FWI for Ultrasonic Imaging

Flaw detection in steel weld

Alice Dinsenmeyer

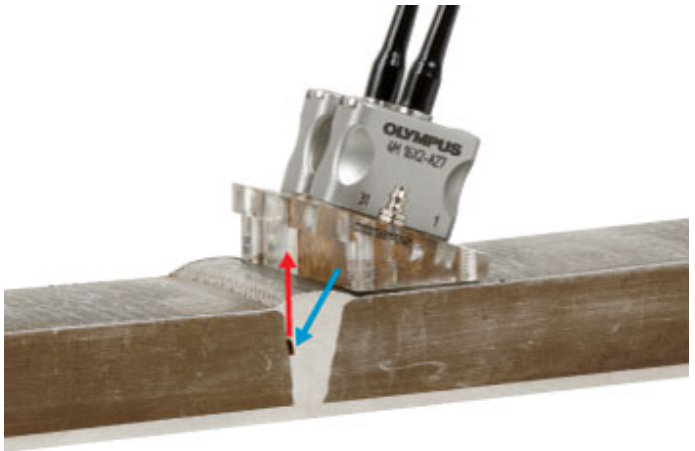
supervised by
Romain Brossier & Ludovic Moreau
Maîtres de conférences, ISTerre

July 8, 2016

NDT for welds

Picture from Davidmack

Pipeline test



Picture from Olympus

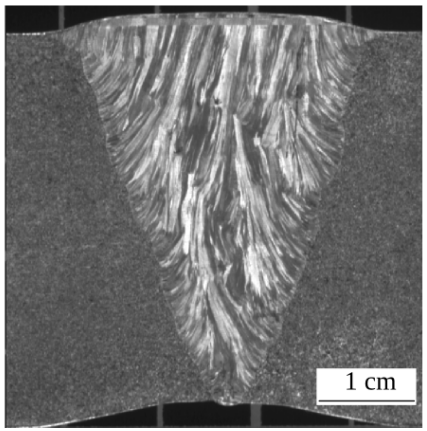
Echo mode testing

Non destructive testing for weld in :

- nuclear reactors (cooling system)
- oil and gaz pipelines

→ porosity, cracks, lack of fusion, corrosion, inclusions,. . .

NDT for welds



Picture from Chassignole, 2010 (PhD thesis)

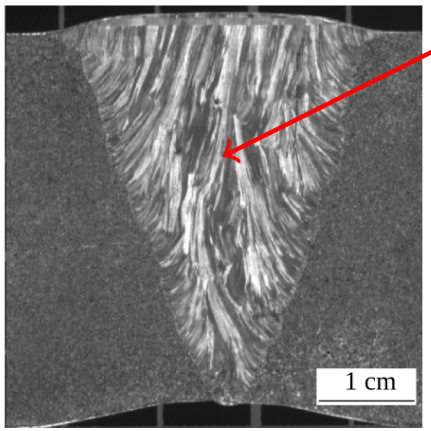
Macrography of a weld

- delay and sum methods
- decomposition of covariance matrix (DORT)

NDT for welds

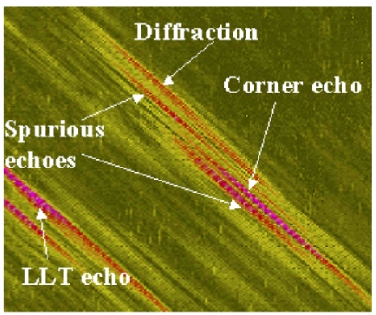
Strong unknown anisotropy

$\hookrightarrow$ distorsion and splitting of the beam



Picture from Chassignole, 2010 (PhD thesis)

Macrography of a weld



Picture from Chassignole, 2010 (PhD thesis)

Comparison of ray based model and experiment result

- delay and sum methods
- decomposition of covariance matrix (DORT)

$\rightarrow$

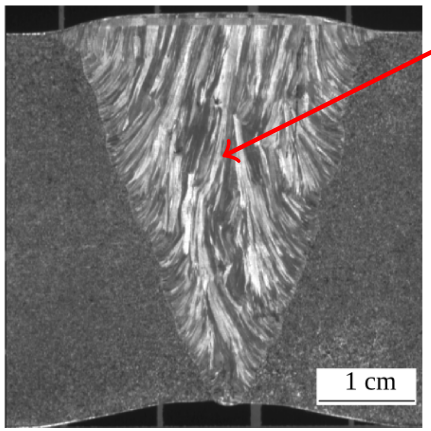
✗ need to know c in advance

✗ strong artefacts

NDT for welds

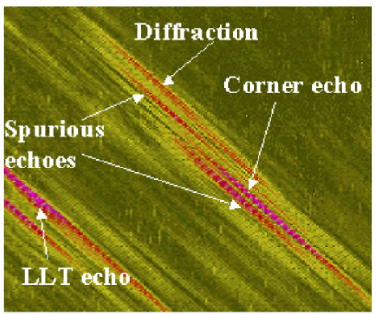
Strong unknown anisotropy

$\hookrightarrow$ distorsion and splitting of the beam



Picture from Chassignole, 2010 (PhD thesis)

Macrography of a weld



Picture from Chassignole, 2010 (PhD thesis)

Comparison of ray based model and experiment result

- delay and sum methods
- decomposition of covariance matrix (DORT)

$\rightarrow$

✗ need to know c in advance

✗ strong artefacts

- solving NL optimization problem

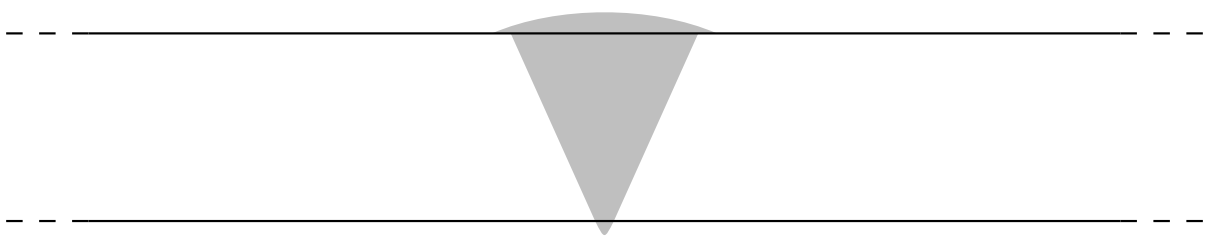
$\rightarrow$

▶ contour reconstruction : *Dominguez et al.*, *Rodriguez et al.*

✓ C_{ij} reconstruction : FWI

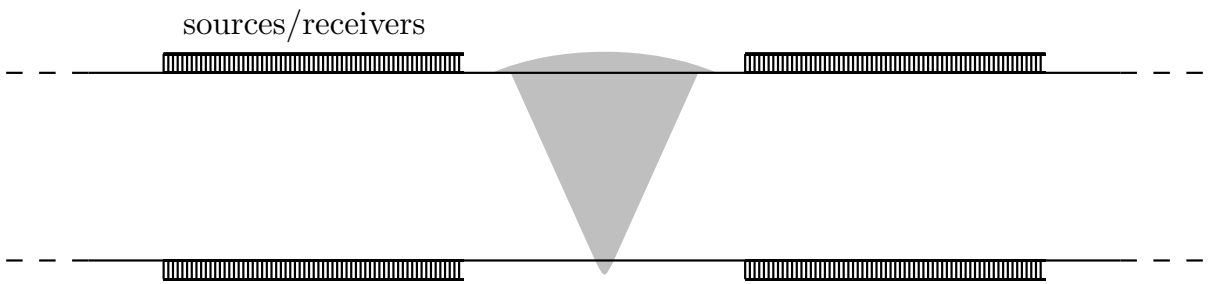
What is specific to weld imaging ?

- 2 free surfaces : more information $\leftrightarrow$ non-linear inversion



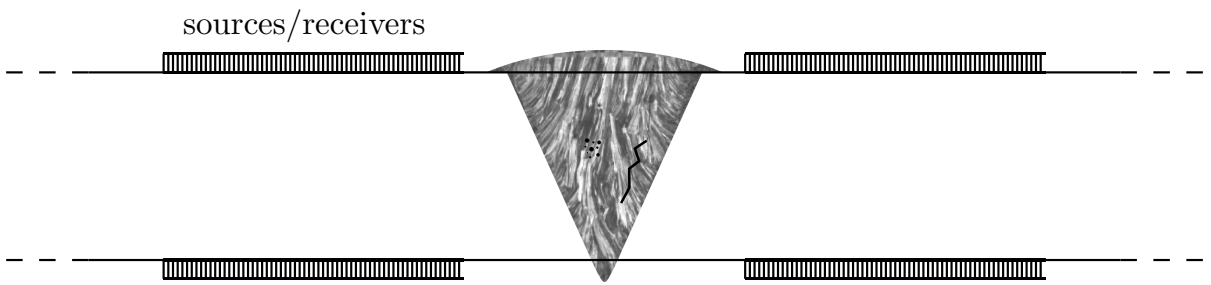
What is specific to weld imaging ?

- 2 free surfaces : more information $\leftrightarrow$ non-linear inversion
- surface acquisition only



What is specific to weld imaging ?

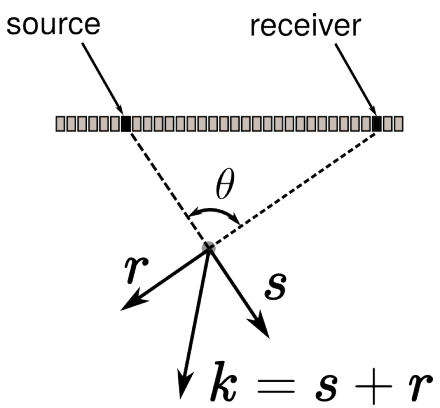
- 2 free surfaces : more information $\leftrightarrow$ non-linear inversion
- surface acquisition only
- anisotropy $\rightarrow$ multi-parameter inversion
  ($C_{ij} \times 6$: weld + defects)



Resolution analysis

$$\frac{\partial C}{\partial m_i} = \underbrace{{}^t\tilde{\boldsymbol{d}}_{cal}}_{\substack{\text{incident} \\ \text{wavefield}}} {}^t\left(\frac{\partial \boldsymbol{A}}{\partial m_i}\right) \underbrace{\boldsymbol{\lambda}}_{\substack{\text{back-propagated} \\ \text{residual wavefields}}}$$

$$\sim \Re\left(e^{jk_0 \boldsymbol{s}.\boldsymbol{x}}\right) \qquad \sim \Re\left(e^{jk_0 \boldsymbol{r}.\boldsymbol{x}}\right)$$



Resolution analysis

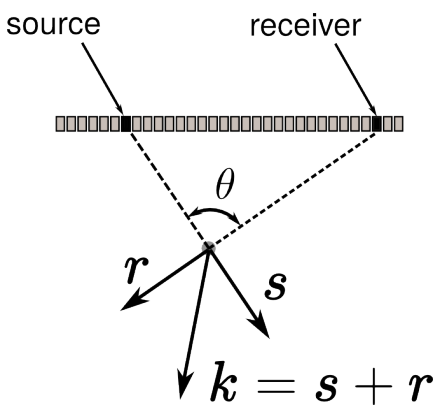
$$\frac{\partial C}{\partial m_i} = \underbrace{{}^t\tilde{\boldsymbol{d}}_{cal}}_{\substack{\text{incident}\\ \text{wavefield}}} {}^t\left(\frac{\partial \boldsymbol{A}}{\partial m_i}\right) \underbrace{\boldsymbol{\lambda}}_{\substack{\text{back-propagated}\\ \text{residual wavefields}}}$$

$$\sim \Re\left(e^{jk_0 \boldsymbol{s}.\boldsymbol{x}}\right) \qquad \sim \Re\left(e^{jk_0 \boldsymbol{r}.\boldsymbol{x}}\right)$$

- Gradient resolution :

$$k = |\boldsymbol{s} + \boldsymbol{r}| = \frac{\omega}{c} 2\cos\left(\frac{\theta}{2}\right) \tag{1}$$

(2)



Resolution analysis

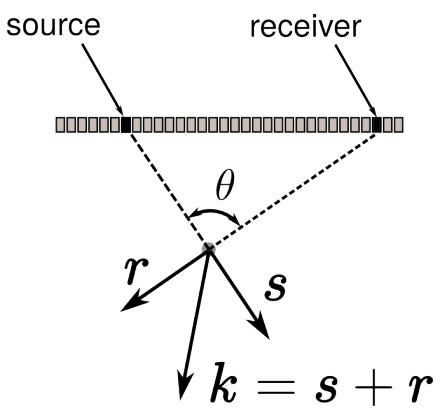
$$\frac{\partial C}{\partial m_i} = \underbrace{{}^t\tilde{\boldsymbol{d}}_{cal}}_{\text{incident wavefield}} \; {}^t\left(\frac{\partial \boldsymbol{A}}{\partial m_i}\right) \; \underbrace{\boldsymbol{\lambda}}_{\text{back-propagated residual wavefields}}$$

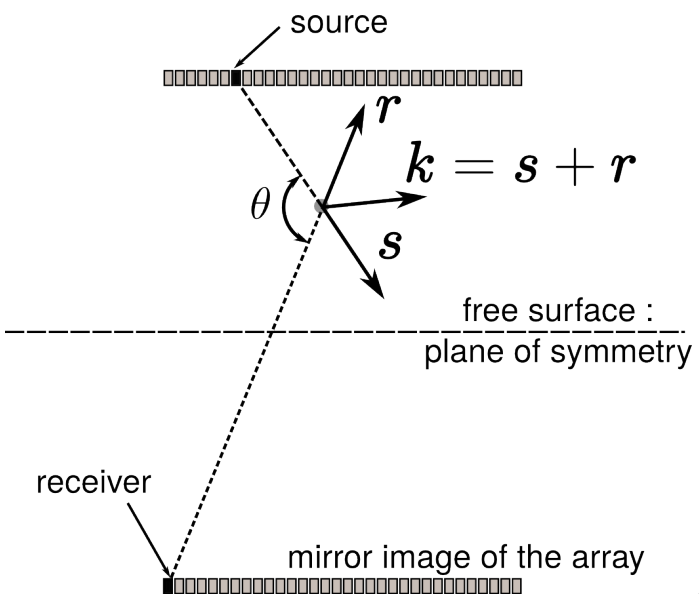
$$\sim \Re\left(e^{jk_0 \boldsymbol{s}.\boldsymbol{x}}\right) \qquad \sim \Re\left(e^{jk_0 \boldsymbol{r}.\boldsymbol{x}}\right)$$

- Gradient resolution :

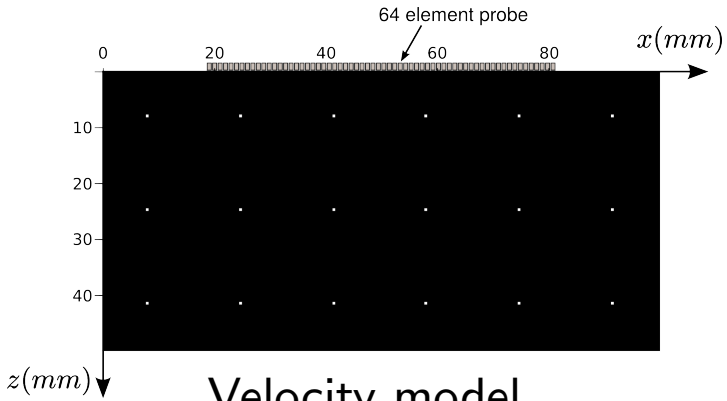
$$k = |\boldsymbol{s} + \boldsymbol{r}| = \frac{\omega}{c} 2\cos\left(\frac{\theta}{2}\right) \tag{1}$$

(2)

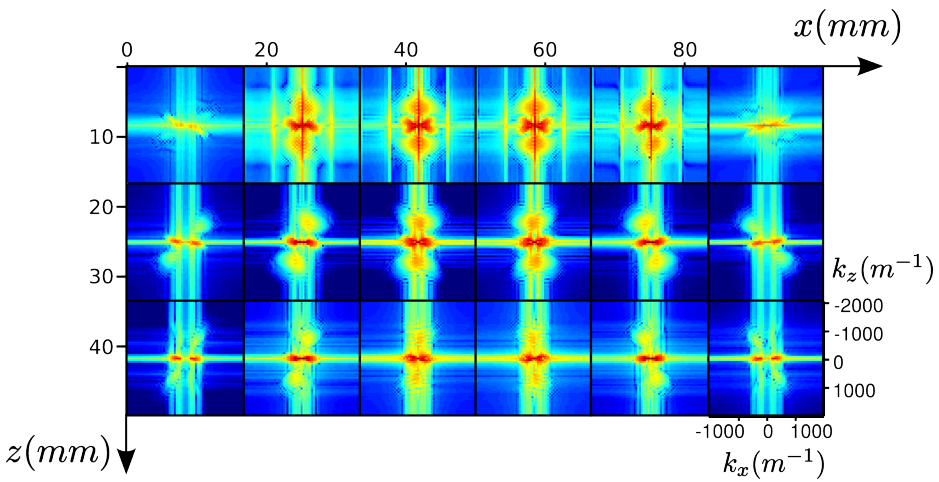




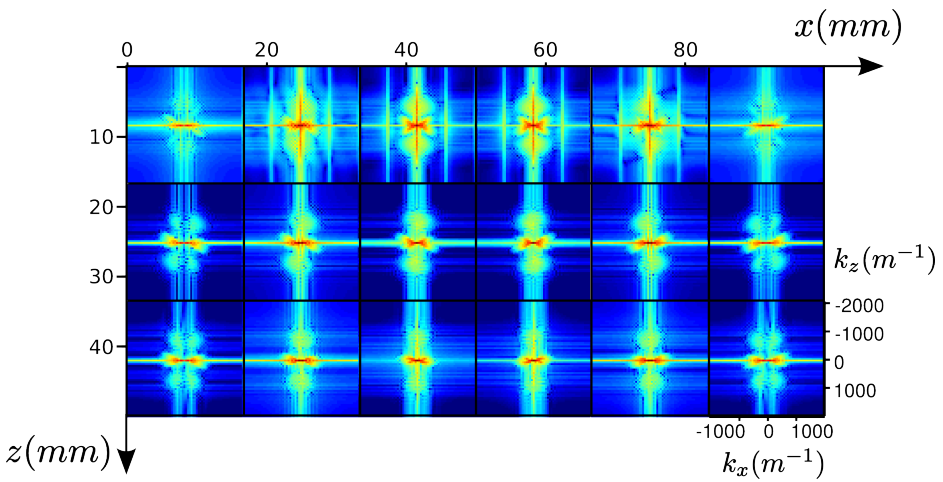
Resolution analysis – Local 2DFT



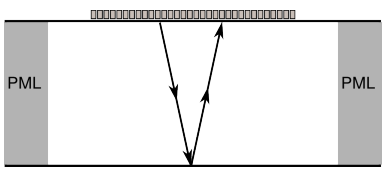
Velocity model

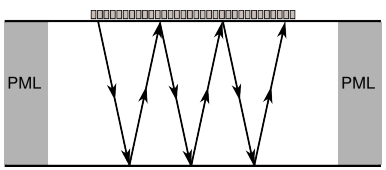


For 1 reflection



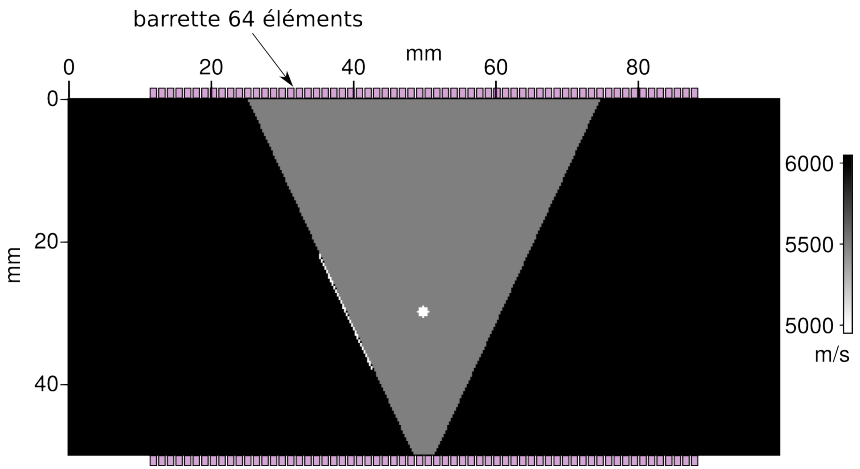
For 5 reflections



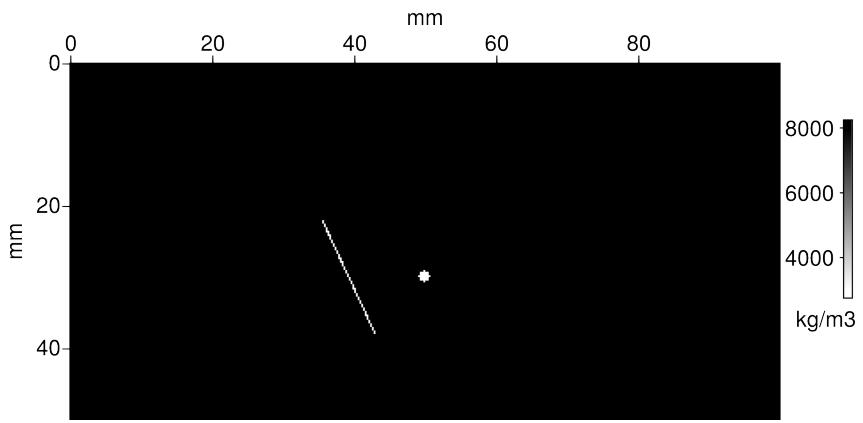


Isotropic Synthetic case

- 2D, isotropic, acoustic (*TOYxDAC_TIME_V1.5*)
- Parametrisation : v_p and ρ
- Recording time : 1 reflexion



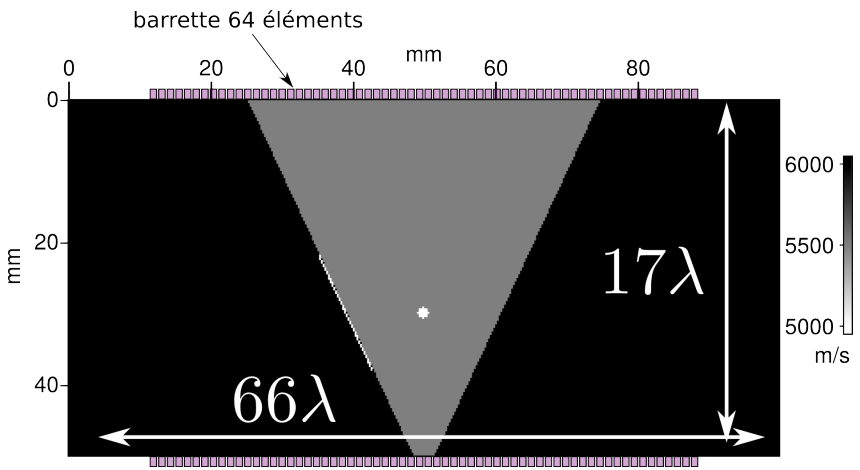
True velocity



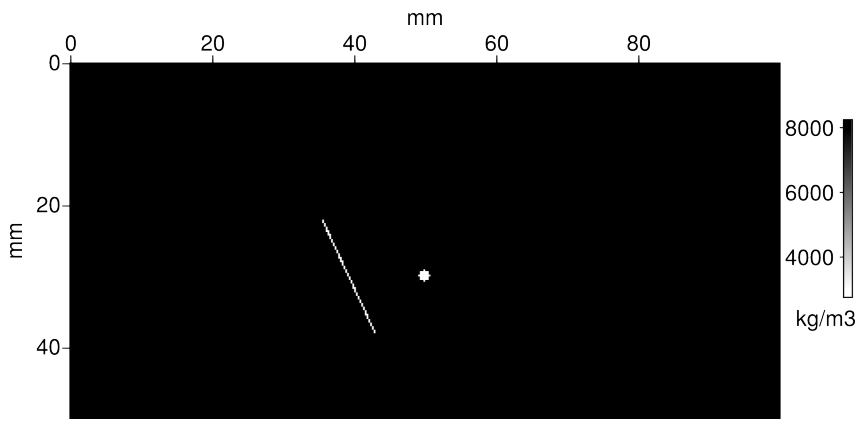
True density

Isotropic Synthetic case

- 2D, isotropic, acoustic (*TOYxDAC_TIME_V1.5*)
- Parametrisation : v_p and ρ
- Recording time : 1 reflexion
- Excitation frequency : 2 MHz



True velocity

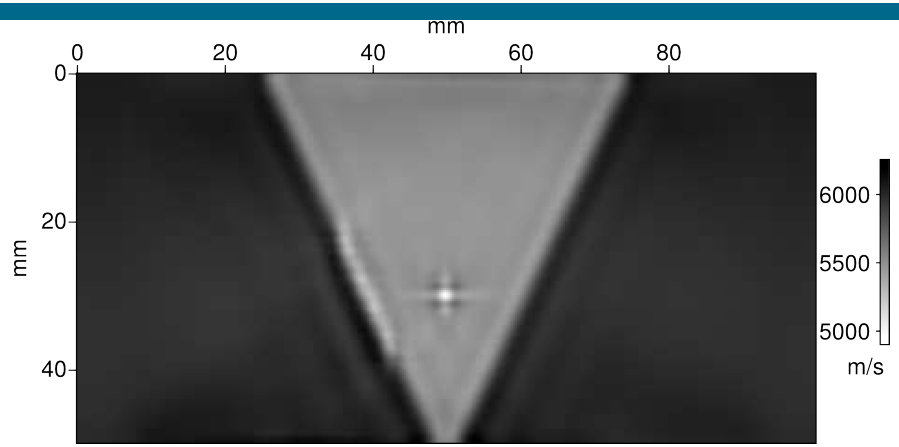


True density

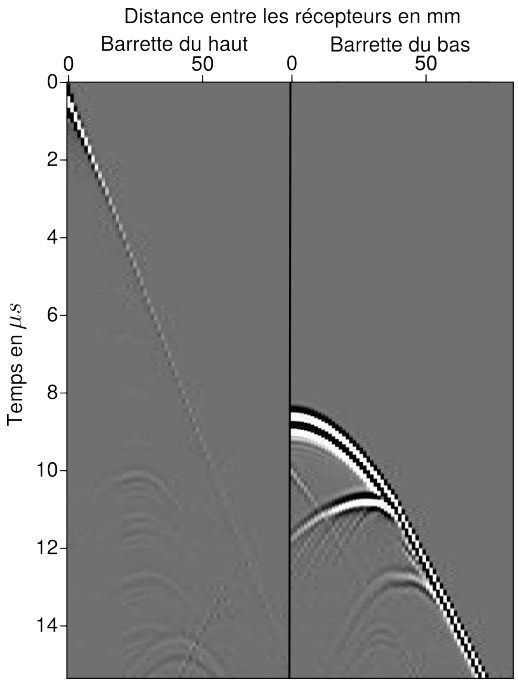
Transitional model

Building of a smooth velocy model :

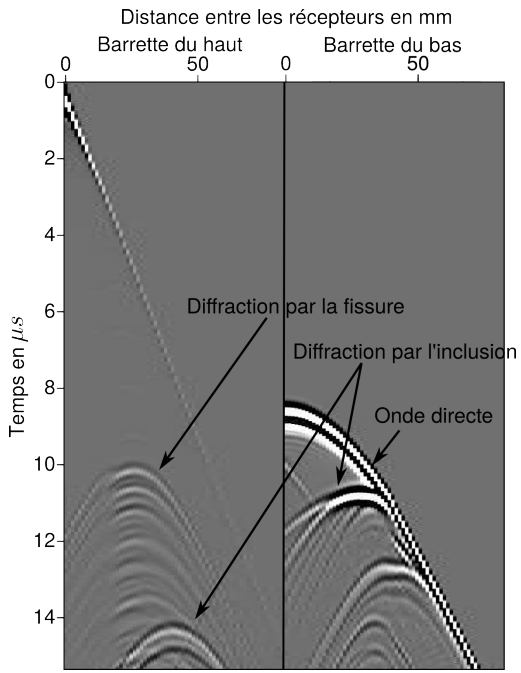
- from 200 kHz to 1 MHz
- strong smoothing of $\boldsymbol{\Delta m}$: Gaussian on 2 wavelengths



Smooth velocity model



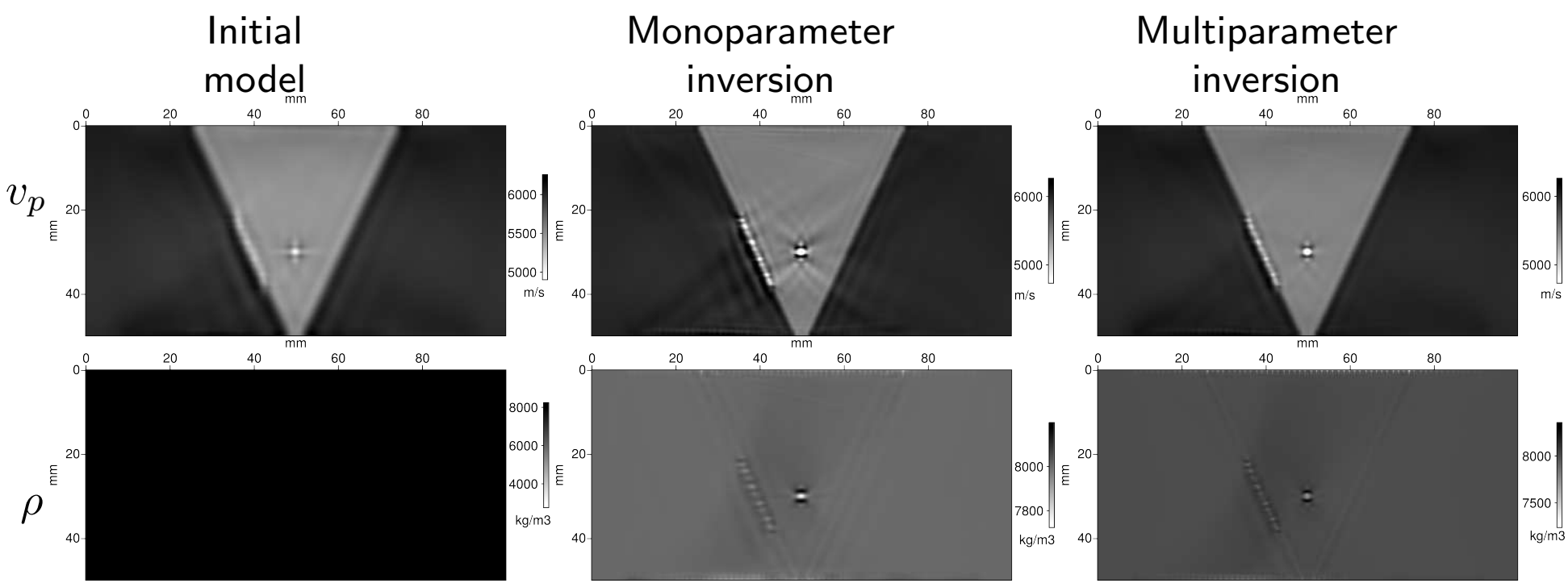
Homogeneous density



True density

Isotropic case

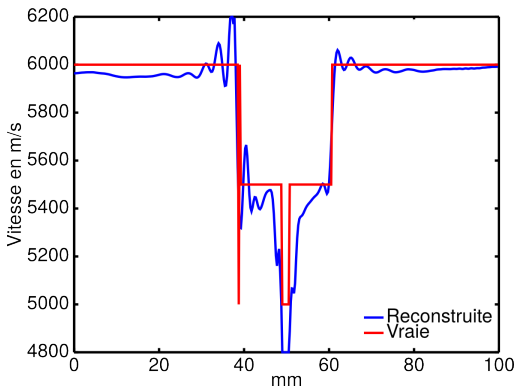
- 9 succesive inversions from 200 kHz to 3 MHz



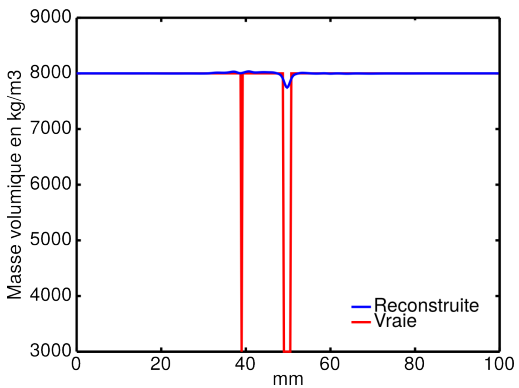
Isotropic case

- Monoparamter inversion :

velocity

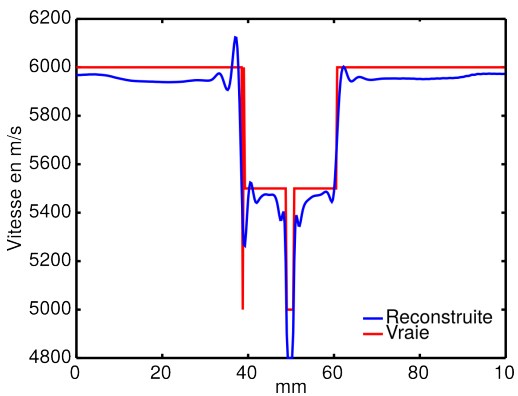


density

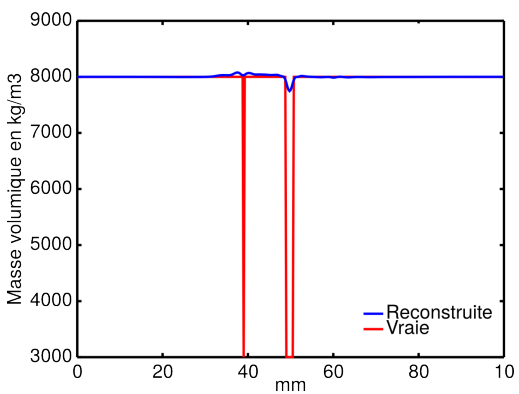


- Multiparameter inversion :

velocity



density

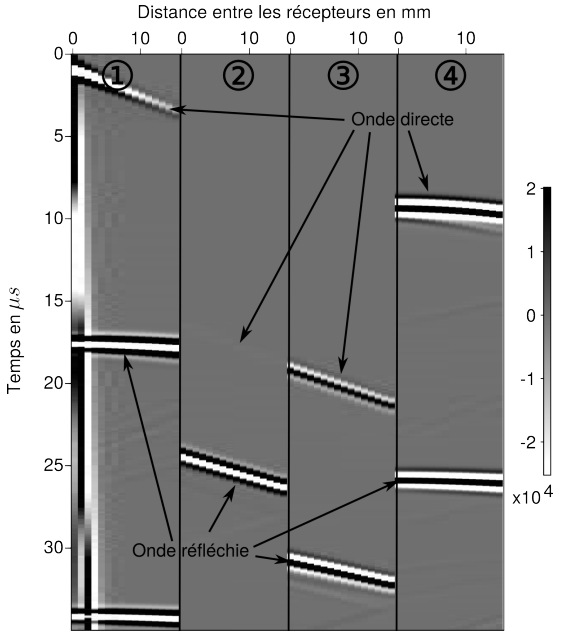


Horizontal profiles at 3 cm depth

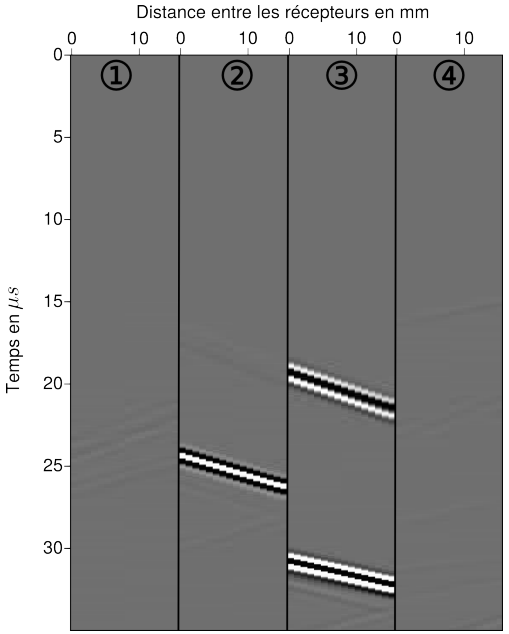
HTI case

- Acoustic approximation, transverse isotropic, horizontal symmetry axis
- Anisotropy parameters :

$$\epsilon = \frac{\boldsymbol{v}_p.\boldsymbol{e}_x - \boldsymbol{v}_p.\boldsymbol{e}_z}{\boldsymbol{v}_p.\boldsymbol{e}_z}$$

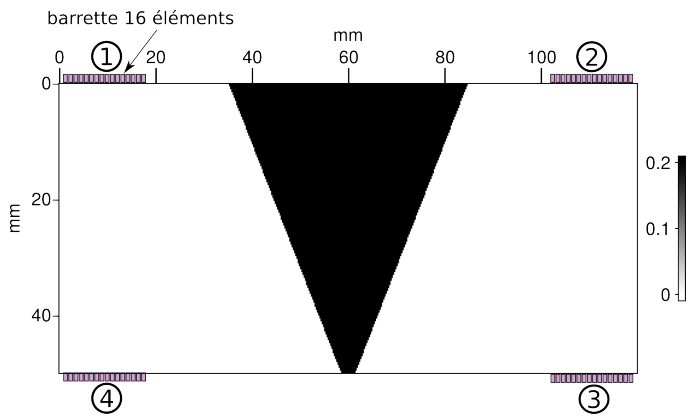


Data from true model

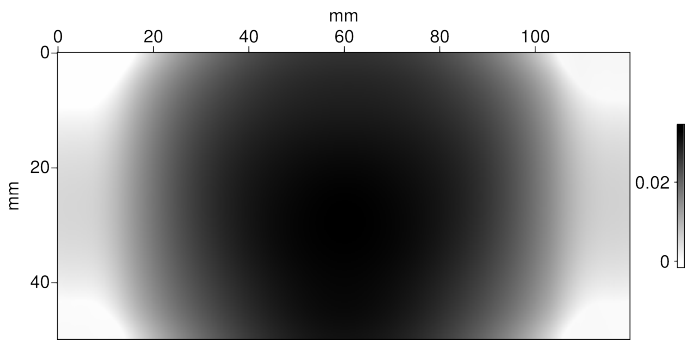


Initial residual data

True ϵ :



Reconstructed ϵ :

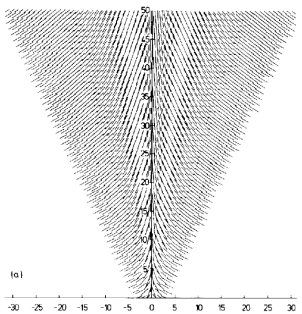


- Get info from horizontal rays : $\theta \sim \pi \quad \rightarrow \quad k \sim 0$
- Not realistic model

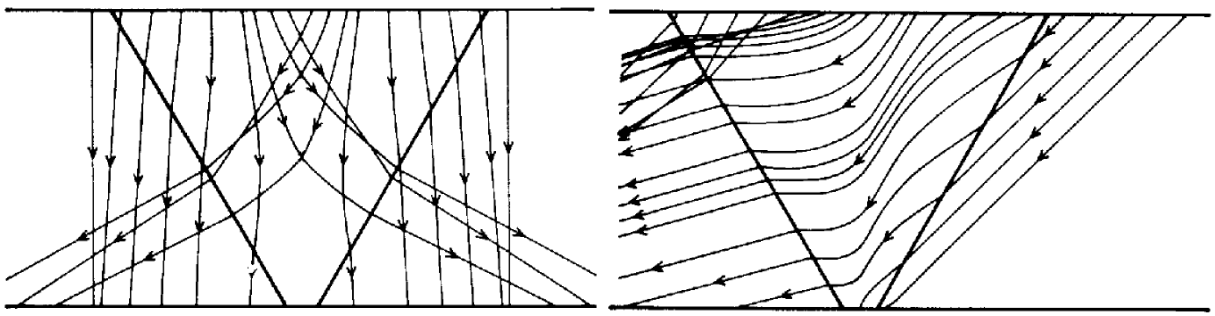
Conclusions

Conclusions

- Anisotropy model :
  - acoustic case : tilted transverse isotropic medium
  - elastic case : $6 \times C_{ij}$



(a) Grain orientation

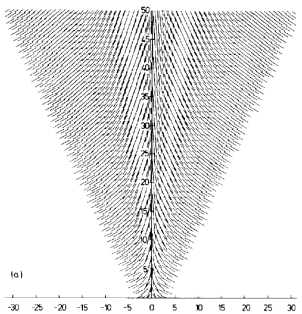


Pictures from Ogilvy, 1986

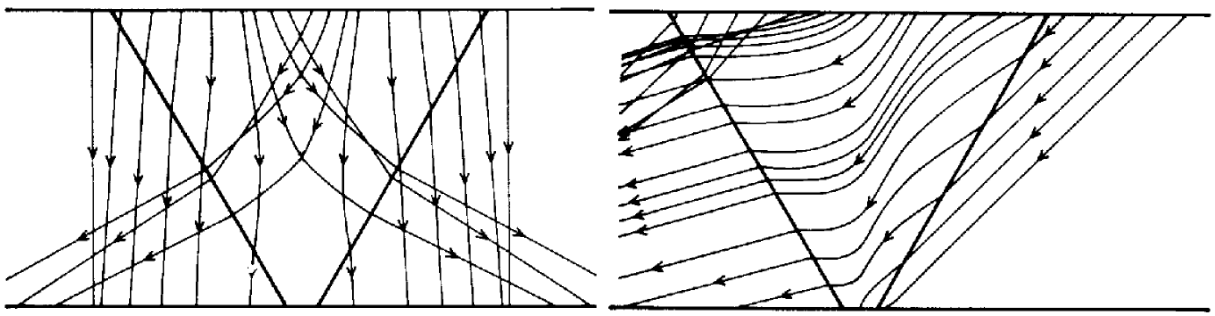
(b) Ray tracing (compressional wave)

Conclusions

- Anisotropy model :
  - acoustic case : tilted transverse isotropic medium
  - elastic case : $6 \times C_{ij}$



(a) Grain orientation



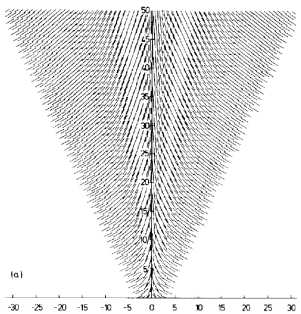
Pictures from Ogilvy, 1986

(b) Ray tracing (compressional wave)

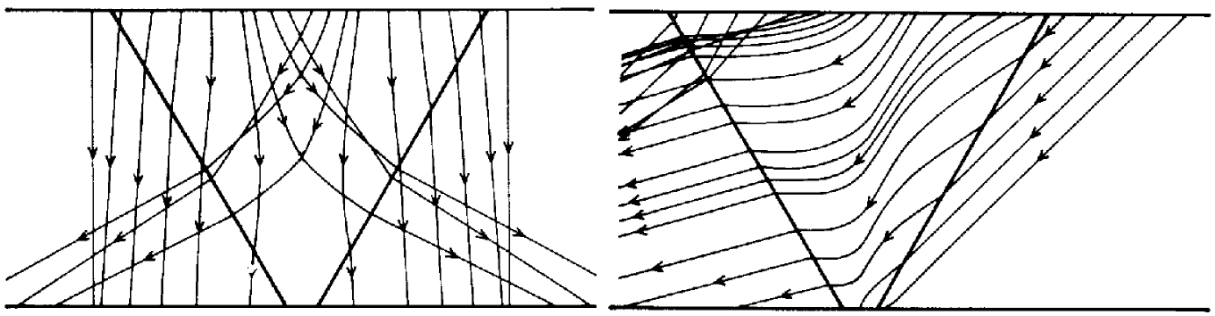
- Building another initial model

Conclusions

- Anisotropy model :
  - acoustic case : tilted transverse isotropic medium
  - elastic case : $6 \times C_{ij}$



(a) Grain orientation



Pictures from Ogilvy, 1986

(b) Ray tracing (compressional wave)

- Building another initial model
- Real data application : 3D case

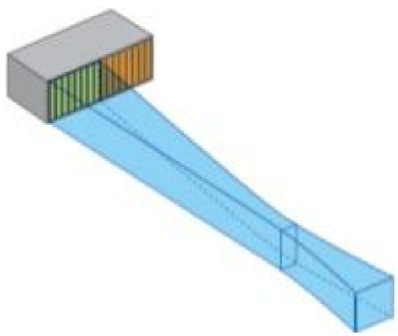
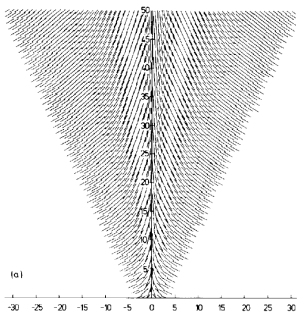
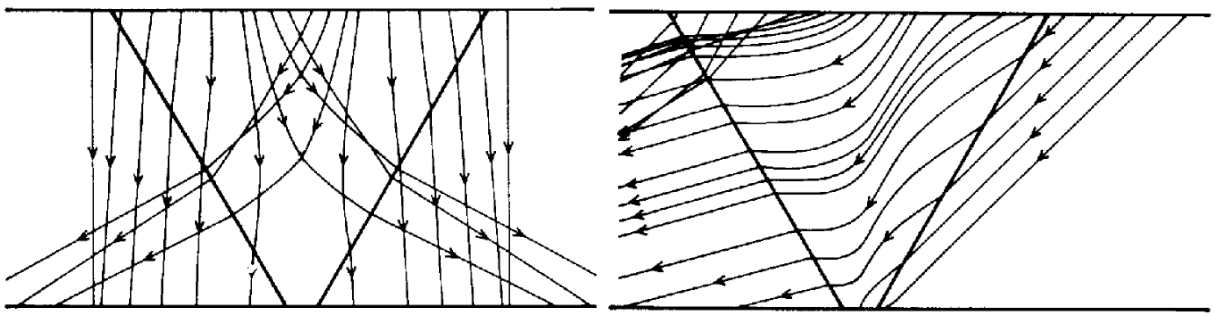


Image Olympus

Conclusions

- Anisotropy model :
  - acoustic case : tilted transverse isotropic medium
  - elastic case : $6 \times C_{ij}$





Pictures from Ogilvy, 1986

(a) Grain orientation

(b) Ray tracing (compressional wave)

- Building another initial model
- Real data application : 3D case
- Real acquisition geometry
  - curvature at the top/root of welds
  - optimial illumination/resolution

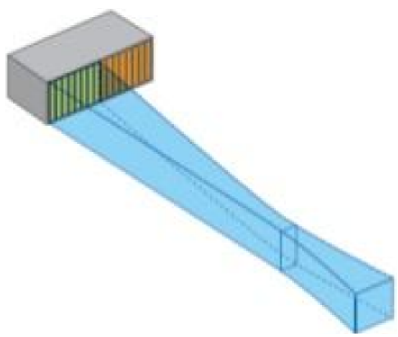


Image Olympus