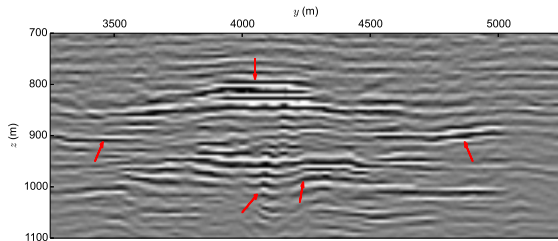
1994 Survey

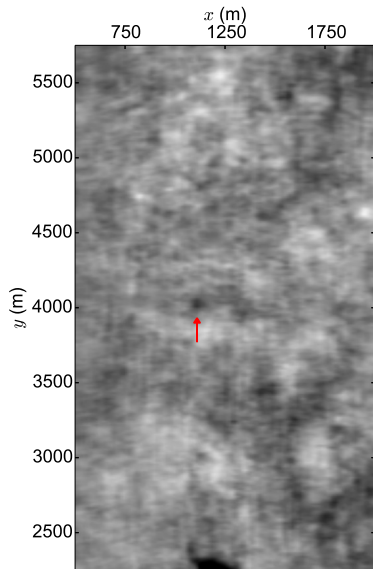## 2006 Survey

Sleipner 3D Elastic Full Waveform Inversion

1994 (zoom)

2006 (zoom)

Sleipner 3D Elastic Full Waveform Inversion

Sleipner 3D Elastic Full Waveform Inversion

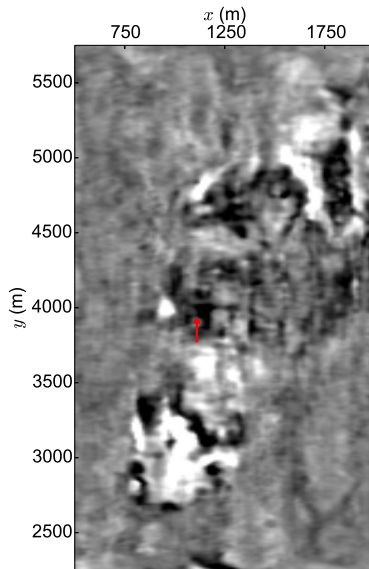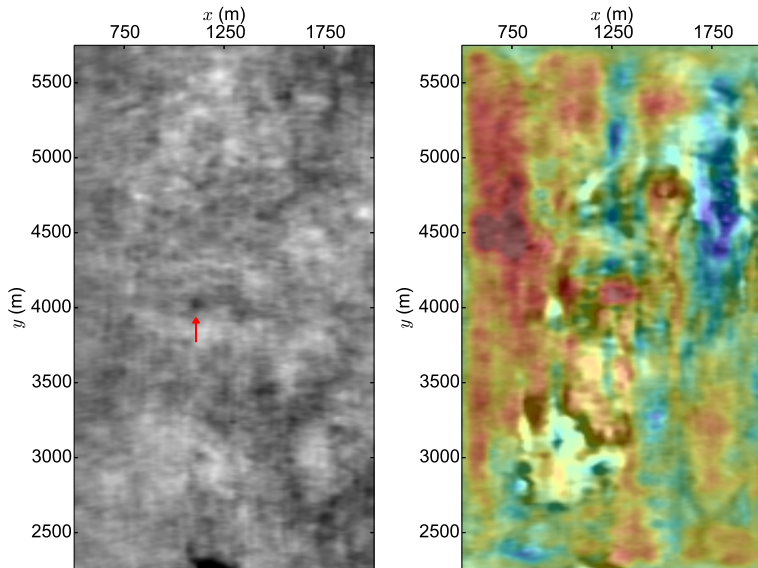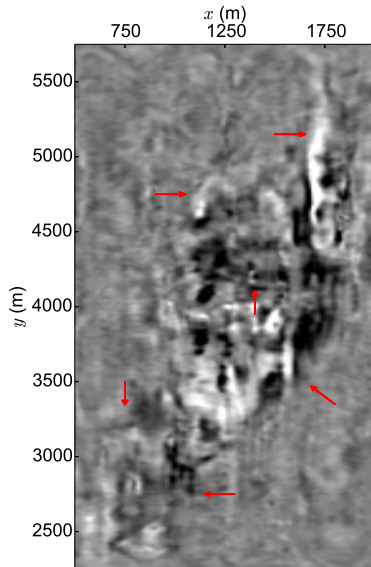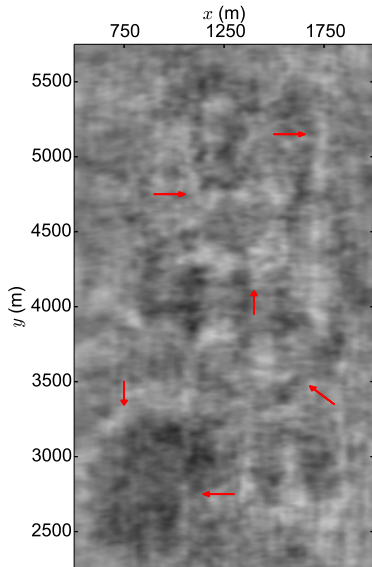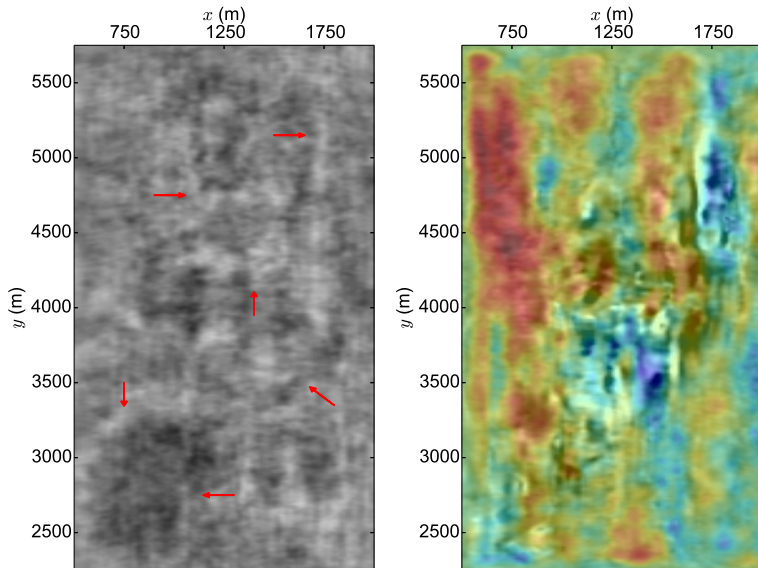# Sleipner 3D Elastic Full Waveform Inversion
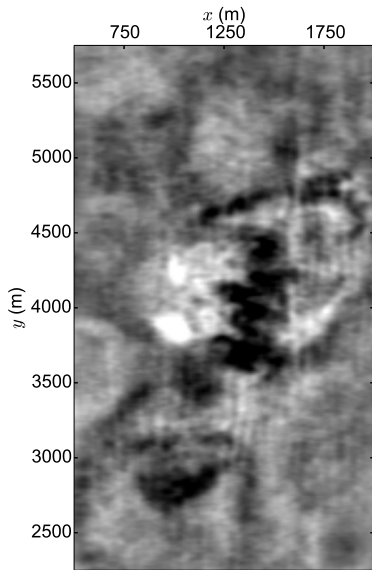
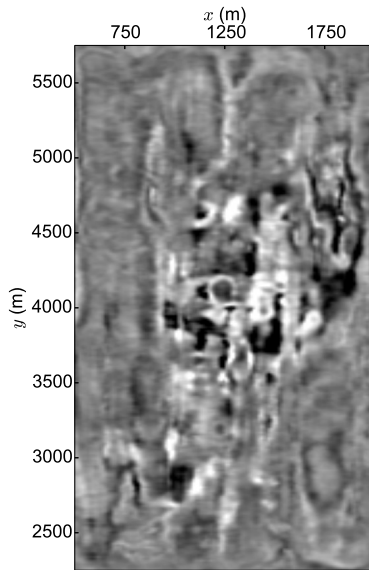# Sleipner 3D Elastic Full Waveform Inversion

Sleipner 3D Elastic Full Waveform Inversion

1994 Velocity model

2006 Velocity model

Conclusions

- MVA produces low resolution velocity models with reasonable good kinematic properties from simple initial models
- MVA velocity models can be used as initial models for FWI to obtain high resolution velocity models
- FWI produces intermediate to high resolution velocity models

Acknowledgements