Multi-component deblending of marine data using a pattern-based approach

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Acknowledgements

1. Thanks to Kietta for providing and allowing us to show the data

2. Thanks to Dr. Stewart A. Levin for his help in rotating and preprocessing the data

3. Thanks to EAGE for sponsoring my travel

Can we use the geophone data to improve the deblending on the hydrophone?

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   (a) Up/Down separation

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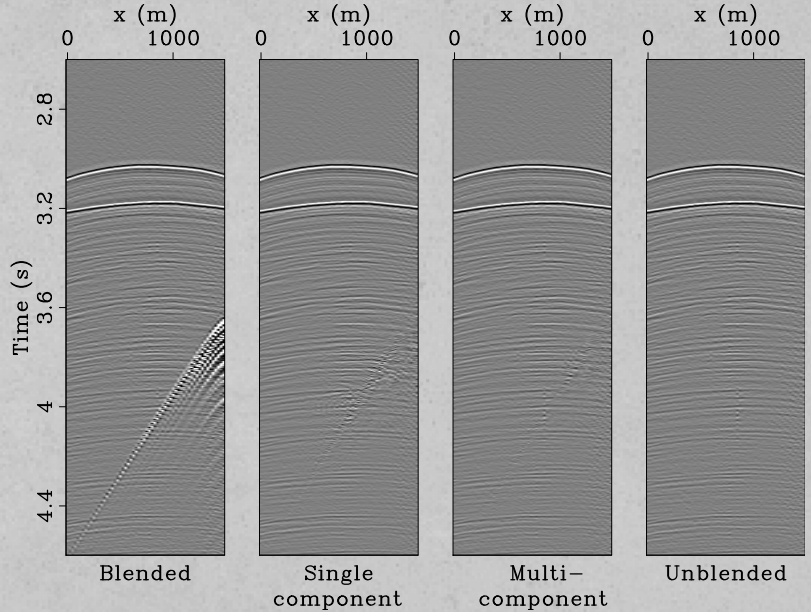
1. Shear waves
2. Ground-roll removal
3. P-wave directivity
   (a) Up/Down separation
   (b) **Deblending**

What I will show you

1. Comparison of single and multi-component approaches

2. Multi-component provides ~3X increase in SNR

Deblended hydrophone



Outline

1. Introduction
2. Theory
   - Pattern-based deblending
   - Multi-component pattern-based deblending
   - Synthetic example
3. Field data example
4. Conclusions and future work

Outline

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2. Theory
   - Pattern-based deblending
   - Multi-component pattern-based deblending
   - Synthetic example

3.

4.

Simultaneous source deblending

$$\widetilde{\mathbf{d}} = \mathbf{d}_1^s + \mathbf{d}_2^s$$

- $\widetilde{\mathbf{d}}$: recorded blended data
- $\mathbf{d}_1^s$, $\mathbf{d}_2^s$: time-shifted sources

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$$J(\mathbf{d}_1^s, \mathbf{d}_2^s) = \frac{1}{2}||\mathbf{d}_1^s + \mathbf{d}_2^s - \widetilde{\mathbf{d}}||_2^2 + \text{Regularization terms}$$

Pattern-based deblending

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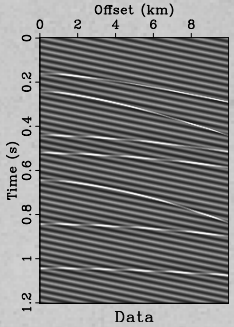
Additive signal and noise ($\mathbf{d} = \mathbf{s} + \mathbf{n}$)



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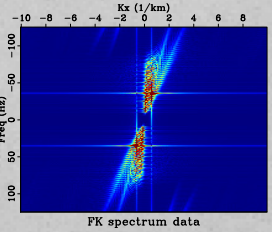
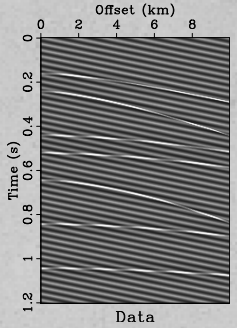


Additive signal and noise ($\mathbf{d} = \mathbf{s} + \mathbf{n}$)



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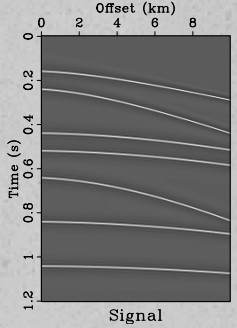

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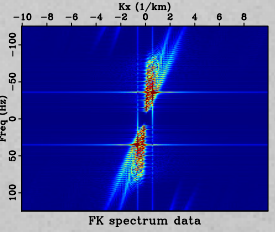
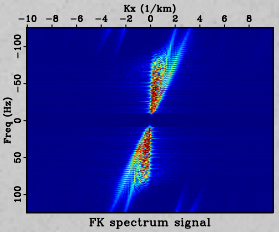
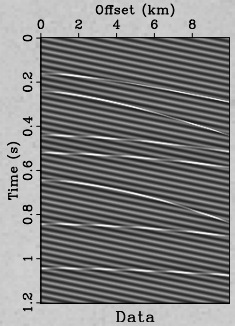




Additive signal and noise ($\mathbf{d} = \mathbf{s} + \mathbf{n}$)



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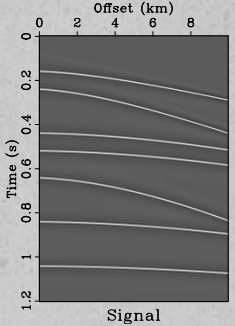

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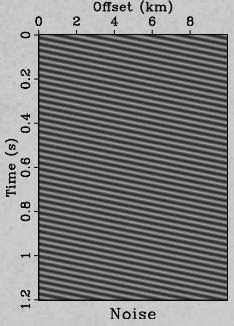
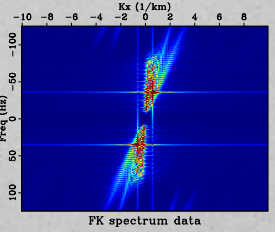
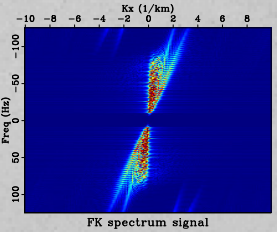
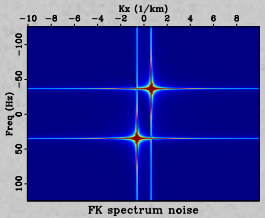
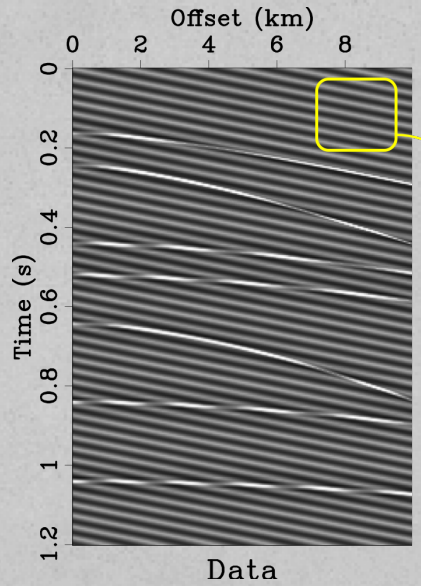


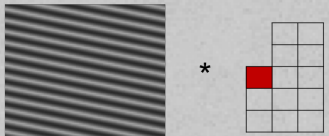






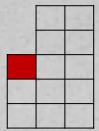
Estimate prediction-error filter (PEF)





$$\mathbf{Nn} \approx \mathbf{0}$$

Apply noise PEF to data



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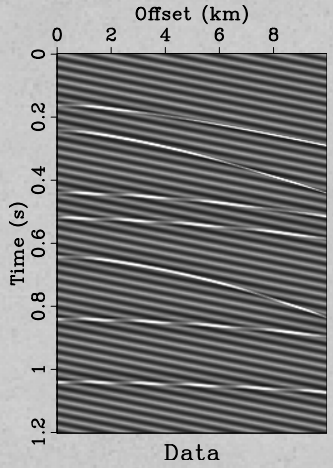

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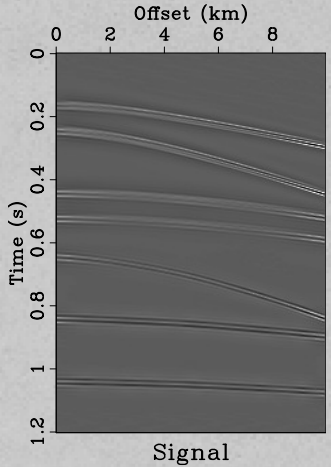

$$\mathbf{Nd} = \mathbf{N}(\mathbf{s} + \mathbf{n}) \approx \mathbf{s},$$

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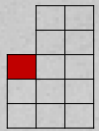

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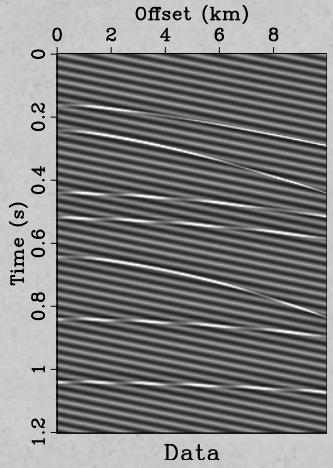

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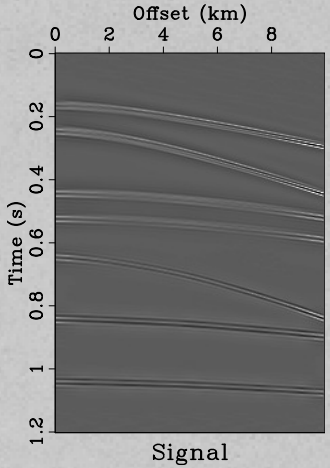


$$\mathbf{Nd} = \mathbf{N}(\mathbf{s} + \mathbf{n}) \approx \mathbf{s},$$

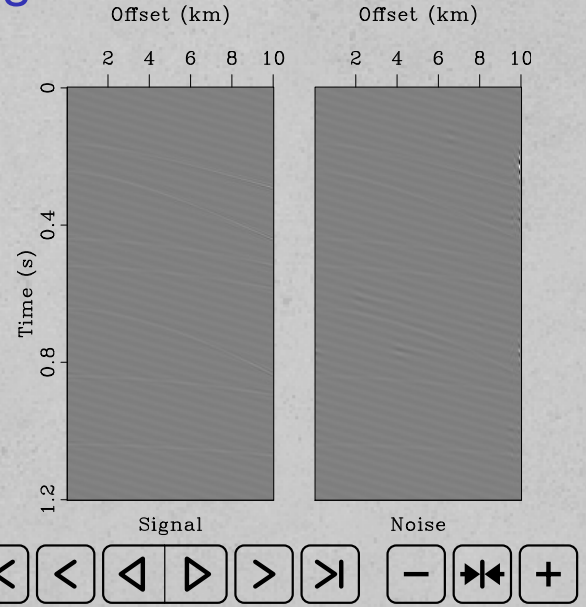
$$\mathbf{Ss} \approx \mathbf{0}$$

Signal and noise separation inversion

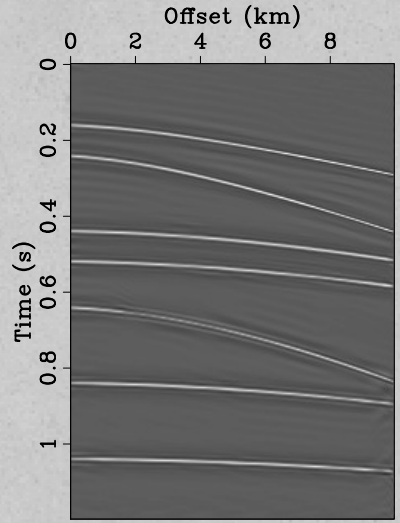
$$\mathbf{s}^*, \mathbf{n}^* = \underset{\mathbf{s},\mathbf{n}}{\text{argmin}} \frac{1}{2}||\mathbf{s}+\mathbf{n}-\mathbf{d}||_2^2 + \frac{\epsilon^2}{2}||\mathbf{S}\mathbf{s}||_2^2 + \frac{\epsilon^2}{2}||\mathbf{N}\mathbf{n}||_2^2$$

- $\mathbf{d}$: data
- $\mathbf{s}^*$: estimated signal
- $\mathbf{n}^*$: estimated noise
- $\mathbf{S}$: PEF estimated on signal pattern (proxy)
- $\mathbf{N}$: PEF estimated on noise pattern (proxy)

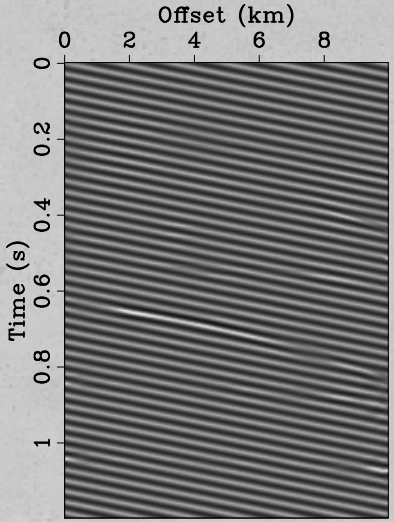
Signal and noise inversion



Estimated signal and noise



Estimated signal



Estimated noise

Pattern-based method and deblending

- Additive signal and noise model: $\tilde{\mathbf{d}} = \mathbf{\Gamma d}$
- Non-stationary PEFs allow for non-stationary signal and noise
- **Biggest challenge**: finding the pattern!

$\tilde{\mathbf{d}}$: blended data, $\mathbf{d}$: unblended data, $\mathbf{\Gamma}$: blending operator

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  - Combining direct imaging and data space deblending - (Jennings et al., SEG 2018)

$\widetilde{\mathbf{d}}$: blended data, $\mathbf{d}$: unblended data, $\mathbf{\Gamma}$: blending operator

MC data and the pattern-based method

- Multi-component data provide directional patterns

- **How can we use PEFs to capture these patterns?**

Relationship between pressure and velocity

- Euler's linearized conservation of momentum (acoustic medium):

$$\rho \frac{\partial \mathbf{v}(\mathbf{x}, t)}{\partial t} = -\nabla p(\mathbf{x}, t)$$

  - $\mathbf{v}(\mathbf{x}, t)$: acoustic particle velocity
  - $p(\mathbf{x}, t)$: pressure
  - ρ: density

Relationship between pressure and velocity

$$\Rightarrow \mathbf{v}(\mathbf{x}, t) = -\frac{1}{\rho} \int_0^T \nabla p(\mathbf{x}, t) dt$$

- They are linearly related
- We can use a PEF to find this relationship

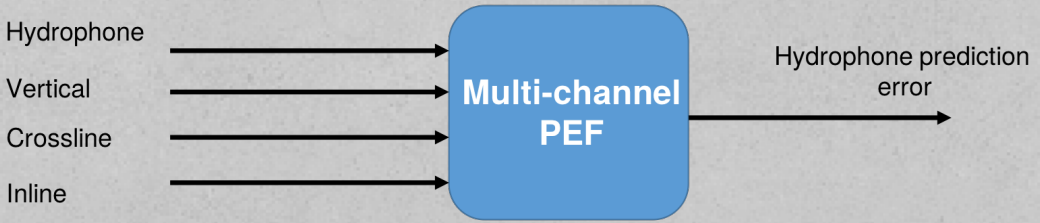
Multi-channel PEF

Single channel PEF:

Multi-channel PEF

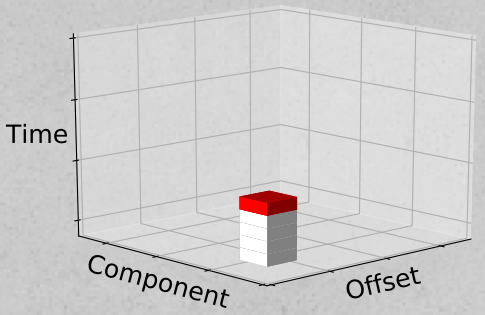
Single channel PEF:

Multi-channel PEF:

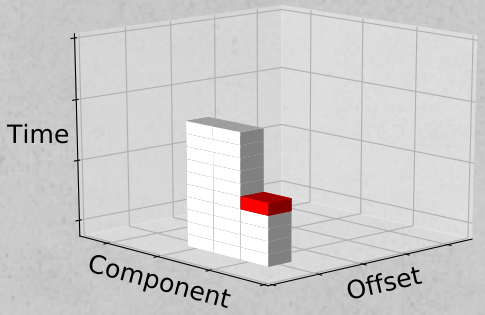


PEF stencils in 1D

Single component

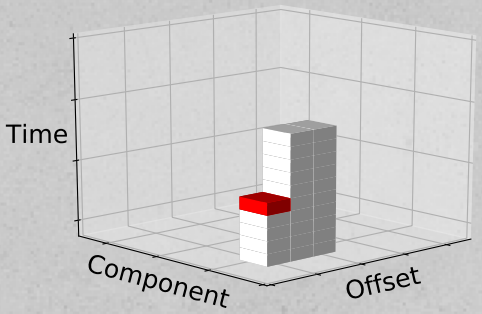


Multi-component

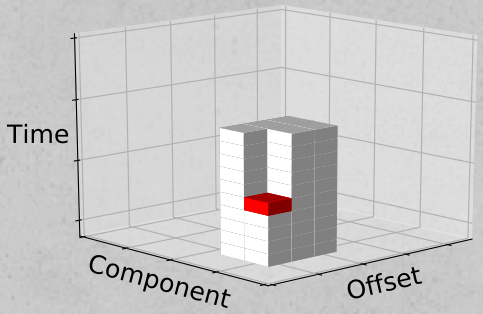


PEF stencils in 2D

Single component



Multi-component

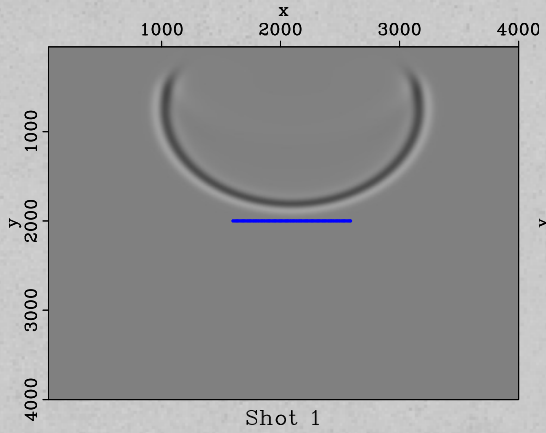


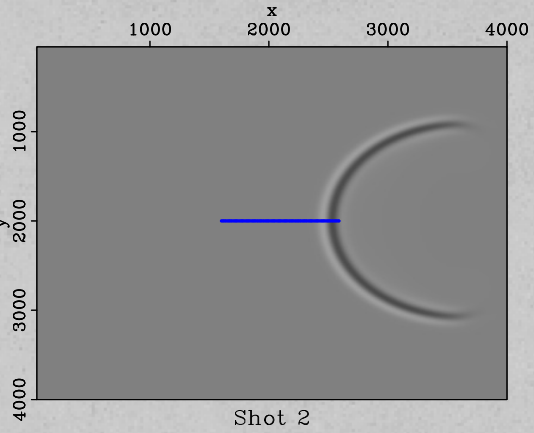
Different units between p and $\mathbf{v}$

- Pressure data: [Pa]
- Particle velocity: [m/s]
- PEFs are dimensionless $\Rightarrow$ scale by acoustic impedance
- PZ summation: $p + \rho c v$

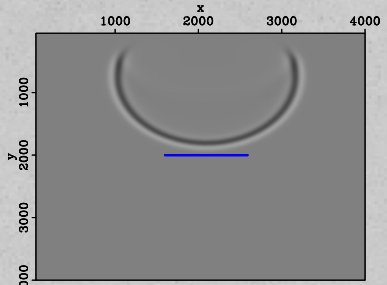
Synthetic example

Two shots - different azimuths

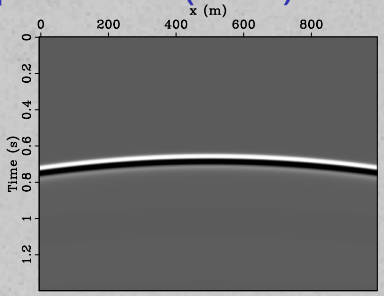




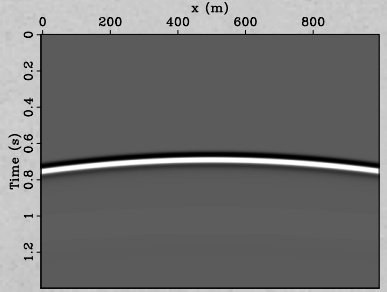
Shot one - multi-component (MC) data



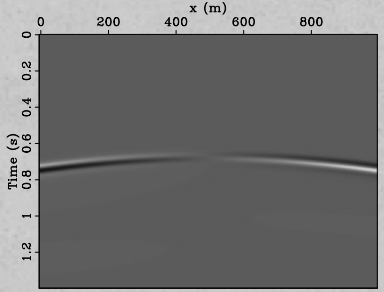
Shot 1



Pressure

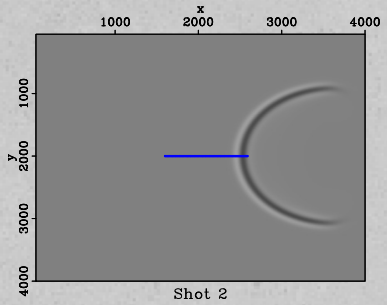


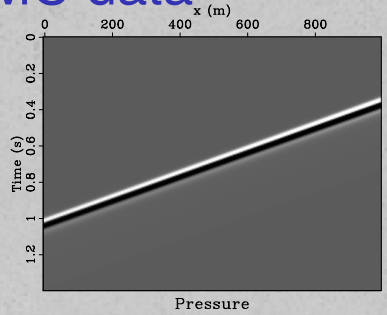
Y component

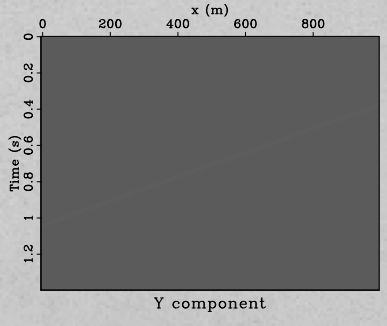


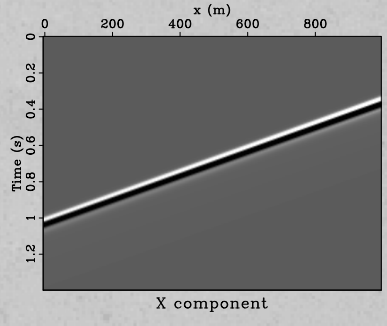
X component

Shot two - MC data

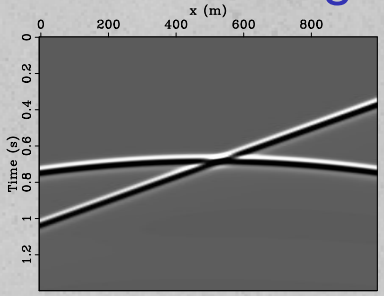


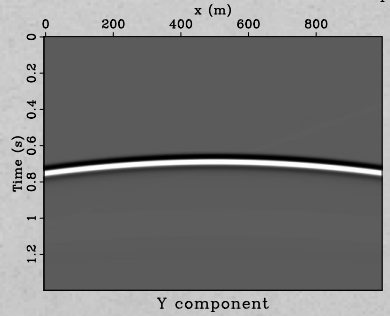


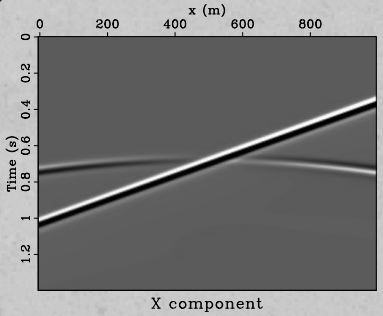




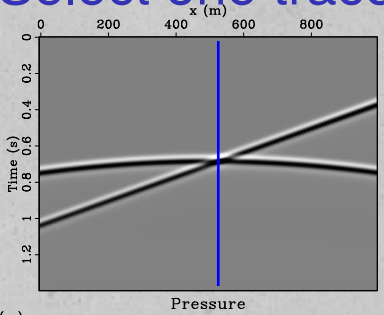
Blended MC shot gathers

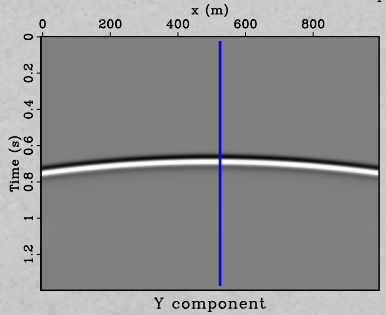


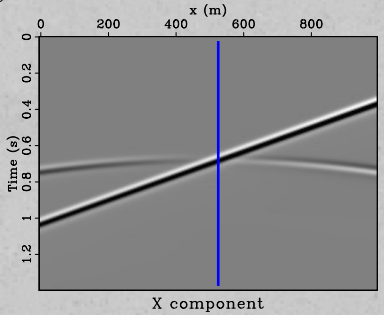




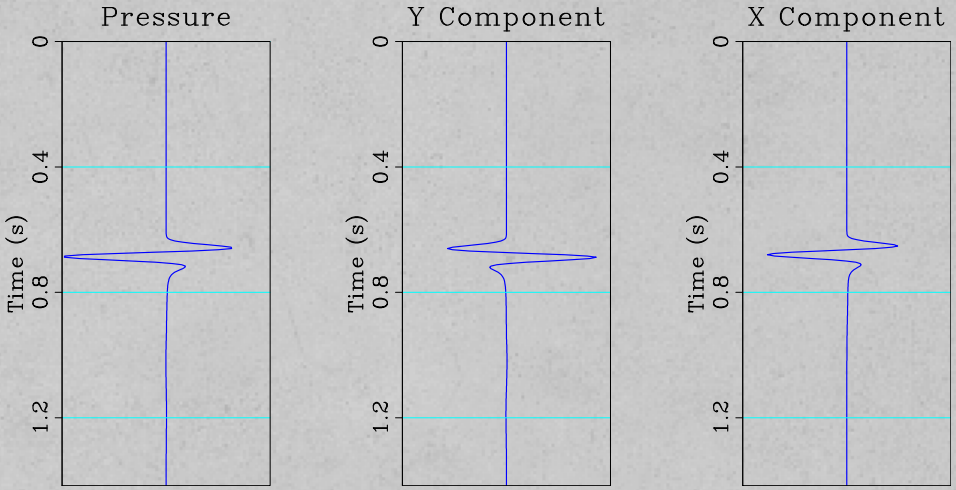
Select one trace



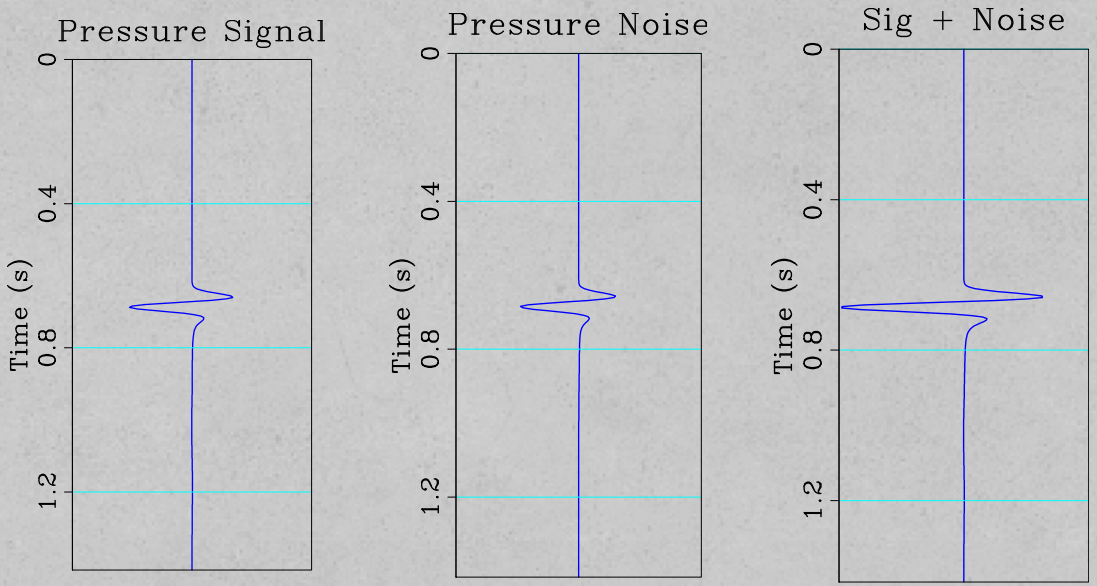




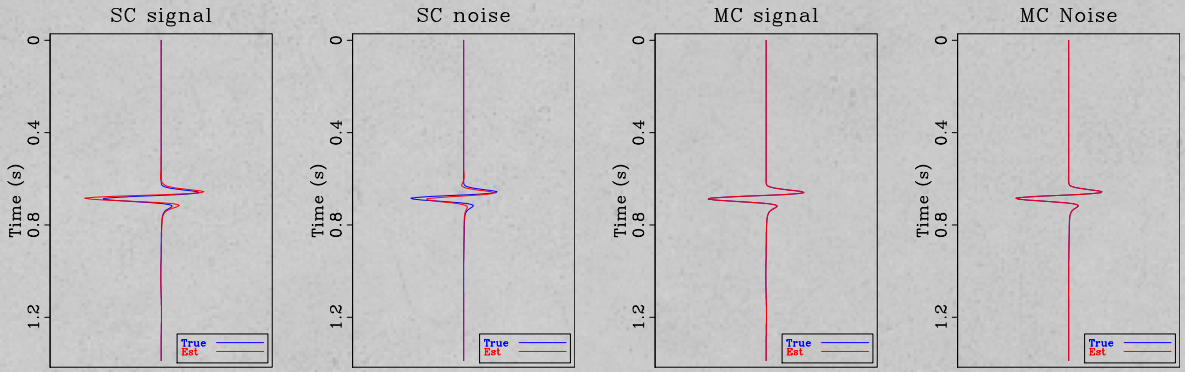
Single trace of blended MC data



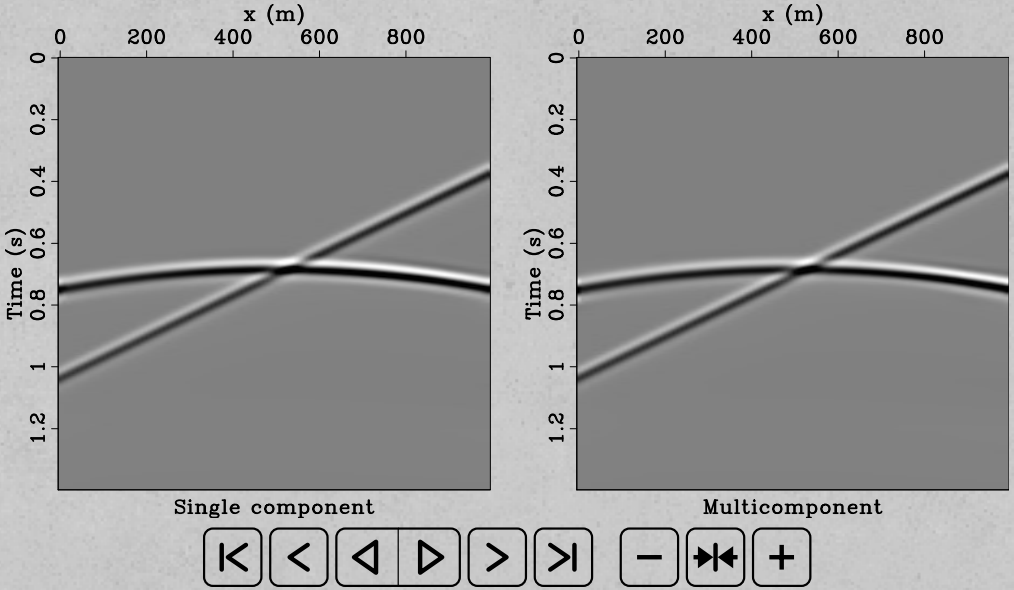
Complete overlap



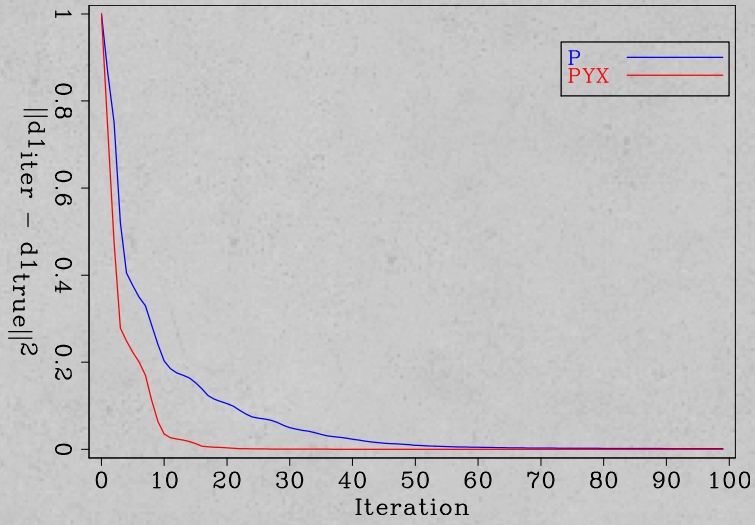
Hydrophone - recovered signal and noise



Hydrophone deblending comparison



Hydrophone model residual



Outline

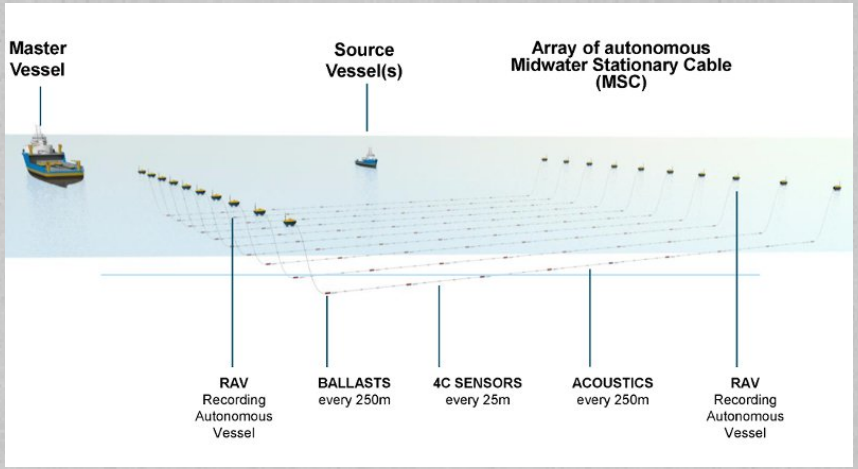
1.

2.

3. Field data example

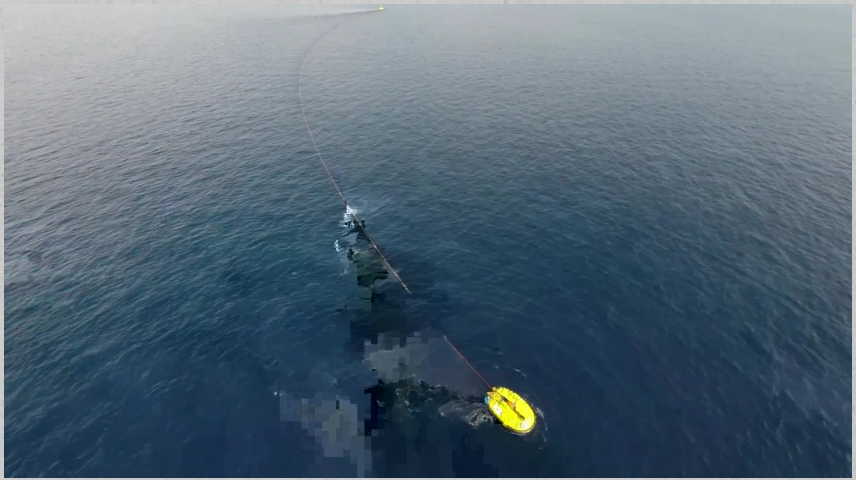
4.

FreeCable™ data



source: https://geoexpro.com/articles/2017/03/the-future-of-marine-seismic-acquisition

Aerial view

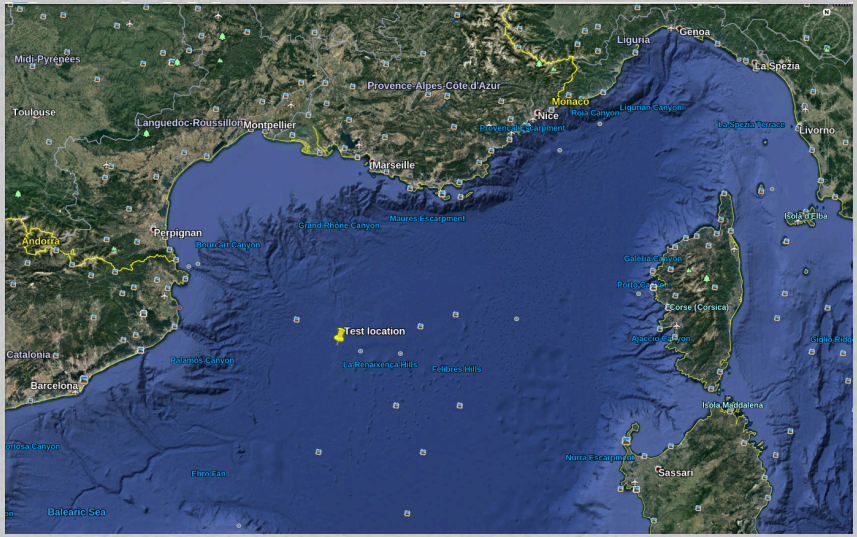


source: Kietta, 2016

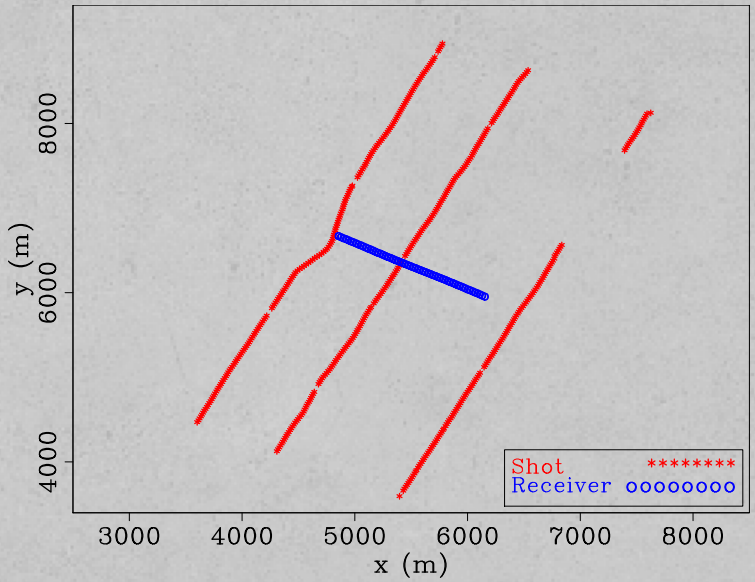
Side view

source: https://geoexpro.com/articles/2017/03/the-future-of-marine-seismic-acquisition

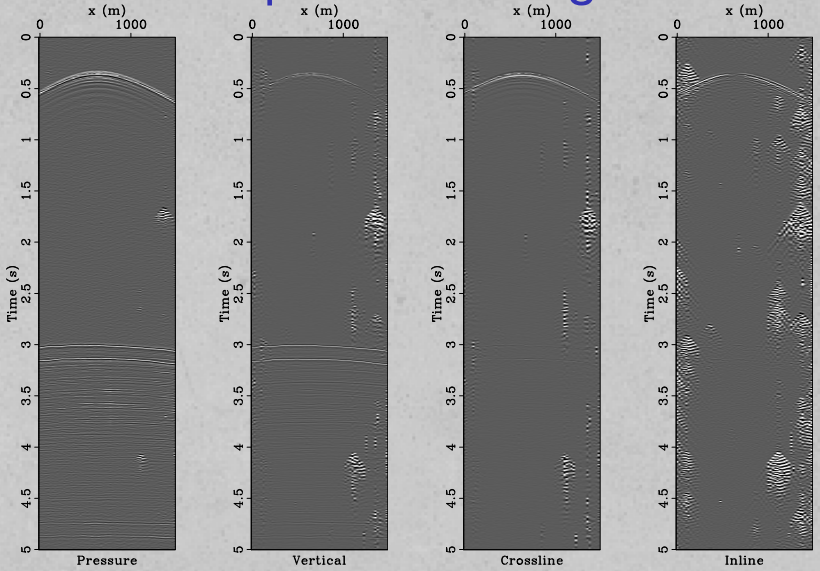
Test survey in Med. Sea



Acquisition geometry

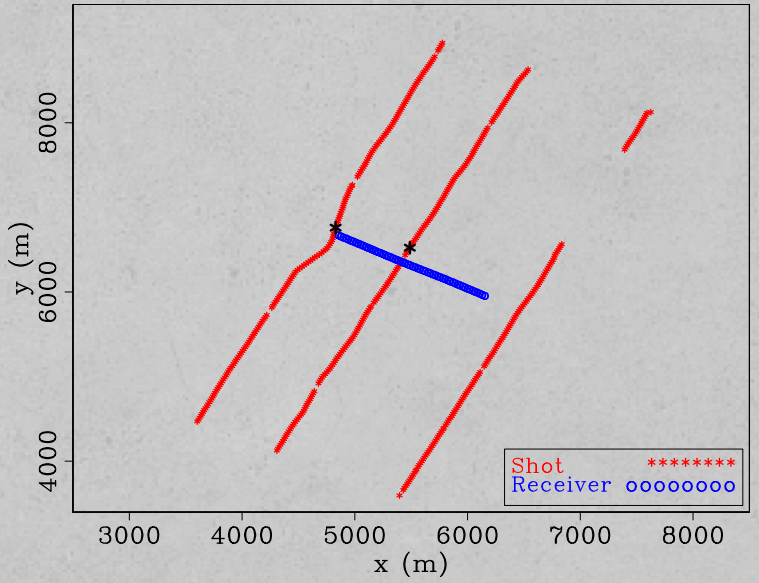


Multi-component shot gathers

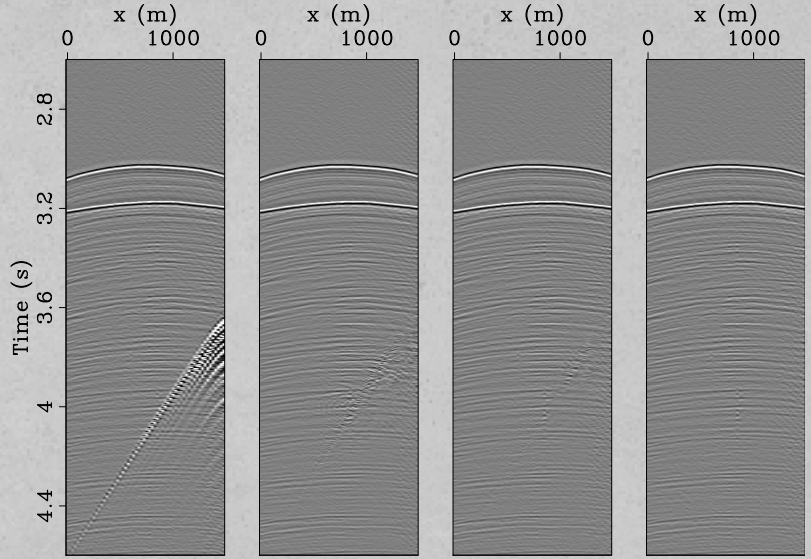


Please note: data from early system. Noise problem has been fixed.

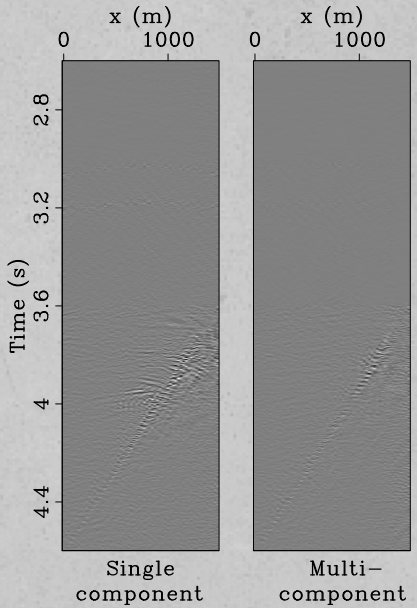
Inline crossline shots



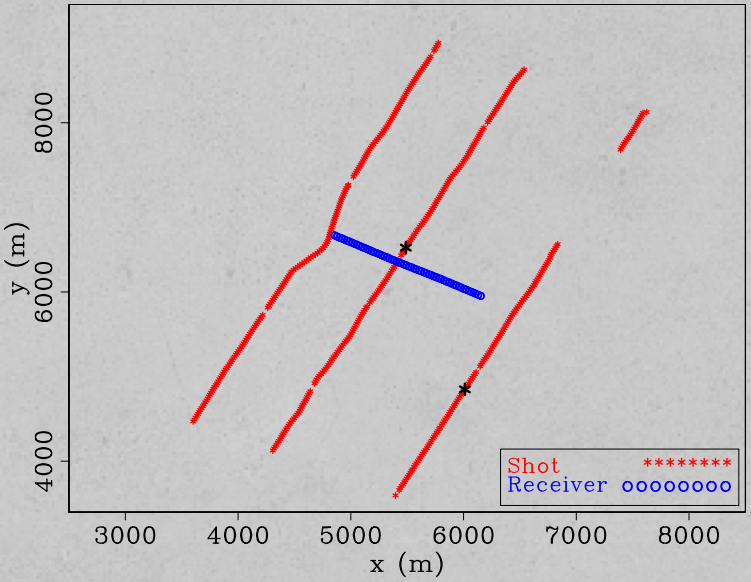
Deblended hydrophone



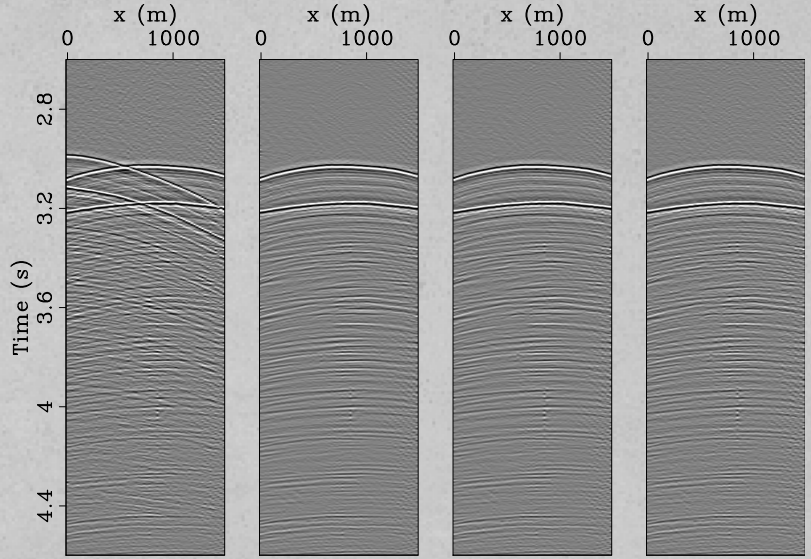
Deblended residual



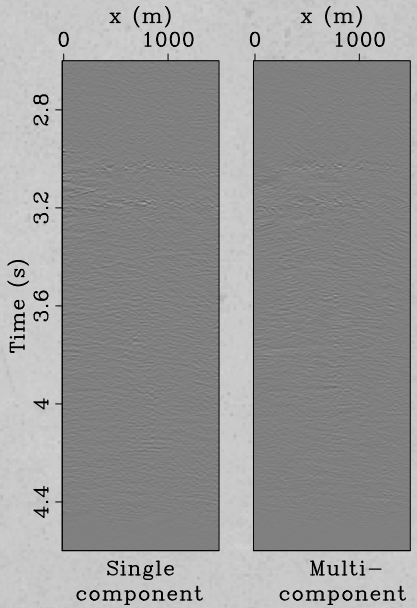
Inline crossline shots



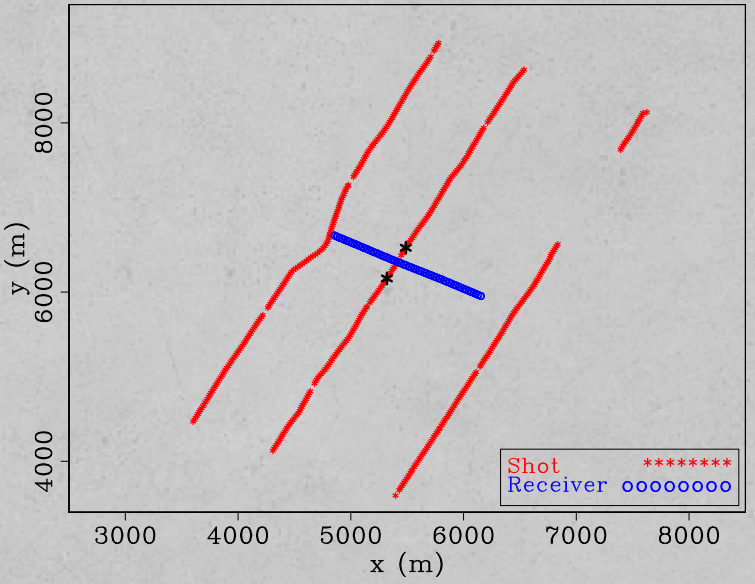
Deblended hydrophone



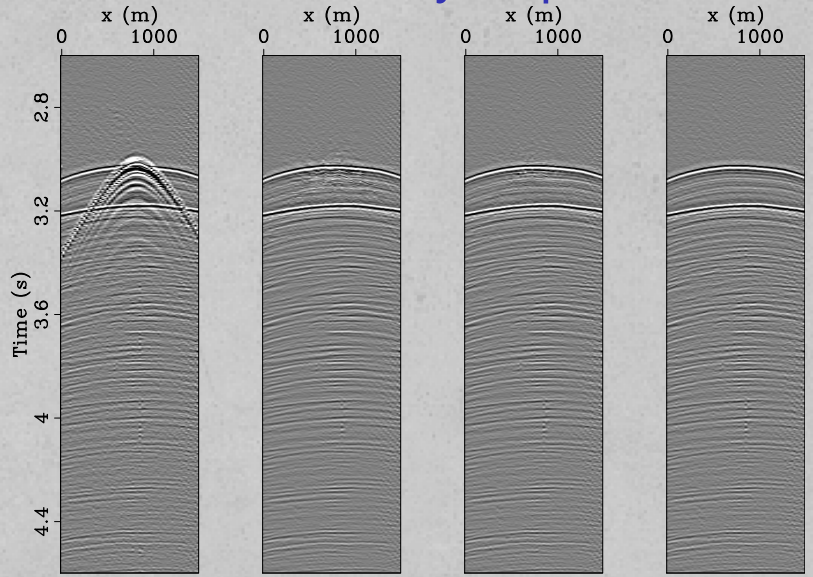
Deblended residual



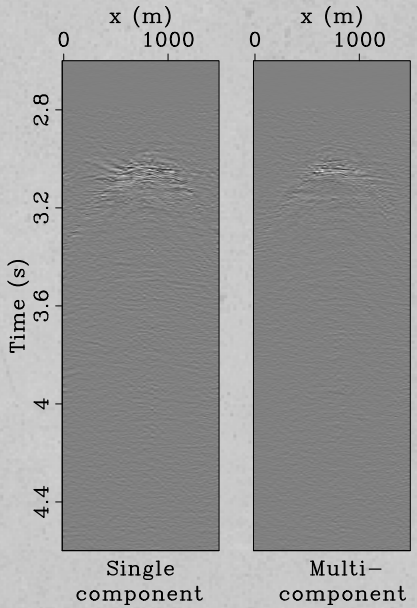
Crossline shots



Deblended hydrophone



Deblended residual



Outline

1.

2.

3.

4. Conclusions and future work

Conclusions/future work

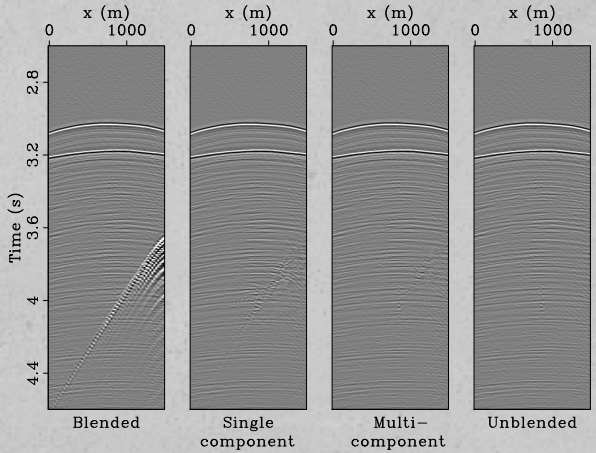
1. Pattern-based method works for multi-component data

2. Provides an increase in SNR (3X)

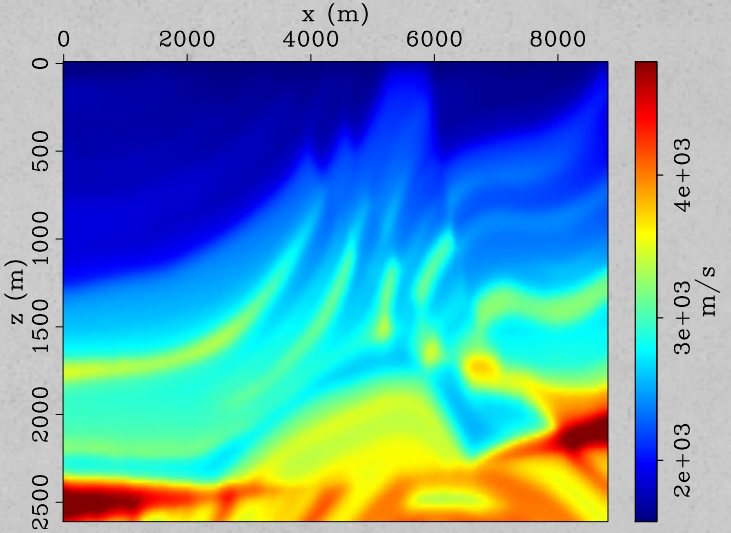
3. Ongoing theoretical development

4. Apply to ocean-bottom node data

Questions?


x (m)
0
1000
x (m)
0
1000
x (m)
0
1000
x (m)
0
1000
Time (s)
2.8
3.2
3.6
4
4.4
Blended
Single component
Multi–component
Unblended

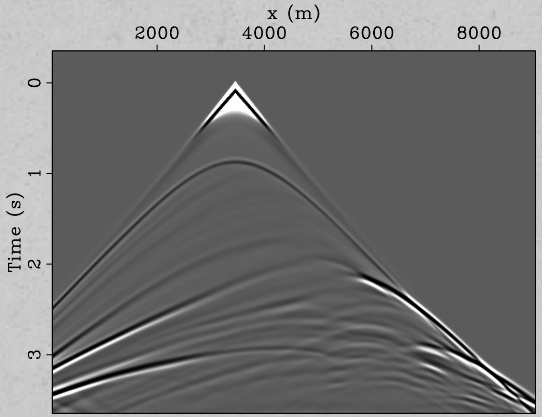
Known quantities

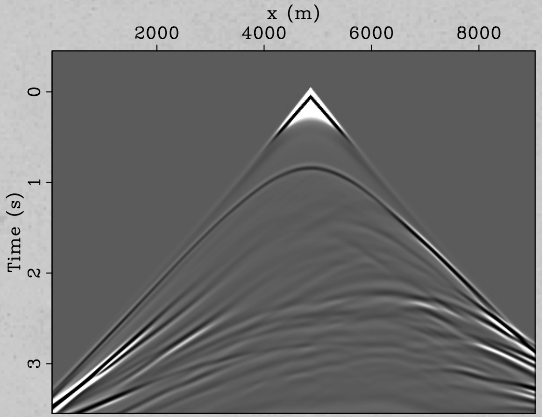


Known

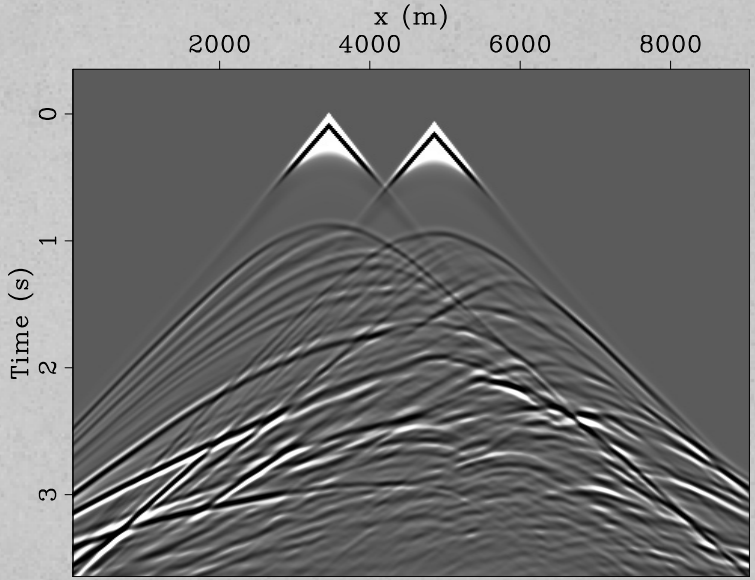
1. $\mathbf{m}_0$
2. Shot positions $\mathbf{x}_i$
3. Shot times t_i

Finite-difference modeling

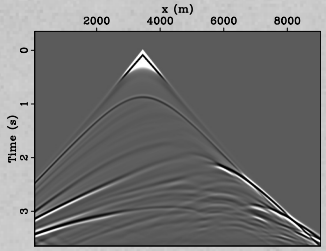


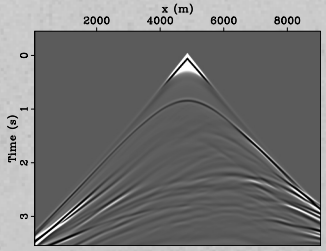


Blended data

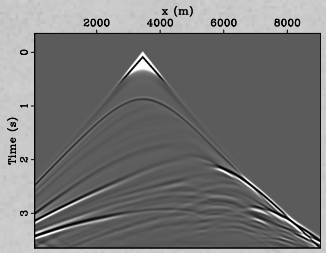


PEF estimation on unblended shots





PEF estimation on unblended shots



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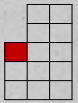

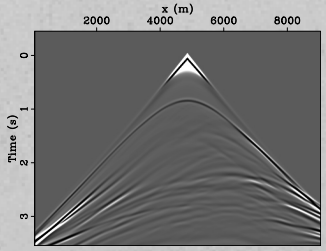

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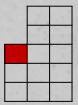
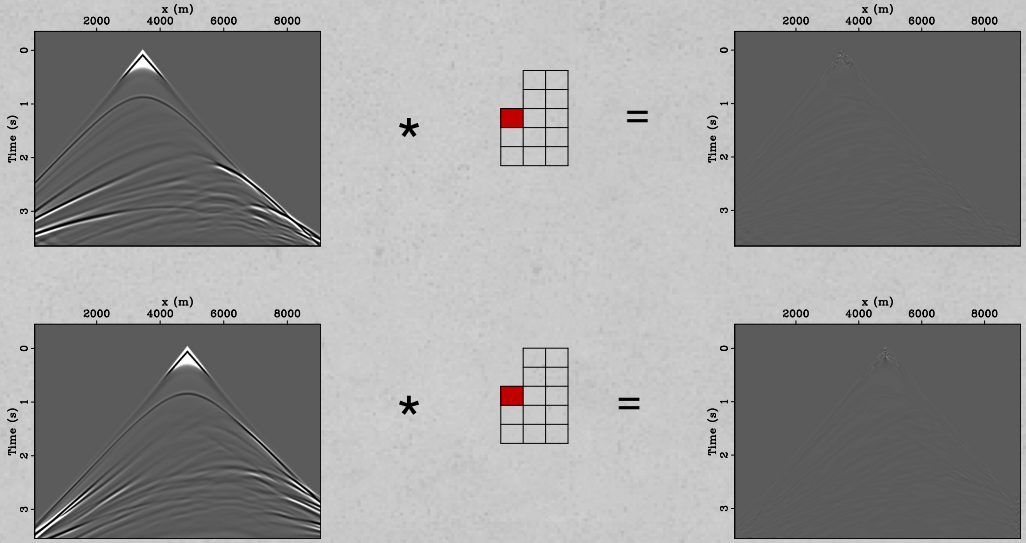
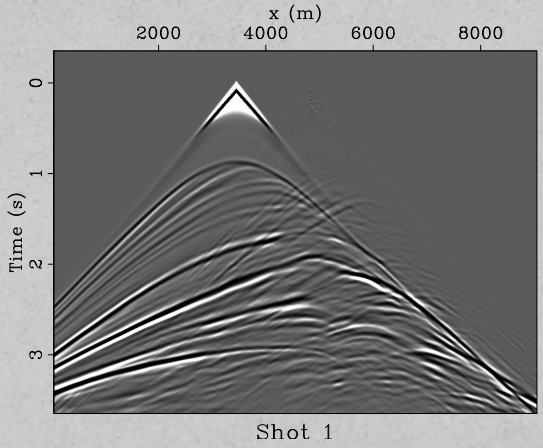
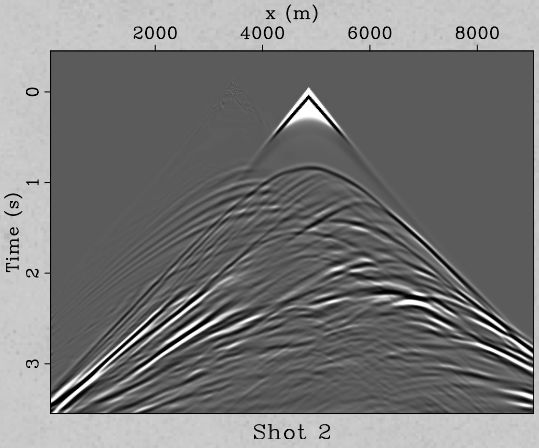


PEF estimation on unblended shots



Deblended data





Direct imaging of blended data

1. Estimate velocity on deblended data

Direct imaging of blended data

1. Estimate velocity on deblended data

2. Perform deblending again on modeled data

Direct imaging of blended data

1. Estimate velocity on deblended data

2. Perform deblending again on modeled data

3. Direct imaging and data-space deblending, Jennings, et al., **SEG 2018**