Full Waveform Inversion algorithm using Common Scatter Points gathers

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2011 CREWES Annual Sponsors Meeting

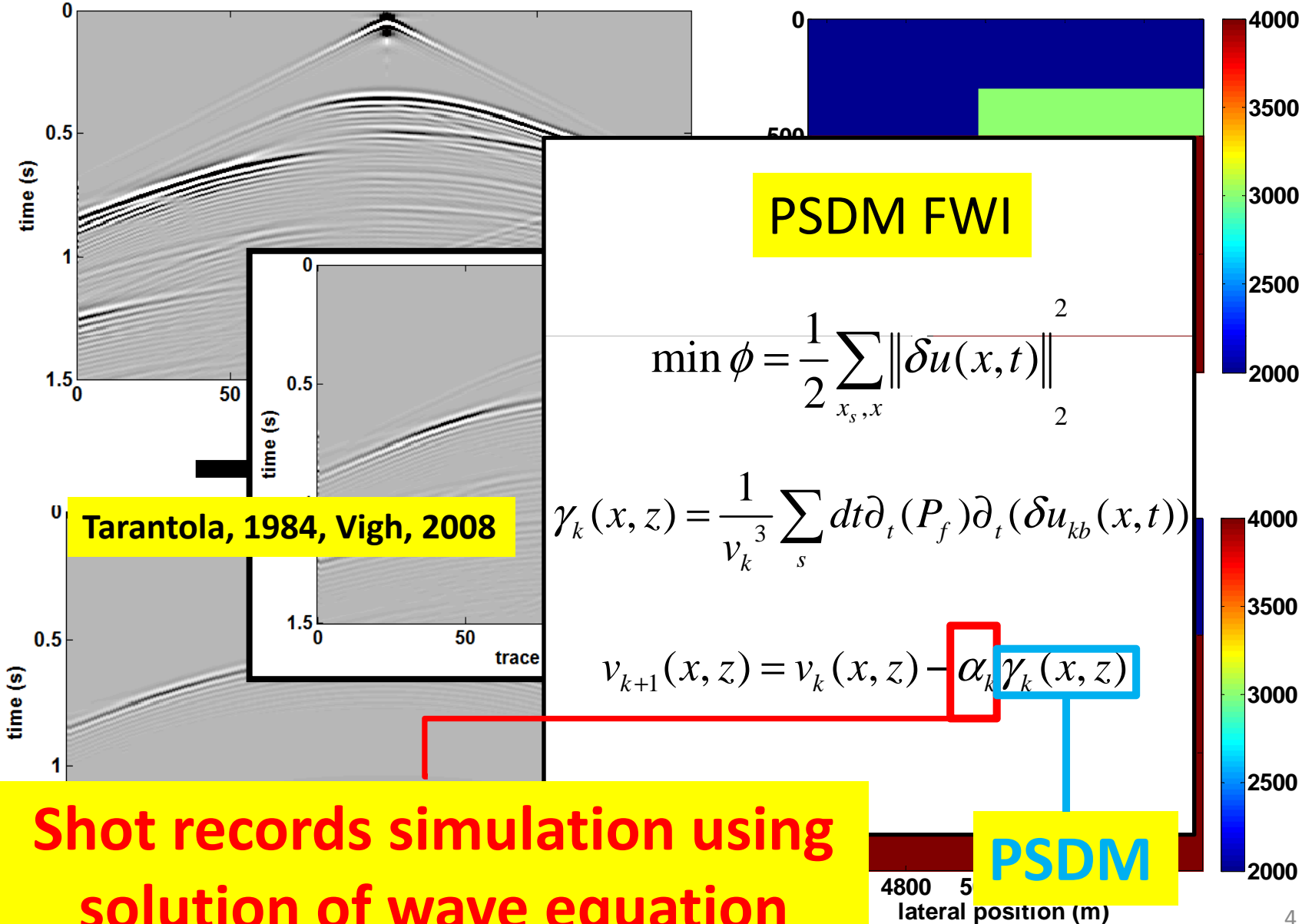December,02,2011

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Outline

- Review of Full Waveform Inversion

- PSTM Full Waveform Inversion algorithm

- Examples

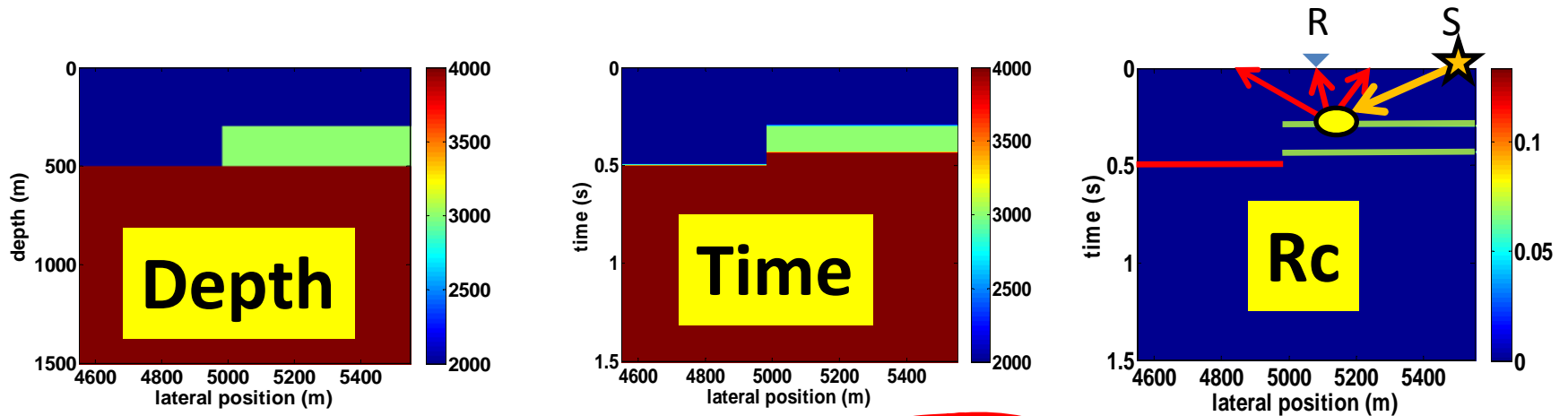- Discussions

- Conclusions

Review

- Nonlinear geophysical optimization process

- Born in mid 1980s due to pioneering work of Lailly(1983) & Tarantola (1984,1986,1988), well developed in more than two decades

- Forward modeling tool including wave equation modeling

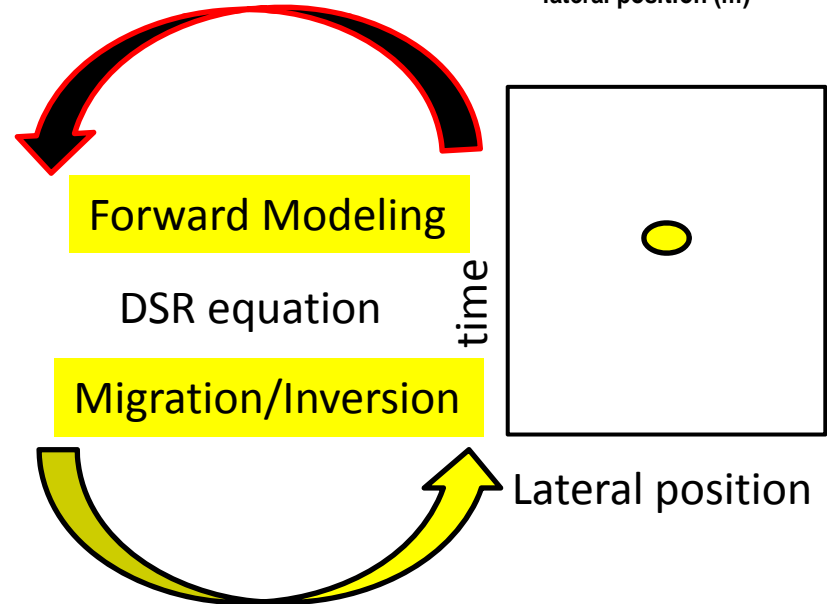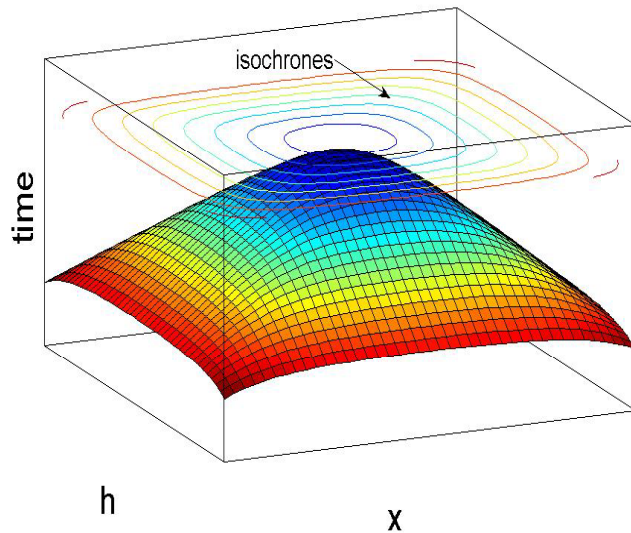- Inverse problem can be solved with gradient based linear iterative methods
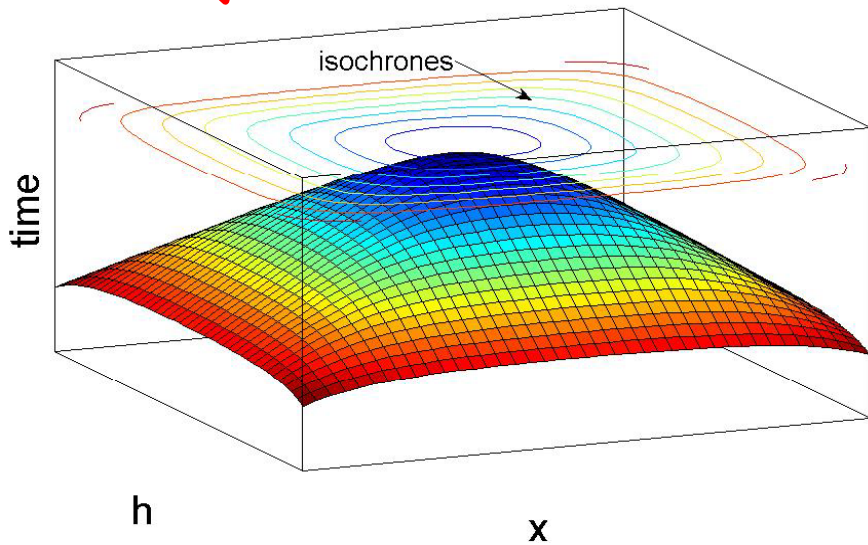
Theory of PSDM FWI

PSDM FWI

Tarantola, 1984, Vigh, 2008

$$\min \phi = \frac{1}{2} \sum_{x_s, x} \overline{\|\delta u(x,t)\|}_2^2$$

$$\gamma_k(x,z) = \frac{1}{v_k^3} \sum_s dt \partial_t (P_f) \partial_t (\delta u_{kb}(x,t))$$

$$v_{k+1}(x,z) = v_k(x,z) - \alpha_k \gamma_k(x,z)$$

Shot records simulation using solution of wave equation

PSDM

trace

time (s)

4800   5

lateral position (m)

4

Prestack Time FWI

X= Distance between scatterpoint and S/R CMP

h=Half S/R offset

CSP gather

CSP gather

DSR curve

isochrones

time

h   x

$$t(S,G) = \sqrt{\frac{\tau^2}{4} + \frac{(X+h)^2}{v^2}} + \sqrt{\frac{\tau^2}{4} + \frac{(X-h)^2}{v^2}}$$

τ

time

0
equivalent offset (h_e)

$$t(S,G) = \sqrt{\tau^2 + \left(\frac{2h_e}{v}\right)^2}$$

X= Distance between scatterpoint and S/R CMP

h=Half S/R offset
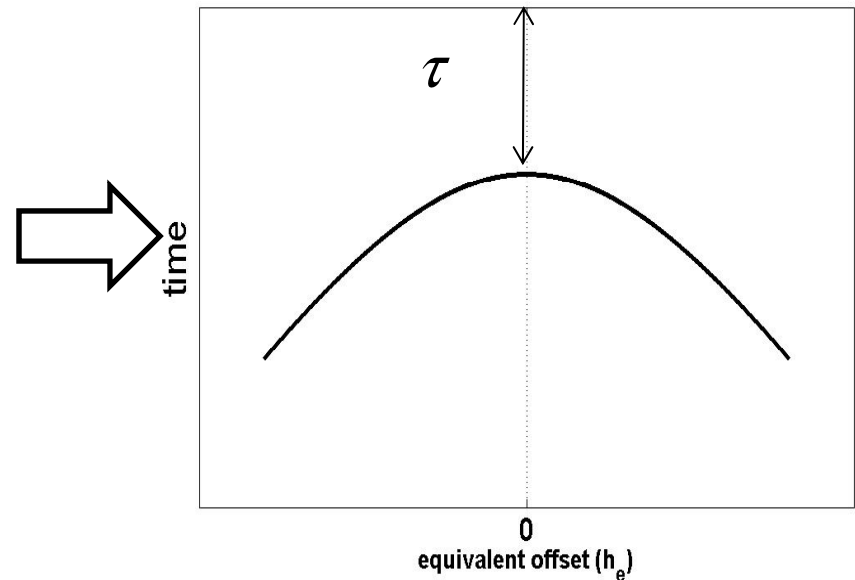
linearization

$$R_c(x,\tau) = -\frac{1}{4}\frac{\partial}{\partial\tau}L\mathrm{n}\left(\frac{1}{v(x,\tau)}\right)^2$$

$$\frac{1}{(v+\delta v)^2} = \frac{1}{v^2(x,\tau)} - \frac{2\delta v}{v^3(x,\tau)} + o(\delta v)^2$$

$$\delta u(x,h,t) = \int K \times \left(\frac{\delta v(x',\tau=\sqrt{t^2-\frac{4h_e^2}{v^2}})}{v^3(x',\tau)} * \ddot{s}(\tau)\right) d\tau dh_e dx'.$$

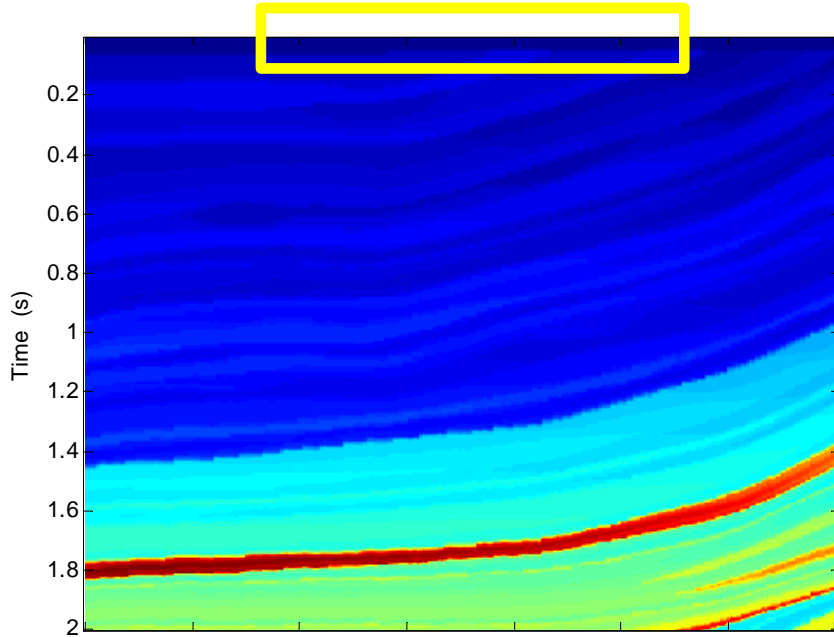$$\gamma(x,\tau)$$

Gradient Computation
PSTM vs PSDM

True Velocity **initial Velocity** **gradient**

z_1

z_2

depth

PSDM FWI

True Velocity **initial Velocity** **gradient**

τ_1

τ_2
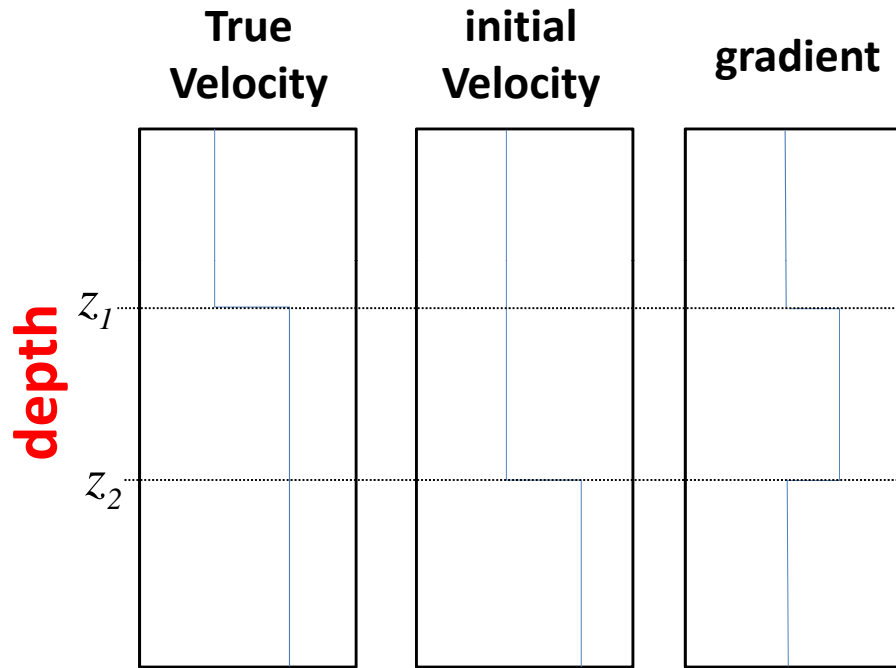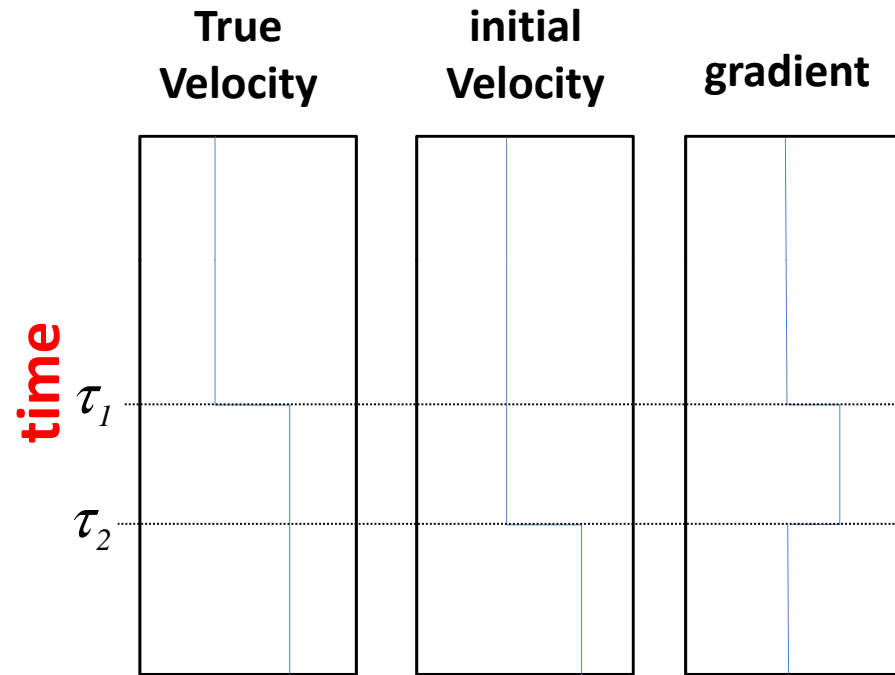
time

PSTM FWI

Innanen, 2011,
Geophysical inversion II: seismic inversion:U of Calgary,
unpublished course notes.

Algorithm of PSTM FWI

$v_{starting}(\,x,\tau\,)$

$v_{rms}(\,x,\tau\,)$

calculate $\delta u(\,x,t\,)$

$\|\delta u(\,x,t\,)\|$ small enough ?

Calculate $\gamma(\,x,\tau\,)$

Scan for optimum α

Update $v(\,x,\tau\,)$

No

yes

End
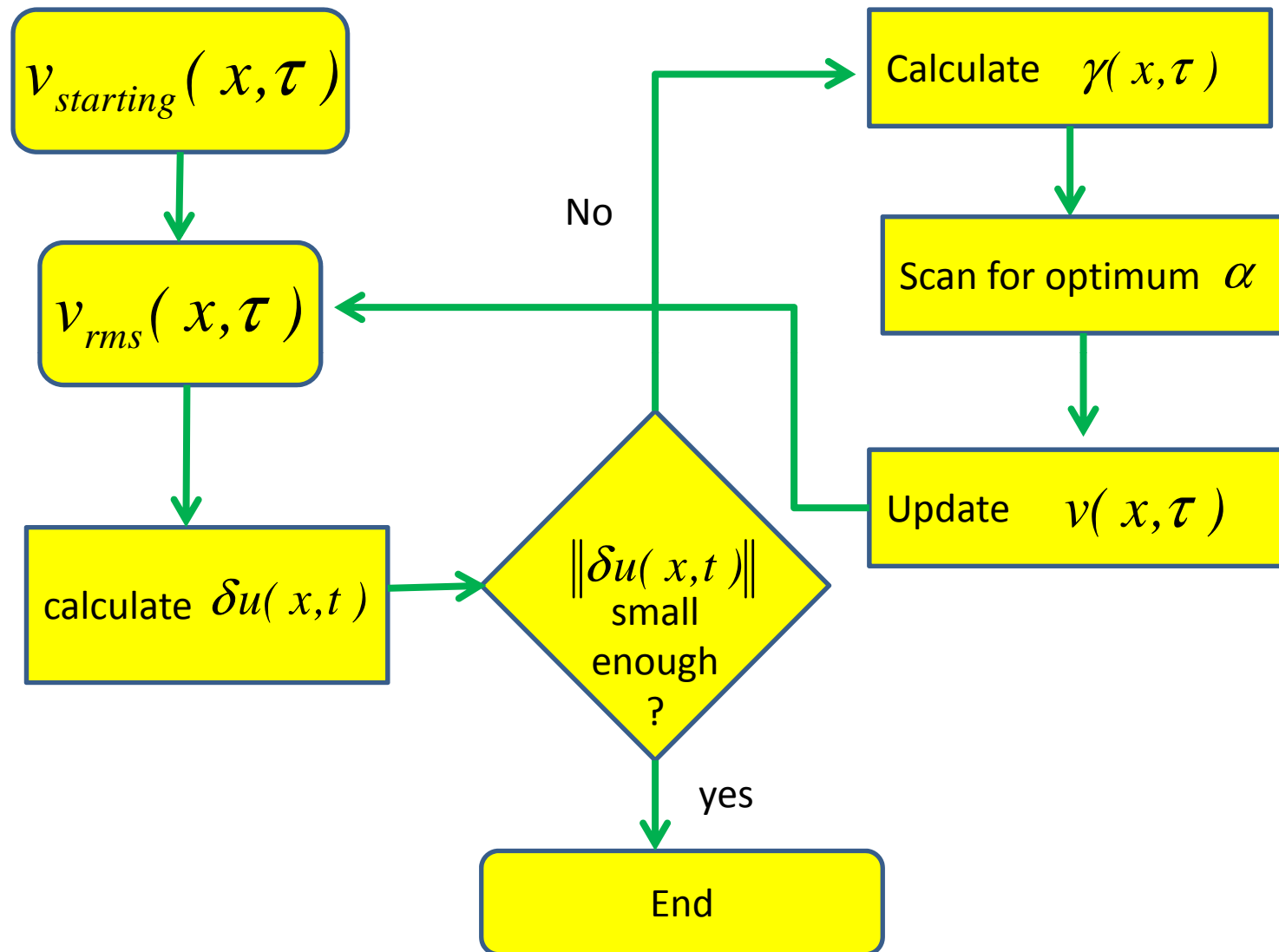
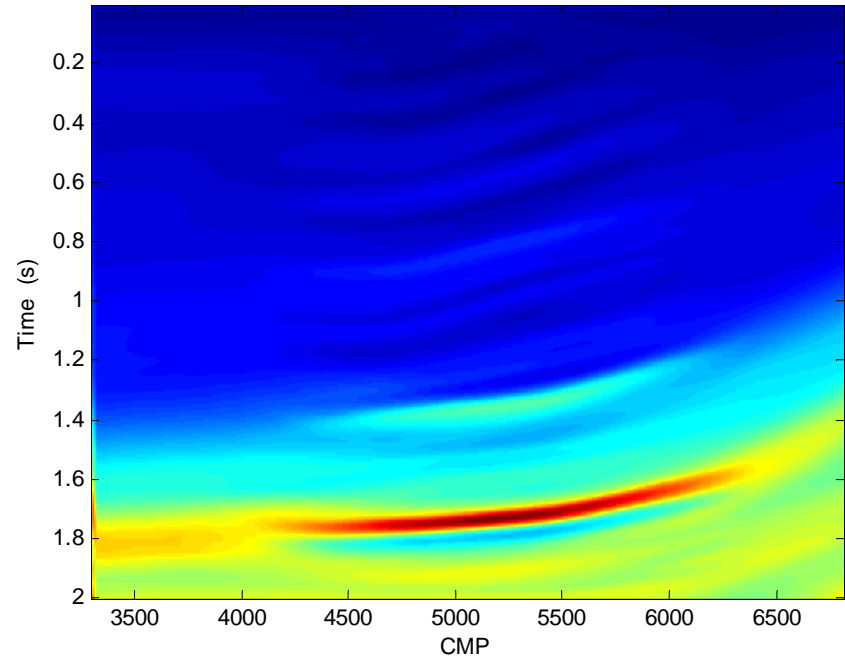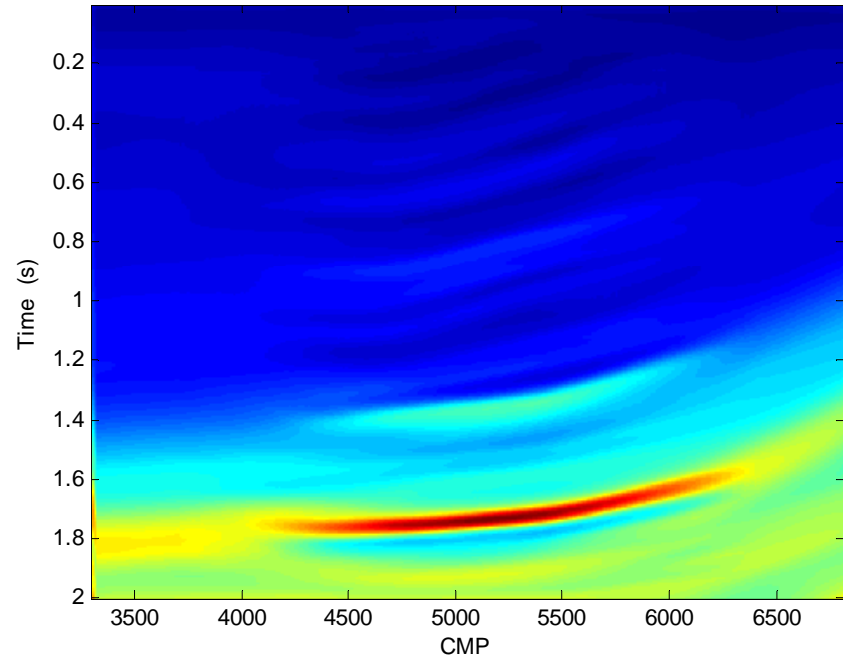# Synthetic Example

21 shot records

true velocity in time
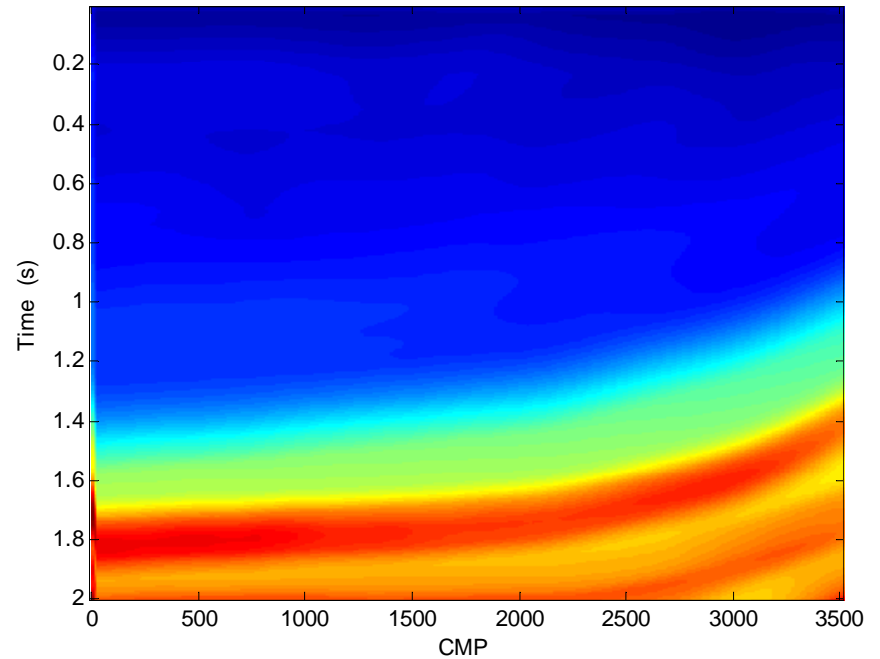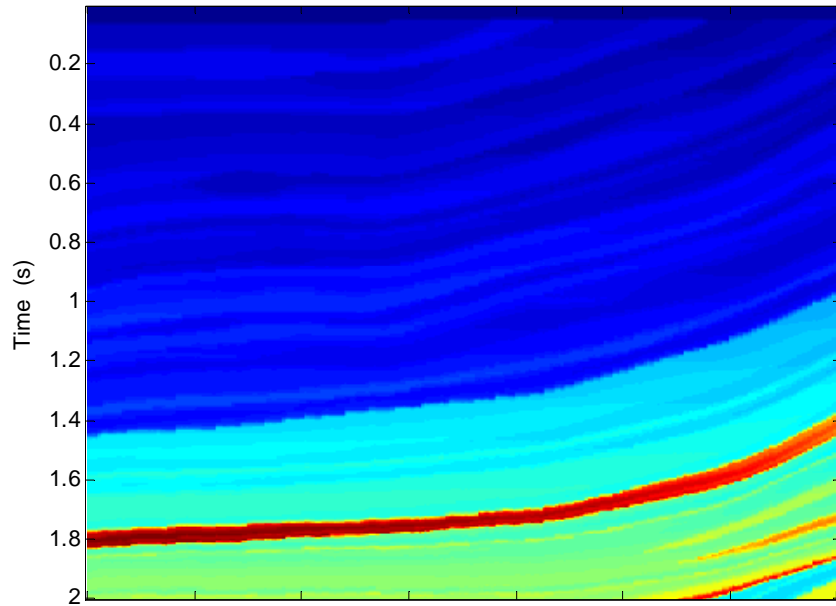
initial velocity in time

Synthetic Example
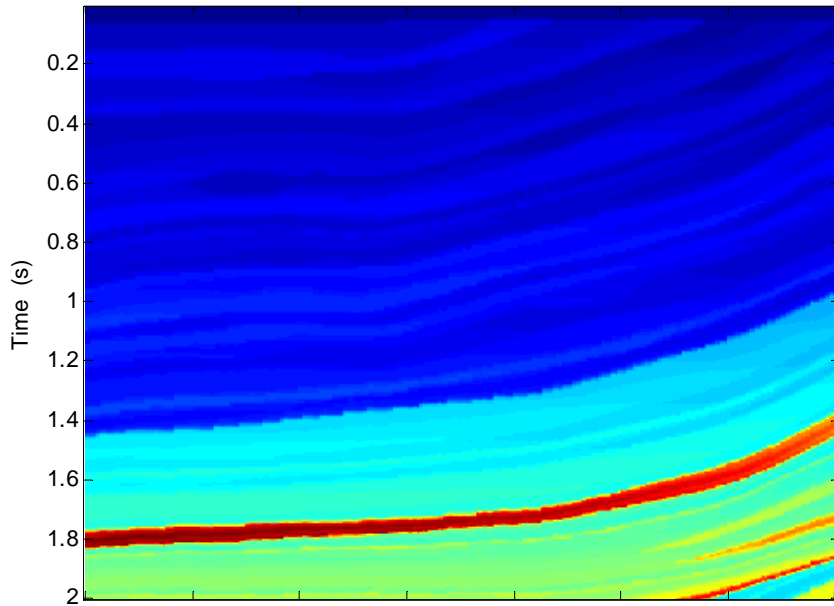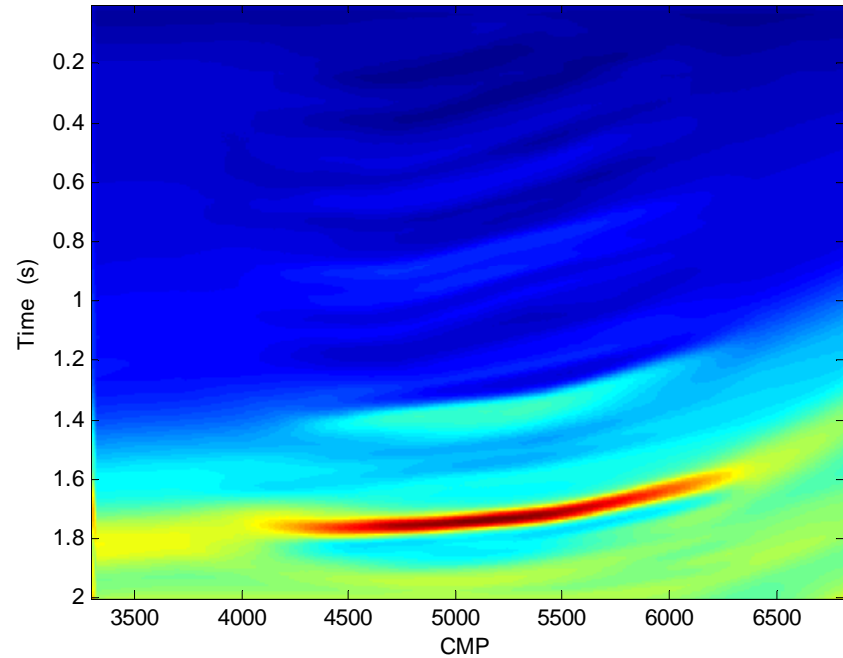

true velocity in time
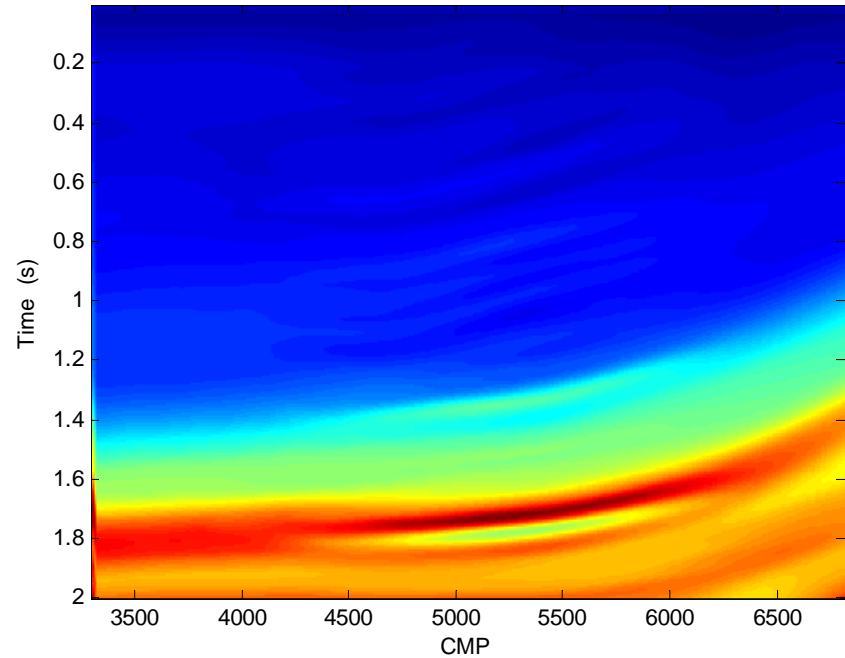
updated velocity Iteration 5

Synthetic Example
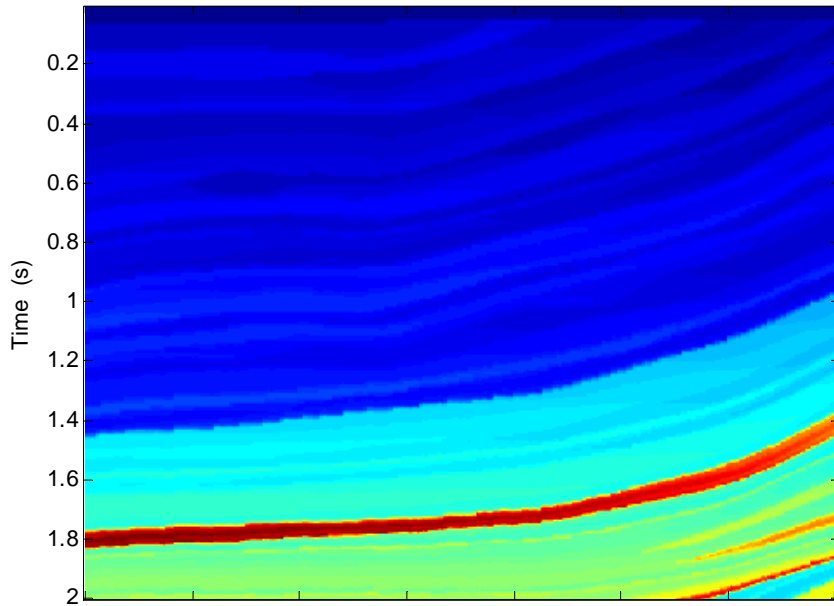
true velocity in time
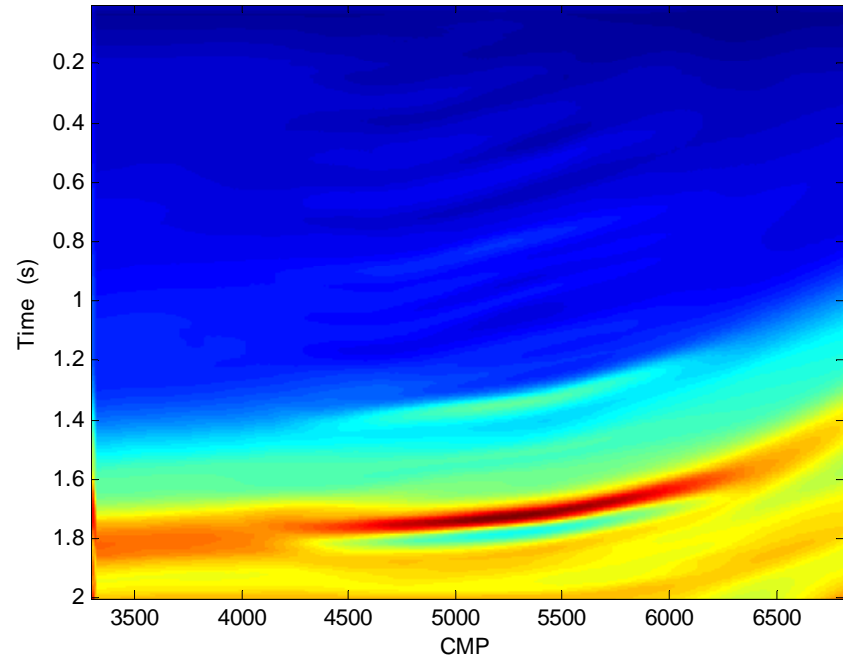
updated velocity Iteration 15

Synthetic Example
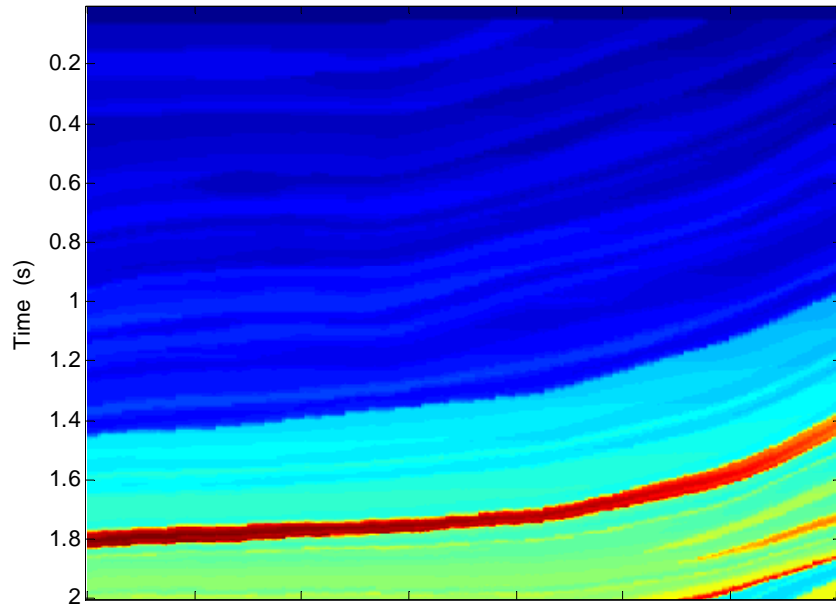
true velocity in time
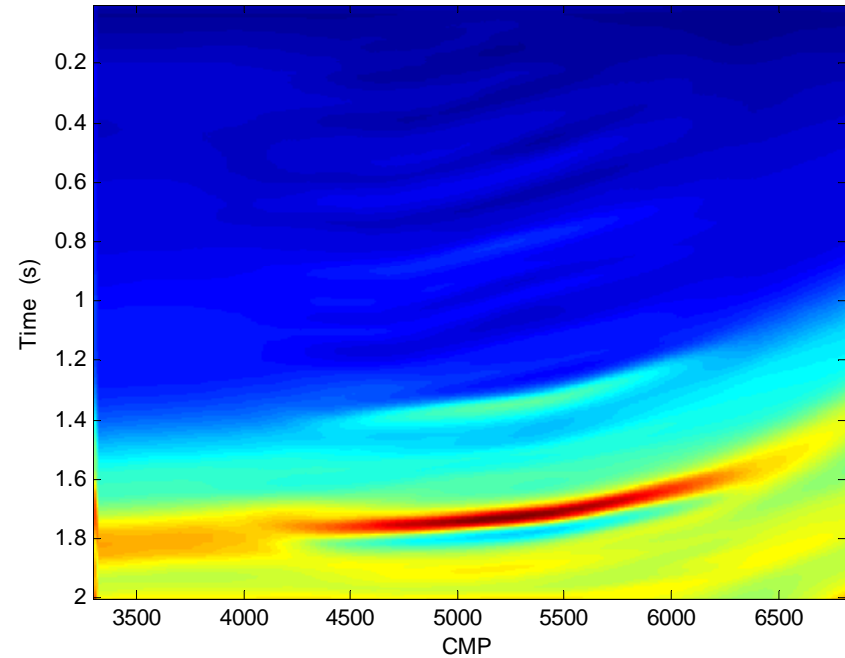
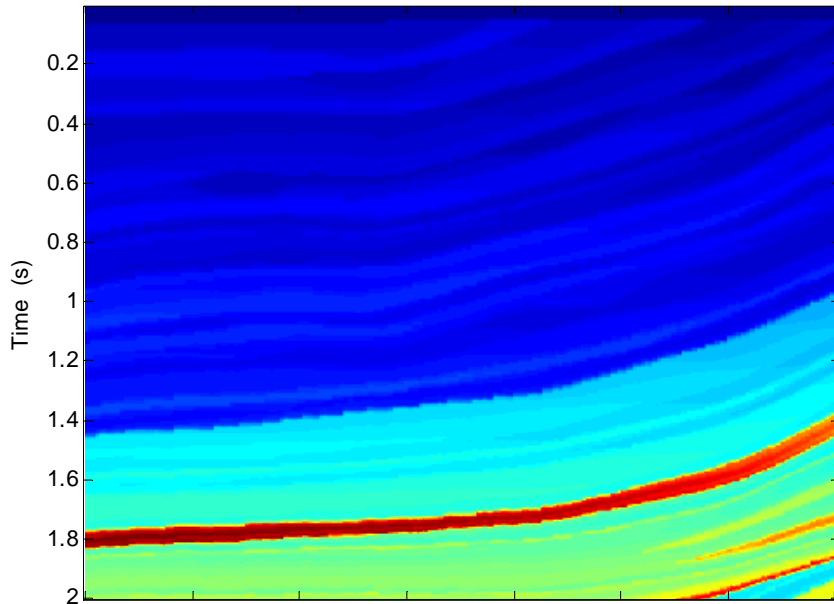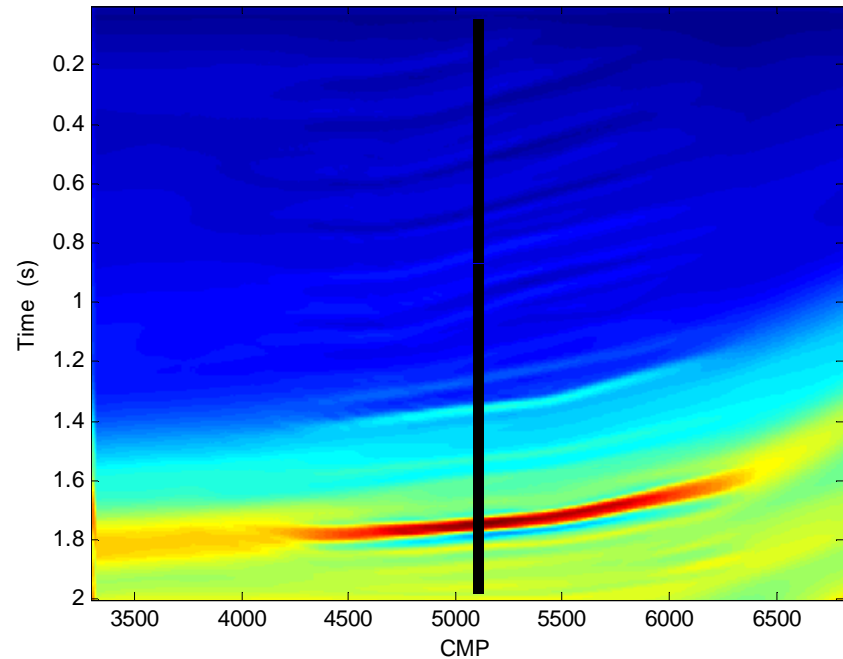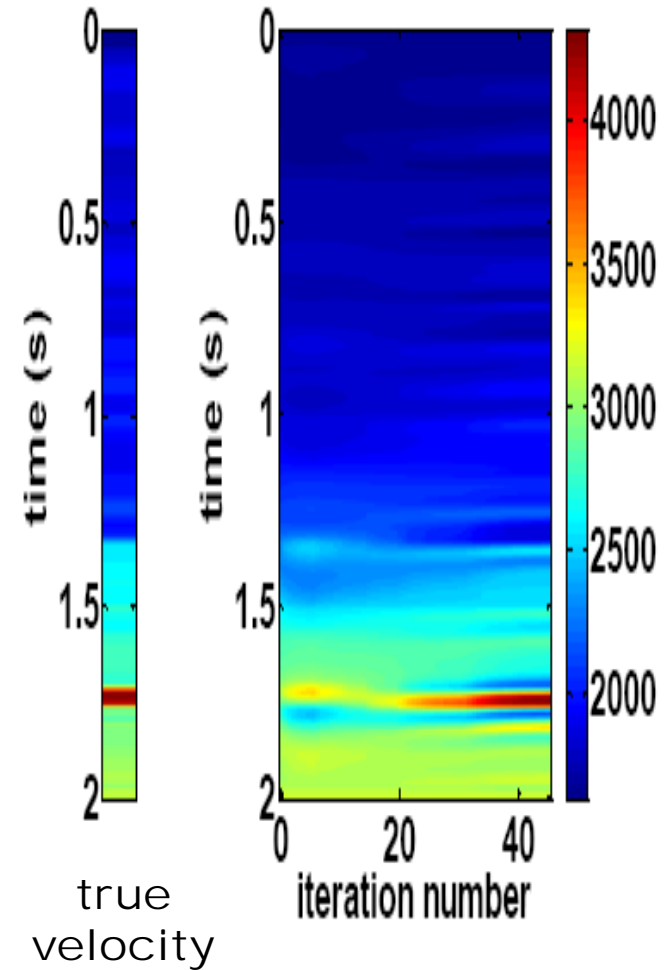**updated velocity Iteration 25**

13
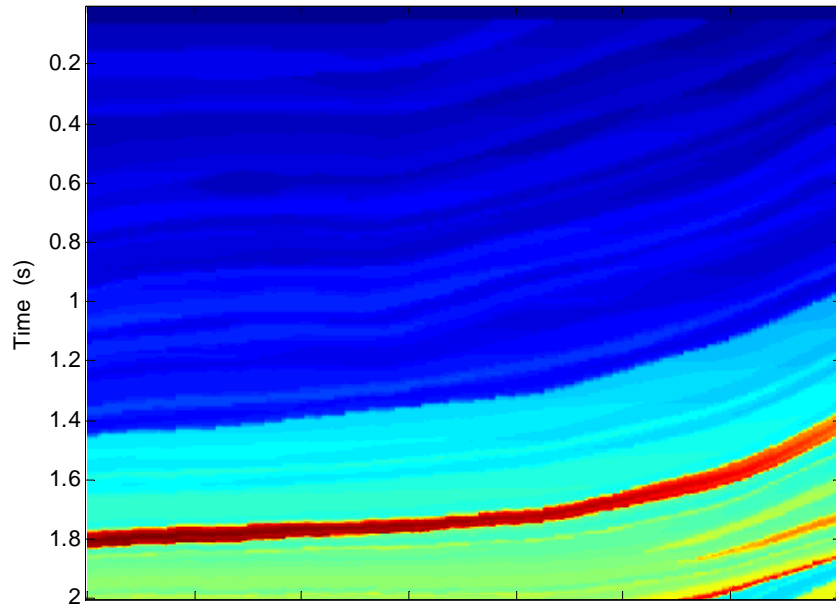
true velocity in time

updated velocity Iteration 30

Synthetic Example
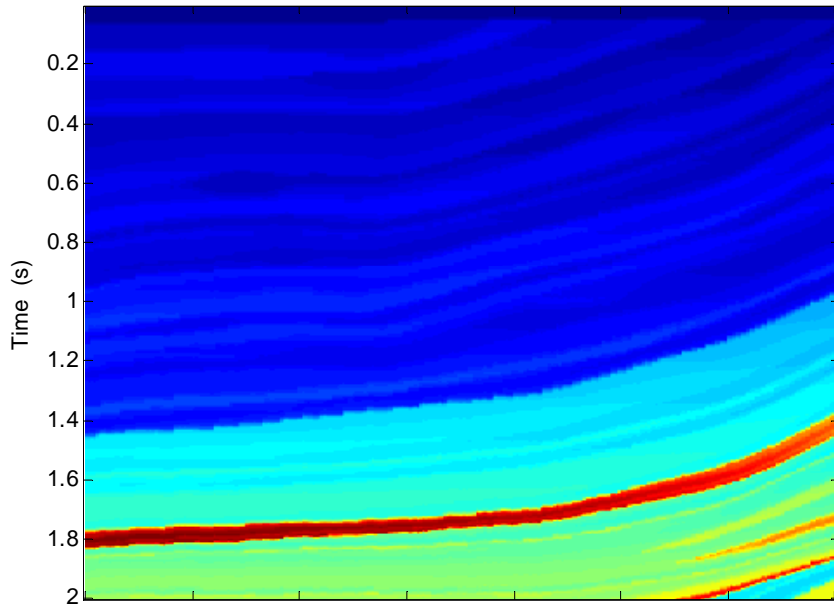
true velocity in time

updated velocity Iteration 35

Synthetic Example

true velocity in time
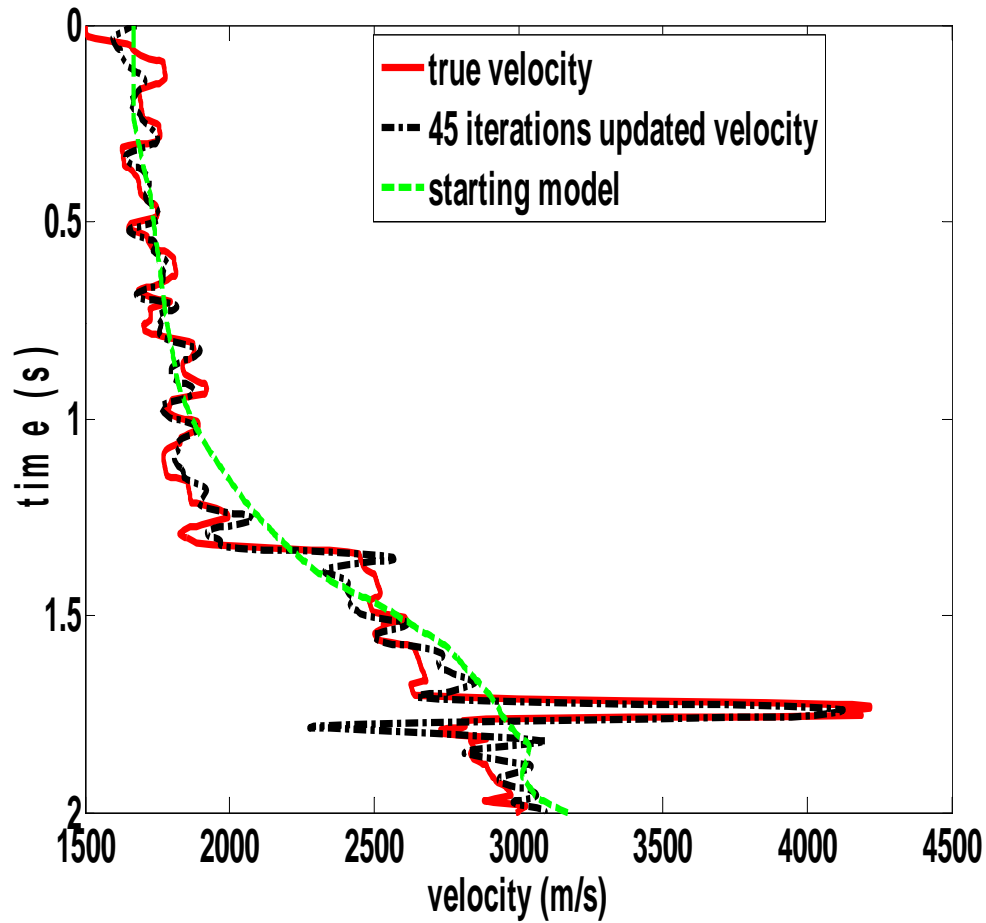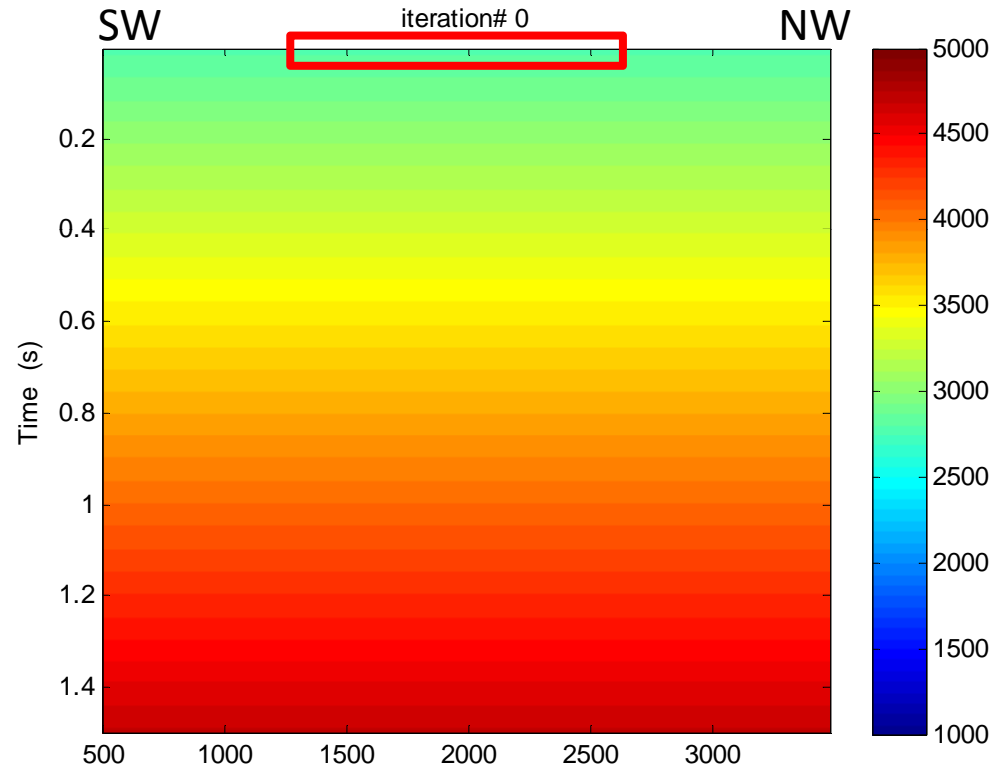
updated velocity Iteration 40

Synthetic Example

true velocity in time

updated velocity
Iteration 55

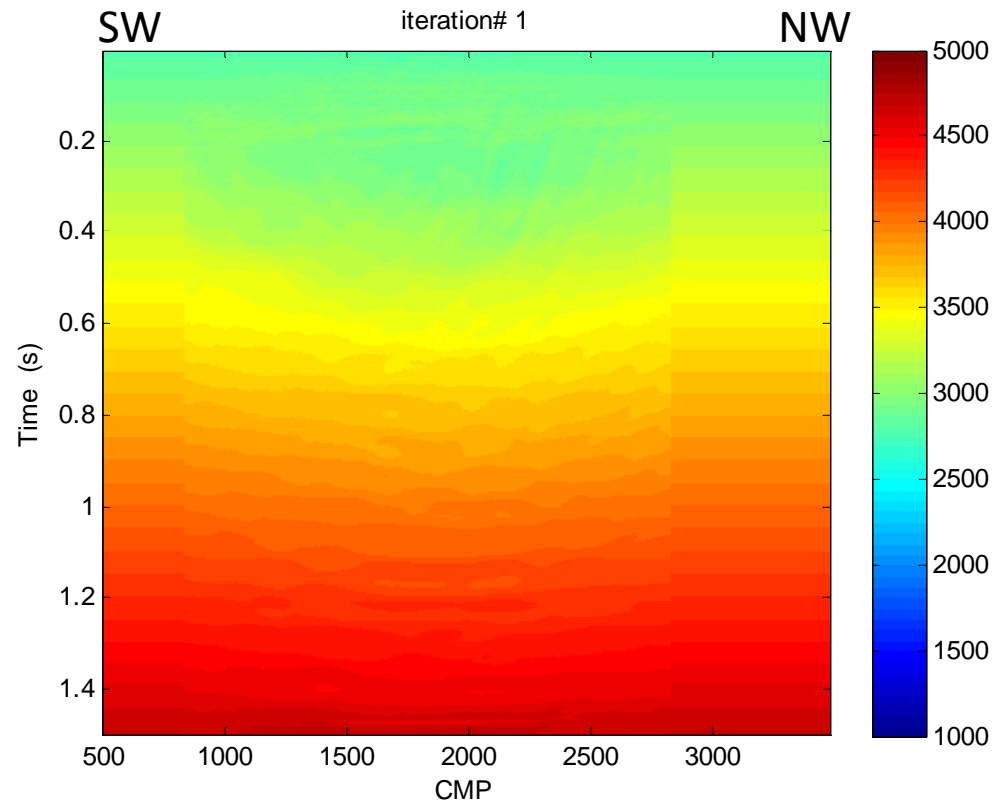# Synthetic Example

Example 2

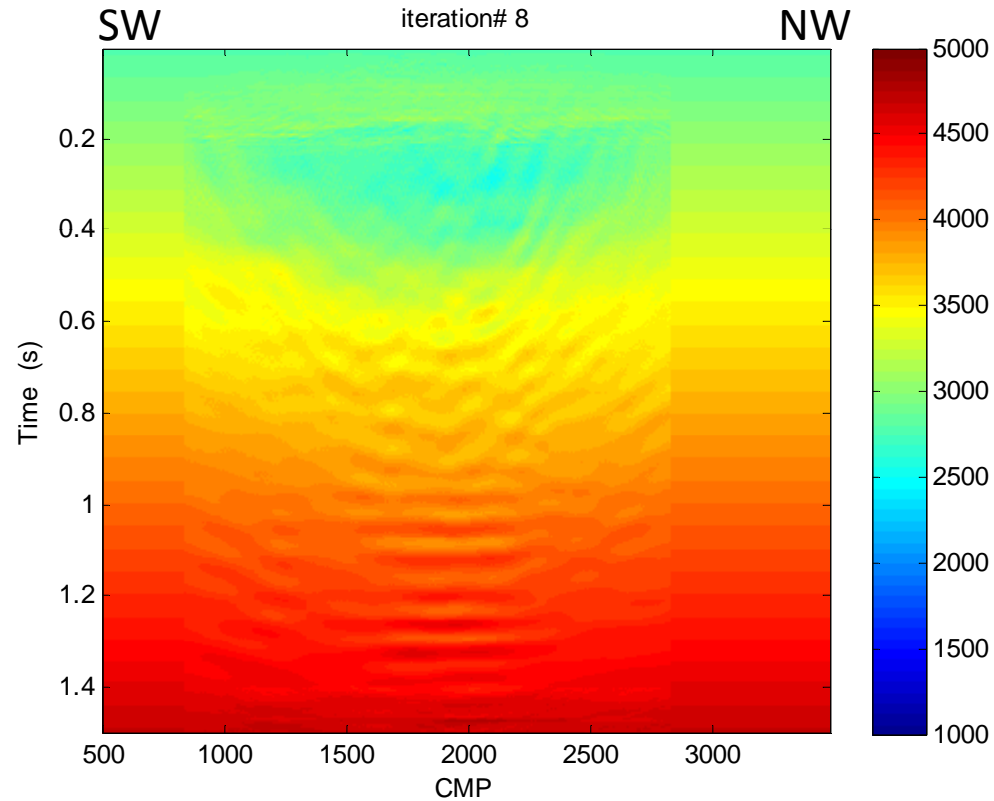# Hussar current results

Hussar example

initial velocity
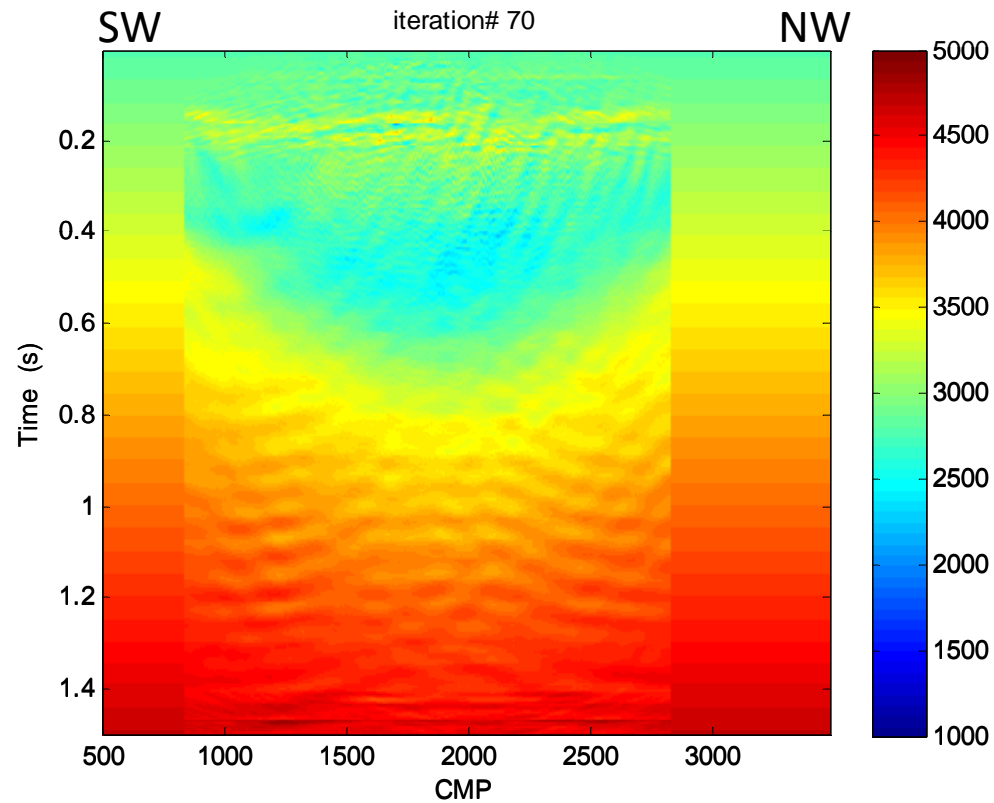
updated velocity

Hussar example

updated velocity

Hussar example

updated velocity

Hussar example

Hussar example

γ(x,t)

sonic log 1435

initial velocity
sonic velocity

Time (s)

CMP

velocity (m/s)
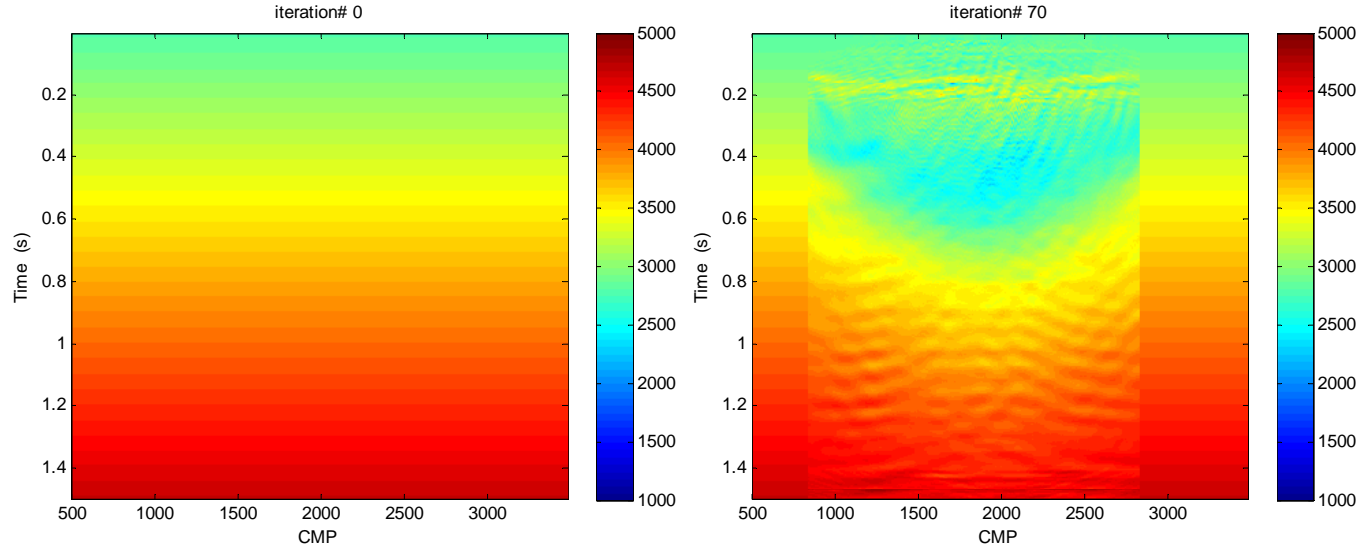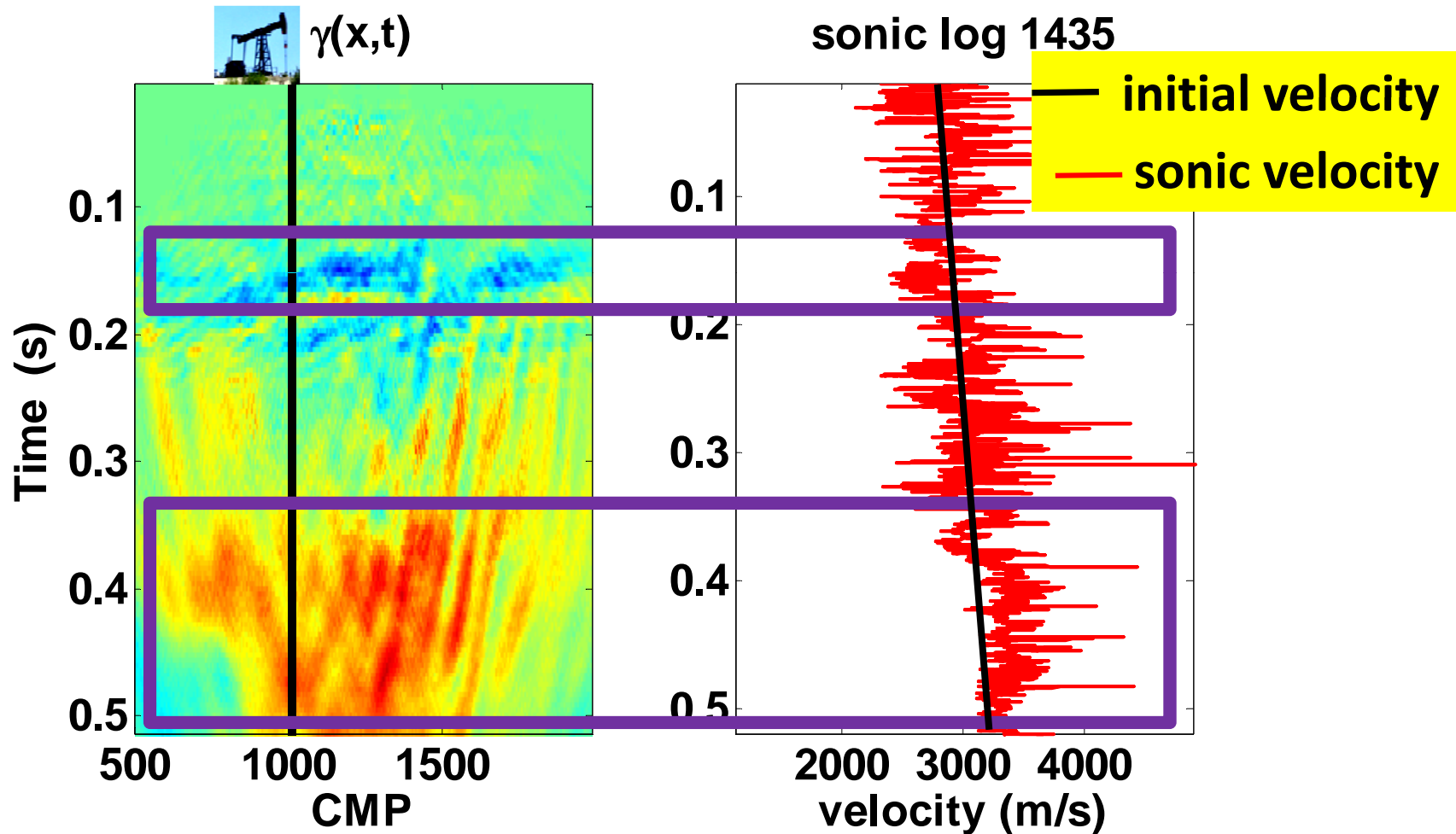
Gredient function In time

25

Shot records comparison

real data
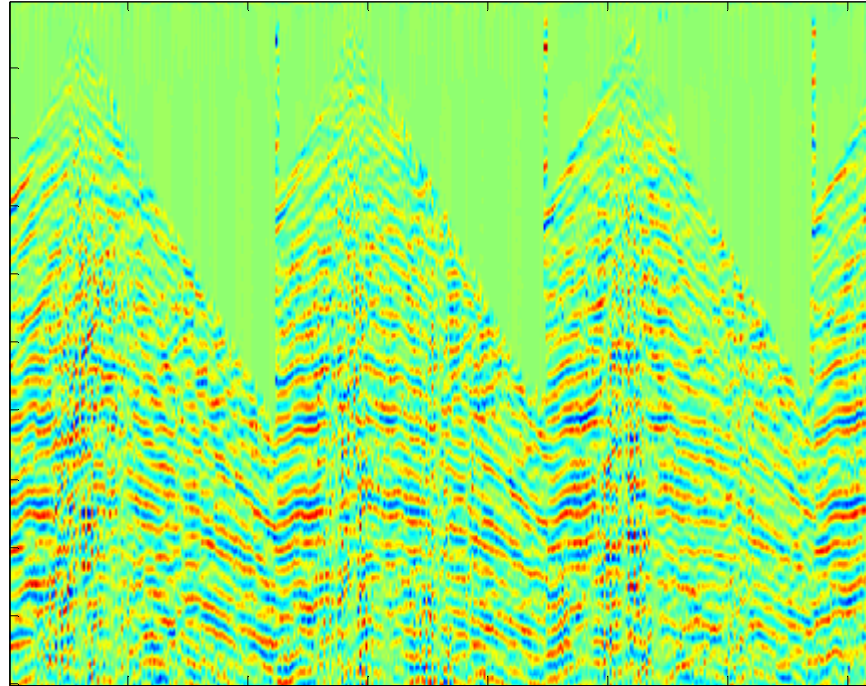
Shot records comparison

predicted data
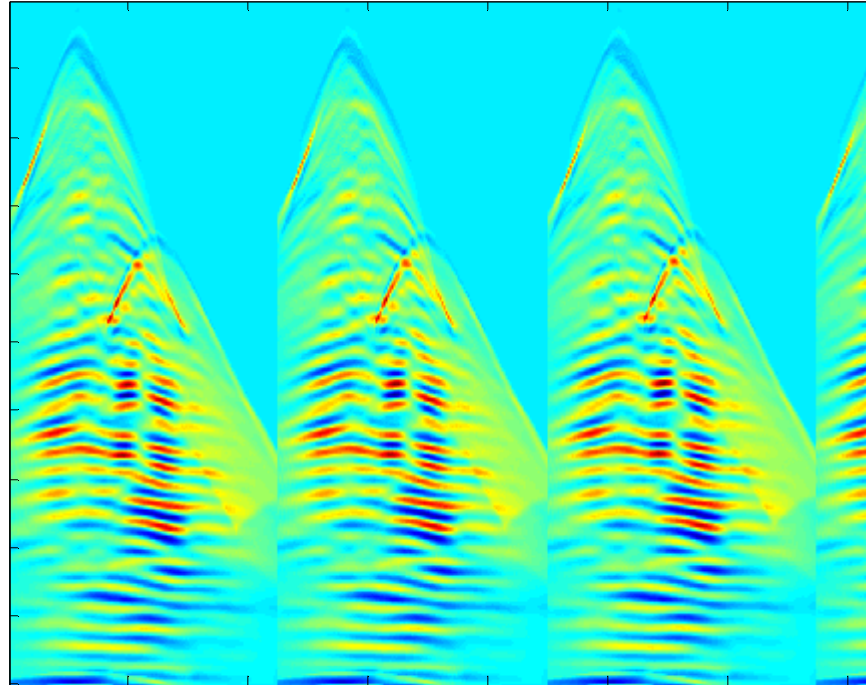
Discussions

real data

sample shot record
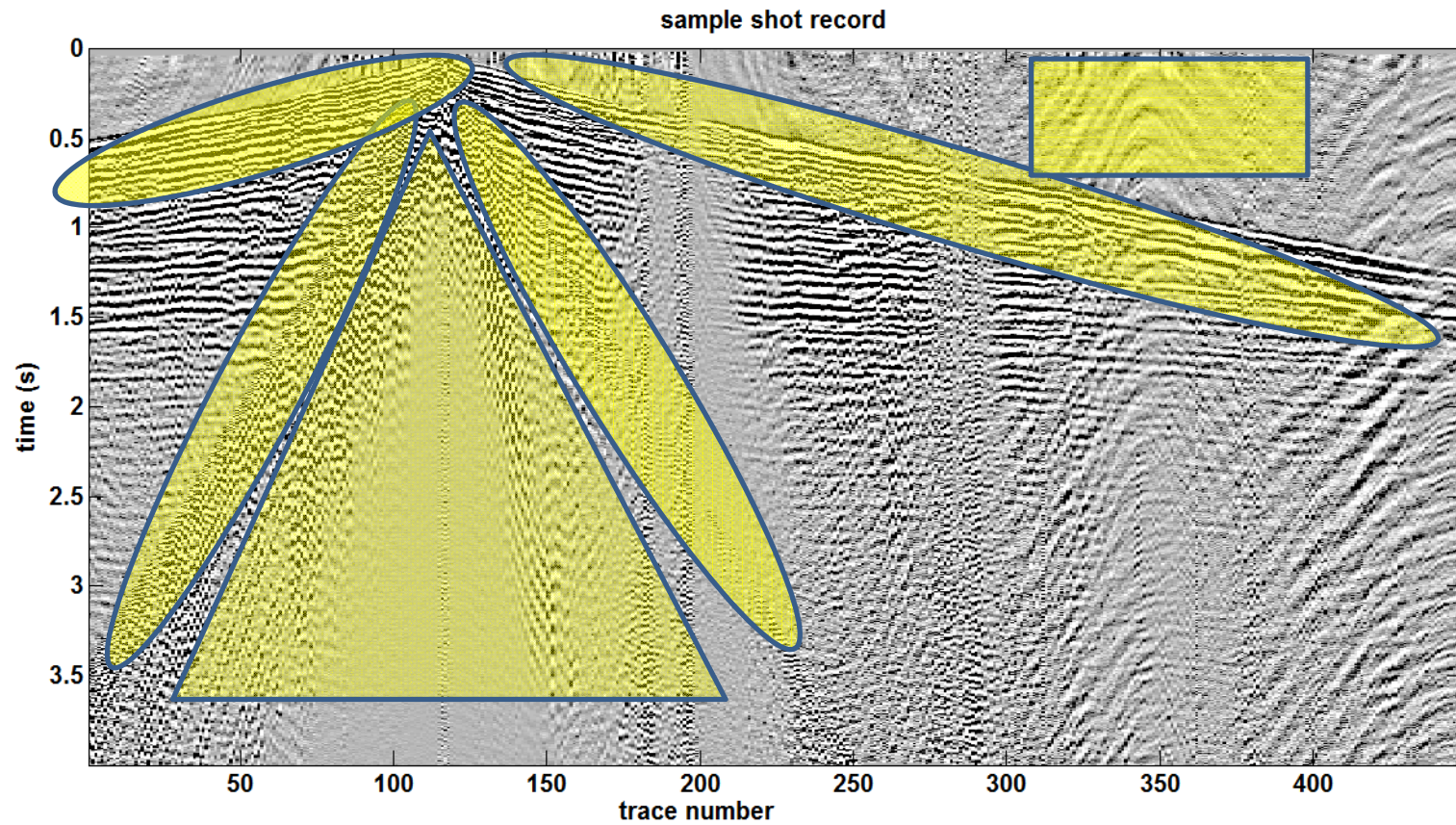
Comments

- Converted wave
- Anisotropic modeling /inversion

Conclusions

✓ Developed a PSTM FWI algorithms for velocity inversion.

✓ Use CSP gathers for initial velocity model.

✓ Not accurate for complex structures because of using time migration forward and inverse process.

✓ Faster.

Acknowledgments

- CREWES Sponsors for supports

- Dr. Kristopher Innanen

- Naser Yousefzadeh

- Marcus Wilson

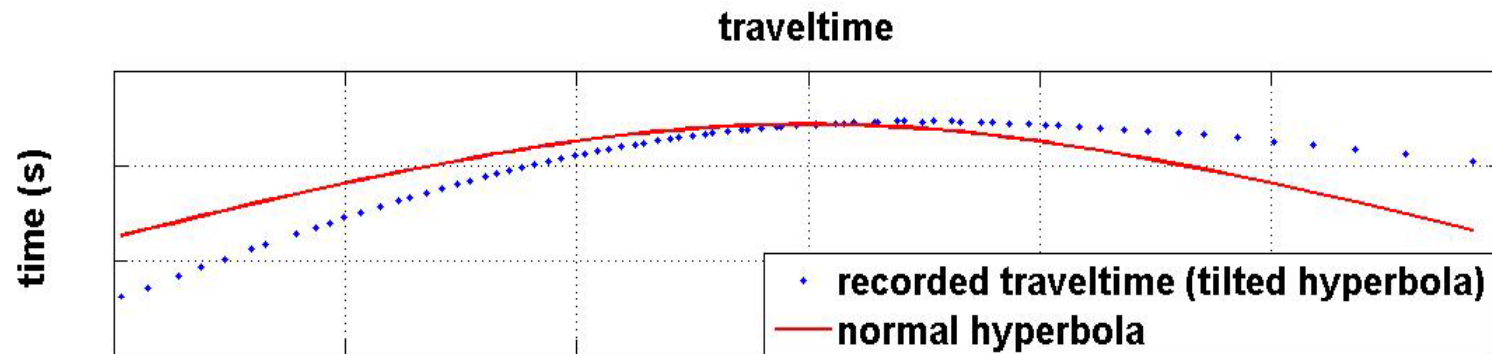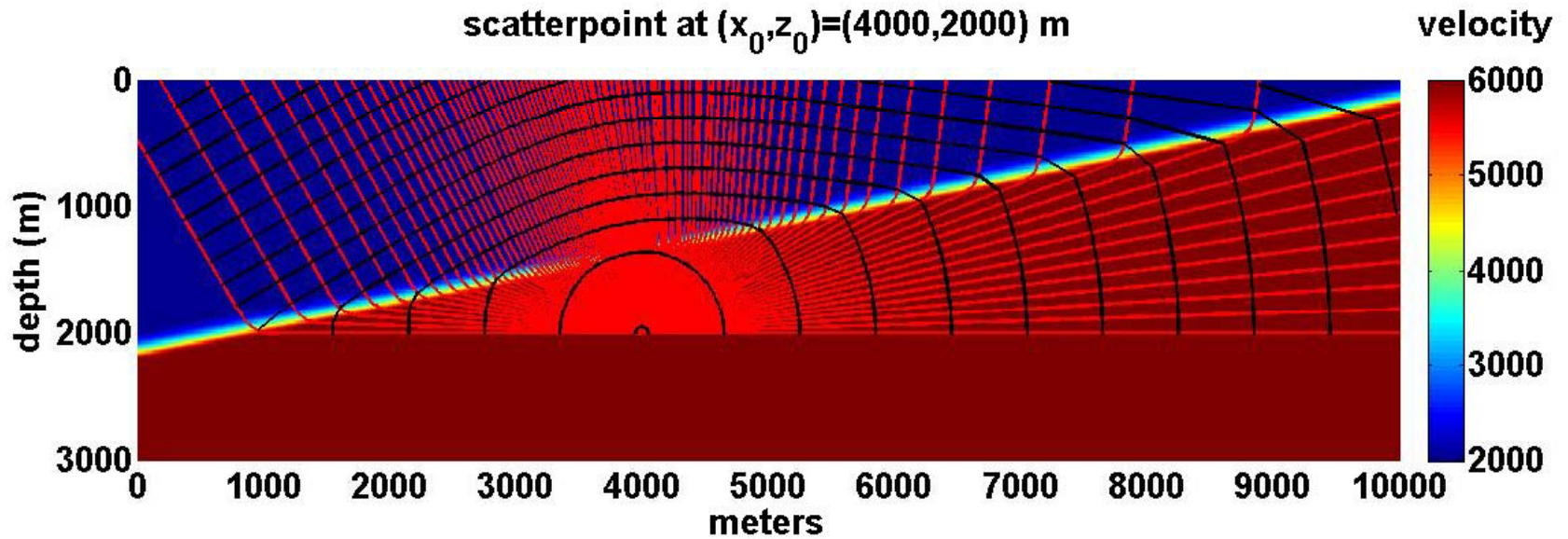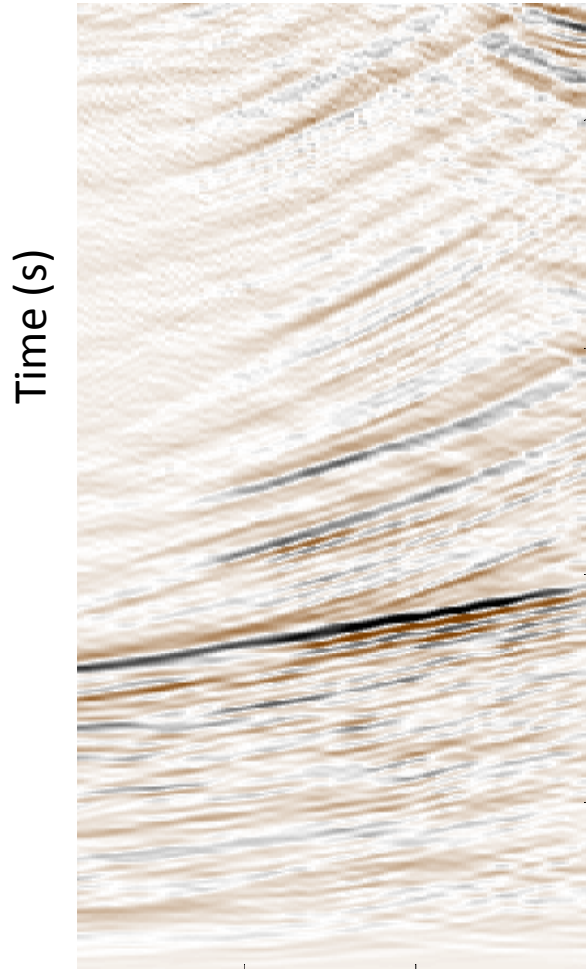- Ben Wards

THANK YOU !

hyperbola tilt

scatterpoint at $(x_0, z_0) = (4000, 2000)$ m

velocity

traveltime

- recorded traveltime (tilted hyperbola)
- normal hyperbola

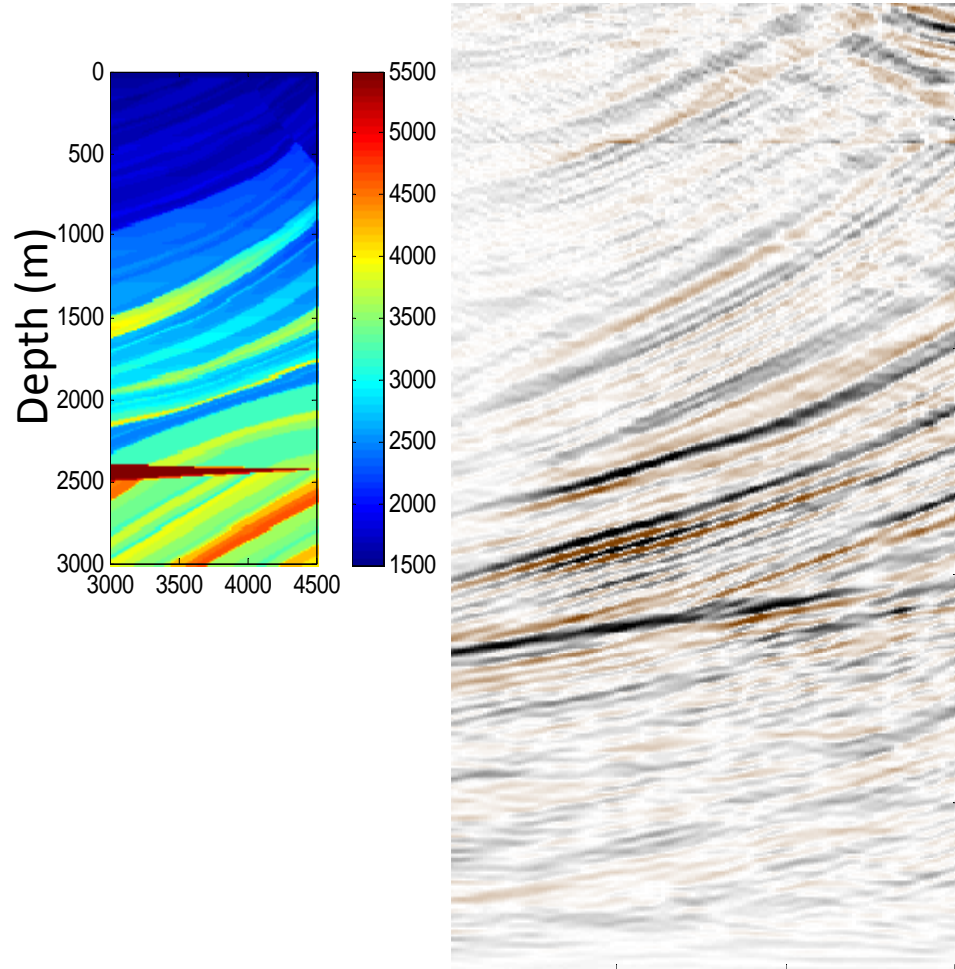# Image Enhancements

Regular PSTM

PSTM + removed Tilt

Image Enhancements

Regular PSTM

PSTM + removed Tilt

Image Enhancements
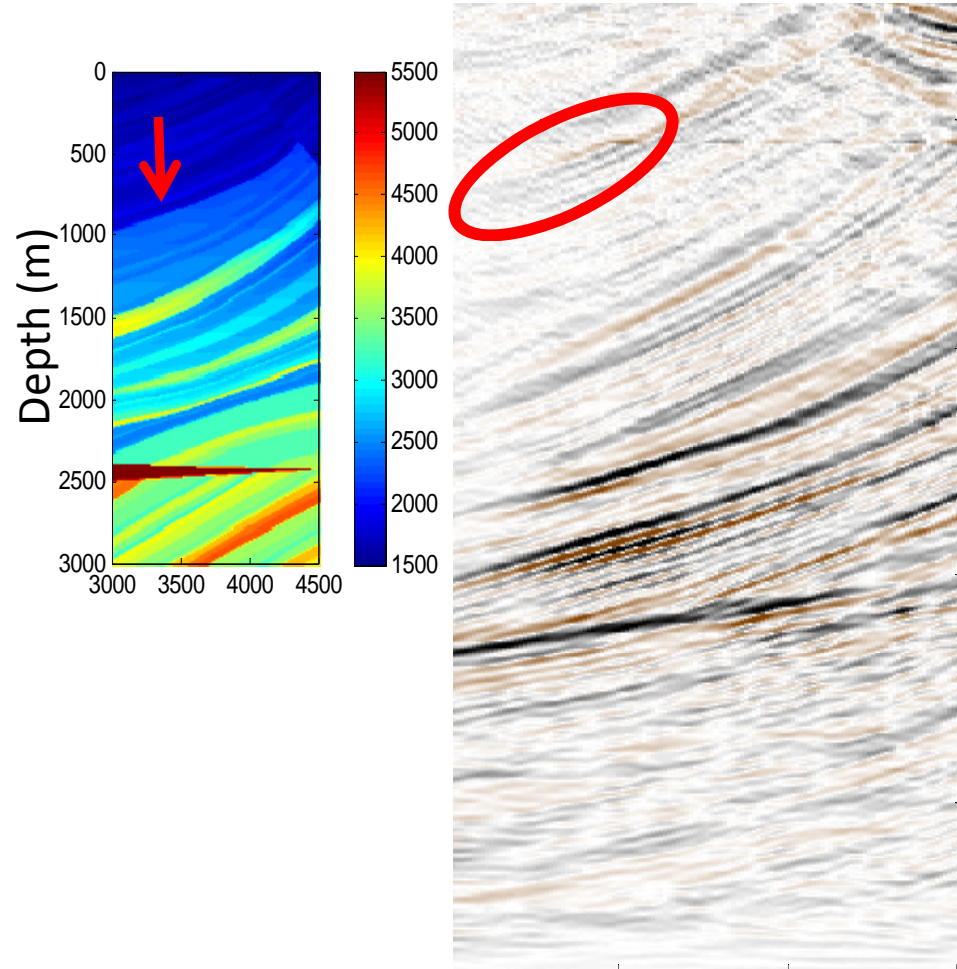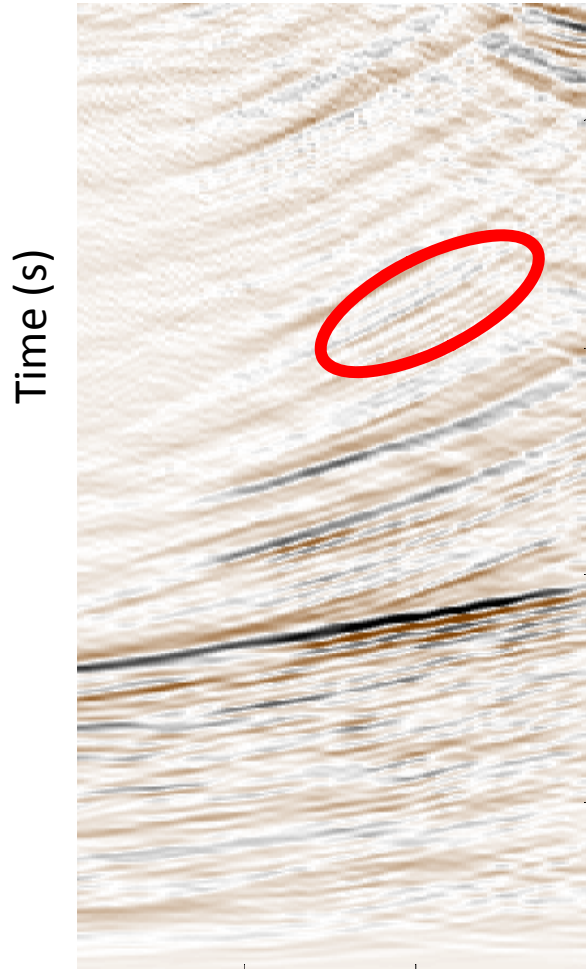
Regular PSTM

PSTM + removed Tilt

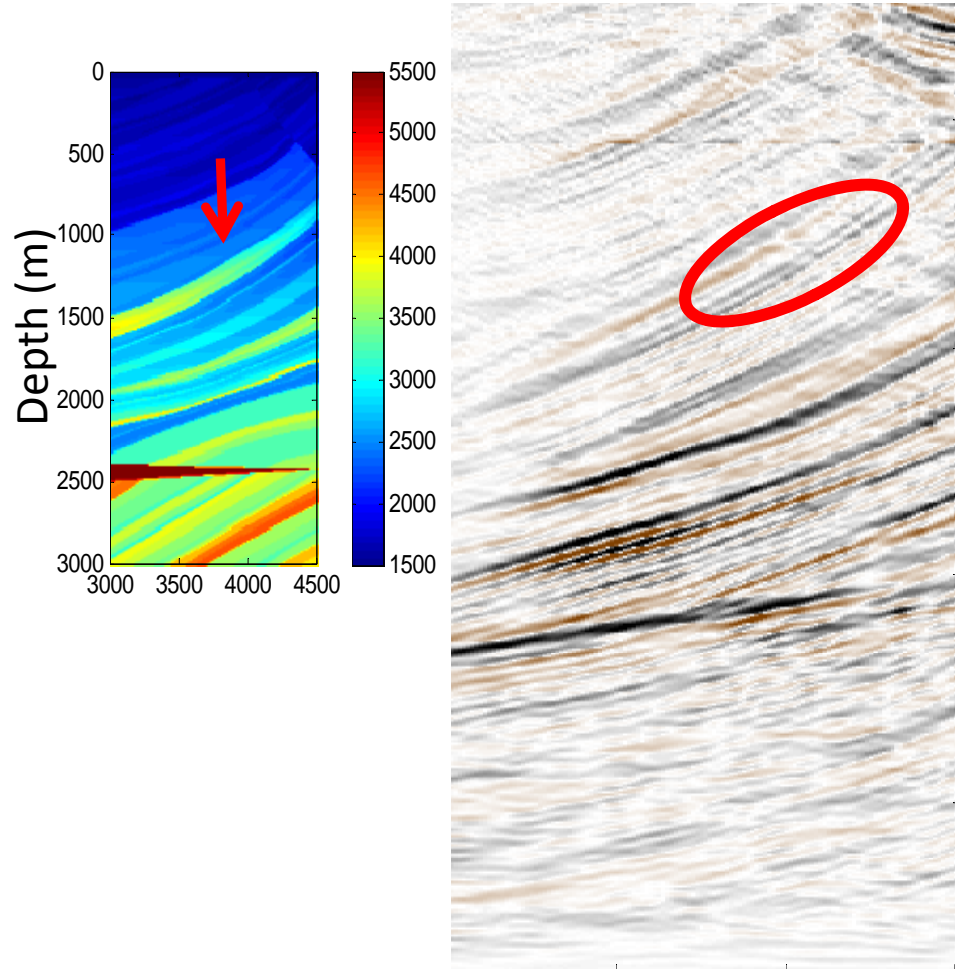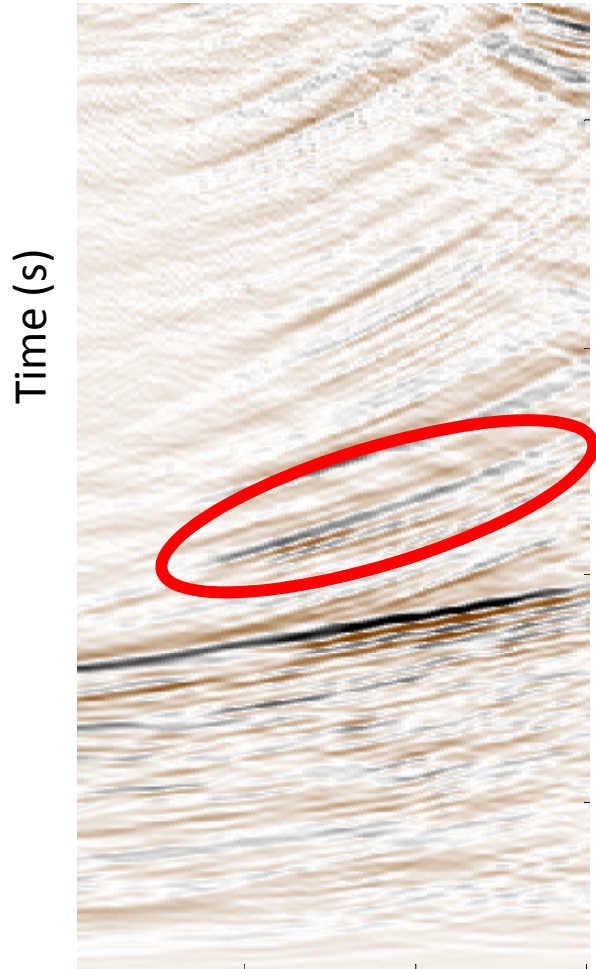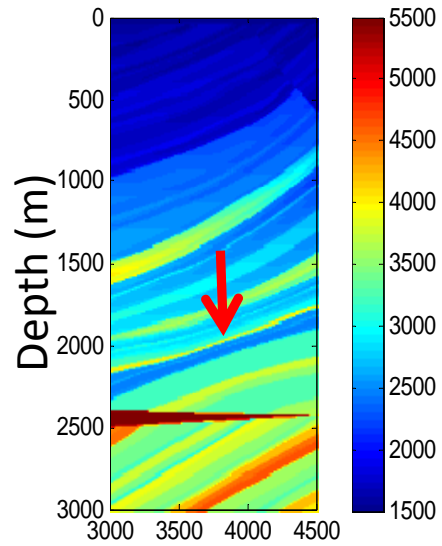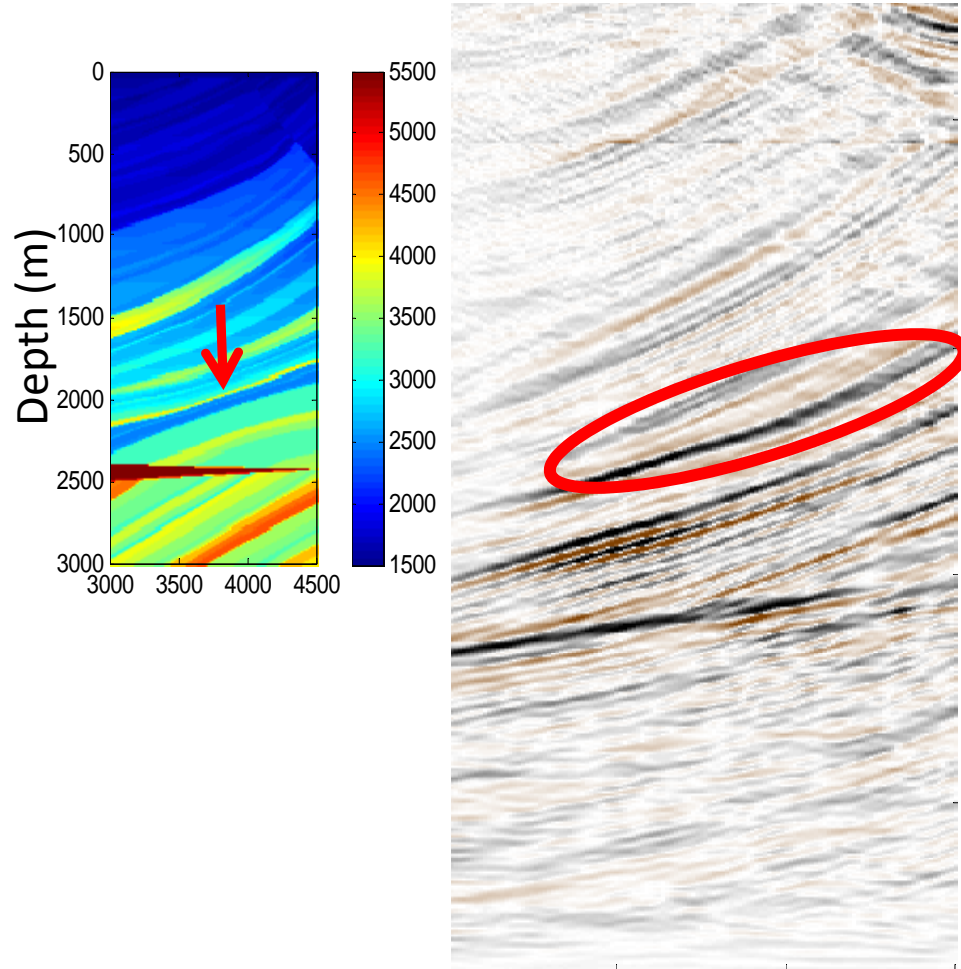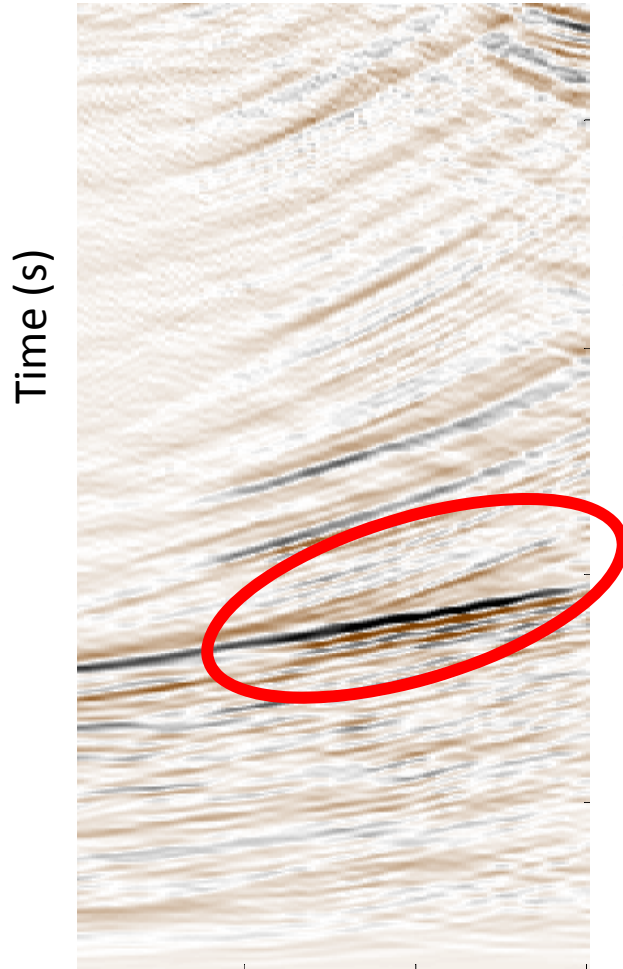# Image Enhancements

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