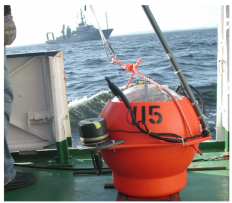
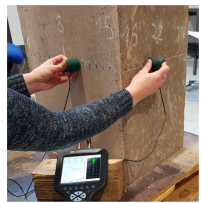
Karlsruhe Institute of Technology

Full Waveform Inversion

Applications of body waves

Thomas Bohlen

Shallow marine data	Shallow land data	Non-destructive testing	Medical imaging
			
2 km	10 m	50 cm	10 cm

Agenda

1. Introduction
2. Top-salt imaging using streamer data
3. FWI of OBC data in shallow water
4. Nondestructive testing
5. Medical imaging
6. Conclusions

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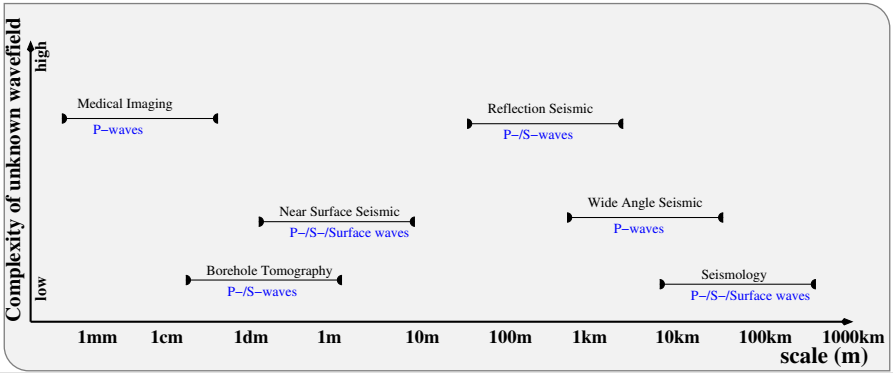
Applications of FWI

In recent 20 years FWI has been applied sucessfully to different wave types on a broad range of spatial scales covering 9 orders of magnitude



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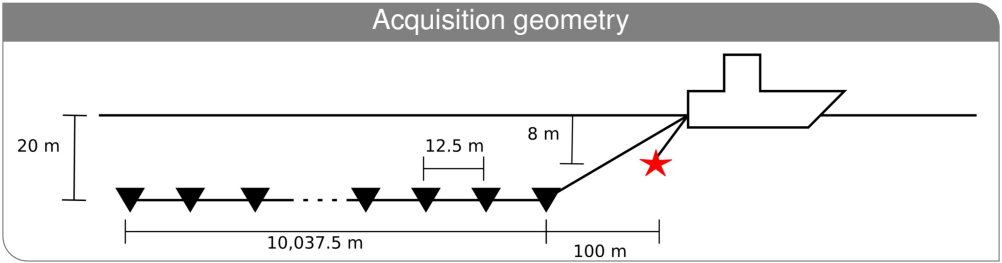
Acoustic/elastic FWI of marine streamer data

Goal

- Imaging of structures above (and below) a salt dome located west of Africa.

Acquisition geometry

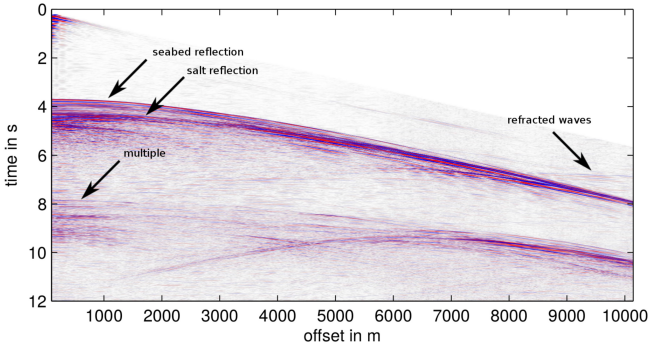


Streamer (length 10 km) record P-waves in the water

(Thiel 2018)
Data was provided by PGS

Marine streamer field data example

Recorded pressure field at the sea surface

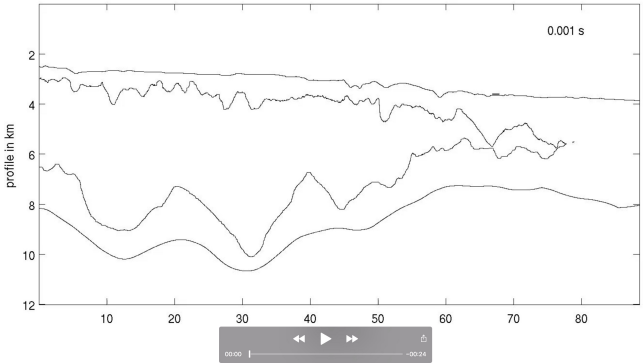


FWI: Conjugate gradients, $N_s = 19$, $I_n \approx 60 - 90$

(Thiel 2018)

Acoustic Finite-Difference Simulation

Click to play



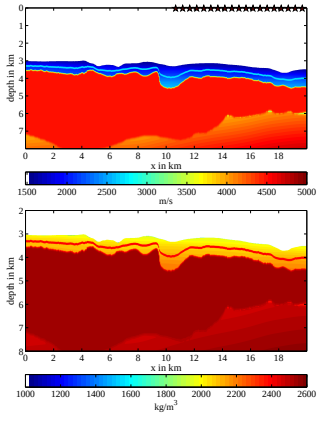
(Thiel 2018)

Synthetic reconstruction test

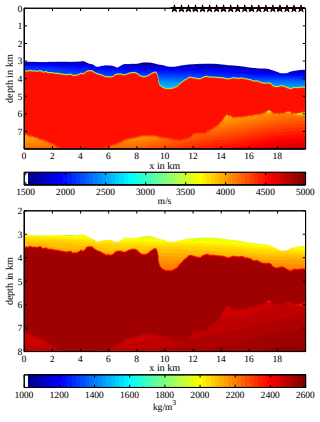
P-wave velocity

Density

True model

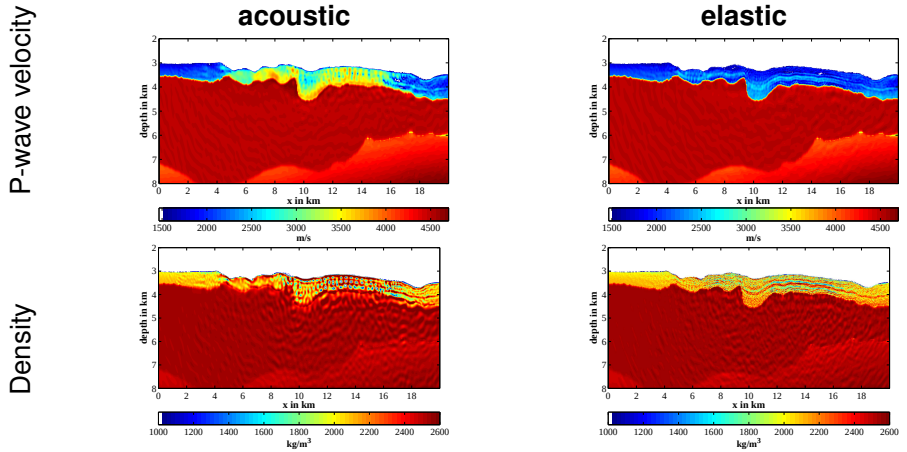


Initial model



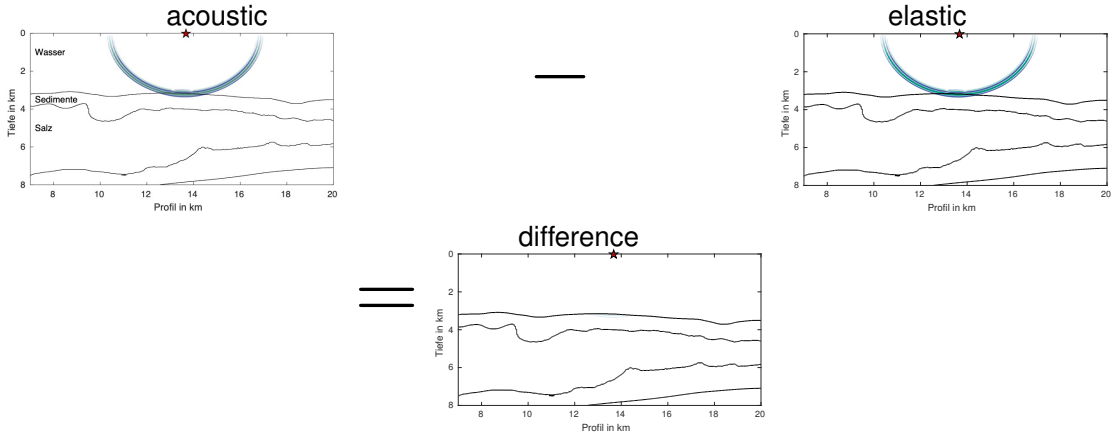
(Thiel 2018)

Synthetic reconstruction test



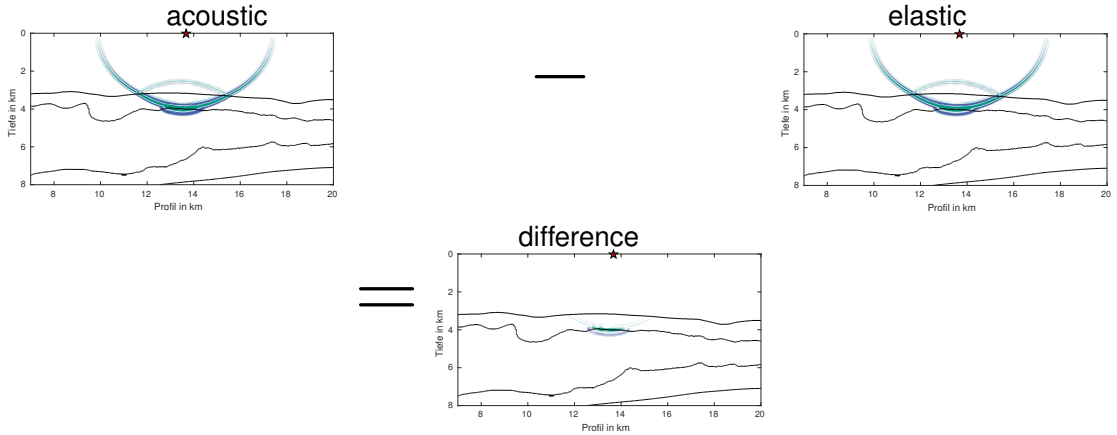
$\longrightarrow$ Elastic Modelling/FWI is necessary

Evolution of pressure in acoustic and elastic simulation



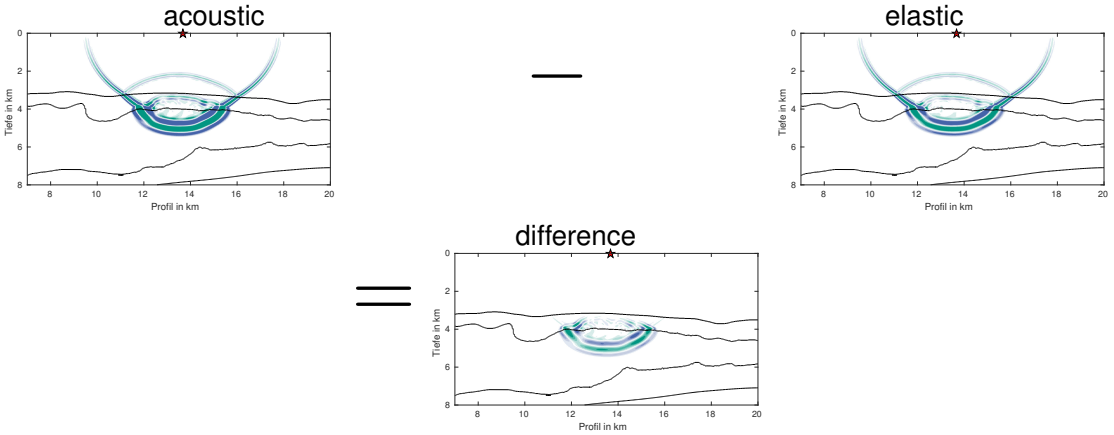
(Thiel 2018)

Evolution of pressure in acoustic and elastic simulation



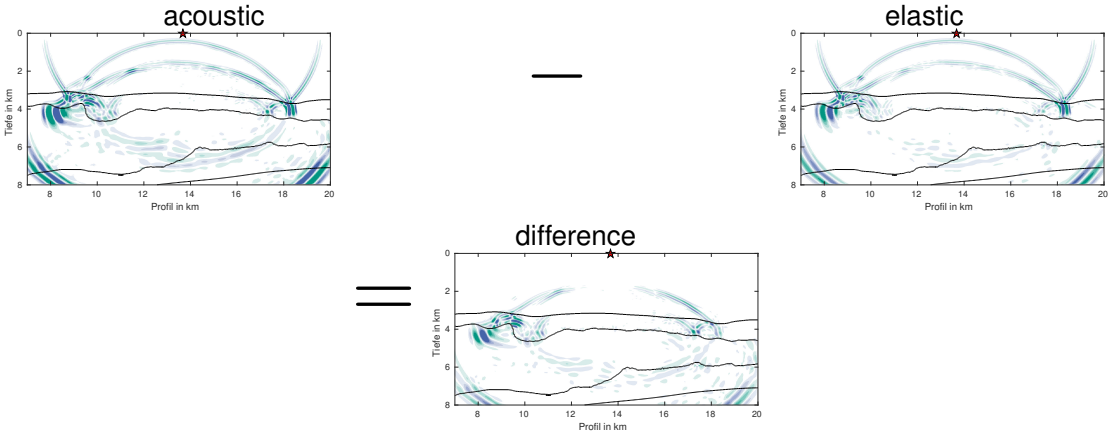
(Thiel 2018)

Evolution of pressure in acoustic and elastic simulation



(Thiel 2018)

Evolution of pressure in acoustic and elastic simulation



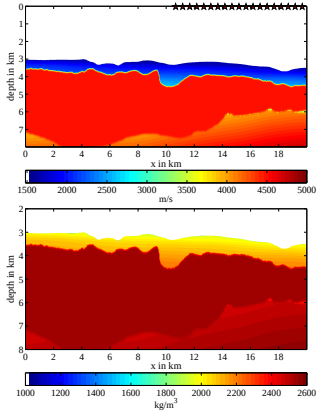
(Thiel 2018)

Comparison of acoustic and elastic simulation

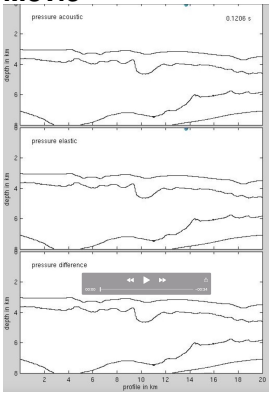
P-wave velocity

Density

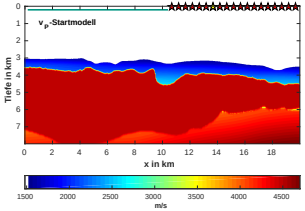
Initial model

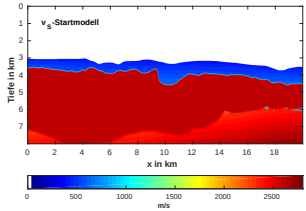


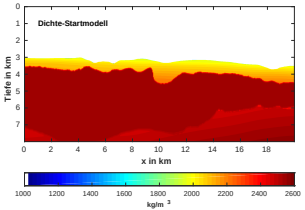
Movie

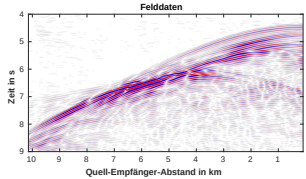


Initial model and field data





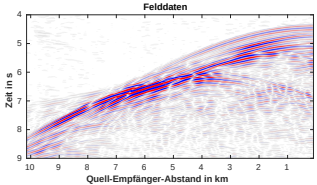


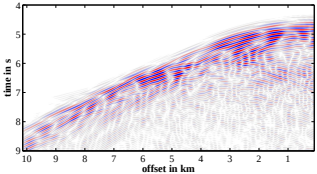


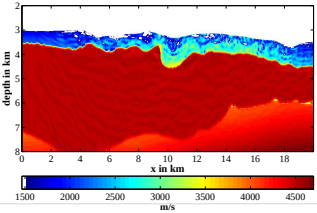
Shot at $x \approx$13,5 km

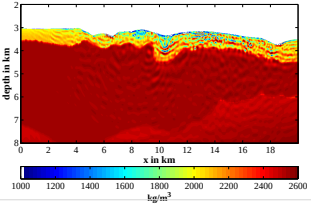
(Thiel 2018)

Application of acoustic FWI to field data



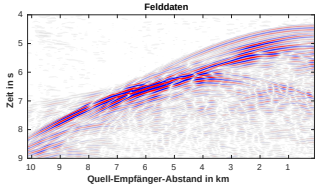


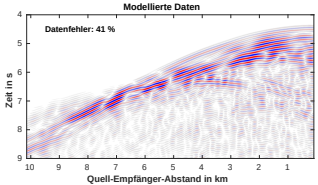


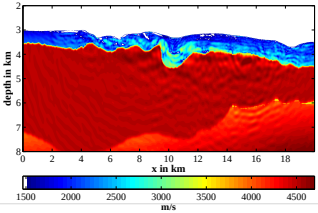


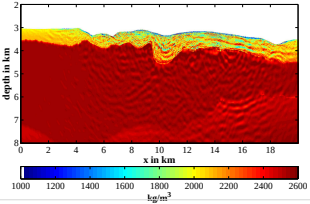
(Thiel 2018)

Application of elastic FWI to field data



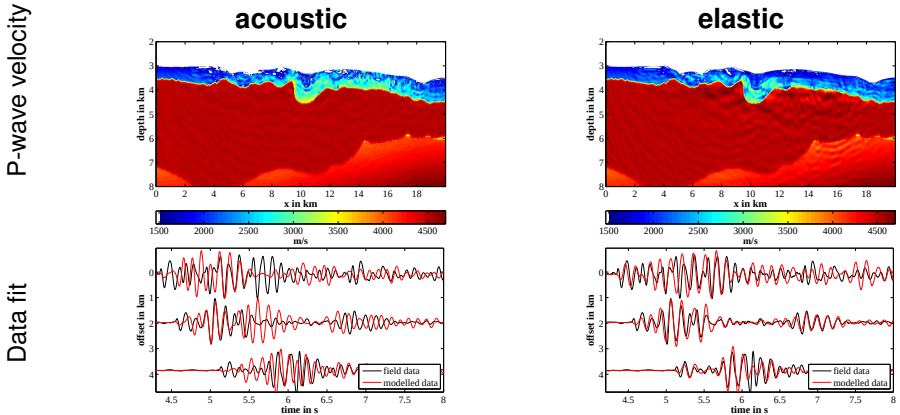






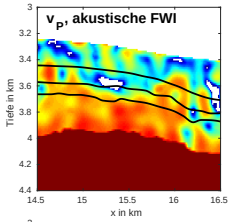
(Thiel 2018)

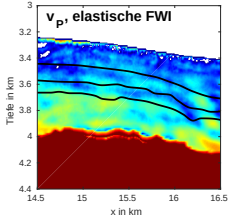
Comparison of acoustic and elastic FWI models

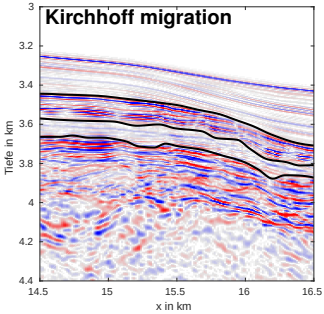


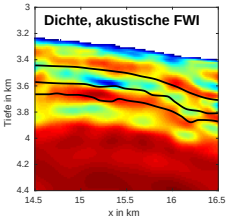
$\longrightarrow$ Elastic FWI yields better data fit

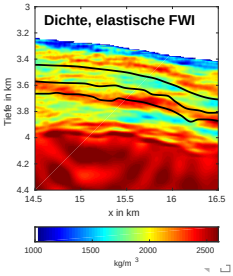
Comparison of acoustic and elastic FWI models











(Thiel 2018)

Acoustic/elastic FWI of marine streamer data for top-salt imaging

Karlsruhe Institute of Technology

Conclusions

- Elastic FWI may be necessary even in marine environment in the presence of strong contrast discontinuities such as salt
- The discontinuities in the P-velocity (and density) show similarities to the reflectivity seen in migrated images

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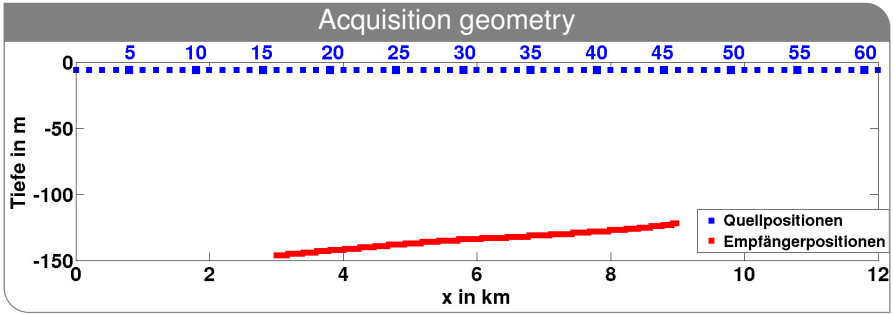
FWI of OBC data in shallow water



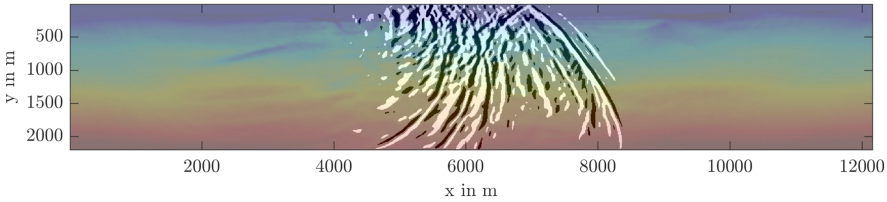
- Ocean-Bottom-Cable
- Length: 6 km, 240 Hydrophones
- 61 Airgun shots

- Water depth approx. 130m
- Maximum offset 9 km

(Kunert 2015, Kunert et al. 2016, Habelitz 2017)
Data was provided by Addax

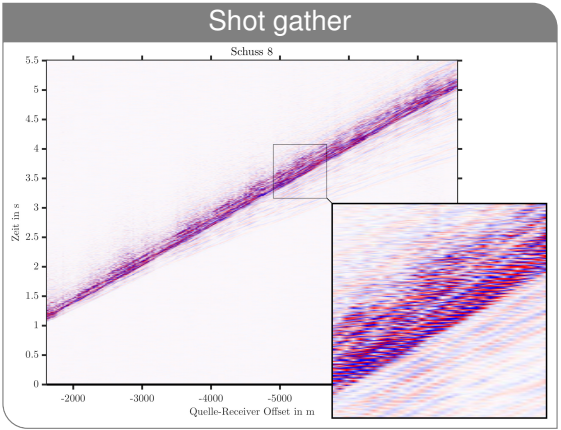
FWI of OBC data in shallow water

Acoustic simulation of wavefield in the final FWI model
Click to play



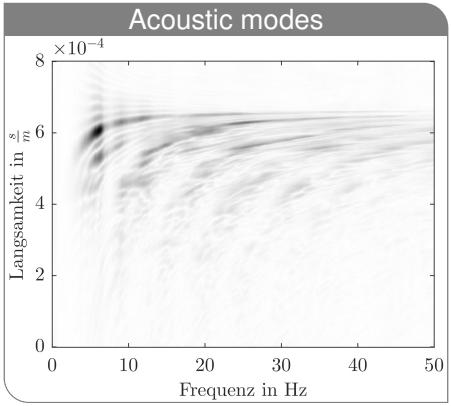
(Habelitz 2017)

FWI of OBC data in shallow water



(Habelitz 2017)

FWI of OBC data in shallow water

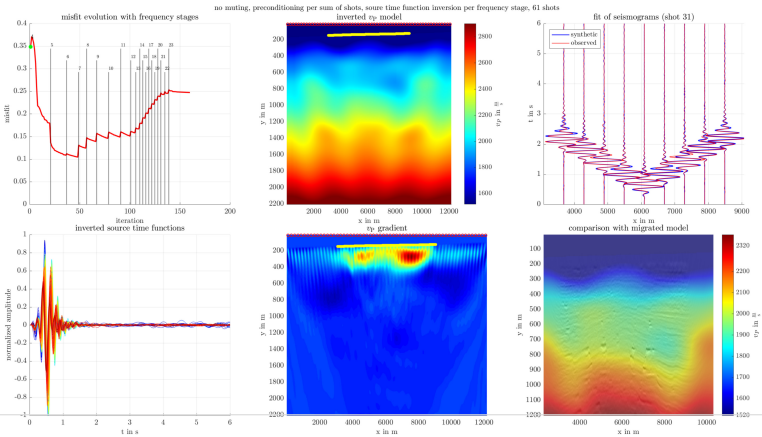


(Habelitz 2017)

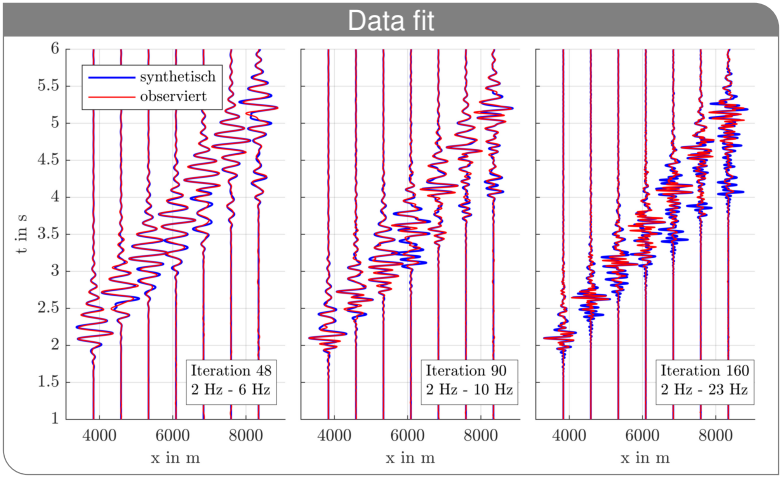
FWI of OBC data in shallow water

Performance of FWI

Click to play

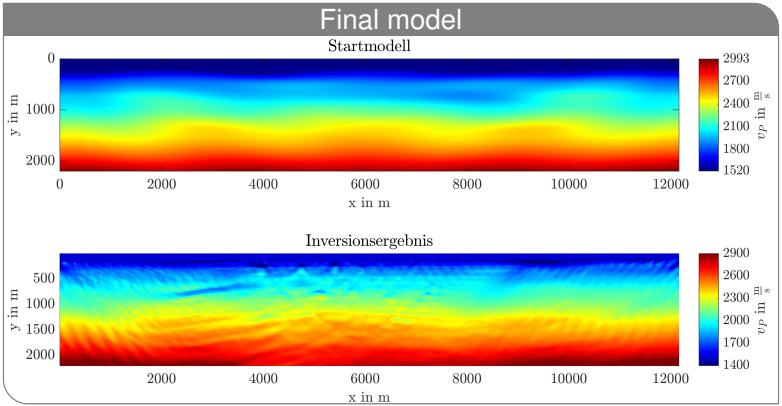


FWI of OBC data in shallow water



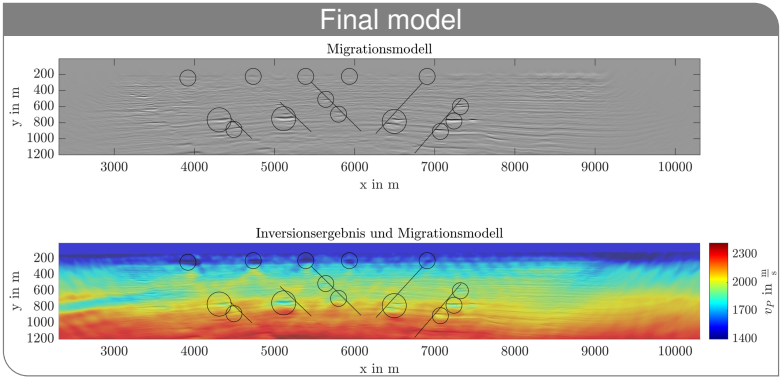
(Habelitz 2017)

FWI of OBC data in shallow water



(Habelitz 2017)

FWI of OBC data in shallow water



(Habelitz 2017)

FWI of OBC data in shallow water

Conclusions

- Acoustic FWI of guided waves in shallow water was successful
- Higher resolution of Vp model reveals gas accumulations and pathways along faults
- Consistent with migrated images of reflected waves (independent data)

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Motivation

Non-destructive testing (NDT):

- Crucial task to prevent failures of building materials
- Current methods are limited in recovering material parameters

IDEA

Full-waveform inversion can help to improve imaging of flaws and other anomalies in building materials

(Mueller 2020)

2D reconstruction test

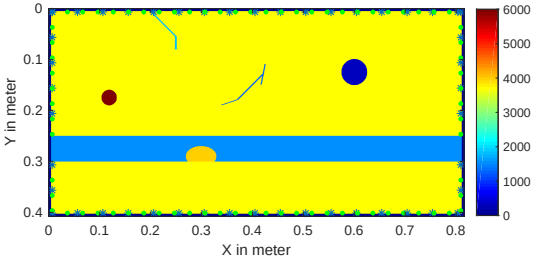
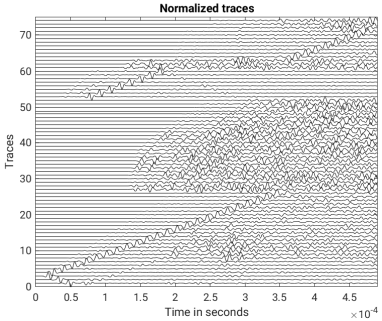


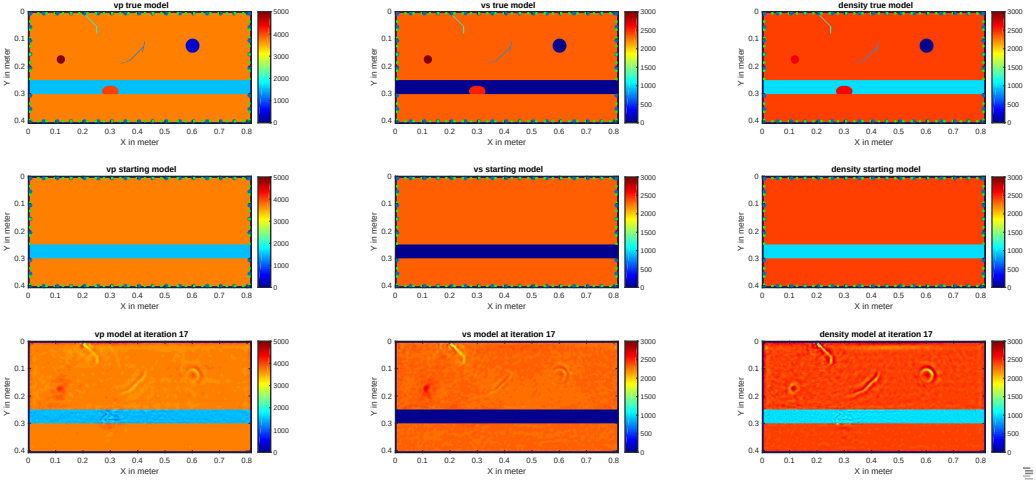
Figure: 2D model with pipe and additional perturbations.



Start animation:

forward simulation

Results of elastic FWI



Data fit

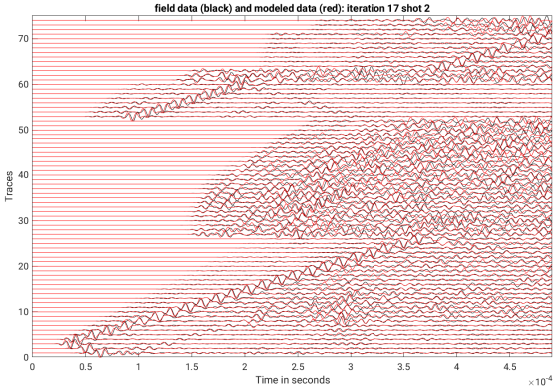


Figure: Initial data (red) and final data (black).

Application of elastic FWI for NDT

Conclusions

- High potential in recovering multi-parameter models with high resolution
- First test with measured data are promising
- Models with complex 3D pertubations and geometries will require 3D FWI

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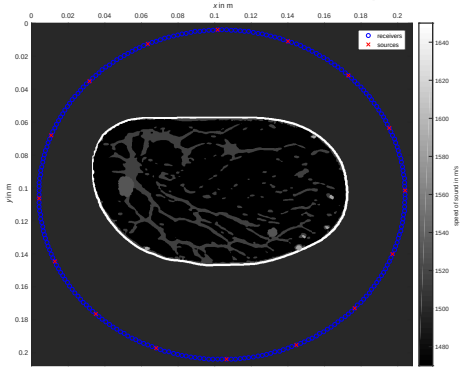
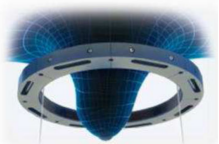
Acquisition geometry

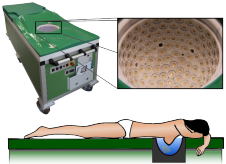
Click on frame to play movie



2D acquisition geometry used in the reconstruction test.
The ring array is equipped with 256 receivers and 16 sources.



Measurement with a 2D ring transducer
(Sandhu et al., 2015)

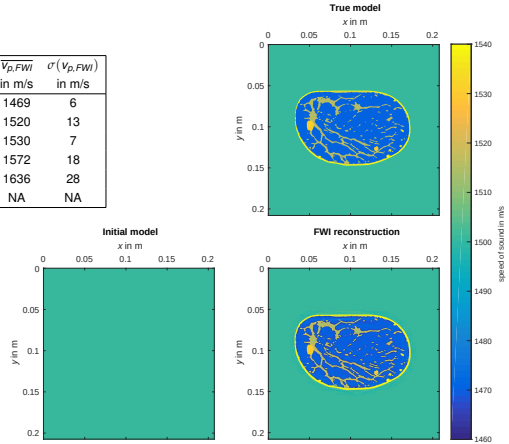


Prototype of a ultrasound device with a full
3D acquisition geometry (Ruiter et al., 2017).

(Kühn 2018)

Reconstruction of speed of sound

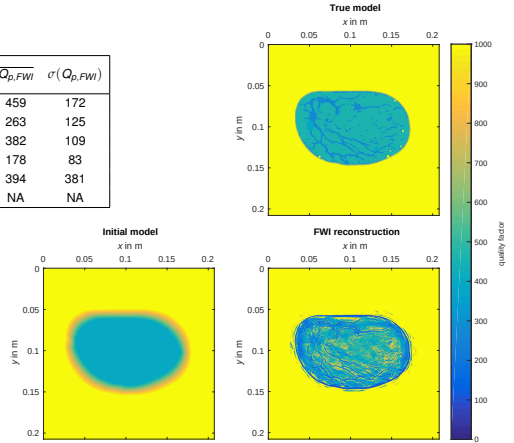
Propagation medium	$v_{p,true}$ in m/s	$\overline{v_{p,FWI}}$ in m/s	$\sigma(v_{p,FWI})$ in m/s
Fat	1470	1469	6
Fibroglandluar	1515	1520	13
Tumour	1530	1530	7
Blood vessels	1584	1572	18
Skin	1650	1636	28
Water	1500	NA	NA



True, initial and inverted speed of sound models (Kühn 2018)

Reconstruction of damping

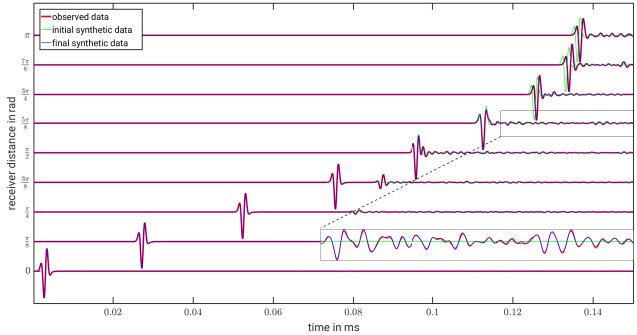
Propagation medium	$Q_{p,true}$	$\overline{Q_{p,FWI}}$	$\sigma(Q_{p,FWI})$
Fat	462	459	172
Fibroglandluar	279	263	125
Tumour	385	382	109
Blood vessels	>1000	178	83
Skin	644	394	381
Water	>1000	NA	NA



True, initial and inverted quality factor models (Kühn 2018)

Data fit

Data for the true, initial and inverted model



(Kühn 2018)

Visco-acoustic FWI for medical imaging

Conclusions

- Forward modelling is very expensive due to the high frequencies in medical imaging
- 3D applications are still prohibitive
- 2D visco-acoustic FWI of synthetic data with good illumination works very well
- Detailed models of P-velocity and attenuation can be recovered

Agenda

1. Introduction
2. Top-salt imaging using streamer data
3. FWI of OBC data in shallow water
4. Nondestructive testing
5. Medical imaging
6. Conclusions

Conclusions

Summary

First applications revealed that FWI is applicable on different wave types acquired on a broad range of spatial scales. We are still in the early stage of the development of this technology.

Current directions of research

- Application to 3D seismic data
- Reduction of number of forward modellings for 3D applications
- Multi-parameter reconstruction techniques using higher order optimization methods
- Quantification of uncertainties

Thank you for your attention

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