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Extended images with surface-related multiples

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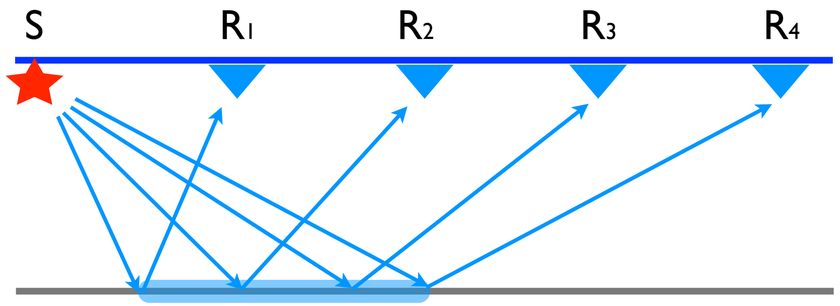
Why need image gathers ?

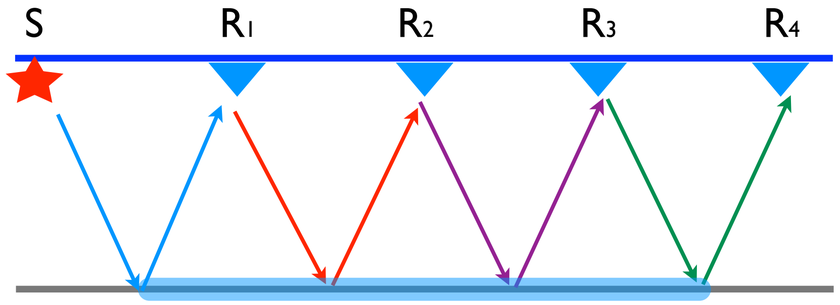
- Effective velocity analysis tool

- *Full*-subsurface *offset* volumes allow us to conduct
  - AVA using information from *all* offset directions.
  - geological dip corrections

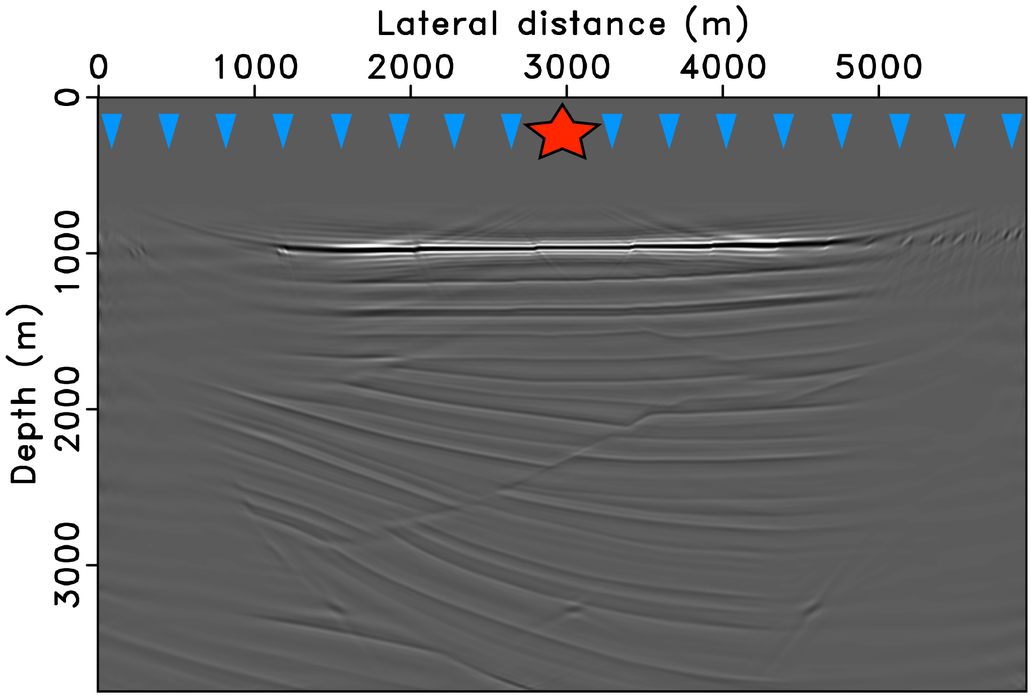
Why need multiples ?



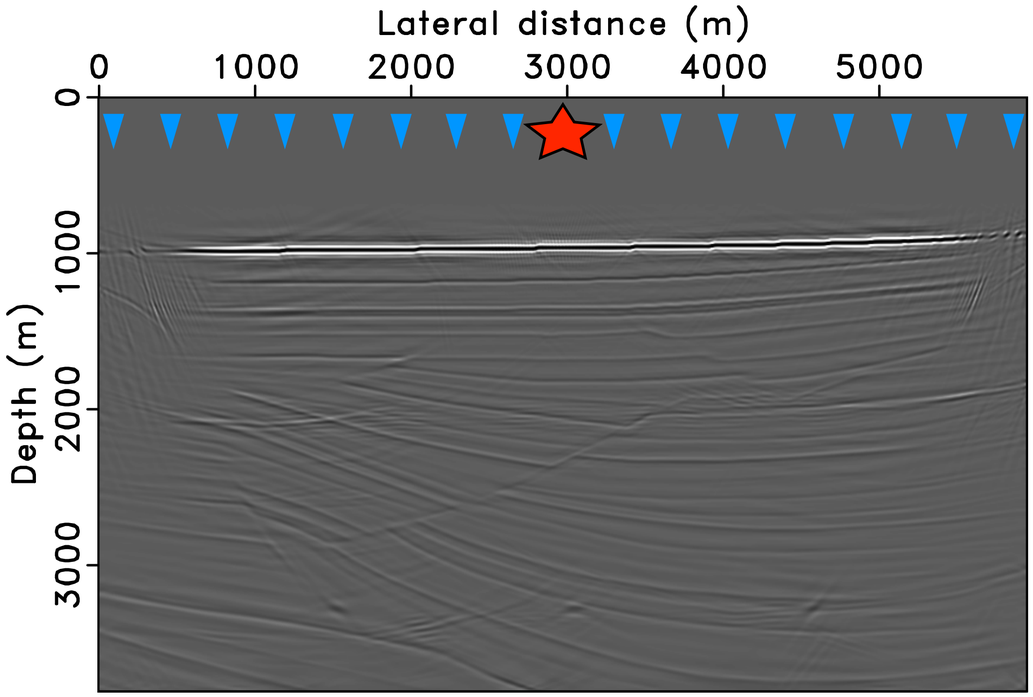
illumination by primaries



illumination by multiples



Least-squares imaging: 1 *primary-only* shot gather



Least-squares imaging: Imaging 1 *multiple-only* shot gather

Motivation

- *Leverage benefits of SRME*
  - highly accurate data-driven multiple prediction

- *All in one go* method
  - we combine SRME within the extended imaging condition

Extended imaging condition

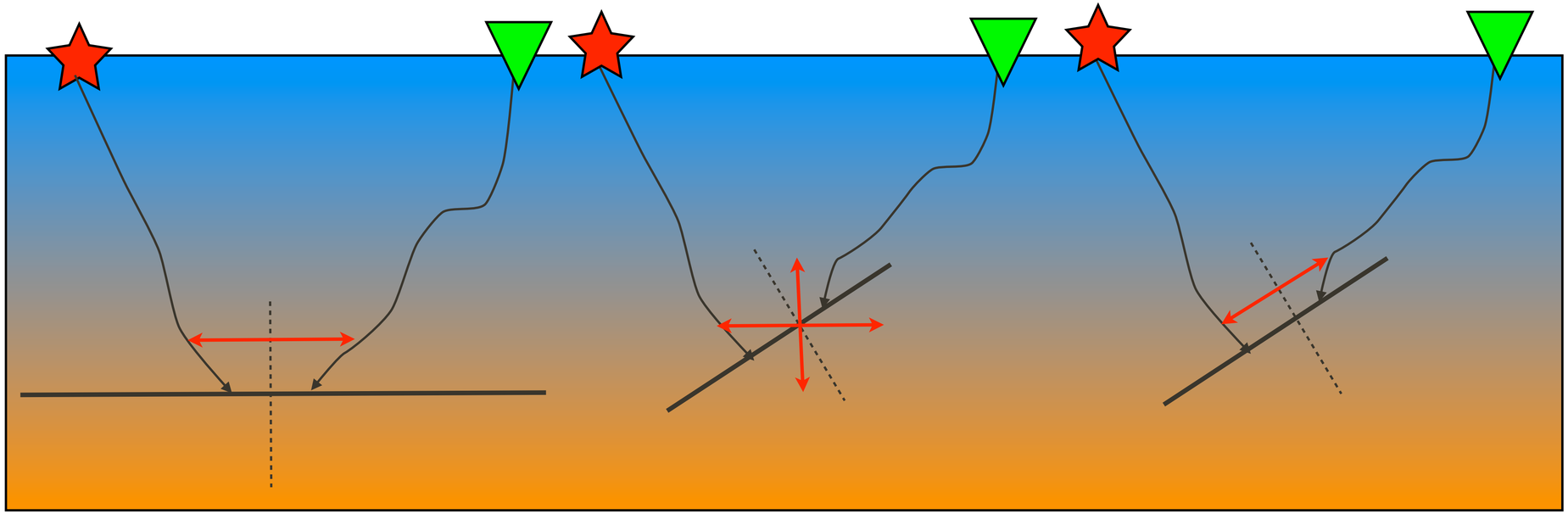
$$e(\omega, \mathbf{x}, \mathbf{x}') = \sum_i u_i(\omega, \mathbf{x}) v_i(\omega, \mathbf{x}')^*$$

- Organize wavefields in monochromatic data matrices

- Express *extended* image volume *tensor* as *matrix*

$$E = UV^*$$

[Biondo & Symes, '04 ; Sava & Vasconcelos, '11]

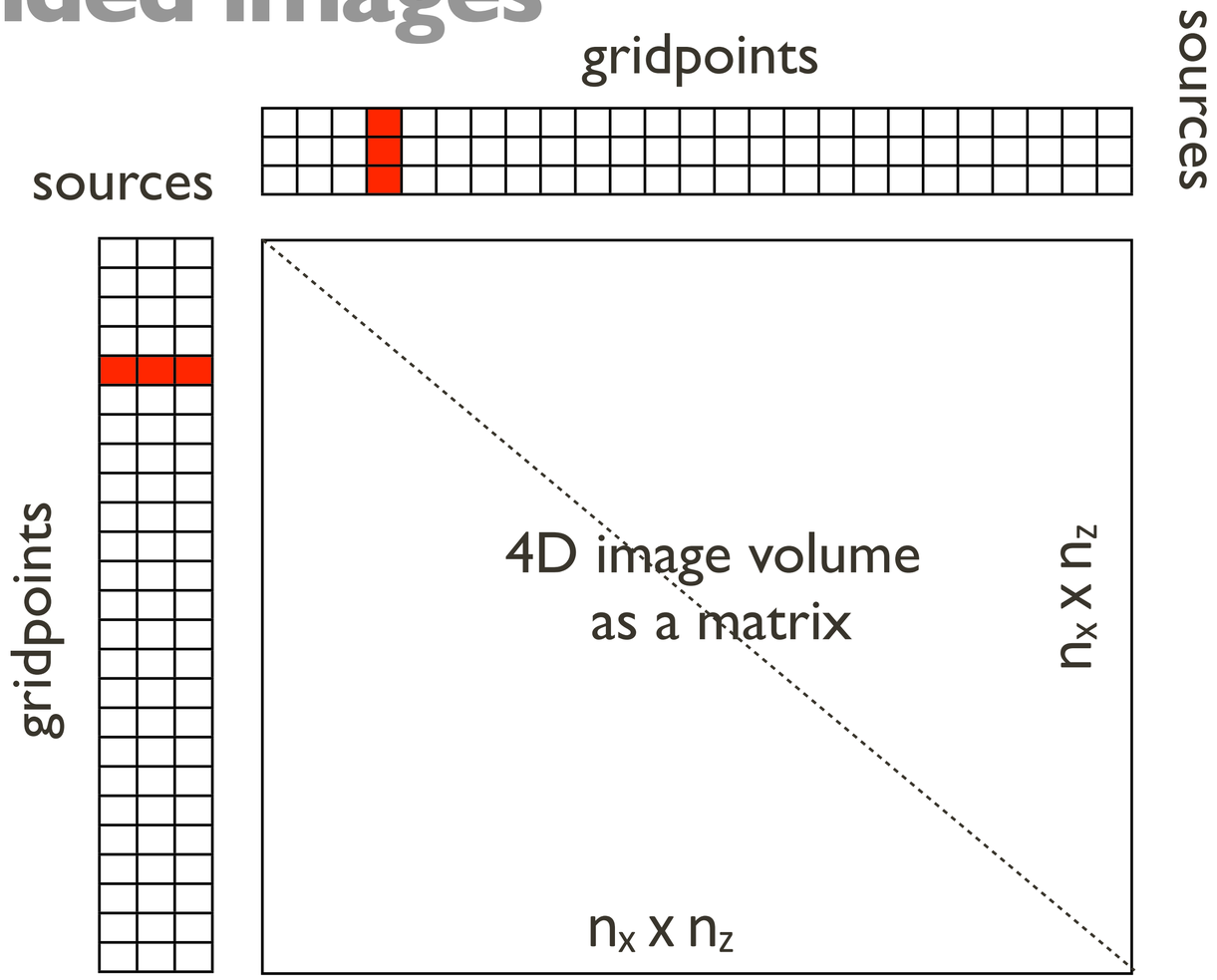


horizontal offset

horizontal +vertical offset

all offsets

Extended images



Computation

- *Complete* image volume too *large* to form: $(n_x \times n_z)^2$
- instead, *probe* volume for information via the action of a vector $E\mathbf{w}$
- $\mathbf{w}$ can be interpreted as subsurface (sim.) *source* function

Computation

- *mat-vec* with extended image :

$$\widetilde{E} = EW = H^{-1} P_s^T Q D^* P_r H^{-1} \mathbf{w}$$

- $\widetilde{\mathbf{d}} = P_r H^{-1} \mathbf{w}$ *(one subsurface source)*
- $\widetilde{\mathbf{y}} = Q D^* \widetilde{\mathbf{d}}$ *(surface source function)*
- $\widetilde{E} = H^{-1} P_s^T \widetilde{\mathbf{y}}$ *(one surface source)*

Computation

computation of an *image point gather*

	# of PDE solves	"flops for correlations"
conventional	$2N_s$	$N_s \times N_h$
ours	$2N_x$	$N_s \times N_r$

N_s - # of sources
N_r - # of receivers
N_h - # of subsurface offsets
N_x - # of sample points

Least-square extended imaging

$$\underset{\tilde{E}}{\text{minimize}} \quad \frac{1}{2}\|D - \mathcal{F}(\tilde{E})\|_F^2$$

where

$$\mathcal{F}(\tilde{E}) = P_r H^{-1} \widetilde{E} (Q^* P_s H^{-*} W)^*$$

How to incorporate the multiples

Linearized modeling with multiples

$$P \doteq \nabla \mathcal{F}_i[\mathrm{m}_0, Q_i - P_i]$$

$\nabla \mathcal{F}_i$: linearized modelling

m_0 : background model

$Q_i - P_i$: areal sources

Extended imaging with multiples

$$\widetilde{E} = EW = H^{-1} P_s^T (Q - P) P^* P_r H^{-1} W$$

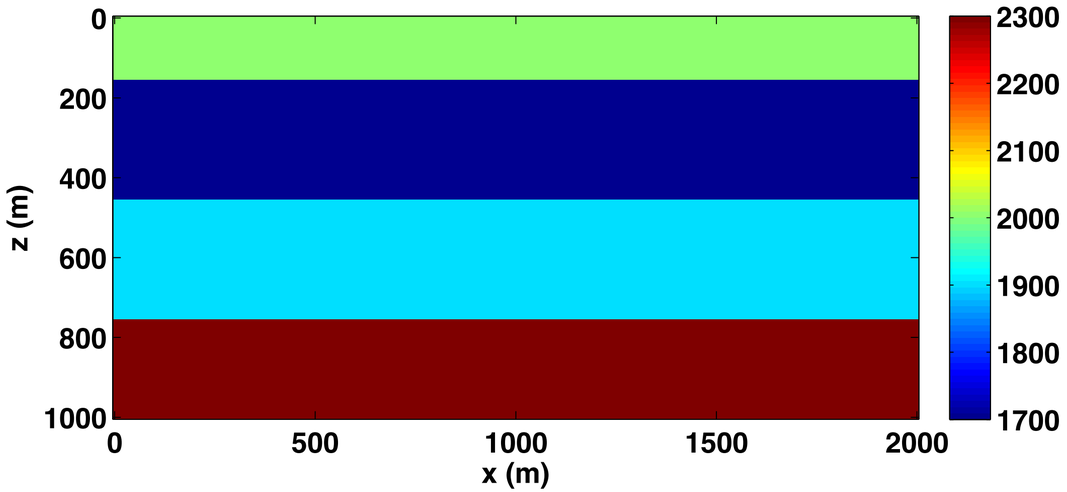
where

$(Q - P)$: areal source

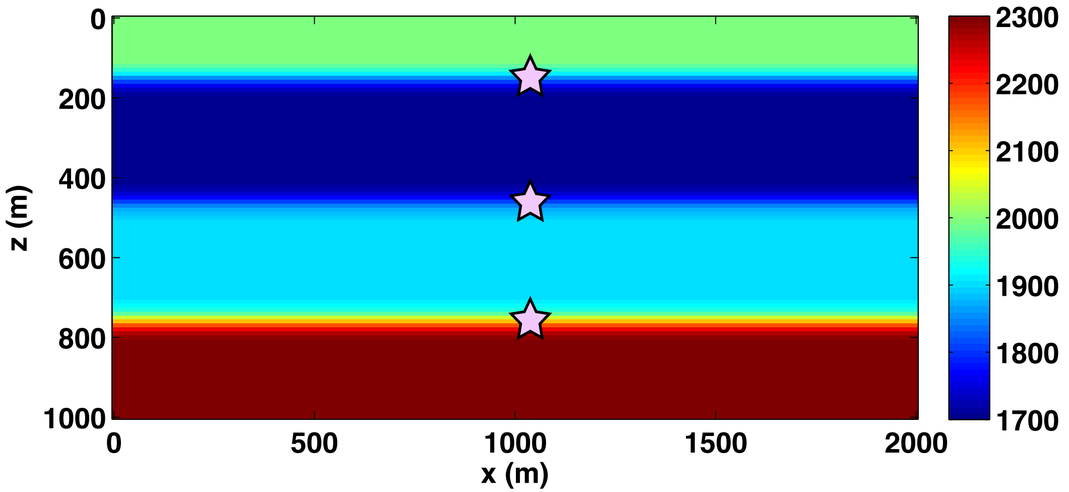
P : total upgoing wavefield

Experimental Results

Velocity model

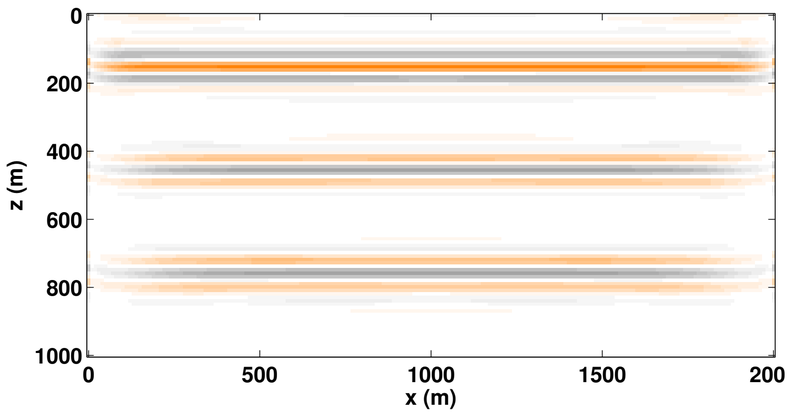


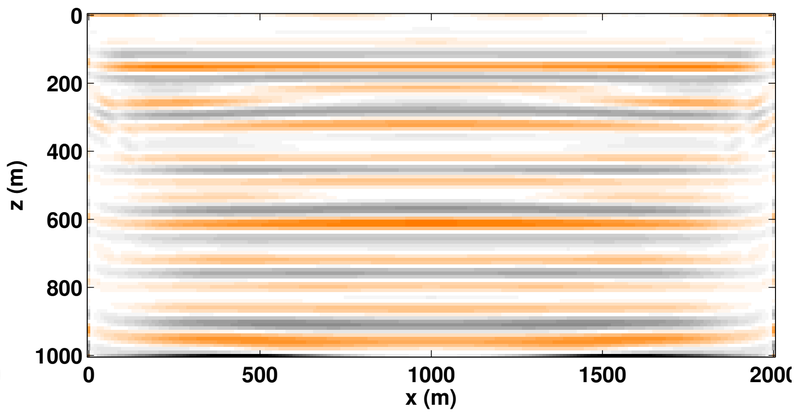
True model

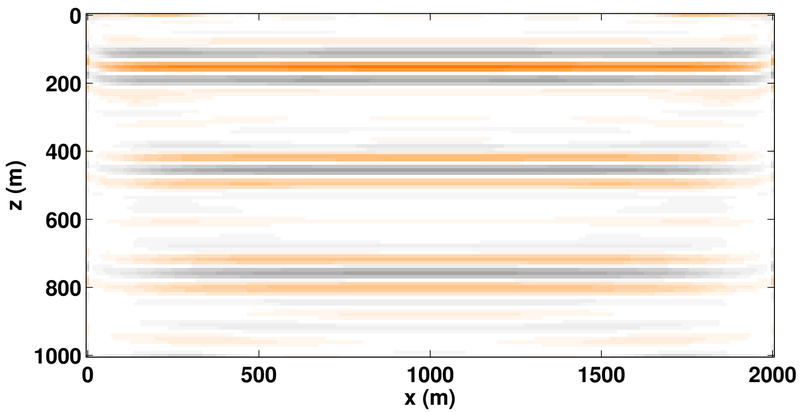


Initial model

Least-squares RTM images



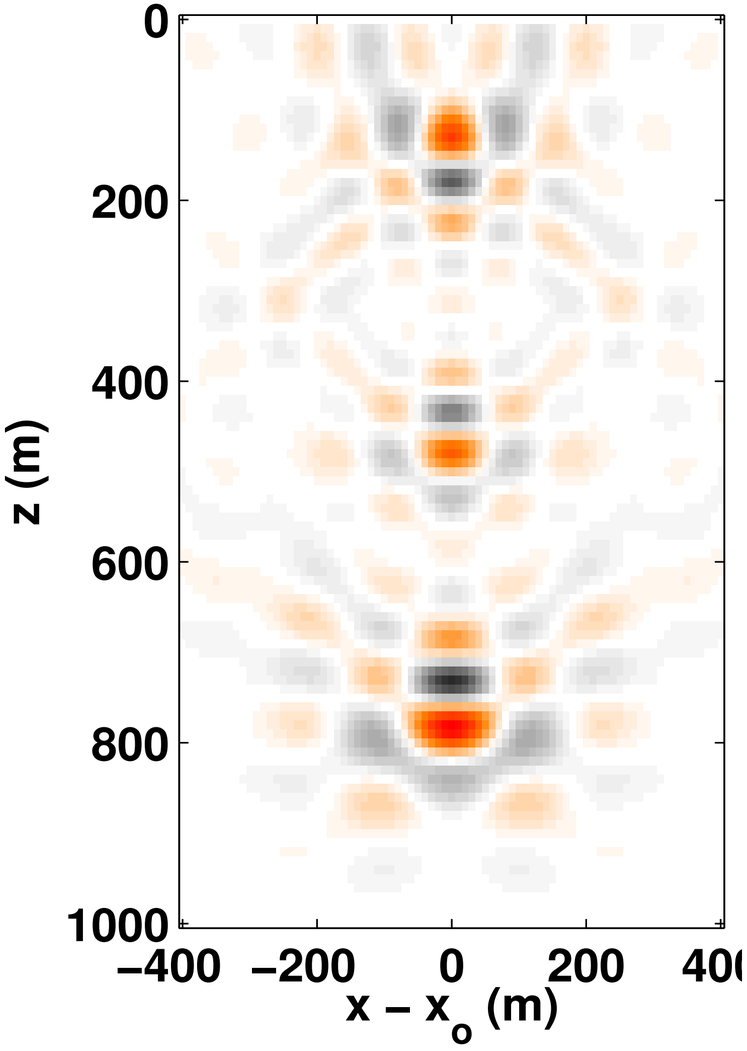




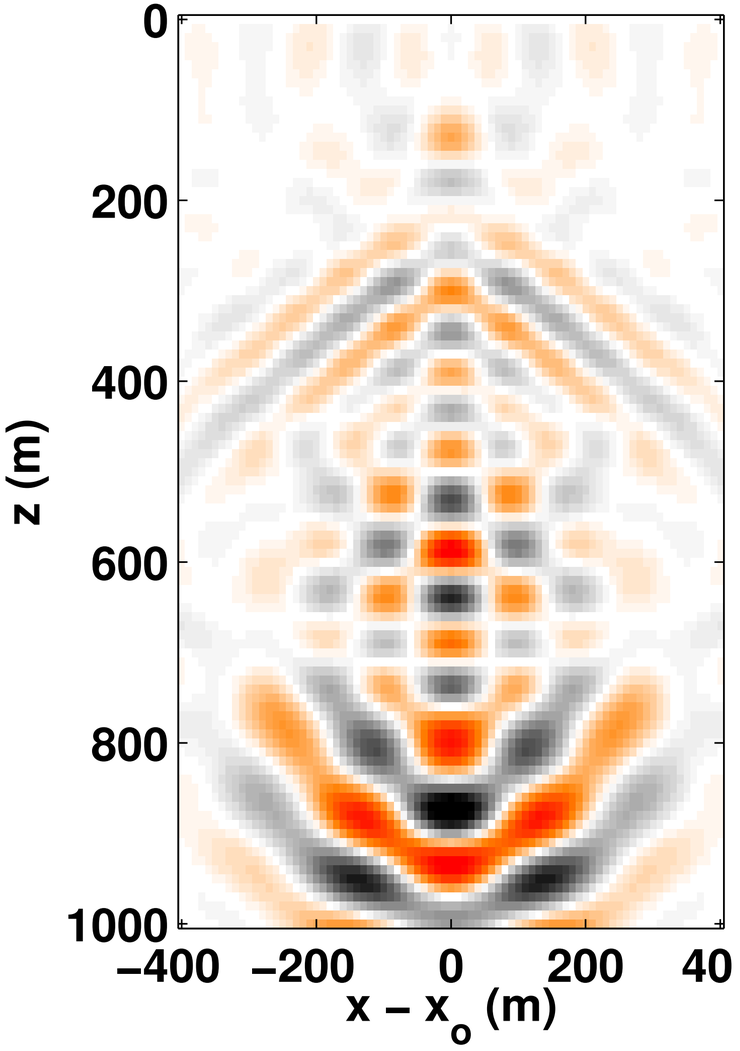
Primary only

Primary + multiples w/o areal sources

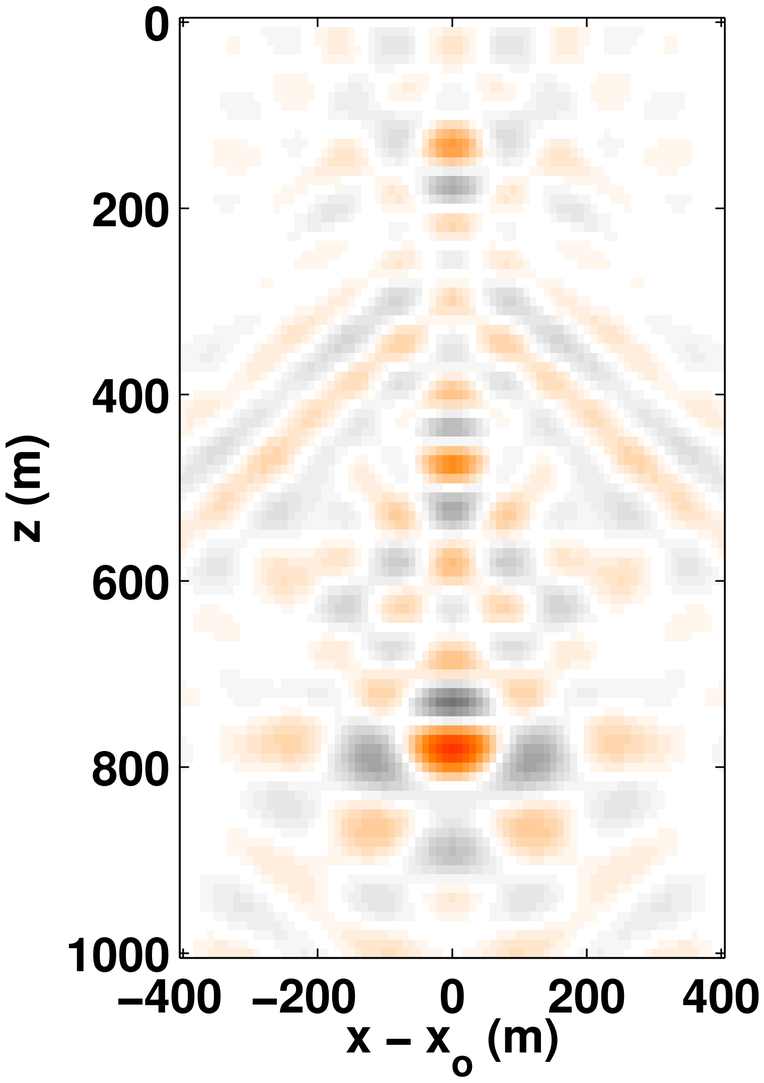
Primary + multiples with areal sources



Primary only



Primary + multiples
w/o areal sources



Primary + multiples
with areal sources

Conclusions

Multiples provide extra illumination that can complement primaries in least-squares seismic imaging.

Multiples can be used with primaries to form subsurface image gathers via least-squares inversion.

Future work

To find by case studies where the extra illumination from multiples can help extended imaging.

To incorporate the proposed method into migration velocity analysis.

Acknowledgements

Thank you for your attention !

This work was in part financially supported by the Natural Sciences and Engineering Research Council of Canada Discovery Grant (22R81254) and the Collaborative Research and Development Grant DNOISE II (375142-08). This research was carried out as part of the SINBAD II project with support from the following organizations: BG Group, BGP, CGG, Chevron, ConocoPhillips, ION, Petrobras, PGS, Statoil, Total SA, Sub Salt Solutions, WesternGeco, and Woodside.

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