Velocity model building by slope tomography

Bernard Law and Daniel Trad

Overview

- Slope tomography is a tomographic method that uses slopes and traveltimes of local coherent events on pre-stack reflection data.

- Velocity model determined from slope tomography can be used as a starting model for depth migration and inversion.

- Without the requirement of continuous reflectors, slope tomography is operationally more efficient than traditional reflection tomography

- Slope tomography methods include
  - CDR tomography
  - Stereotomography
  - Adjoint stereotomography

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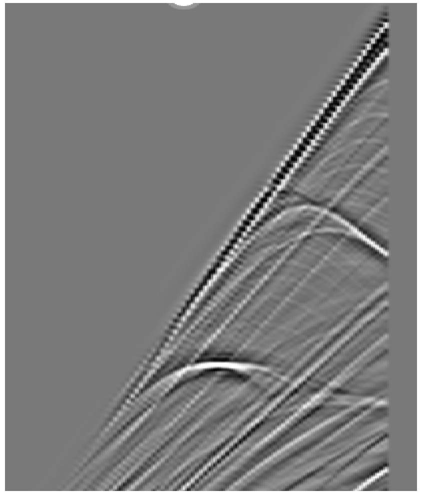

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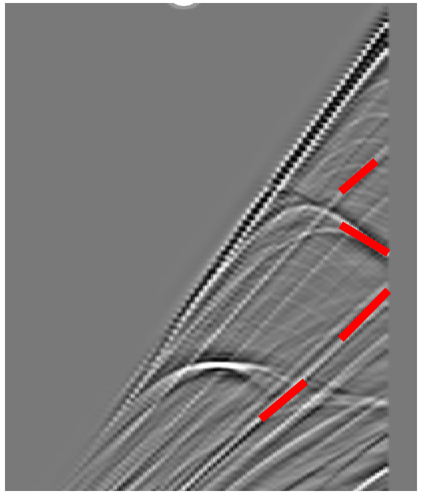
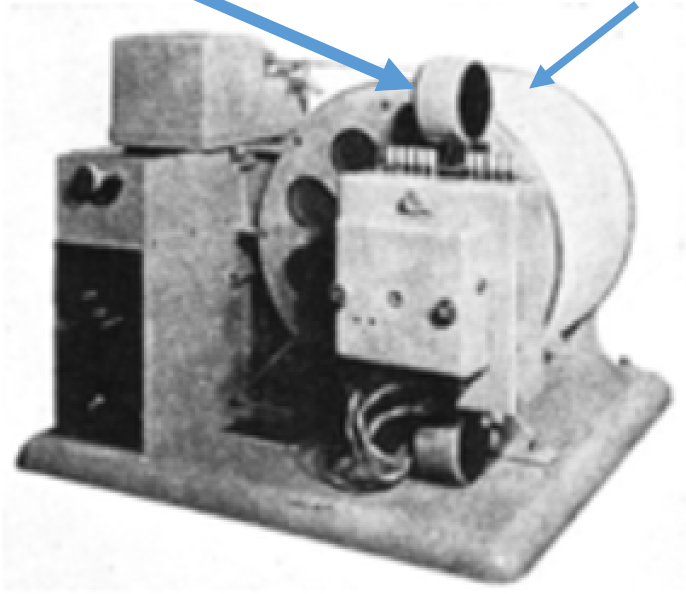


Controlled Directional Reception (C.D.R.)

Single phone seismic traces

Variable density film

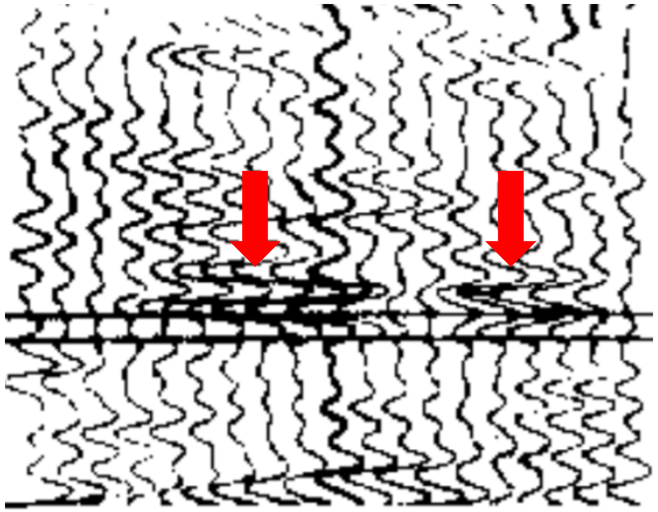
Paper drum

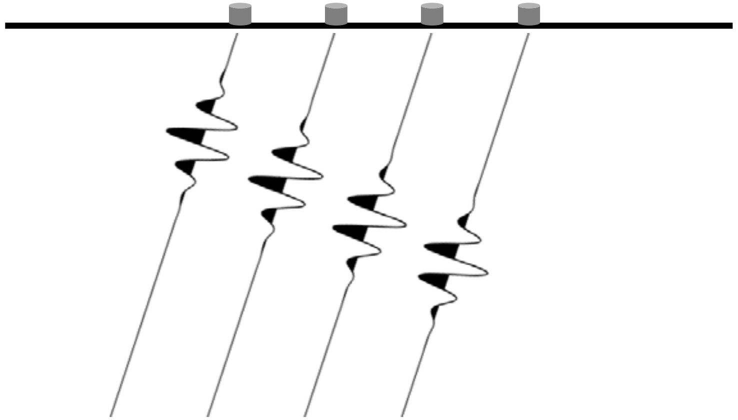


Optical analyzer

Dip scan record

$-'ve$ 0 $+'ve$



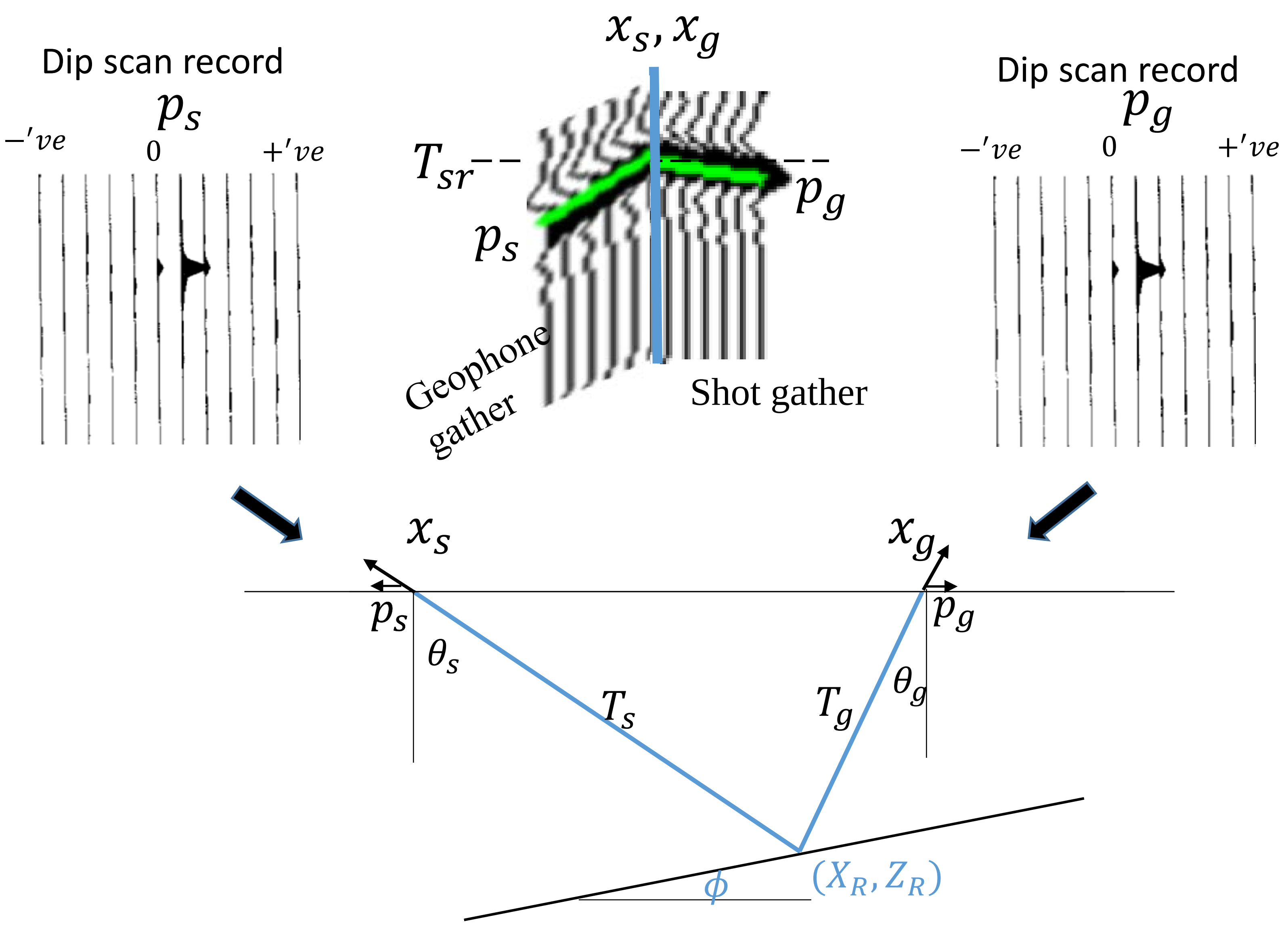


Reflected wave from
dipping reflector

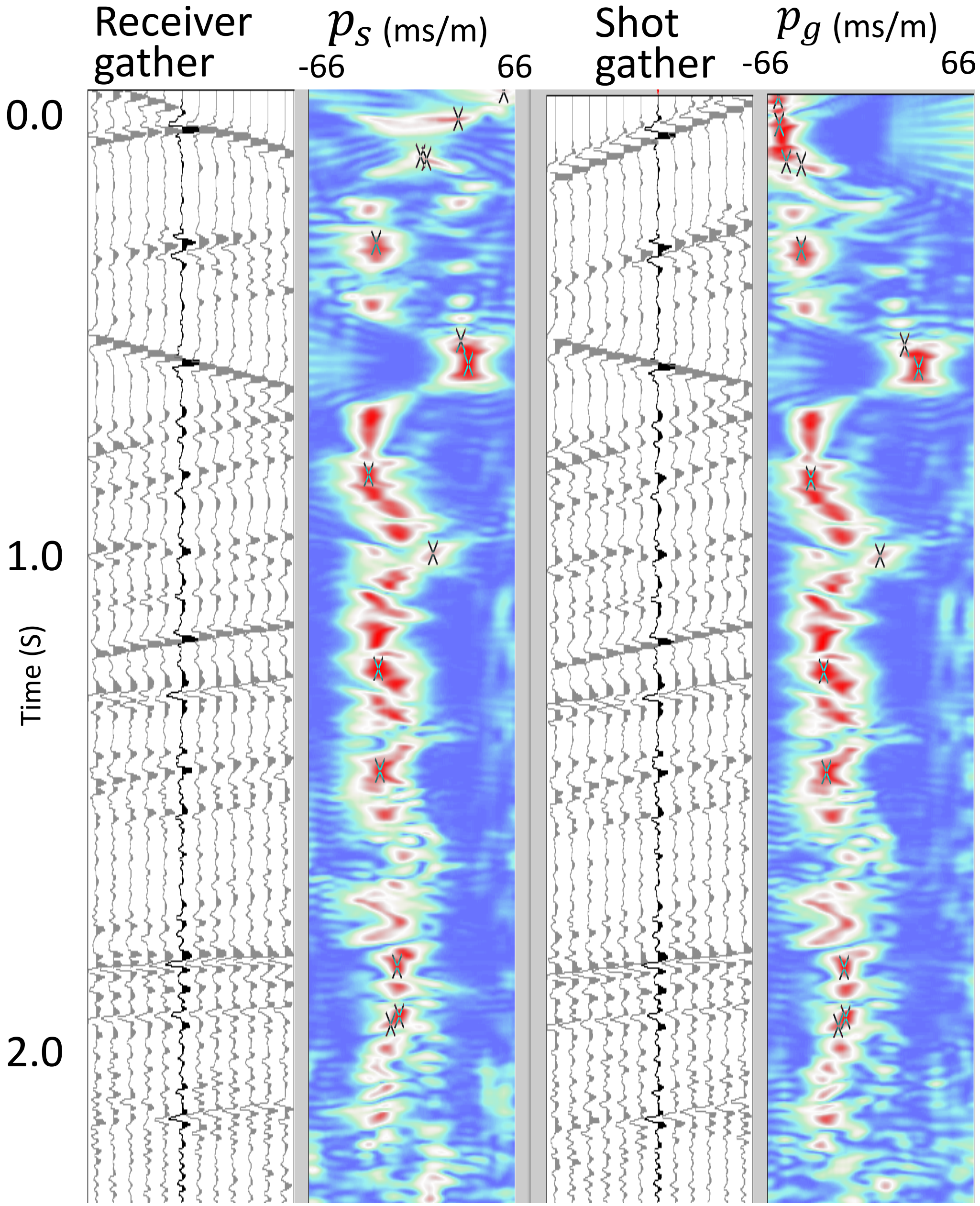
Controlled Directional Sensitivity (C.D.S.)

(Rieber 1936)

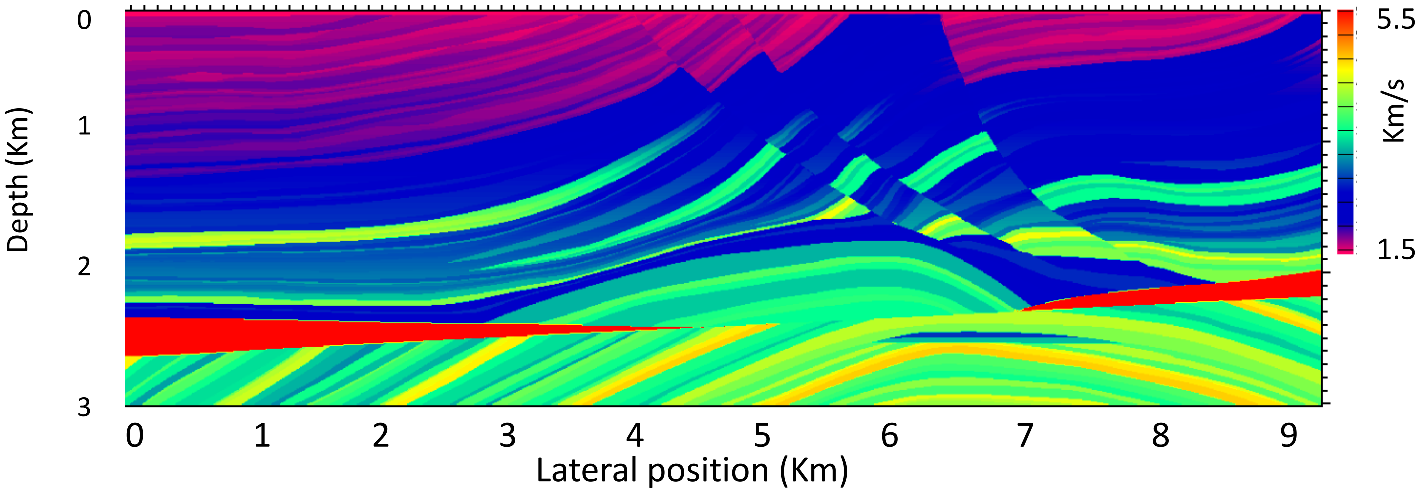
Controlled Directional Reception (C.D.R.)



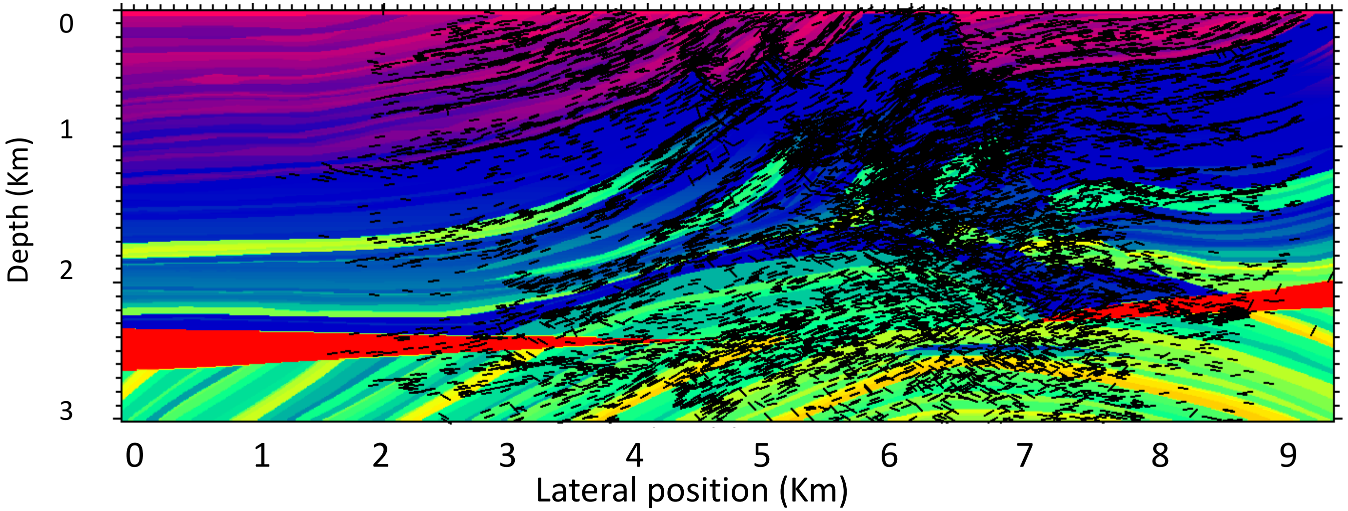
Controlled directional Reception (C.D.R.)



Marmousi model



Dip bars computed from slopes and traveltime picks



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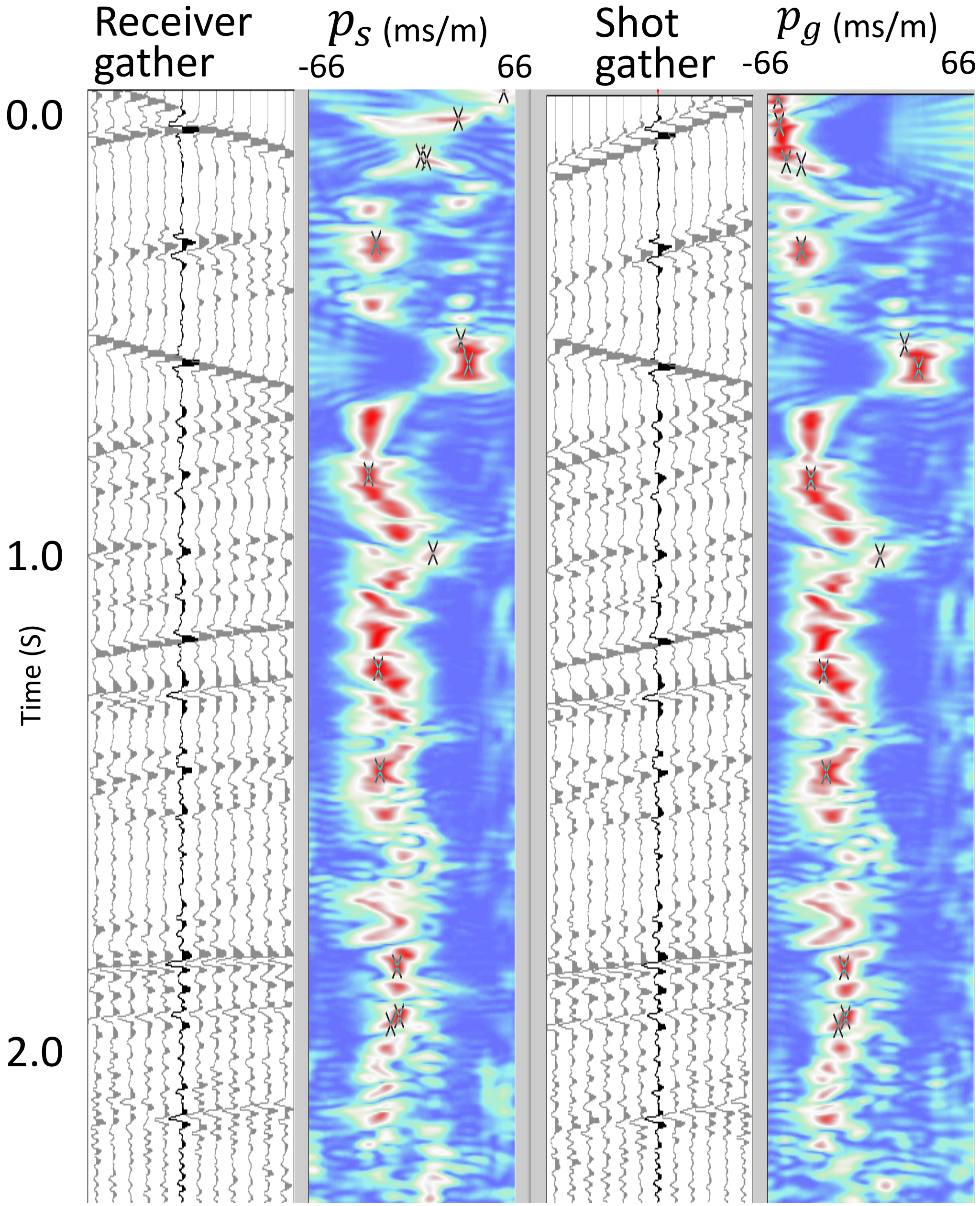

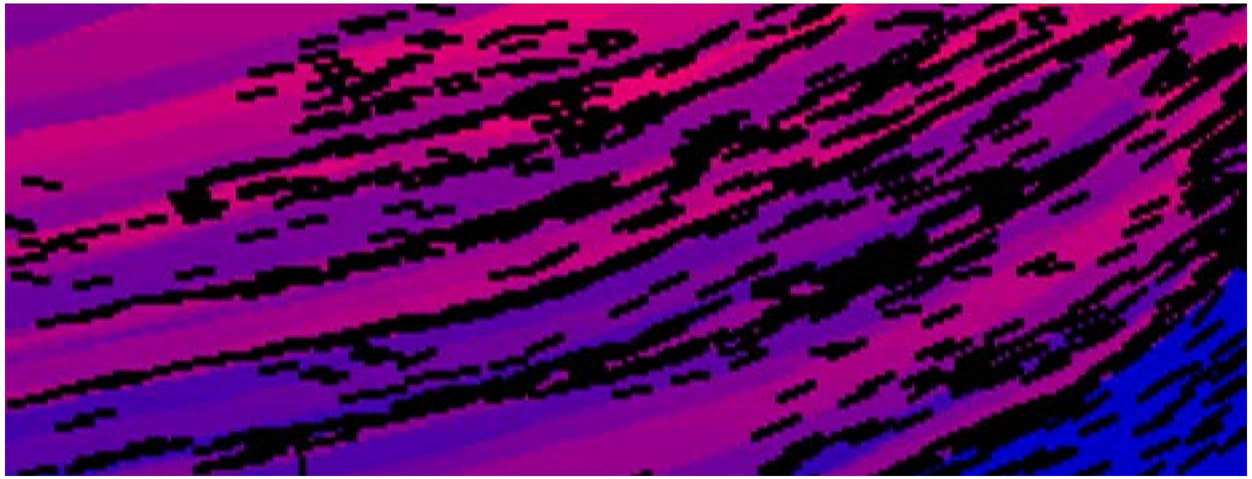

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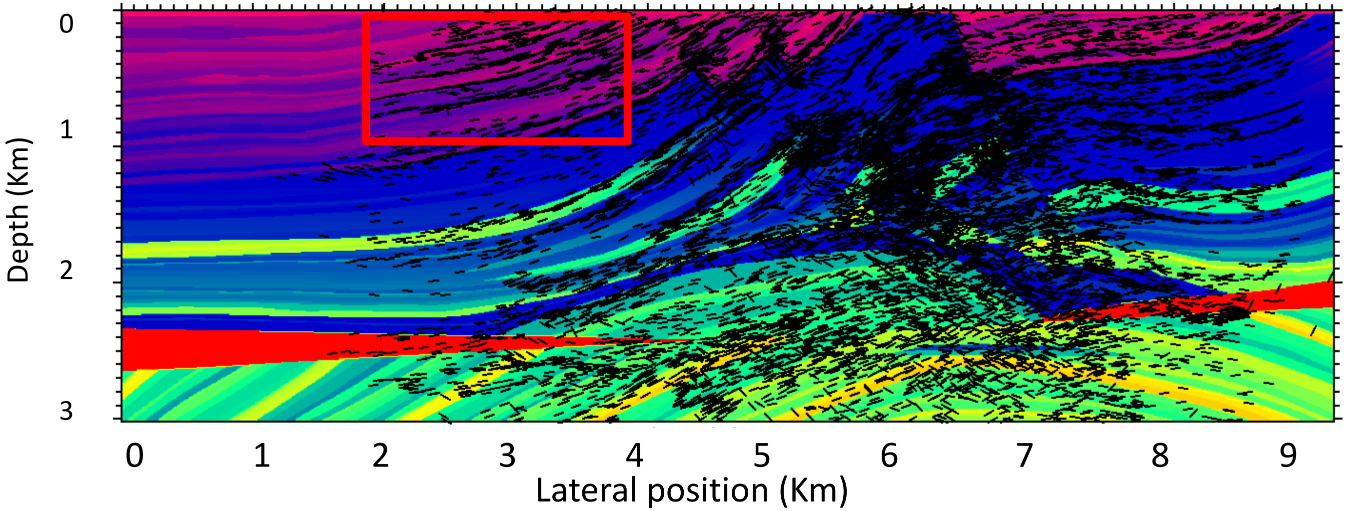

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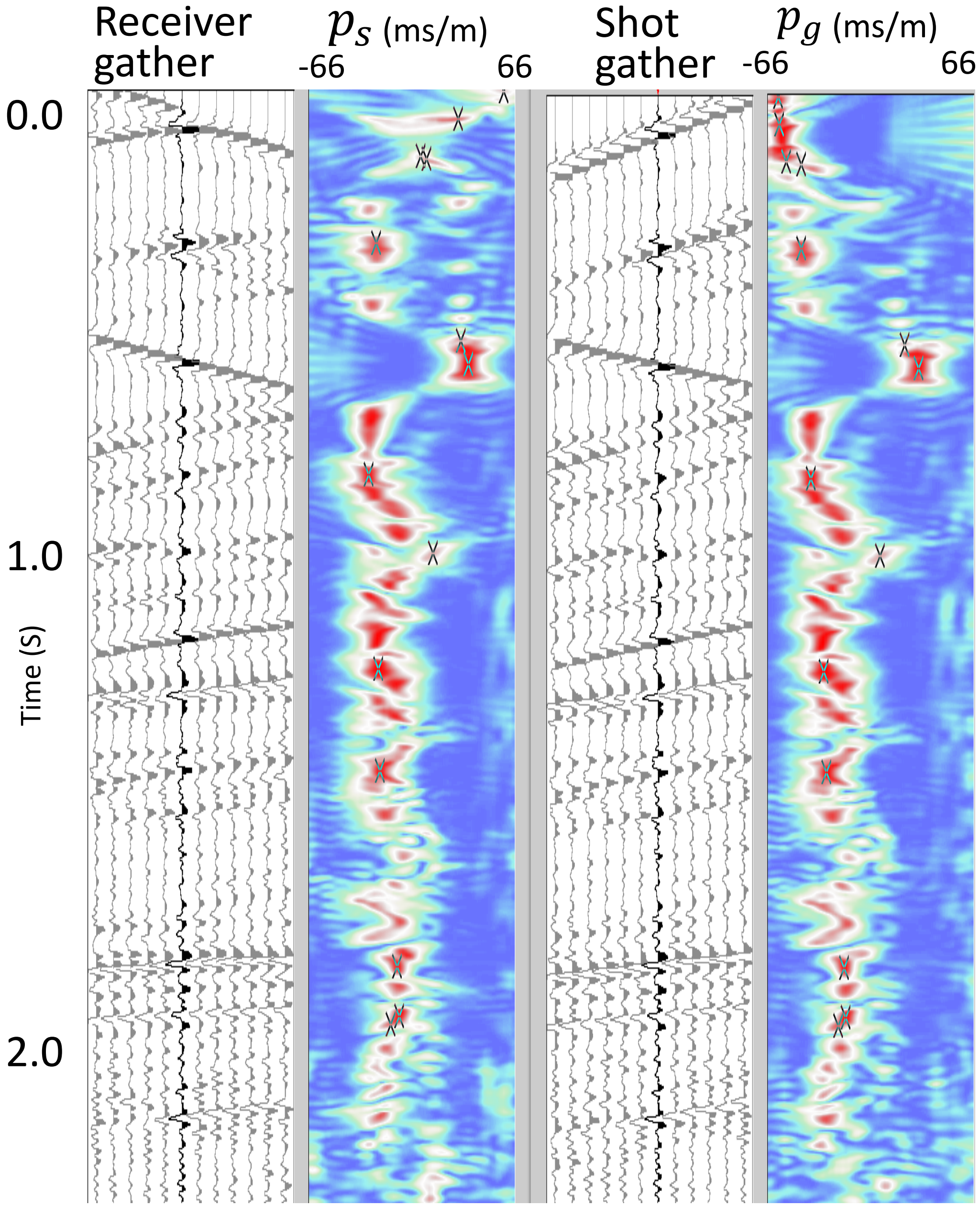

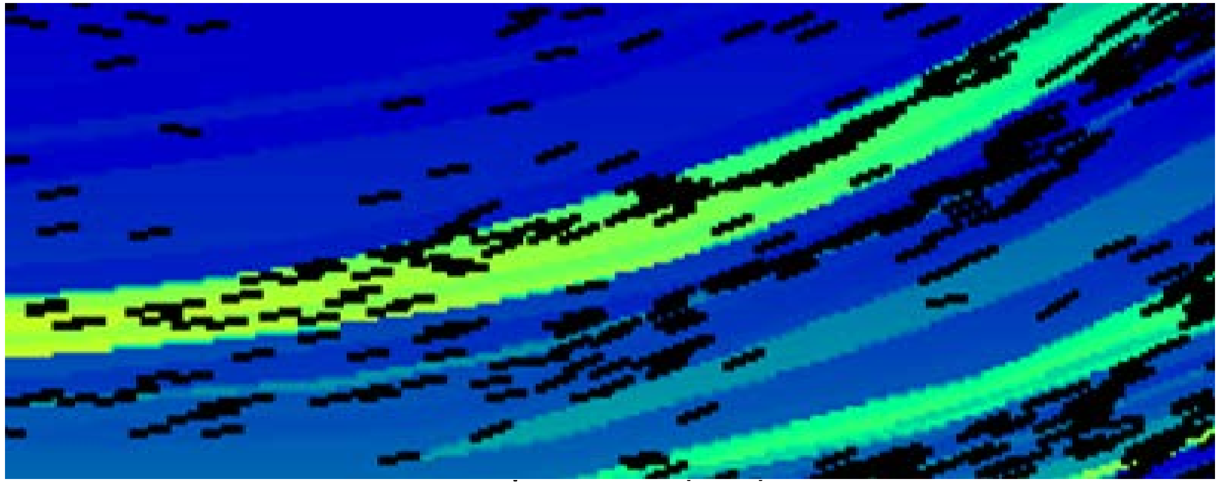

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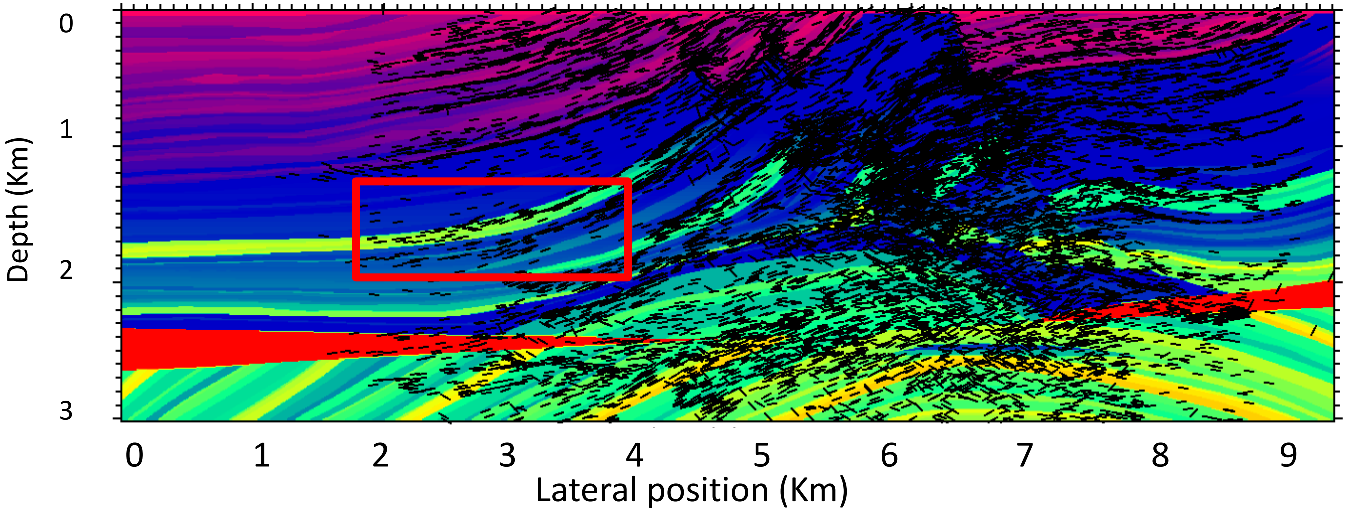
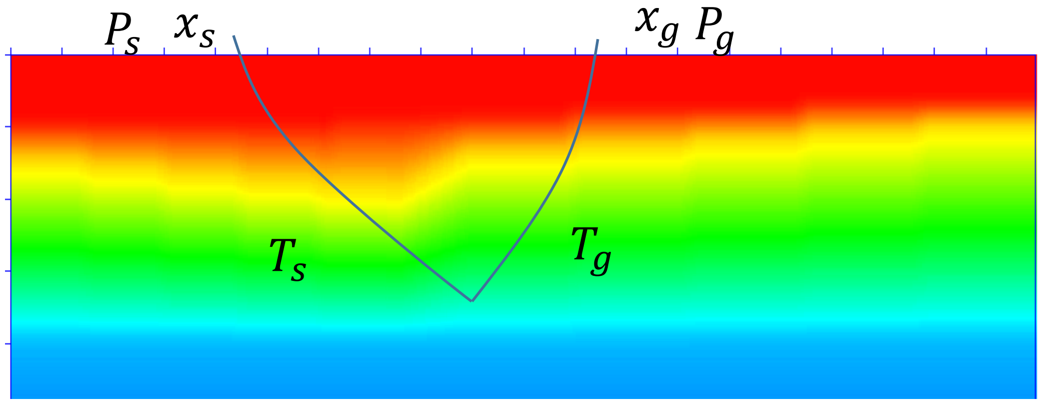


CDR tomography



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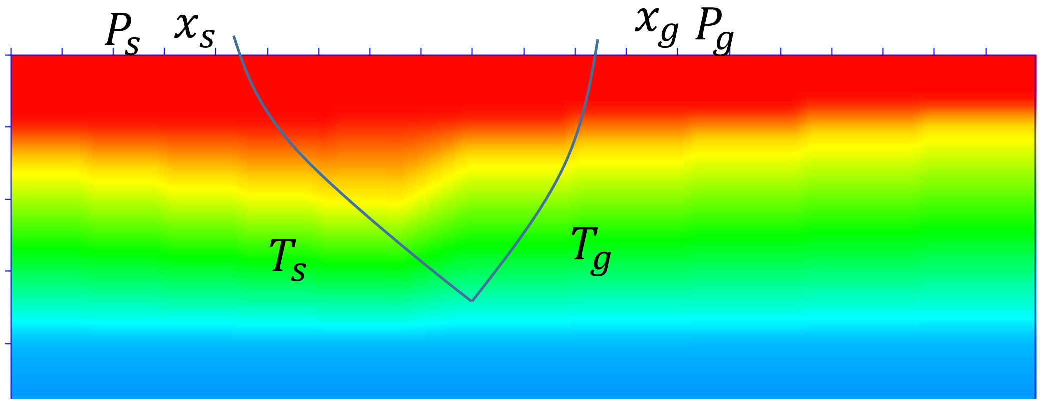
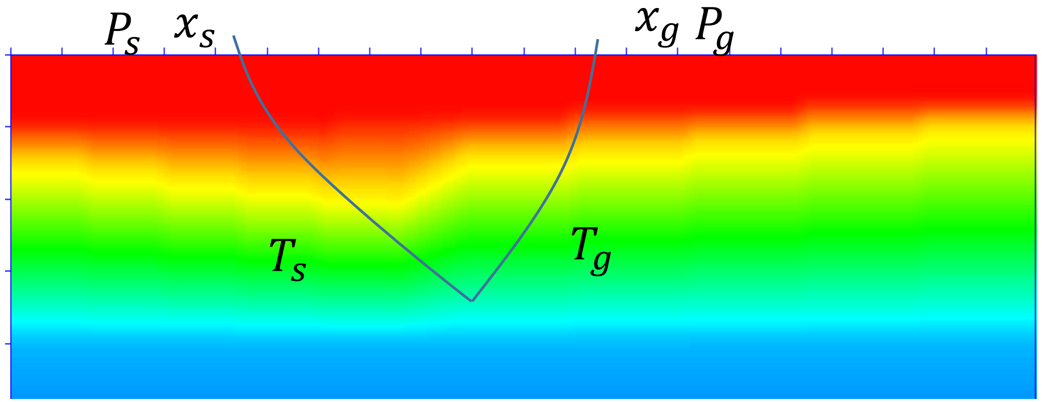


Correct velocity model

CDR tomography



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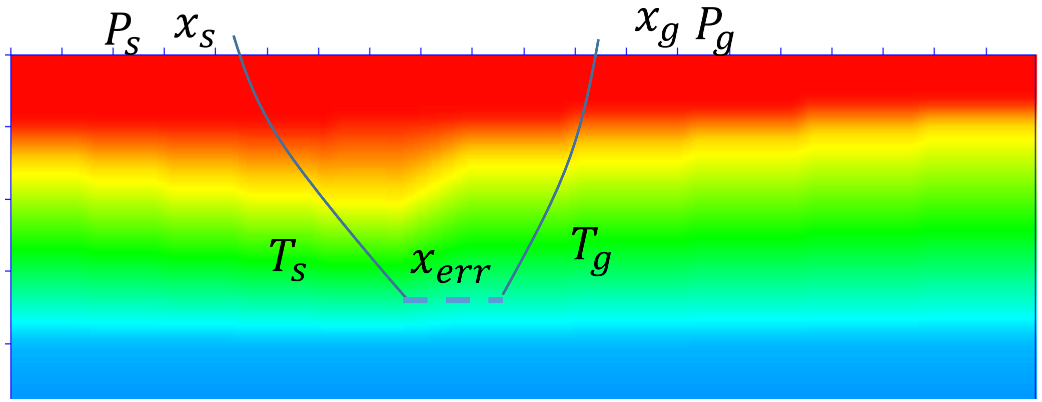

Incorrect velocity model

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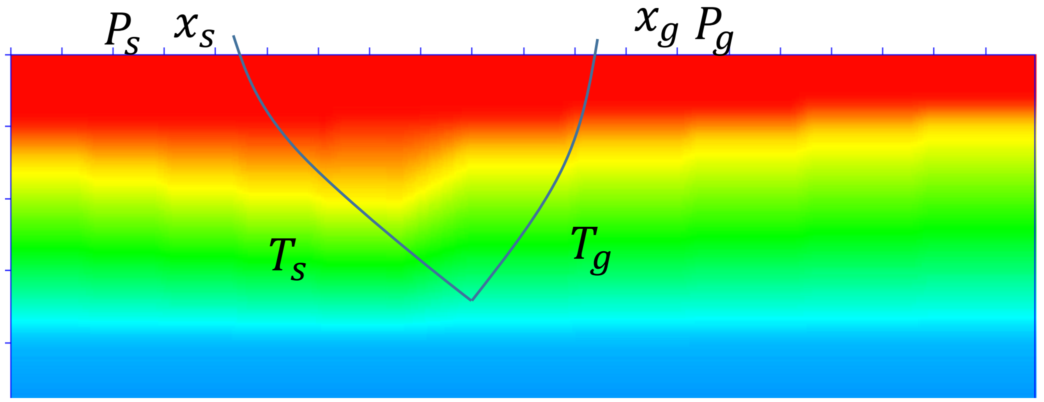

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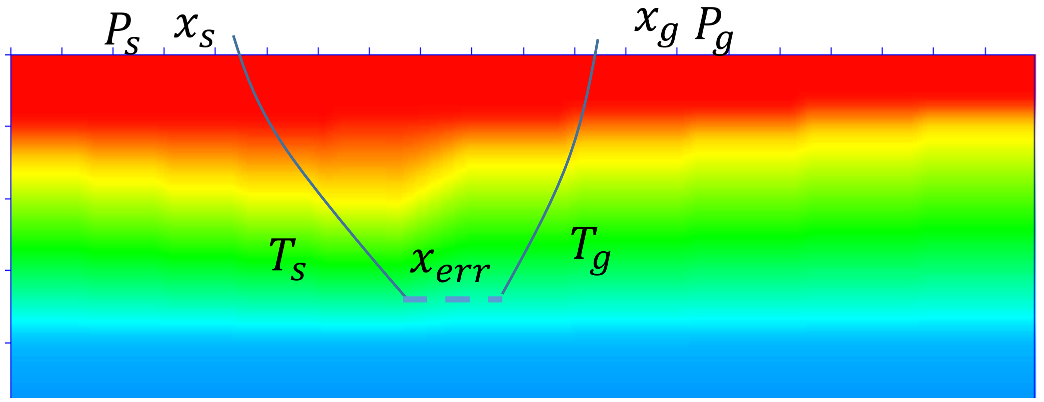


Incorrect velocity model

Model space : $[V]_{i=1,M}$

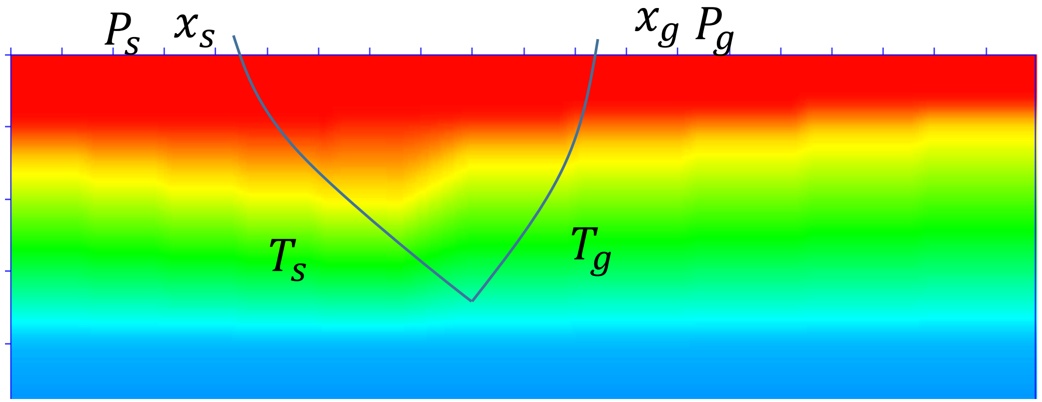
Data space : $[X_{err}]_{j=1,N}$

Fréchet derivative: $A_{ij} = \frac{\partial X_{err\,j}}{\partial V_i}$

Inversion: $\mathbf{A\ \Delta V} = -\mathbf{X_{err}}$

Sword 1988

CDR tomography



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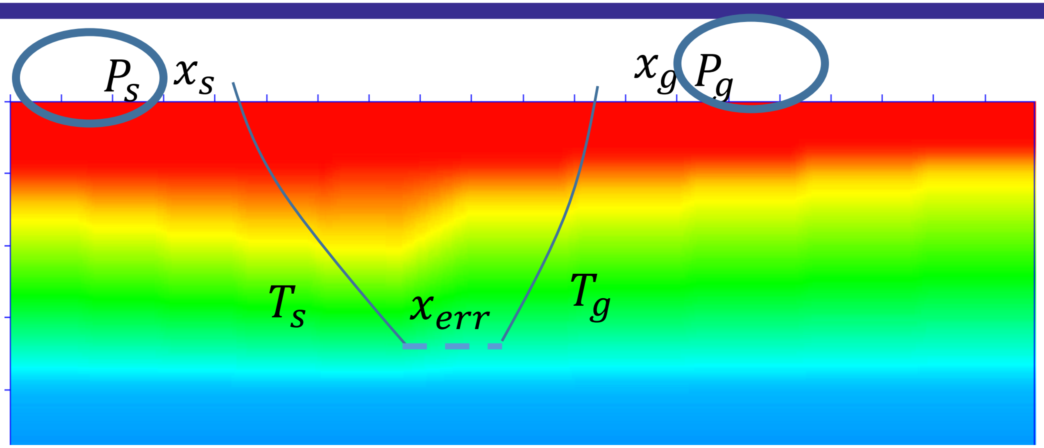

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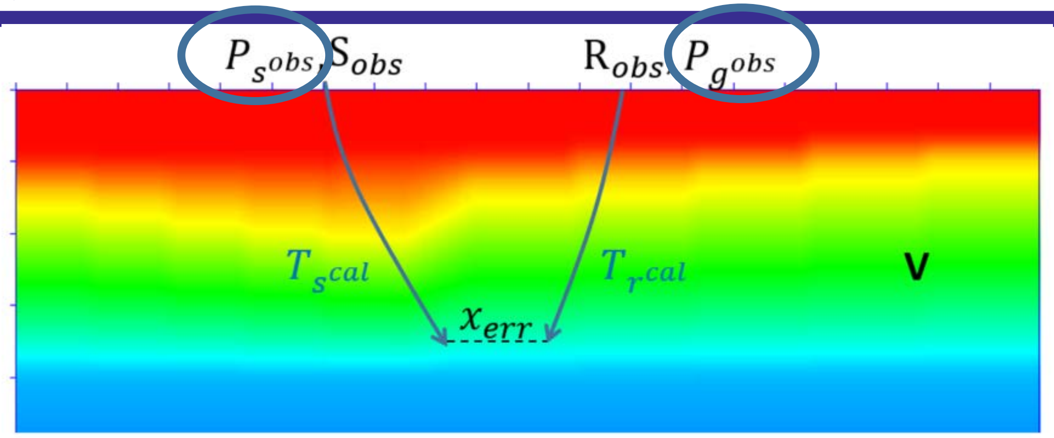

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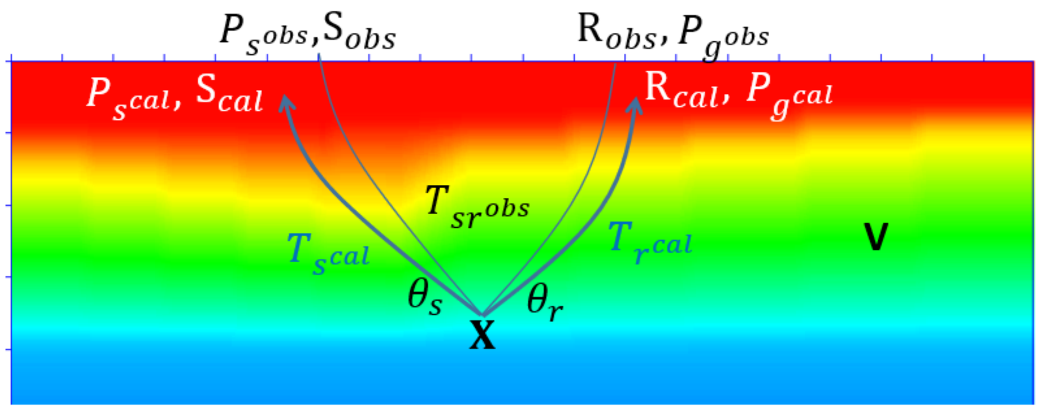

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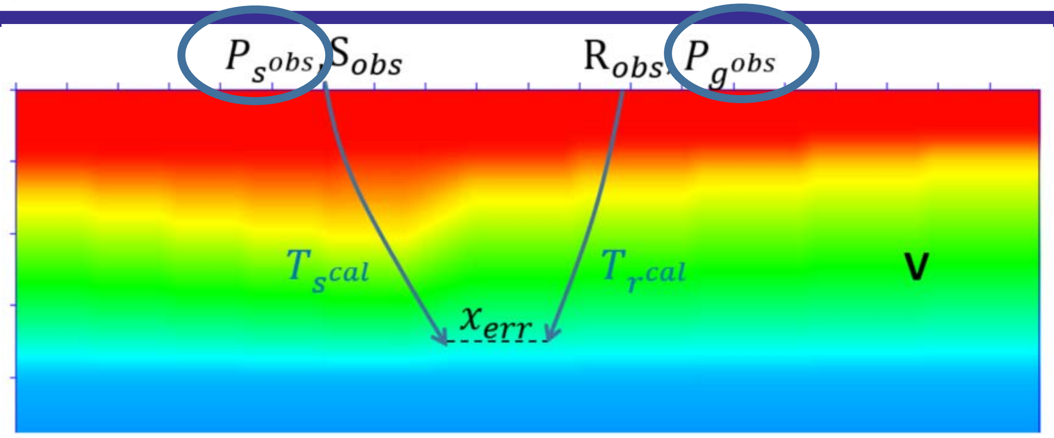

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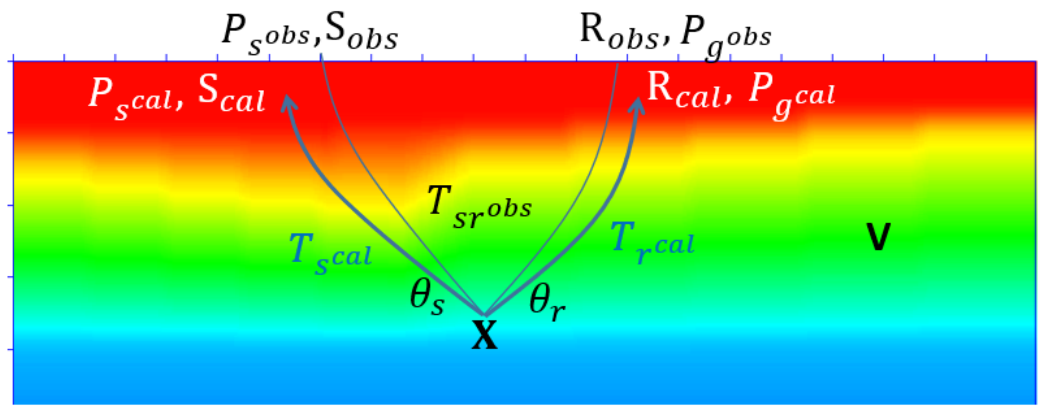
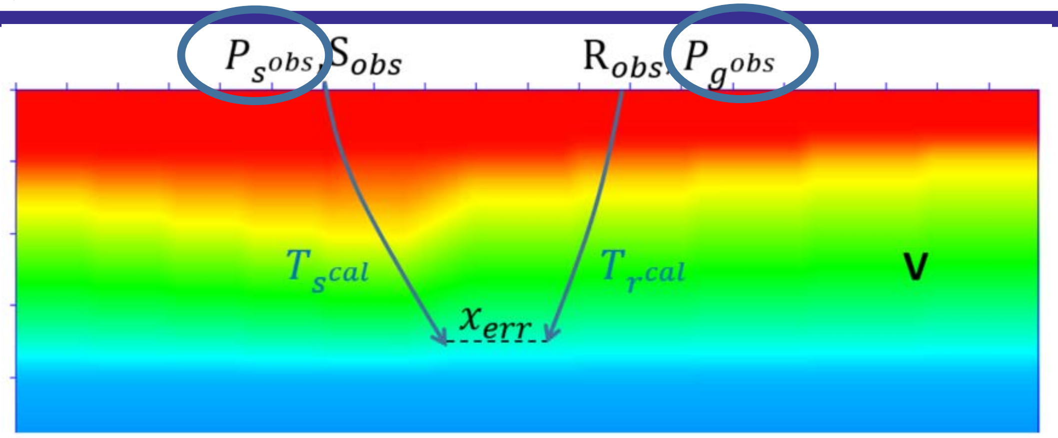


Stereotomography

Model space: **m** = $[(X, \Theta_s, \Theta_r, T_s, T_r)_{i1=1,N}],[V]_{i2=1,M}\ ]$

Stereotomography



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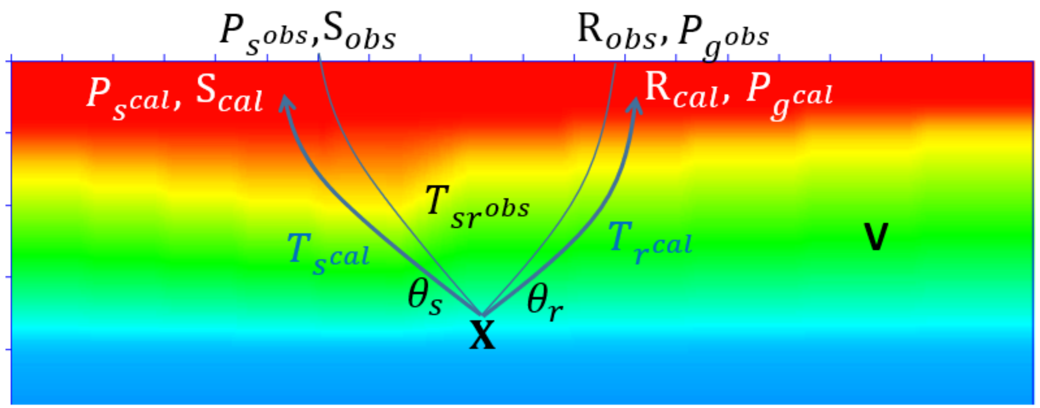
Sword 1988



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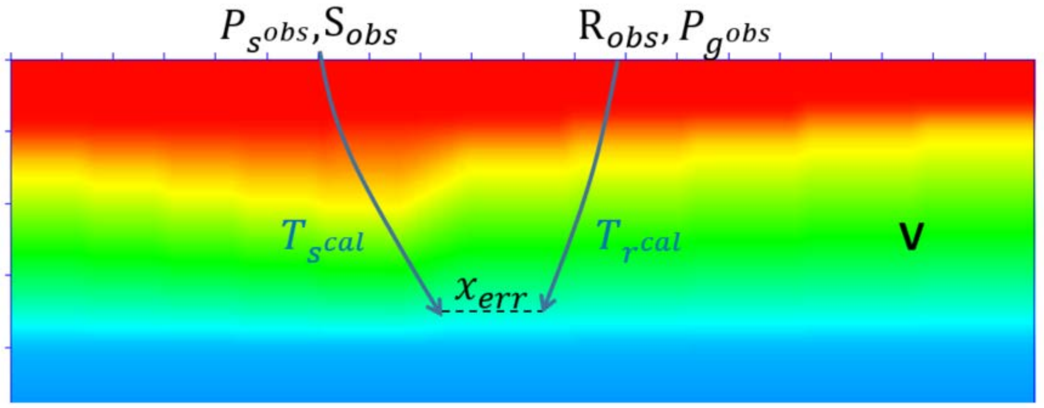
Model space: $\mathbf{m} = [(X, \Theta_s, \Theta_r, T_s, T_r)_{i1=1,N}], [V]_{i2=1,M}\ ]$

Data space : $\mathbf{d} = [S, R, T_{sr}, P_s, P_g\ ]_{j=1,N}$

Stereotomography



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$\mathbf{A}[\mathrm{N},\mathrm{M}]$

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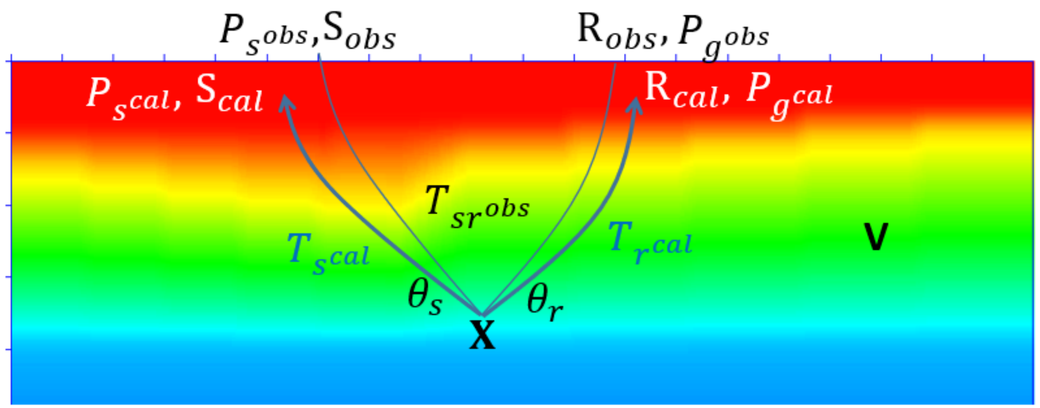

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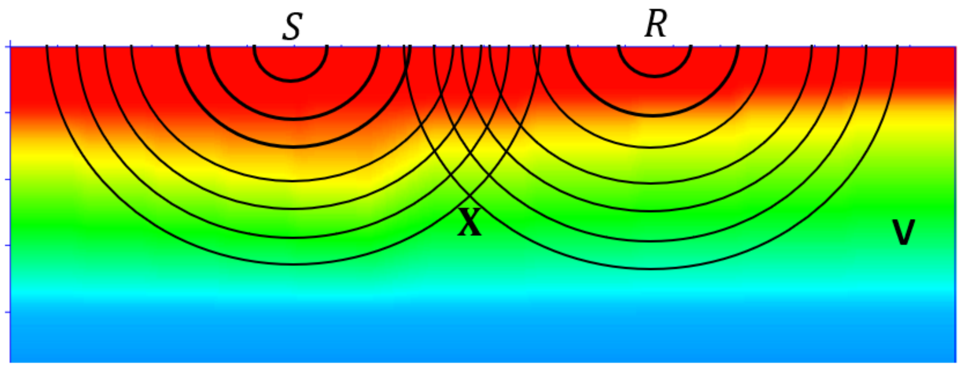
Fréchet derivative: $A_{ij} = \frac{\partial(S,R,P_s,P_r,T_{sr})}{\partial(X,\Theta_s,\Theta_r,T_s,T_r,V)}$

Inversion: $\mathbf{A}\,\mathbf{\Delta m} = \mathbf{\Delta d}$

$\mathbf{A}[5\mathrm{N},5\mathrm{N}+\mathrm{M}]$

Billette and Lambaré 1998

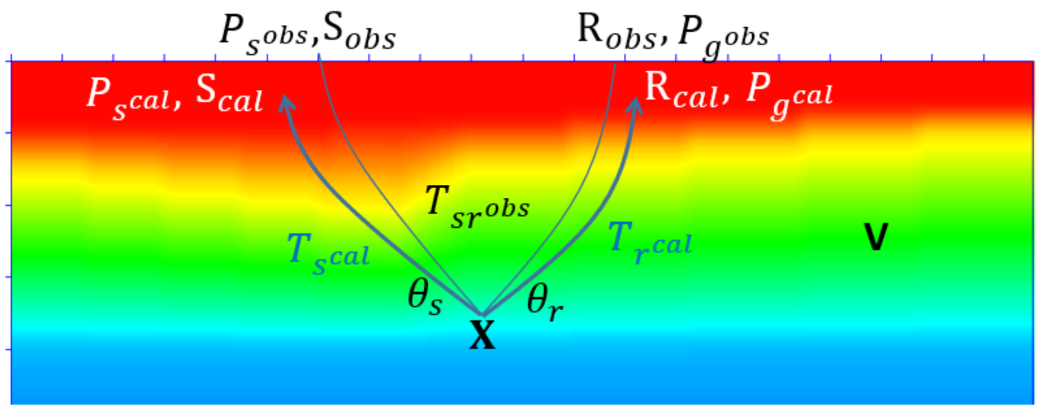
Adjoint stereotomography



Adjoint stereotomography   Tavakoli 2017

Model space : $[X_{j=1,N}],[V]_{i=1,M}]$

Data space : $\left[T_{sr}, P_s, P_g\right]_{j=1,N}$



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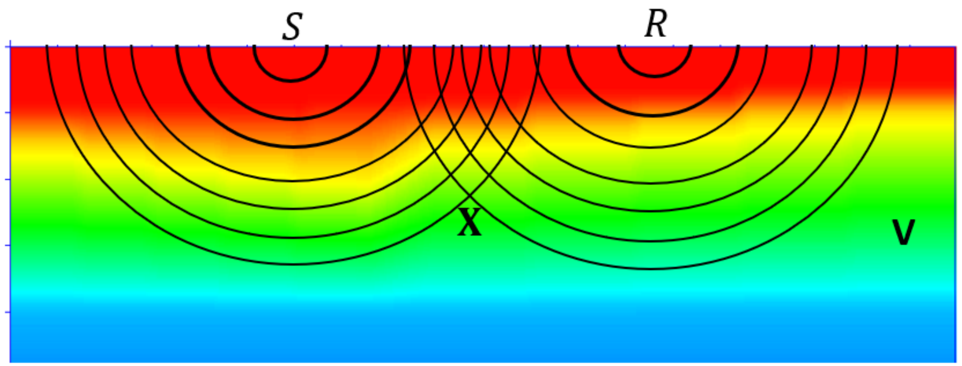

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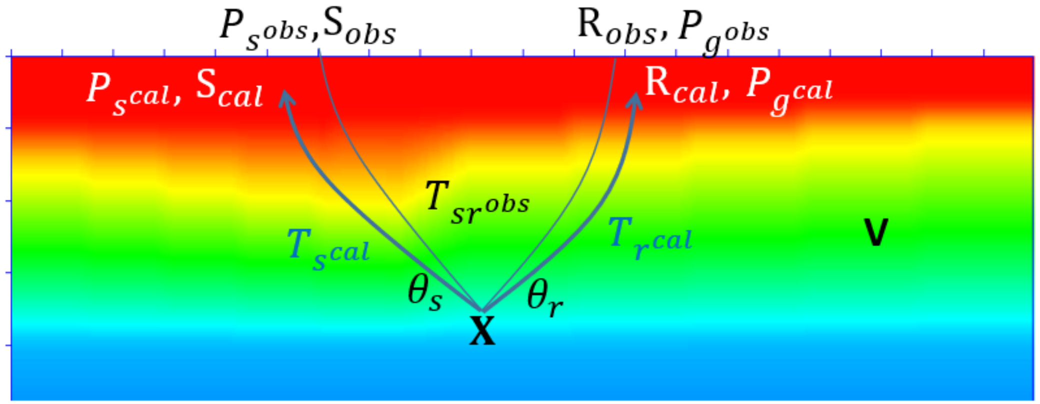
Data space : $\left[T_{sr}, P_s, P_g\ \right]_{j=1,N}$

Model update: $\mathbf{m}_{\,k+1} = \mathbf{m}_{\,k} + \alpha_k \frac{\partial J}{\partial m}$



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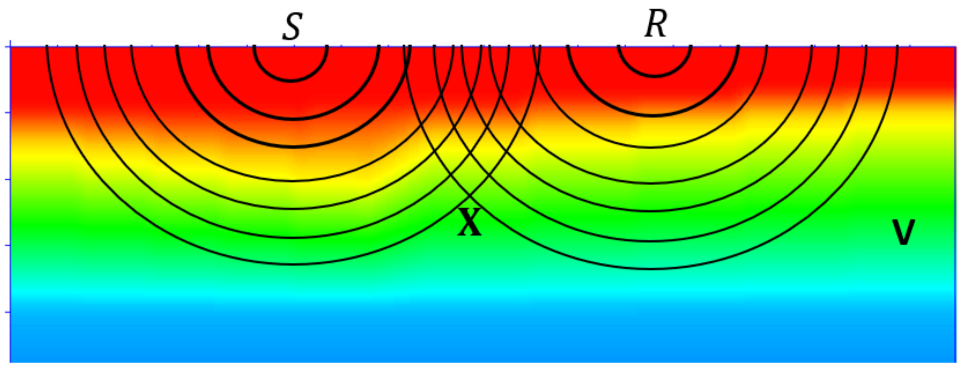
Billette and Lambaré   1998

Adjoint stereotomography



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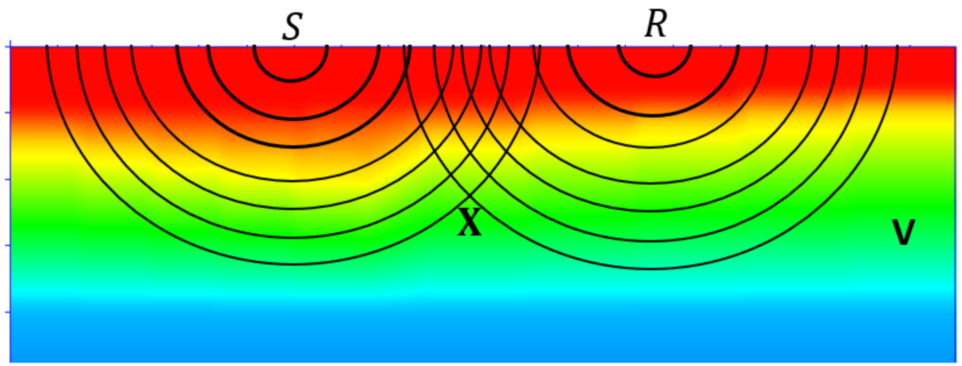
Data space : $\left[T_{sr}, P_s, P_g\right]_{j=1,N}$

Model update: $\mathbf{m}_{k+1} = \mathbf{m}_k + \alpha_k \frac{\partial \boldsymbol{J}}{\partial \boldsymbol{m}}$

Adjoint stereotomography



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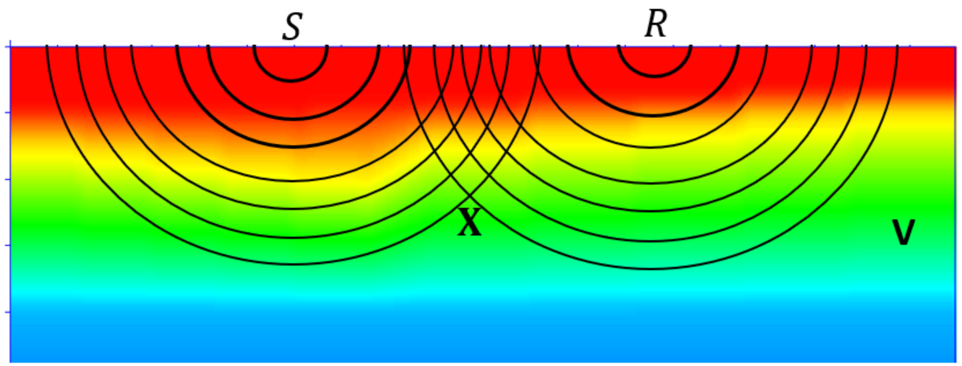
$$\frac{\partial J}{\partial v(x)} = -\frac{1}{v(x)^3} \sum (\lambda_s + \lambda_r)$$

$$\mathcal{L}(\nabla T_s)\lambda_s = S(\Delta T_{sr}, \Delta P_s)$$

$$\mathcal{L}(\nabla T_r)\lambda_r = S(\Delta T_{sr}, \Delta P_g)$$

Adjoint stereotomography



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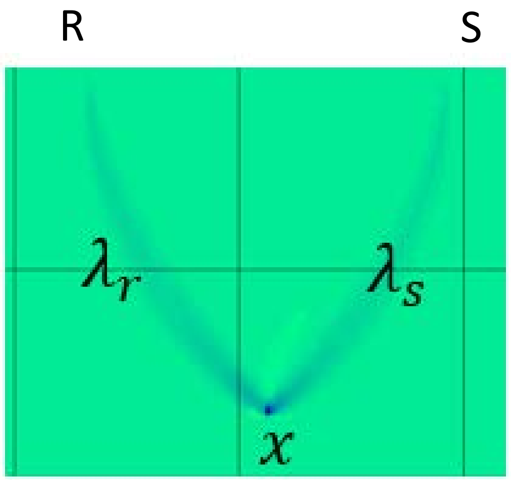
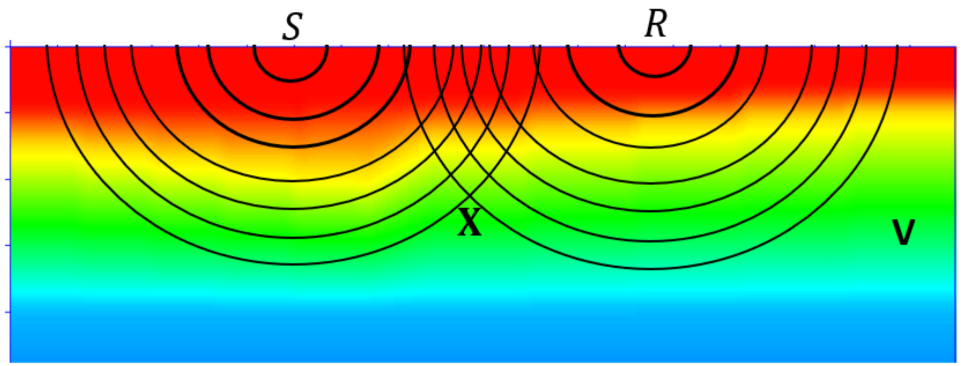


Adjoint stereotomography



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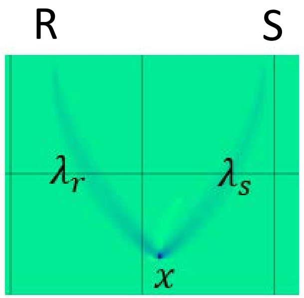
$$\frac{\partial J}{\partial v(x)} = -\frac{1}{v(x)^3} \sum$$



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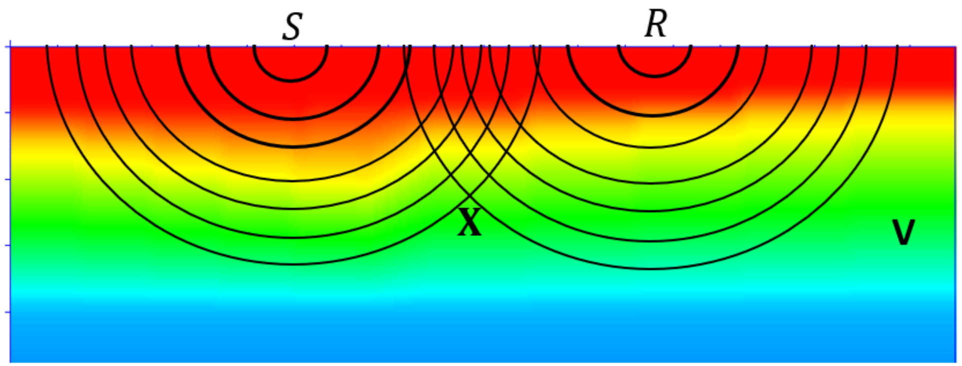

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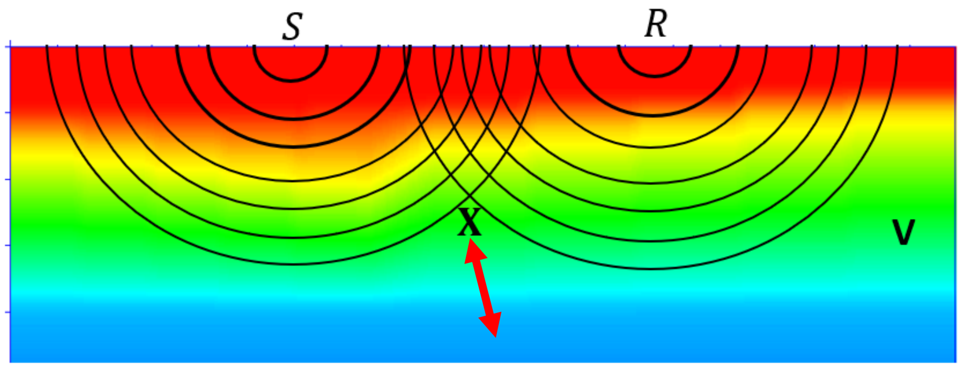
$$\frac{\partial J}{\partial X} =$$

Adjoint stereotomography



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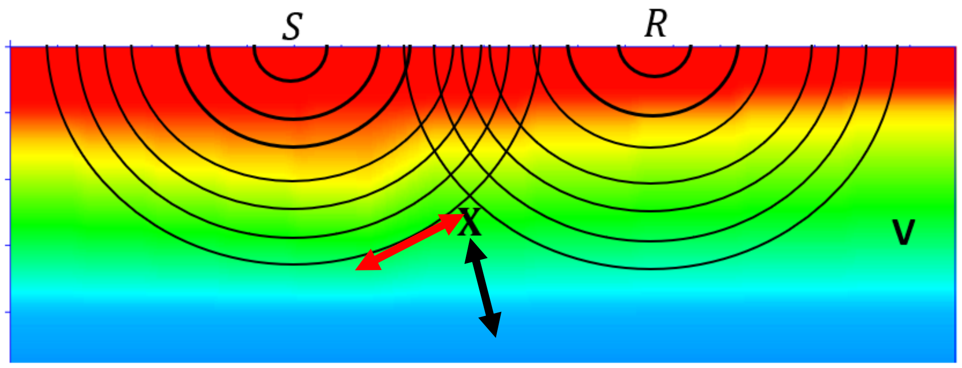
$$\frac{\partial J}{\partial X} = \Delta T_{sr} \frac{\partial}{\partial X}(T_s + T_r) +$$

Adjoint stereotomography



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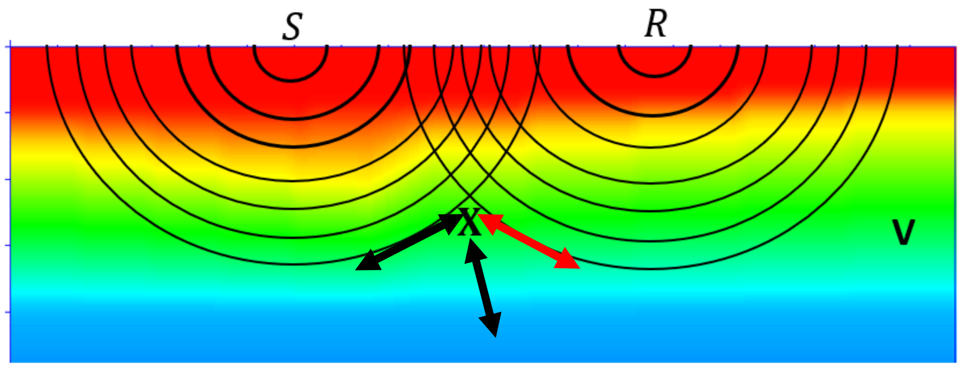
$$\frac{\partial J}{\partial X} = \Delta T_{sr} \frac{\partial}{\partial X}(T_s + T_r) + \frac{\Delta p_s}{2\Delta s}\frac{\partial}{\partial X}(T_{s+1} - T_{s-1}) +$$

Adjoint stereotomography



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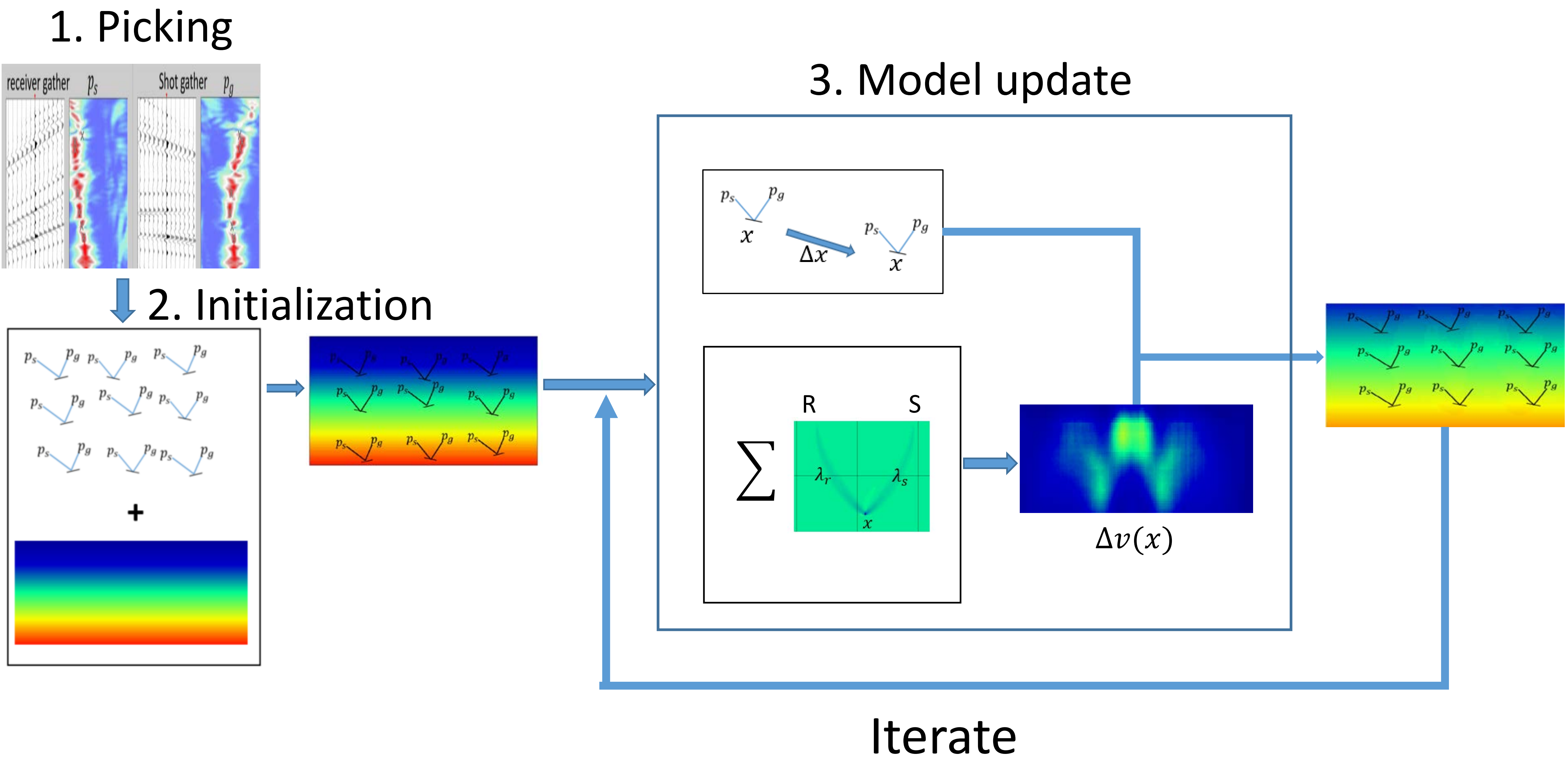
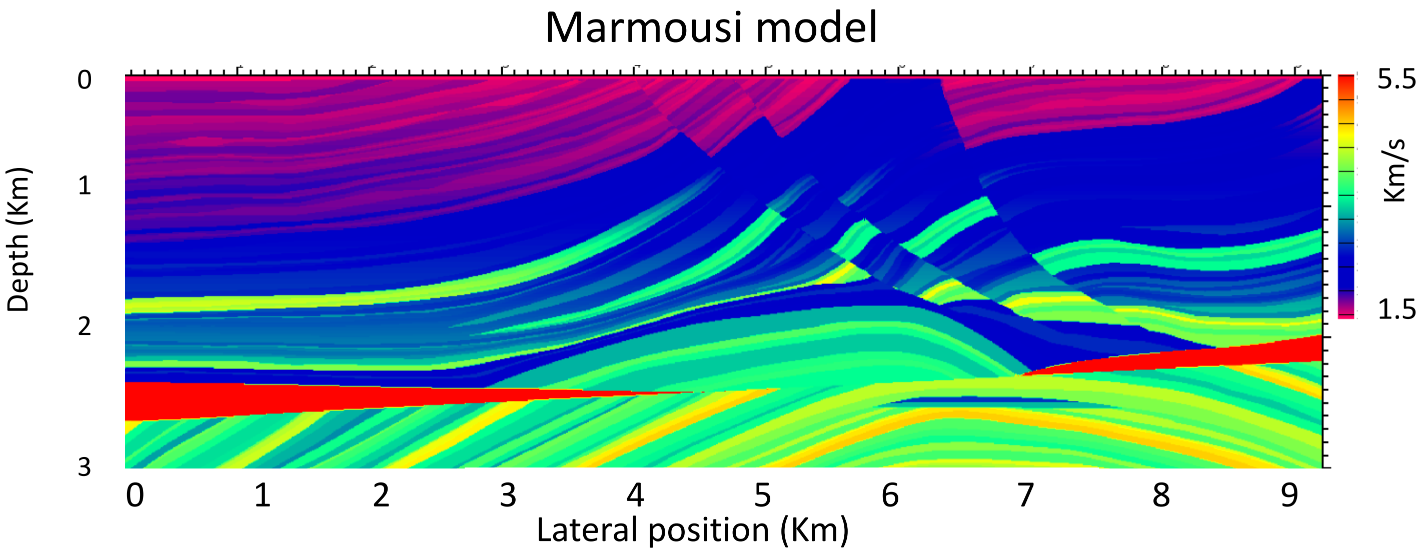
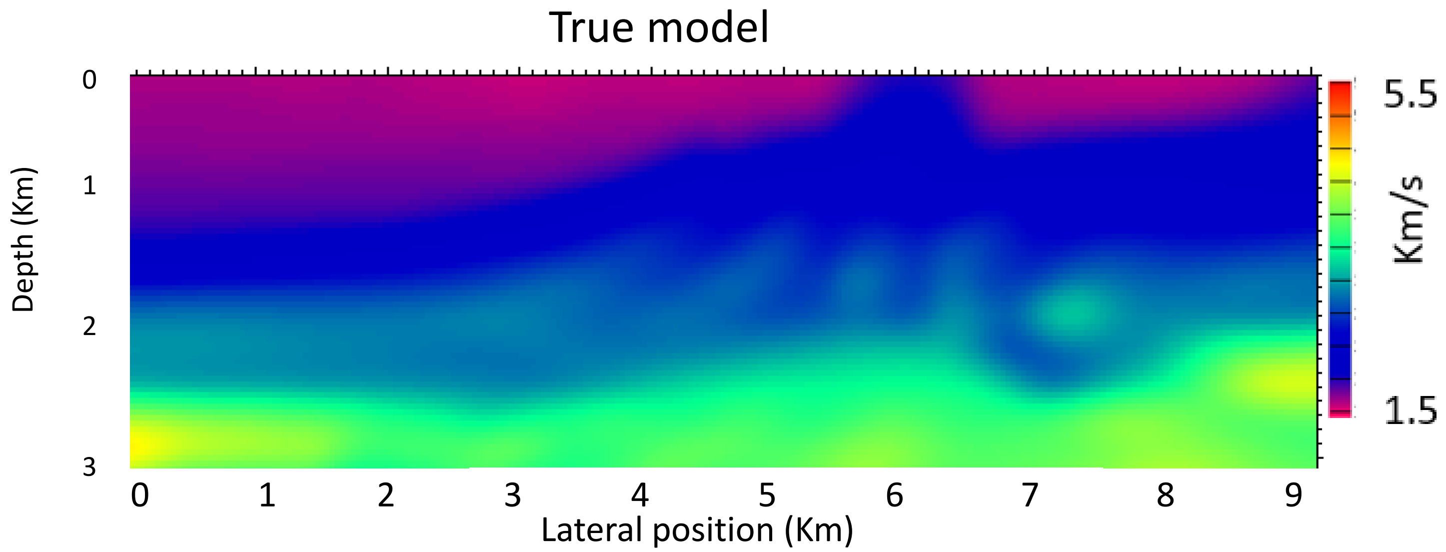
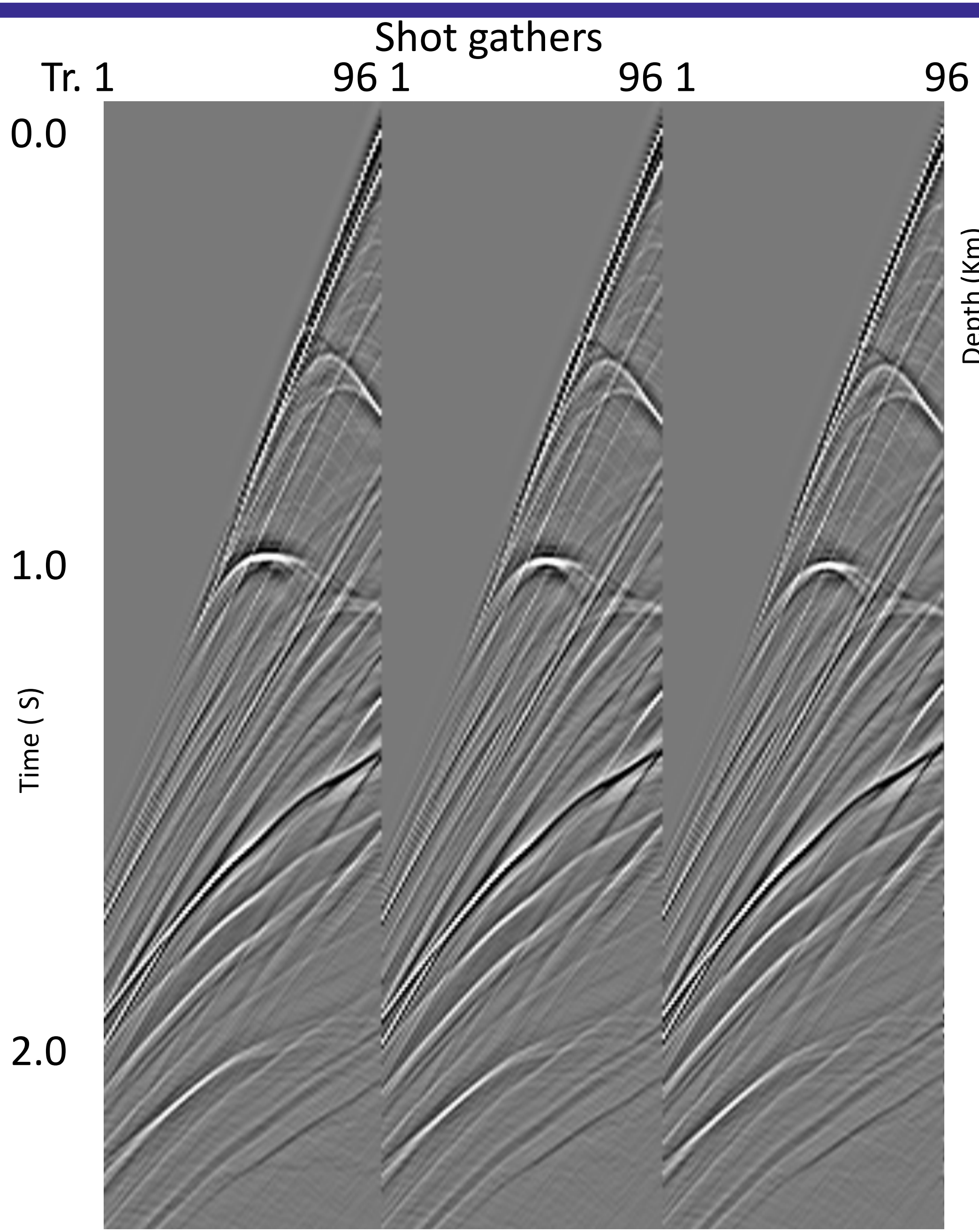
$$\frac{\partial J}{\partial X} = \Delta T_{sr} \frac{\partial}{\partial X}(T_s + T_r) + \frac{\Delta p_s}{2\Delta s}\frac{\partial}{\partial X}(T_{s+1} - T_{s-1}) + \frac{\Delta p_g}{2\Delta r}\frac{\partial}{\partial X}(T_{r+1} - T_{r-1})$$

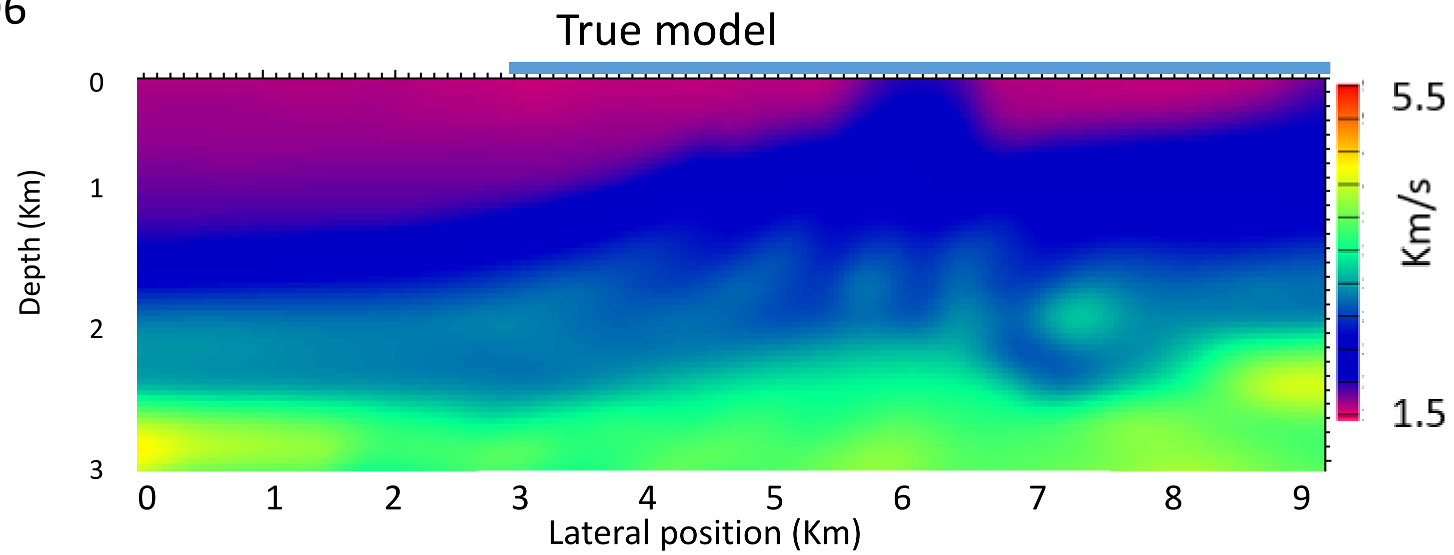

1. Picking
receiver gather
Shot gather
2. Initialization
+
3. Model update
p_s p_g
x
Δx
$\sum$
R
S
λ_r
λ_s
$\Delta v(x)$
Iterate


Marmousi model
Depth (Km)
0
1
2
3
0 1 2 3 4 5 6 7 8 9
Lateral position (Km)
5.5
1.5
Km/s


True model
Depth (Km)
0
1
2
3
0 1 2 3 4 5 6 7 8 9
Lateral position (Km)
5.5
1.5
Km/s

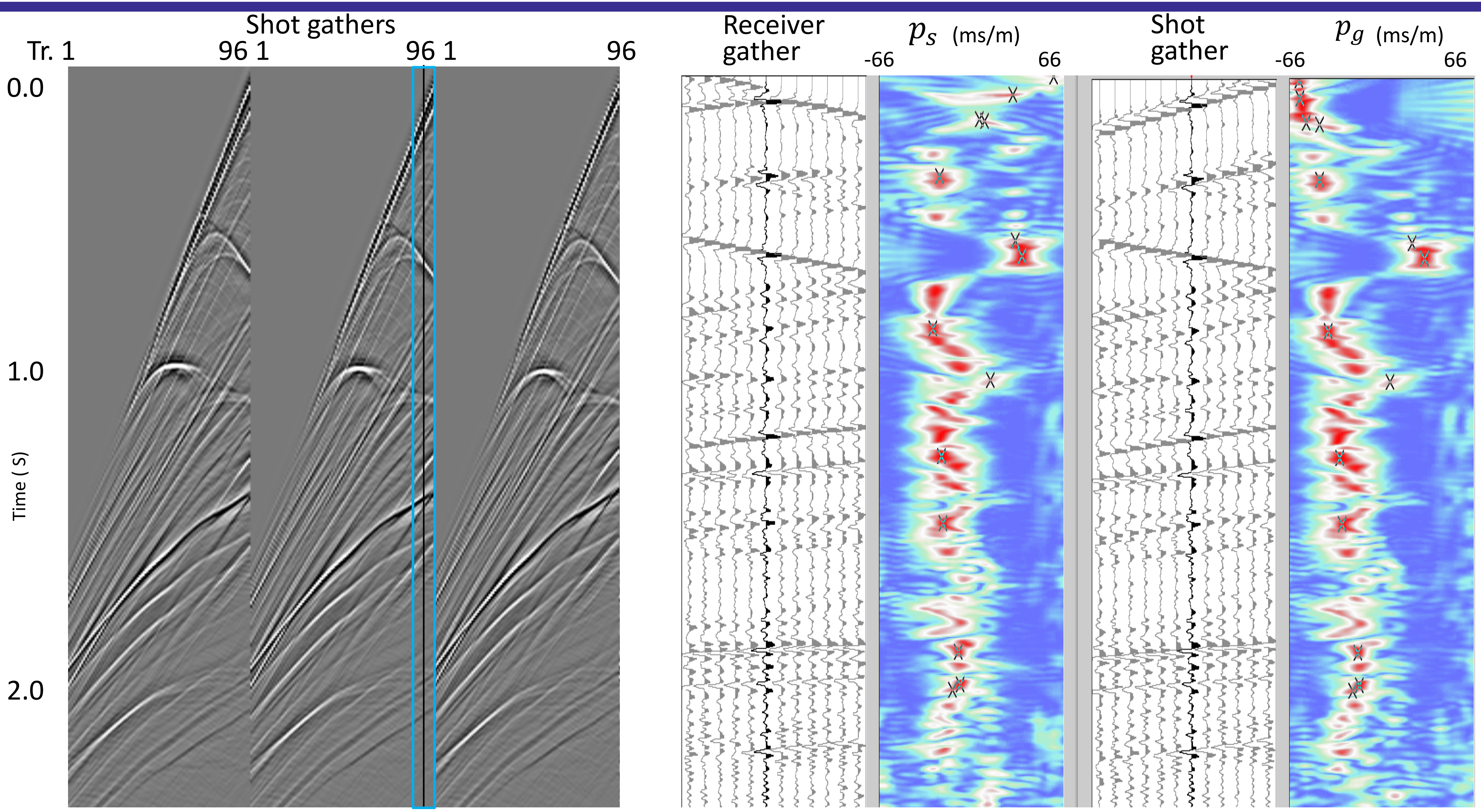
Controlled directional Reception (C.D.R.)



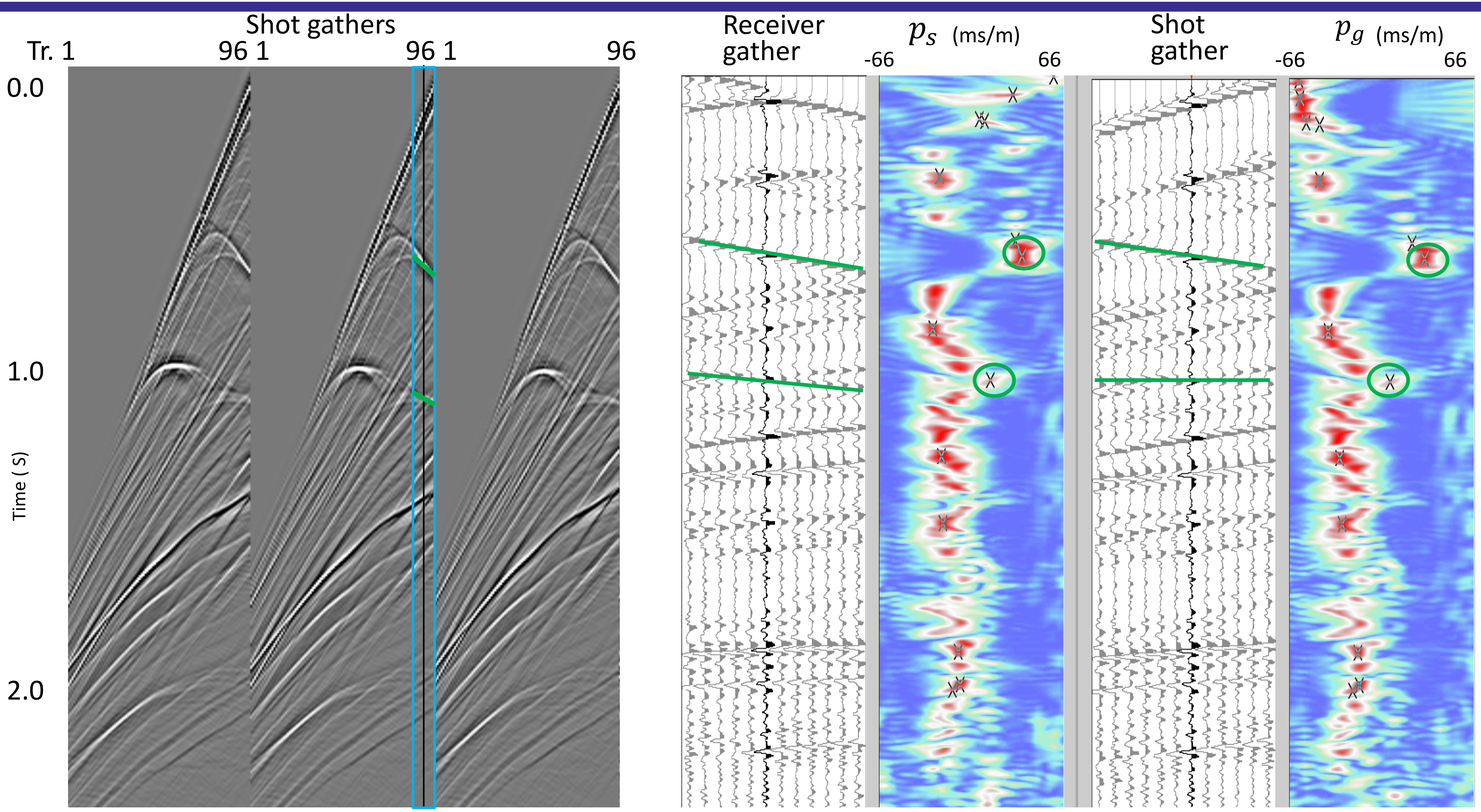


270 shots
96 channels per shot
25 m shot and receiver spacing

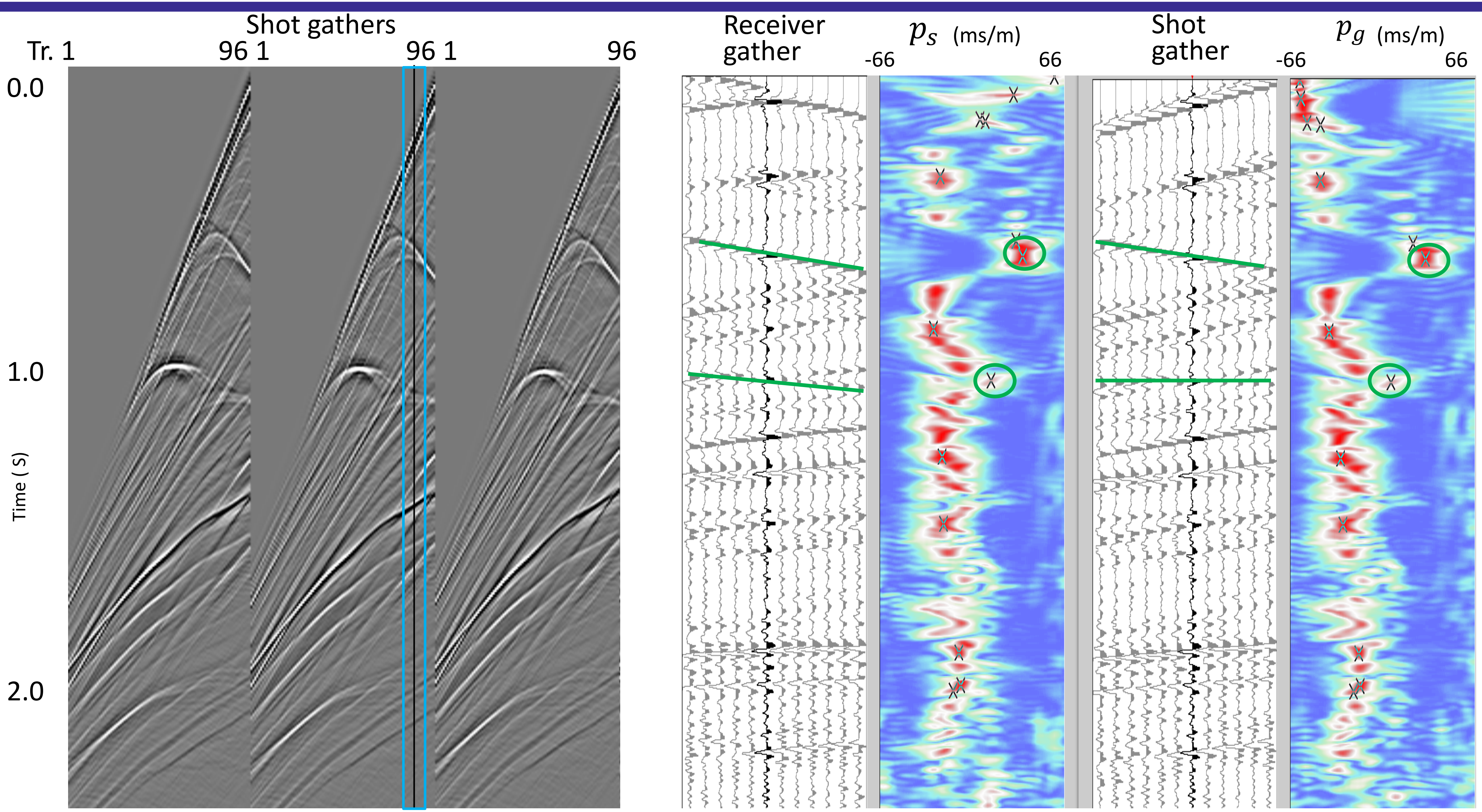
Controlled directional Reception (C.D.R.)



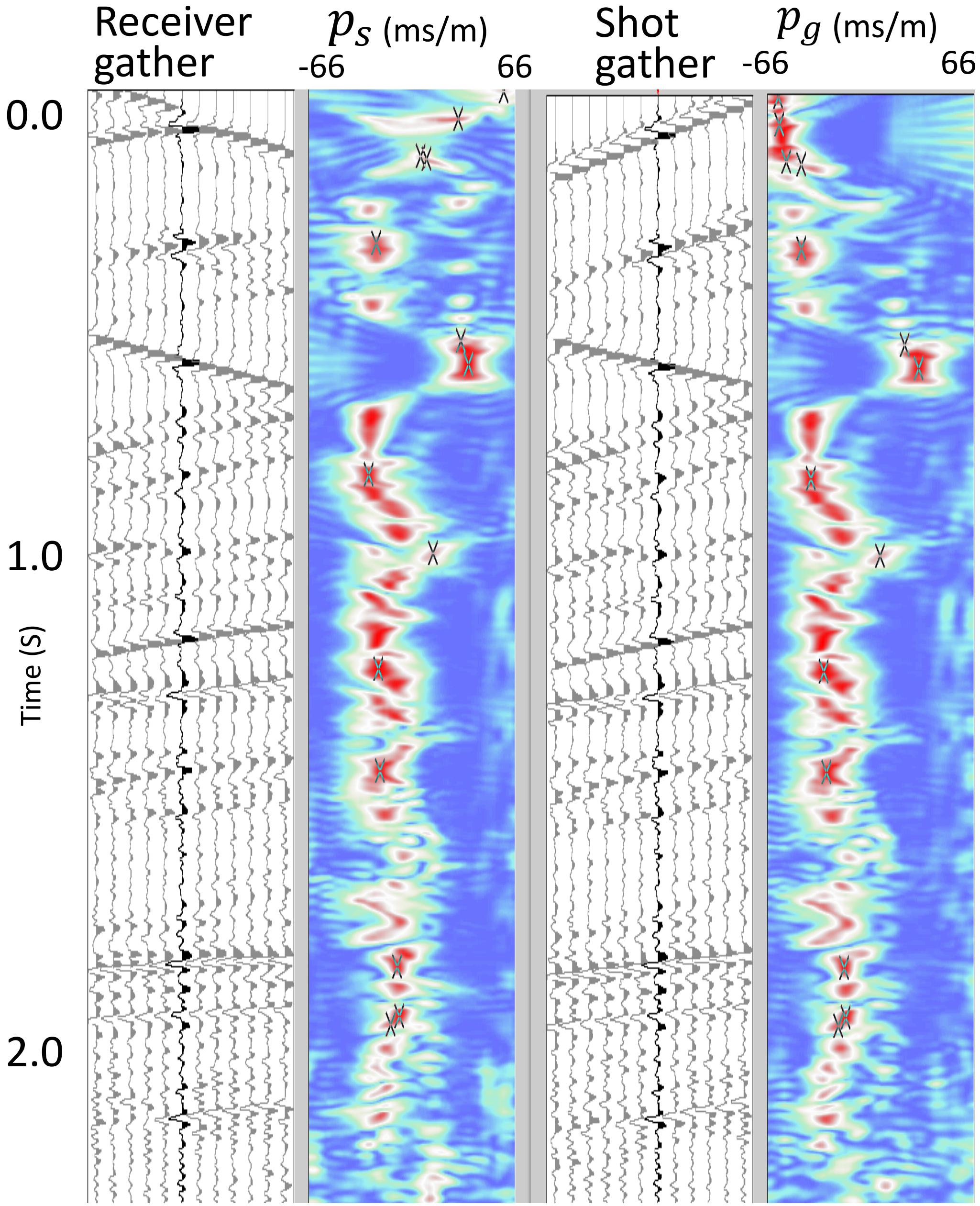
Controlled directional Reception (C.D.R.)

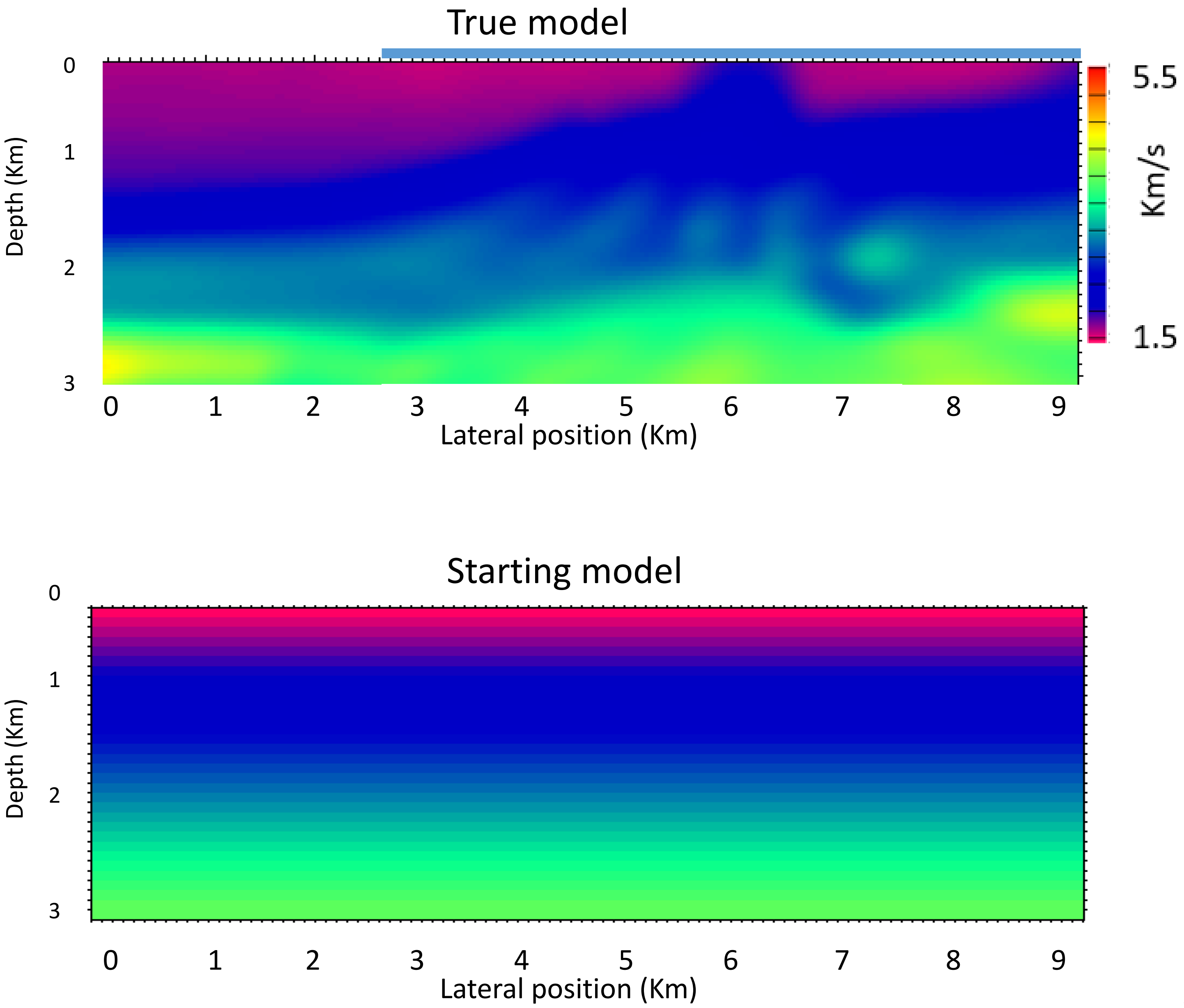


Controlled directional Reception (C.D.R.)



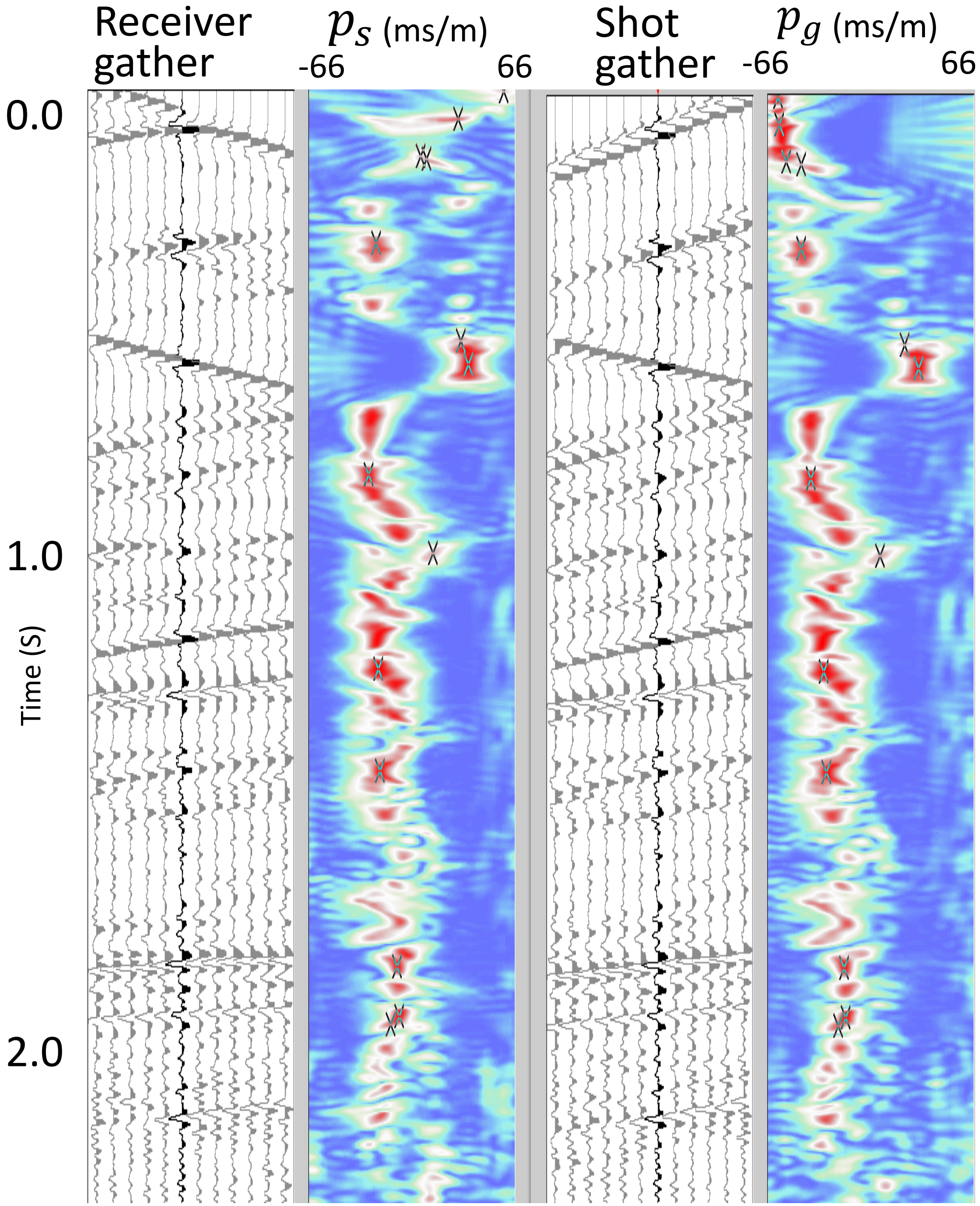
Synthetic example

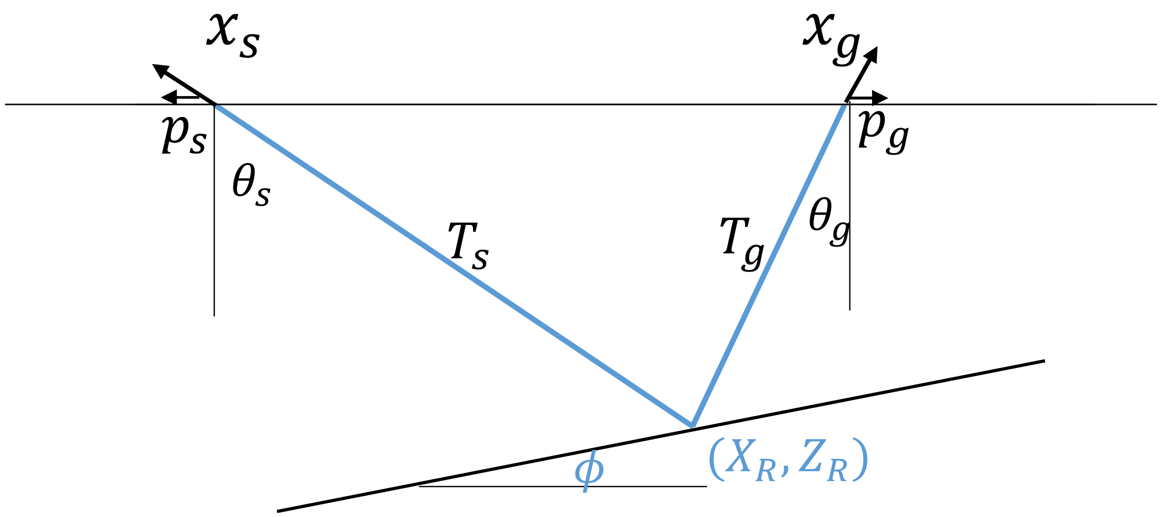




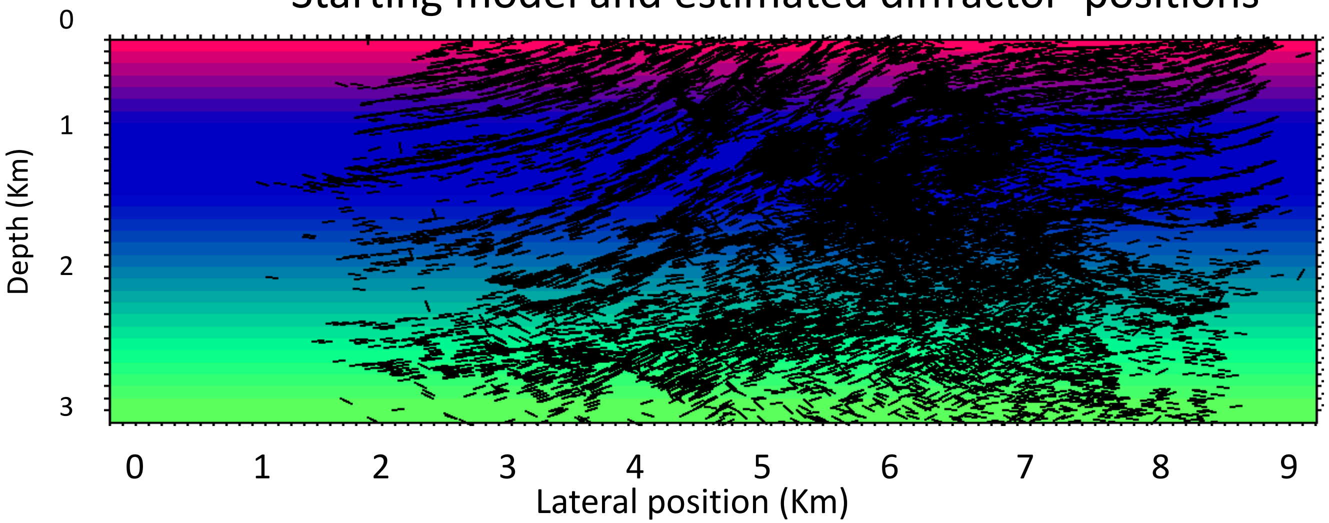
Adjoint stereotomography

Synthetic example



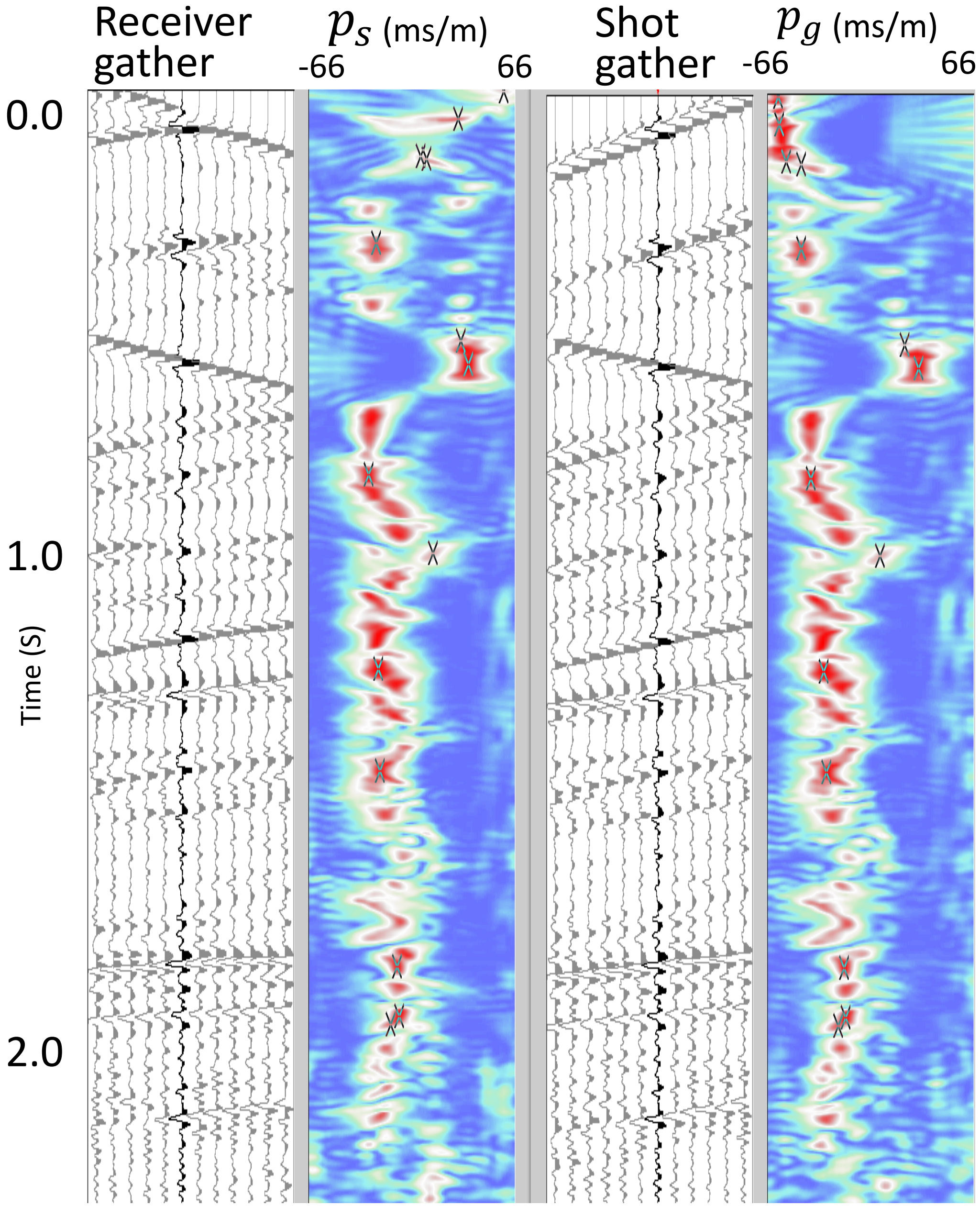


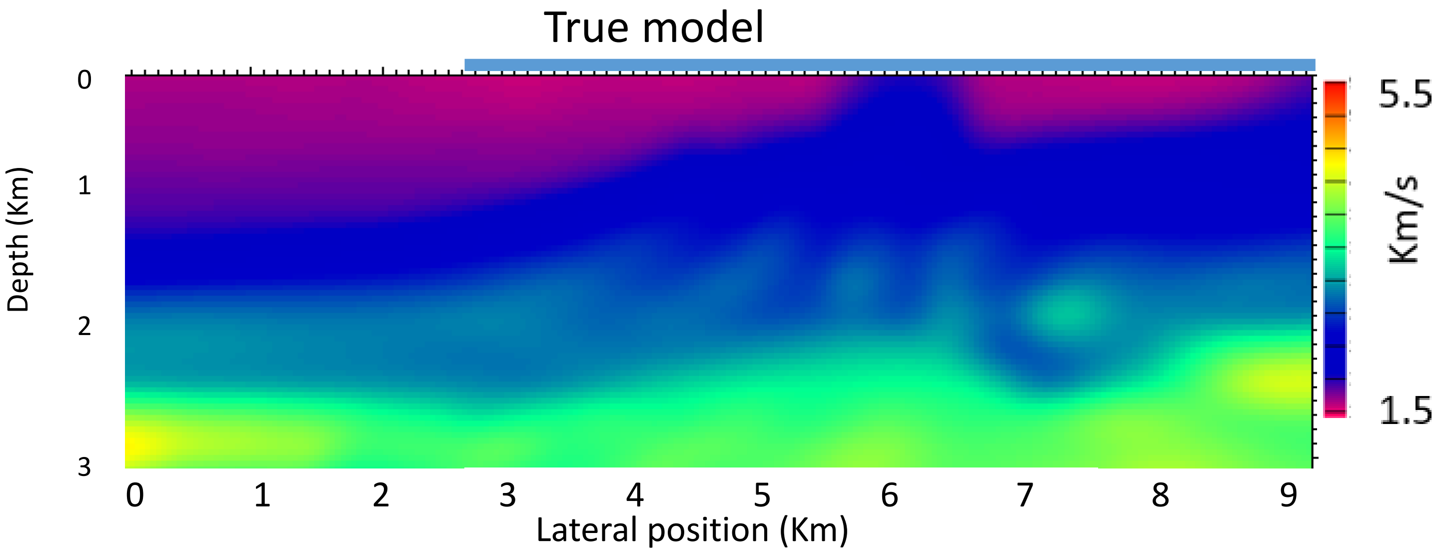
Starting model and estimated diffractor positions

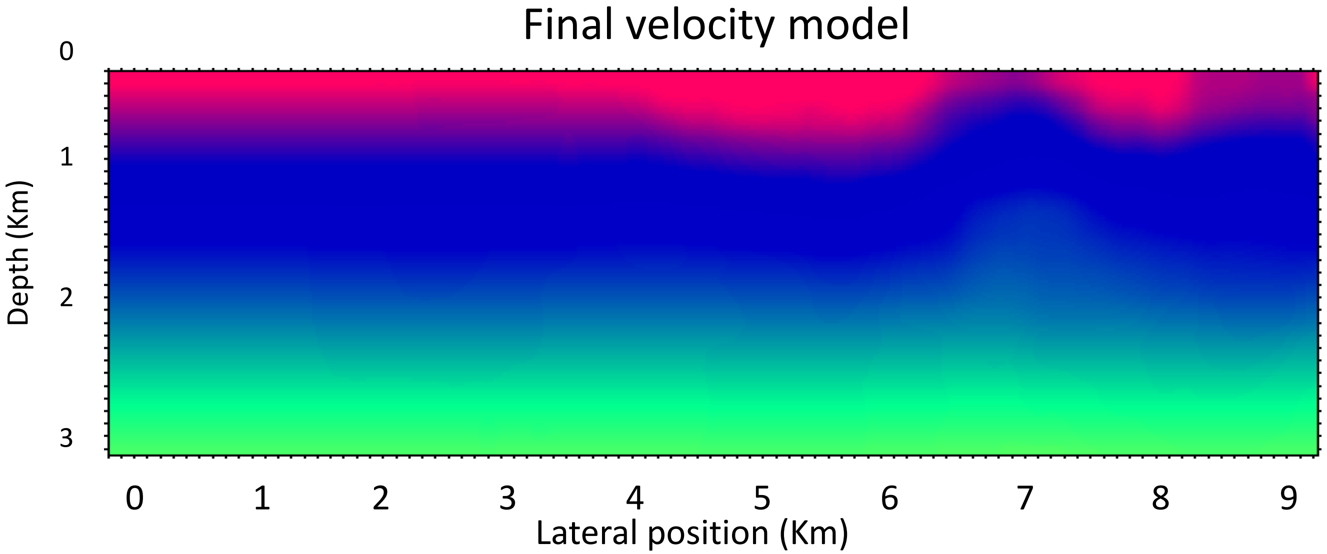


Adjoint stereotomography

Synthetic example







Conclusions and future work

Conclusions:

- Both stereotomography and adjoint stereotomography account for uncertainties in slopes and traveltime picks
- Adjoint stereotomography is computationally more efficient than the classical stereotomography

Future work:

- Testing on real data including multi-component data
- Picking traveltimes and slopes in migrated domain to eliminate the diffractor position from the model domain
- Extending the adjoint stereotomography method to include anisotropic parameters

Acknowledgments

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CREWES faculty, staff and students

NSERC