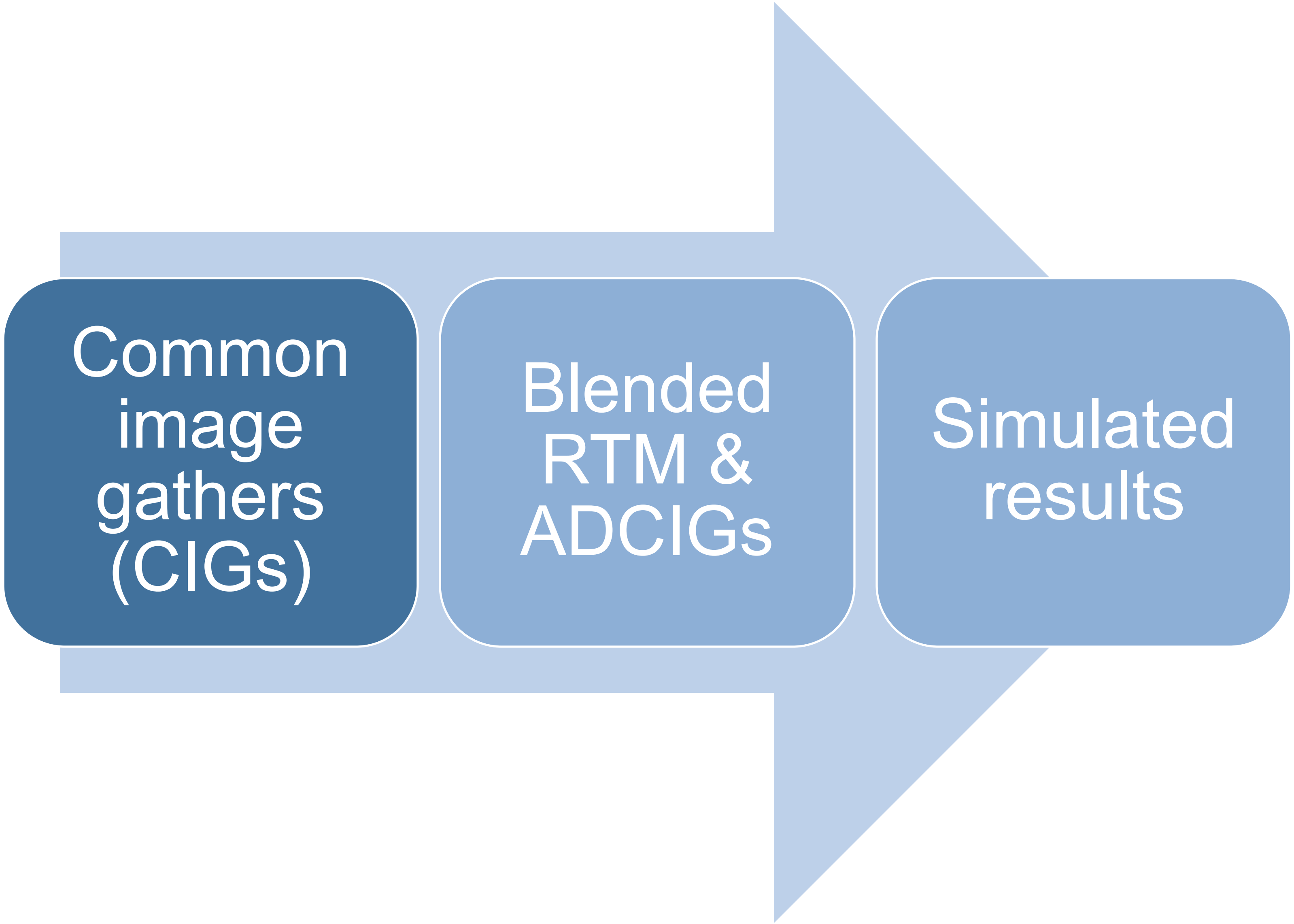
Common image gathers from blended data

Ziguang Su and Daniel Trad

Dec. 2 2022

NSERC CRSNG
UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
Department of Geoscience


Common image gathers (CIGs)
Blended RTM & ADCIGs
Simulated results

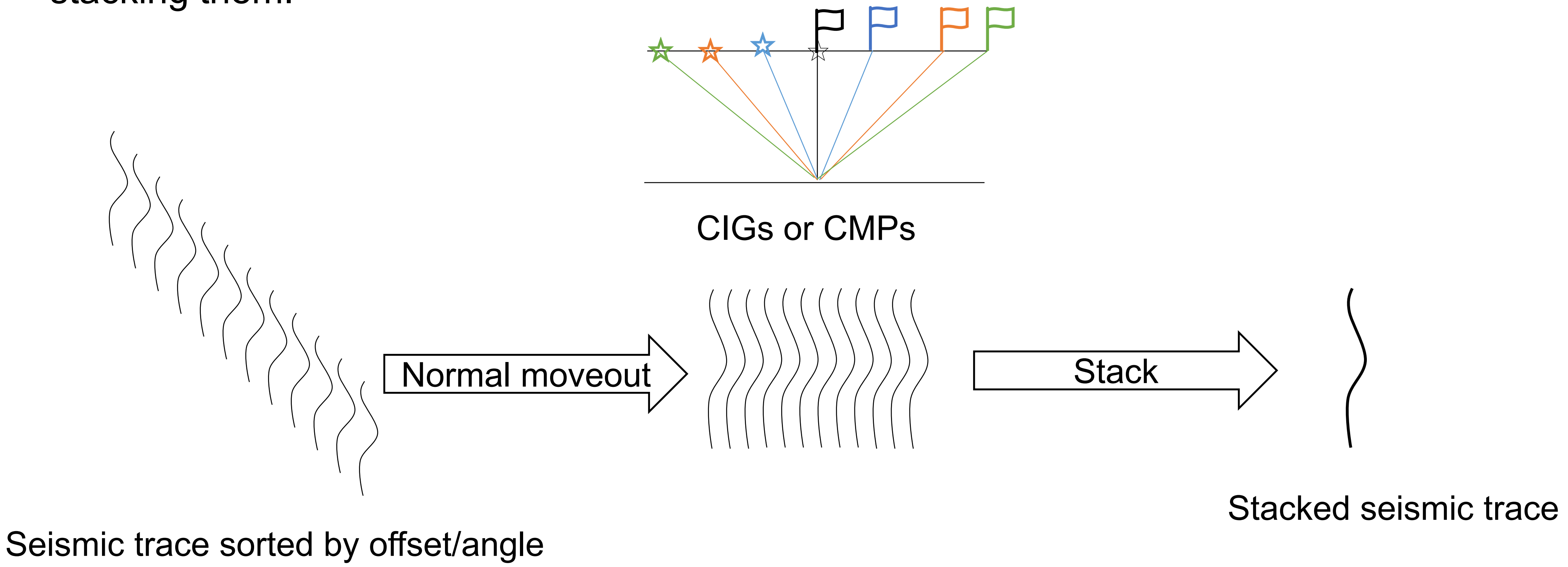
Why CIGs?

CIGs: a series of prestack migrated trace for subsurface attribute interpretation

Common midpoint gathers/CMPs are to stack data, CIGs are to migration.

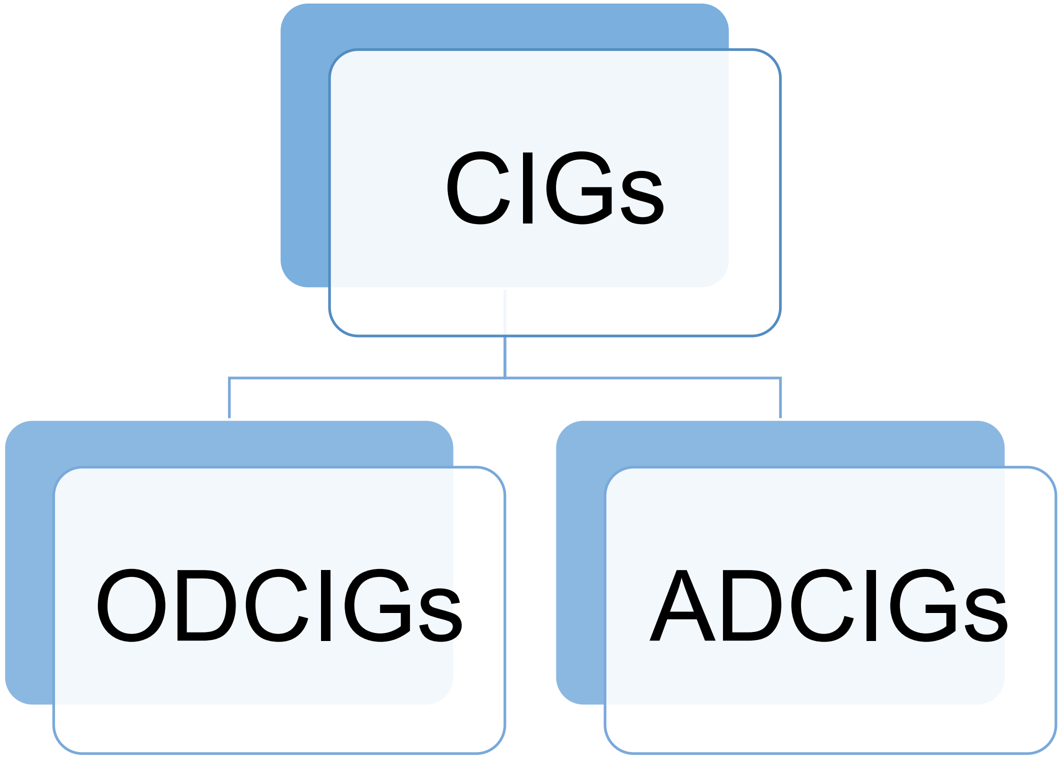
When we stack CIGs, we lose some amplitude information.

If we want reflectivity as a function of offset/angle, we need to look into CIGs before stacking them.



Why CIGs?

CIGs are primary data for:
amplitude-versus-offset (AVO) analysis
amplitude-versus-angle (AVA) analysis
migration velocity analysis



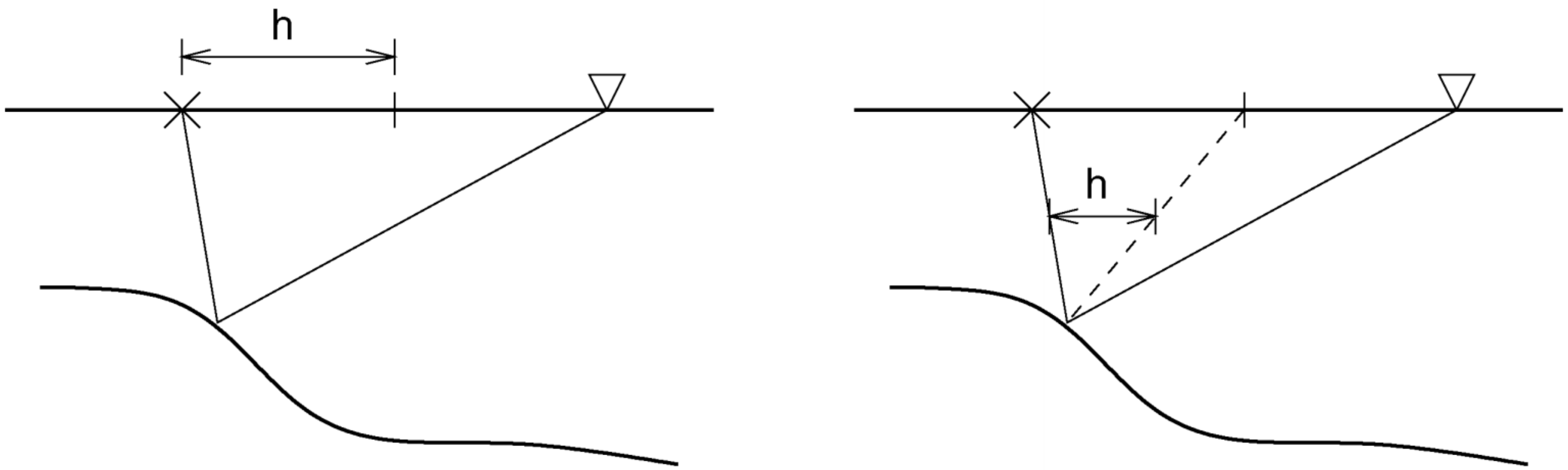
Types of CIGs:
offset domain common image gathers (ODCIGs)
angle domain common image gathers (ADCIGs)

ODCIGs

Definition of offset extended to subsurface.

distance between source and receiver on the surface ->

distance between source wavefield and receiver wavefield in the subsurface



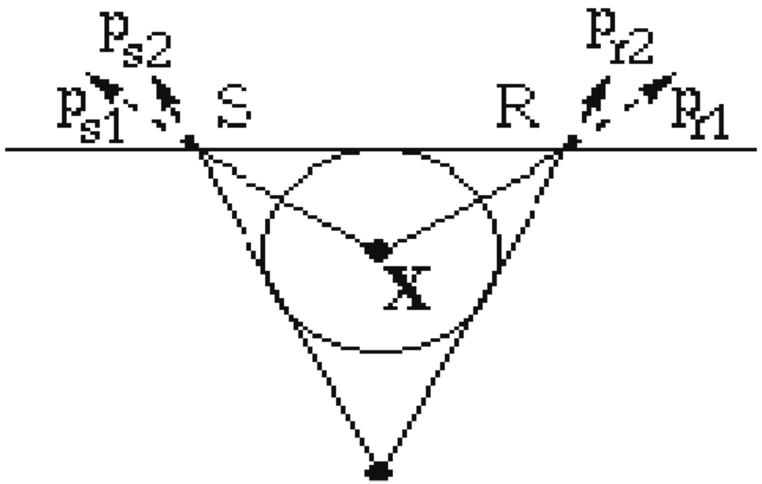
(a) Before migration (b) During migration

Rickett, James E., and Paul C. Sava. "Offset and angle-domain common image-point gathers for shot-profile migration." Geophysics 67.3 (2002): 883-889.

Why not ODCIGs? multipathing

ODCIGs can't handle multipathing for complex velocity model.

Multipath:



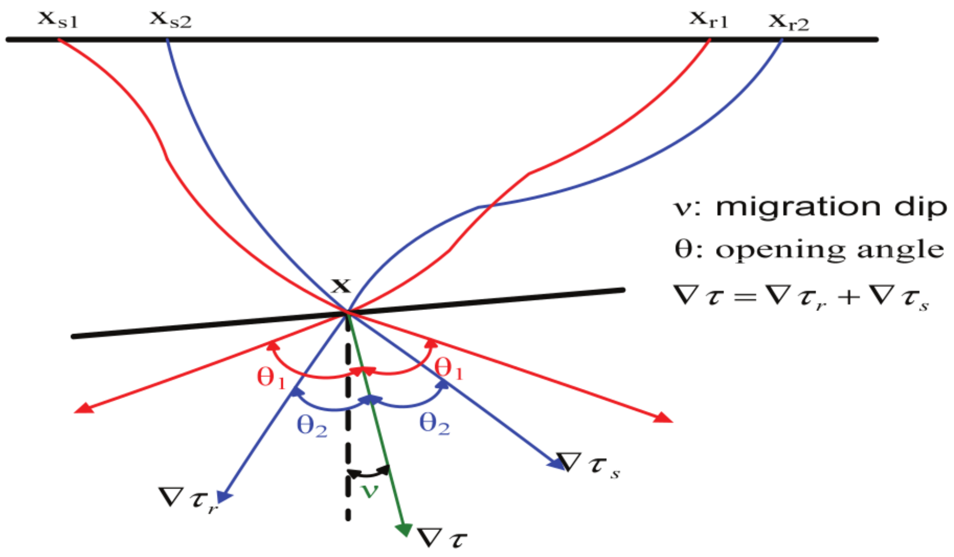
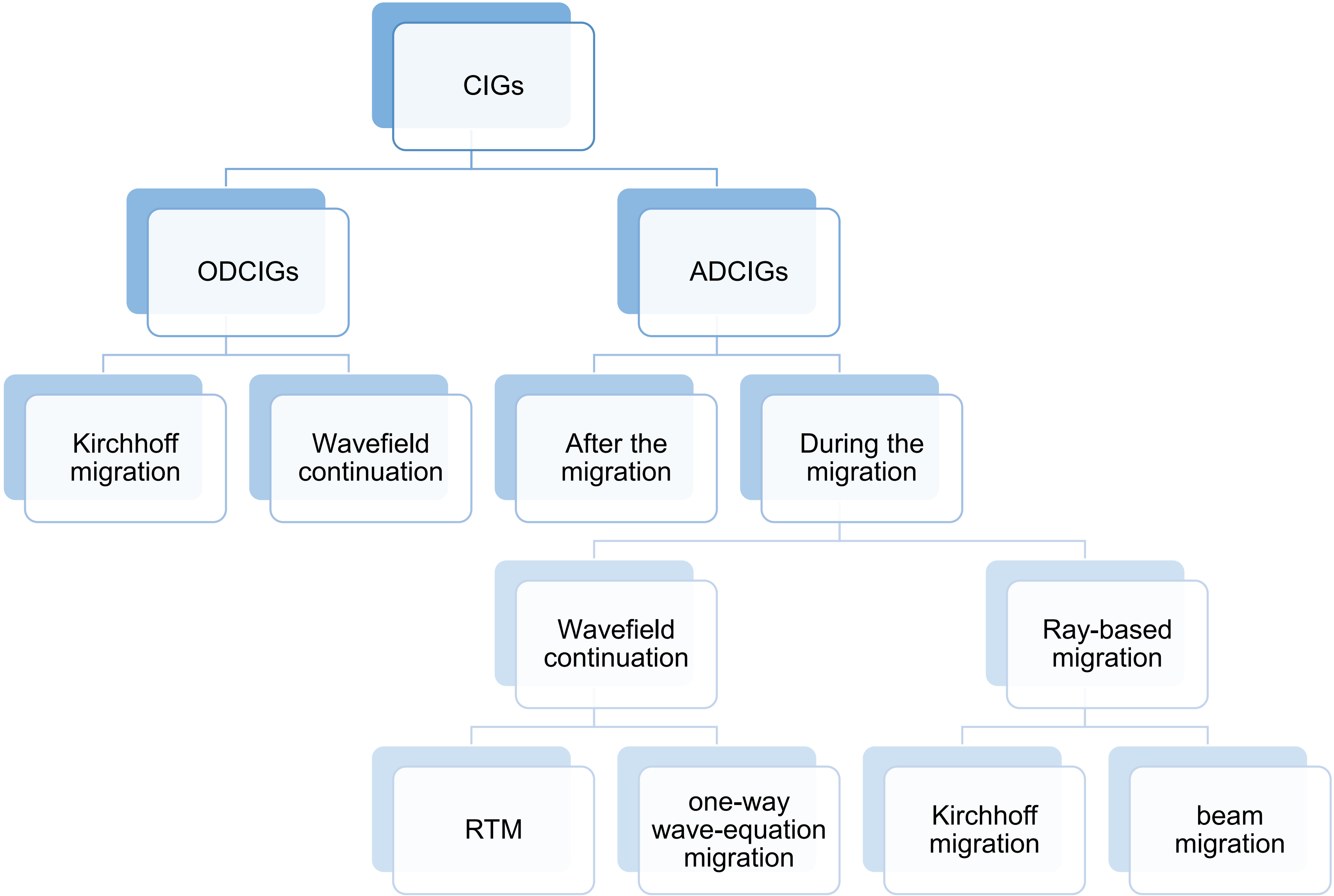


FIG. 3. A dipping reflector with two sets of specular rays that have the same offset but different opening angles at depth.

Same source-receiver wavefield location and traveltime but different image point.
Same subsurface offset and image point but different source-receiver wavefield location .
They have different raypath and reflection angle.

Bleistein and Gray (2002), Faranak Mahmoudian and Gary F. Margrave(2009)

How to get CIGs?



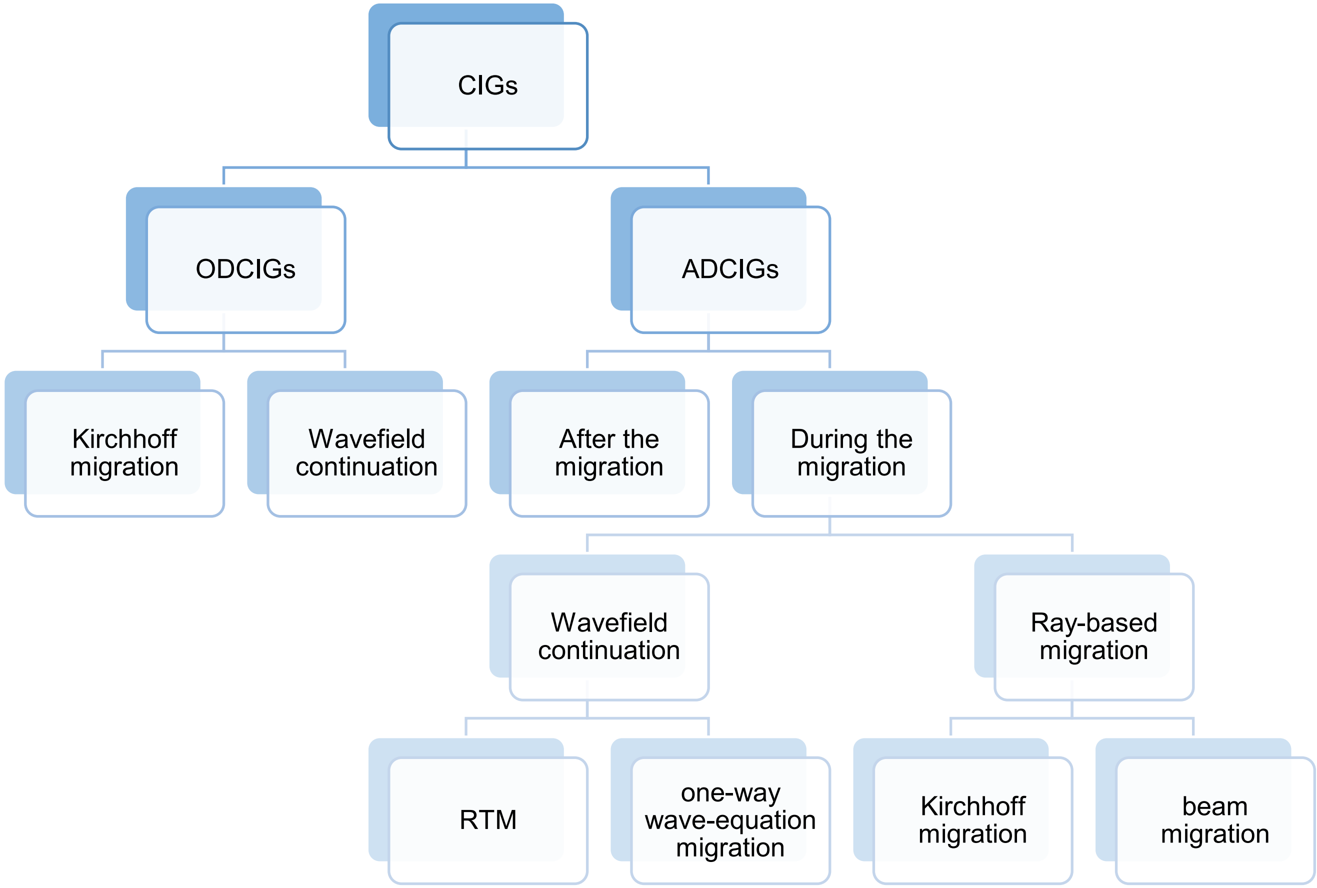
How to get CIGs?

assumption & approximation

Kirchhoff depth migration: high frequency approximation

beam migration: Green's function

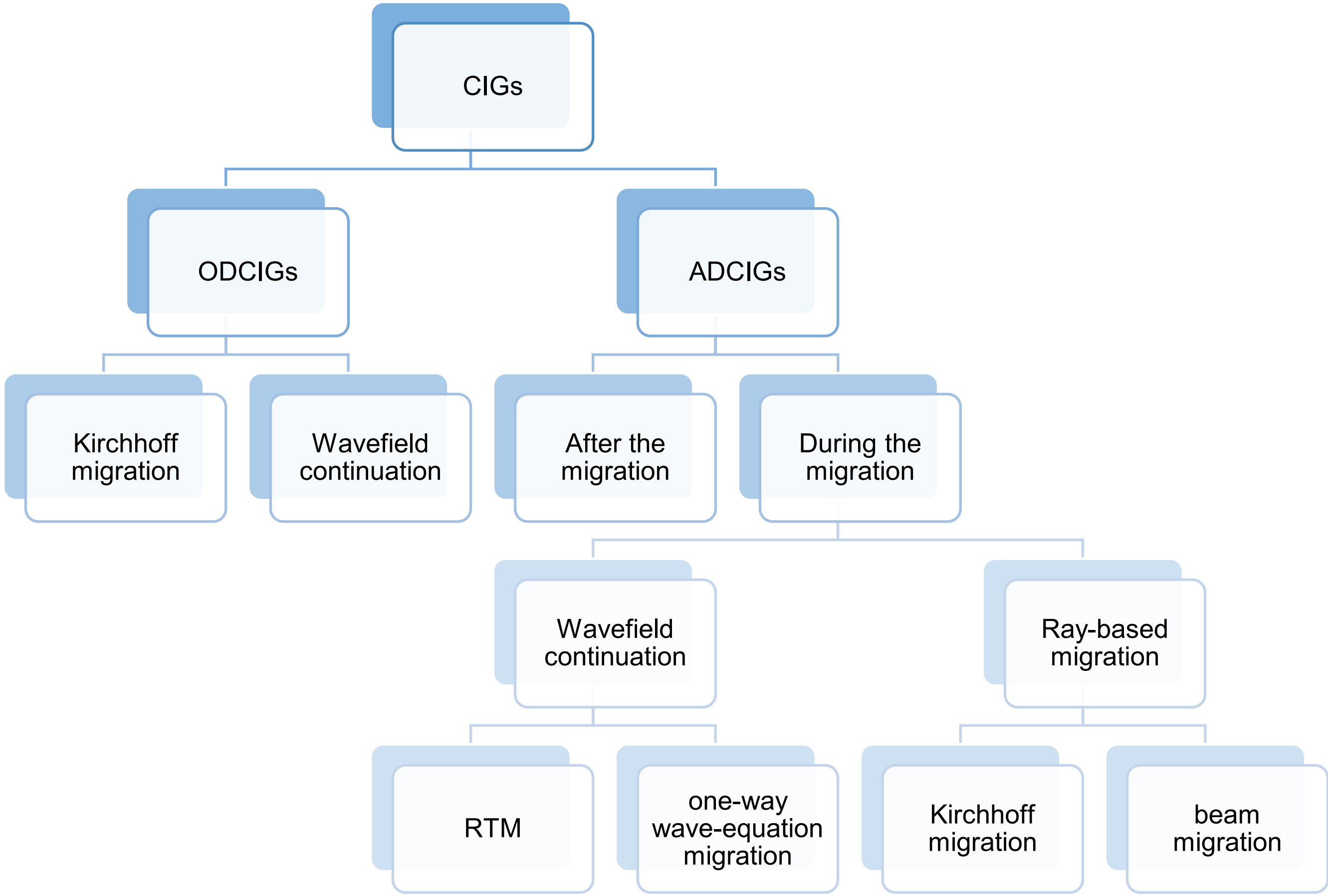
one-way wave-equation migration: one way approximation assumption

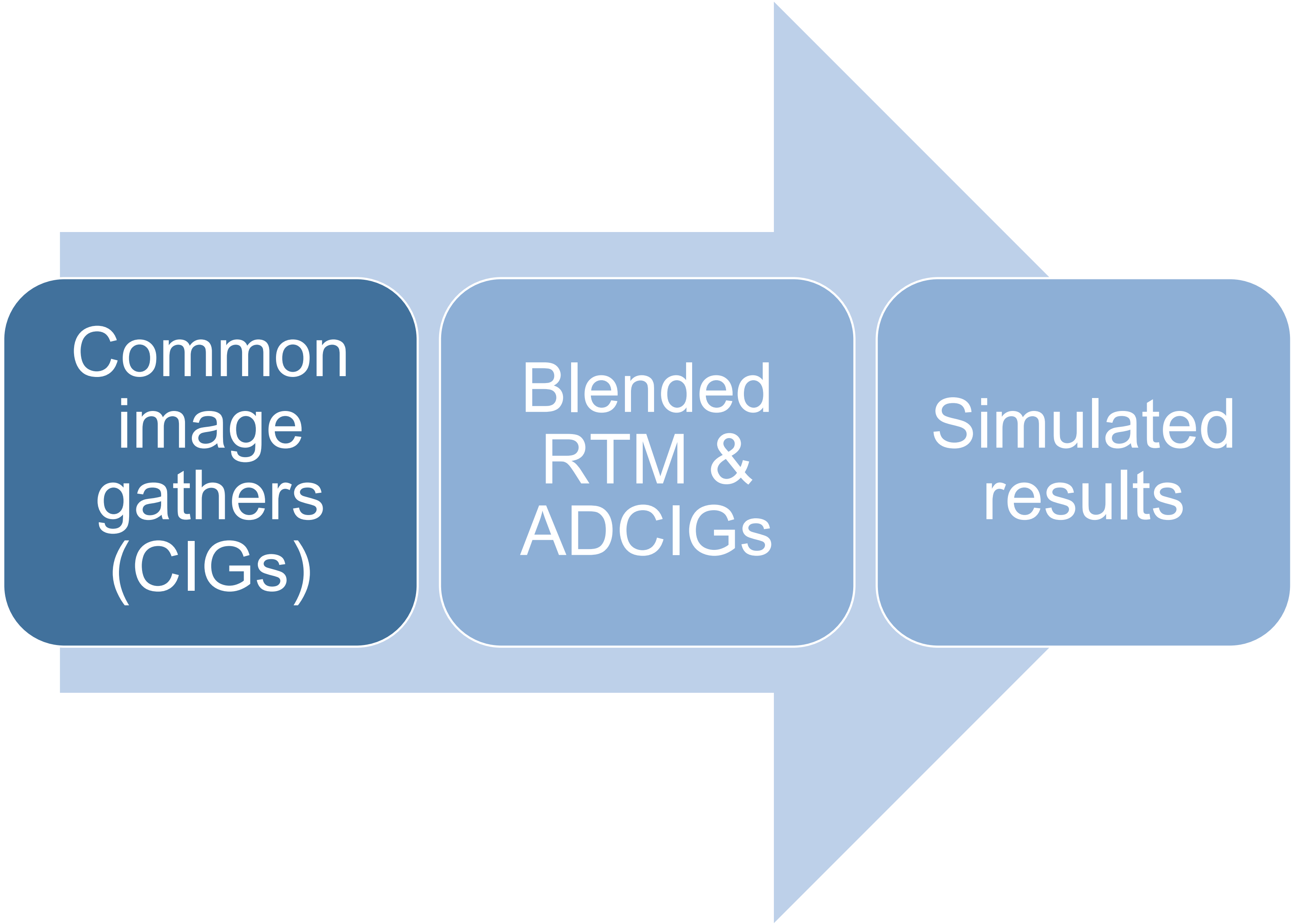


How to get CIGs?

Because the Reverse time migration/RTM is based on the direct solutions of the wave equation, it requires less assumption and approximation.

Itself naturally carries the correct propagation amplitude.

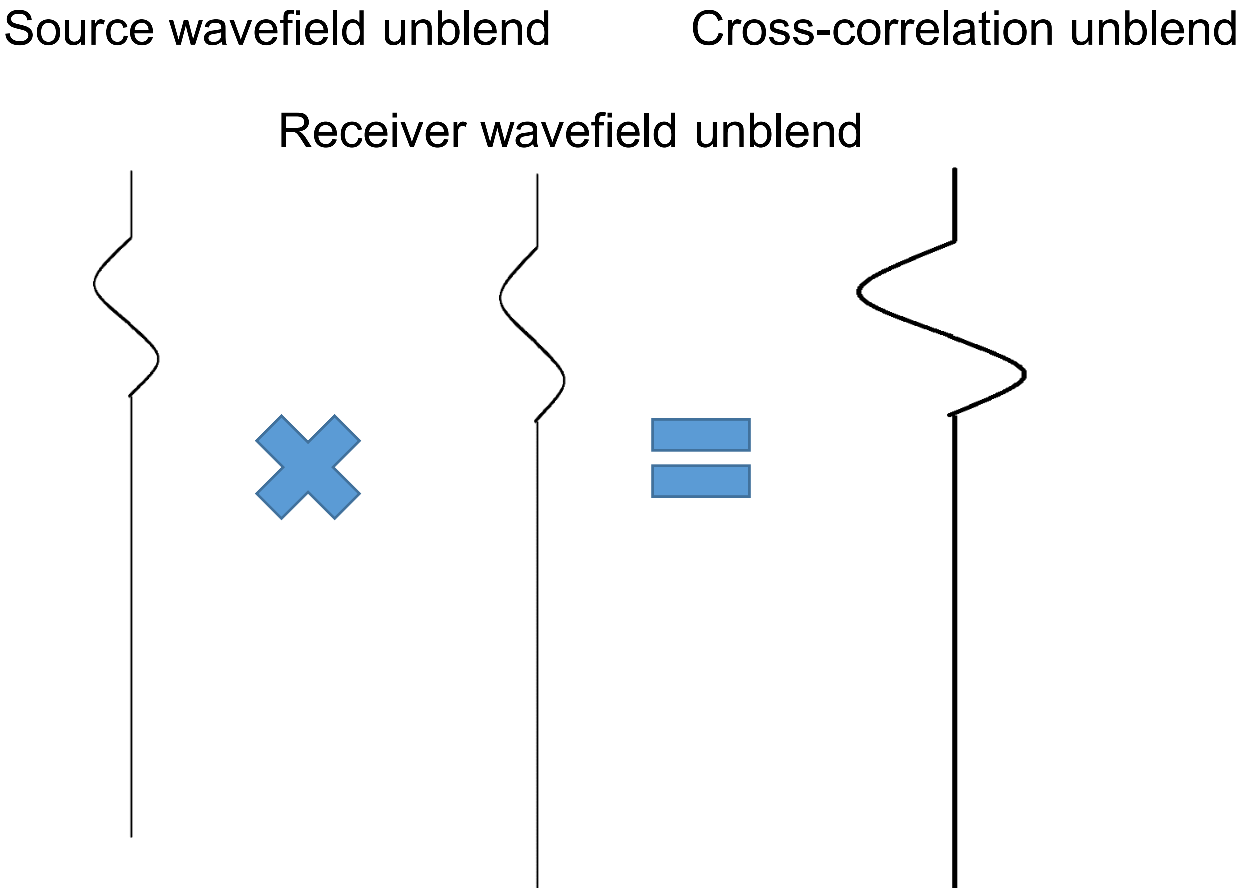



Common image gathers (CIGs)
Blended RTM & ADCIGs
Simulated results

Blended RTM & ADCIGs

How to solve RTM?

The image condition/IC in conventional RTM is the cross-correlation in the image point containing all reflection angles for unblended acquisition.



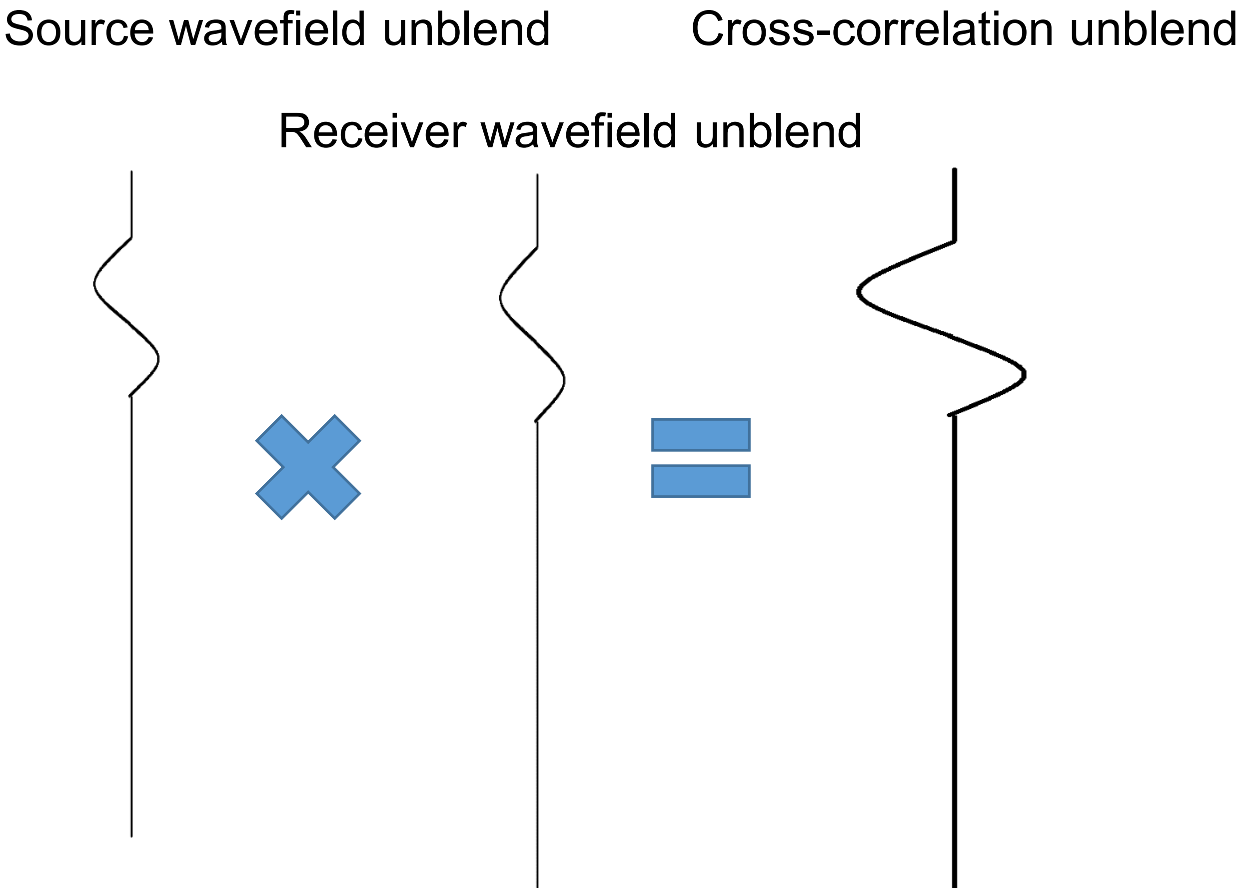
$$\text{image}(x,z) = \sum_{\text{time}} S(x,z,t)R(x,z,t),$$

Claerbout, 1971; Kaelin and Guitton, 2006

Blended RTM & ADCIGs

The deconvolution IC can be obtained by normalizing the square of the source illumination strength.

It contains all reflection angles for unblended acquisition.



$$R(\overrightarrow{x}) = \int p_B(\overrightarrow{x};t)p_F^{-1}(\overrightarrow{x};t)dt$$

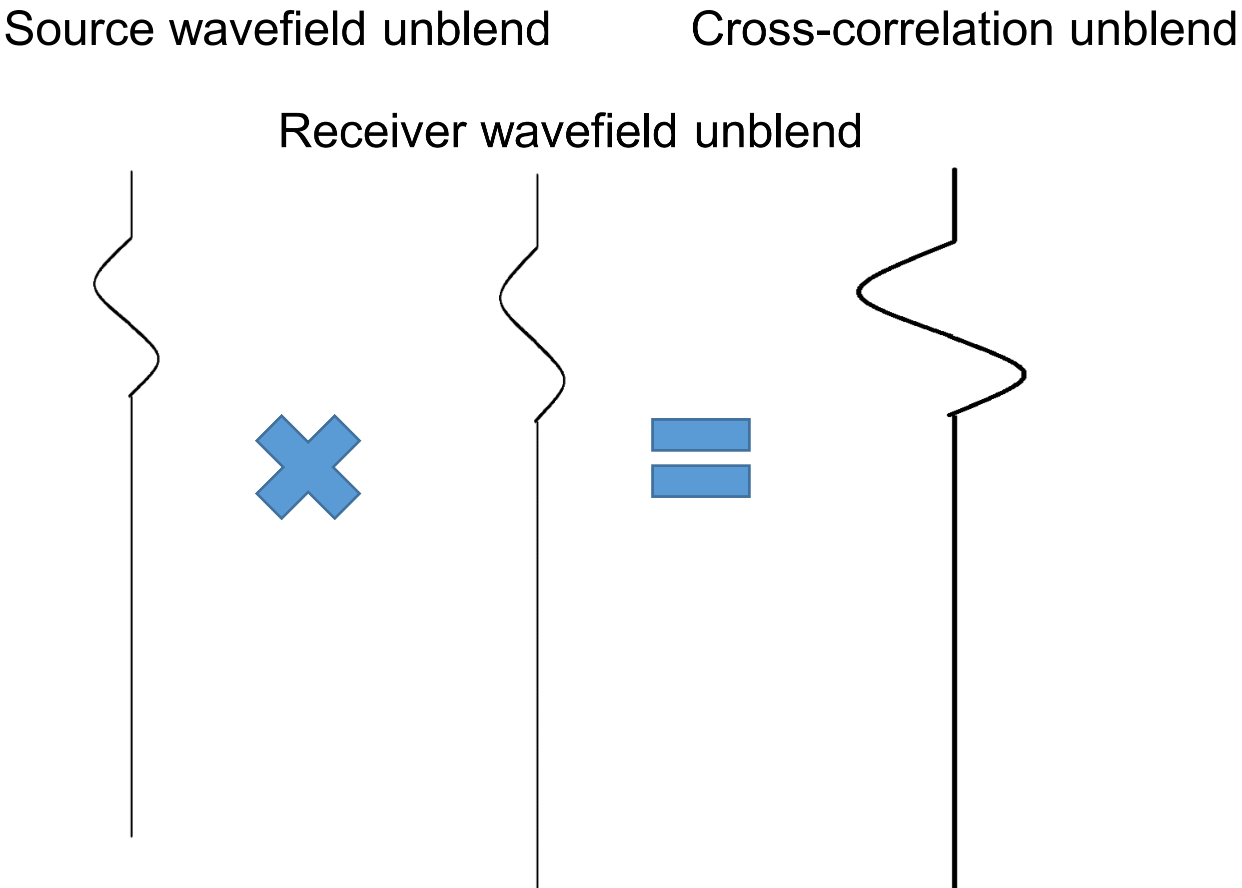
$$\text{image}\,(x,z) = \frac{\sum_{\text{time}} S\,(x,z,t)\,R\,(x,z,t)}{\sum_{\text{time}} S^2\,(x,z,t)},$$

Claerbout, 1971; Kaelin and Guitton, 2006

Blended RTM & ADCIGs

The ADCIG IC adds the angle dimension to the output

It contains the given reflection angles for unblended acquisition.

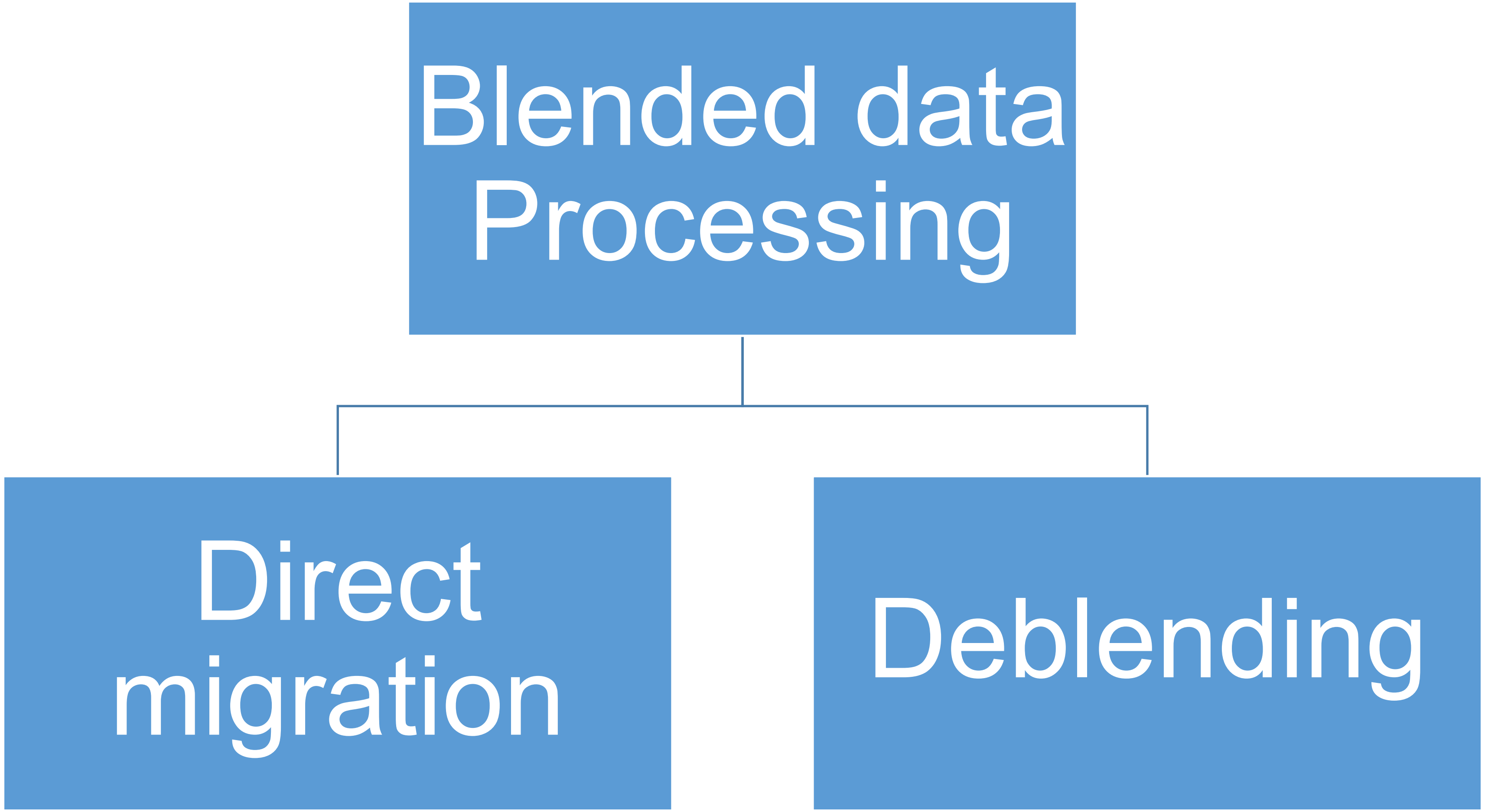


$$R(\vec{x}) = \int p_B(\vec{x};t)p_F^{-1}(\vec{x};t)dt$$

$$R(\vec{x},\theta) = \int p_B(\vec{x},\theta;t)p_F^{-1}(\vec{x},\theta;t)dt$$

Claerbout, 1971; Kaelin and Guitton, 2006

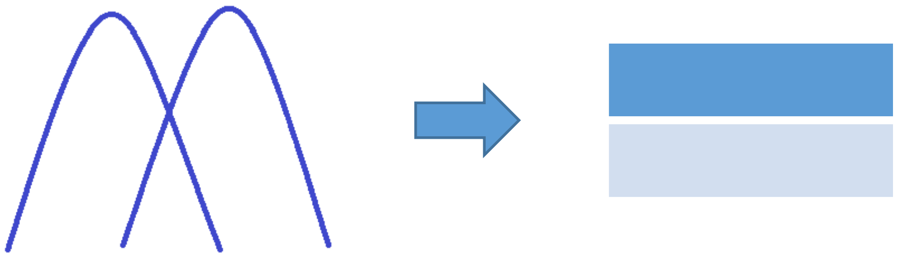
Blended RTM & ADCIGs

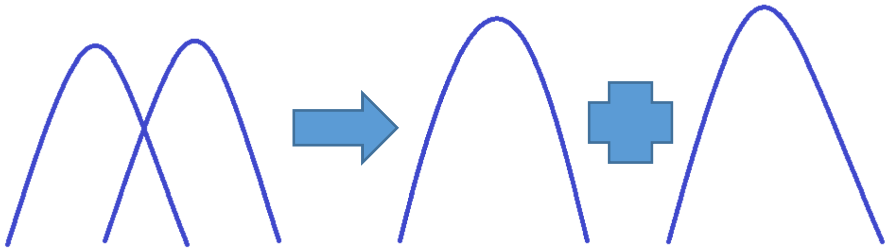


Blended RTM & ADCIGs

Blended data Processing

- Direct migration
- Deblending





Blended data Processing restrictions

Direct migration:

Requires velocity model accuracy

Deblending:

difficult when shot spacing is close and many shots are blended

for complex models containing many scatter points

may rely on random source timings and positions

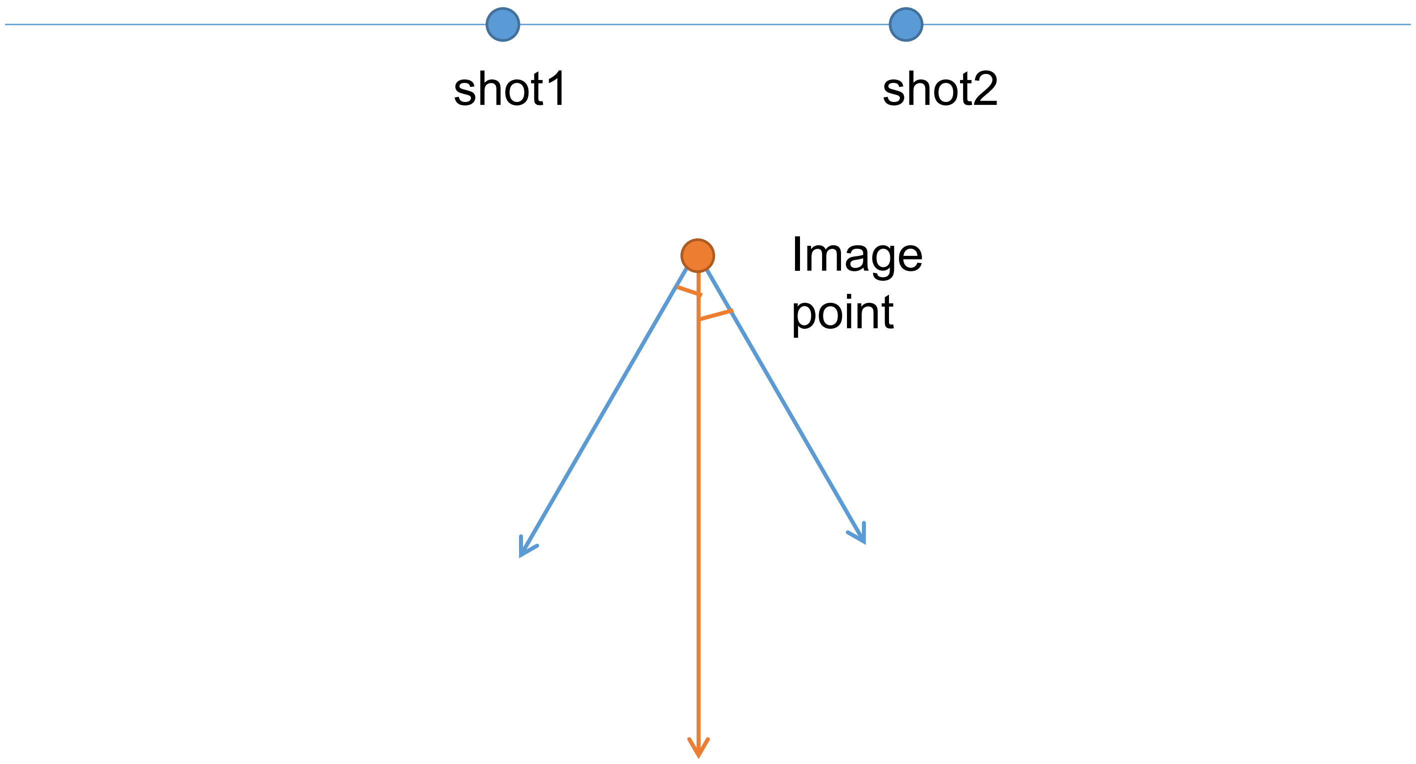
Hypotheses

1. The earth's response can generally be approximated as linear
2. There is only one wave direction per image point per image time. (Vyas et al., 2011)

Blended acquisition in RTM

If simultaneous arrival

If energy from different sources arrive at the same time.
The addition of the vectors applied.



Blended RTM & ADCIGs

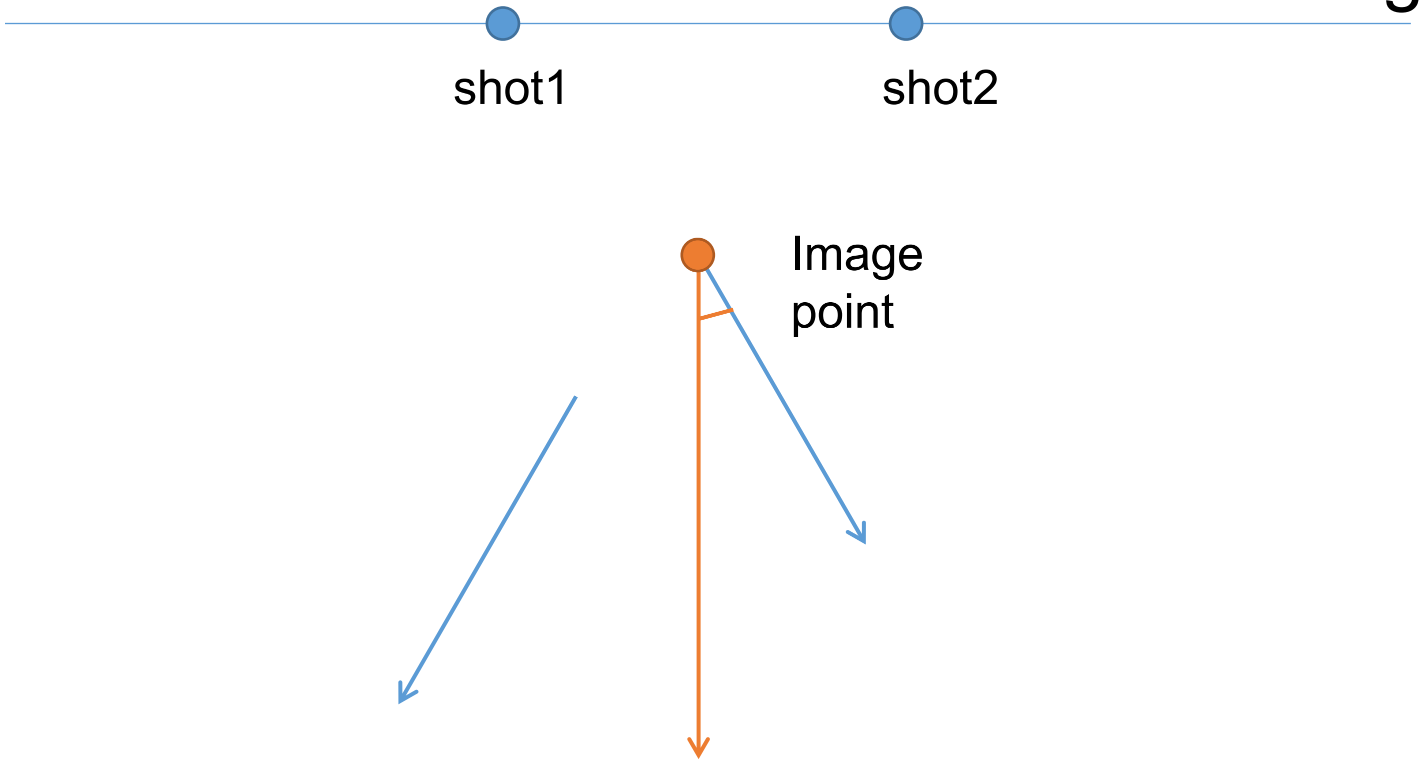
Blended acquisition in RTM

If sequential arrival

If energy from different sources arrive at different time. The cross-correlation of RTM IC will become risky.

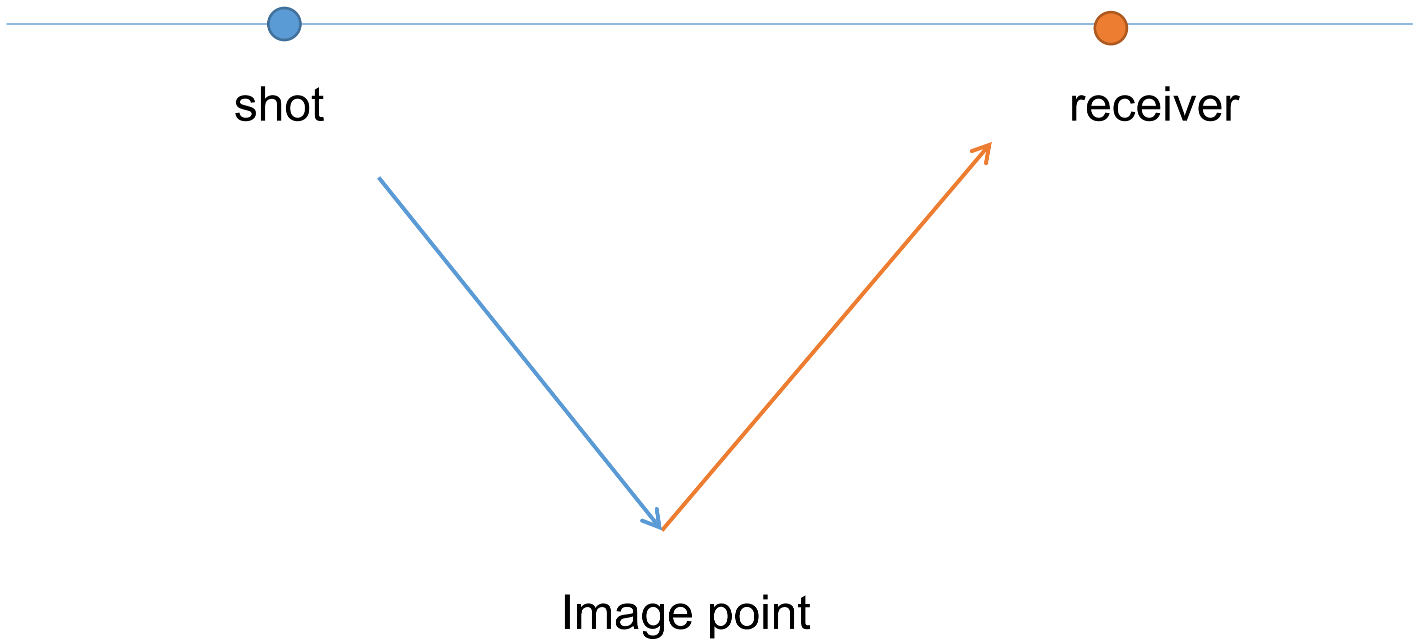
Crosstalk from other sources will add noise.

How to attenuate that? Discuss at each reflection angle in ADCIGs



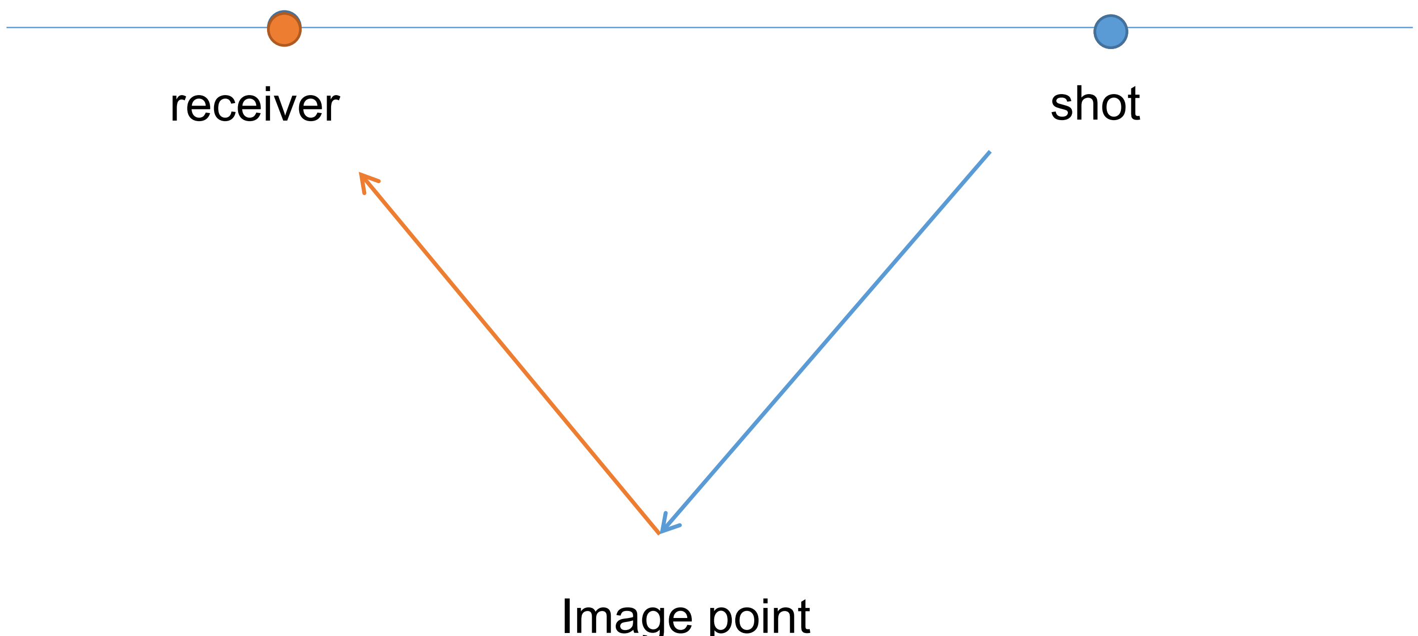
Blended acquisition in ADCIGs

For a given reflection angle at an image point, reflection amplitude is proportional to the incident amplitude.



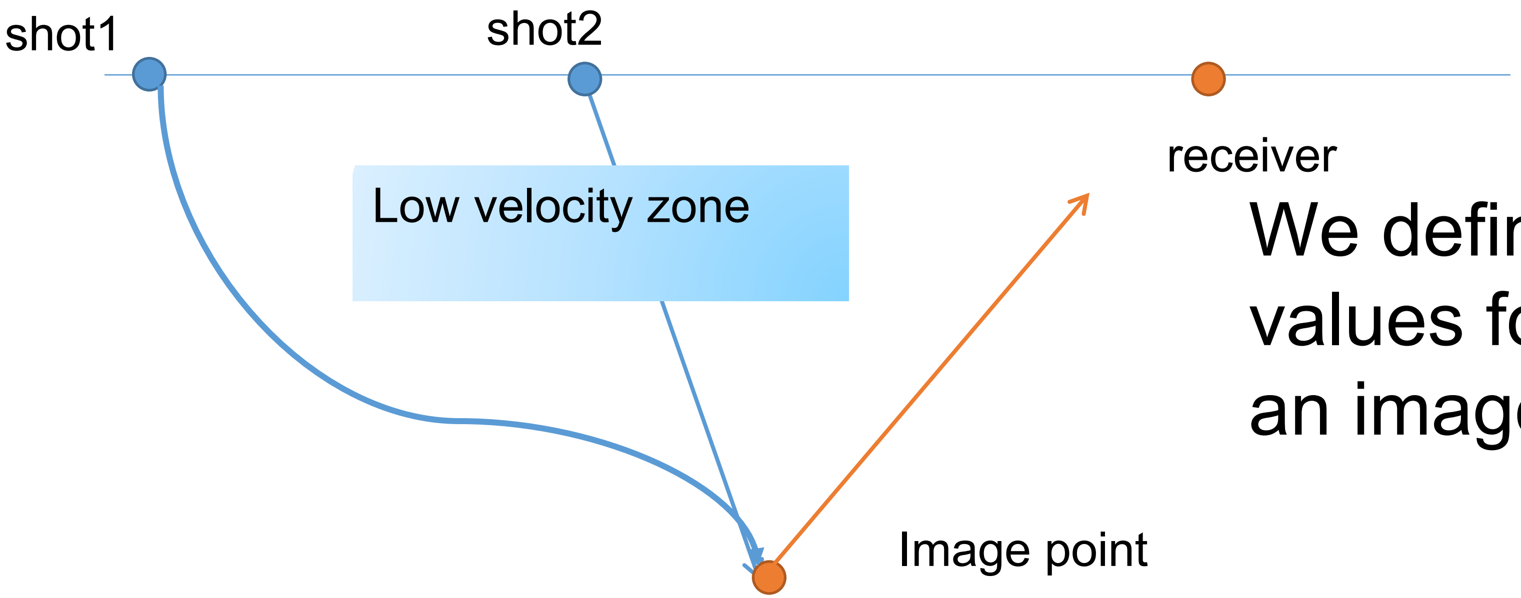
Blended acquisition in ADCIGs

For a given reflection angle at an image point, reflection amplitude is proportional to the incident amplitude.
For a given reflection angle at an image point, that reflection may happens more than once, so there will be multiple IC values.



Blended acquisition in ADCIGs

For a given reflection angle at an image point, reflection amplitude is proportional to the incident amplitude.
For a given reflection angle at an image point, that reflection may happens more than once, so there will be multiple IC values, especially in blended data.

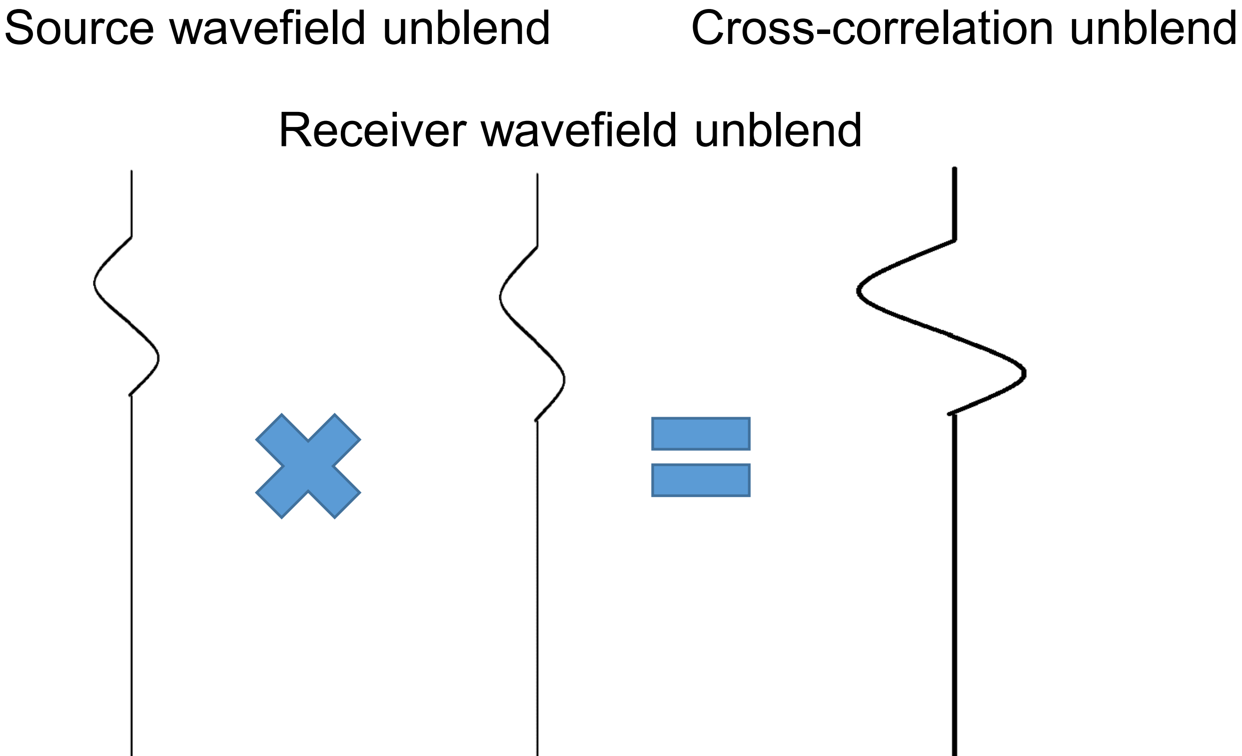


We define the quantity of the IC values for a given reflection angle at an image point "subsurface fold"

Blended RTM & ADCIGs

Blended acquisition in ADCIG

For a given reflection angle at an image point, reflection amplitude is proportional to the incident amplitude.
For a given reflection angle at an image point, that reflection may happens more than once, especially in blended data.



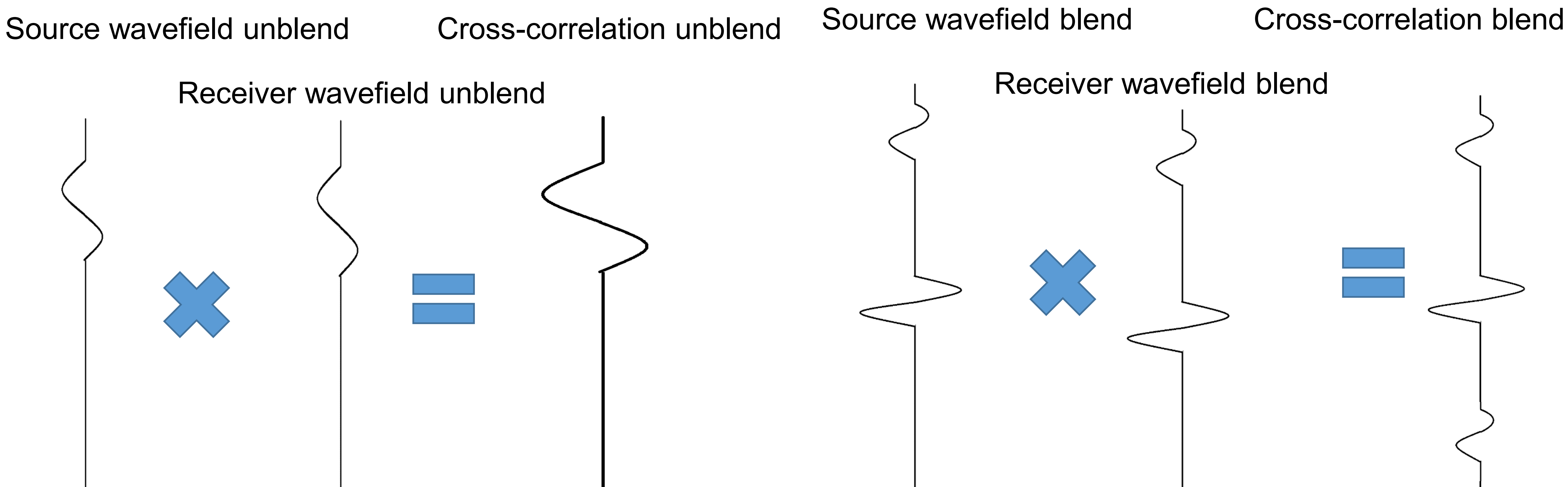
Conventional cross-correlation IC is the sum of all IC values. Its output amplitude will be affected by subsurface fold.

Blended acquisition in ADCIG

Subsurface Fold included in the IC:

$R(x,\theta)$ -> $R(x,\theta,\text{subsurface fold})$

...ne
cross-correlation always indicates the right source and receiver signal pair.



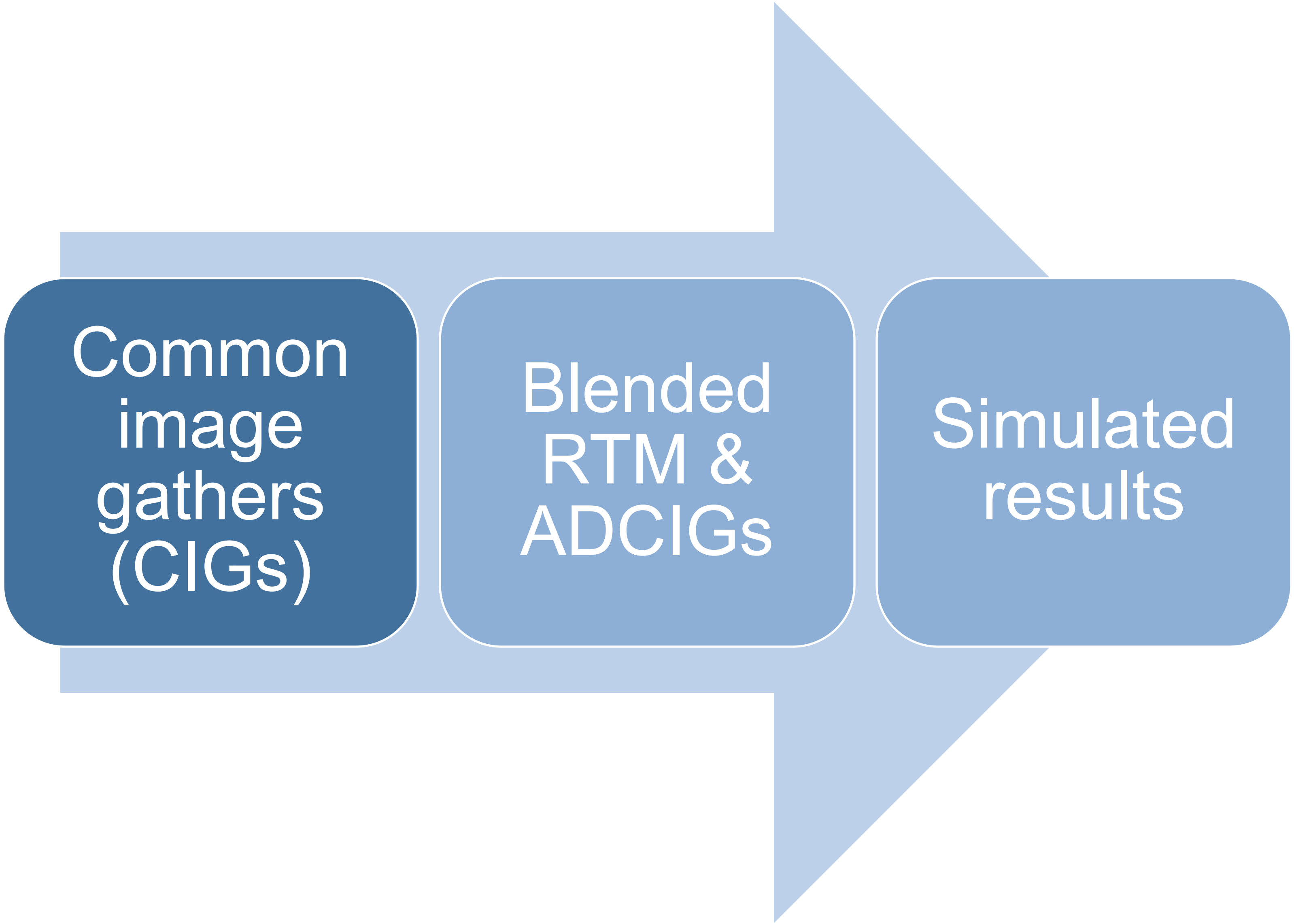
Blended RTM & ADCIGs

Blended acquisition in ADCIG

For a given reflection angle at an image point, reflection amplitude is proportional to the incident amplitude.
Wrong source-receiver pairs cause crosstalk, yet the maximum value in the cross-correlation always indicates the right source and receiver signal pair.

Subsurface Fold included in the IC:
R(x,θ) -> R(x,θ,subsurface fold)

In simulation, we not only included highest amplitude in IC R(x,θ,subsurface fold), but also add a mean function of the a range of R. Also, outliars are filtered out based on the prior info of the velocity.


Common image gathers (CIGs)
Blended RTM & ADCIGs
Simulated results

AVA response in Elastic SH wave media / acoustic with density

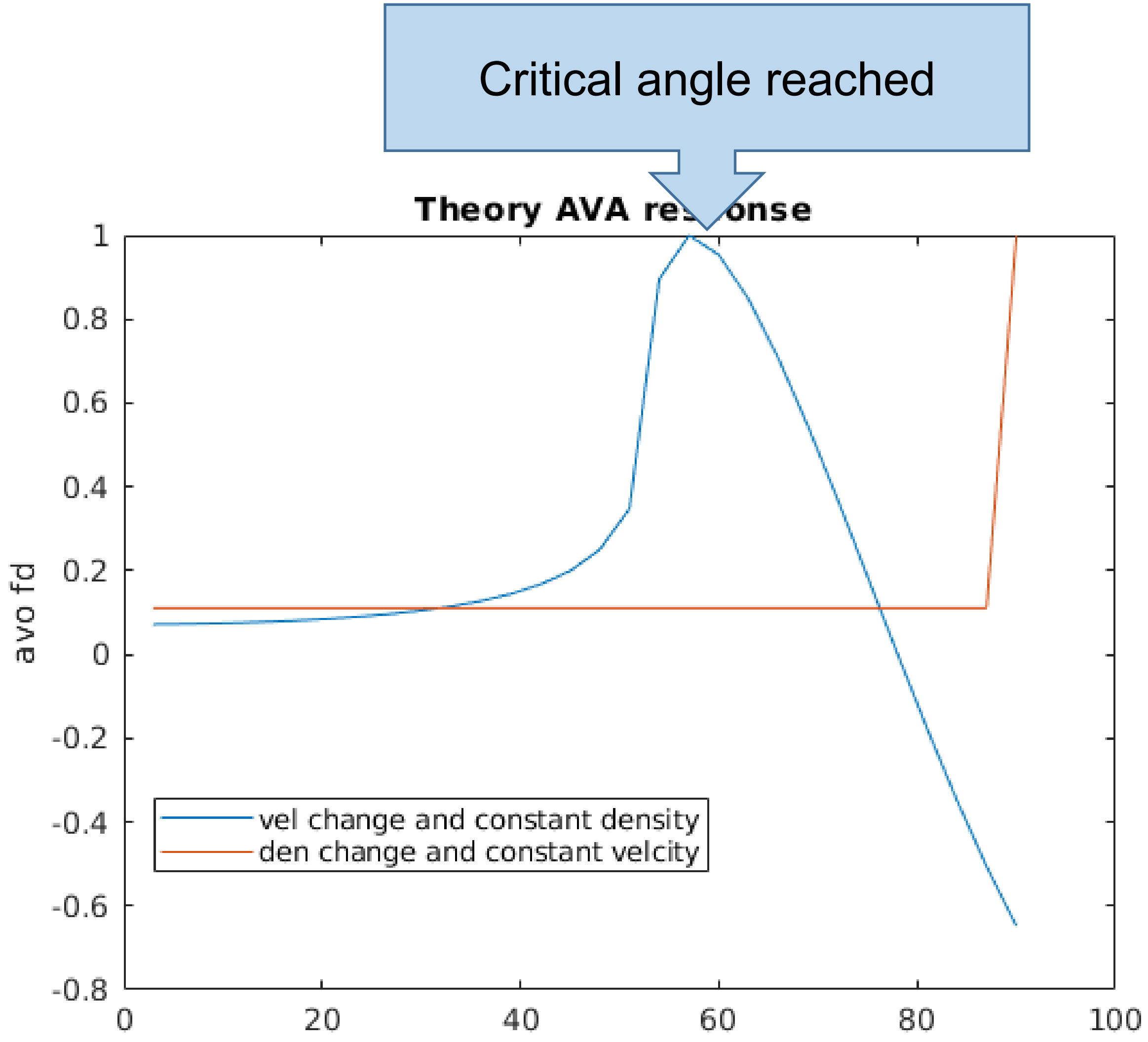
$$\begin{cases} \frac{\partial P}{\partial t} = -\rho c^2 \left(\frac{\partial v_x}{\partial x} + \frac{\partial v_z}{\partial z} \right) \\ \frac{\partial v_x}{\partial t} = -\frac{1}{\rho} \frac{\partial P}{\partial x} \\ \frac{\partial v_z}{\partial t} = -\frac{1}{\rho} \frac{\partial P}{\partial z} \end{cases}$$

$$R(\theta) = \frac{1 - \Omega(\theta)}{1 + \Omega(\theta)},$$

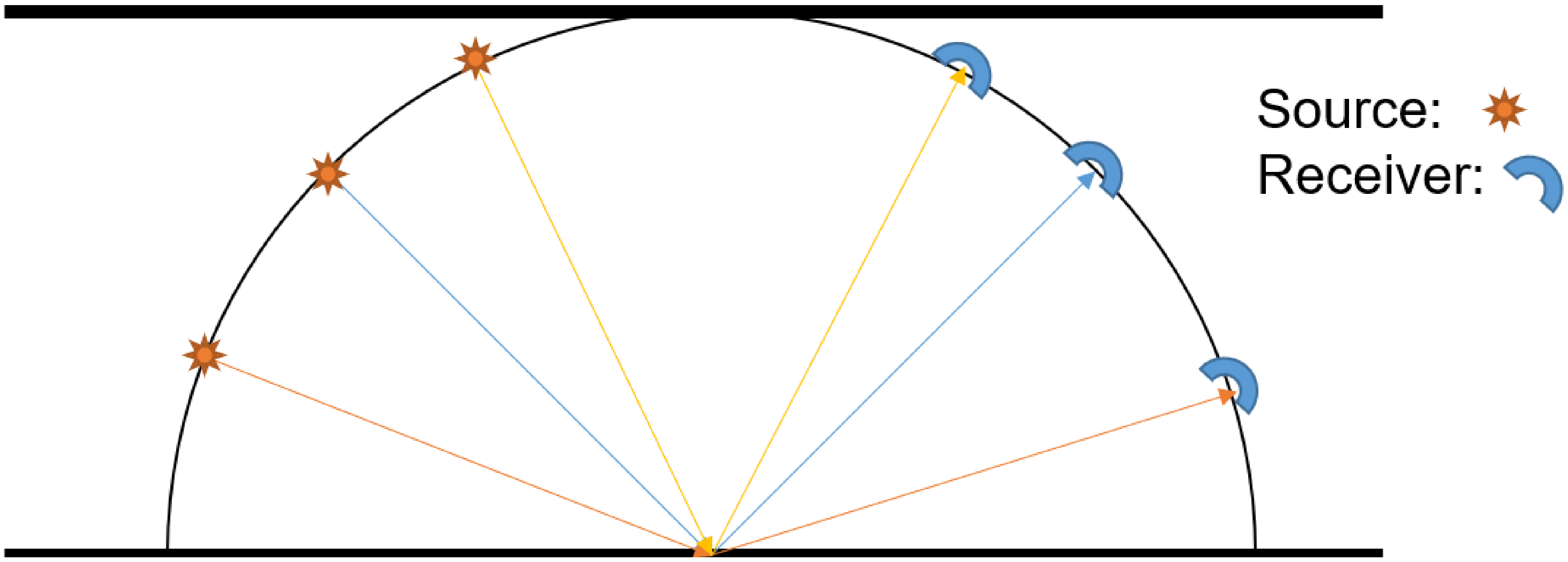
$$\Omega(\theta) = \left(\frac{\rho_0}{\rho_1} \right) \sqrt{\frac{\kappa_0}{\kappa_1} \frac{\rho_1}{\rho_0}} \left(\frac{1}{\cos\theta} \right) \sqrt{1 - \frac{\kappa_1}{\kappa_0} \frac{\rho_0}{\rho_1} \sin^2\theta}.$$

Innanen, Kristopher A. "Seismic AVO and the inverse Hessian in precritical reflection full waveform inversion." *Geophysical Journal International* 199.2 (2014): 717-734.

AVA response in Elastic SH wave media / acoustic media with density



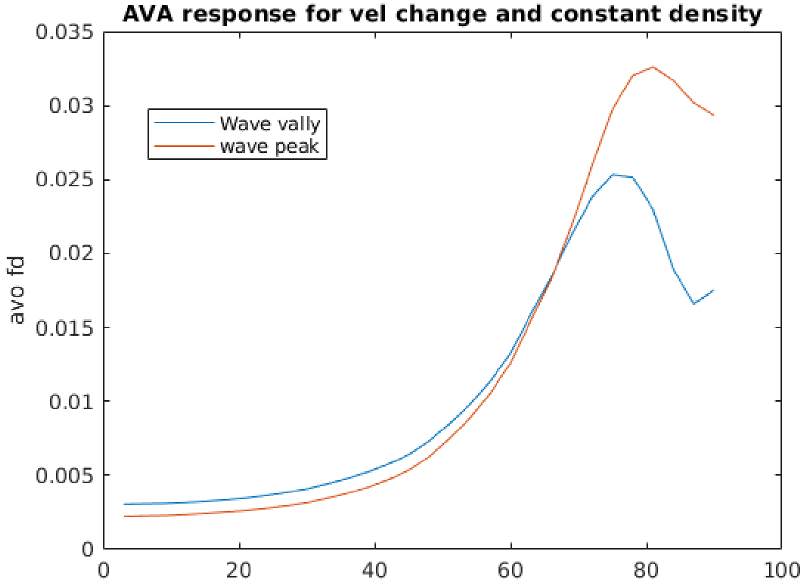
AVA response in Elastic SH wave media / acoustic with density from Finite-difference

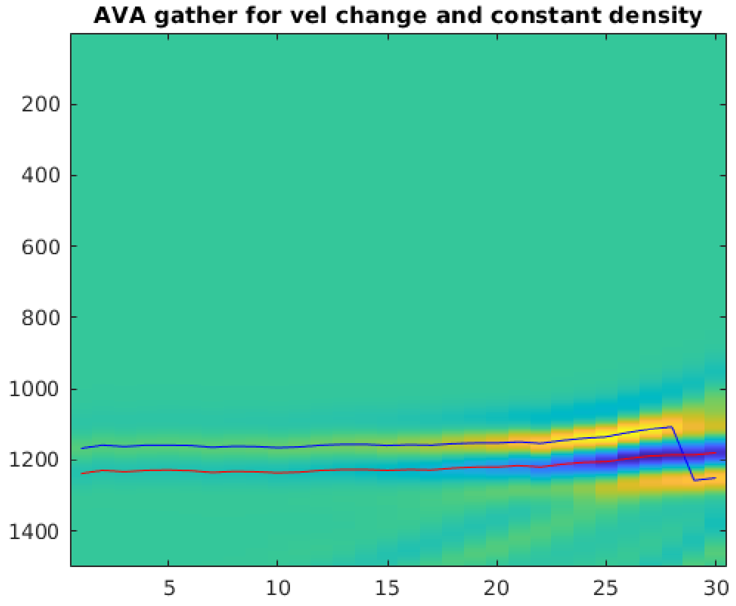


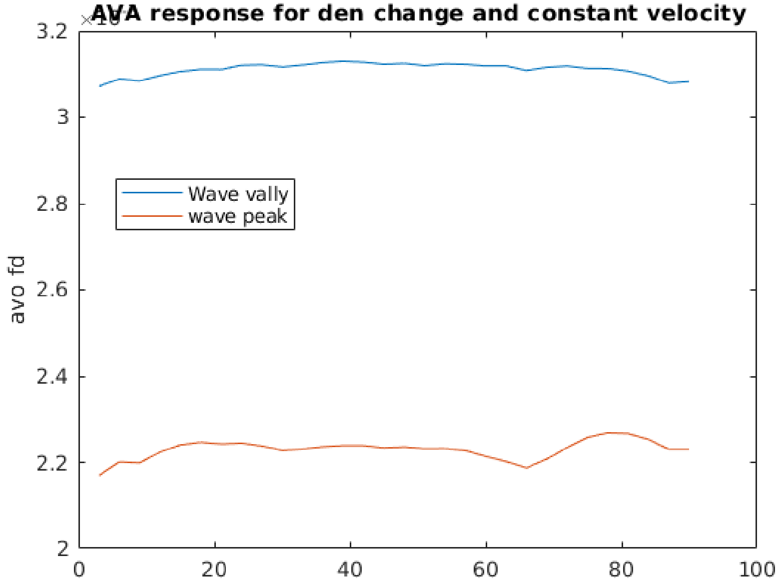
Results

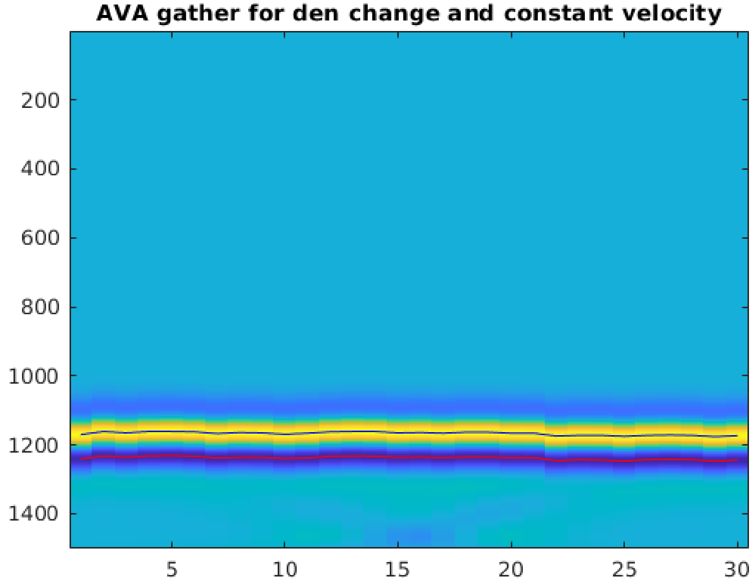
AVA response from Finite-difference

Unblended



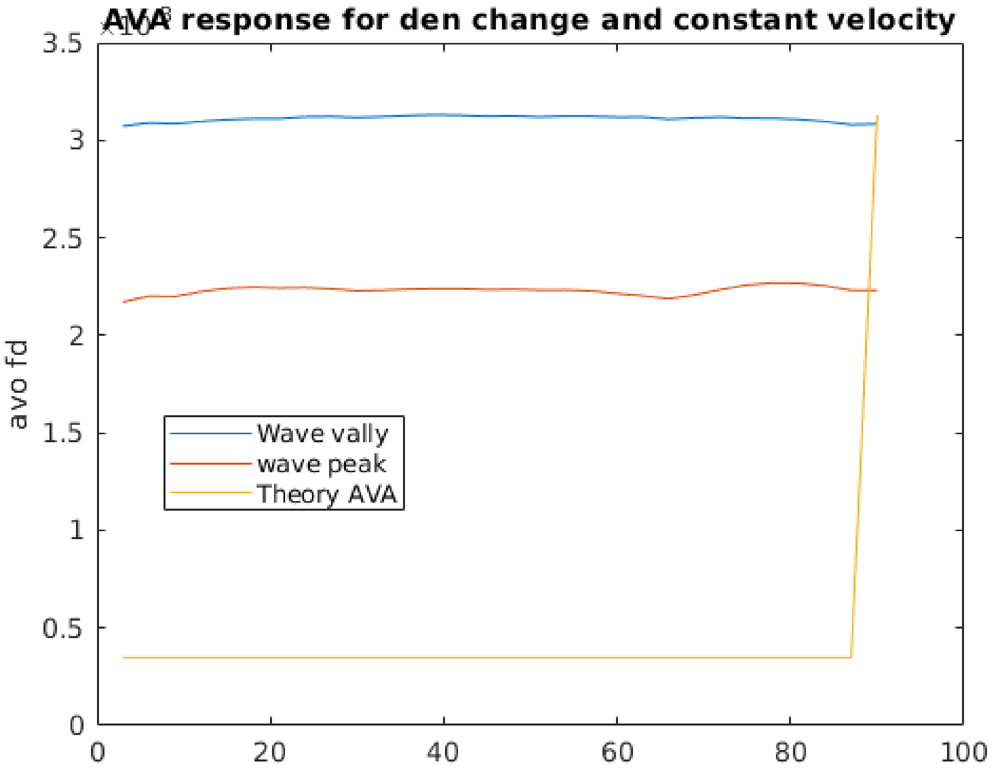


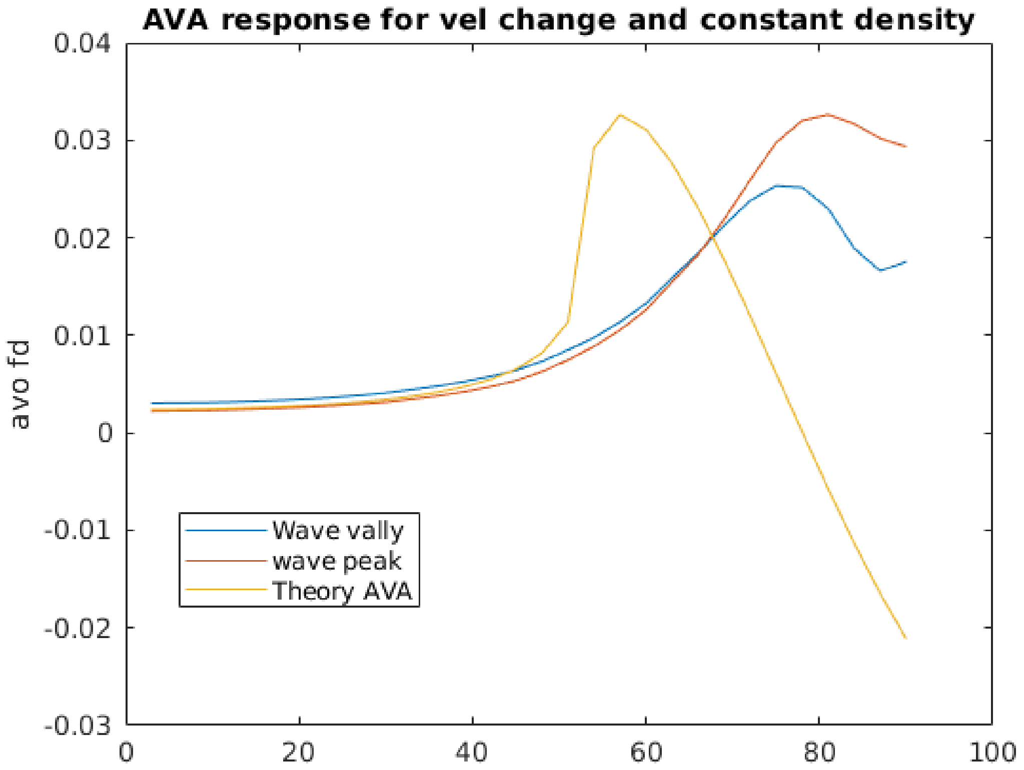




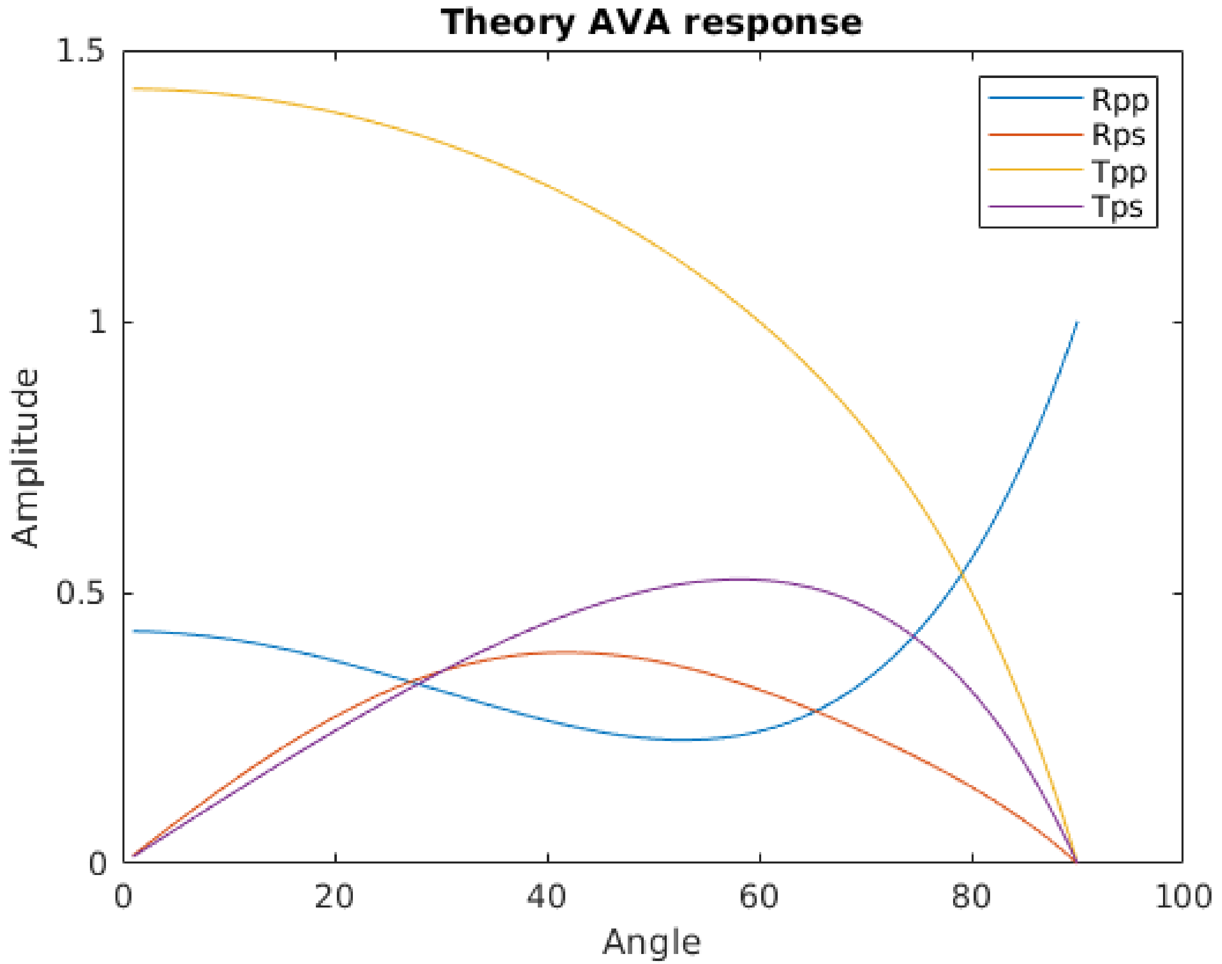
AVA response from Finite-difference

Unblended





AVA response in Elastic P-SV wave media



Zoeppritz Equation in a 2-layered model

Results

Decoupled elastic wave equation to separate P/S wave

Amplitude preserved compared with the Helmholtz decomposition

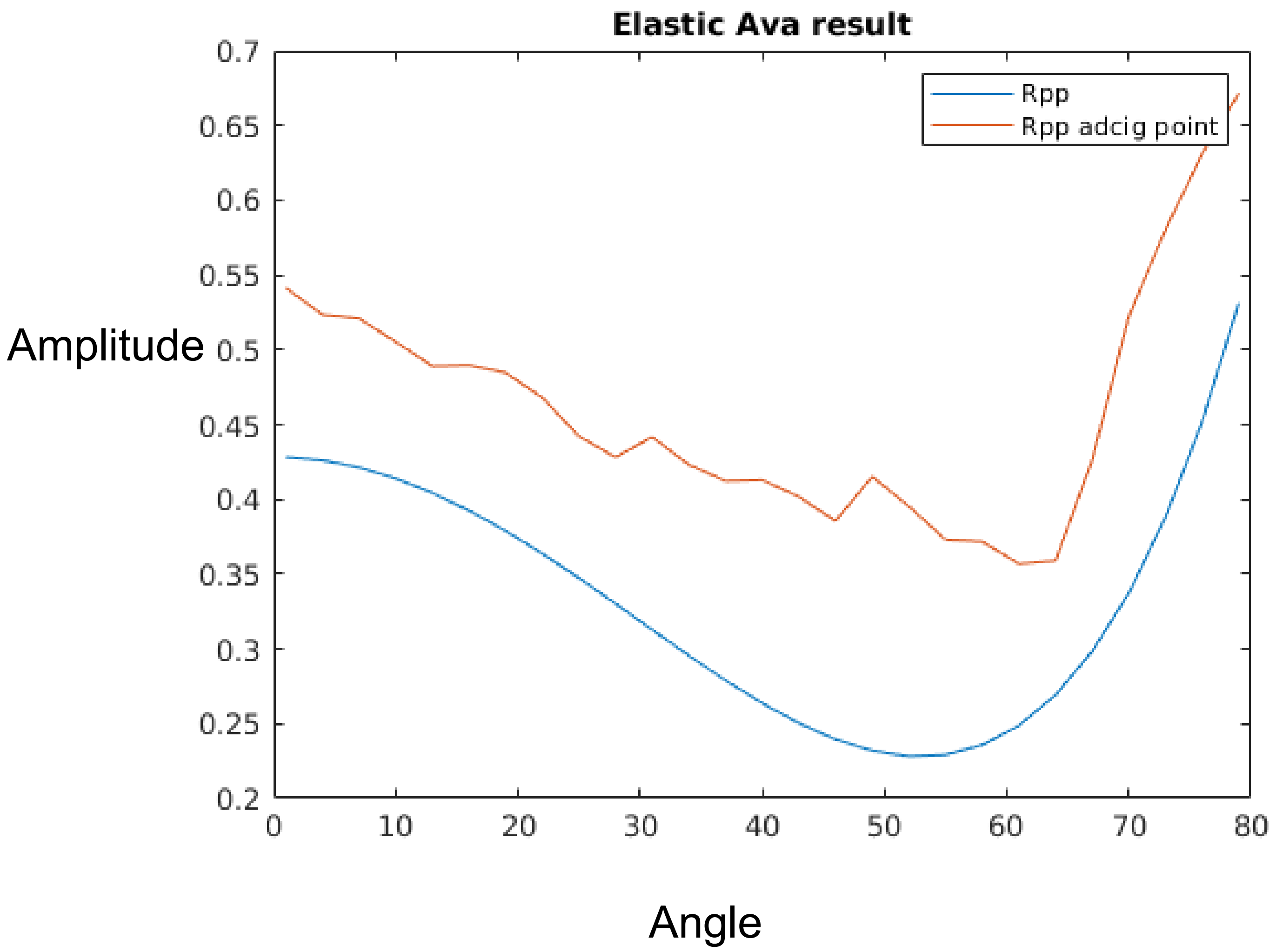
$$v_x = v_x^{\mathrm{P}} + v_x^{\mathrm{S}},\, v_z = v_z^{\mathrm{P}} + v_z^{\mathrm{S}}, \tag{39}$$

$$\begin{aligned}
&\rho \frac{\partial v_x^{\mathrm{P}}}{\partial t} = \frac{\partial \tau_{xx}^{\mathrm{P}}}{\partial x}, \quad \rho \frac{\partial v_z^{\mathrm{P}}}{\partial t} = \frac{\partial \tau_{zz}^{\mathrm{P}}}{\partial z}, \\
&\frac{\partial \tau_{xx}^{\mathrm{P}}}{\partial t} = (\lambda + 2\mu)\left(\frac{\partial v_x}{\partial x} + \frac{\partial v_z}{\partial z}\right), \quad \frac{\partial \tau_{zz}^{\mathrm{P}}}{\partial t} = (\lambda + 2\mu)\left(\frac{\partial v_x}{\partial x} + \frac{\partial v_z}{\partial z}\right),
\end{aligned} \tag{40}$$

$$\begin{aligned}
&\rho \frac{\partial v_x^{\mathrm{S}}}{\partial t} = \frac{\partial \tau_{xx}^{\mathrm{S}}}{\partial x} + \frac{\partial \tau_{xz}^{\mathrm{S}}}{\partial z}, \quad \rho \frac{\partial v_z^{\mathrm{S}}}{\partial t} = \frac{\partial \tau_{xz}^{\mathrm{S}}}{\partial x} + \frac{\partial \tau_{zz}^{\mathrm{S}}}{\partial z}, \\
&\frac{\partial \tau_{xx}^{\mathrm{S}}}{\partial t} = -2\mu \frac{\partial v_z}{\partial z}, \quad \frac{\partial \tau_{zz}^{\mathrm{S}}}{\partial t} = -2\mu \frac{\partial v_x}{\partial x}, \quad \frac{\partial \tau_{xz}^{\mathrm{S}}}{\partial t} = \mu\left(\frac{\partial v_z}{\partial x} + \frac{\partial v_x}{\partial z}\right),
\end{aligned}$$

Zhiming Ren, 2017, Temporal high-order staggered-grid finite-difference schemes for elastic wave propagation

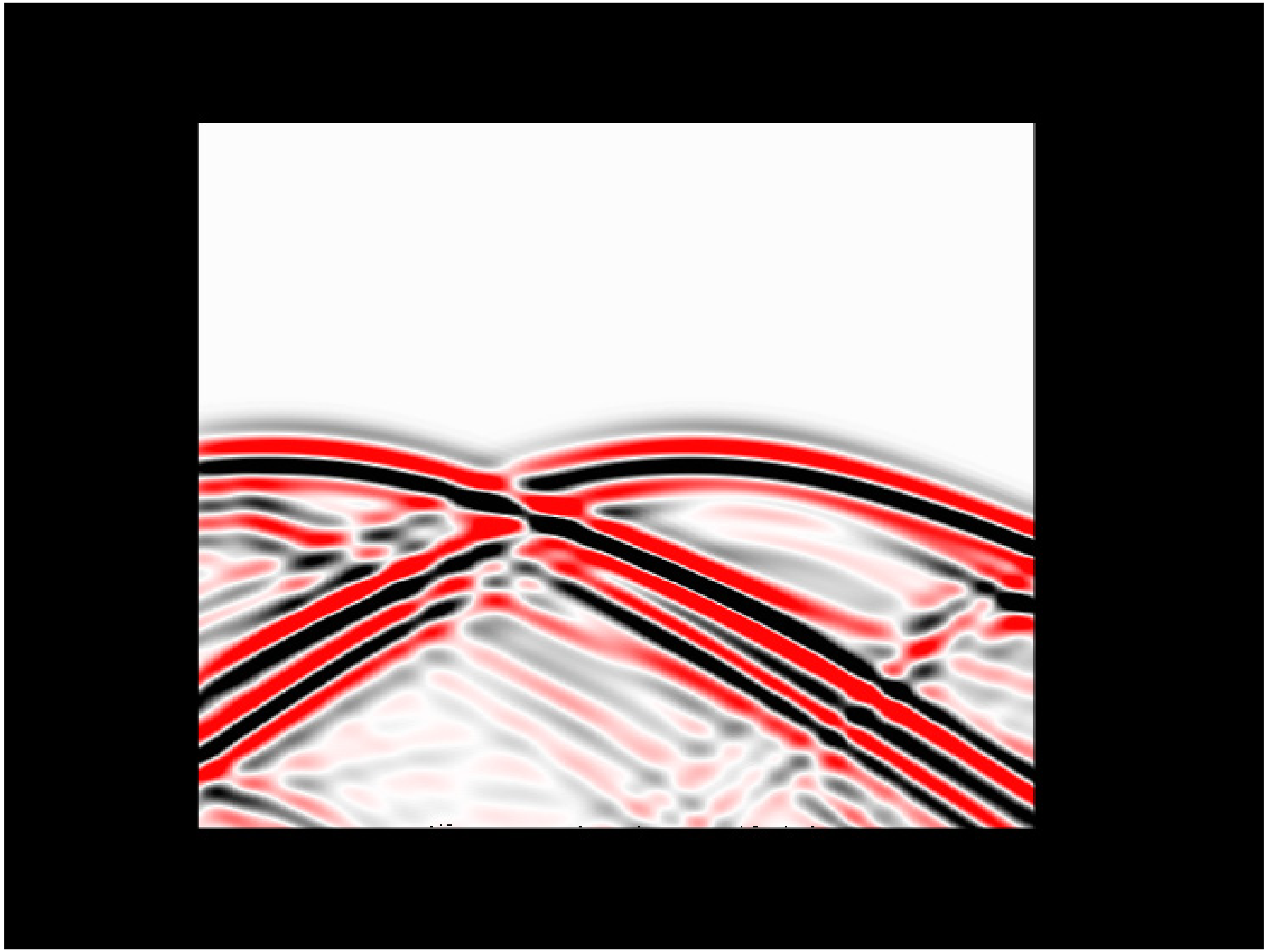
AVA response Rpp from Zoeppritz and ADCIGs for unblended data



Results

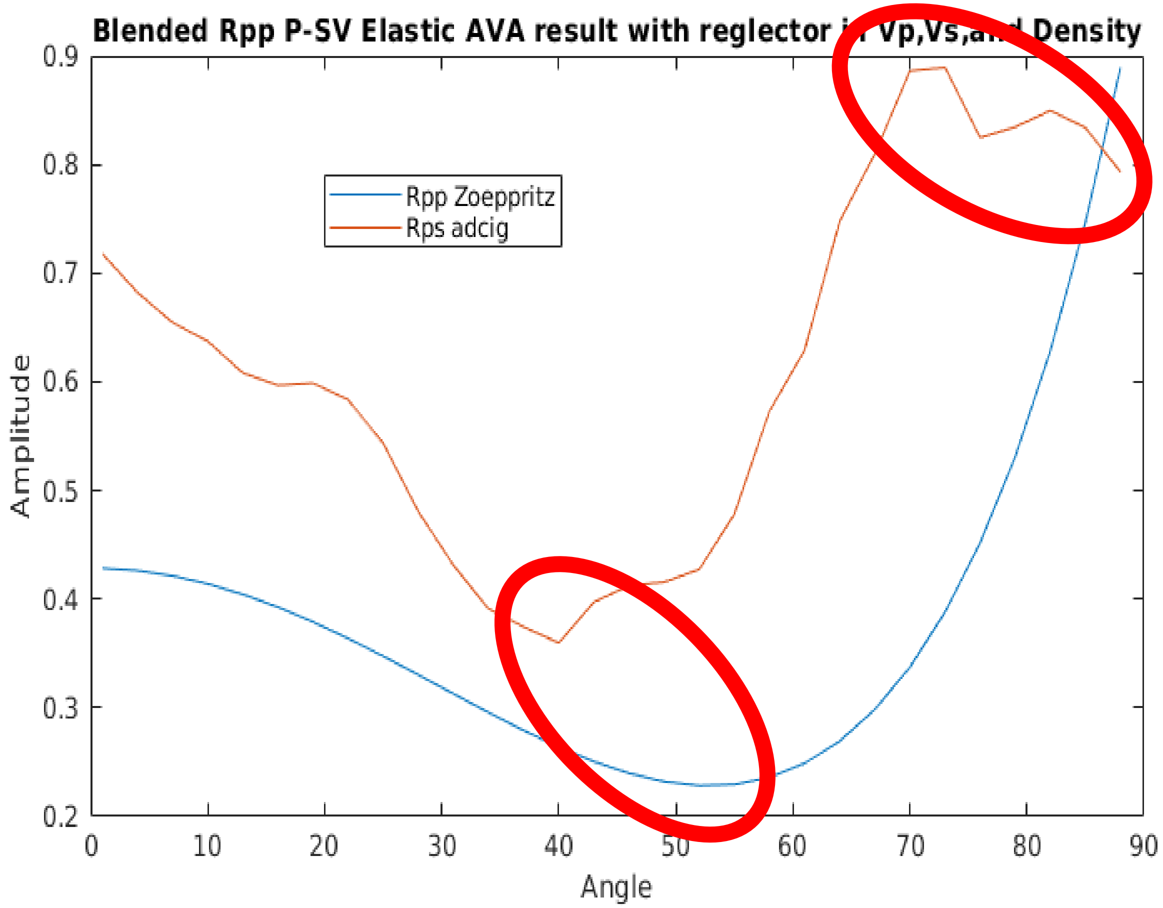
Blended data

Horizontal component of P wave in blended shot gather, Vpx

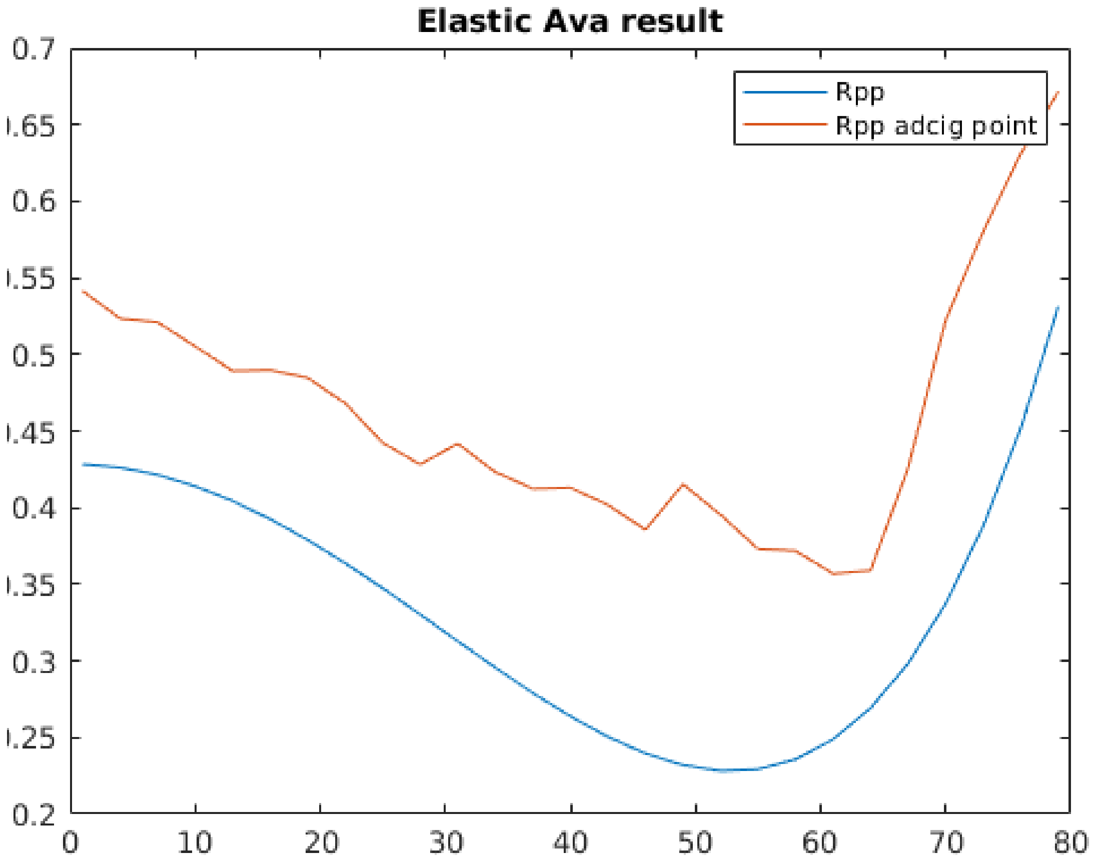


Results

AVA response Rpp from Zoeppritz and ADCIGs for blended data



Blended



Unblended

Conclusions

Extract ADCIGs from RTM

subsurface fold: the fold in subsurface imaging

Add subsurface fold into ADCIGs RTM IC

Test AVA response with the Zoeppritz equations and simulating forward modelling in a layered model for elastic SH media

Test AVA response with the Zoeppritz equations and ADCIGs for elastic P-SV media in unblended and blended data:

ADCIG extraction method could be effective for blended acquisition

Acknowledgements

Thanks for the help with Jing Wang, Xin Fu, Xiaohui Cai.

We thank the sponsors of CREWES for continued support. This work was funded by CREWES industrial sponsors and NSERC (Natural Science and Engineering Research Council of Canada) through the grant CRDPJ 543578-19.

Questions?