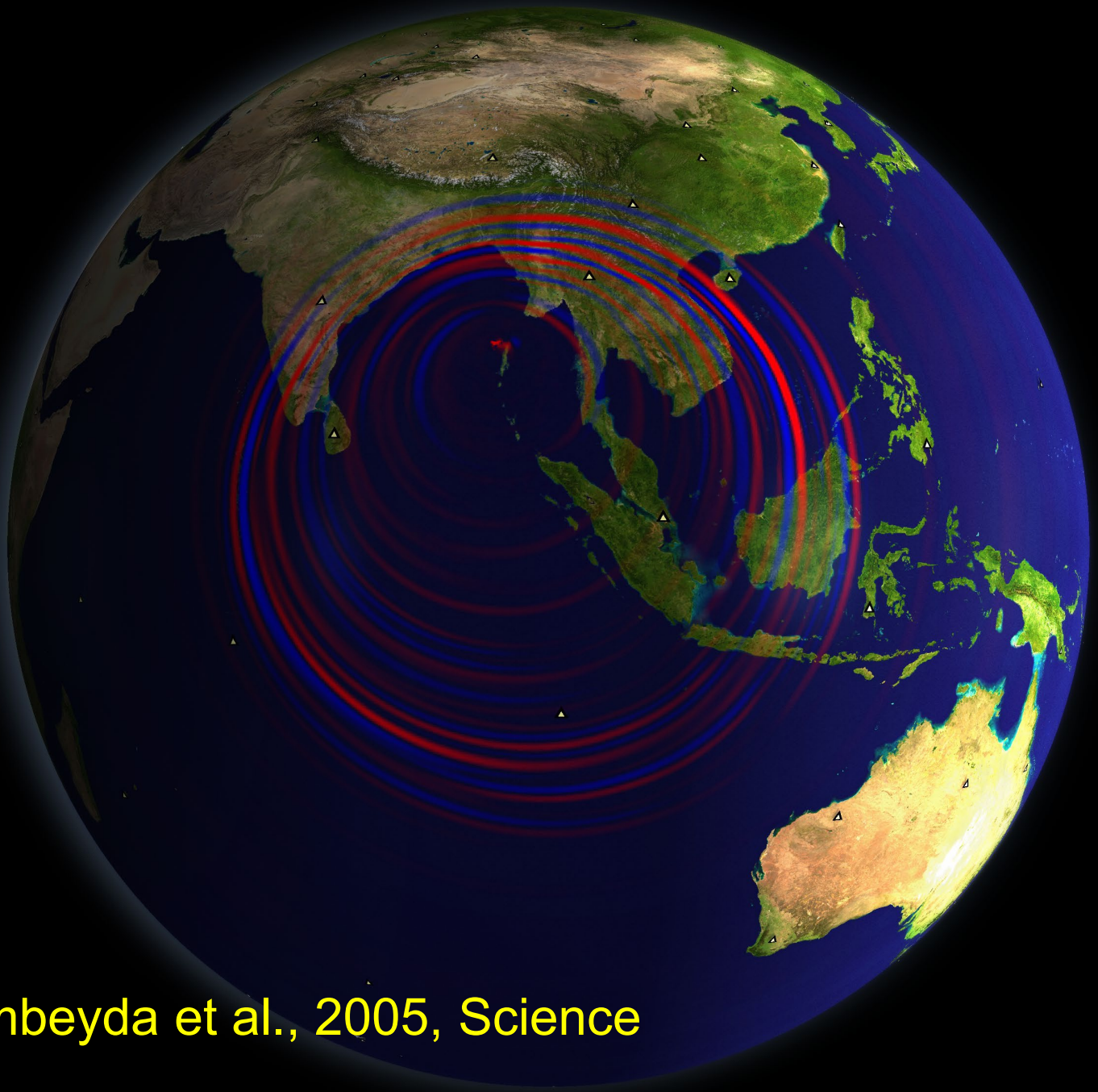
Computational Infrastructure for Geodynamics-Computational Seismology

Priorities for Computational Seismology in the Intermediate Term

Where will machine performance be in 6 years?

- Moore's law cpu speed increase is 16X
  - What takes an hour will take 4 minutes
  - 16-32 GHz cpus
- Disk space increase is ~ 64X
  - Active source seismologists and modelers will probably still fill it to capacity
- Network speedup is > 64X to 4096X
  - This is possibly the most valuable increase but could conceivably be absorbed by Cialis manufacturers, pornographers, and interactive video chat
- Above argues for both local and grid computing
- Visualization will be phenomenal stereoscopic



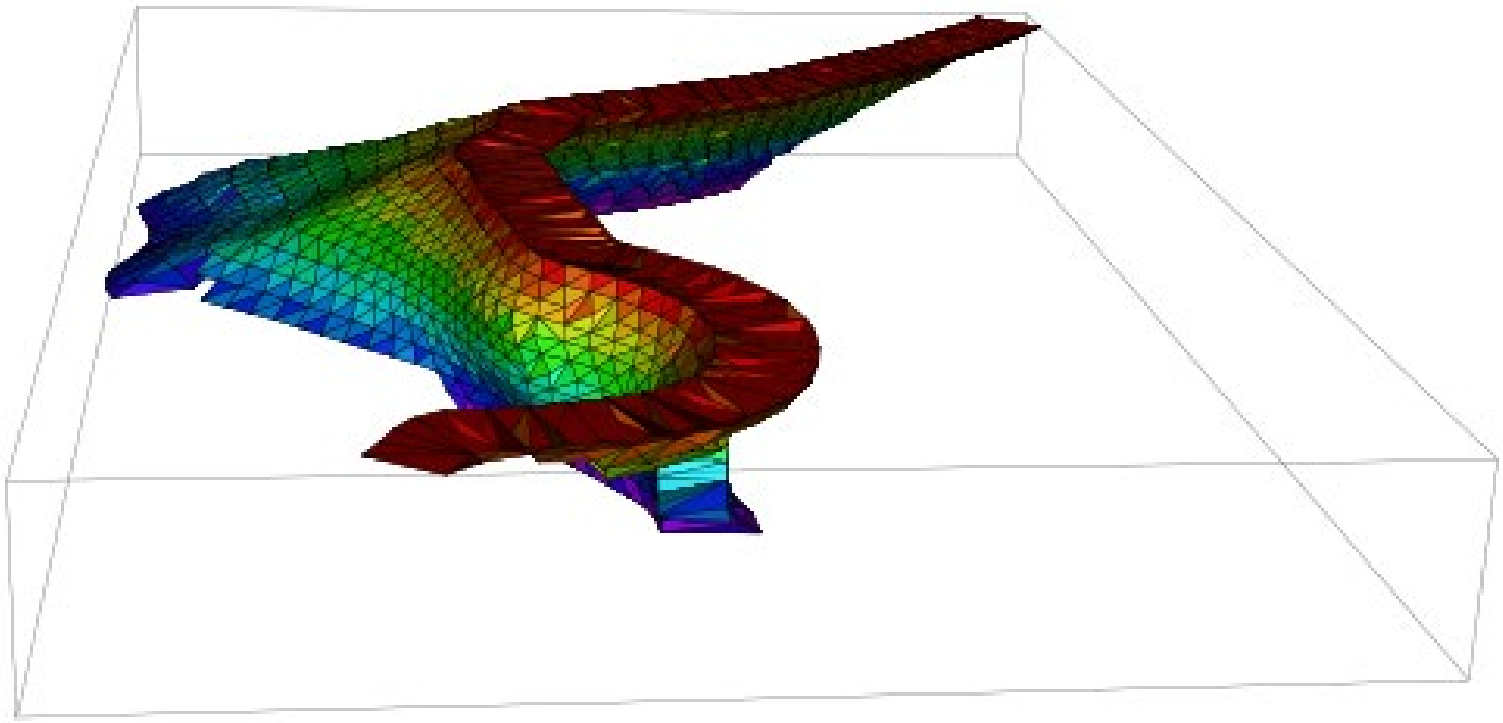
Lombeyda et al., 2005, Science

What are the current bottlenecks?

- 3D forward modeling is just practical
- 2D waveform tomography is just practical
- Commonly exchanged codes are often misunderstood and misused
  - You can't bulletproof for ignorance
  - You can provide sensible benchmarks
- Researchers have difficulty exchanging models
- Earth models derived from seismology are not usually verified
- Joint seismology-{seismology or other Earth science data} are rarely jointly inverted.

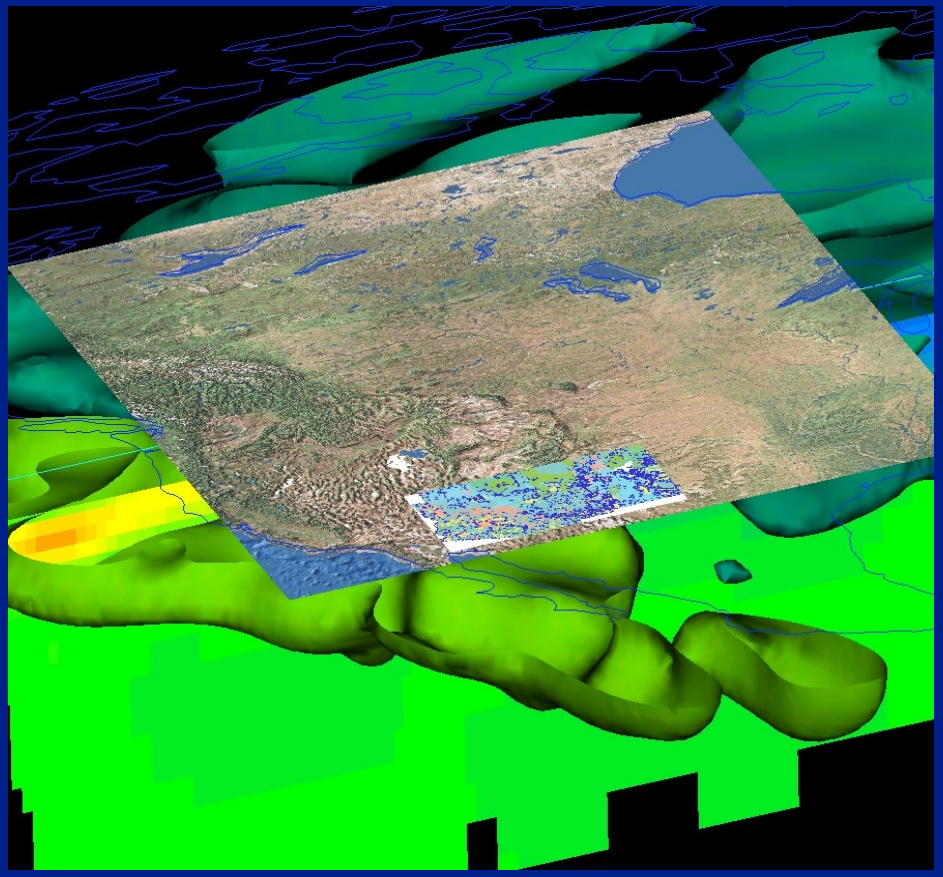
3D Wavefield Calculations

- Do we really want to be tracing rays?
  - I hope that ray tracers will be entirely replaced by 3D eikonal solvers (e.g. Zelt's FAST code), paraxial solvers (acoustics community/CalTech), and true wave equation calculations (spectral elements and finite differences)
  - Can eikonal solvers efficiently solve global problems?
  - Gaussian beams are now widely used in 3D imaging in the exploration industry but are not in widespread use for anything in academia
  - FE wavefield methods are Nx by Ny by Nz by N
  - FD wavefield methods are Nx by Ny by Nz by Nsource



Malcolm Sambridge, 2005, AGU Monograph

North American Tomography
NA04

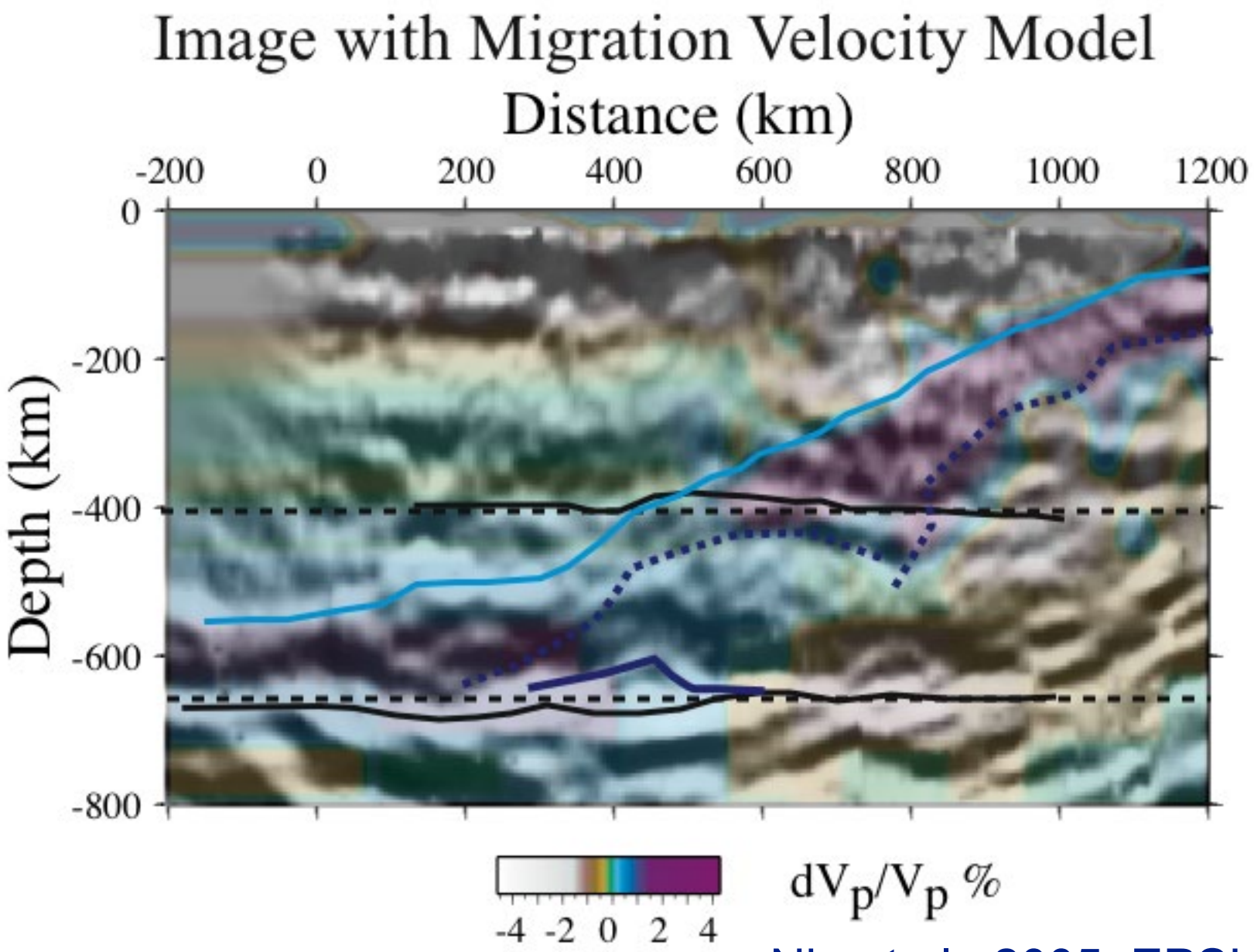


Meertens, GEON

WUSSeis: Van der Lee 2005

3D & 2D Earth Models

- Model representation on regular grids is relatively straightforward but: Are there any current standard formats that are used informally that can be adopted formally?
- For more complicated parameterizations can we develop standard translation tools?
- Representation of geological surfaces can be complex - GOCAD Consortium is an example of complex geologic surface development.
  - Probably not required for global seismology given current resolution-> might be soon.
  - Required in exploration and crustal seismology



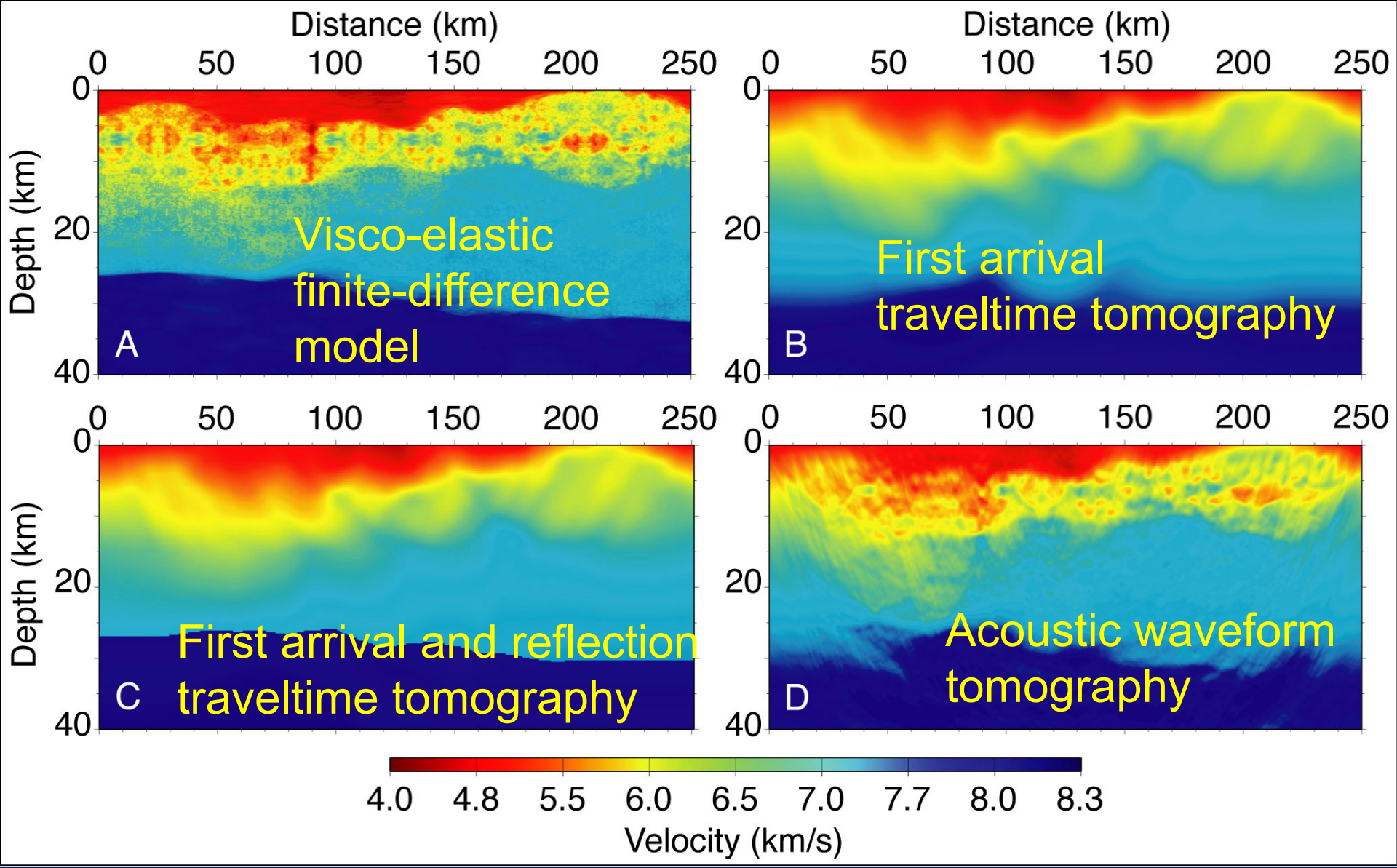
Niu et al., 2005, EPSL

1000 Individual Migrations

Poster here

Combining seismic (and nonseismic?) data and models

- At least in regional studies image registration between models remains a big problem
  - From different datasets
  - Same dataset, different researchers
  - Registration, interpolation, extrapolation codes
- How do we sensibly blend results with different resolution?
- How do we invert seismic data with different inherent resolutions?



CCSS Model: Zelt et al., 2005, EOS

Waveform Inversion in 2D&3D

- Waveform Tomography:
  - Nx by Nz per frequency per iteration of a nonlinear inverse problem : $O(N^3)$ for LU decomposition per frequency but then sources are free
    - 400 Nx by 200 Nz by 10 frequencies by 5 iterations for 2D -> 5 min/f/iteration on a 750 MHz machine
    - Will require 20s in 6 years
    - N ~$10L/\lambda$ $2–2$ frequency-domain finite-difference
    - $L/\lambda \sim 50–100$ for active source & upper mantle/TZ seismology and ~100-1000 for global seismology
    - Requires traveltime model as initial guess
- 3D will require $O(N^4\text{-}N^5)$ calculations (?)

Questions

- How much time do we spend reinventing the software wheel?
  - I personally spend a lot of time coding/recoding/reinventing and then find other peoples codes that do almost the same mine do.
  - Are our careers so long that we can afford to reinvent?
- Periodic recoding is healthy
- Methods development is healthy
- How do we self-organize to minimize redundancy?

What might self-organization look like?

- Want to encourage innovation and graduate student education
- Want to avoid stifling creativity
- At the same time we want to move forward quickly

- For direct imaging we have submitted and will resubmit a proposal for a virtual center
  - Low overhead virtual think tank for idea exchange

Virtual Center

- Direct Imaging Virtual Center will (hopefully) consist of a series of workshops accompanied by special sessions at meetings
  - First workshop held at Rice in 2003 sponsored by IRIS
  - Second held at Stanford in 2004 sponsored by SEP
  - Sessions at AGU Fall 2004, Spring 2005
  - Next meeting is likely to be at Rice in the fall but
  - LDEO, MIT, and UBC have been offered recently as venues for future workshops/meetings

•Levander, Symes, Zelt, Niu, (Rice) Biondi and SEP (Stanford), Rondenay (MIT), Bostock (UBC), Pavlis (IU), Weglein (UH), Snieder and CWP (CSM), Sen and D. Wilson (UT), C. Wilson (LDEO), Aster (NMT), Wu (UCSC), Schuster (UU), Fehler (LANL), Anyone else interested?

Workshops

- Focus on more WORKING and less on shopping. (A change from the community-building exercises).
- Validation and comparison of methods (somewhat like the CCSS model): Generate or adopt test datasets?
- Somewhat similar to Mathematical Geophysics summer schools
- Think “Penrose Conference where the field trips is computer based imaging research”, or “a tennis camp for seismic imaging”

Suggestions

- What should CIG seismology do?
  1. Develop or adopt a Framework
  2. Provide some relatively simple, useful tools like model exchange/translation/registration/model display software
  3. Provide 1D wrapped TT and reflectivity if its simple
  4. Provide 2D-3D TT w amplitudes code
  5. Focus on wavefield for 2D & 3D:
     - Develop for local & grid computing
     - Wrap 2D/3D forward modeling (Tromp's spectral elements, Robertsson's visco-elastic FD, Wu's phase screen)
     - Wrap 2D wavefield tomography (Pratt, 1998)

Suggestions

- Establish, encourage or network with working groups for computational seismology:
  - Model exchange, Forward modeling, Tomography, Waveform tomography, Direct imaging & wavefield inversion, Visualization, International outreach
- Use the Swiss compromise

- Until waveform inversion is routine in 3D validation of models with forward modeling would be an