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Imaging the Nelson data set using surface-related multiples

Ning Tu

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University of British Columbia

Field data example

- North Sea data set, courtesy of PGS
- water depth ~90m
- 100m missing near-offset, filled by Radon interpolation
- **dual-sensor** streamer data, **up / down decomposition** applied
- 401 co-located sources / receivers, 12.5m spacing
- data after 75Hz low-pass-filter to remove receiver aliasing
- imaging data up to 48Hz with a 6.25m grid spacing
- simulation cost of **fast inversion**s **~1 RTM** with all the data
- for comparisons, REPSI used to separate primaries / multiples

Caveat

Little knowledge about the geological setting of this data set was released to the speaker.

Field data may contain substantial 3D propagation effects (besides 3D amplitude).

Modelling / velocity errors are expected.

Sets of examples

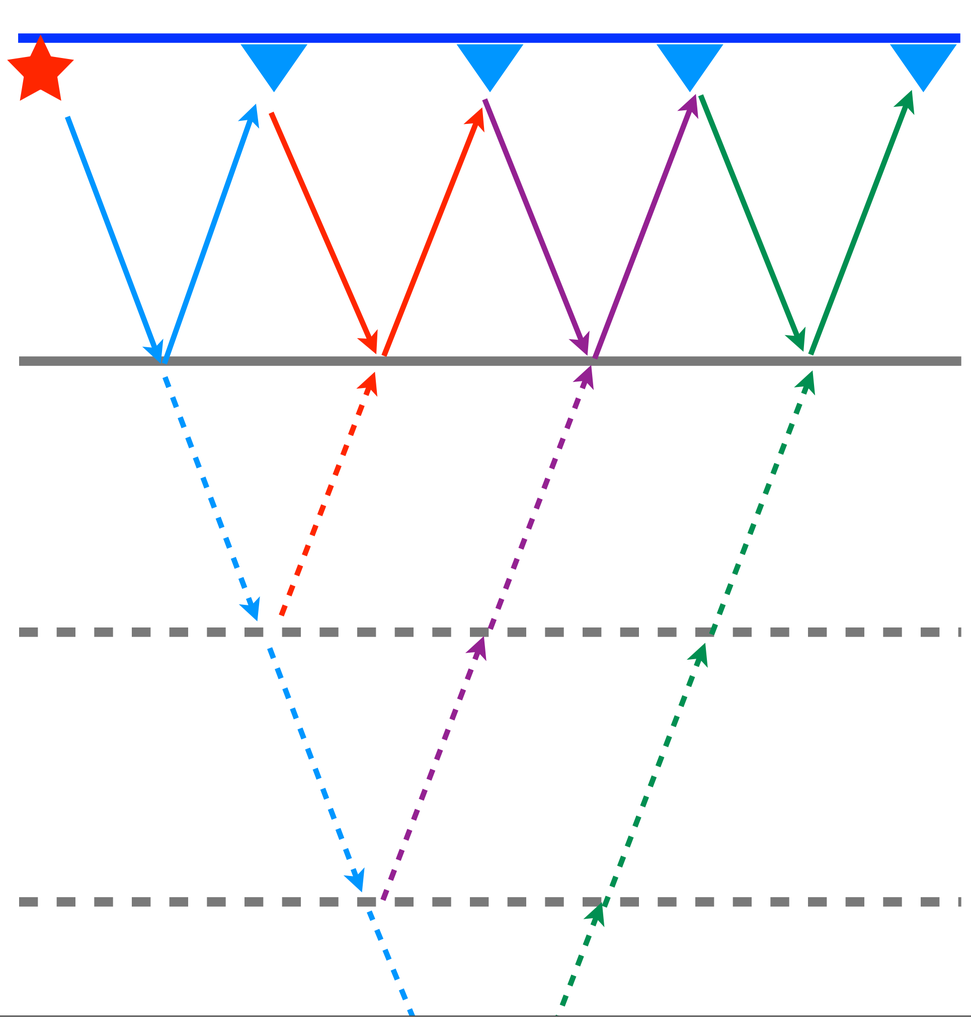
- turning multiples from noise to signal
- comparing images of multiples and primaries
- joint imaging of primaries and multiples

Turning multiples from noise to signal

We compare:

- *conventional* RTM of multiples
  - conventional RTM before and after de-multiple
  - compute the difference
- RTM of multiples, treating receivers as virtual sources
- fast inversion of multiples

Multiples in conventional RTM



Source wavefield:
point sources

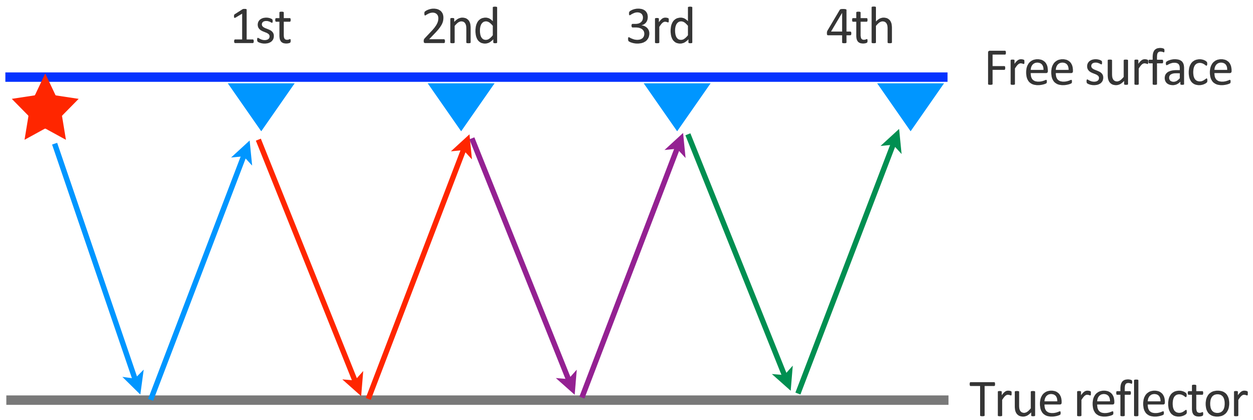
Receiver wavefield:
multiples

Turning multiples from noise to signal

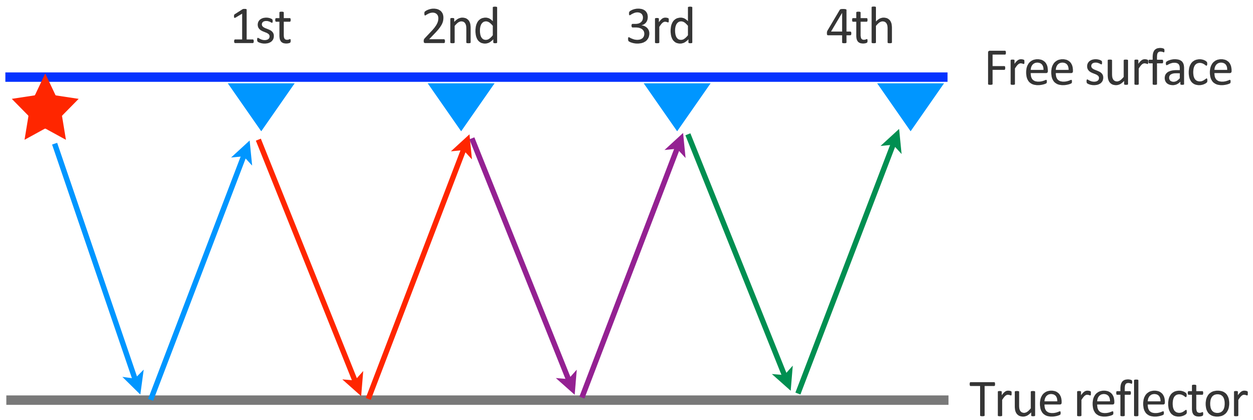
We compare:

- conventional RTM of multiples
- RTM of multiples, treating receivers as virtual sources
  - forward propagate total downgoing data
  - backward propagate multiples
- fast inversion of multiples

Treating receivers as virtual sources



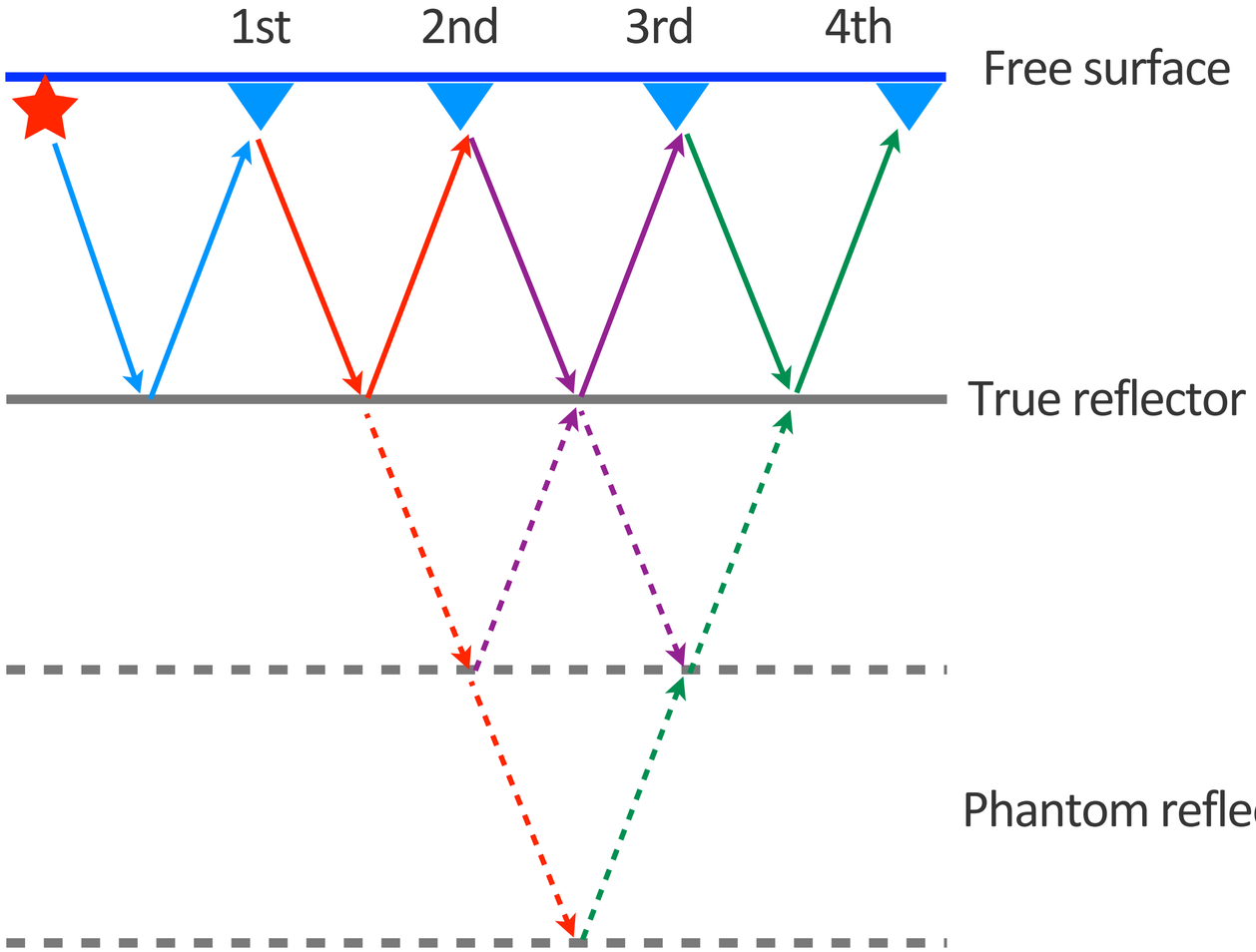
Treating receivers as virtual sources



Looks familiar? Remember the SRME relation?

$$\mathbf{P} = \mathbf{X}(\mathbf{Q} - \mathbf{P})$$

Cross-correlation imaging



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multiples

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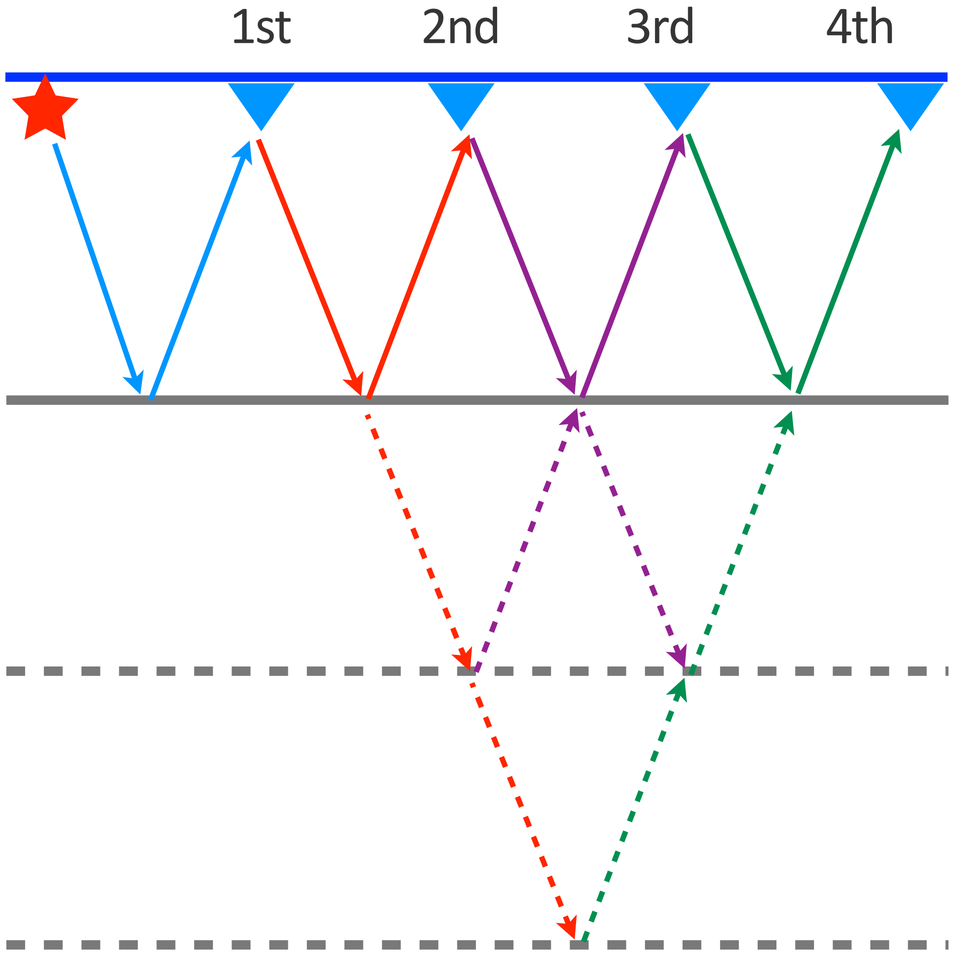
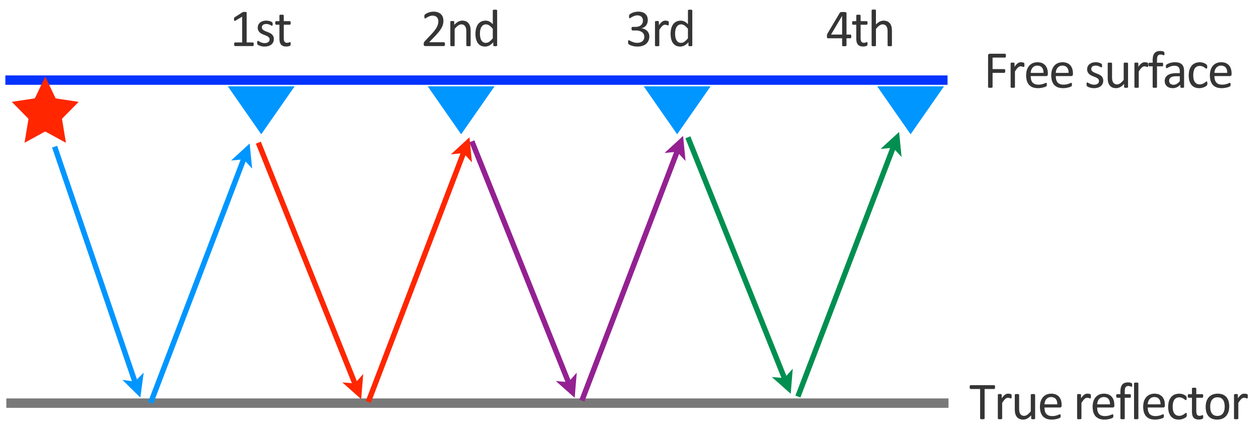


Source wavefield:
total downgoing data

Receiver wavefield:
multiples

Inversion of multiples



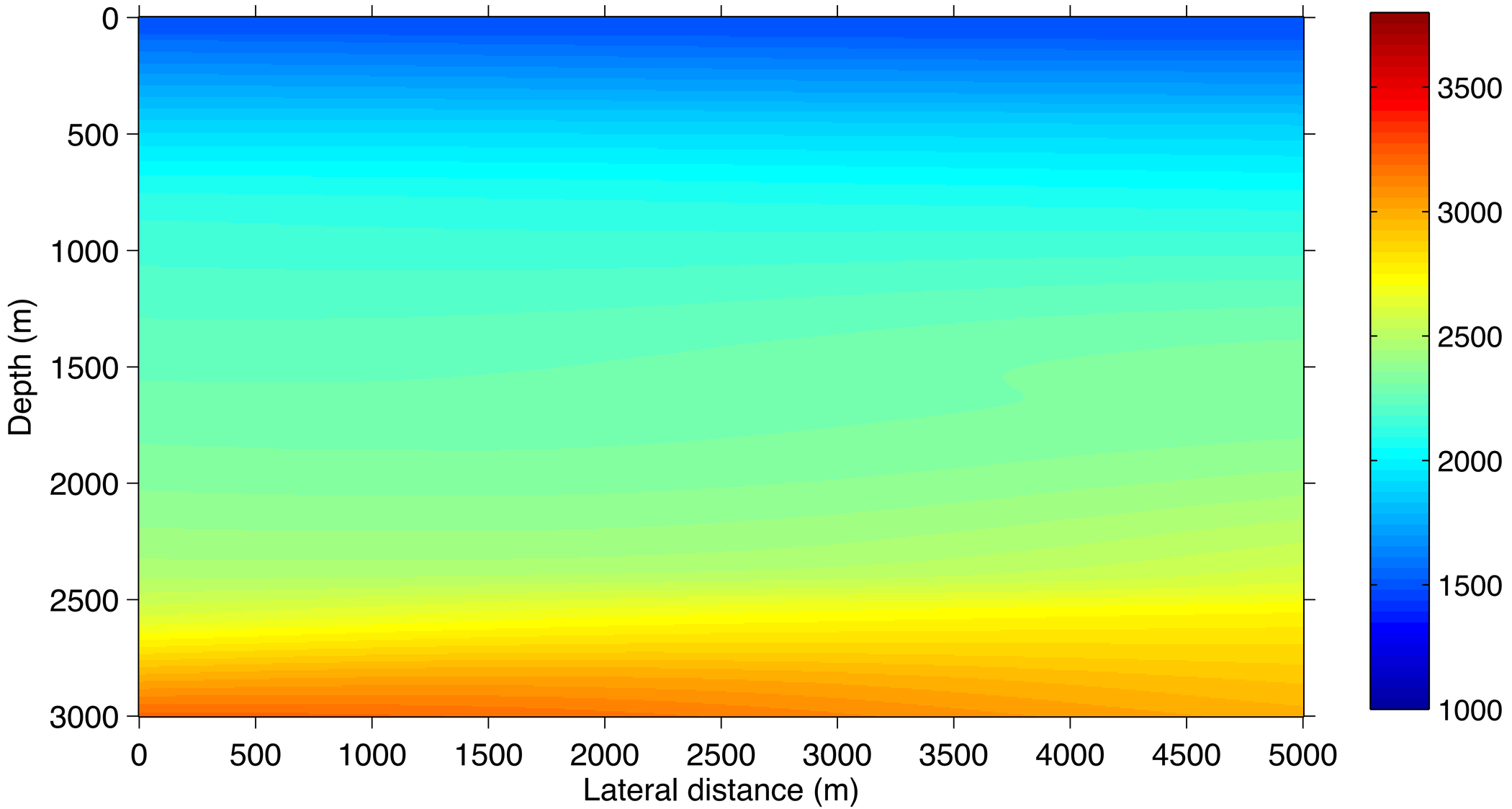
Source wavefield:

total downgoing data

Receiver wavefield:

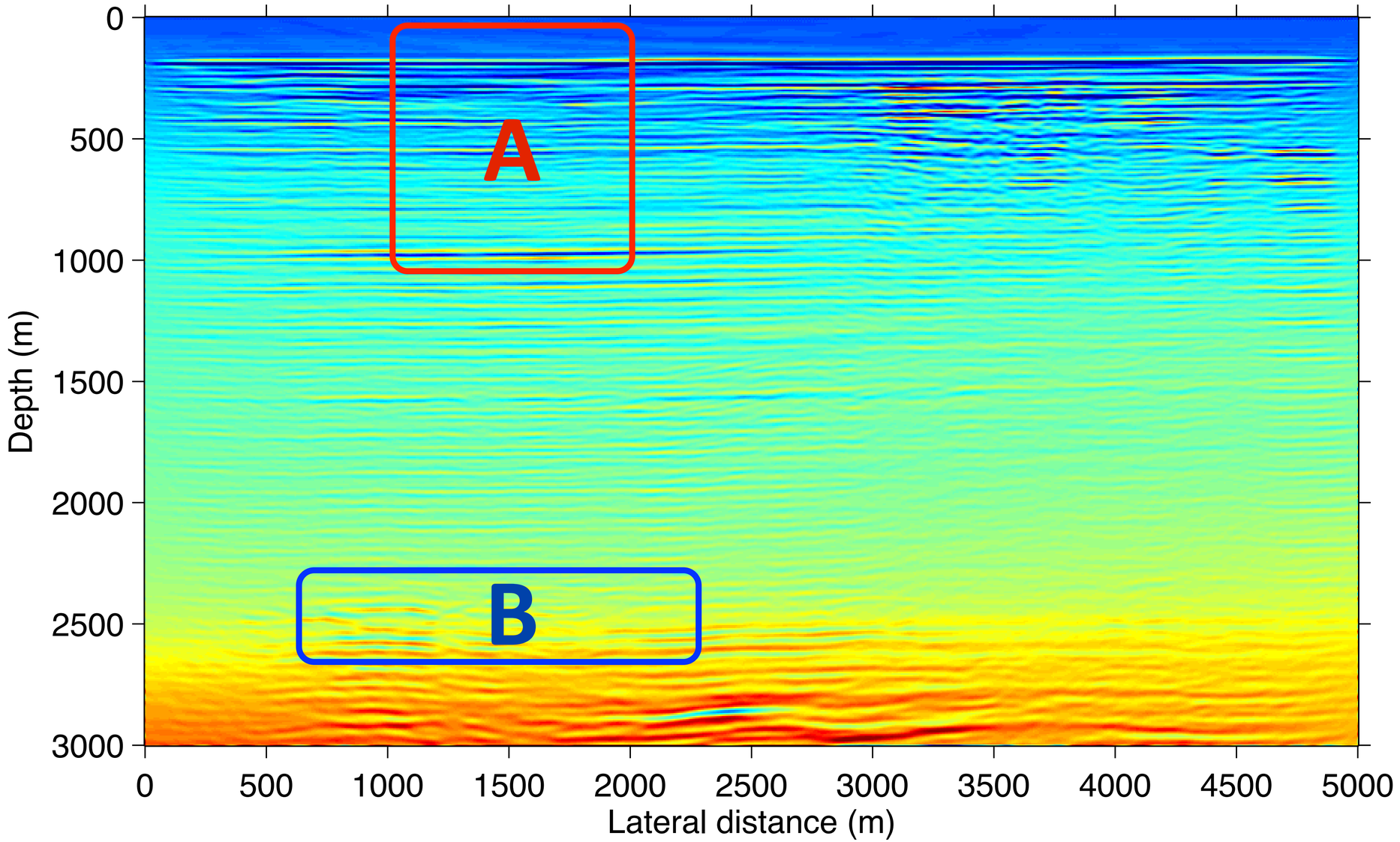
multiples

Background model

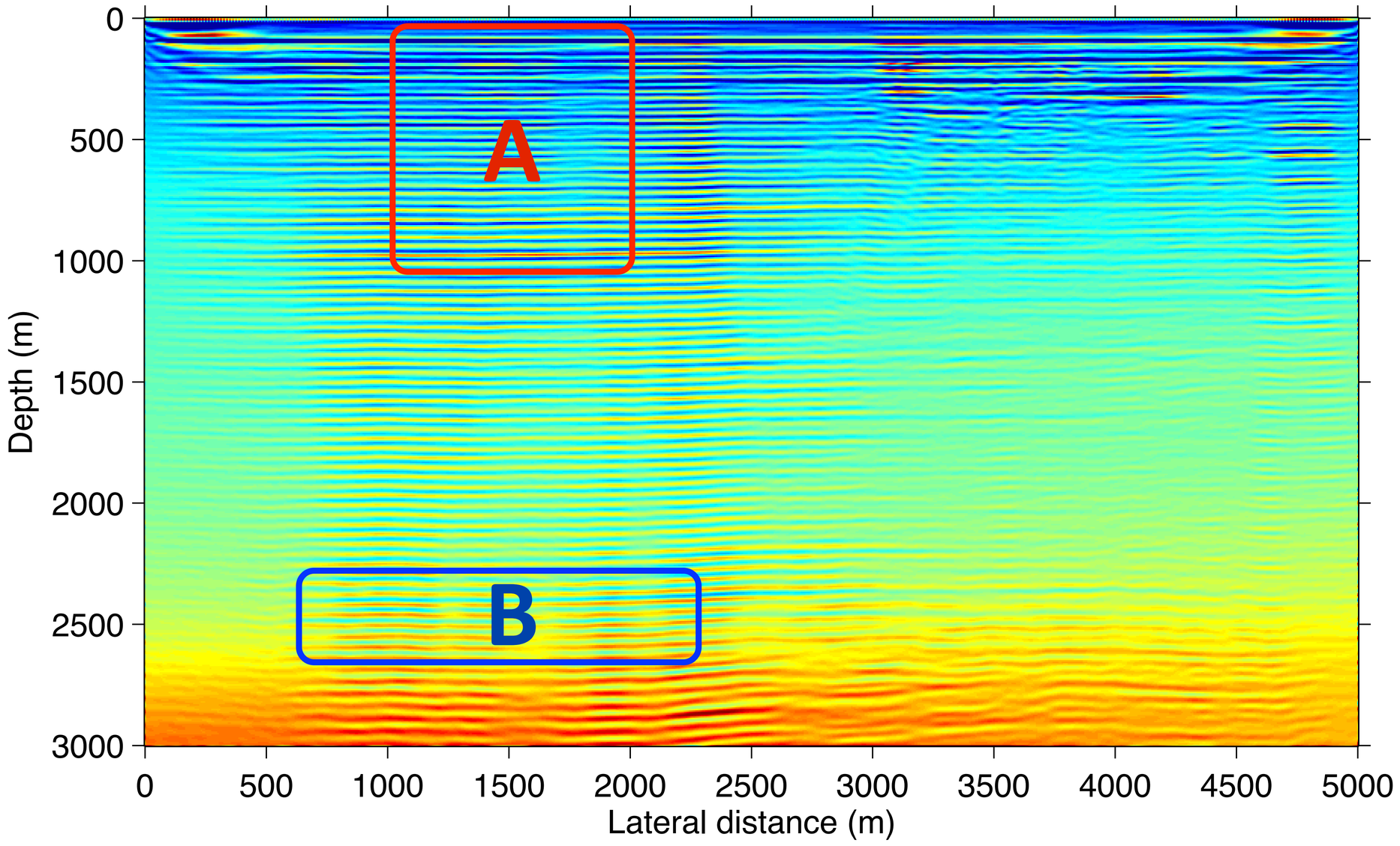


Conventional RTM of multiples

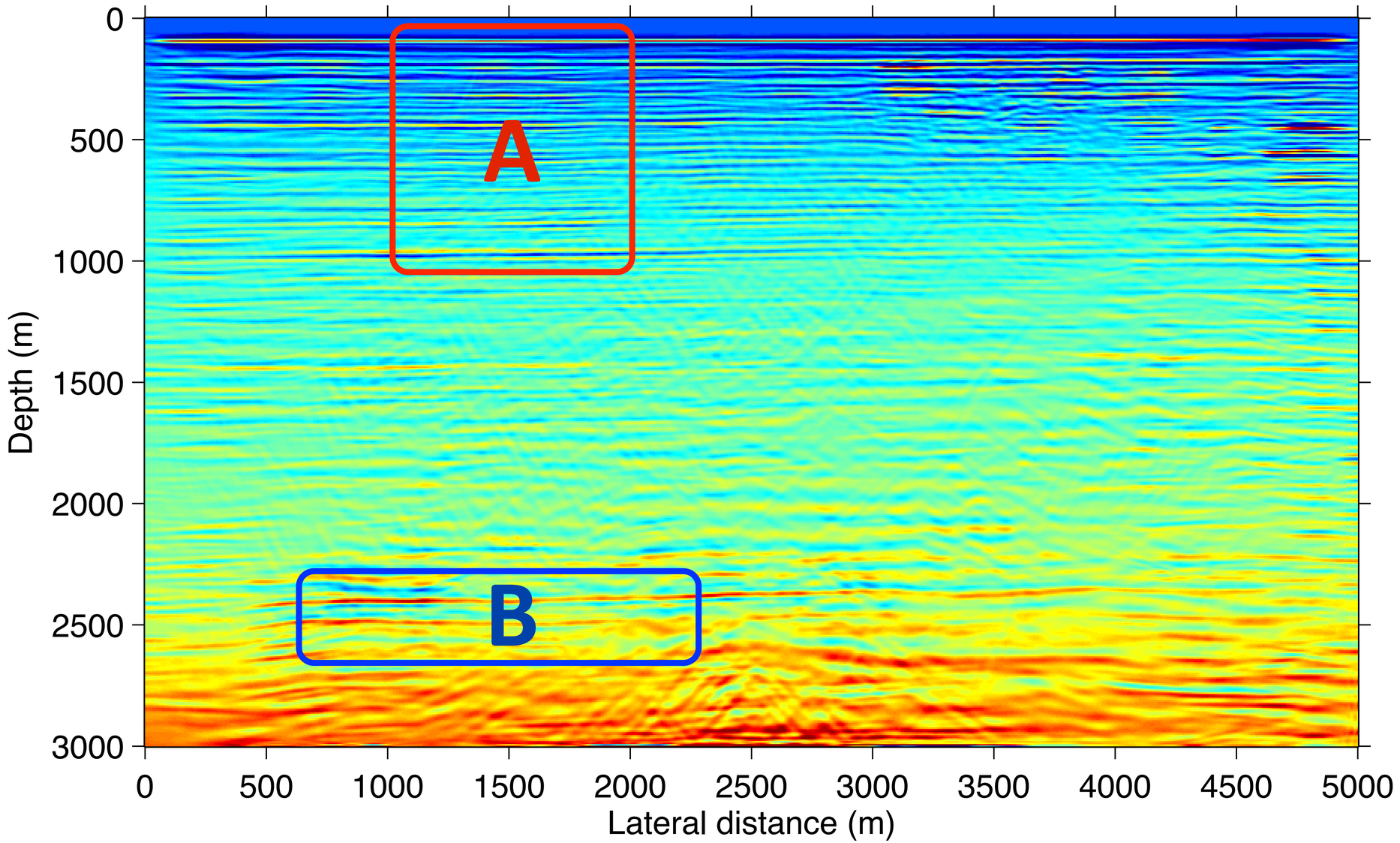
[source wavelet estimated by REPSI]



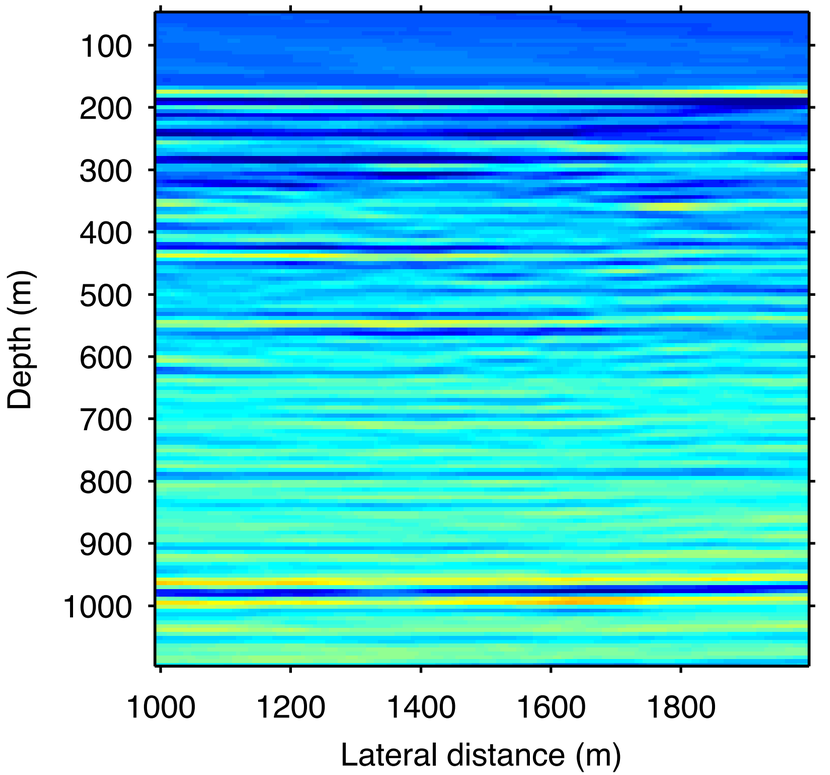
RTM of multiples using receivers as virtual sources



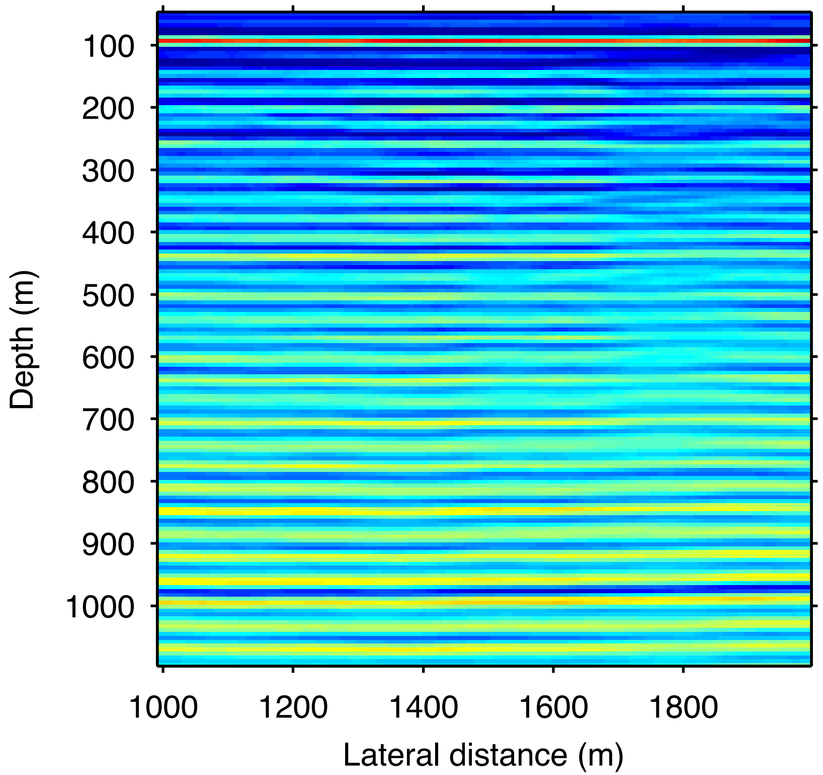
Inversion of multiples using receivers as virtual sources



Section A: zoomed in



Conventional RTM



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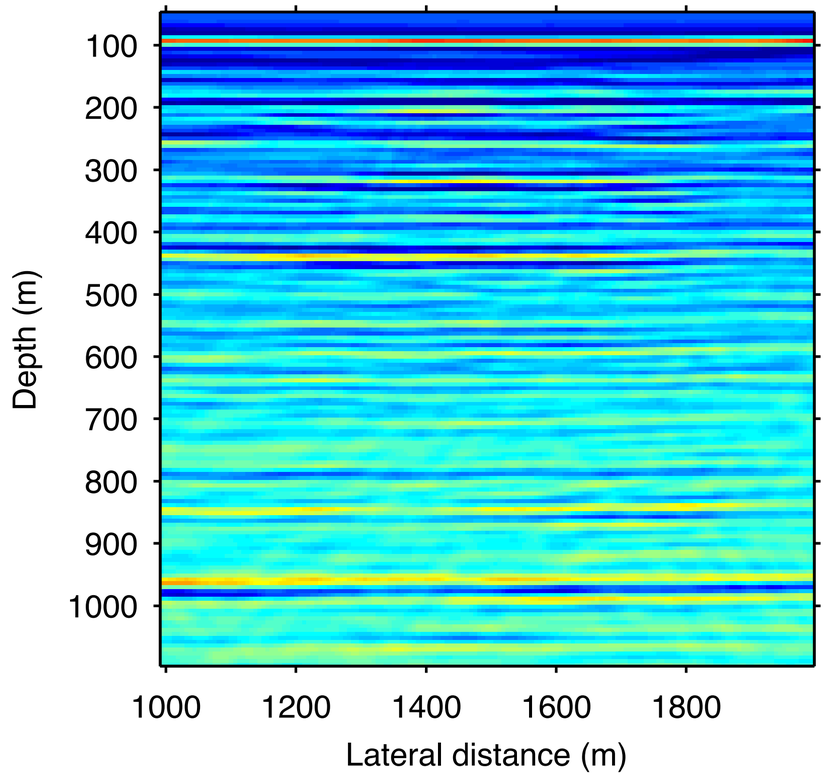

Inversion of multiples

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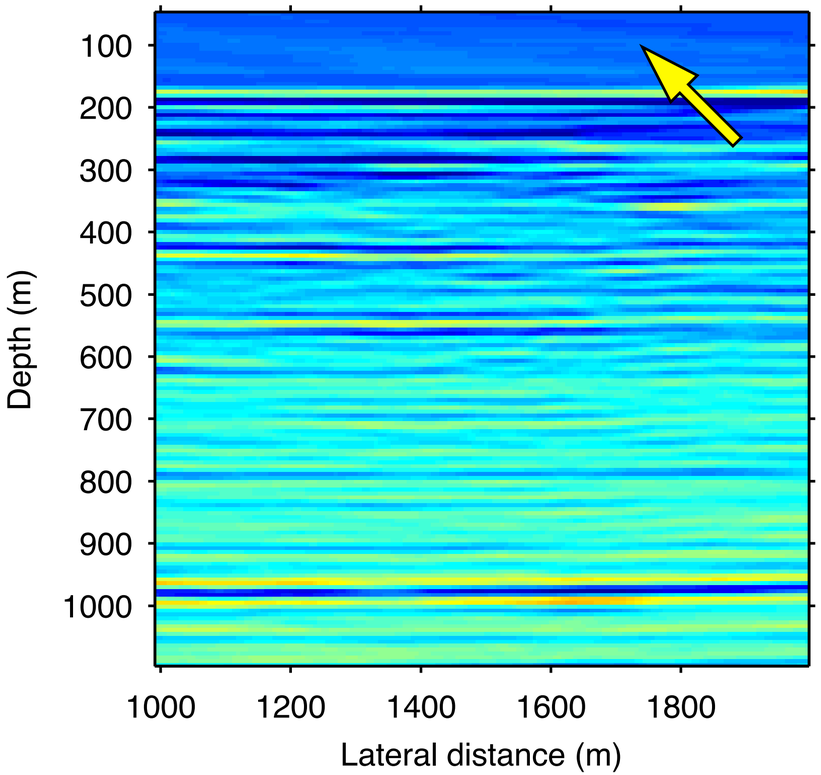
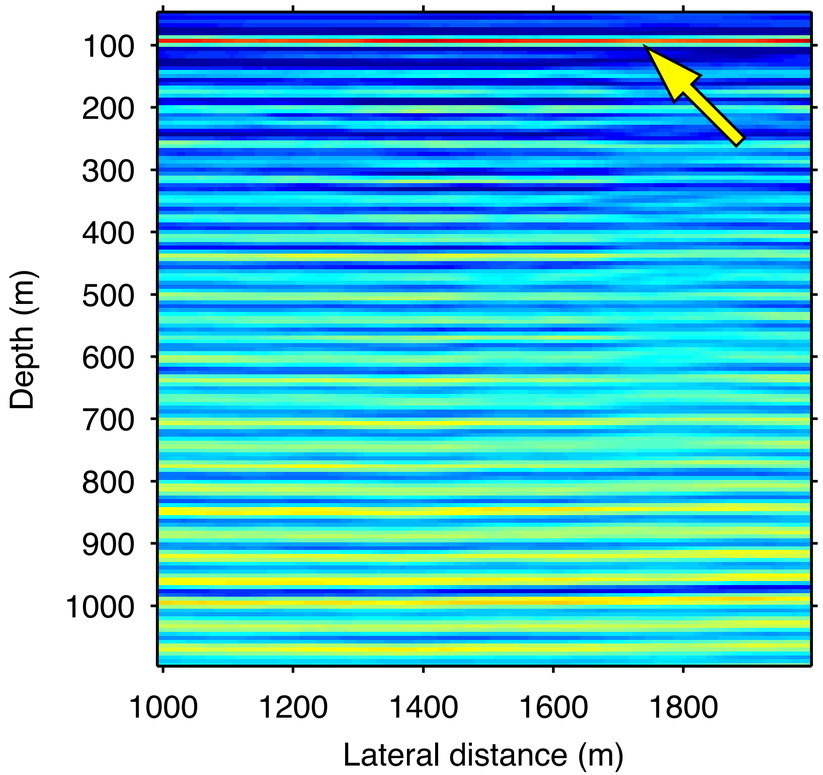
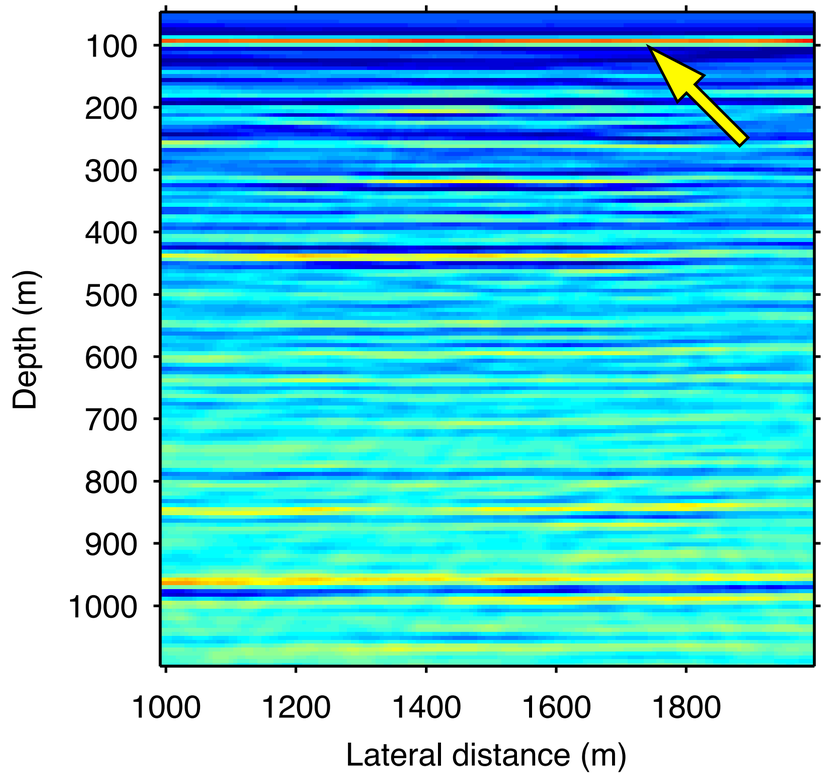


Conventional RTM



RTM of multiples



Inversion of multiples

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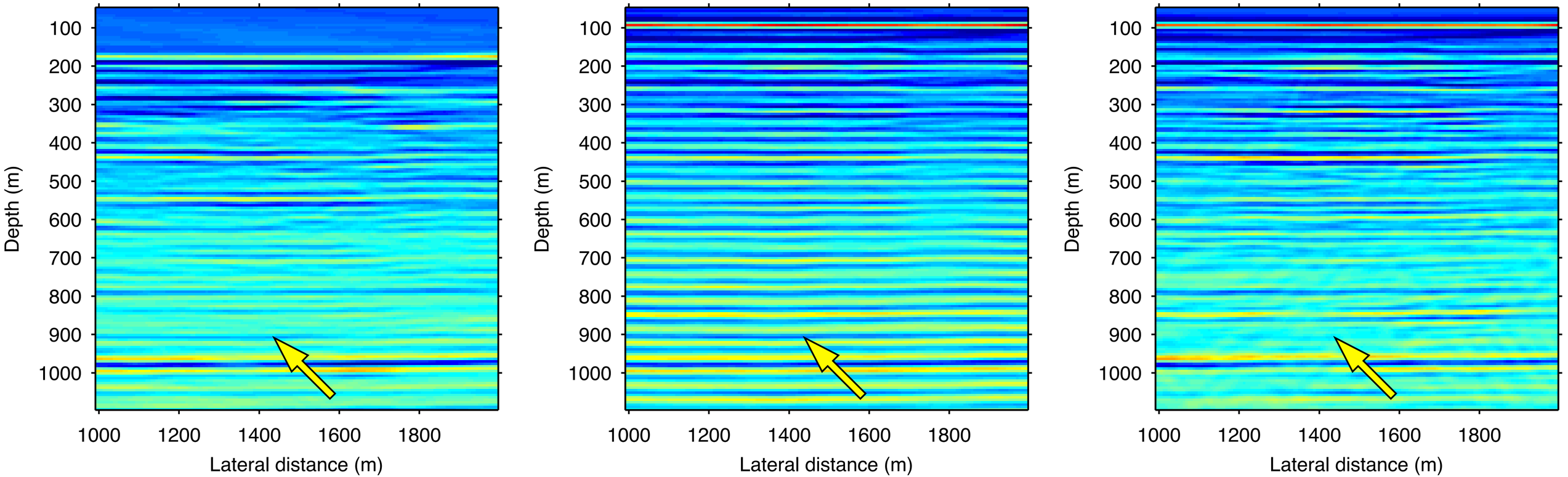

Conventional RTM

RTM of multiples

Inversion of multiples

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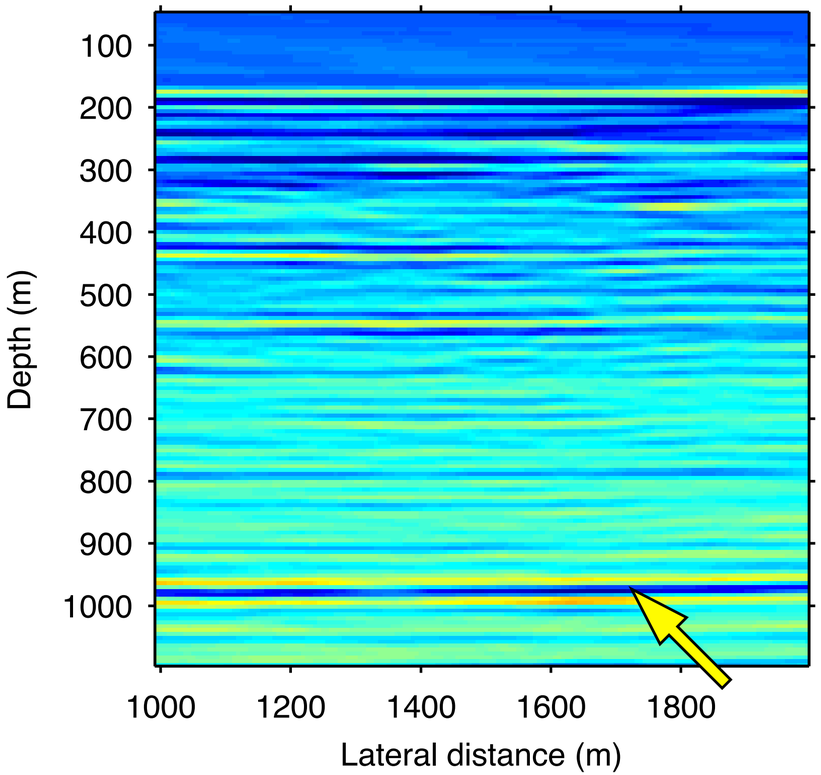

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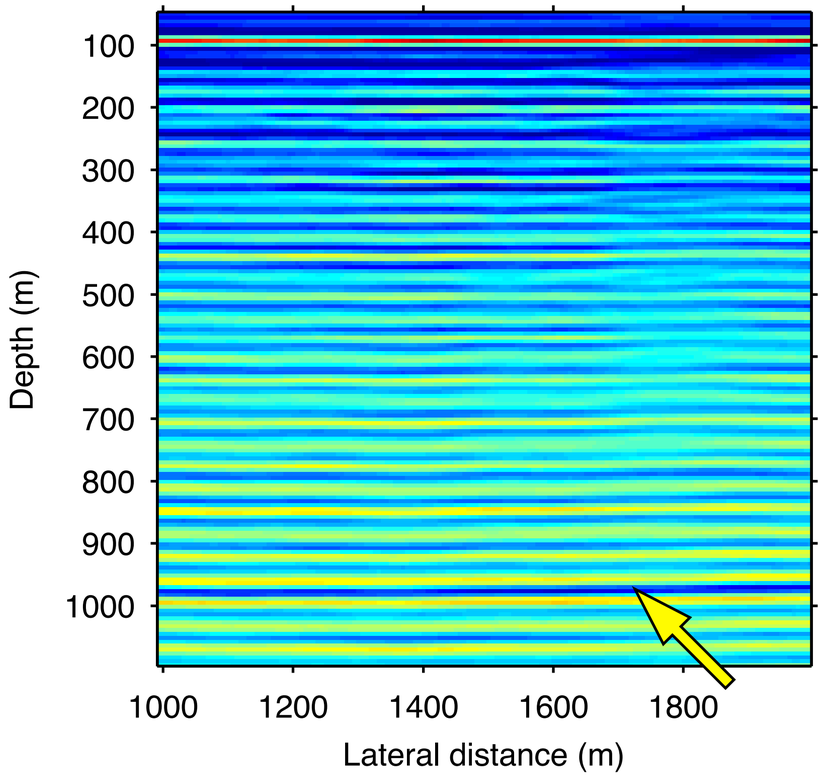

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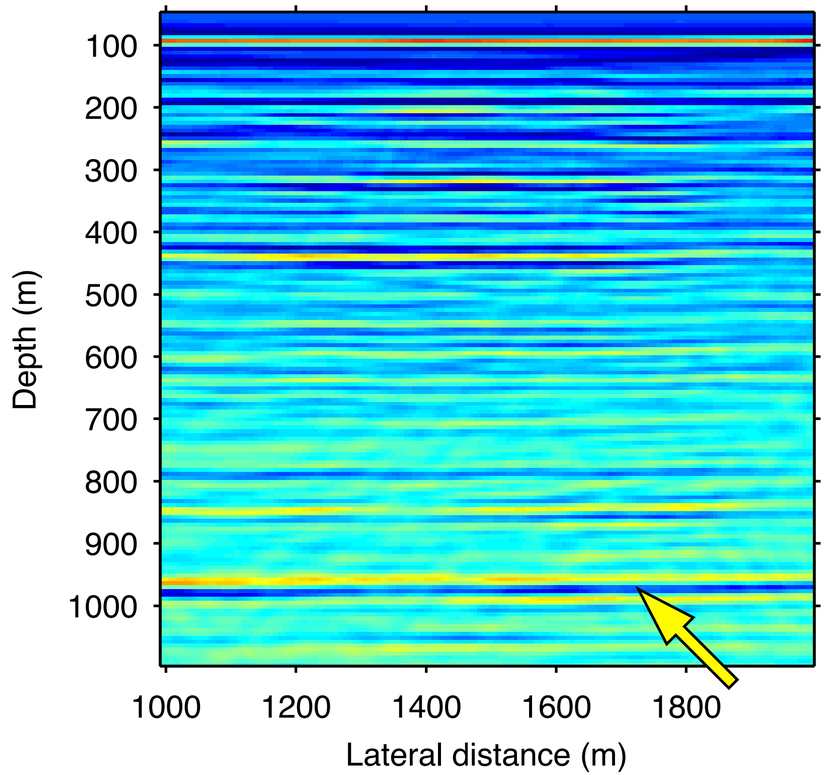


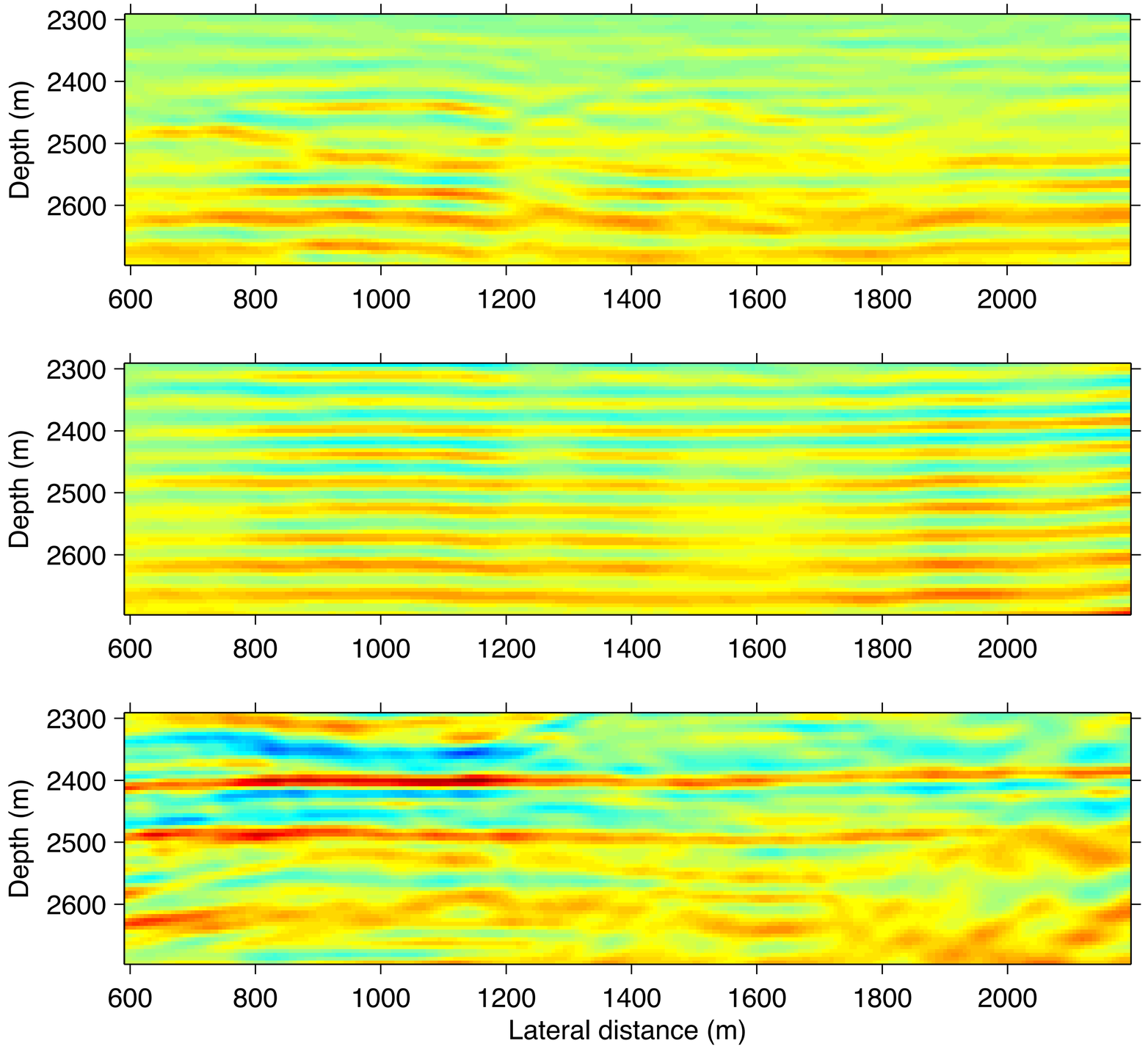
Inversion of multiples

Section B: zoomed in

Conventional RTM

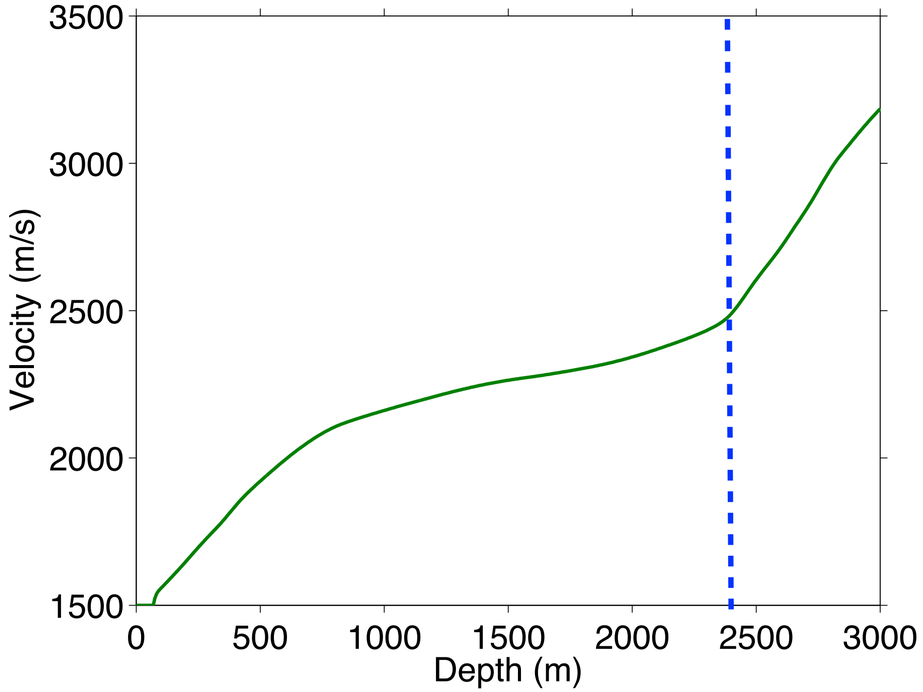
RTM of multiples

Inversion of multiples



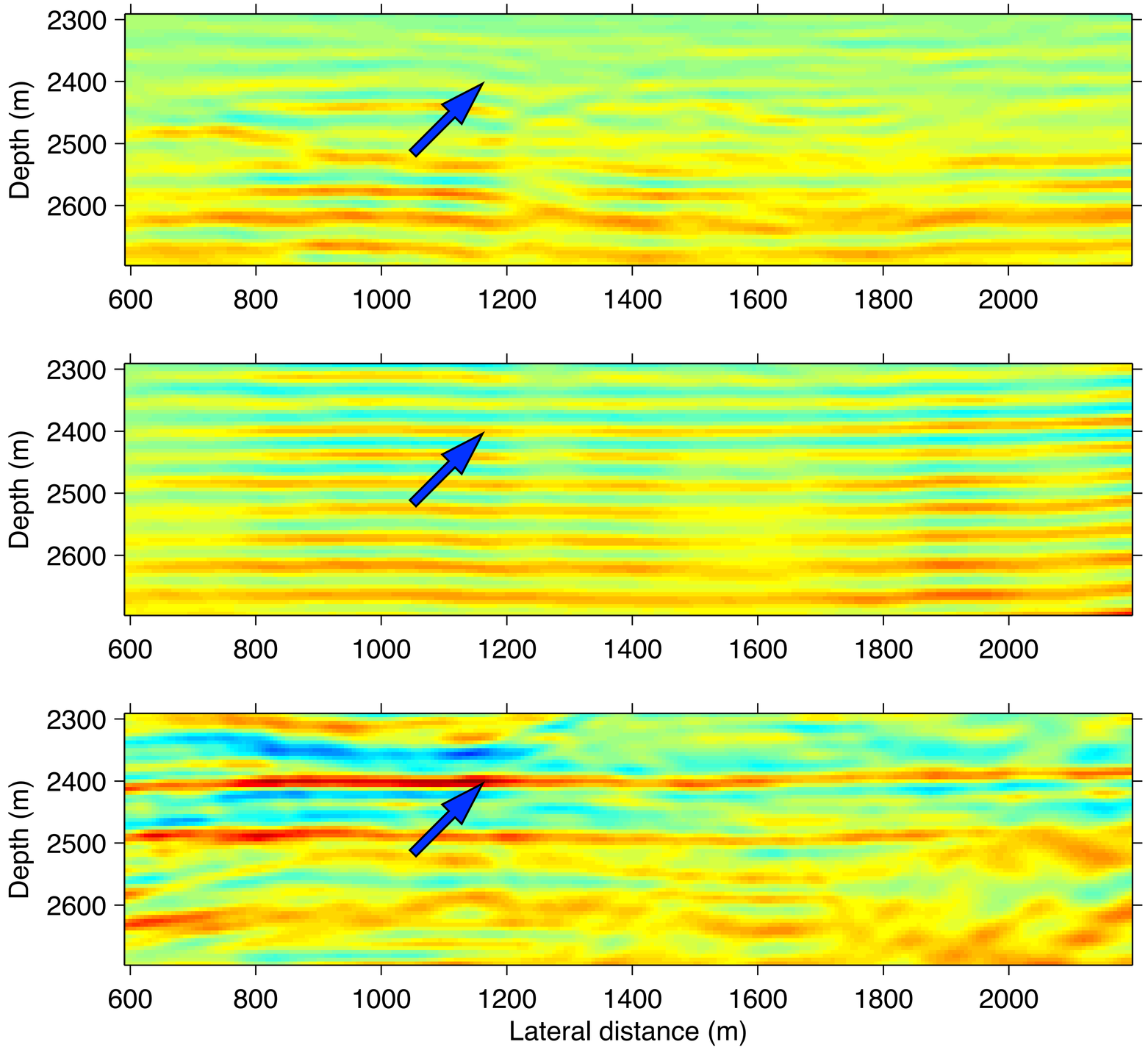
Section B: zoomed in

Conventional RTM



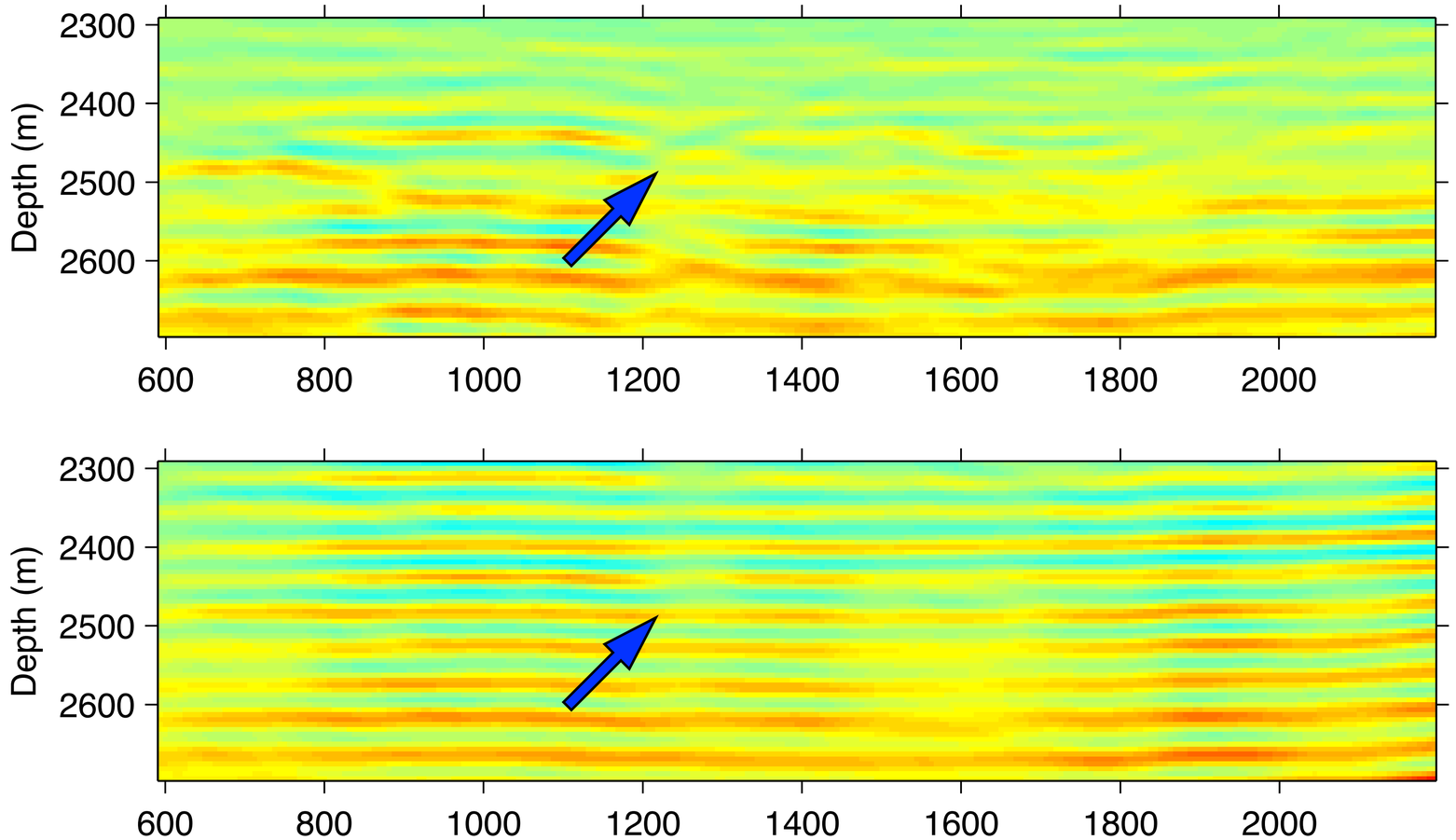
Velocity profile at 1400m laterally

Inversion of multiples



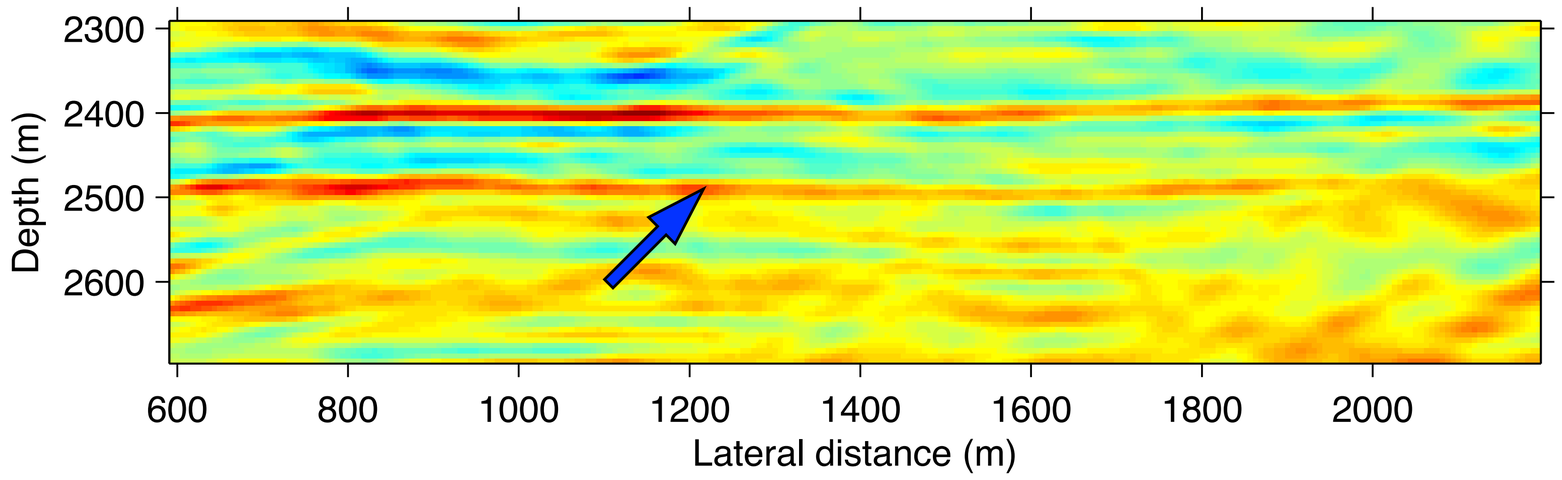
Section B: zoomed in

Conventional RTM



RTM of multiples

Inversion of multiples



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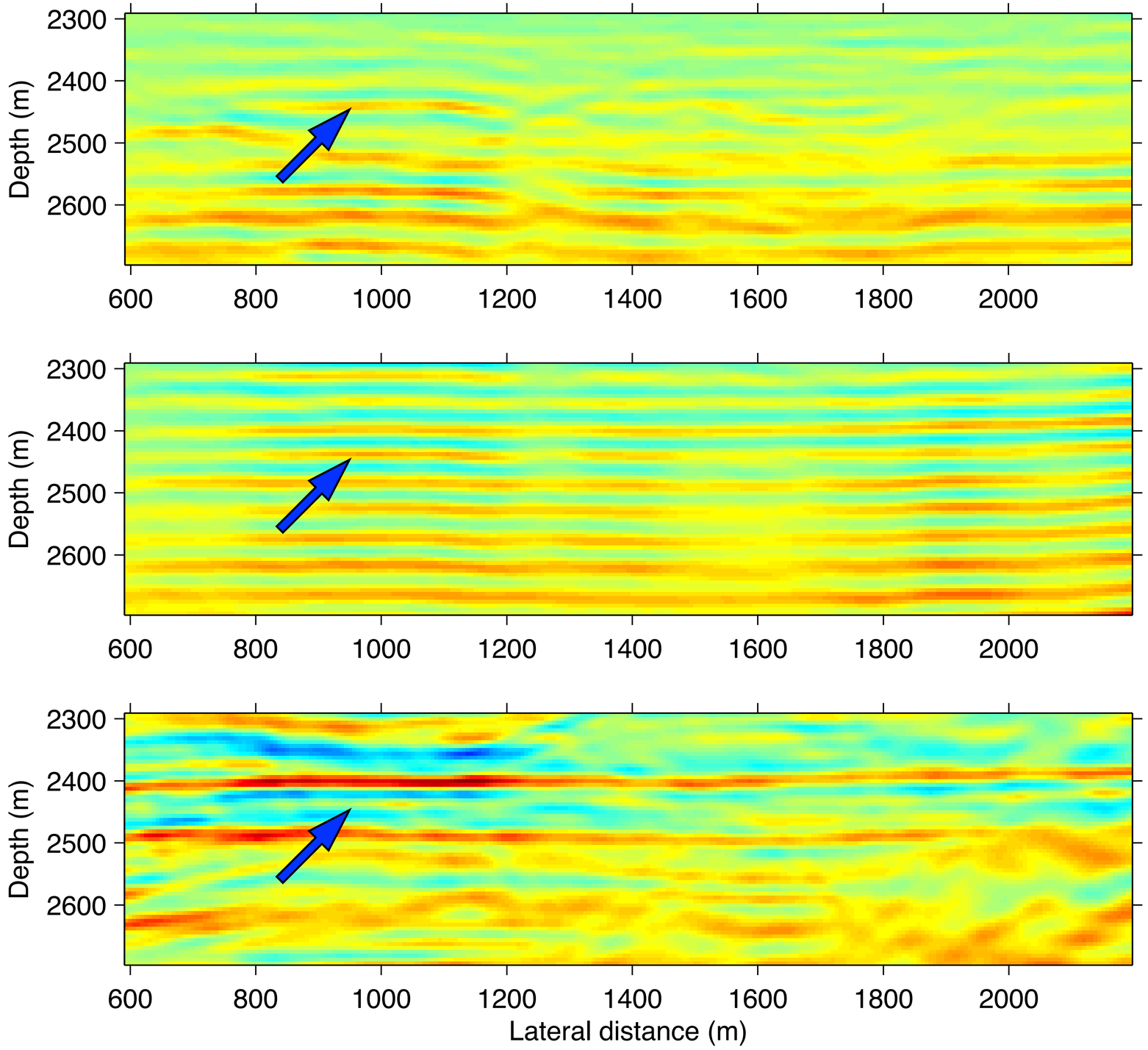


Conclusions

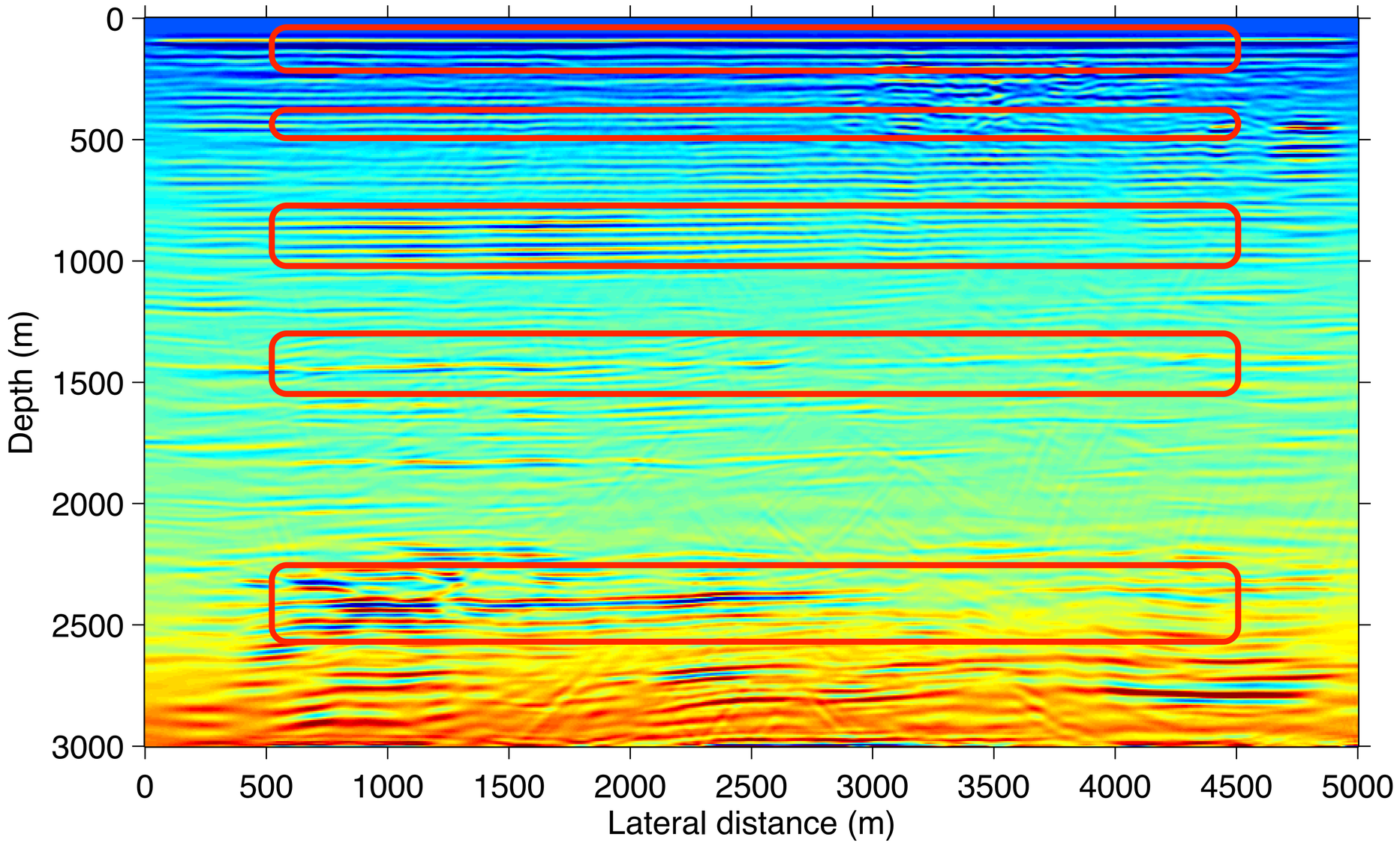
- Multiples cause artifacts if not treated properly.
- Traveltime of multiples can be corrected by identifying receivers as virtual sources.
  - cross-correlation imaging not a choice
  - acausal artifacts suppressed by inversion

Questions

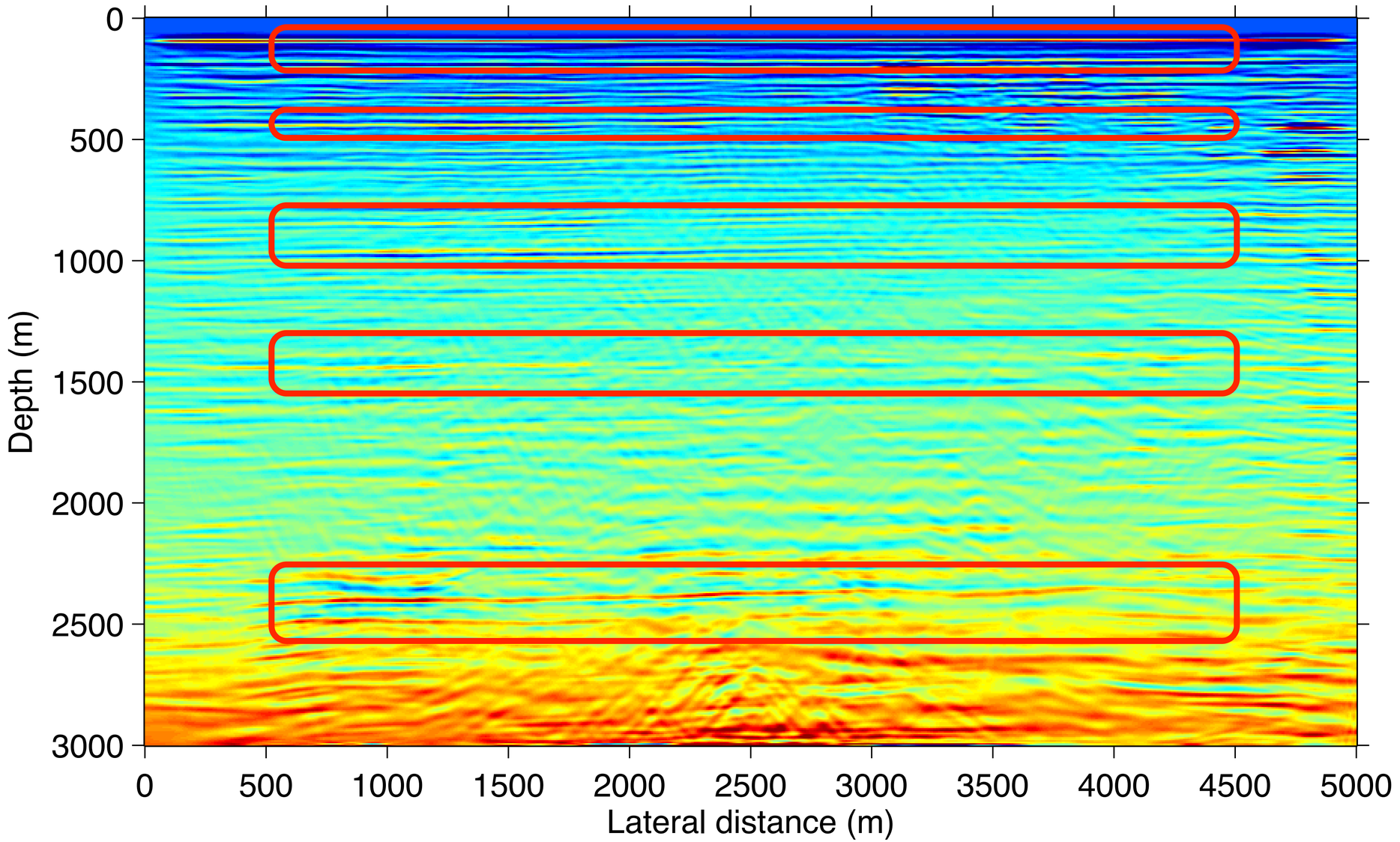
How does the image of multiples stack up to the image of primaries?

- Which features are comparable?
- What do we gain by using multiples?
- What do we lose by *only* using multiples?

Inversion of primaries



Inversion of **multiples**



Observations

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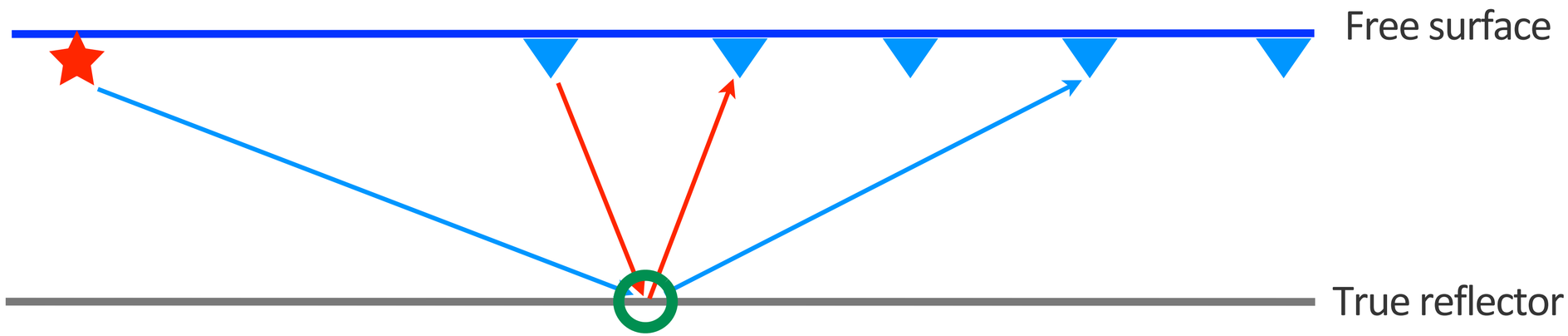
Question:

What are the benefits of using multiples?

Benefits of multiples in imaging shallow earth

[because of missing/inaccurately-interpolated near-offsets and missing far-offsets in the data]



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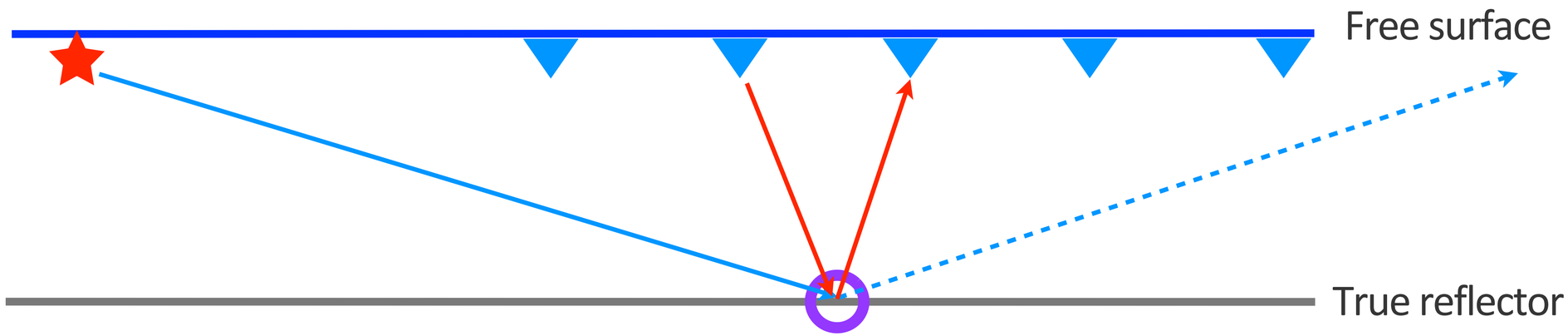

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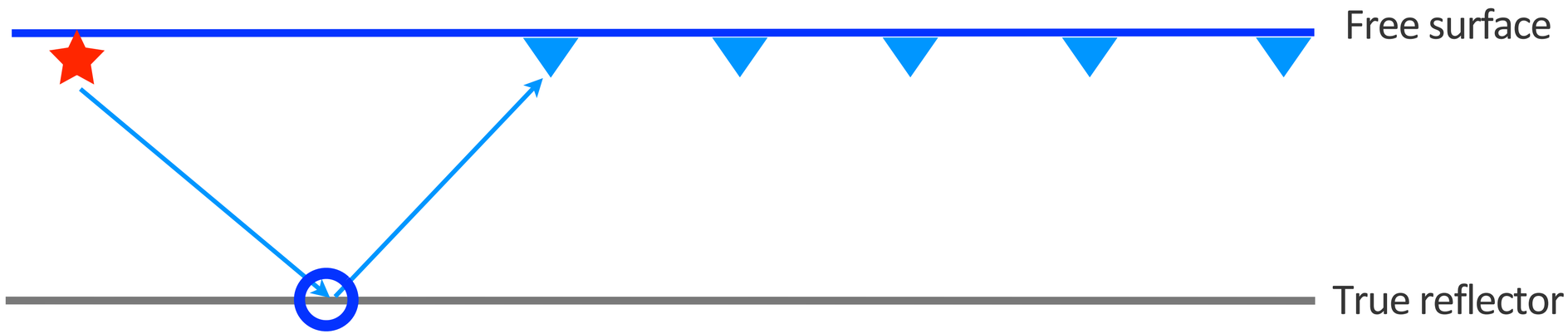

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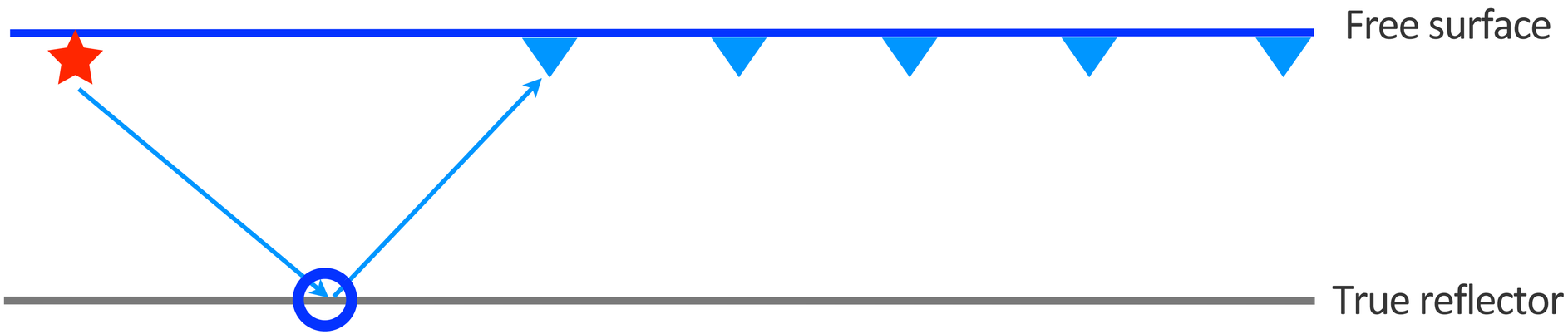
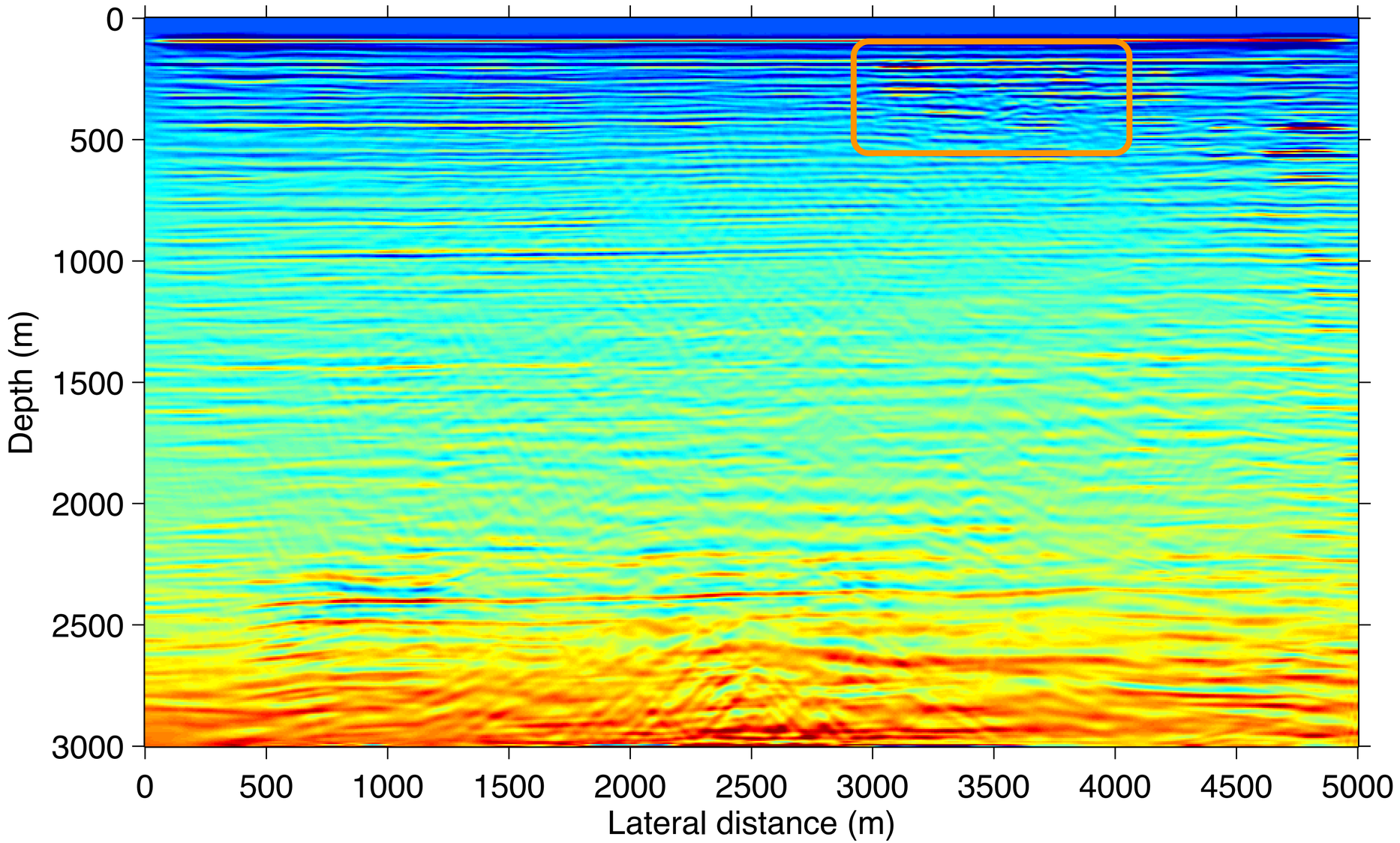


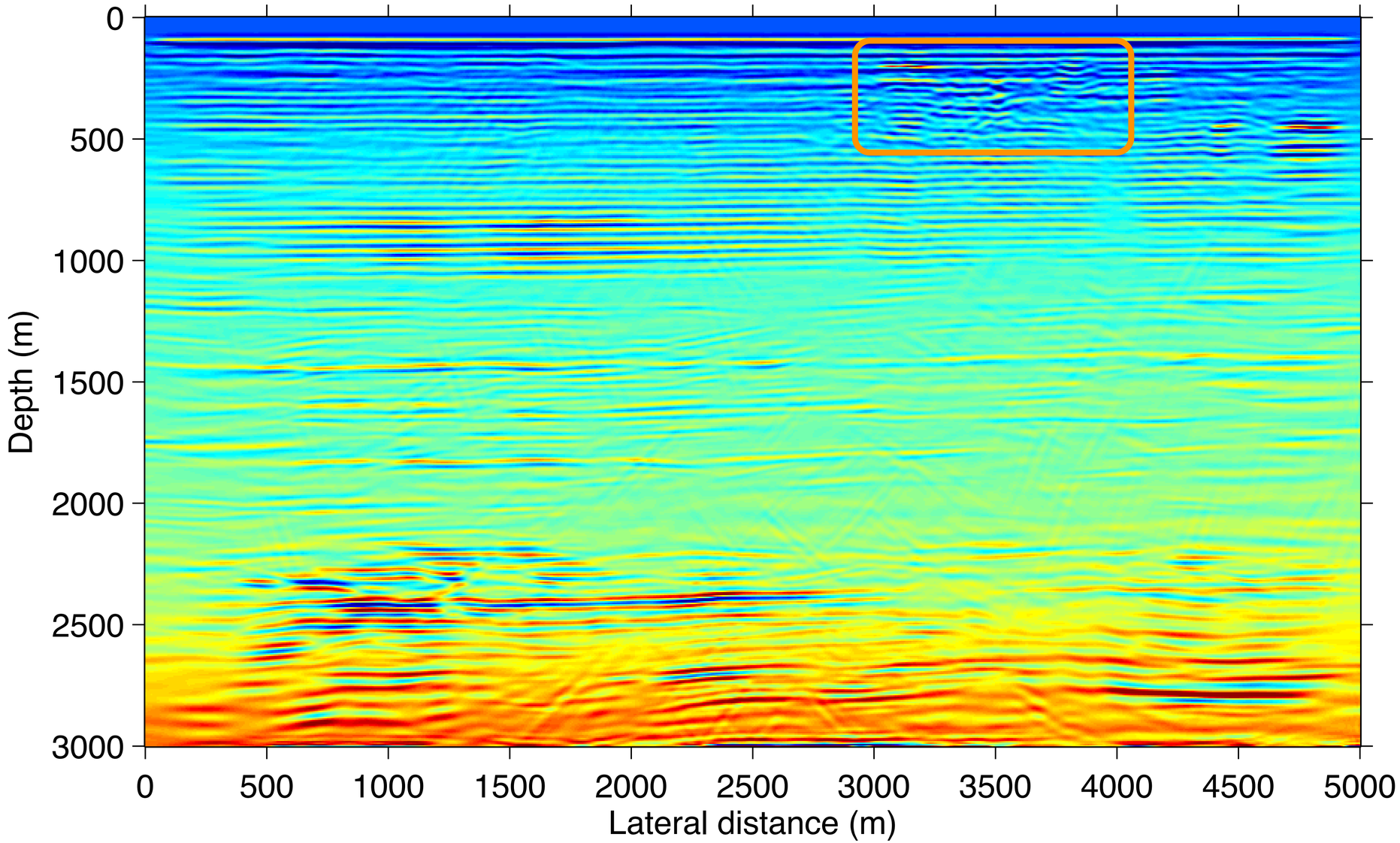
Smallest incident angles dictated by

- nearest-offset for **primaries**
- receiver spacing for **multiples**

Inversion of **multiples**

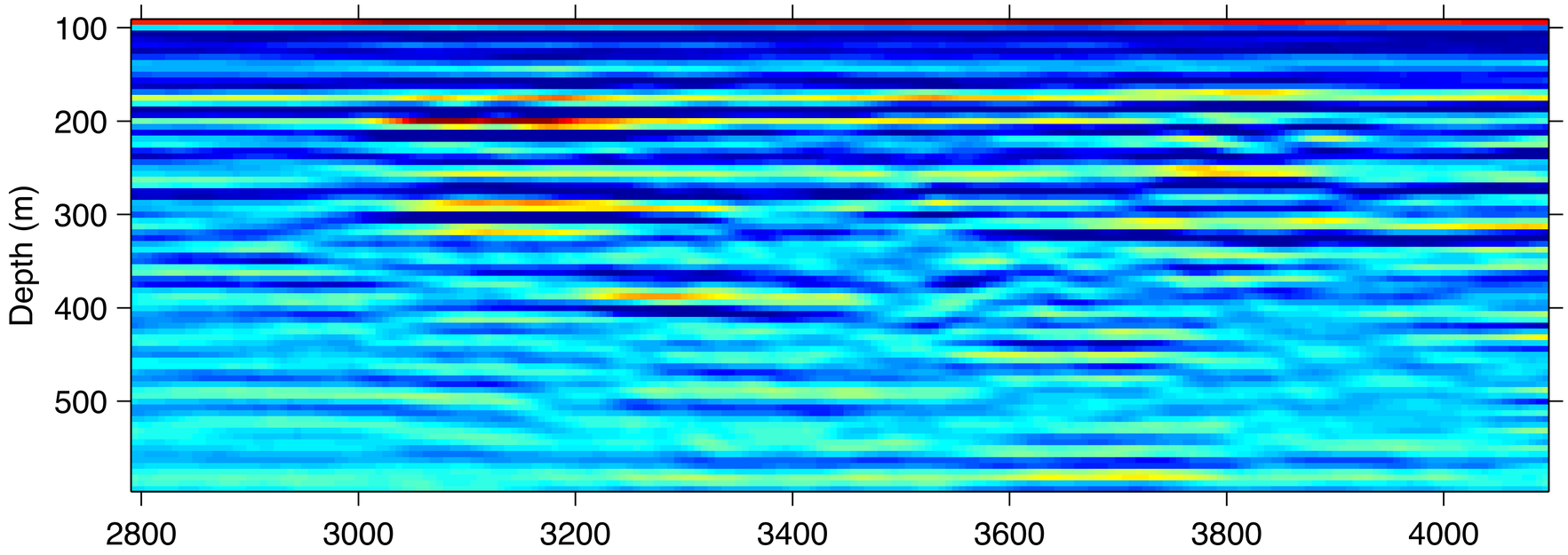


Inversion of primaries



Zoomed in

Inversion of multiples



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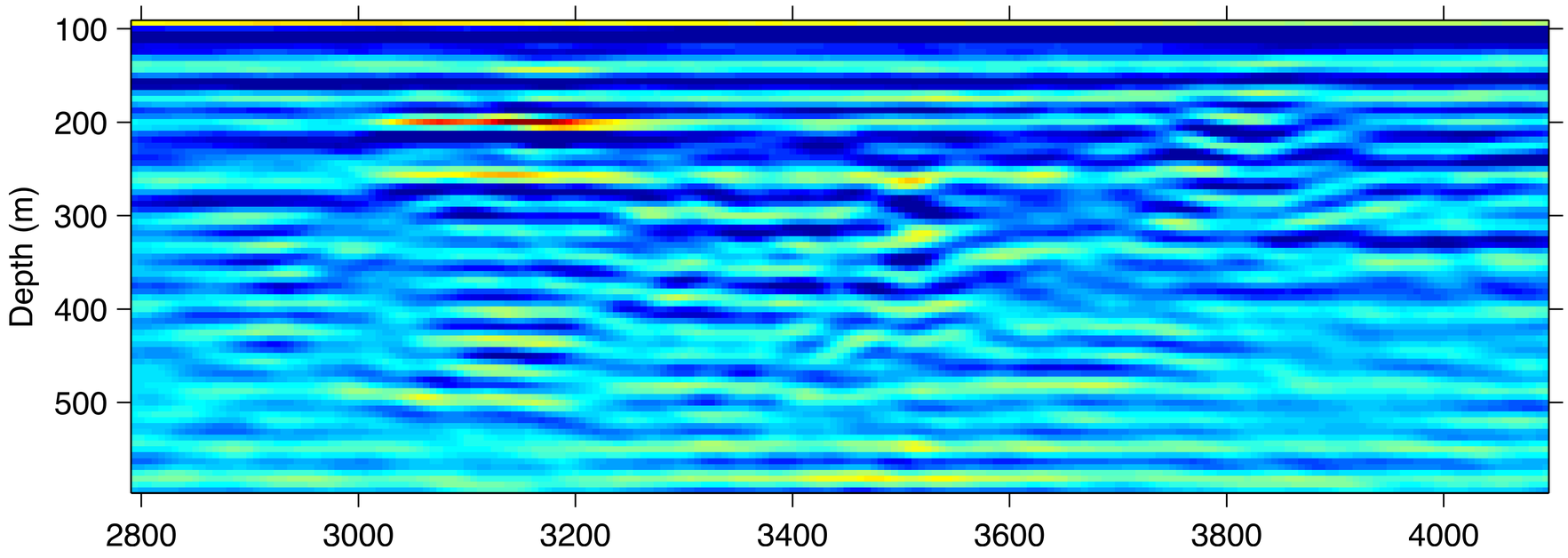
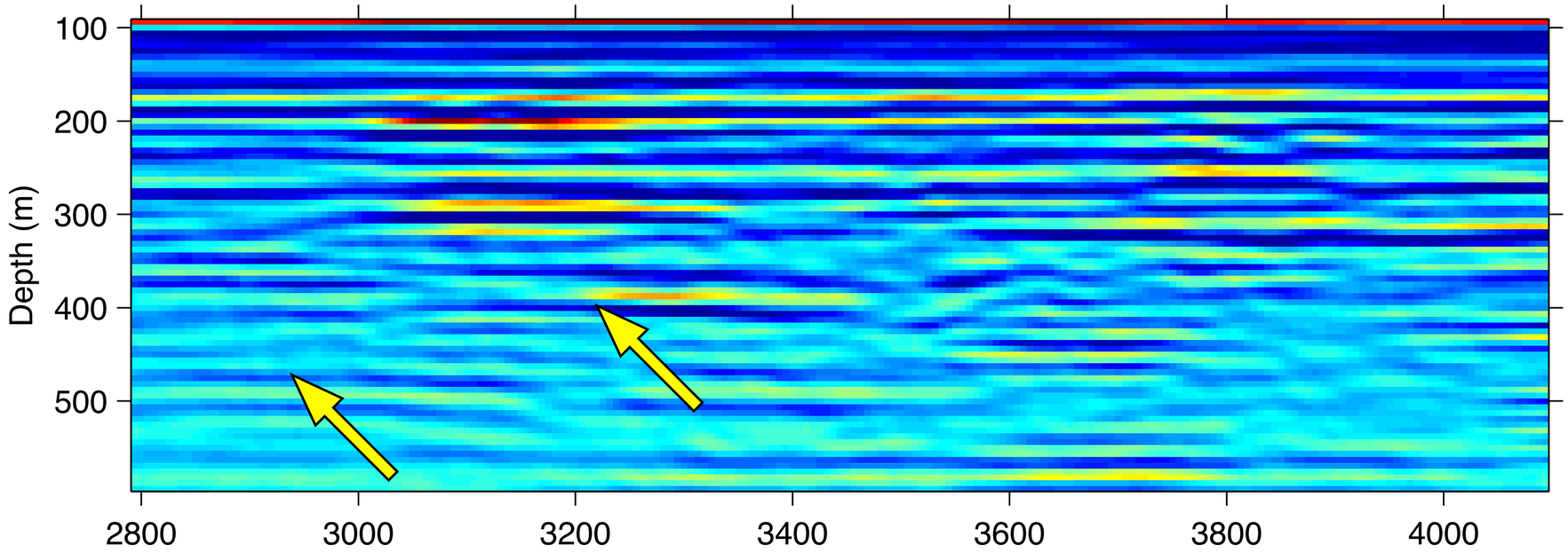


Zoomed in

Inversion of multiples



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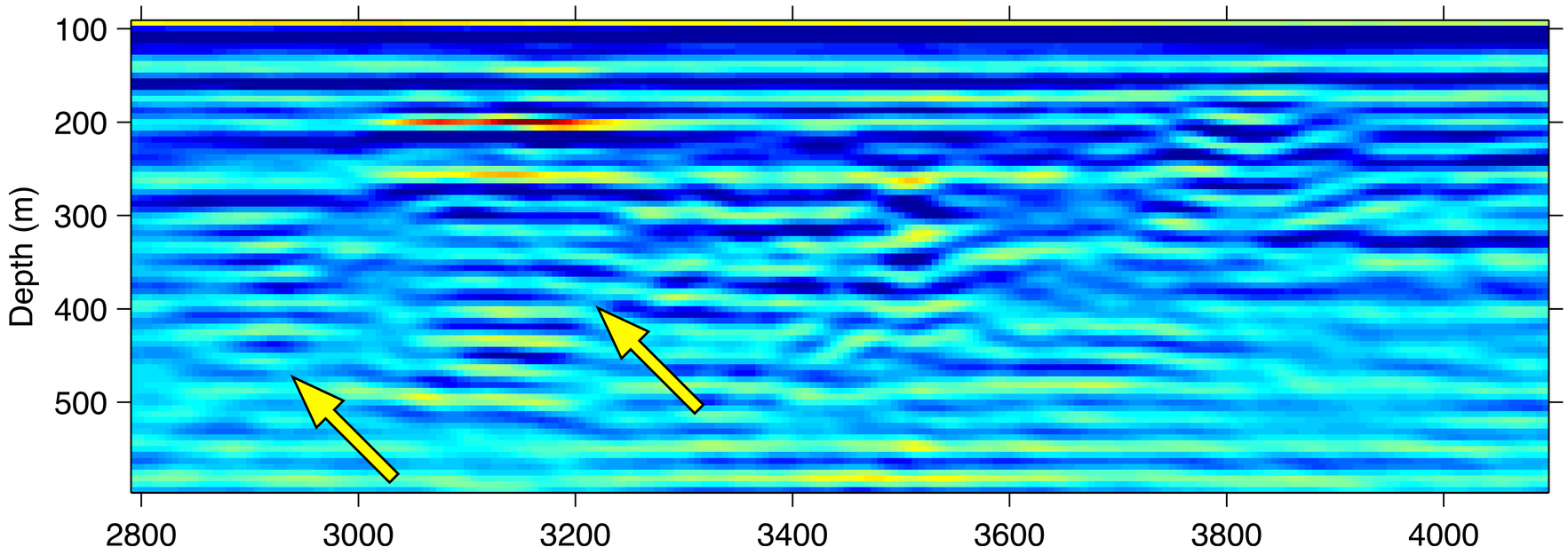
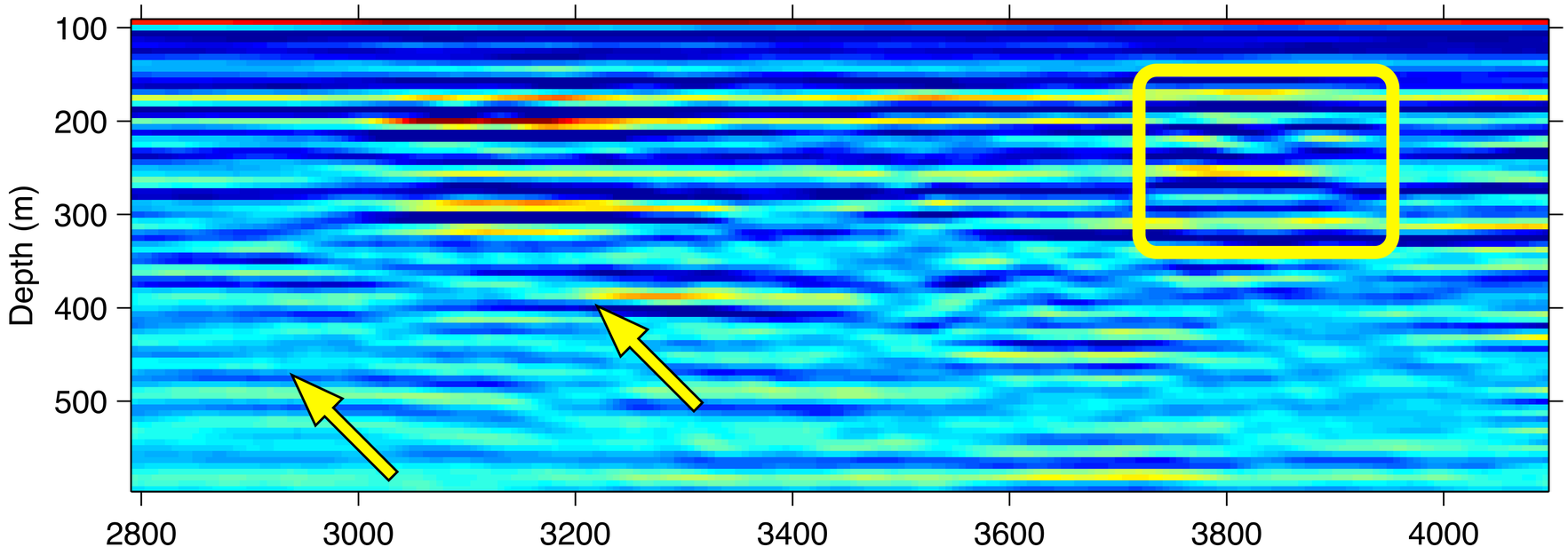


Zoomed in

Inversion of multiples



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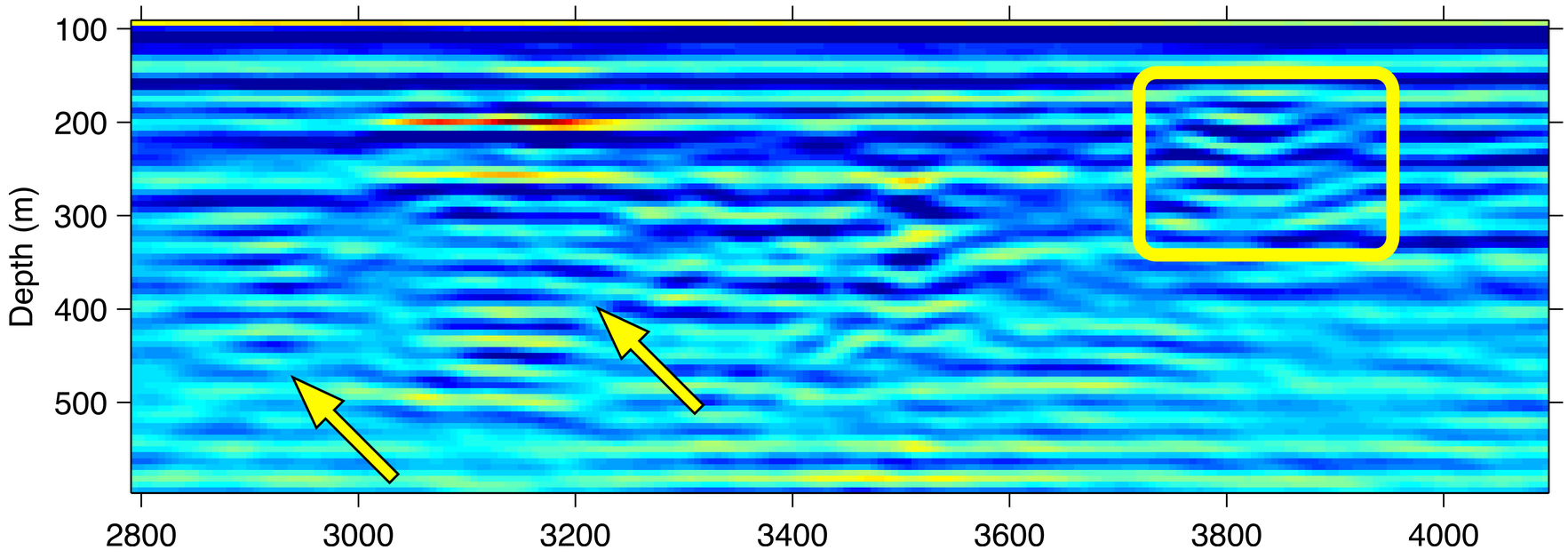

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Question:
What do we lose if we only use multiples?

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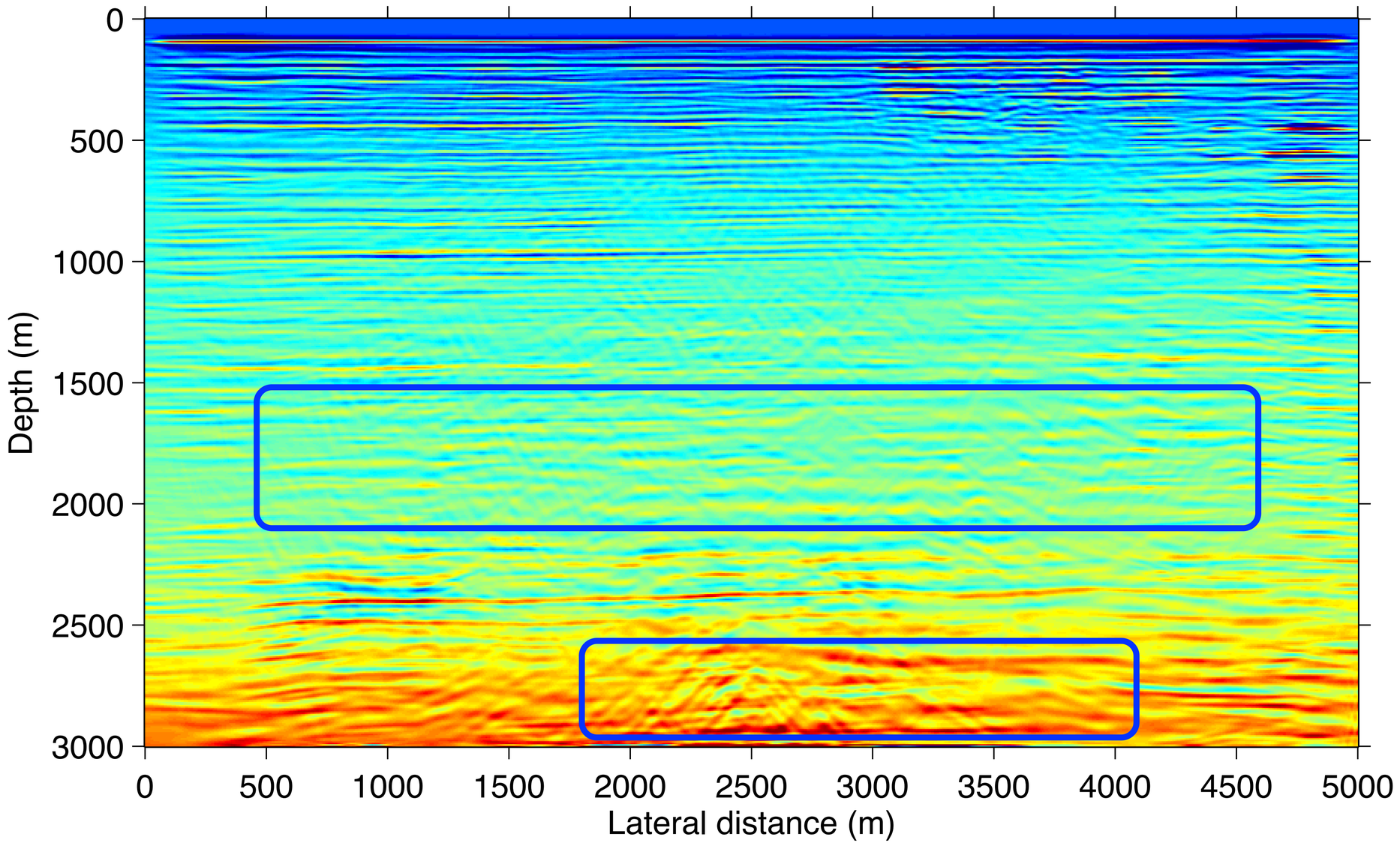
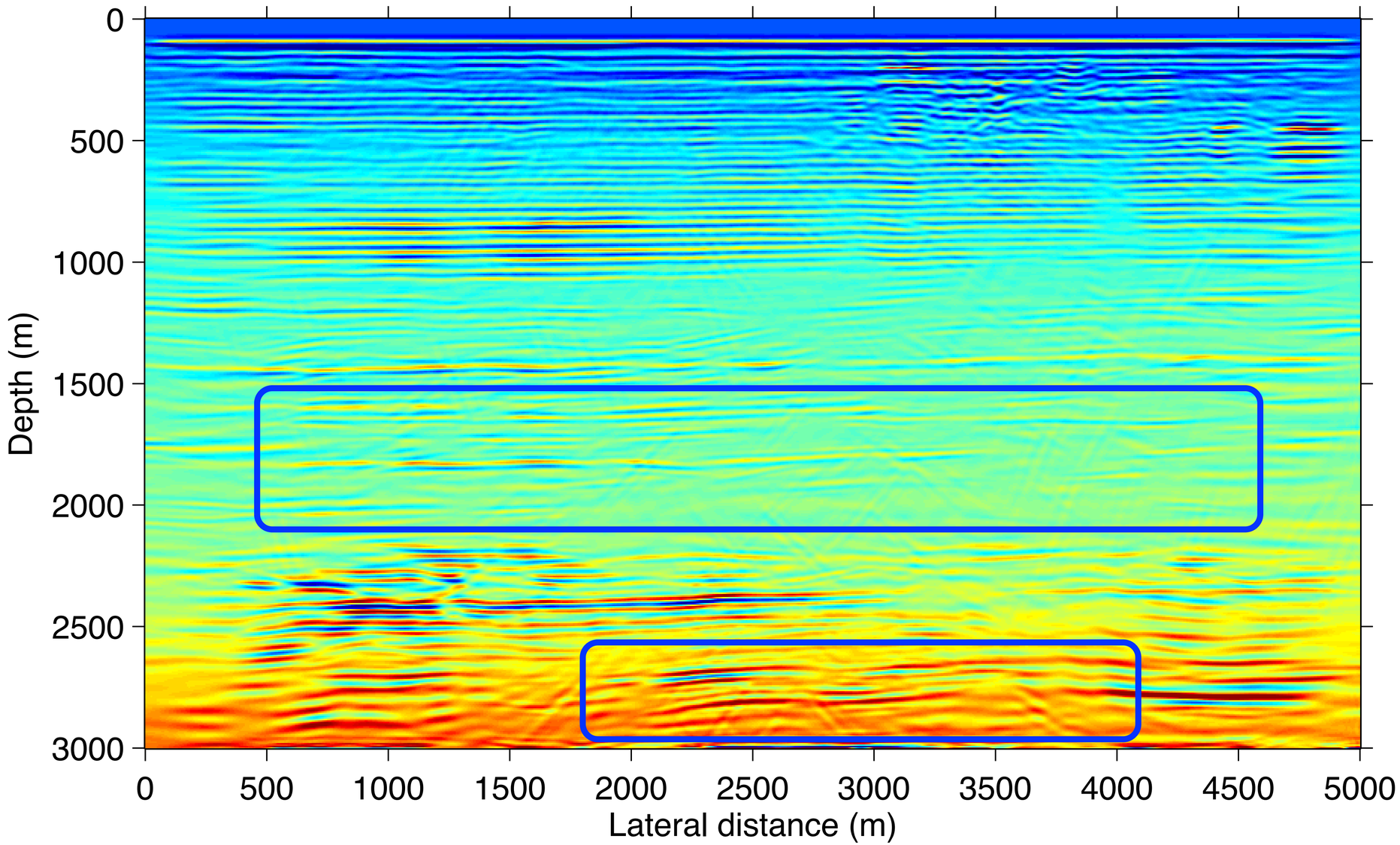


Inversion of primaries



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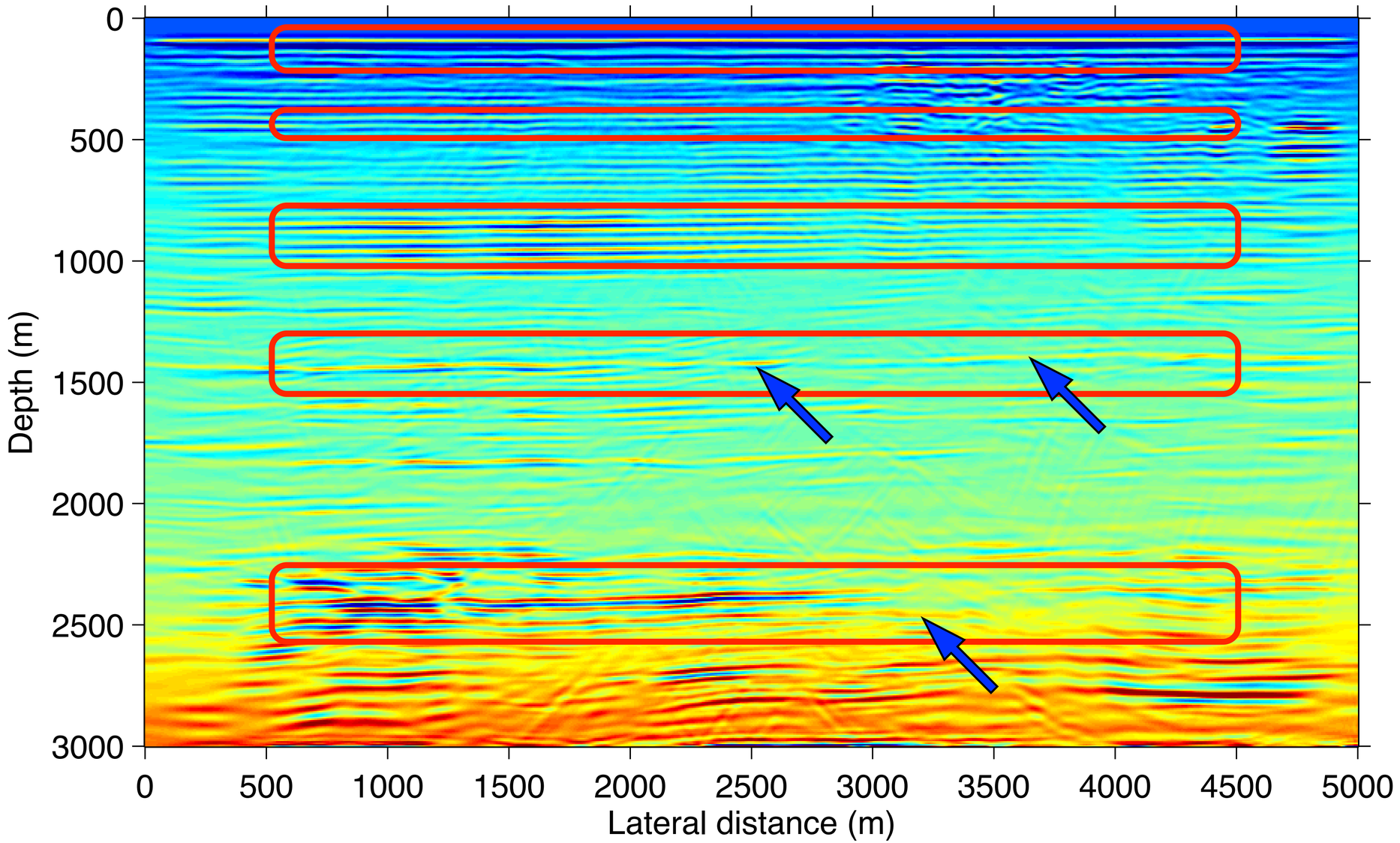
Question:

How to combine the advantages of primaries and multiples?

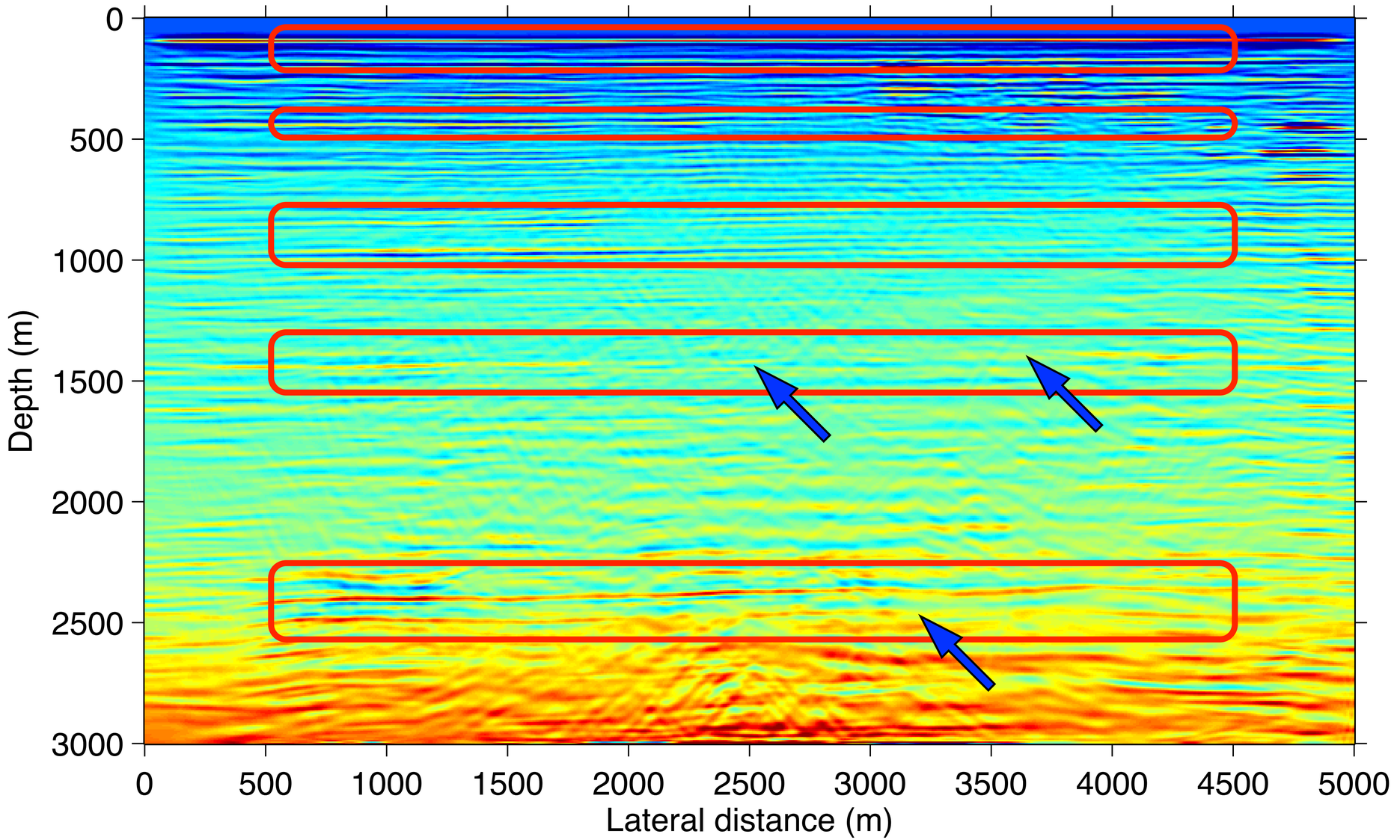
Joint imaging of primaries and multiples

- higher SNR from primaries
- extra illumination from multiples
- made possible by source estimation

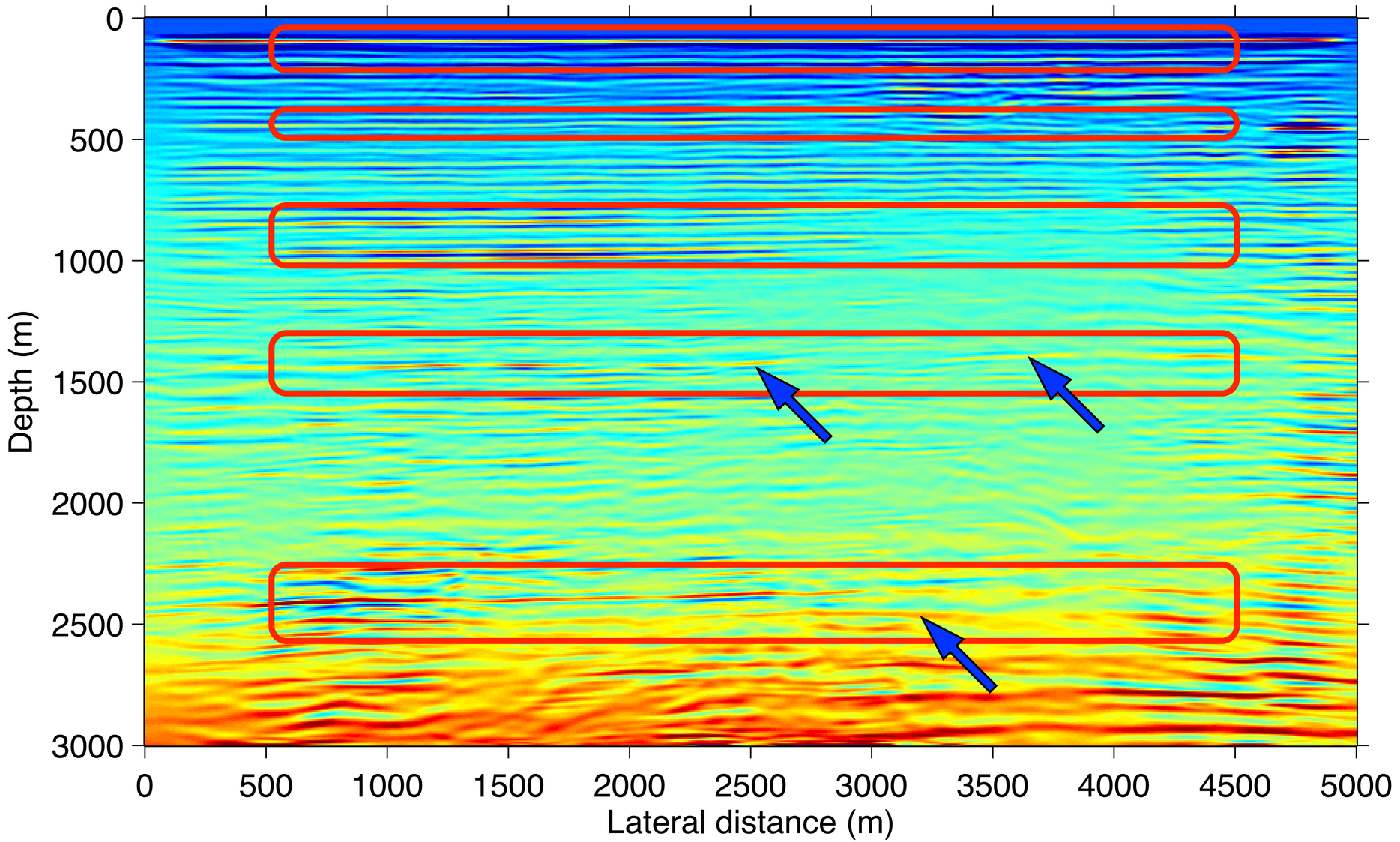
Inversion of primaries



Inversion of **multiples**



Inversion of **total data**

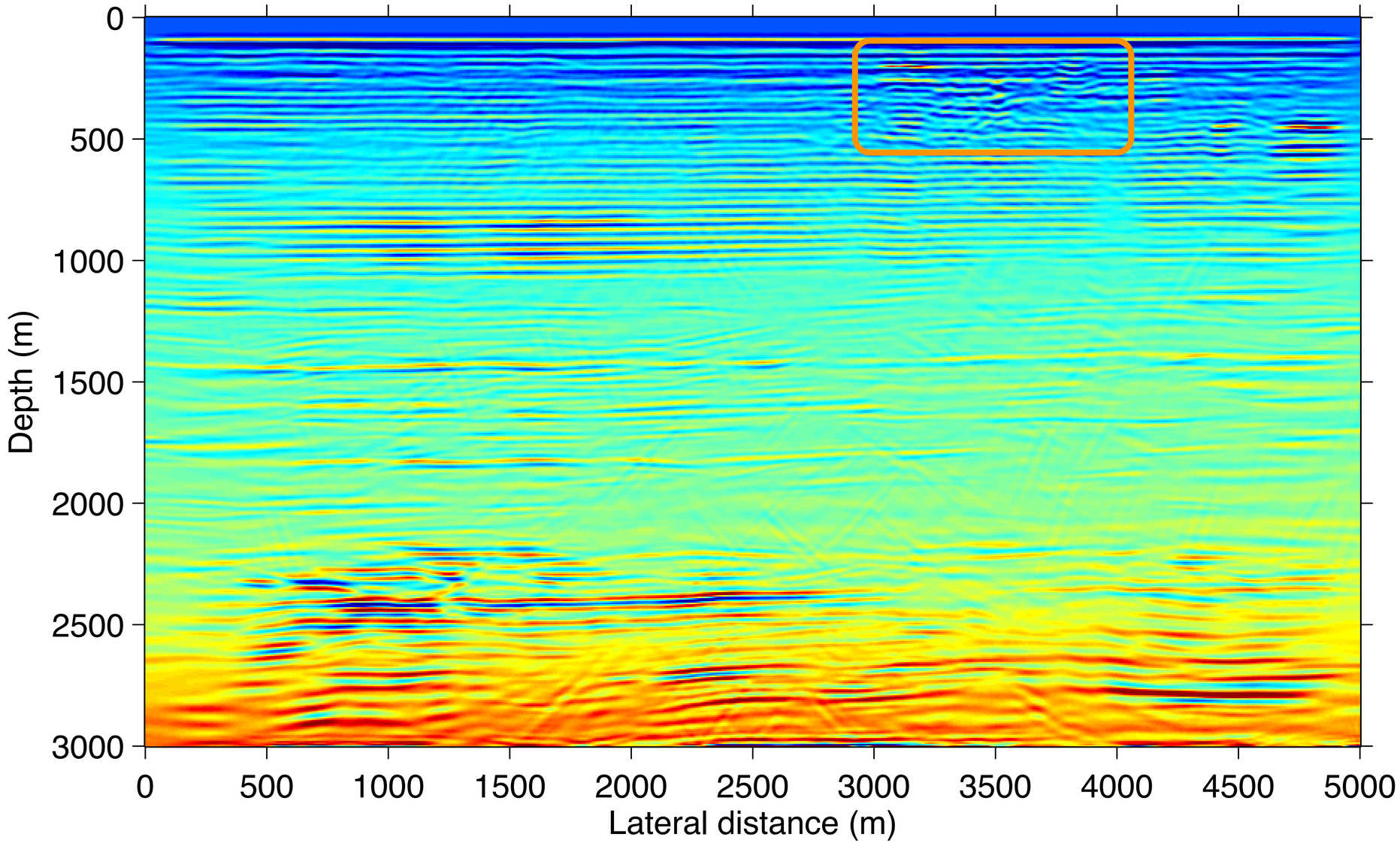


Observations

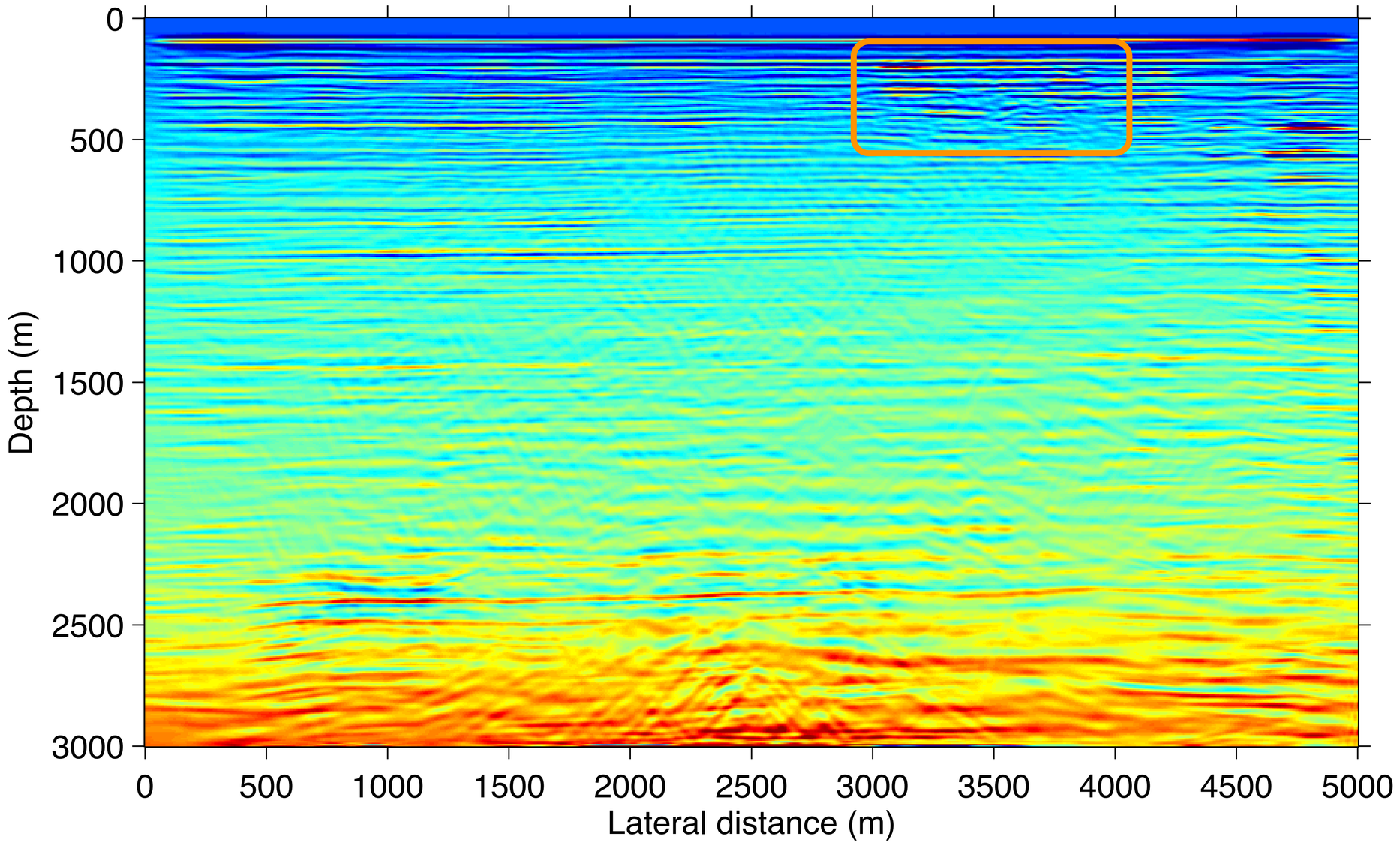
The image of total data

- better preserves major reflectors compared with using multiples alone.

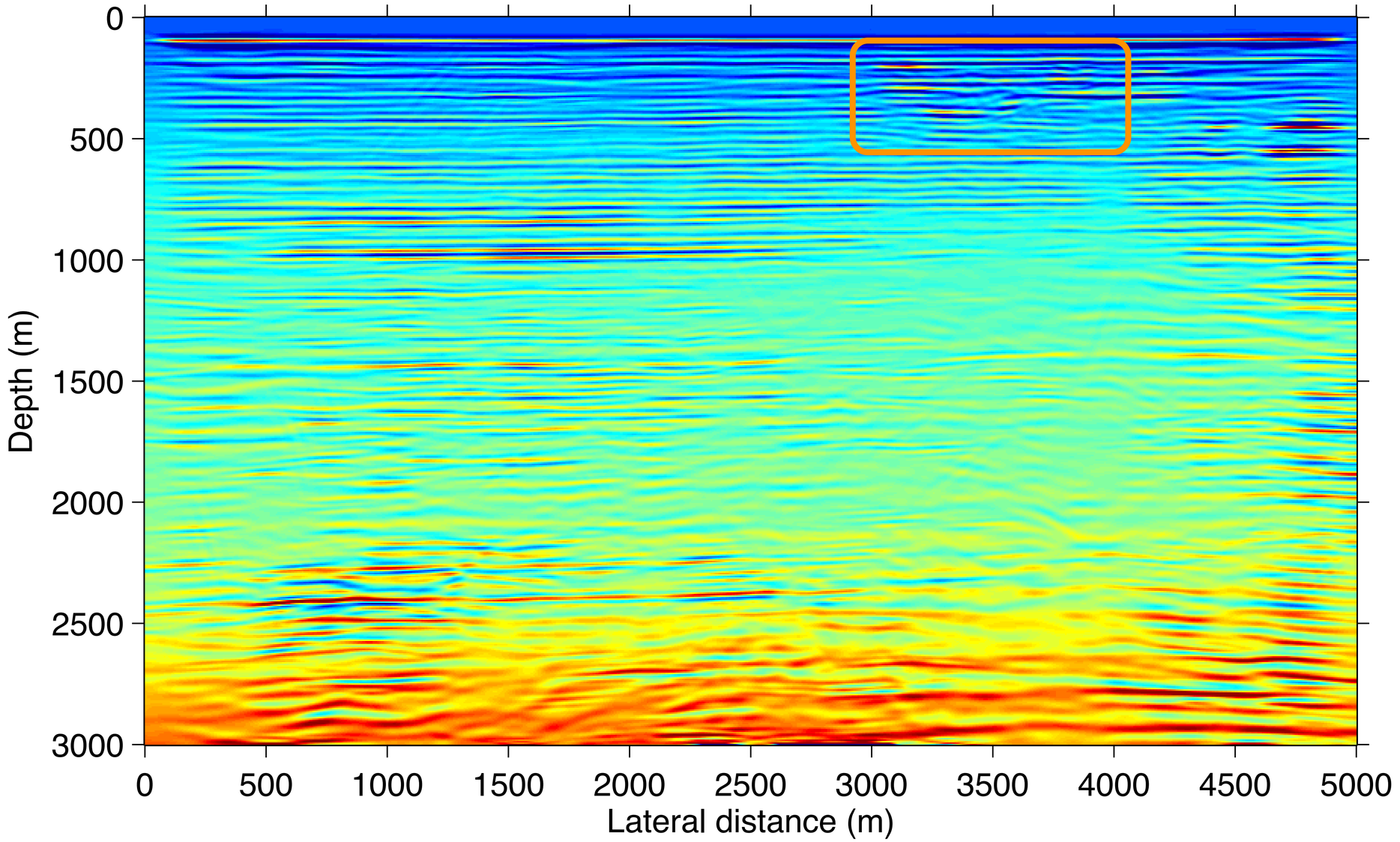
Inversion of primaries



Inversion of **multiples**

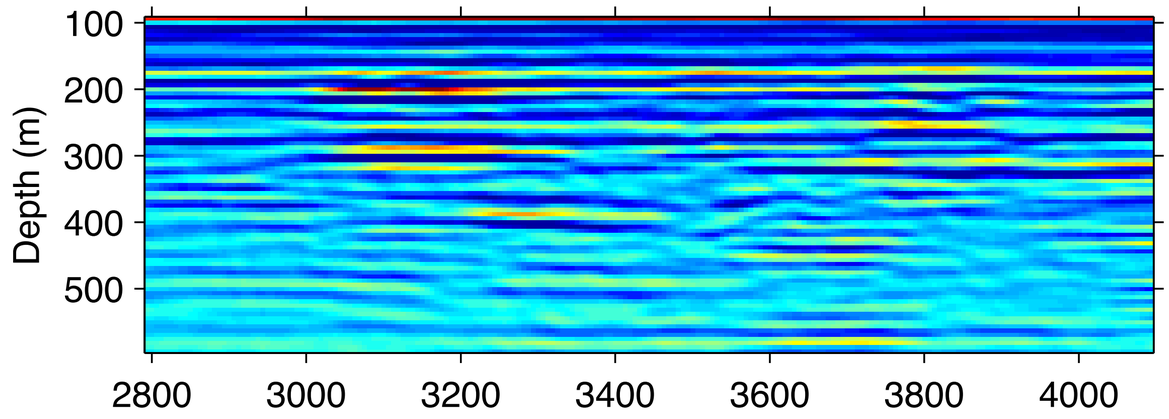


Inversion of **total data**

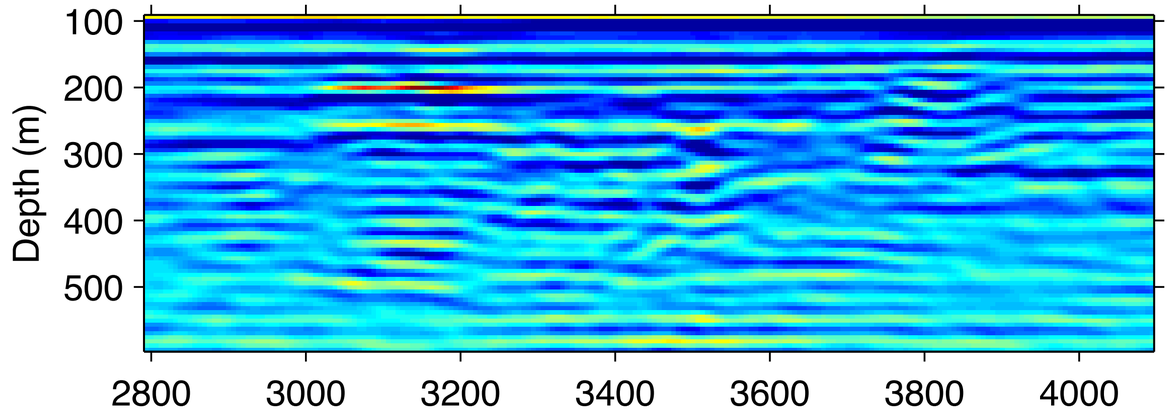


Zoomed in

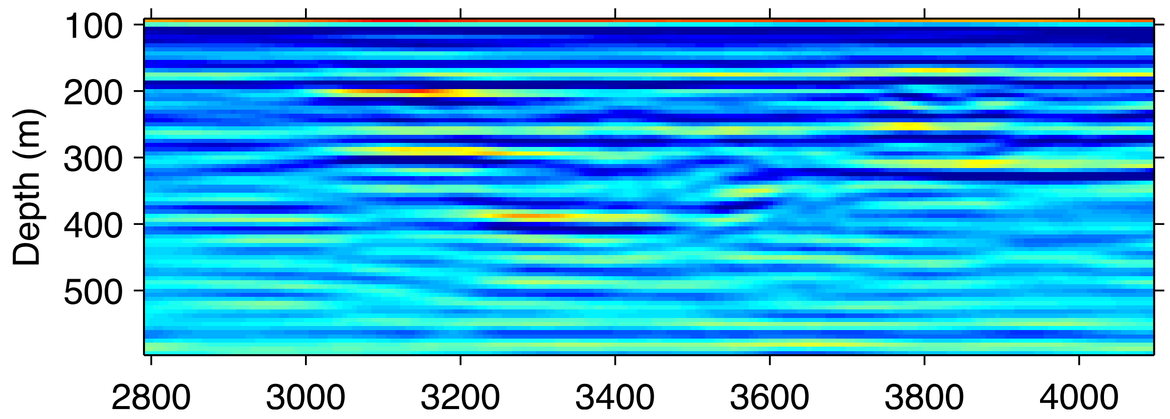
Inversion of multiples



Inversion of primaries

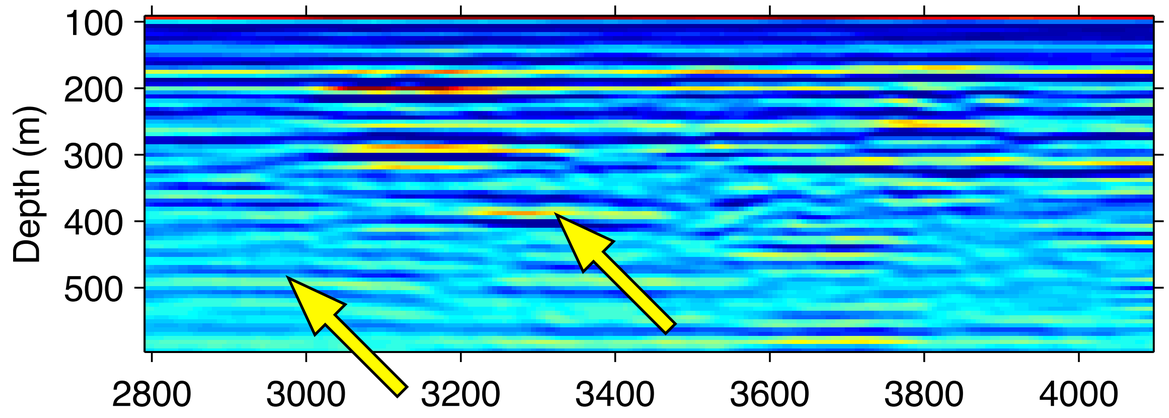


Inversion of total data

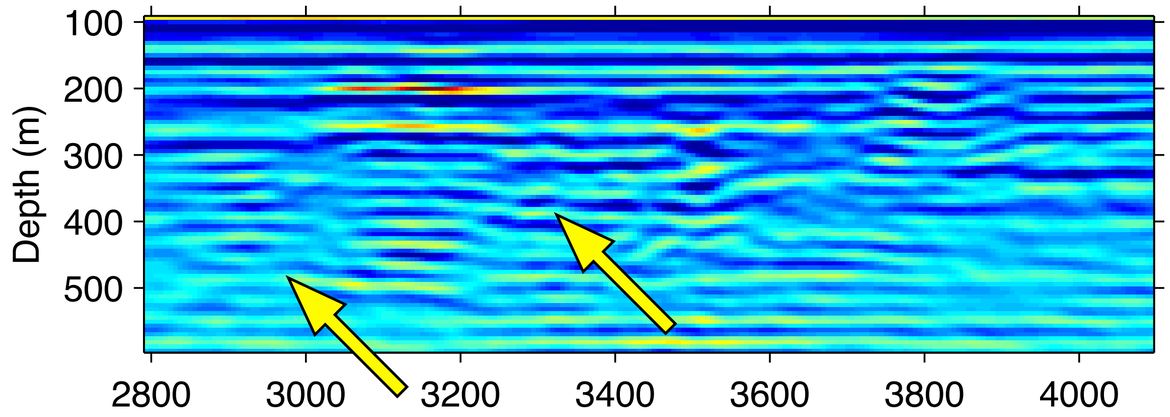


Zoomed in

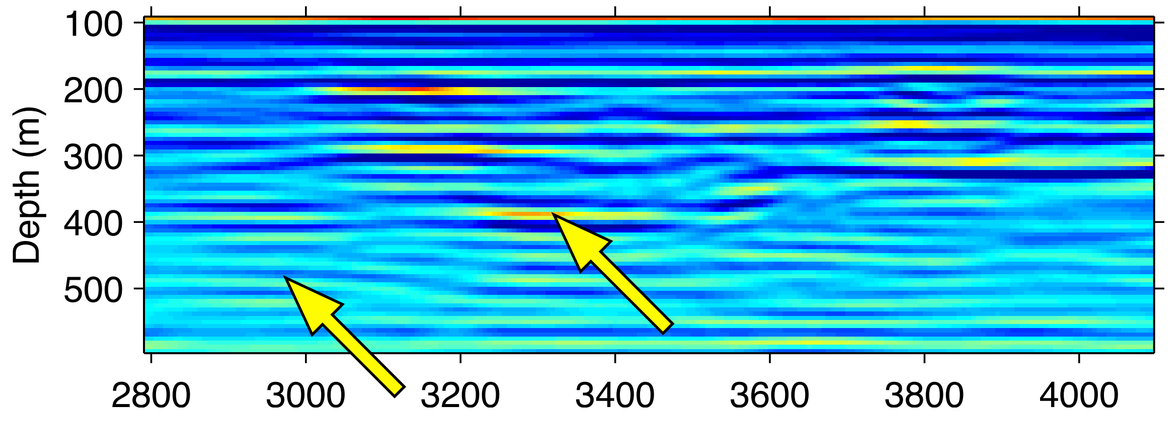
Inversion of multiples



Inversion of primaries

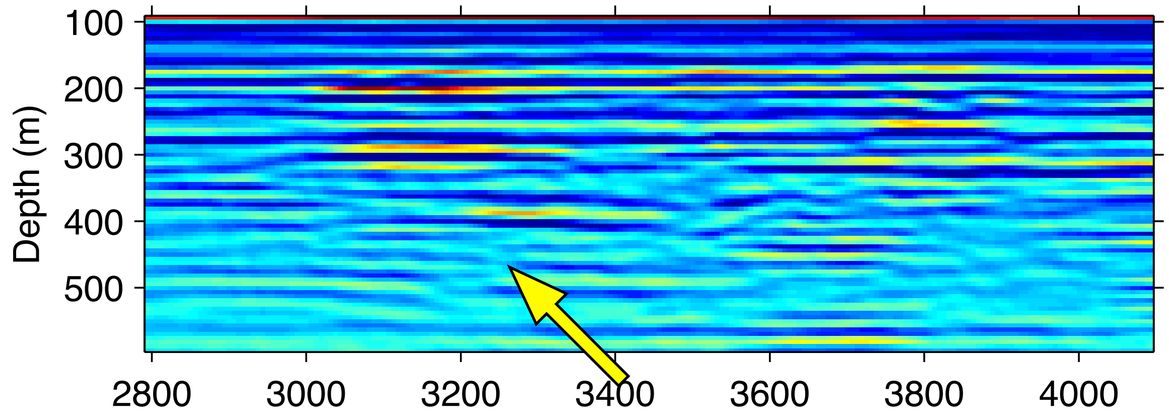


Inversion of total data

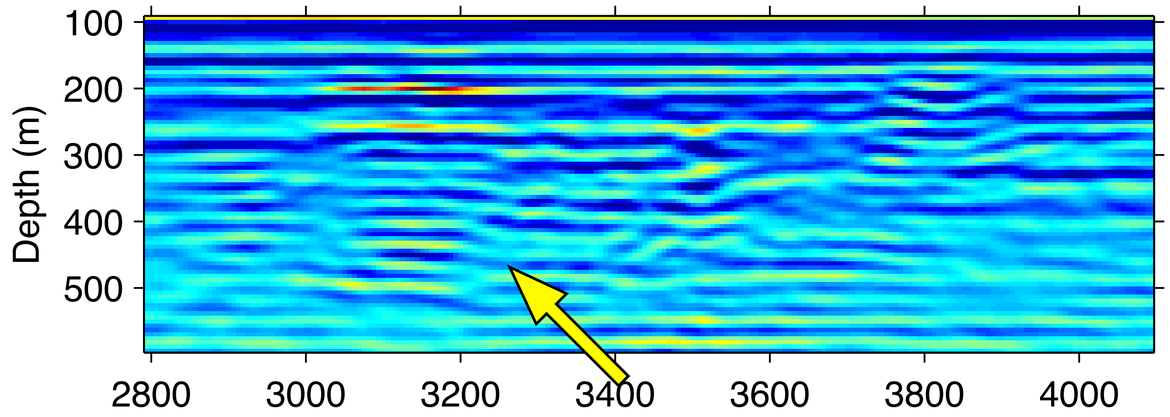


Zoomed in

Inversion of multiples



Inversion of primaries



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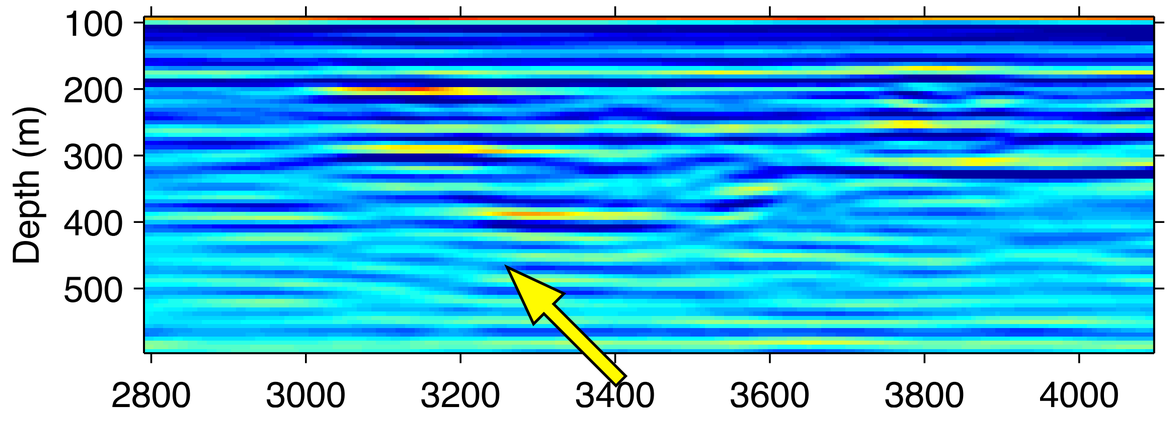
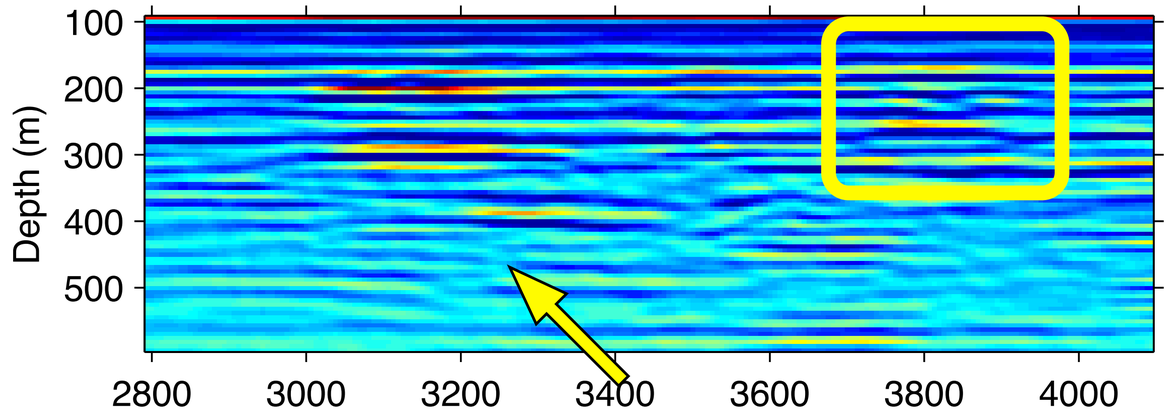
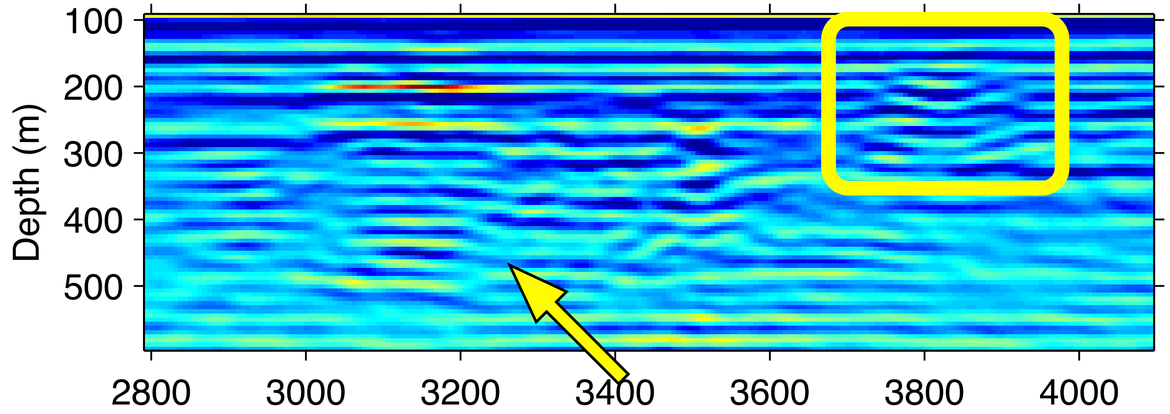


Zoomed in

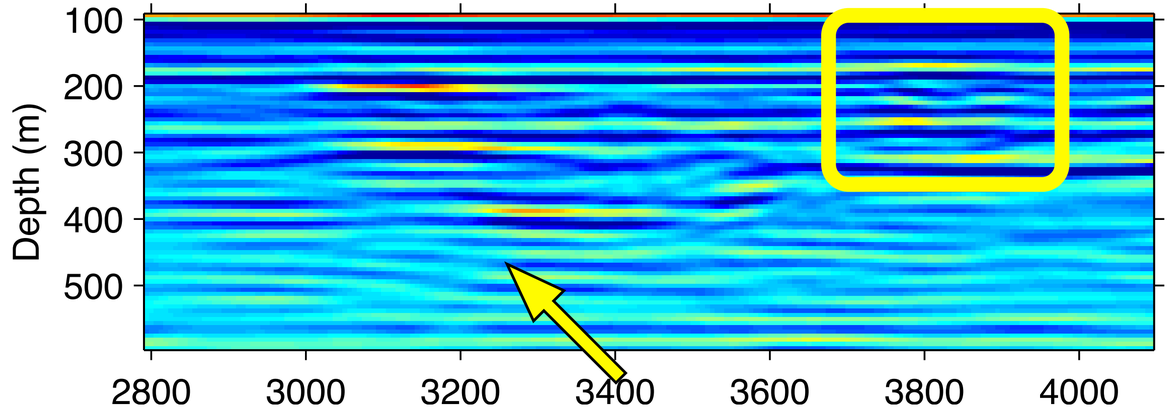
Inversion of multiples



Inversion of primaries



Inversion of total data

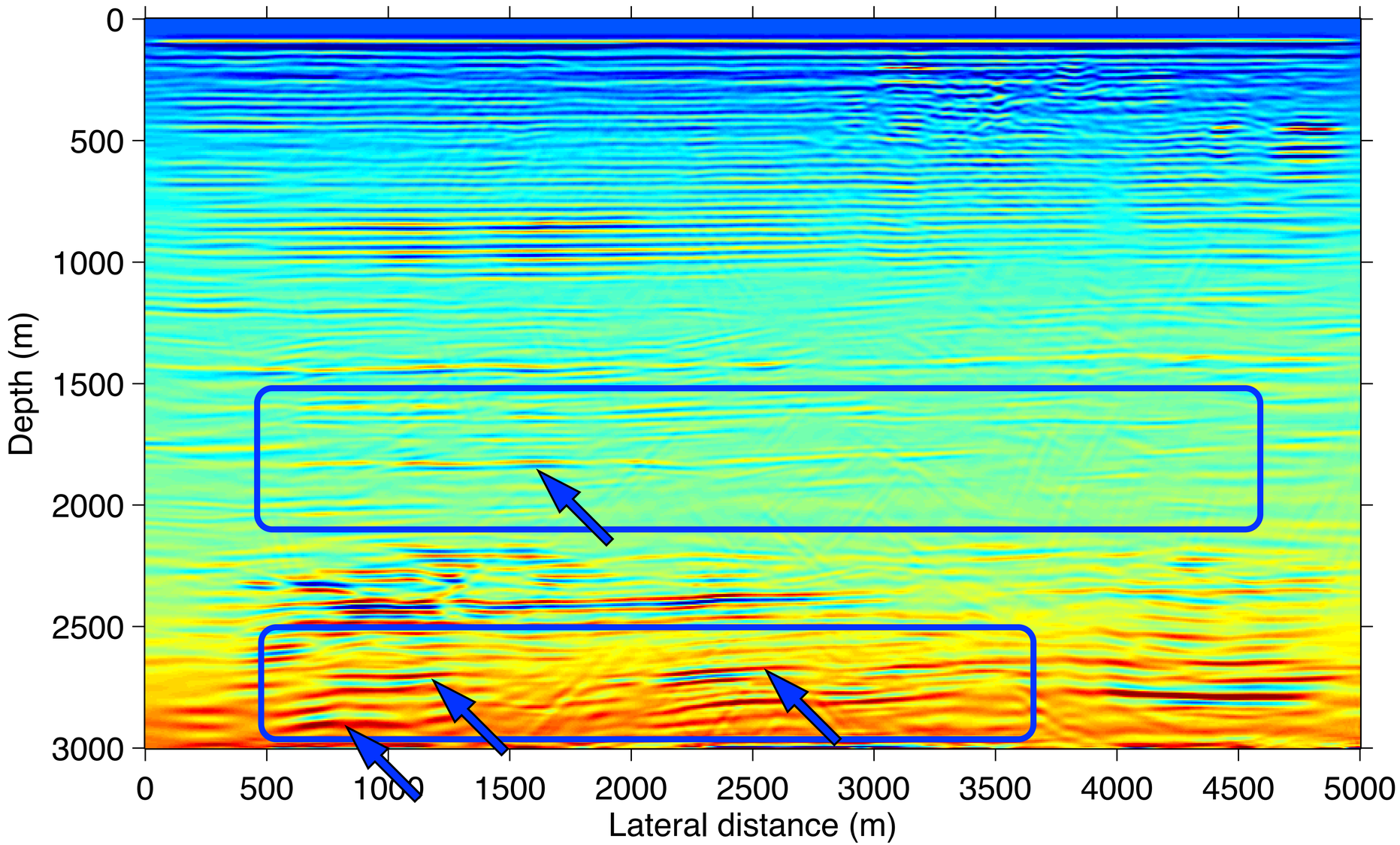


Observations

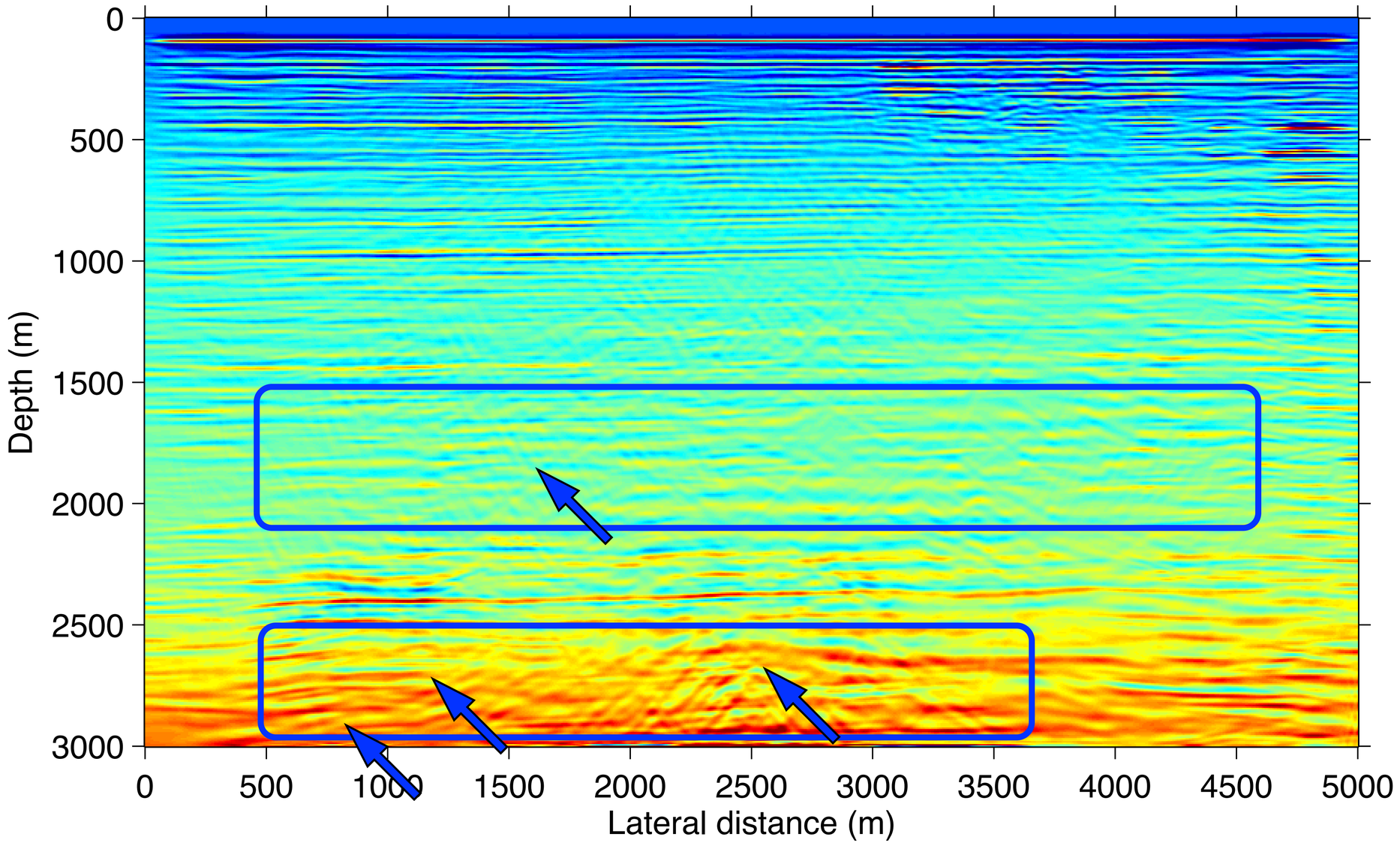
The image of total data

- better preserves major reflectors compared with using multiples alone.
- has *probably* better-resolved shallow part than using primaries or multiples alone.

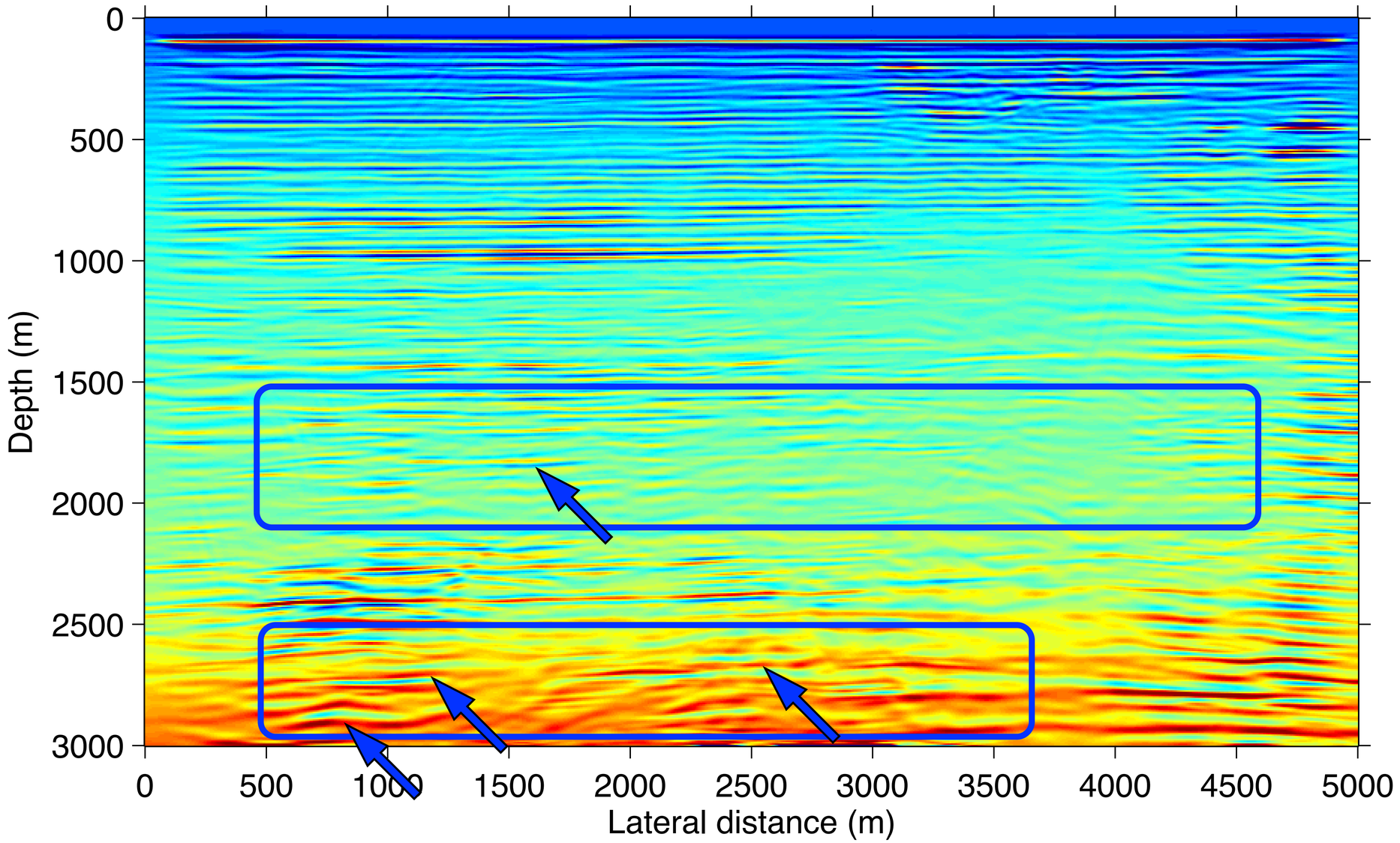
Inversion of primaries



Inversion of **multiples**



Inversion of **total data**



Observations

The image of total data

- better preserves major reflectors compared with using multiples alone.
- has *probably* better-resolved shallow part than using primaries or multiples alone.
- resolves the deeper part better than using multiple alone.

Conclusions

- Multiples are signals in seismic imaging if used properly.
  - Cross-correlation imaging does not apply to multiples.
  - Multiples can be imaged effectively by sparse inversion.
  - Multiples alone may not be enough to image deep earth.
- Compared to primaries, multiples
  - provide smaller incident angles.
  - complement primaries to image shallow earth.
- Joint imaging of primaries and multiples
  - is feasible using on-the-fly source estimation.
  - combines the benefits of primaries and multiples.

Future work

To further improve the image quality of the deeper part:

- more accurate modelling to improve the accuracy of multiple prediction.
- more robustness to velocity errors/noise in the data.

To extend the method for 3D field data applications.

Acknowledgements

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SINBAD

NSERC CRSNG

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