

FWI for Ultrasonic Imaging

Flaw detection in steel weld

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Maîtres de conférences, ISTerre

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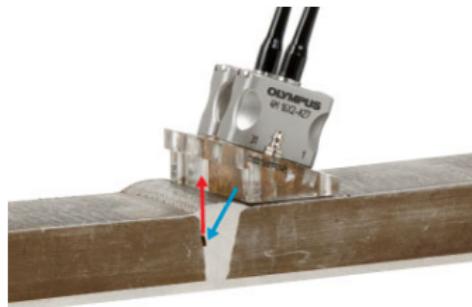


NDT for welds



Picture from Davidmack

Pipeline test



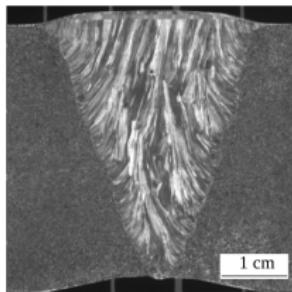
Picture from Olympus

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

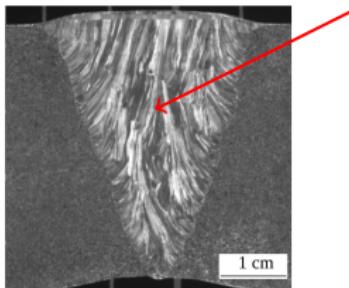
Macrography of a weld

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

NDT for welds

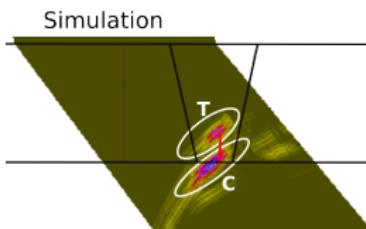
Strong unknown anisotropy

→ distortion and splitting of the beam

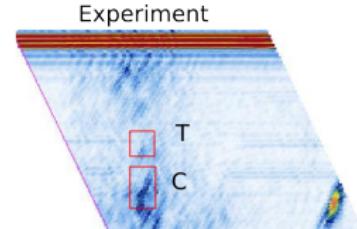


Picture from Chassignole, 2010

Macrography of a weld



Picture from Gardahaut, 2014



Comparison of ray based model and experiment result

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

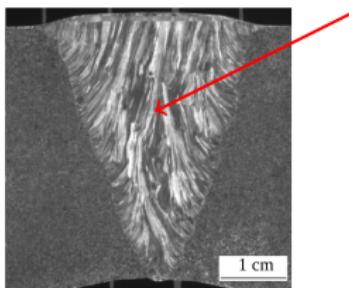


✗ need to know c in advance
✗ strong artefacts

NDT for welds

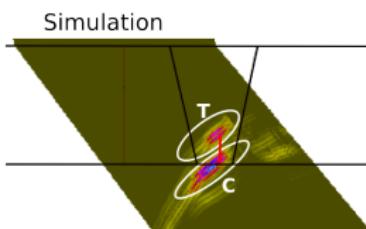
Strong unknown anisotropy

→ distortion and splitting of the beam

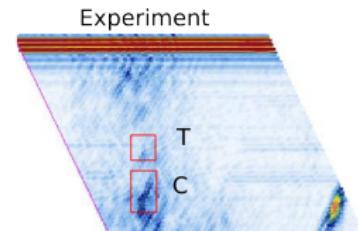


Picture from Chassignole, 2010

Macrography of a weld



Picture from Gardahaut, 2014



Comparison of ray based model and experiment result

- delay and sum methods
- decomposition of covariance matrix (DORT)
- solving NL optimization problem



✗ need to know c in advance

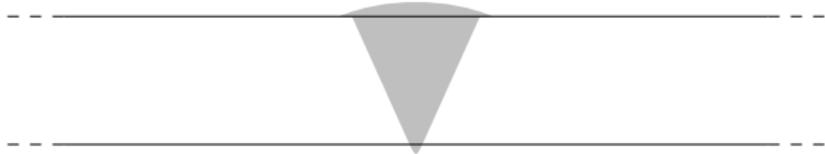
✗ strong artefacts



► contour reconstruction :
Dominguez et al., Rodriguez et al.
✓ C_{ij} reconstruction : FWI

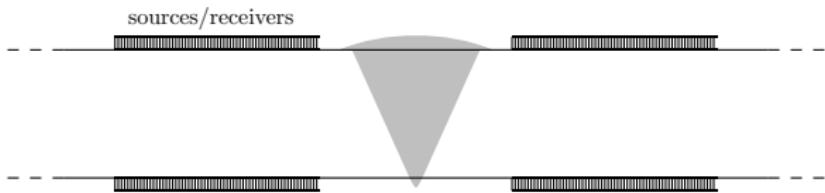
What is specific to weld imaging ?

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



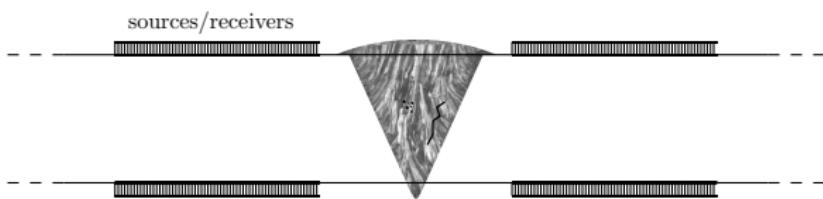
What is specific to weld imaging ?

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



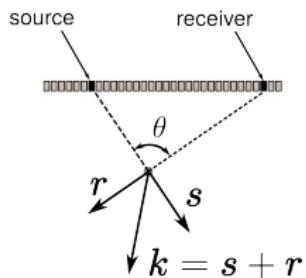
What is specific to weld imaging ?

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



Resolution analysis

$$\frac{\partial C}{\partial m_i} = \underbrace{^t \tilde{d}_{cal}}_{\text{champ incident}} \left(\frac{\partial \mathbf{A}}{\partial m_i} \right) \underbrace{\lambda}_{\text{résidus rétropagés}}$$
$$\sim \Re(e^{jk_0 \mathbf{s} \cdot \mathbf{x}}) \quad \sim \Re(e^{jk_0 \mathbf{r} \cdot \mathbf{x}})$$



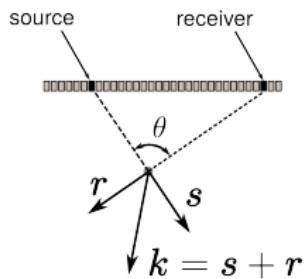
Resolution analysis

$$\frac{\partial C}{\partial m_i} = \underbrace{\tilde{d}_{cal}^t}_{\text{champ incident}} \left(\frac{\partial \mathbf{A}}{\partial m_i} \right) \underbrace{\lambda}_{\text{résidus rétropagés}} \sim \Re(e^{jk_0 \mathbf{s} \cdot \mathbf{x}}) \sim \Re(e^{jk_0 \mathbf{r} \cdot \mathbf{x}})$$

► Gradient resolution :

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

(2)



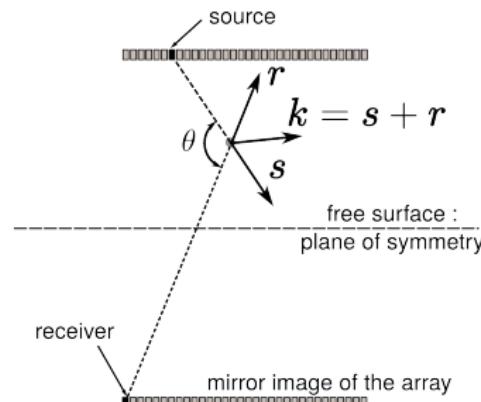
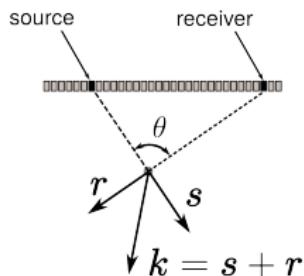
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Resolution analysis

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(2)

Resolution analysis – Local 2DFT

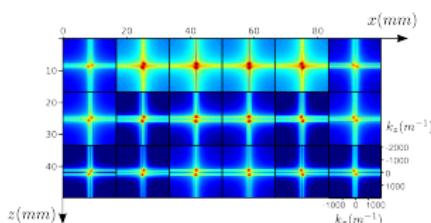
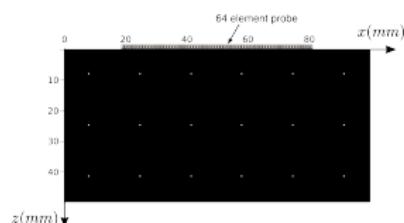


FIGURE : Excitation : 150 kHz

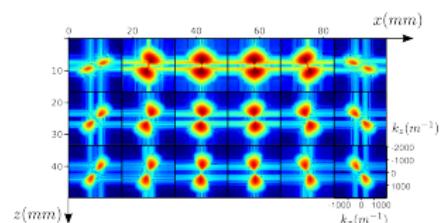
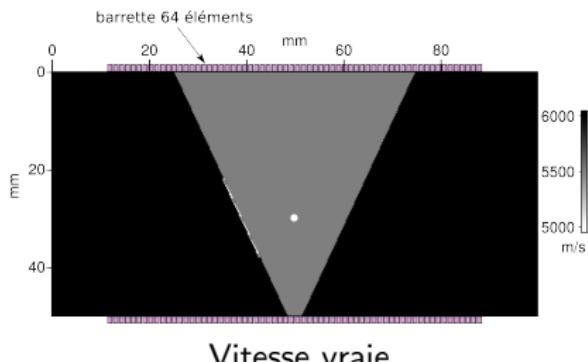


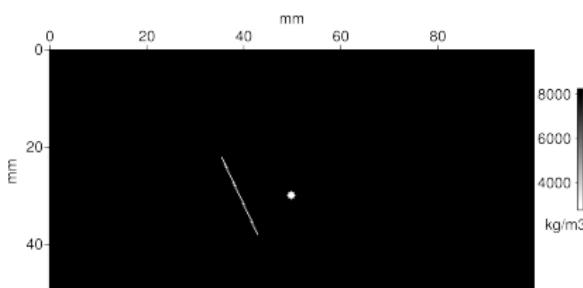
FIGURE : Excitation : 2 MHz

Inversions en milieu isotrope

- ▶ Milieu 2D, isotrope, acoustique
- ▶ Paramétrisation : vitesse + masse volumique
- ▶ Excitation : Ricker centré à 2 MHz



Vitesse vraie

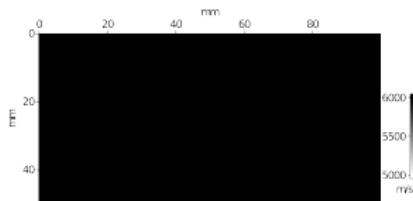


Masse volumique vraie

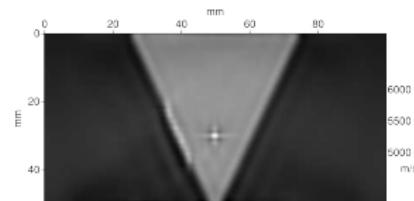
- ▶ 9 inversions successives de 200 kHz à 3 MHz pour
 - ▶ mieux contraindre le problème
 - ▶ lever les ambiguïtés de déphasage

Inversions en milieu isotrope – Vitesse

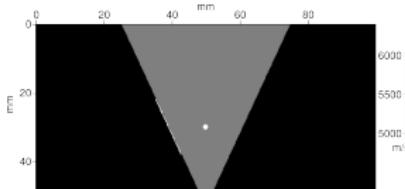
Modèle initial de vitesse :



Modèle initial de vitesse :

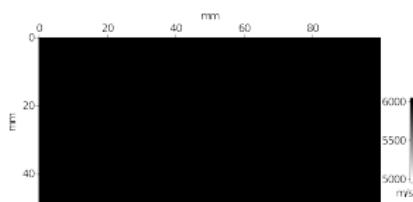


Vitesse vraie :

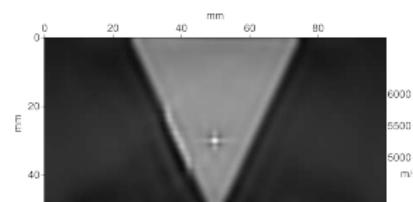


Inversions en milieu isotrope – Vitesse

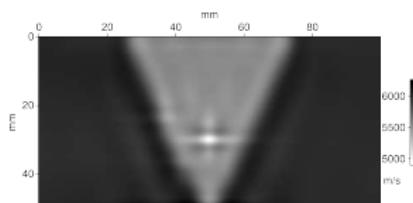
Modèle initial de vitesse :



Modèle initial de vitesse :

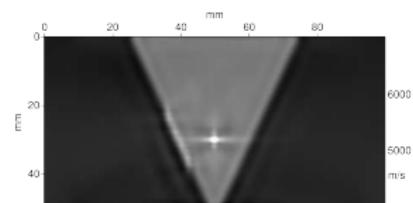


Vitesse Reconstituée :

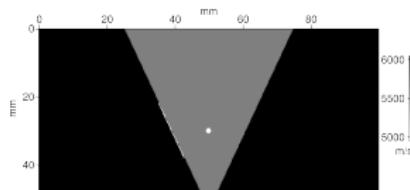


$f \approx 400 \text{ kHz}$

Vitesse Reconstituée :

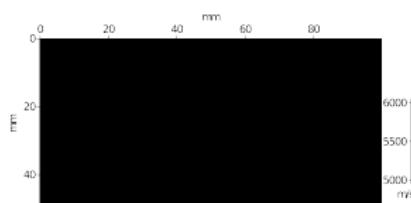


Vitesse vraie :

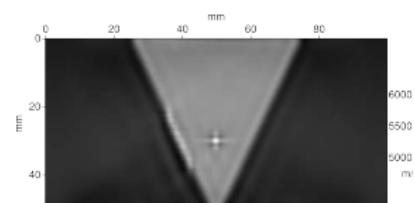


Inversions en milieu isotrope – Vitesse

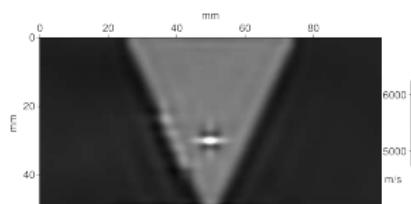
Modèle initial de vitesse :



Modèle initial de vitesse :

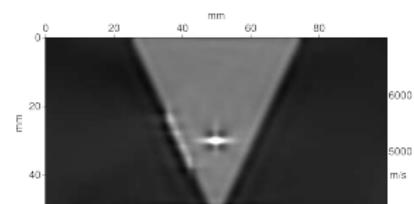


Vitesse Reconstituée :

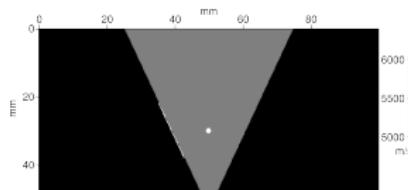


$f \approx 1 \text{ MHz}$

Vitesse Reconstituée :

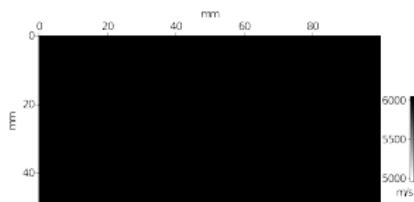


Vitesse vraie :

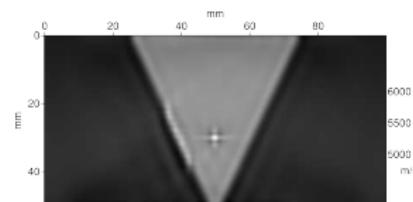


Inversions en milieu isotrope – Vitesse

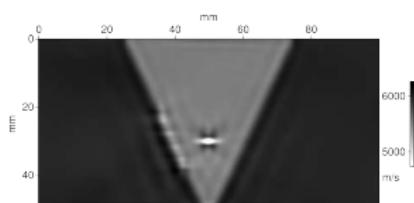
Modèle initial de vitesse :



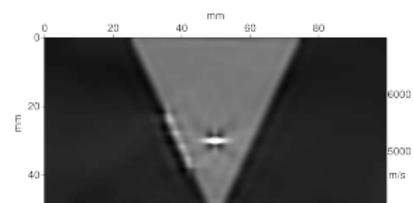
Modèle initial de vitesse :



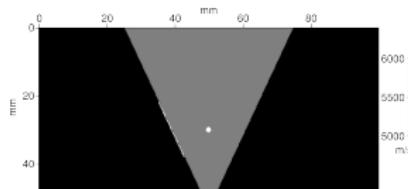
Vitesse Reconstituée :



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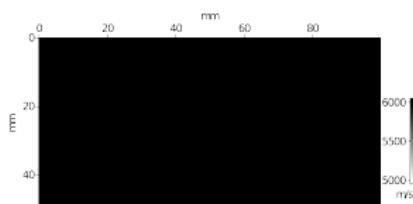


Vitesse vraie :

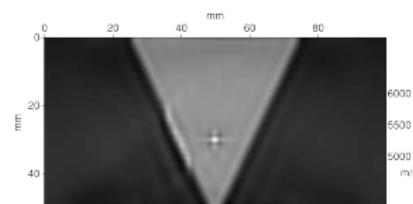


Inversions en milieu isotrope – Vitesse

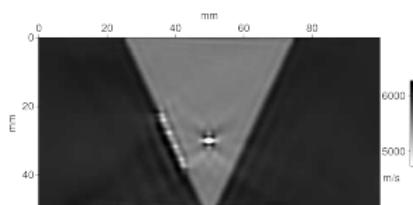
Modèle initial de vitesse :



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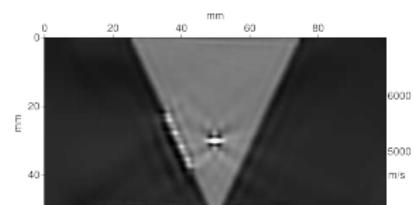


Vitesse Reconstituée :

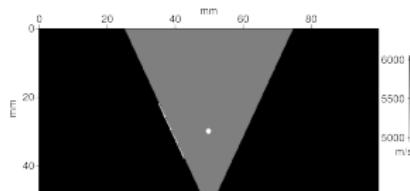


$f \approx 2 \text{ MHz}$

Vitesse Reconstituée :

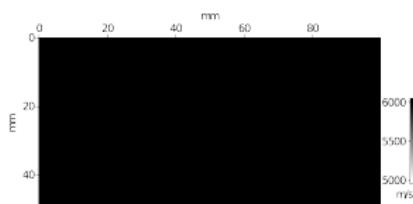


Vitesse vraie :

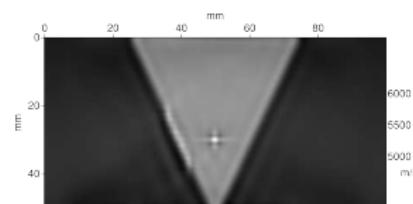


Inversions en milieu isotrope – Vitesse

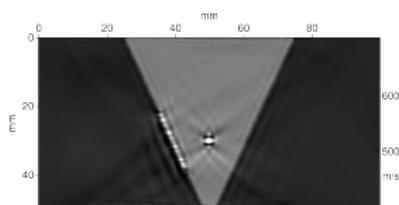
Modèle initial de vitesse :



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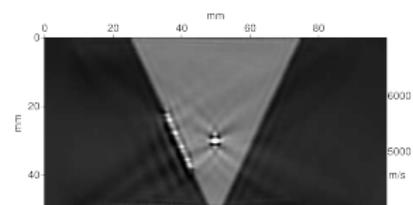


Vitesse Reconstituée :

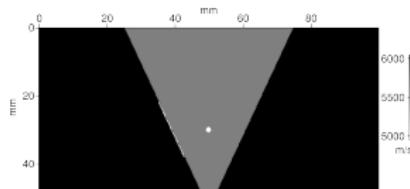


$f \approx 3 \text{ MHz}$

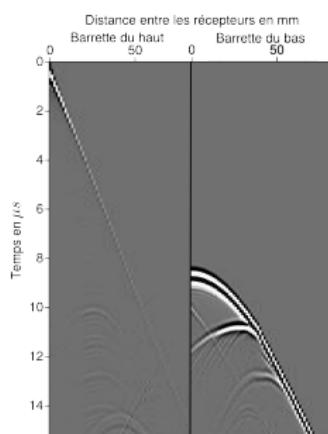
Vitesse Reconstituée :



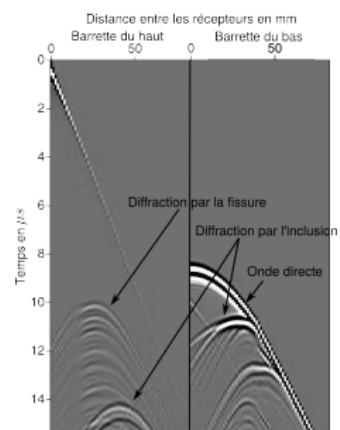
Vitesse vraie :



Inversions en milieu isotrope – Densité

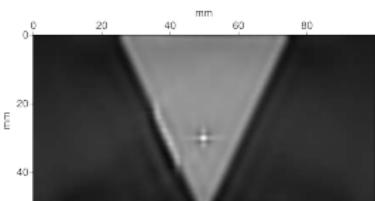


Signaux issus de ρ homogène



Signaux issus de ρ vraie

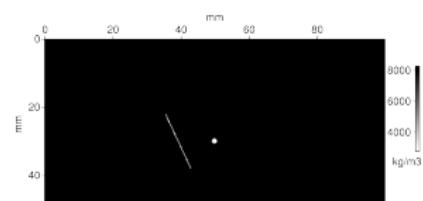
Modèle initial de vitesse :



Masse volumique
reconstruite :

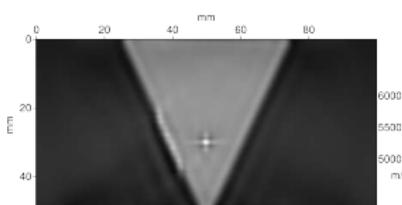


Masse volumique vraie :

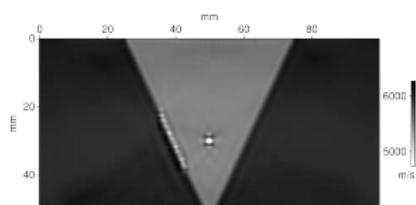


Inversions en milieu isotrope – Multiparamètre

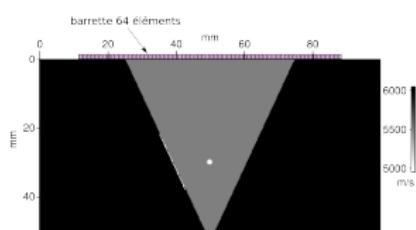
Vitesse initiale :



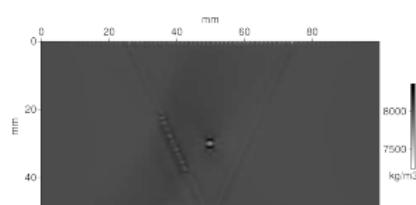
Vitesse reconstruite :



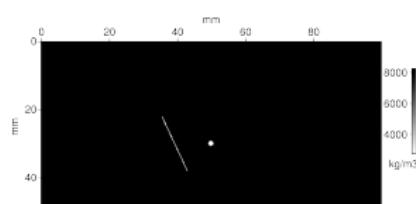
Vitesse vraie :



Masse volumique reconstruite :

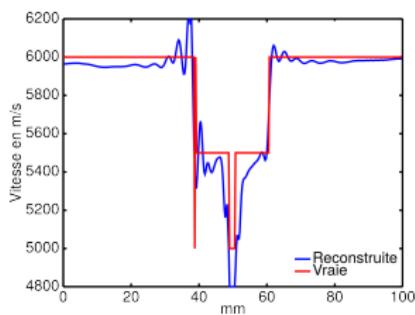


Masse volumique vraie :

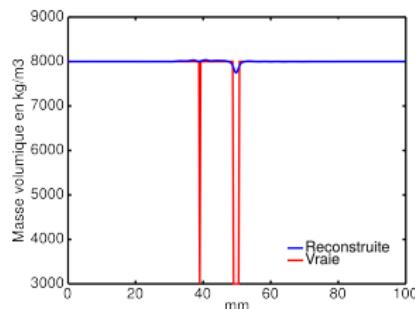


► Inversion monoparamètre :

Vitesse :

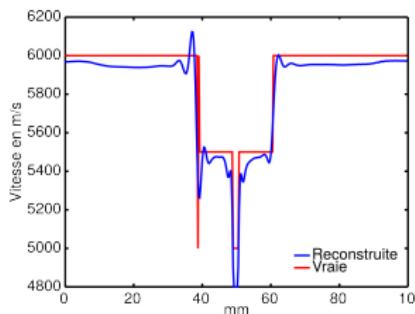


Masse volumique :

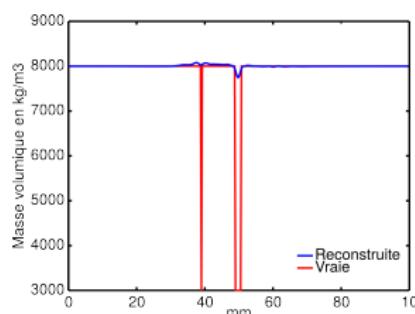


► Inversion multiparamètre :

Vitesse :



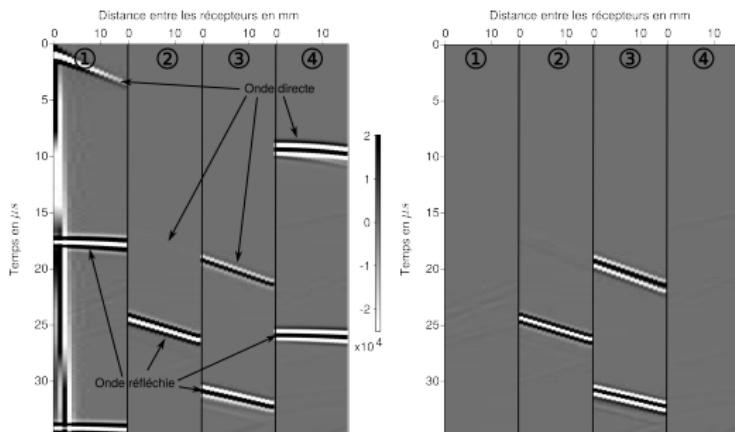
Masse volumique :



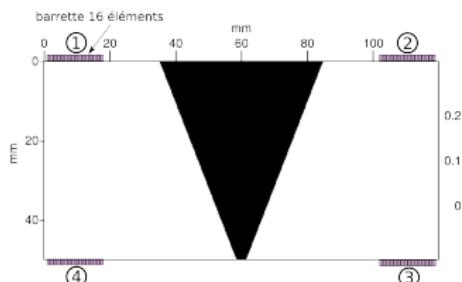
Inversions en milieu anisotrope

- Milieu acoustique, isotrope transverse (axe de symétrie horizontal)
- Paramètre d'anisotropie :

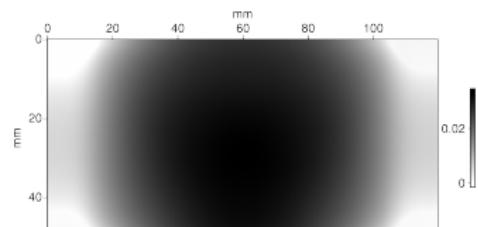
$$\epsilon = \frac{\mathbf{v}_p \cdot \mathbf{e}_x - \mathbf{v}_p \cdot \mathbf{e}_z}{\mathbf{v}_p \cdot \mathbf{e}_z}$$



ϵ vrai :



ϵ reconstruit :

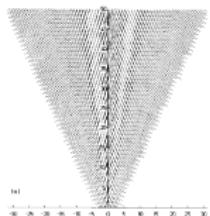


Conclusions et perspectives

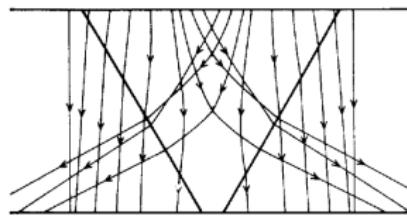
- ▶ Inversion multiparamètre : corrige les artefacts

Conclusions et perspectives

- ▶ Inversion multiparamètre : corrige les artefacts
- ▶ Prise en compte de l'anisotropie :
 - ▶ en acoustique : par un modèle isotrope transverse incliné
 - ▶ en élastique : par $6 \times C_{ij}$

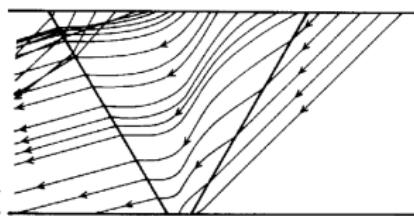


(a) Modèle d'orientation des grains



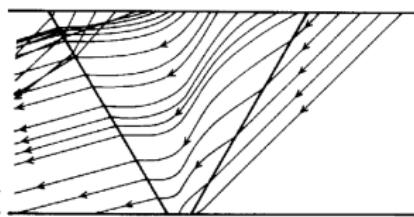
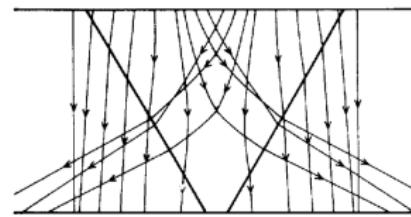
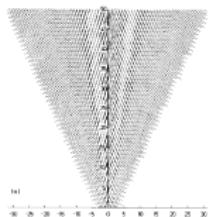
Images extraits de Ogilvy, 1986

(b) Courbure des rayons (ondes de compressions)



Conclusions et perspectives

- ▶ Inversion multiparamètre : corrige les artefacts
- ▶ Prise en compte de l'anisotropie :
 - ▶ en acoustique : par un modèle isotrope transverse incliné
 - ▶ en élastique : par $6 \times C_{ij}$



Images extraites de Ogilvy, 1986

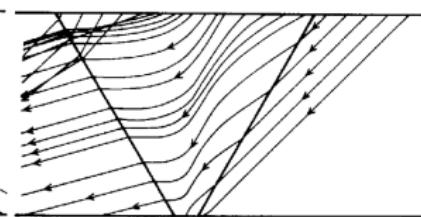
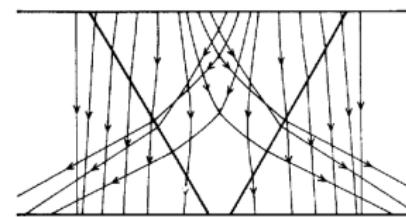
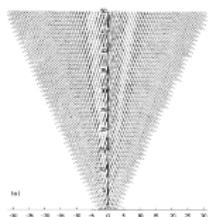
(a) Modèle d'orientation des grains

(b) Courbure des rayons (ondes de compressions)

- ▶ Élaboration d'un modèle initial fiable

Conclusions et perspectives

- ▶ Inversion multiparamètre : corrige les artefacts
- ▶ Prise en compte de l'anisotropie :
 - ▶ en acoustique : par un modèle isotrope transverse incliné
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Images extraits de Ogilvy, 1986

(a) Modèle d'orientation des grains

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- ▶ Élaboration d'un modèle initial fiable
- ▶ Prise en compte de la propagation 3D

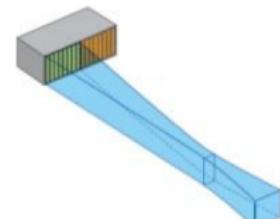
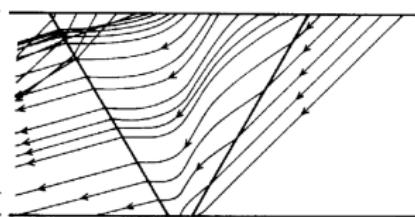
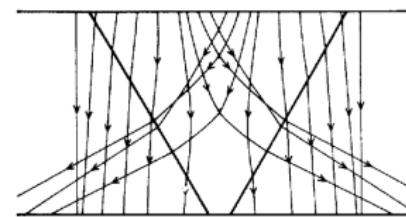
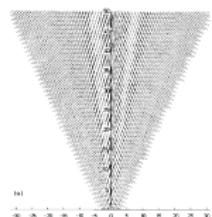


Image Olympus

Conclusions et perspectives

- ▶ Inversion multiparamètre : corrige les artefacts
- ▶ Prise en compte de l'anisotropie :
 - ▶ en acoustique : par un modèle isotrope transverse incliné
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Images extraits de Ogilvy, 1986

(a) Modèle d'orientation des grains

(b) Courbure des rayons (ondes de compressions)

- ▶ Élaboration d'un modèle initial fiable
- ▶ Prise en compte de la propagation 3D
- ▶ Géométrie d'acquisition à adapter
 - ▶ à la géométrie de la soudure réelle
 - ▶ pour une bonne illumination/résolution

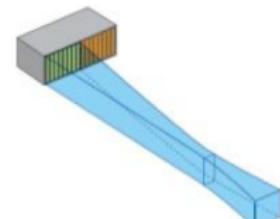


Image Olympus

questions :
défaut : air
focalisation