TRIP in 2008

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Announcements

- TRIP 07 report is online:

  www.trip.caam.rice.edu/
  private/xLN7eX/trip07_report.html

- Lunch at Cohen House (faculty club), Esther's Room (upstairs, back) - go through line, take plate upstairs.
- Parking passes available from me at lunchtime.
- Oil & Gas HPC Workshop: Tuesday, March 4, here in Duncan Hall. Focus: accelerators, hybrid/multicore computing, software tools, storage and i/o. See

  citi2.rice.edu/OG-HPC-WS

TRIP 2008

Staff:

- William W. Symes, Director
- Postdoctoral Research Associates:
  - Kirk D. Blazek
  - Tetyana W. Vdovina
- Graduate Research Associates:
  - Rami Nammour
  - Dong Sun
  - Igor Terentyev
  - Chao Wang

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Sponsors:

- Amerada Hess
- BP
- Chevron
- ConocoPhillips
- ExxonMobil
- Halliburton Geophysical Services
- Shell
- Total
- WesternGeco

TRIP 2008

History:

- Started 1993
- 25+ alumni (MA and PhD students, postdocs)
- Contributions:
  - Differential semblance
  - Eikonal solvers
  - Viscoelastic finite difference modeling
  - Source inversion
  - Kinematic artifacts in prestack imaging
  - Asymptotic inversion

TRIP Goals

Waveform Inversion in Reflection Seismology

- enable - devise effective methods for model-based data fitting
- evaluate - assess information gained through inversion

Provide solutions to core mathematical and computational problems posed by waveform inversion

Agenda

Waveform Inversion

Migration Velocity Analysis

Effective Inversion = WI + MVA

Waveform Inversion

The usual set-up:

- $\mathcal{M}$ = a set of *models*;
- $\mathcal{D}$ = a Hilbert space of (potential) data;
- $\mathcal{F} : \mathcal{M} \rightarrow \mathcal{D}$: modeling operator or "forward map".

Waveform inversion problem: given $d \in \mathcal{D}$, find $v \in \mathcal{M}$ so that

$$\mathcal{F}[v] \simeq d$$

.

$\mathcal{F}$ can incorporate *any physics* - acoustics, elasticity, anisotropy, attenuation,.... (and v may be more than velocity...).

Waveform Inversion

Least squares formulation: given $d \in \mathcal{D}$, find $v \in \mathcal{M}$ to minimize

$$J_{LS}(v,d) = \frac{1}{2}\|d - \mathcal{F}[v]\|^2$$

$$\equiv \frac{1}{2}(d - \mathcal{F}[v])^T(d - \mathcal{F}[v])$$

Has long and productive history in geophysics (eg. reflection tomography)- but not in reflection waveform inversion.

Problem size $\Rightarrow$ Newton and relatives $\Rightarrow$ find local minima.
BUT....

Waveform Inversion

Albert Tarantola, many others: J_{LS} has lots of useless local minima, for typical length, time, and frequency scales of exploration seismology

⇒ least squares waveform inversion with Newton-like iteration "doesn't work" - can't assure convergence from reasonable initial estimates.

See: Gauthier 86, Kolb 86, Santosa & S. 89, Bunks 95, Shin 01, 06, Chung SEG07-SI 2.4, Chao Wang TRIP08.

Waveform Inversion

Postmortem on J_{LS}: missing low frequency data is culprit - obstructs estimation of large-scale velocity structure, hence everything else.

Rule of thumb derived from layered Born modeling:

to estimate velocity structure on length scale L, with mean velocity v, data must have significant energy at

$$f_{\min} \simeq \frac{v}{2L}$$

$v \sim 3$ km/s, $L = 3$ km $\Rightarrow$ need good s/n at $0.5 Hz$ - not commonly available.

Waveform Inversion

Caveats: least squares WI works

- with synthetic data containing very low frequencies ($<< 1$ Hz): Bunks 95, Shin 06, Dong Sun TRIP08.
- for basin inversion from earthquake data: target of several major efforts. QuakeShow (Ghattas), SpecFEM3D (Tromp, Komatisch), SPICE (Käser, Dumbser). Typical $L \sim 20$ km, $f_{\min} = 0.1 Hz$, $v \sim 4$ km/s - just OK! Will be done, in 3D, in near future.
- for *transmission* waveform inversion (cf Gauthier 86) with good initial v from traveltime tomography (plus other tweaks) - Pratt 99, Brenders SEG07-TOM 1.5.

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Migration Velocity Analysis

Effective Inversion = WI + MVA

Migration Velocity Analysis

TRIP contributions:

- Waveform MVA as approximate linearized inversion plus *model extension*.
- Differential Semblance - method for converting MVA to optimization problem without introducing local minima.
- Theory - DS is only asymptotically stable velocity inversion objective (Stolk & WWS 03).
- DS using wave equation migration - Shen 03, many others.
- Review, to appear in *Geophys. Prosp.* - WWS TRIP08.
- DS vs. Reflection Tomography -Kabir SEG 07, Shen & WWS TRIP08.

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Migration Velocity Analysis

Shen: 2D shot profile migration $\Rightarrow$ *image volume* $I(x, z, h)$ (= extended model).

Semblance principle for WE migration: image focused at $h = 0$ for correct velocity.

DS functional - no spurious minima far from correct velocity:

$$J_{DS}[v] = \sum_{x,z,h} |hI(x, z, h)|^2$$

Shen's modification - add multiple of image power, robust against imaging noise for near-correct velocity:

$$J_{MDS}[v] = \sum_{x,z,h} |hI(x, z, h)|^2 - \beta^2 \sum_{x,z} |I(x, z, 0)|^2$$

Migration Velocity Analysis

Gas chimney example:

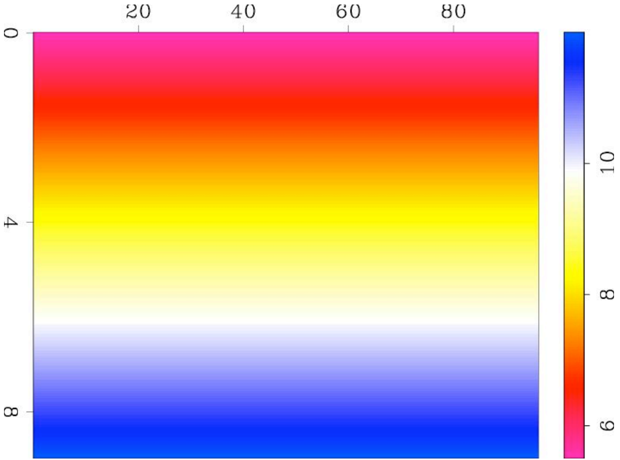
Marine 2D line - preliminary imaging with regional velocity model shows gas-induced sag.

Reflection tomography partially removes sag effect, but interpreters not happy.

MDS to rescue - 20 iterations of Newton-like optimization algorithm produces more interpretable model, image.

[Iterative algorithm follows Shen's PhD thesis - adjoint state method for gradient computation.]

Migration Velocity Analysis



Initial Velocity Model for MDS

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Migration Velocity Analysis

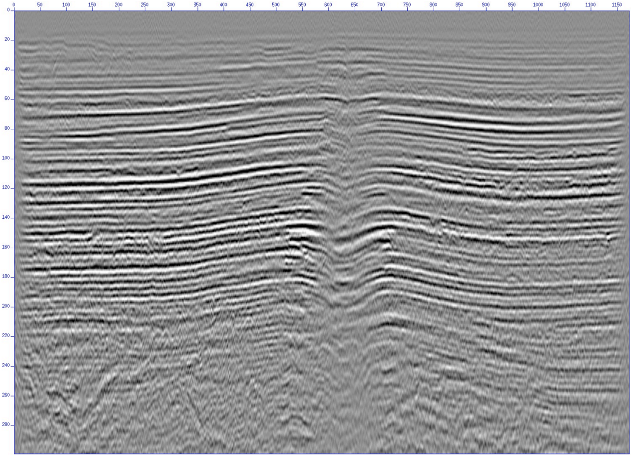

Image at Initial Model

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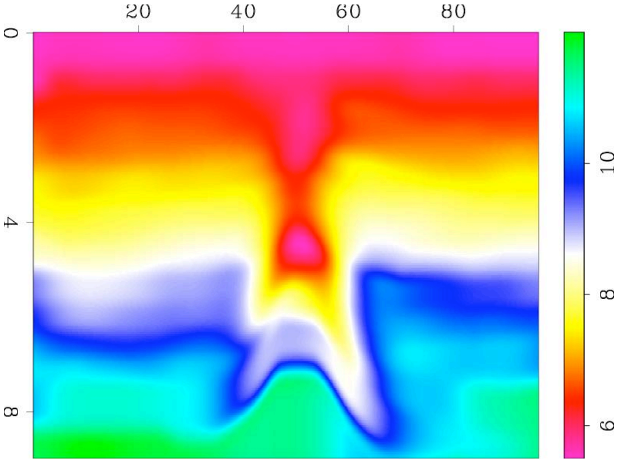
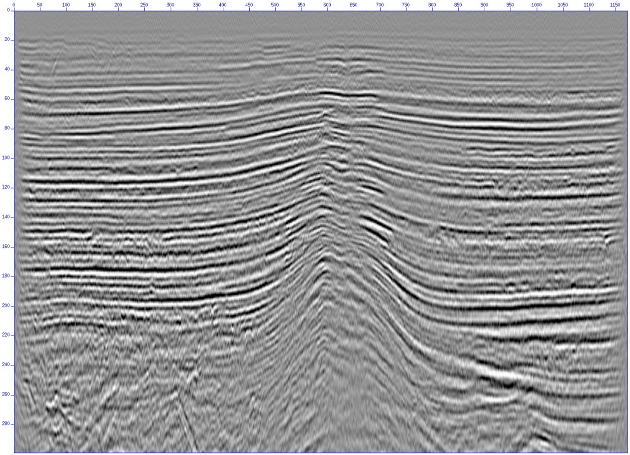
Migration Velocity Analysis



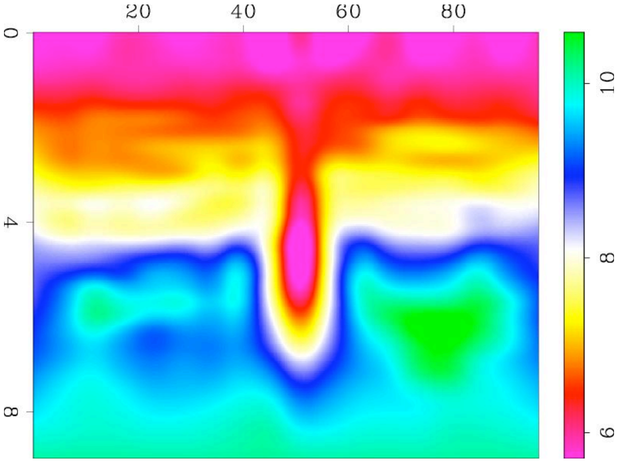
Model produced by Reflection Tomography

Migration Velocity Analysis



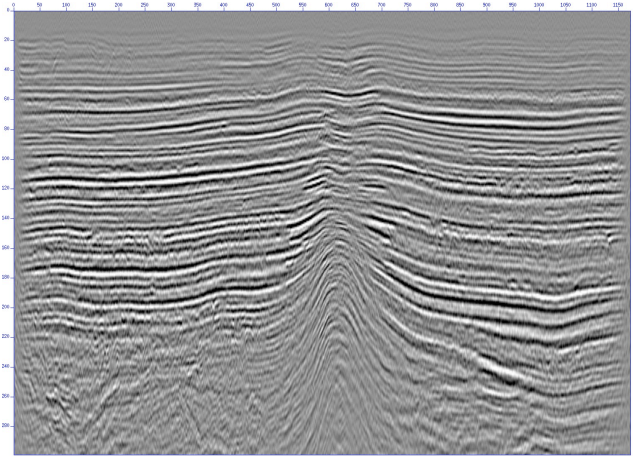
Reflection Tomography Image

Migration Velocity Analysis



Model produced by 20 MDS Iterations

Migration Velocity Analysis



MDS Image

Migration Velocity Analysis

Image gathers provide direct evidence of kinematic correctness.

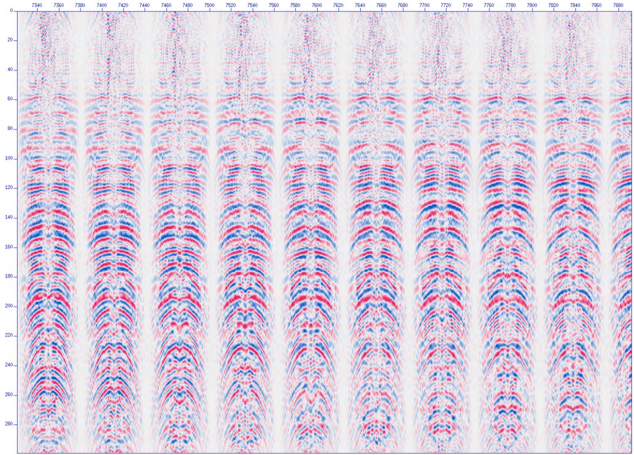
Angle image gathers (Sava & Fomel 03) - Radon transform in depth/offset, should be flat at correct velocity.

Initial velocity - dramatic failure to flatten.

RT velocity - much better, but RMO at larger depths.

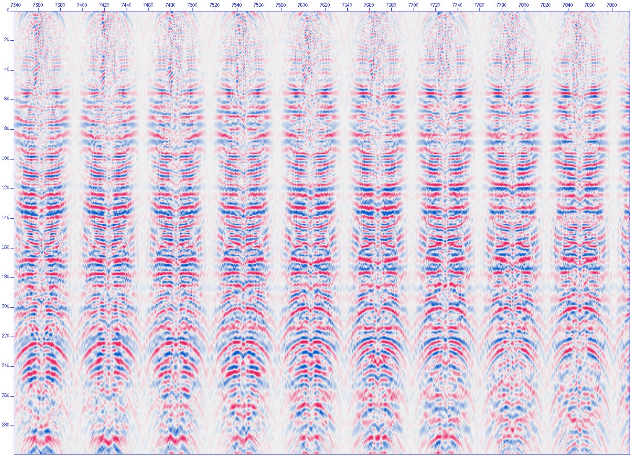
MDS velocity - flat throughout depth range.

Migration Velocity Analysis



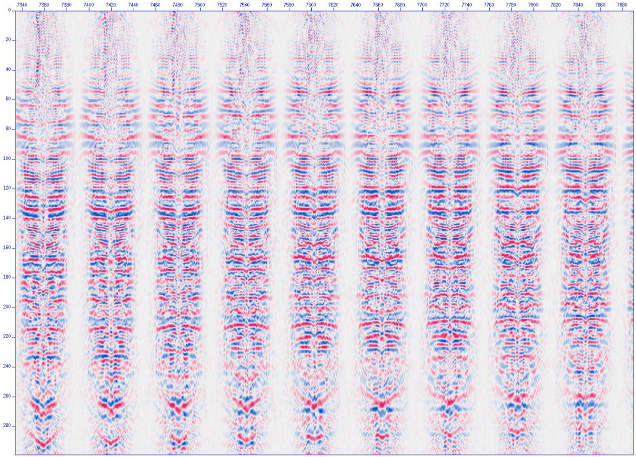
ADCIGs, Initial Model

Migration Velocity Analysis



ADCIGs, RT Model

Migration Velocity Analysis



ADCIGs, MDS Model

Agenda

Waveform Inversion

Migration Velocity Analysis

Effective Inversion = WI + MVA

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Waveform MVA - all very well, but...

- MVA based on *linearized modeling*, generally acoustic, neglects multiple reflections, mode conversions, out-of-plane events (2D), anisotropy, attentuation,...
- DS based on WE migration sensitive to extrapolator error (high angle velocity error & numerical anisotropy - Khoury SEG 06).
- DS strongly influenced by coherent noise (multiples, mode conversions,...) - Gockenbach & WWS SEG 99, Mulder & ten Kroode 01, Verm & WWS SEG 06, Li & WWS Geophysics 07.
- Repeated modeling, migration - s l o w.

A blue-sky approach to overcoming these obstacles: combine DS & *full waveform* 3D modeling, incorporate necessary physics, accelerate convergence.

Effective Inversion = WI + MVA

The TRIP Research Program: recently initiated projects on

- flexible, extensible, parallel 3D modeling tool (Igor Terentyev MA project, SEAM) ⇒ RTM, Born modeling;
- accuracy control for simulation (SEAM), beyond finite differences (Tanya Vdovina);
- DS-MVA based on RTM;
- acceleration techniques for linear (Newton) inversion step (Herrmann 07, WWS Geophysics 08, Rami Nammour MA project;
- accommodate limitations imposed by sampling, dynamic data definition, in all inversion methods (Chao Wang MA project);
- DS based on nonlinear modeling - MVA with multiples (WWS, Dong Sun MA project);
- Physics of attenuation, elastic anisotropy - mathematics of nonlinear inversion (Kirk Blazek).