Automatic anisotropic migration velocity analysis for reverse-time migration

Wiktor Waldemar Weibull[1], Børge Arntsen[1], Marianne Houbiers[2] and Joachim Mispel[2]
[1] Norwegian University of Science and Technology
[2] Statoil ASA

SEG Annual Meeting, November 2012

Statoil

NTNU – Trondheim
Norwegian University of Science and Technology

Outline

Outline

Introduction

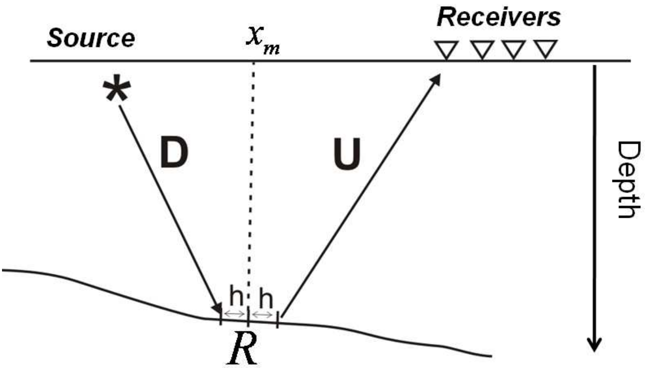
- Reverse-time migration can handle strong and sharp contrasts in velocity and anisotropy
- Accurate estimate of seismic velocities is of key importance
- How to automatically obtain the velocities from surface seismic data using RTM based WEMVA

Outline

Anisotropic reverse-time migration

$$R(x,h,z) = \sum_s \sum_t U(x+h,z,t,s)D(x-h,z,t,s)$$

[Rickett and Sava, 2002]



Anisotropy

Density normalized anisotropic wave equation
[Ikelle and Amundsen, 2005]

$$\frac{\partial^2 u_i}{\partial t^2}(\mathbf{x}, t) - \frac{\partial}{\partial x_j}\left[v_{ijkl}(\mathbf{x})\frac{\partial u_l}{\partial x_k}(\mathbf{x}, t)\right] = F_i(\mathbf{x}, t),$$

where v_{ijkl} is the density normalized elasticity tensor.

Assuming:

- VTI medium
- constant V_S
- $\delta(\mathbf{x}) = k\varepsilon(\mathbf{x})$

  [Thomsen, 1986]

Anisotropy

Density normalized anisotropic wave equation
[Ikelle and Amundsen, 2005]

$$\frac{\partial^2 u_i}{\partial t^2}(\mathbf{x}, t) - \frac{\partial}{\partial x_j}\left[v_{ijkl}(\mathbf{x})\frac{\partial u_l}{\partial x_k}(\mathbf{x}, t)\right] = F_i(\mathbf{x}, t),$$

where v_{ijkl} is the density normalized elasticity tensor.

Assuming:

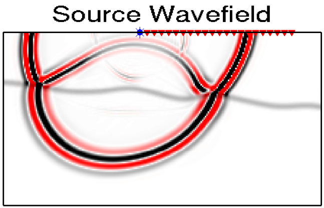
- VTI medium
- constant V_S
- $\delta(\mathbf{x}) = k\varepsilon(\mathbf{x})$

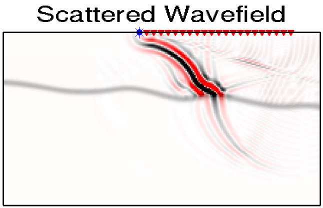
  [Thomsen, 1986]

Parameter space reduces to two!

$V_{P0}(\mathbf{x})$ and $\delta(\mathbf{x}) = k\varepsilon(\mathbf{x})$

Wavefield reconstruction

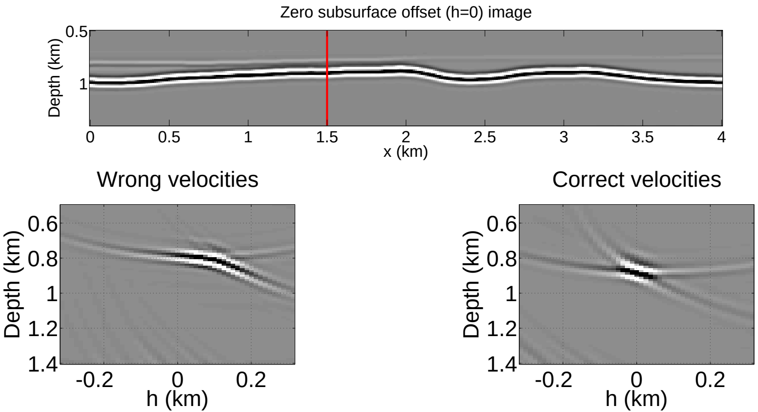




$$P(\mathbf{x}, t) \approx V_{P0}^2(\mathbf{x}) \nabla \cdot \mathbf{u}(\mathbf{x}, t).$$

Example of CIPs output by RTM

$$R(x,h,z) = \sum_s \sum_t U(x+h,z,t,s)D(x-h,z,t,s)$$



Outline

The error measure
(Objective function)

$$\mathcal{J} = \mathcal{DS} - \mathcal{SI}.$$

Differential semblance
[Shen and Symes, 2008, Weibull and Arntsen, 2011]

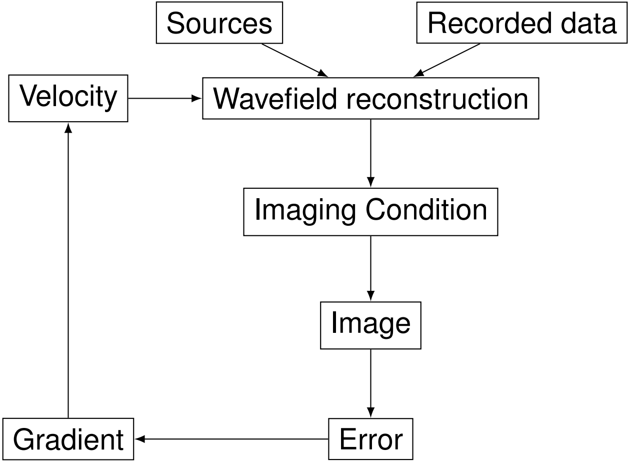
$$\mathcal{DS} = \frac{1}{2} \int dx \ \int dz \ \int dh \, h^2 \left[\frac{\partial R}{\partial z}(x, z, h) \right]^2$$

Similarity index
[Chavent and Jacewitz, 1995, Shen and Symes, 2008]

$$\mathcal{SI} = \frac{\gamma}{2} \int dx \ \int dz \ \left[\frac{\partial R}{\partial z}(x, z, h = 0) \right]^2$$

γ = weight of $\mathcal{SI}$ over $\mathcal{DS}$

WEMVA


Sources
Recorded data
Velocity
Wavefield reconstruction
Imaging Condition
Image
Error
Gradient

Outline

Introduction

Anisotropic reverse-time migration

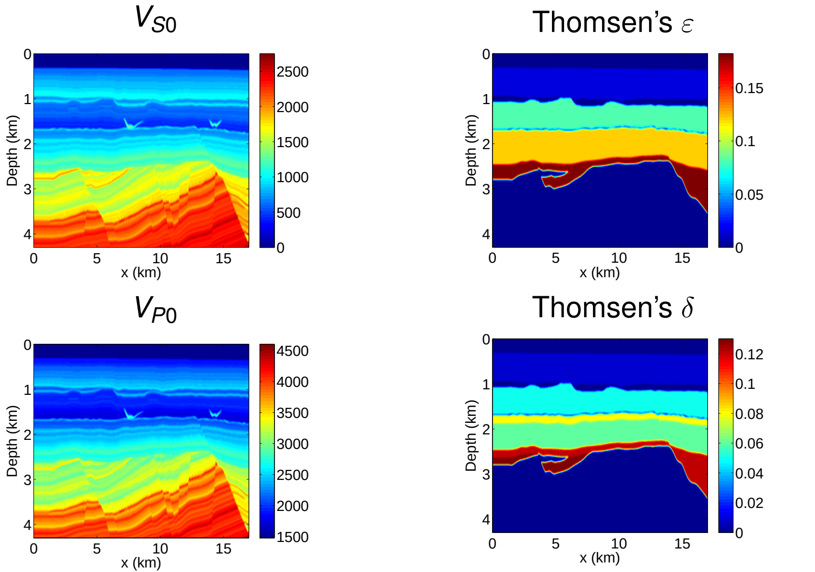
WEMVA

Numerical examples

Summary and remarks

Synthetic data example

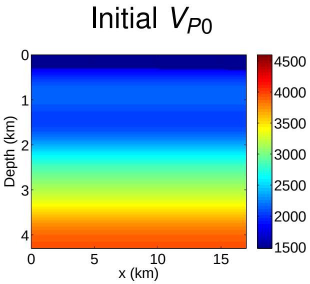
Synthetic model



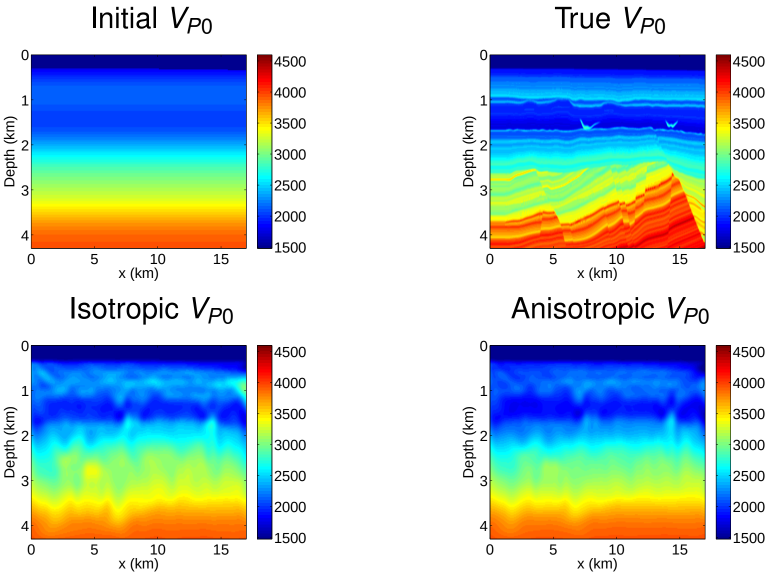
Synthetic data

- Source spacing = 40 m
- Receiver spacing = 20 m
- Maximum offset = 5 km
- Maximum frequency = 30Hz
- Recording time = 4 s

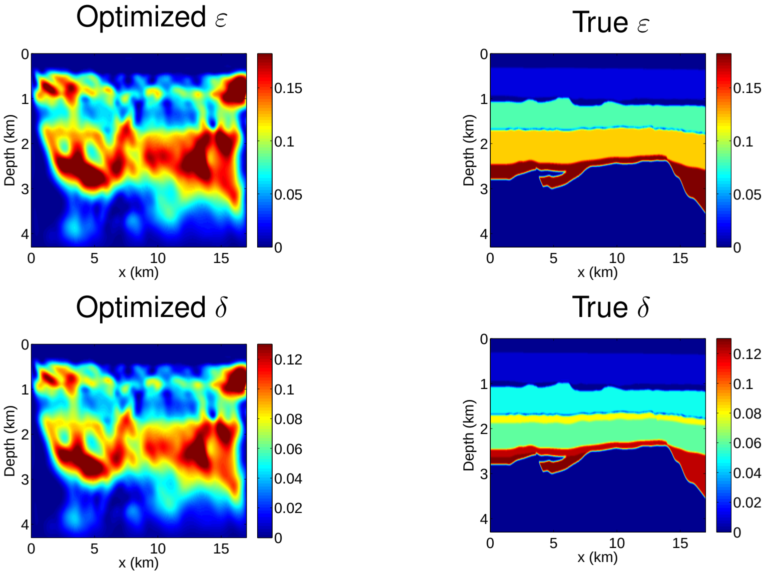
Optimized velocities



Optimized velocities

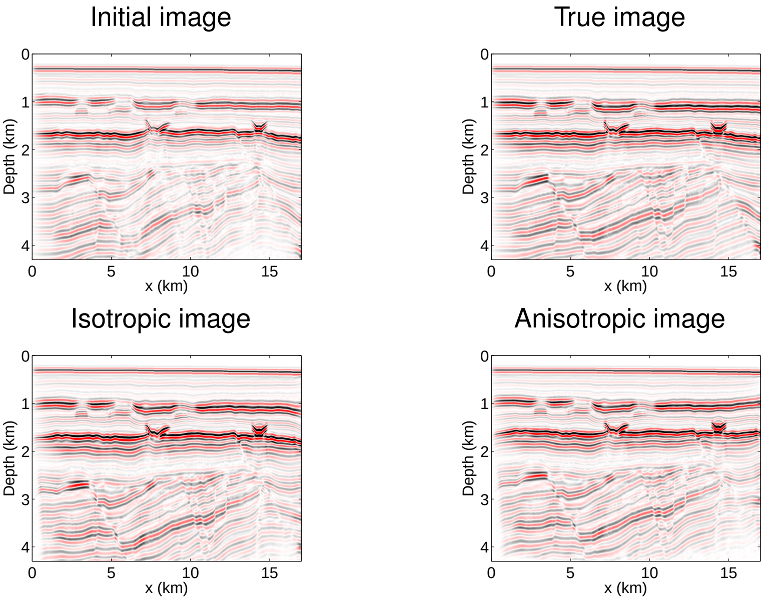


Anisotropy

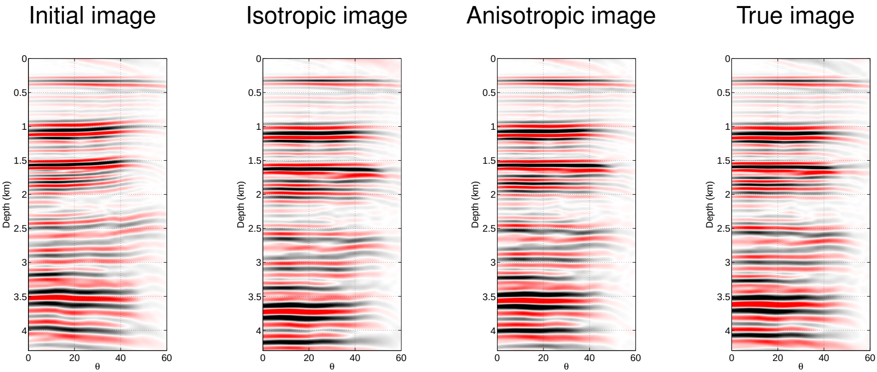


Optimized ε
True ε
Optimized δ
True δ
Depth (km)
x (km)
0
1
2
3
4
5
10
15
0.15
0.1
0.05
0.12
0.08
0.06
0.04
0.02

Migration


Initial image
True image
Isotropic image
Anisotropic image
Depth (km)
x (km)
0
1
2
3
4
0
5
10
15

Subsurface angle gathers



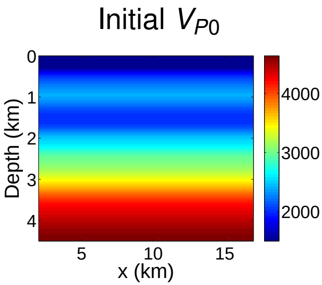
Field data example

Field data

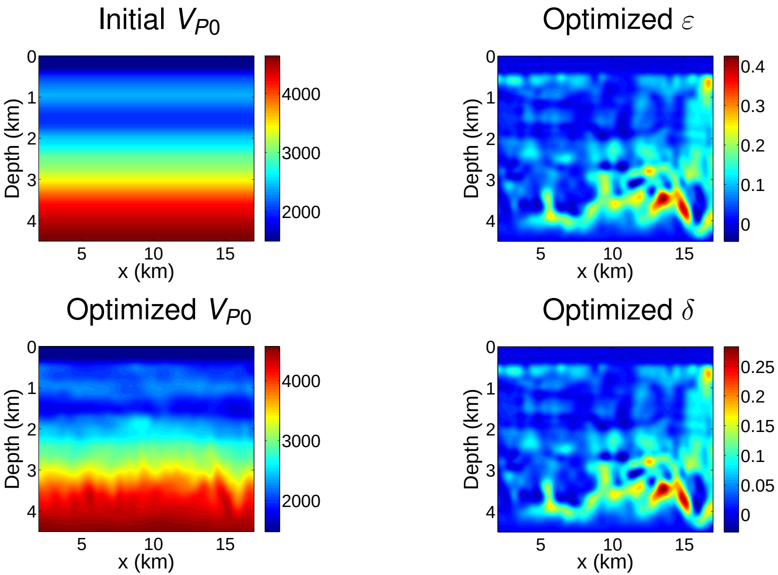
2D line extracted from a 3D marine dataset

- Source spacing = 40 m
- Receiver spacing = 20 m
- Maximum offset = 5 km
- Maximum frequency = 30Hz
- Recording time = 4 s

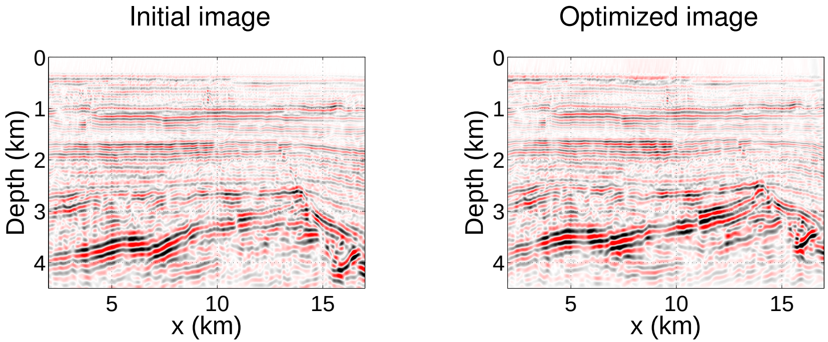
Velocity model



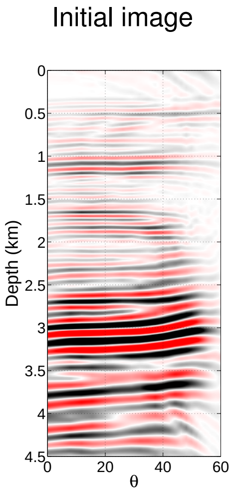
Velocity model

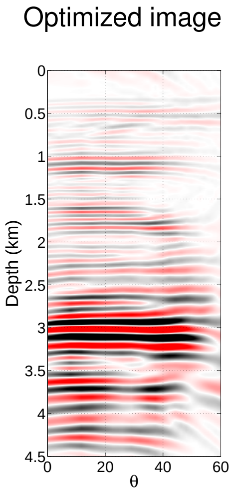


Migration



Subsurface angle gathers





Outline

Summary and remarks

- WEMVA provides a fast and automatic way of improving the quality of the reverse-time migrated image
- In spite of the reduction of the model space to only two parameters, there is still a strong trade off between the parameters
- High computational cost is limiting the application of the velocity analysis to 2D and low frequency datasets

Acknowledgments

We acknowledge the partners in the Snorre license, Statoil ASA, Petoro, ExxonMobil E&P Norway, Idemitsu Petroleum Norge, RWE, Dea Norge, Total E&P Norge and Core Energi AS for permission to publish the results.

Statoil

NTNU – Trondheim
Norwegian University of Science and Technology

Bibliography

- Chavent, G., and C. A. Jacewitz, 1995, Determination of background velocities by multiple migration fitting: Geophysics, **60**, 476–490.
- Ikelle, L. T., and L. Amundsen, 2005, Introduction to petroleum seismology: Society of exploration geophysicists.
- Rickett, J. E., and P. C. Sava, 2002, Offset and angle-domain common image-point gathers for shot-profile migration: Geophysics, **67**, 883–889.
- Shen, P., and W. W. Symes, 2008, Automatic velocity analysis via shot profile migration: Geophysics, **73**, 49–59.
- Thomsen, L., 1986, Weak elastic anisotropy: Geophysics, **51**, 1954–1966.
- Weibull, W. W., and B. Arntsen, 2011, Reverse time migration velocity analsysis: Presented at the 73th EAGE Conference & Exhibition, European Association of Geoscientists and Engineers.