Extended images in *action*

image gather with surface-related multiples

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Why need image gathers ?

- Effective velocity analysis tool

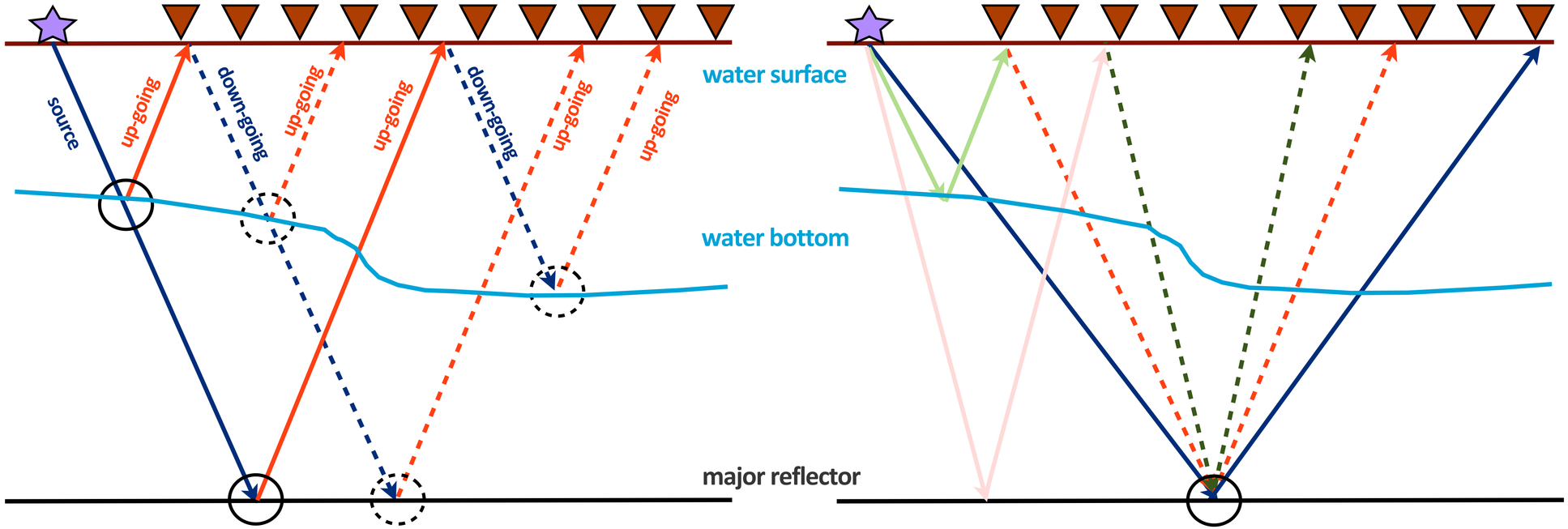
- *Full*-subsurface *offset* volumes allow us to conduct
  - AVA using information from *all* offset directions.
  - geological dip corrections

Requirement's

- Primaries only **Kumar et. al. '14**
  - limited by subsurface illumination

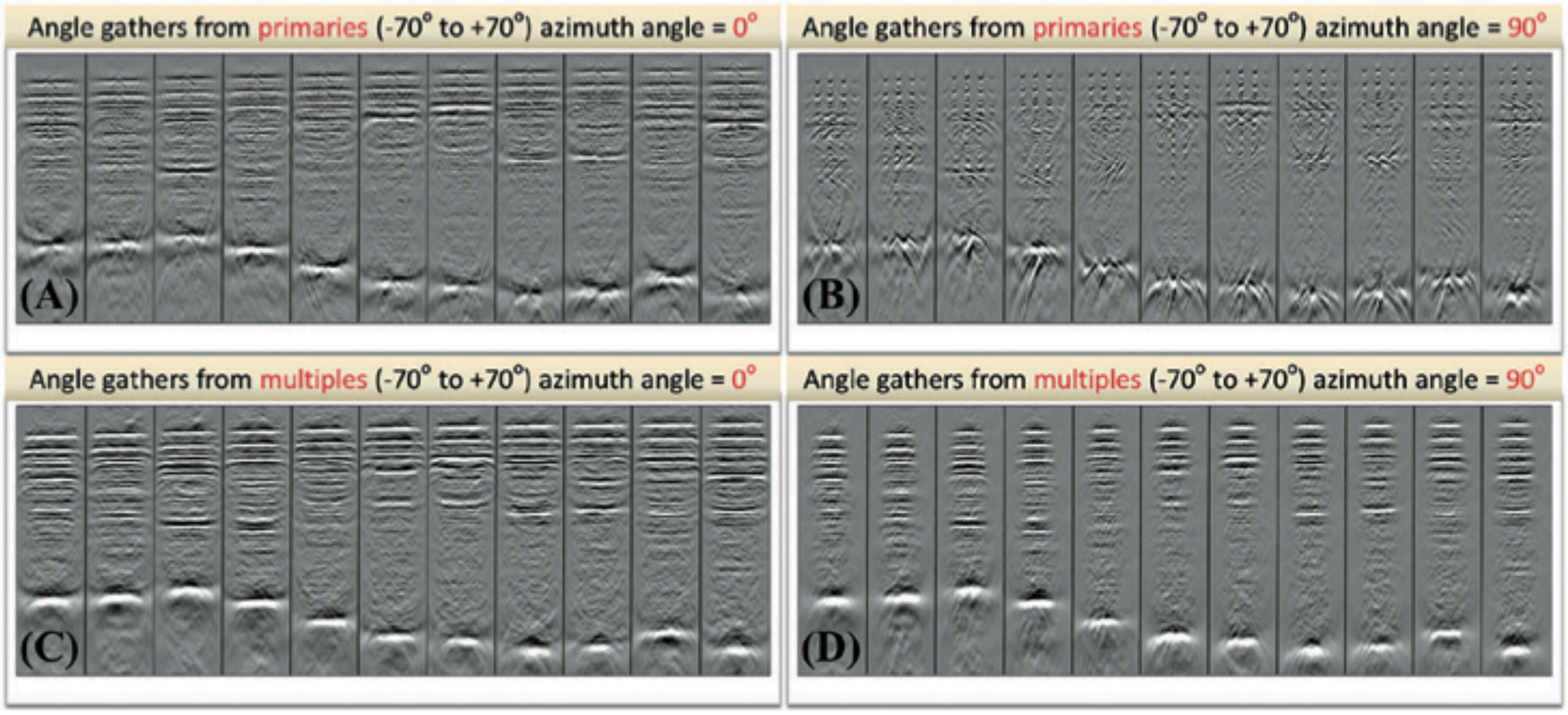
- Multiples only **Lu et. al. '14**
  - wider illumination of subsurface
  - cumbersome process

Why need multiples ?



Lu et. al. '14

Image gathers w/ multiples



Impediments

- *"Sloppy"* – ad hoc processing (move-out / dip filtering)
  - not accurate

- *Accurate* – model driven (SRME, EPSI)
  - computationally expensive

Motivation

- *Leverage benefits of SRME*
  - perform multi-dimensional convolution within imaging condition

- *All in one go* method

Quick recap

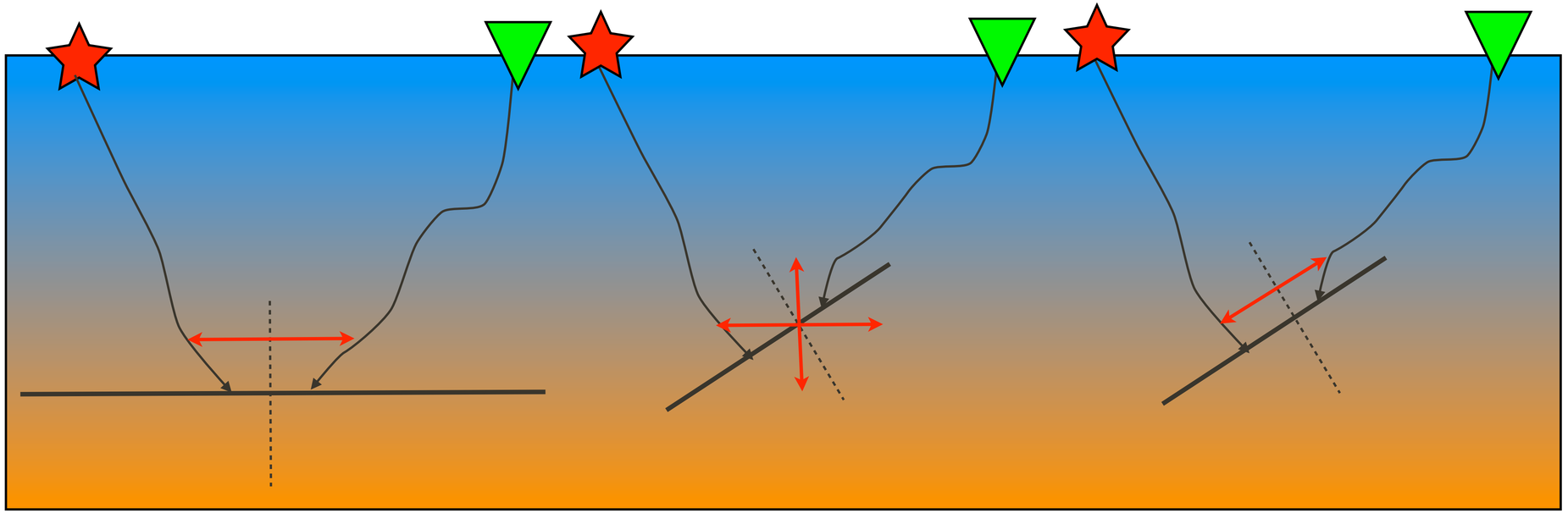
$$e(\omega, \mathbf{x}, \mathbf{x}') = \sum_i u_i(\omega, \mathbf{x}) v_i(\omega, \mathbf{x}')^*$$

- Organize wavefields in monochromatic data matrices [Berkhout, 84]

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

$$E = UV^*$$

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

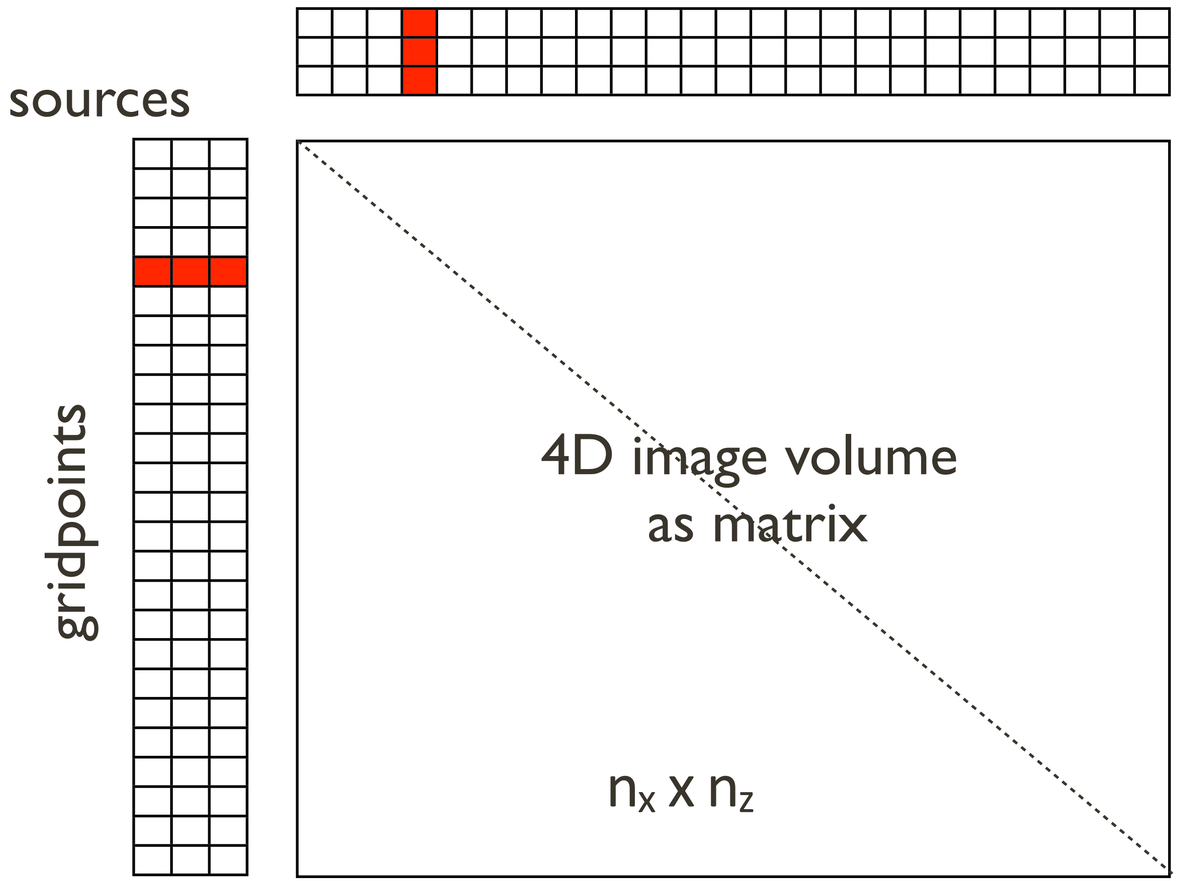


horizontal offset

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 *mat-vecs* $E\mathbf{w}$ VAN LEEUWEN 2012

- $\mathbf{w}$ can be interpreted as subsurface (sim.) *source* function

Computation

- *mat-vec* with extended image :

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

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

Computation

computation of an *image point gathe*

	# of PDE solves	"flops for correlations"
conventional	$2N_s$	N_s x N_h
mat-vecs	$2N_x$	N_s x N_r

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

How to incorporate the multiples

Linearized modeling
w\ 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 source array

Extended imaging
w\ 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

Least-square extended imaging

w\ multiples

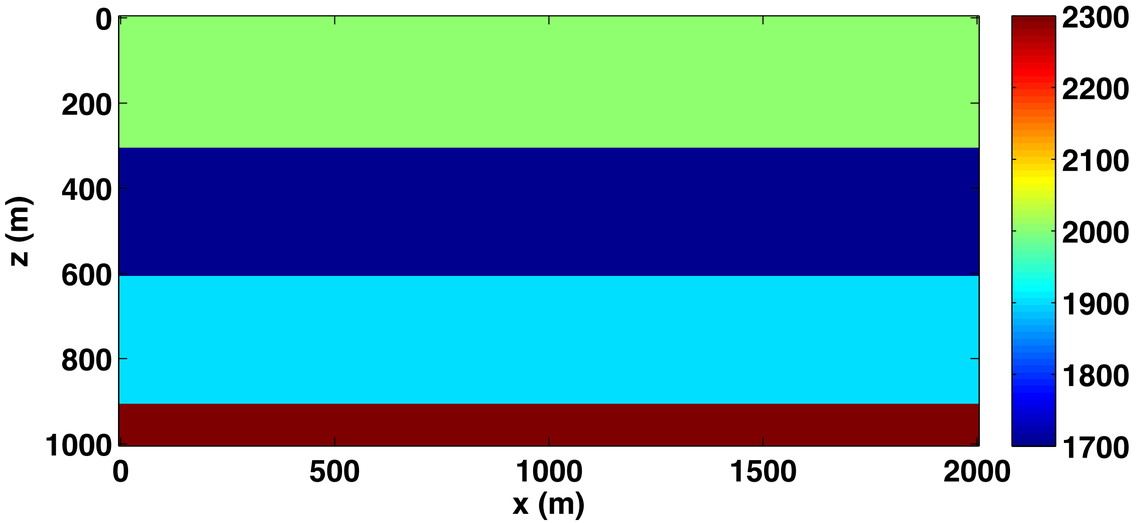
$$\underset{\tilde{E}}{\text{minimize}} \quad \frac{1}{2}\|P - \mathcal{F}(\tilde{E})\|_F^2$$

where

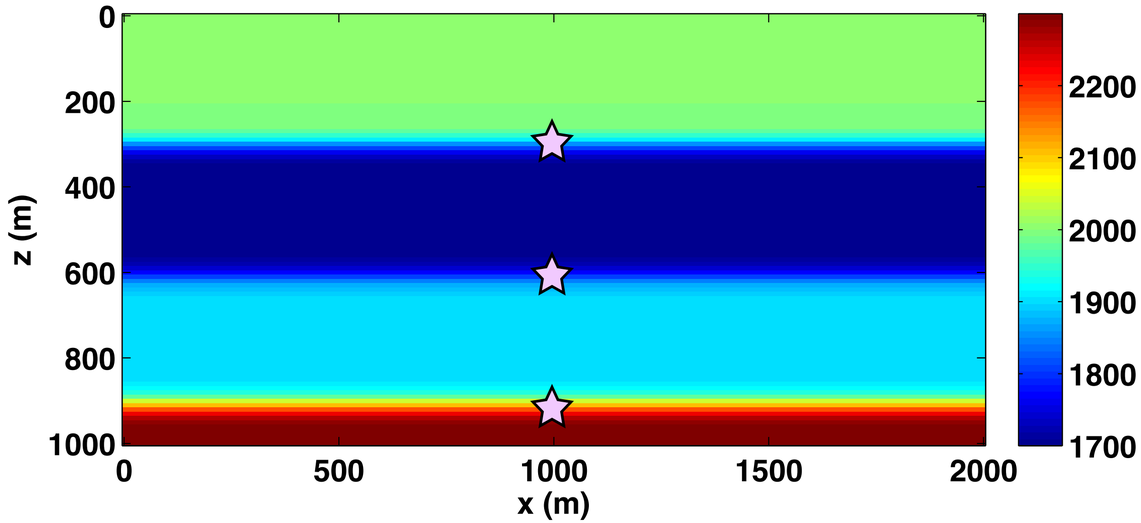
$$\mathcal{F}(\tilde{E}) = P_r H^{-1} \widetilde{E}((Q - P)^* P_s H^{-*} W)^*$$

Experimental Results

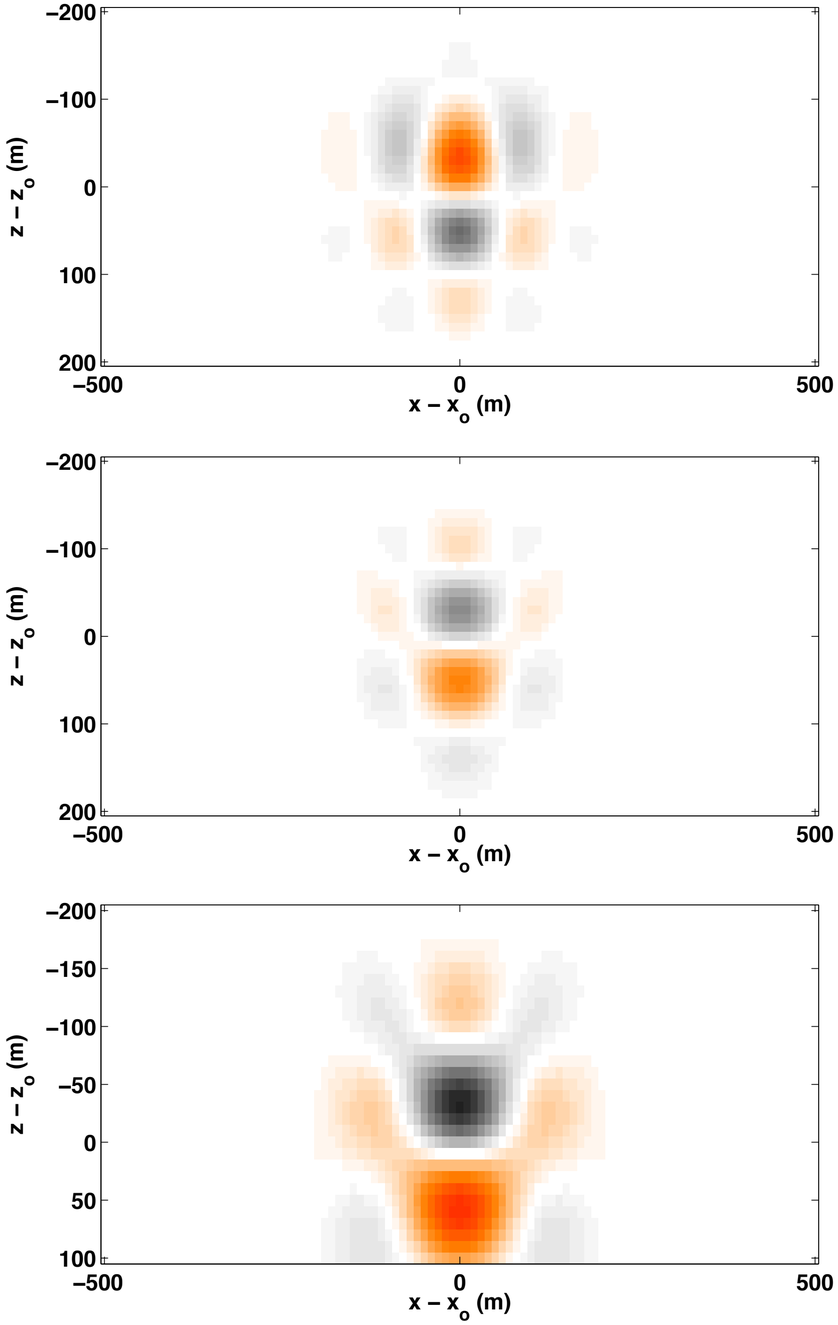
Velocity model



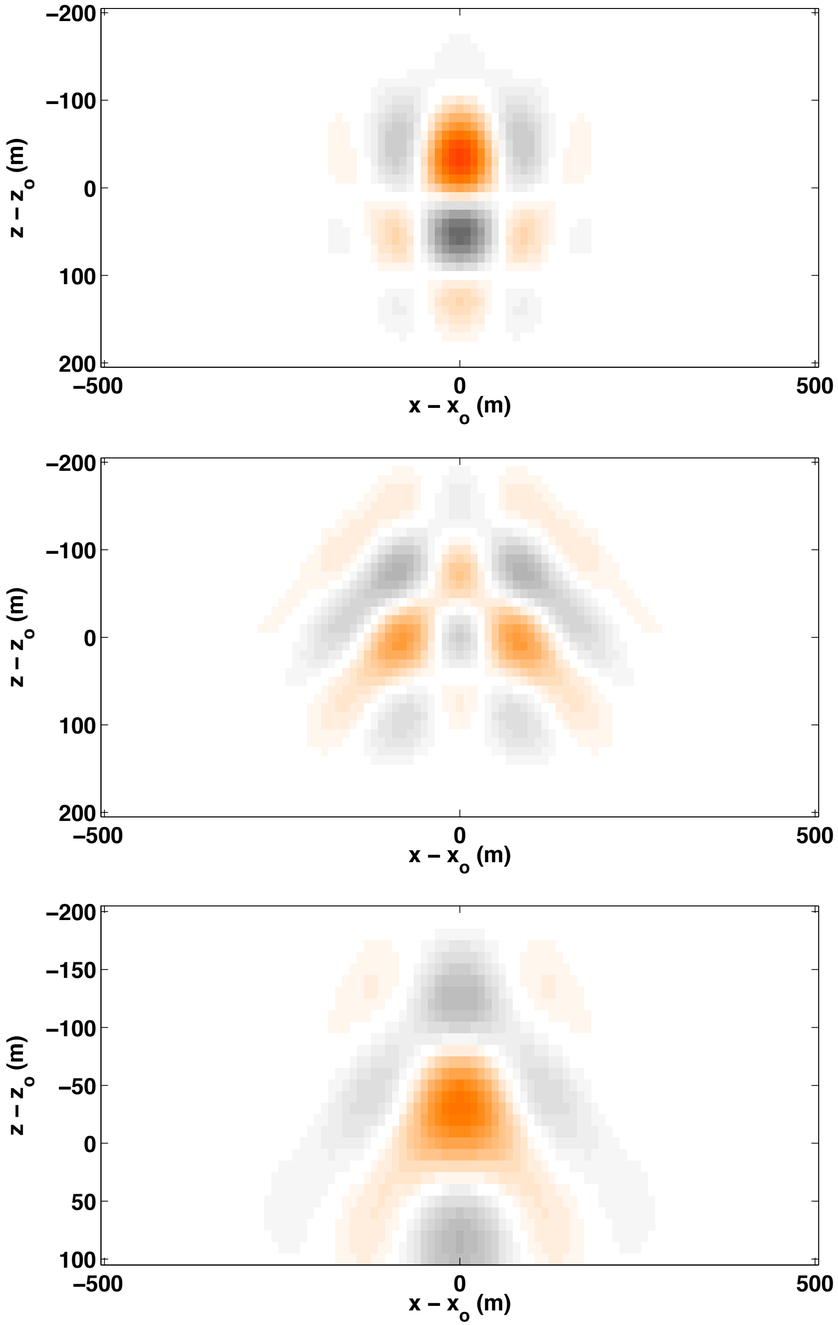
True model



Initial model

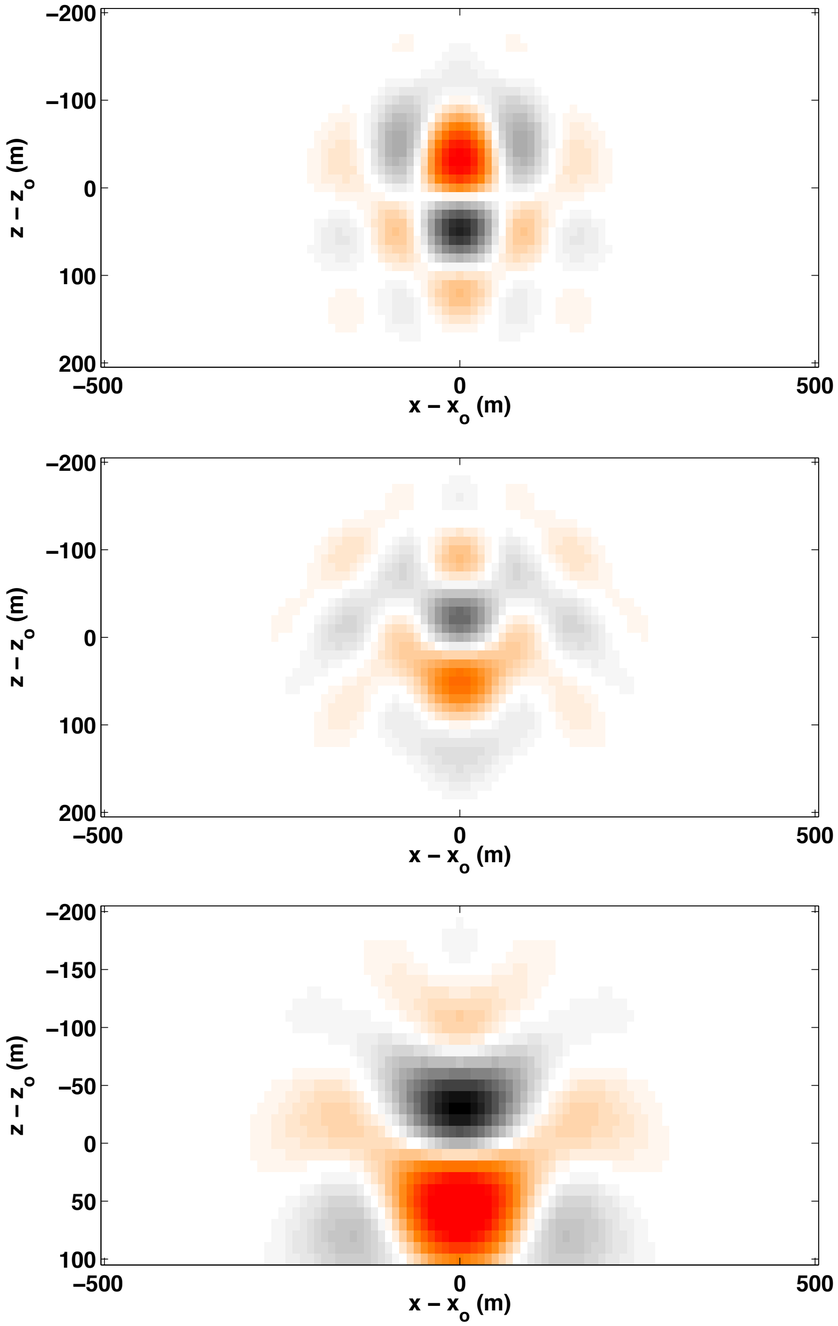


Primary only



Primary + Multiples

w/o areal source

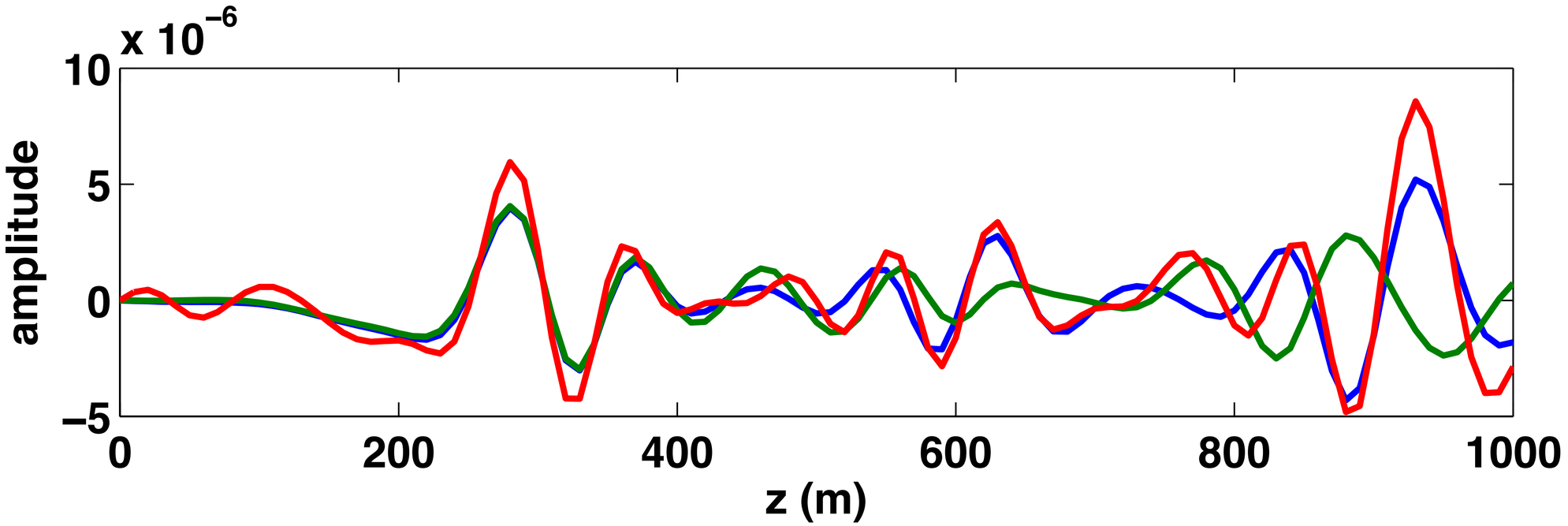


Primary + Multiples

w/ areal source

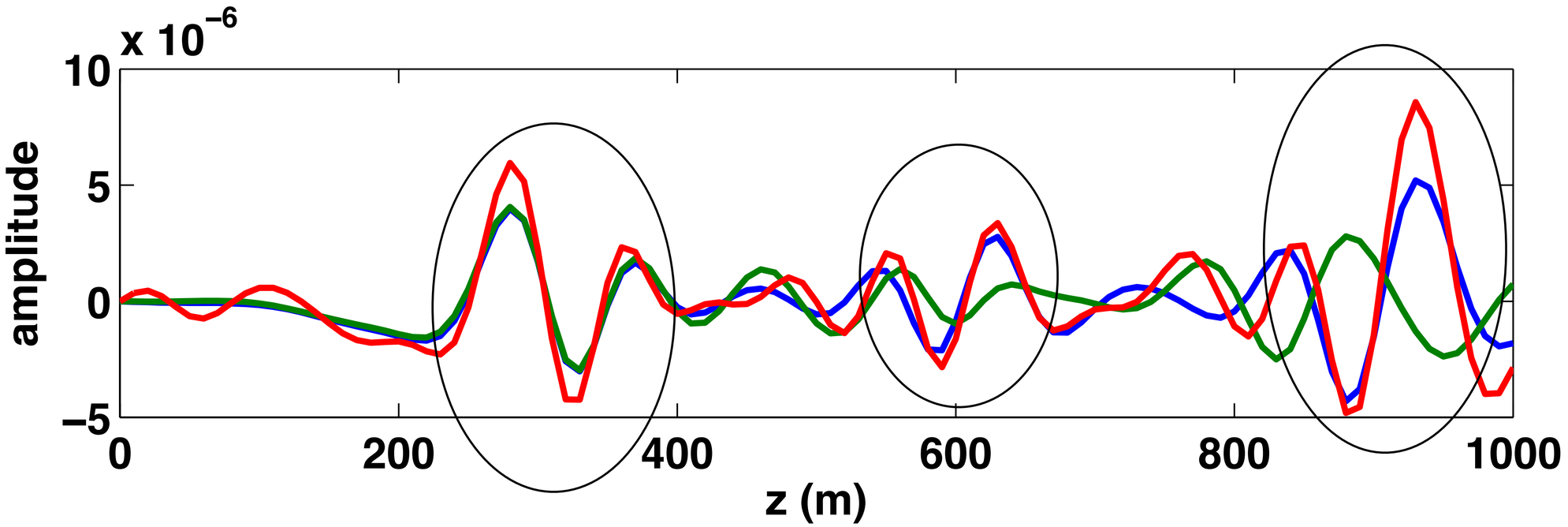
Vertical Trace

primaries only
primaries + multiple (w/o areal source)
primaries + multiple (w areal source)



Vertical Trace

primaries only
primaries + multiple (w/o areal source)
primaries + multiple (w areal source)



Conclusions

- Multiples illuminate the subsurface at larger azimuthal angle

- Provide extra degree of freedom to improve image-gathers

- Multiples should be use with primary to mitigate the acquisition related artifacts

Future Work

- Testing on real data set

- Incorporation of multiples in migration velocity analysis

Acknowledgements

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