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Title: Determination of Shallow Crust Properties from Physical Predictors

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Determination of Shallow Crust Properties from Physical Predictors

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R. Herrmann (SLU)
E. Syracuse (LANL)

May 28, 2014

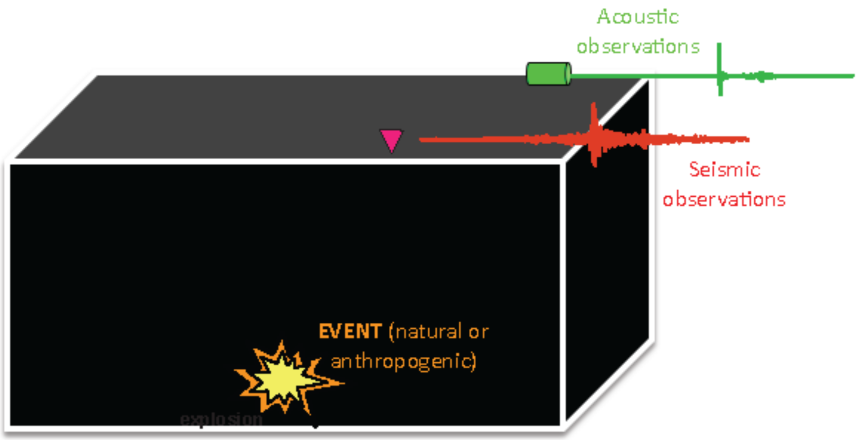
Talk Outline

- This work and SoS
- Motivation – why joint inversion for Earth models?
- Surface waves, receiver functions and gravity
  - Case studies
- Addition of body wave travel times
  - Case studies
- Conclusions
- Near future challenges and needs

This work and SoS

- Signatures characterize an event as either natural or anthropogenic.
- EES-17 GMAC (Geophysical Modeling And Association) team makes use of seismic and acoustic signatures to detect, locate and characterize smaller seismoacoustic events.

This work and SoS



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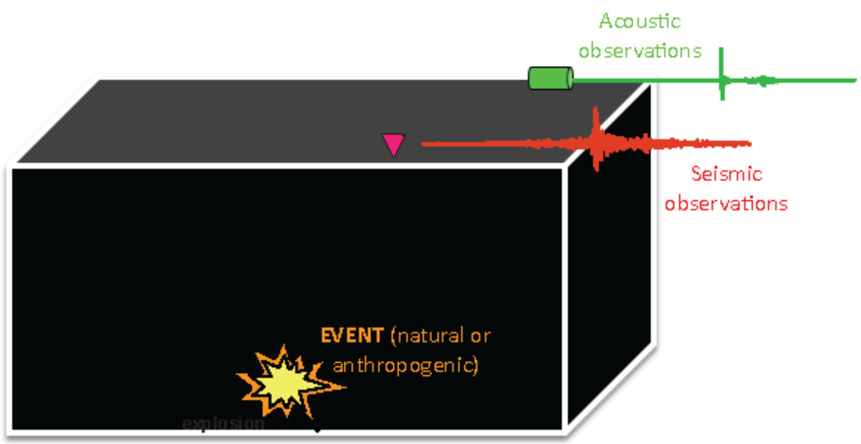

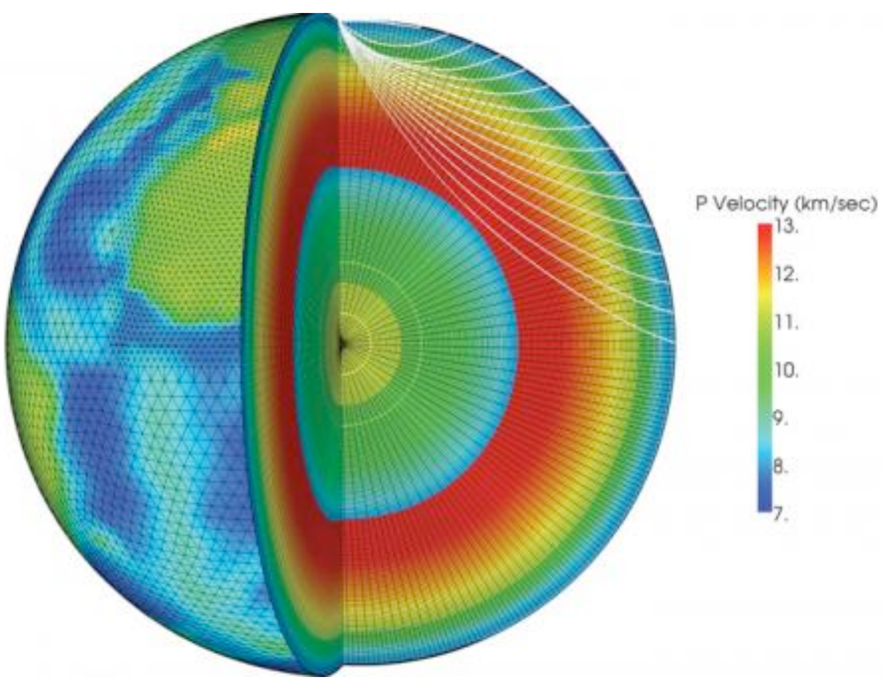

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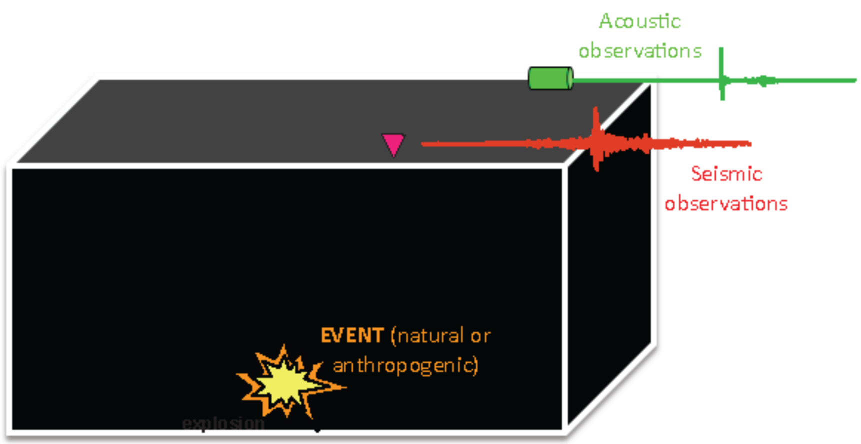

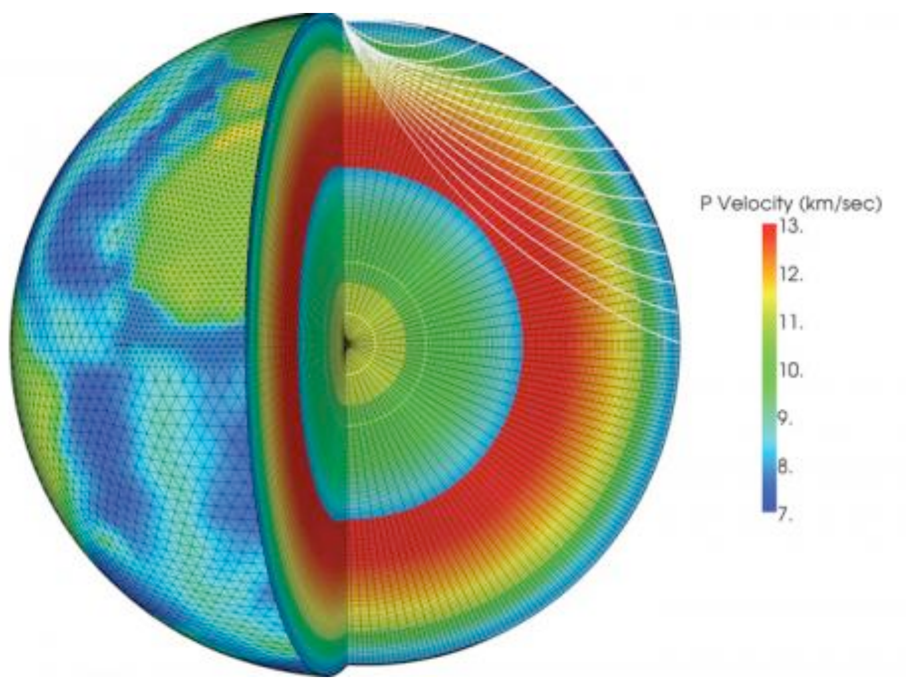

- Accurate Earth models of the 3D seismic structure
- Focus on shallow crust and upper mantle by using **simultaneous joint inversion** of multiple and independent datasets.

Motivation

Can we construct accurate and precise 3D Earth models from only seismic observations?

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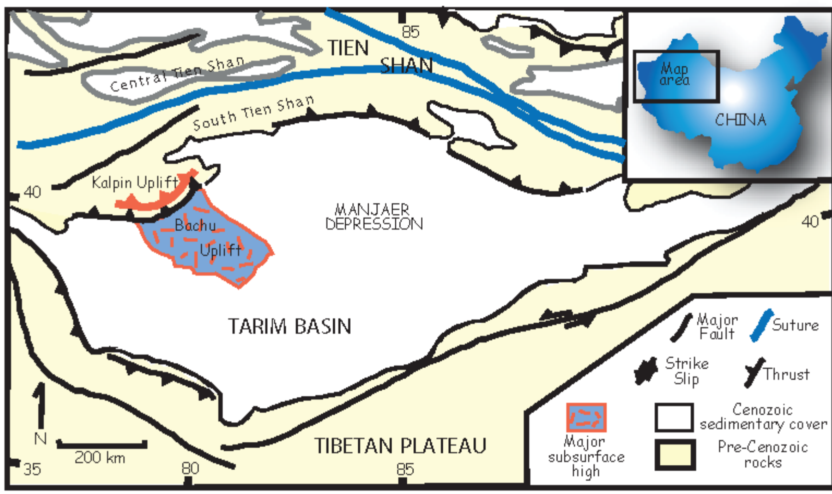
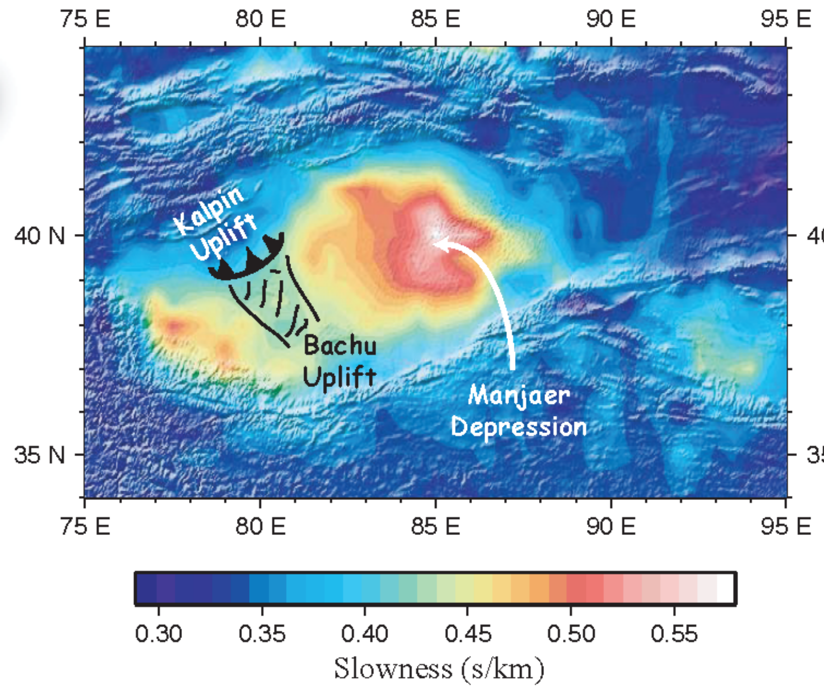
Simplified geological map of the Tarim basin

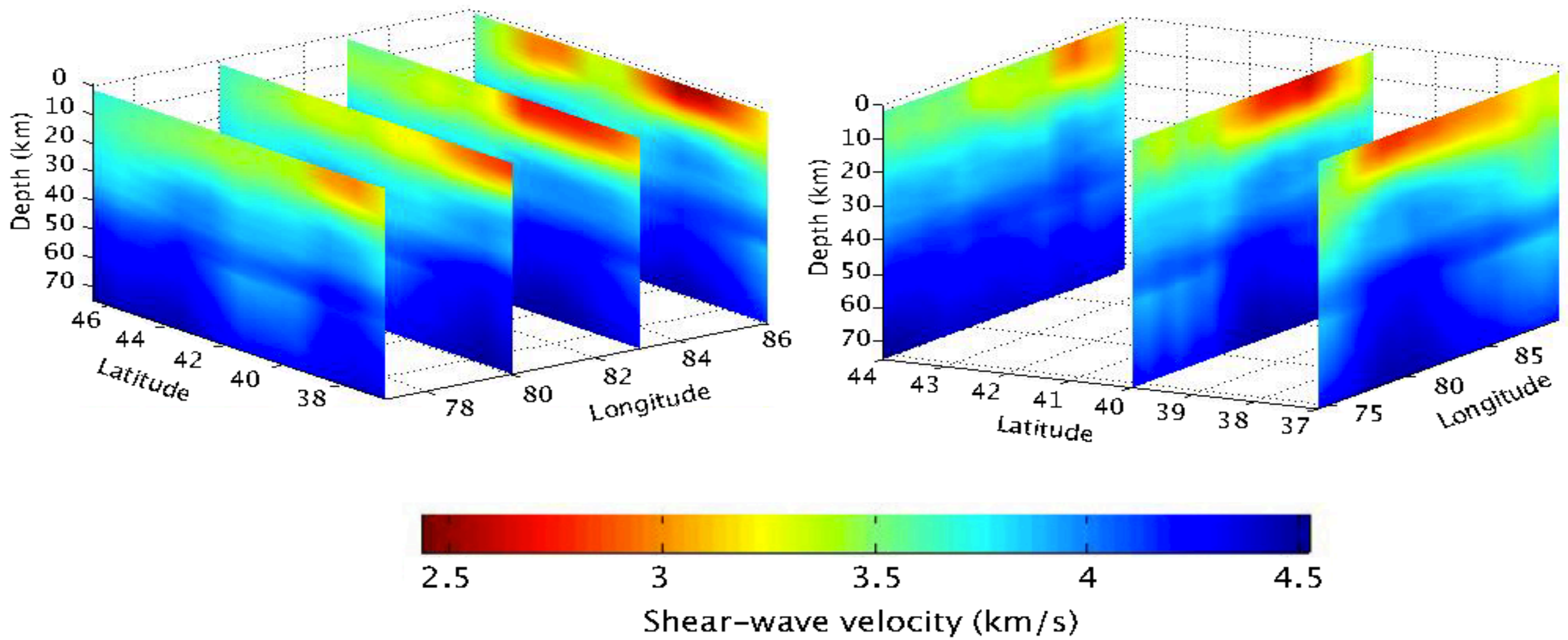


Surface wave tomography map at T=10s



Working with surface waves, we developed high-resolution Rayleigh wave slowness tomographic maps (Maceira *et al.*, 2005)

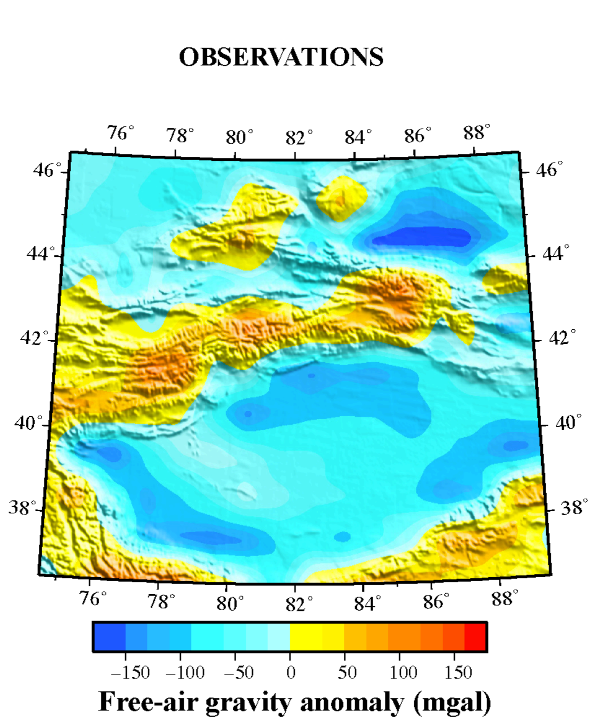
Motivation

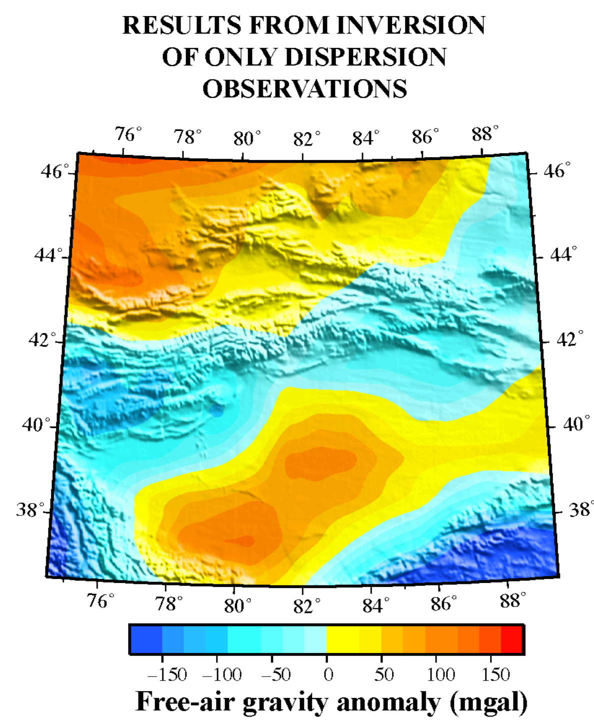


Following the traditional approach, we generated a 3D S-wave seismic model from the surface wave tomographic model.

Motivation

Can a model derived from one type of geophysical data predict a second type of data?



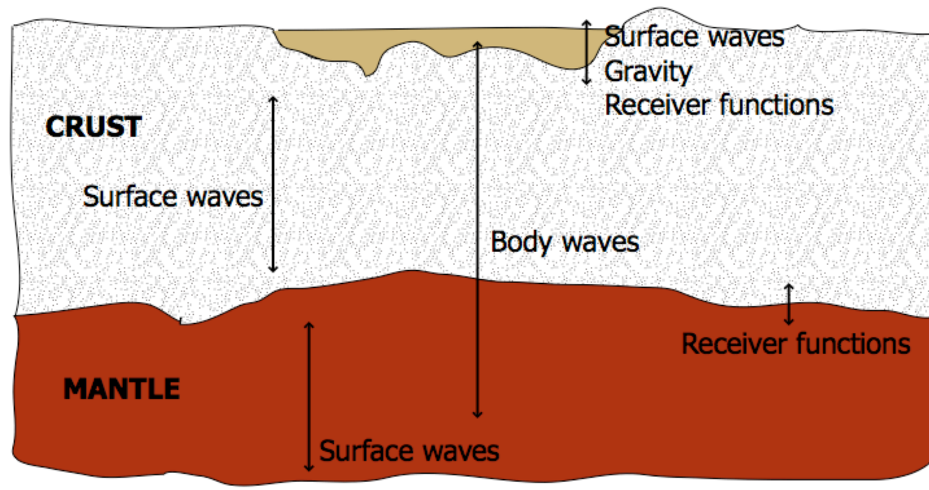


PROBLEM: It has long been recognized that derivation of geophysical models for a given observable often provides poor prediction capabilities for other parameters. *In theory however, earth models should be consistent among a variety of measurements, as the material whose properties we are modeling does not change.*

Why simultaneous joint inversion? It enables spanning spatial and data scales!

Multiple benefits

- Different data sets have different spatial coverage and resolution.
- "Standard" geophysical models are developed only to fit one type of data.
- Different data types have different strengths.



Multiple challenges

- Deal with different data bandwidths.
- Design responsive misfit norms; relative weighting of data sets.
- Make assumptions to model the different data; relationships between independent data sets.

Evolution of Analysis Codes:

It takes a village

SLU/LANL
1989
Ammon & Randall
P Receiver Functions

→

SLU
1998
Julia, Ammon, Herrmann
\+ Surface Wave Dispersion (Saito Functions)

→

PSU
2002
Julia
\+ Local Traveltimes

→

PSU
2008
Julia
\+ SV Receiver Functions

LANL
Maceira
\+ Gravity, "3D"
2006

→

LANL/MIT
Maceira & Zhang
\+ Body-wave traveltimes
2009-11

Ammon
\+ Period Weights, Transverse Isotropy (Saito Functions)
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Herrmann
Computer Programs in Seismology
P Receiver Functions + Surface Wave Dispersion
SLU

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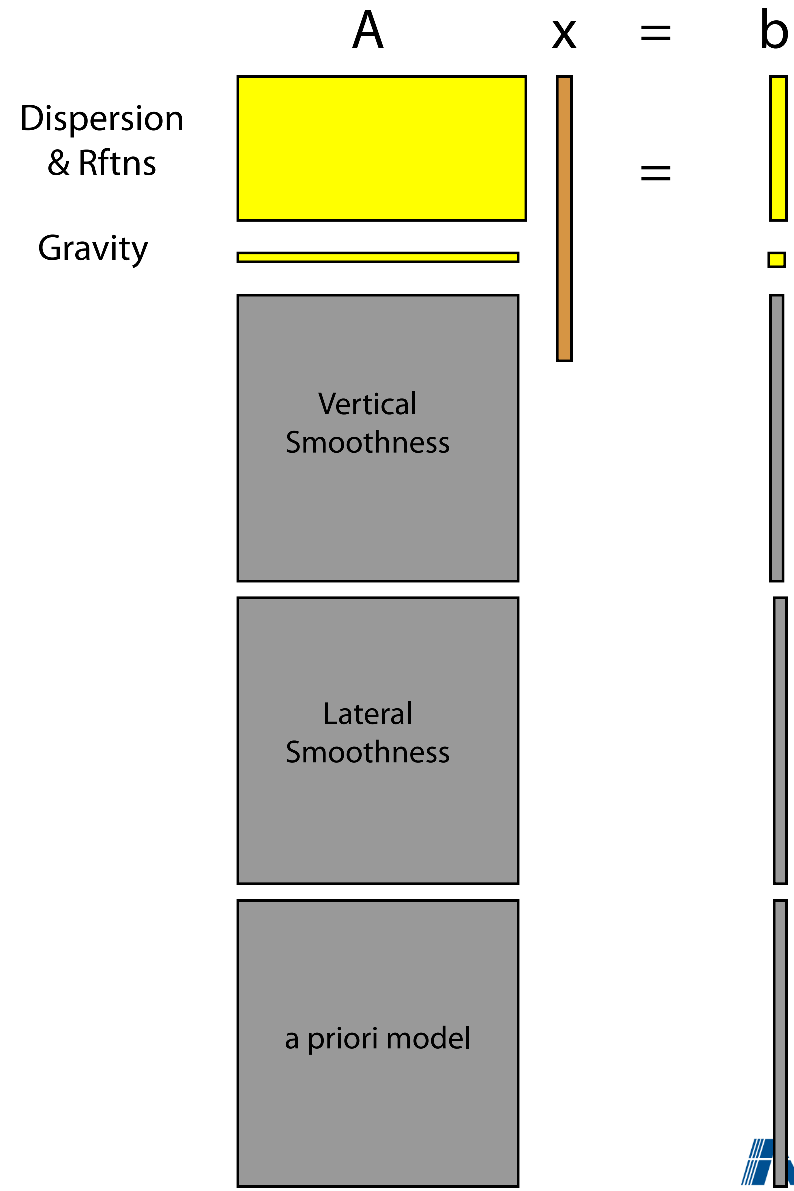
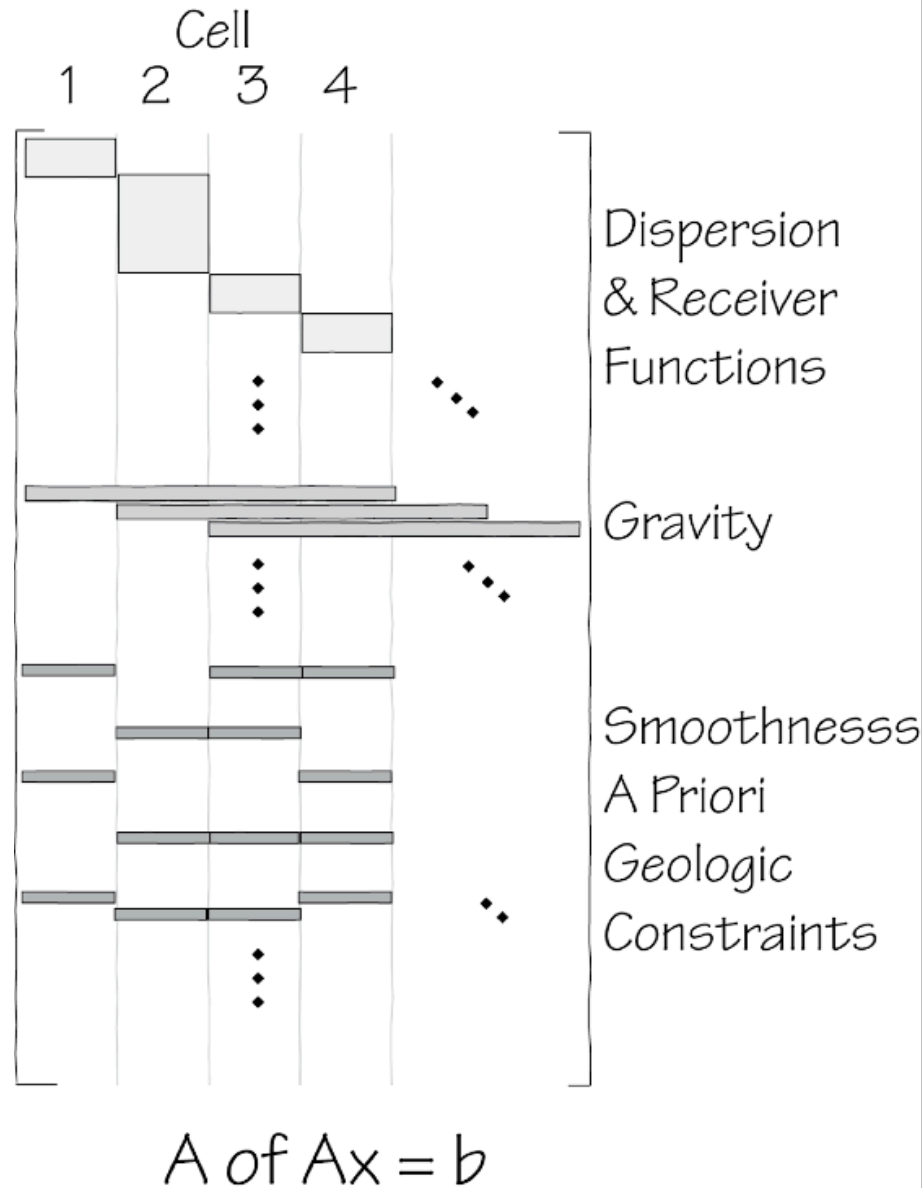
LANL pioneers simultaneous joint inversion of surface waves, receiver functions, and gravity



x -> Earth seismic model … unknown!
b -> data
A -> matrix of equations relating model to data

LANL pioneers simultaneous joint inversion of surface waves, receiver functions, and gravity



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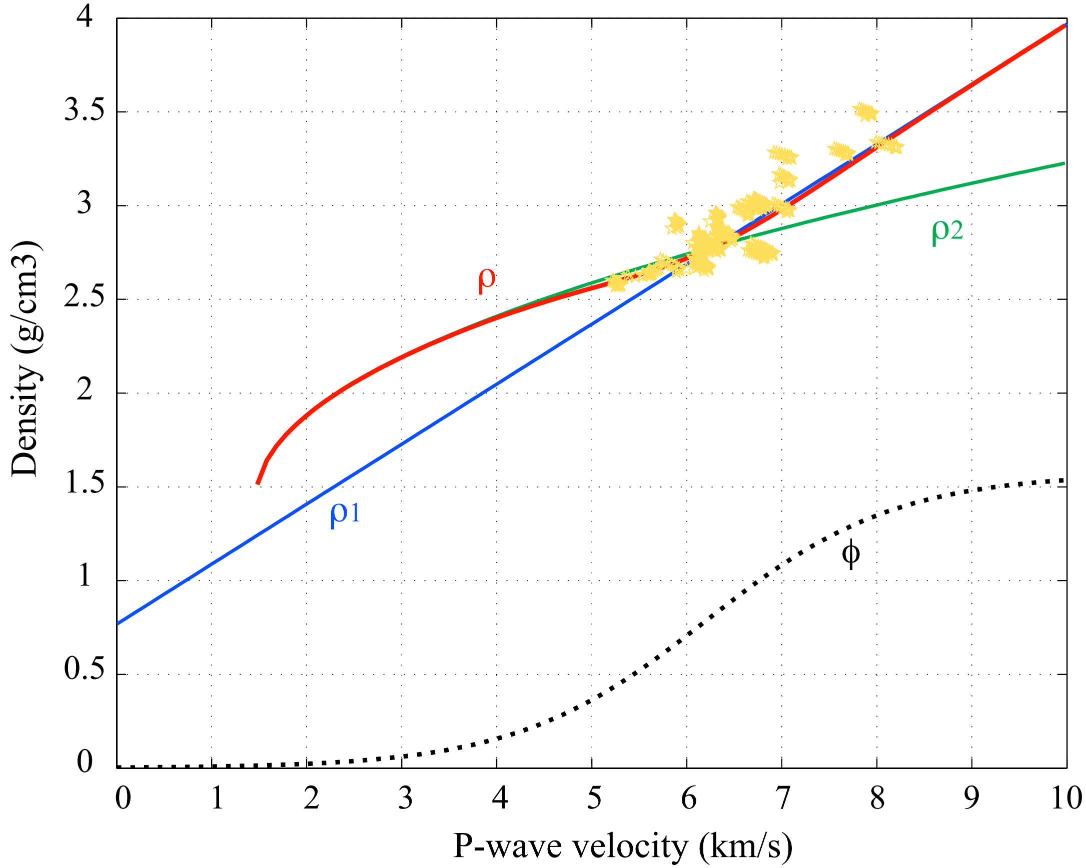
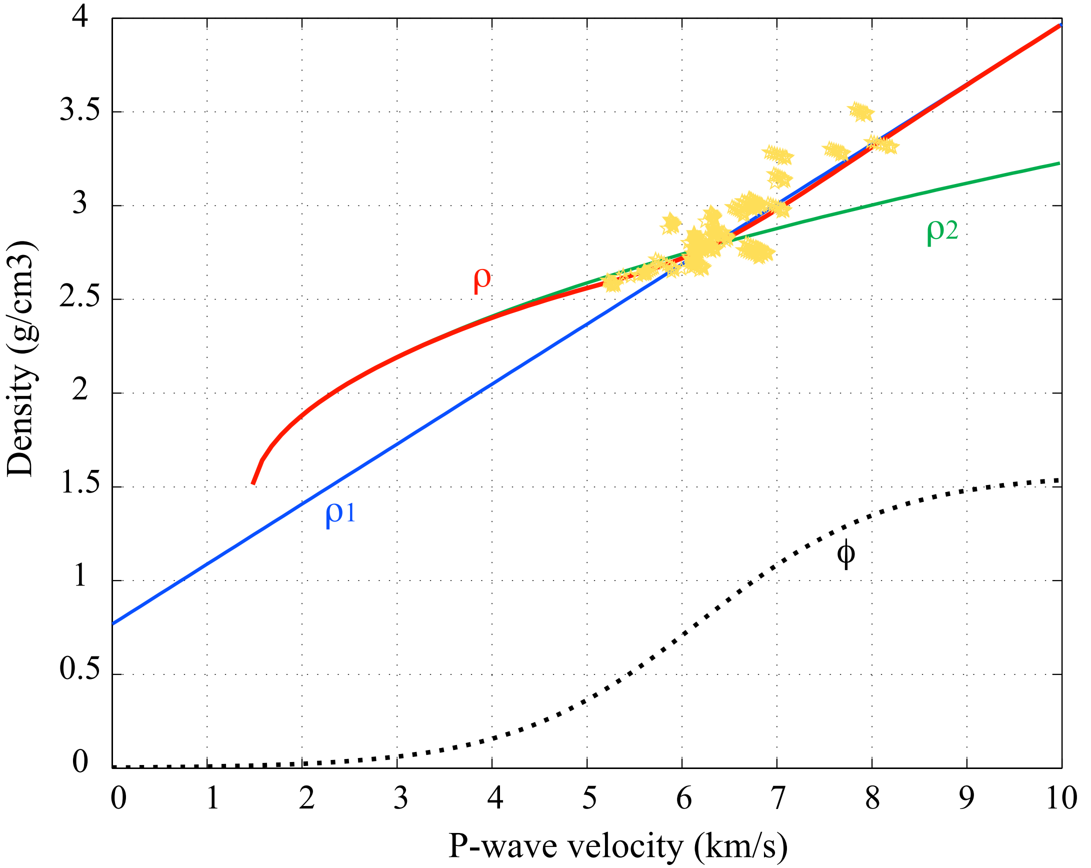
Challenge:
Relationship between independent variables



Maceira (2006)

Challenge:
Relationship between independent variables

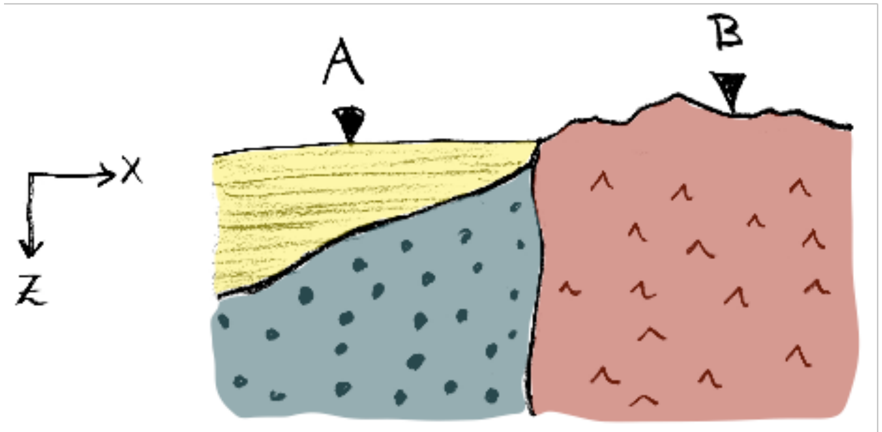


Maceira (2006)

Now known as the Maceira & Ammon relationship!!!

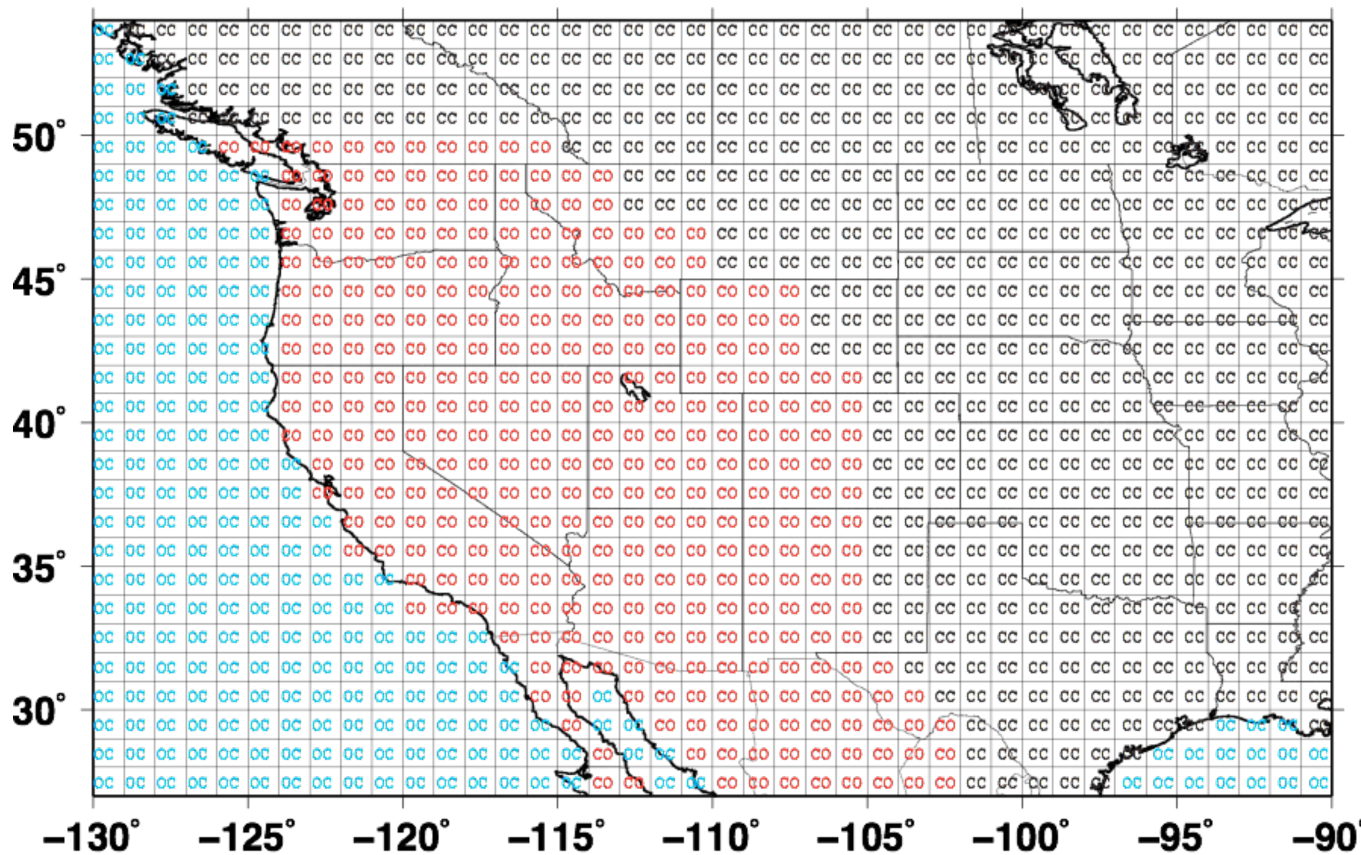
Creative and better use of geologic information to address challenges

- Most geophysical tomography results use a relatively simple mathematical smoothing
  - ✓ Laplacian smoothing
  - ✓ Gaussian averaging



- Such mathematically simple smoothing is appropriate for dispersion tomography, but not always for shear-velocity inversions

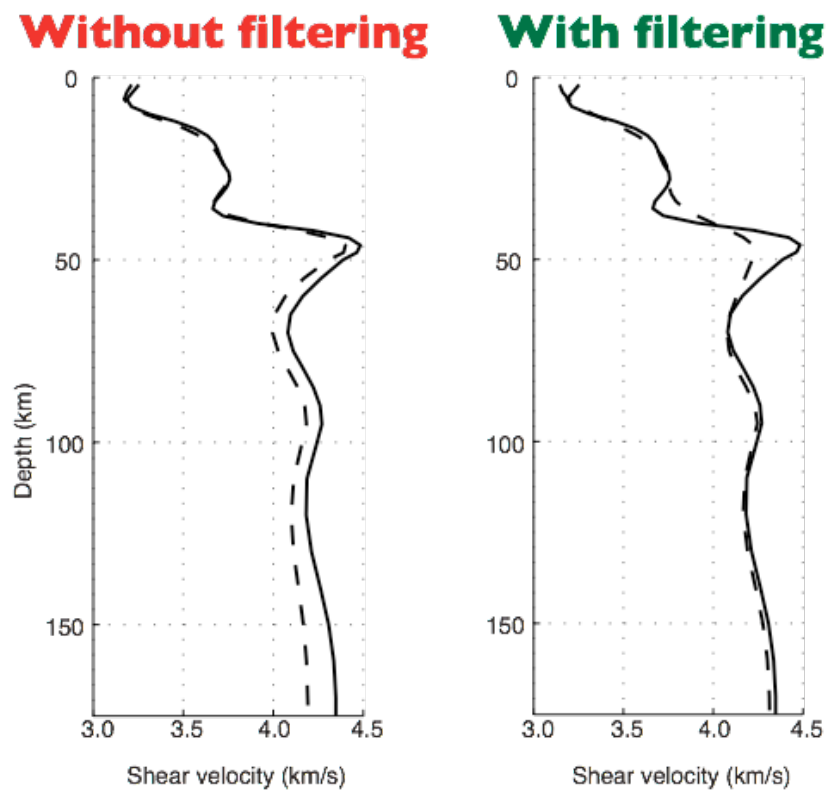
Creative and better use of geologic information to address challenges



Smoothing allowed inside the same geological/tectonic unit to preserve known boundaries

Gravity challenges … what to do? Depth-dependent smoothing, filtering, …

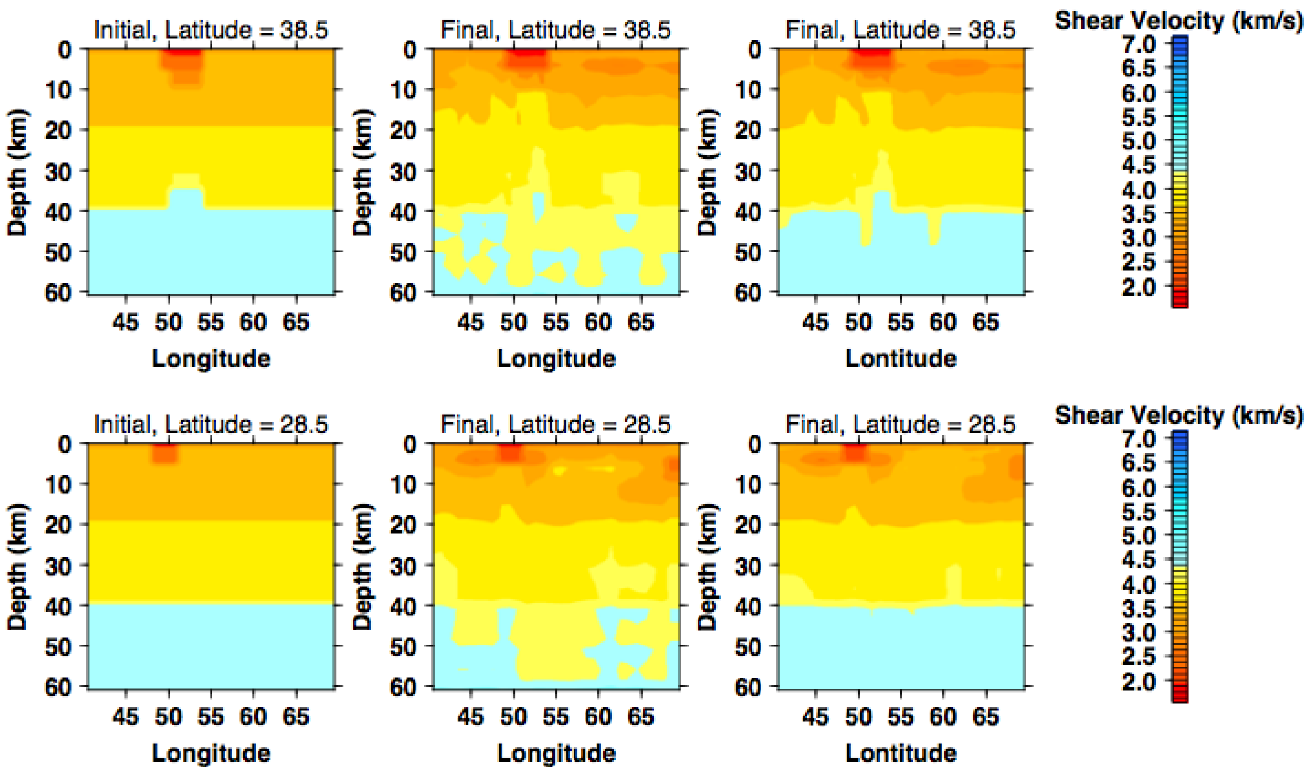
- We noticed leakage of high wavenumber gravity features into the deep structure.
- Our solution: filtering of the gravity data.



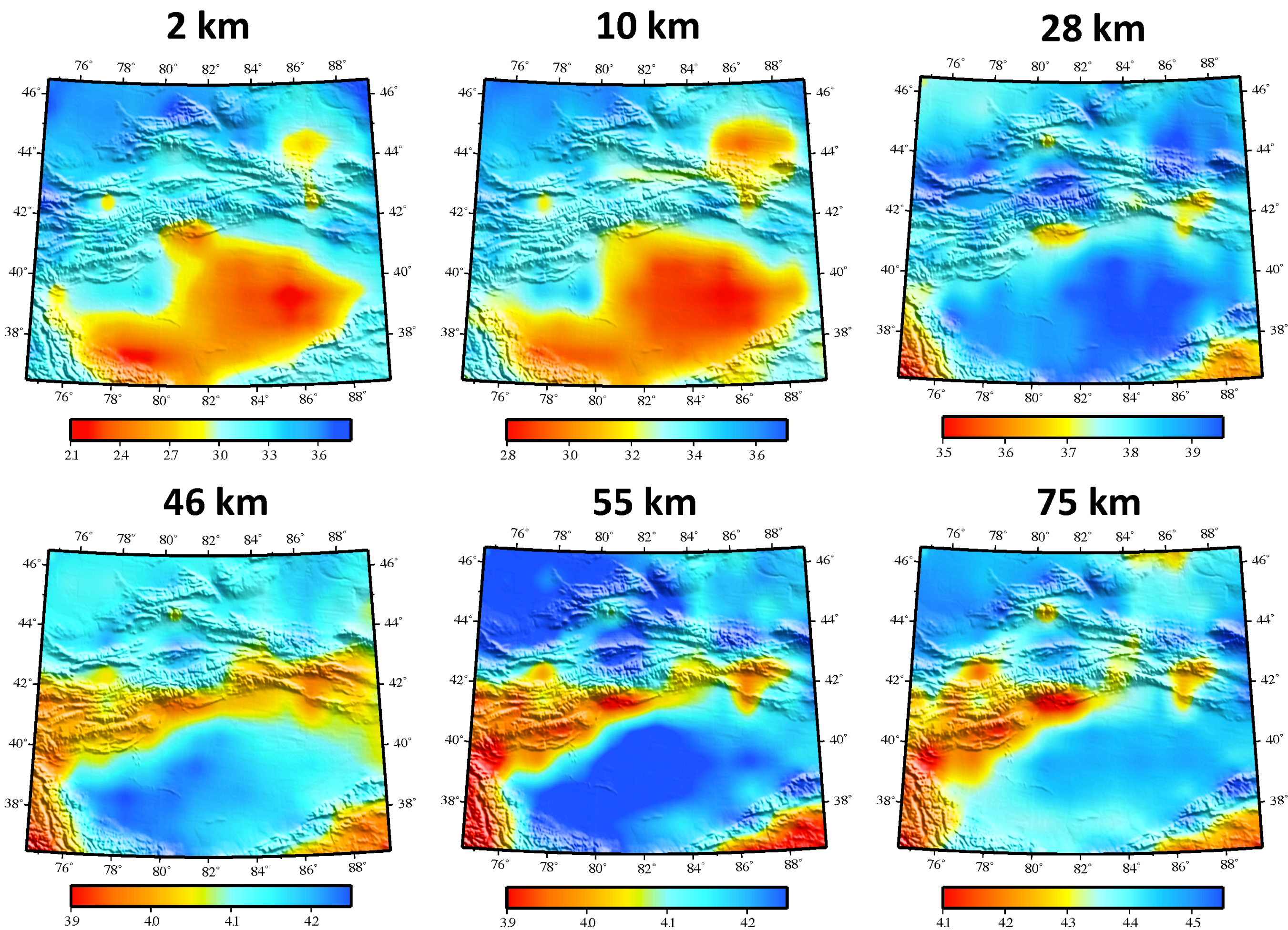
1D inversion with only surface waves data
1D inversion with surface wave & gravity

TRADITIONAL approach
(only gravity data filter)

LANL approach
(equalizing Ax=b)



Case Study I:
Tarim basin and application to monitoring mission

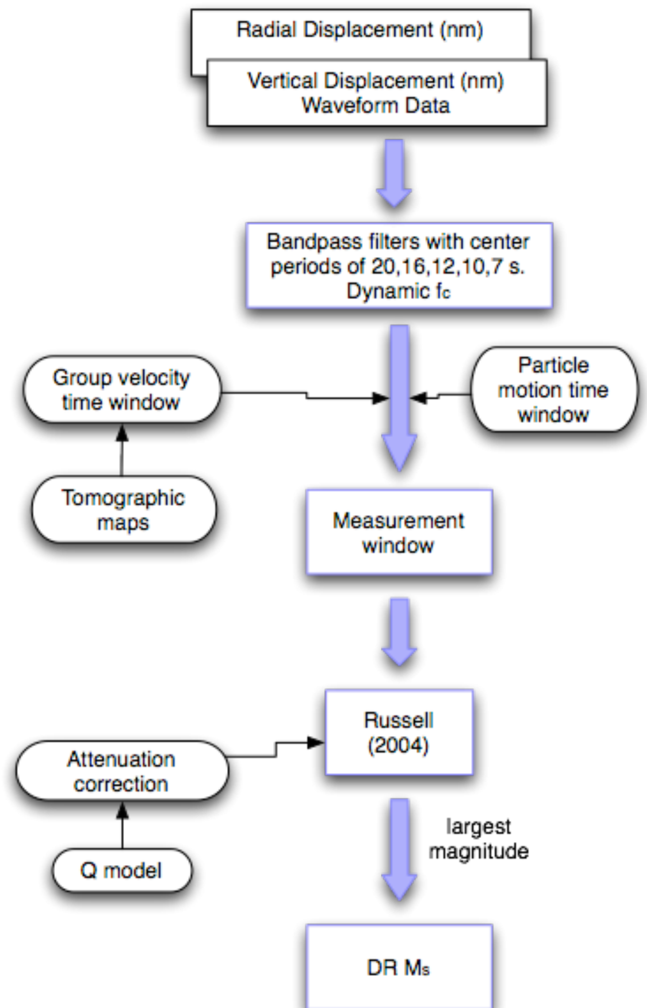


S-wave velocity (km/s)

Maceira and Ammon (2009)

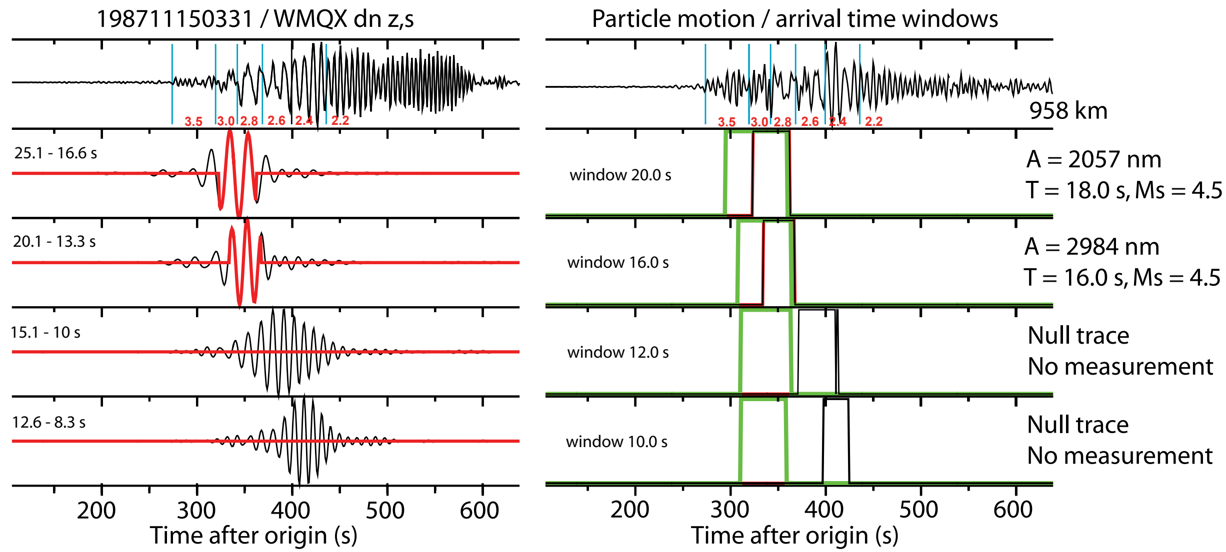
Case Study I: Tarim basin and application to monitoring mission

- Sedimentary basins show very slow in the new 3D shear-velocity model. Is this an improvement?
- We tested the ability of the new joint 3D model to predict surface wave arrivals at short periods – essential for measuring surface wave magnitude at shorter periods than 20 s (discrimination implications for smaller events)

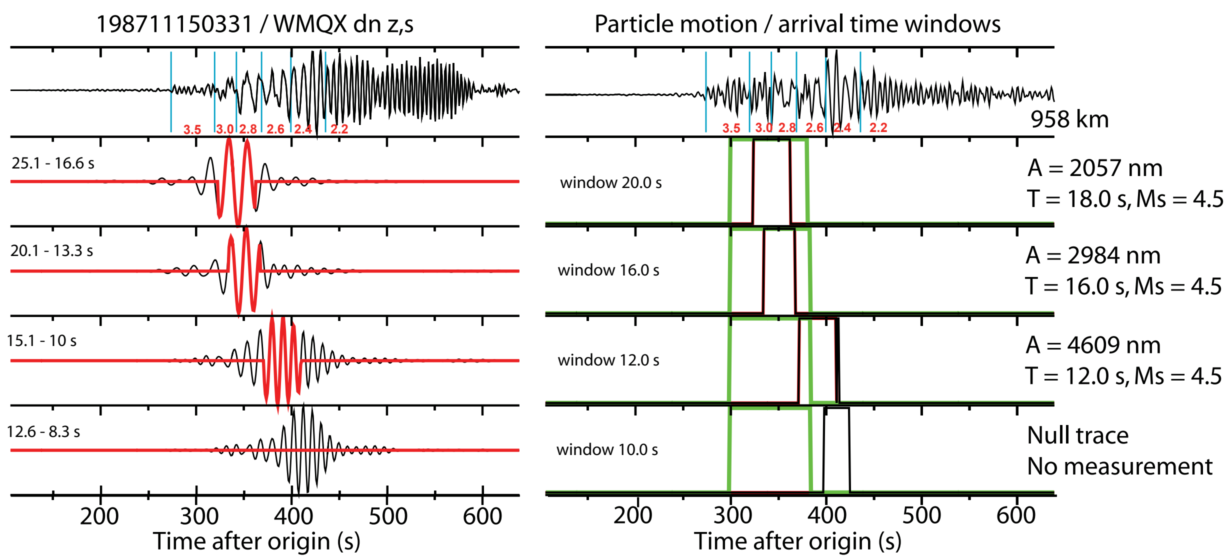


Case Study I: Successful discrimination for monitoring mission

USING MODEL FROM INVERSION OF ONLY DISPERSION OBSERVATIONS



USING MODEL FROM JOINT INVERSION



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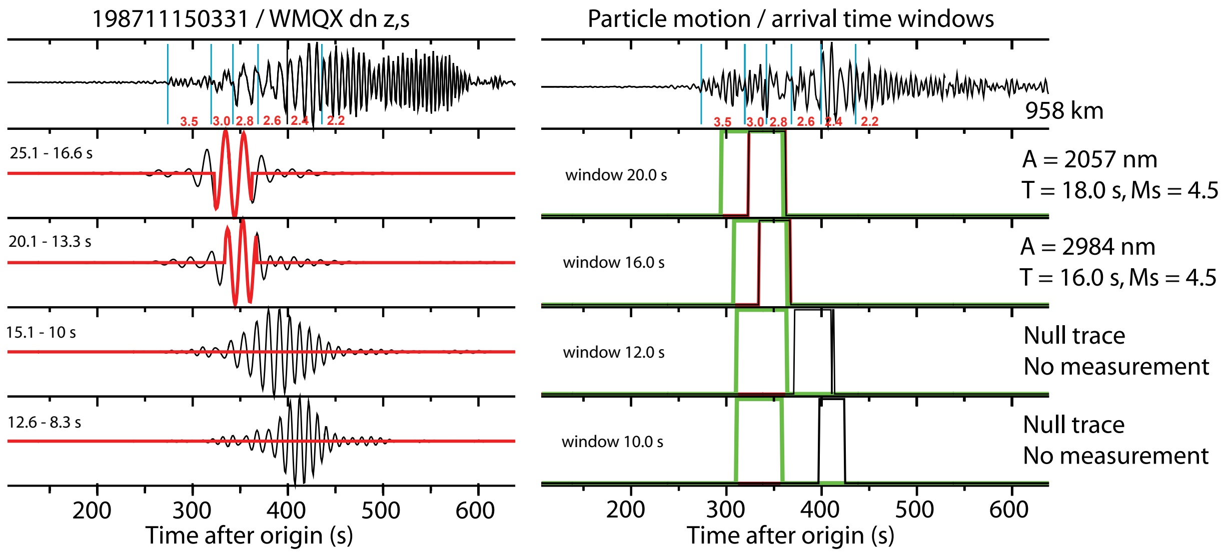
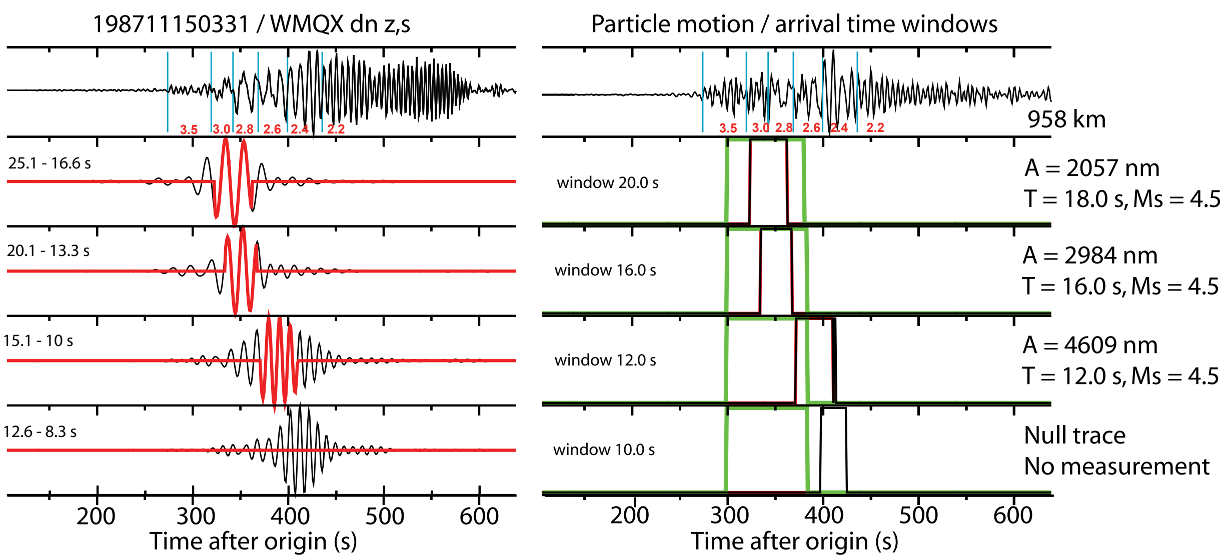
Case Study I: Successful discrimination for monitoring mission

USING MODEL FROM INVERSION OF ONLY DISPERSION OBSERVATIONS



DETECTION

USING MODEL FROM JOINT INVERSION



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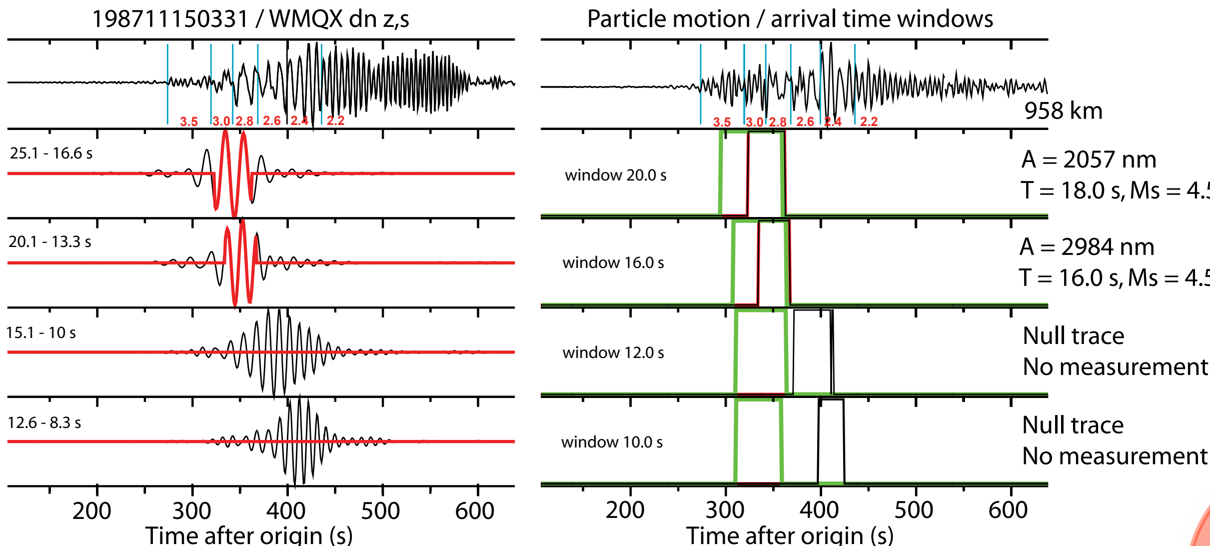
Case Study I:
Successful discrimination for monitoring mission

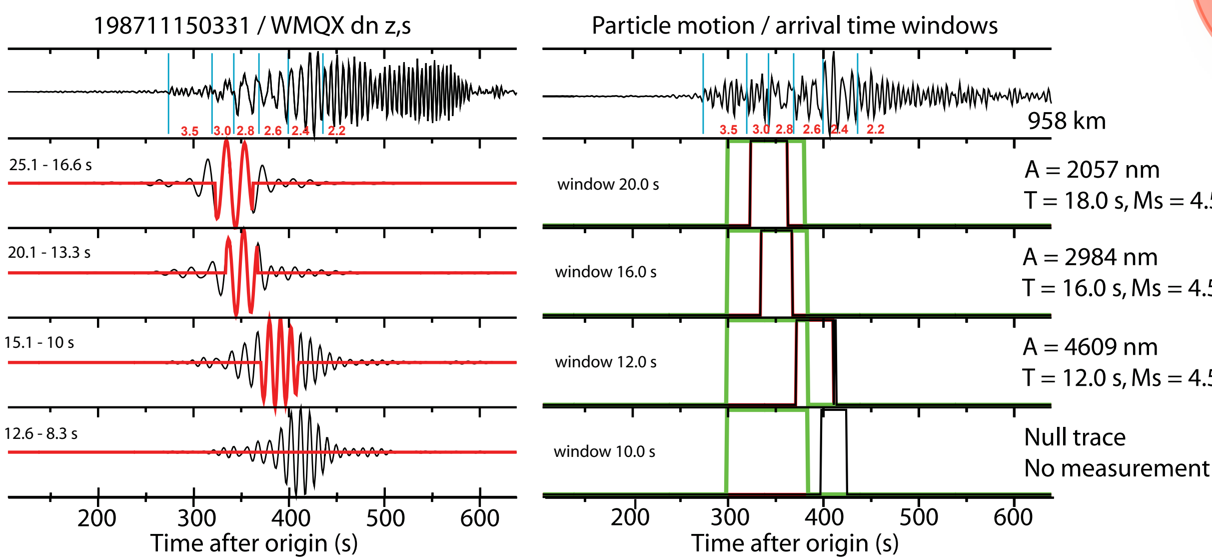
US… ROM
INVE… ONLY
DIS…
OB…ATI…



—— DETECTION

73%
improvement

USING MODEL FROM JOINT INVERSION



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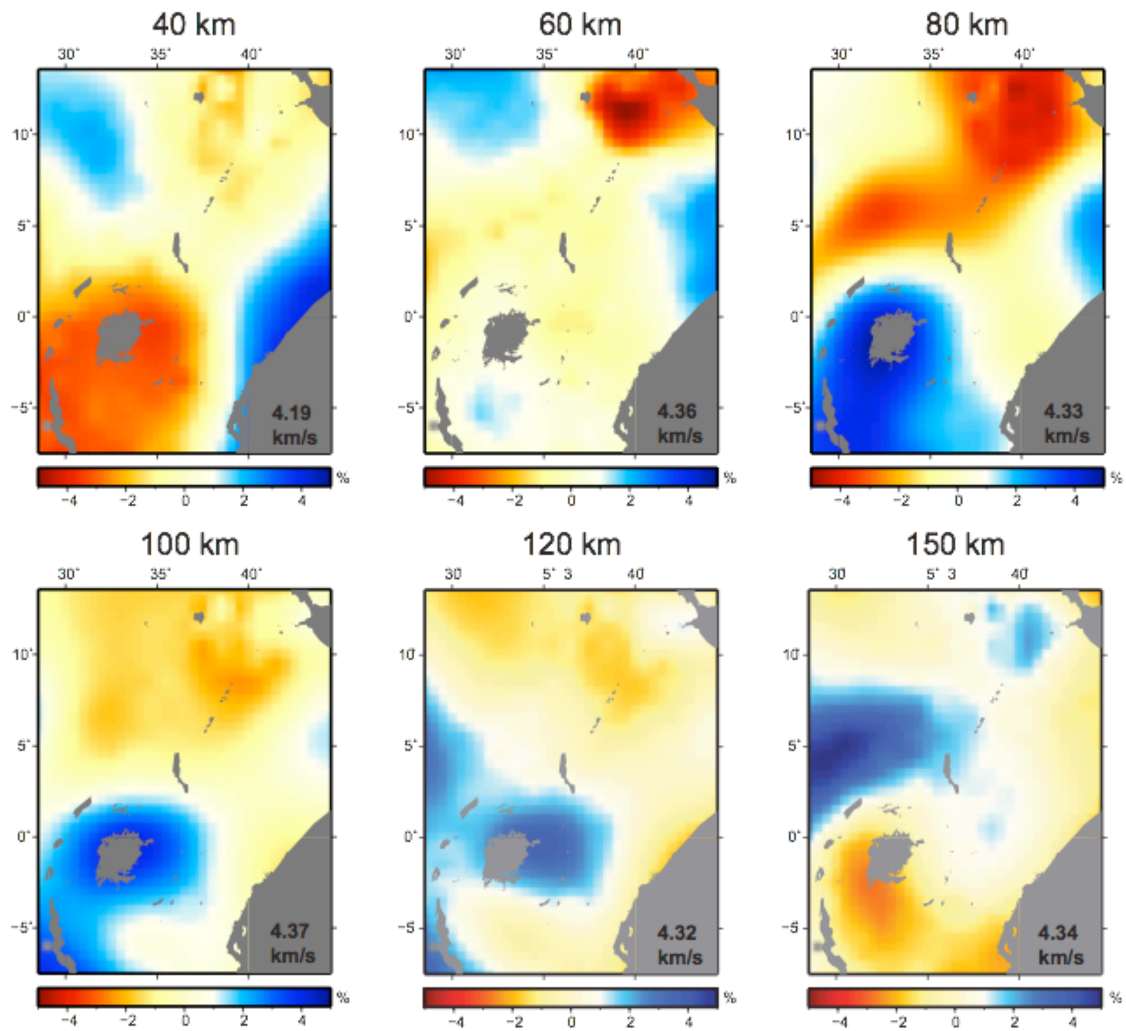
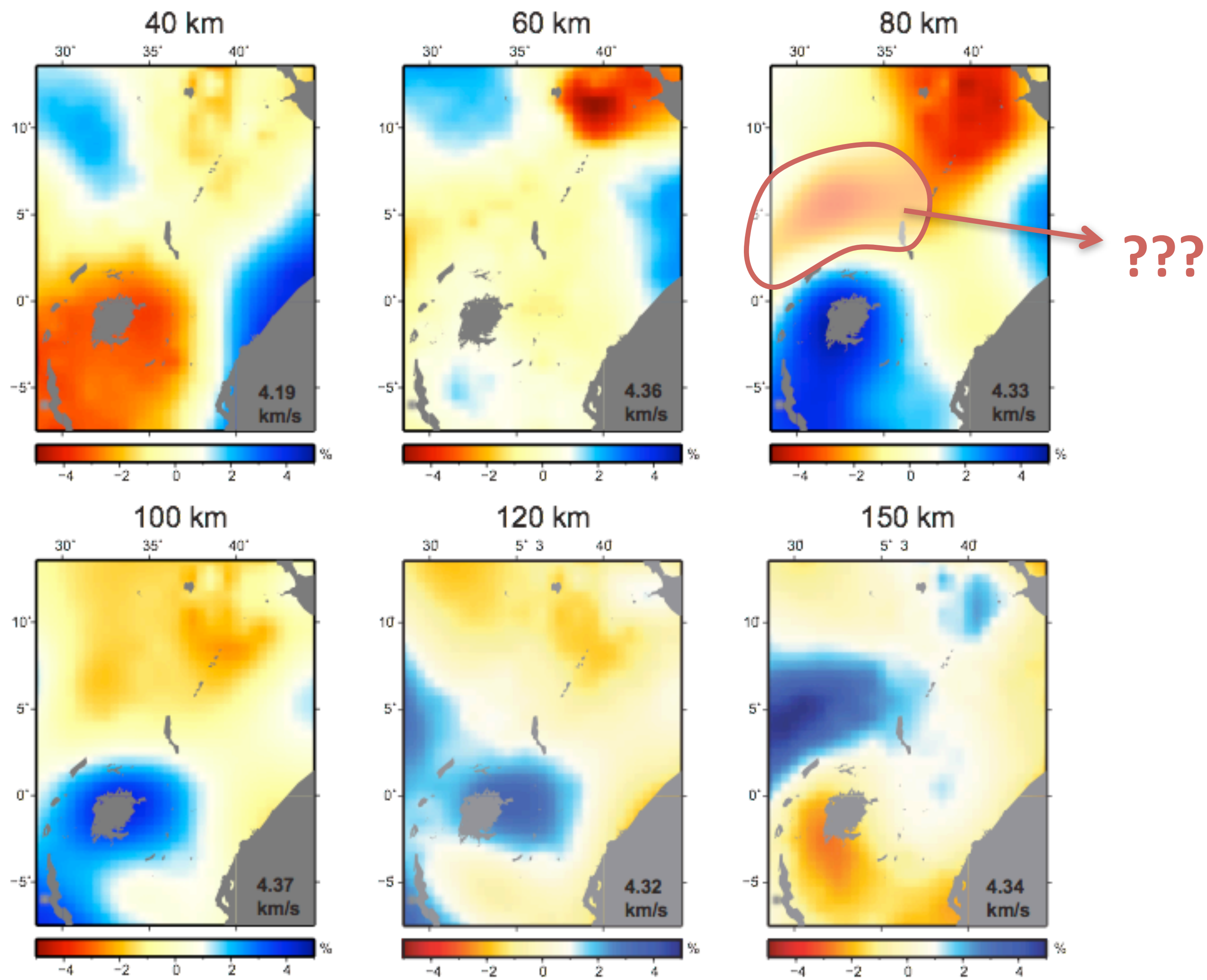
Case Study II:
East Africa Rift System and geodynamics



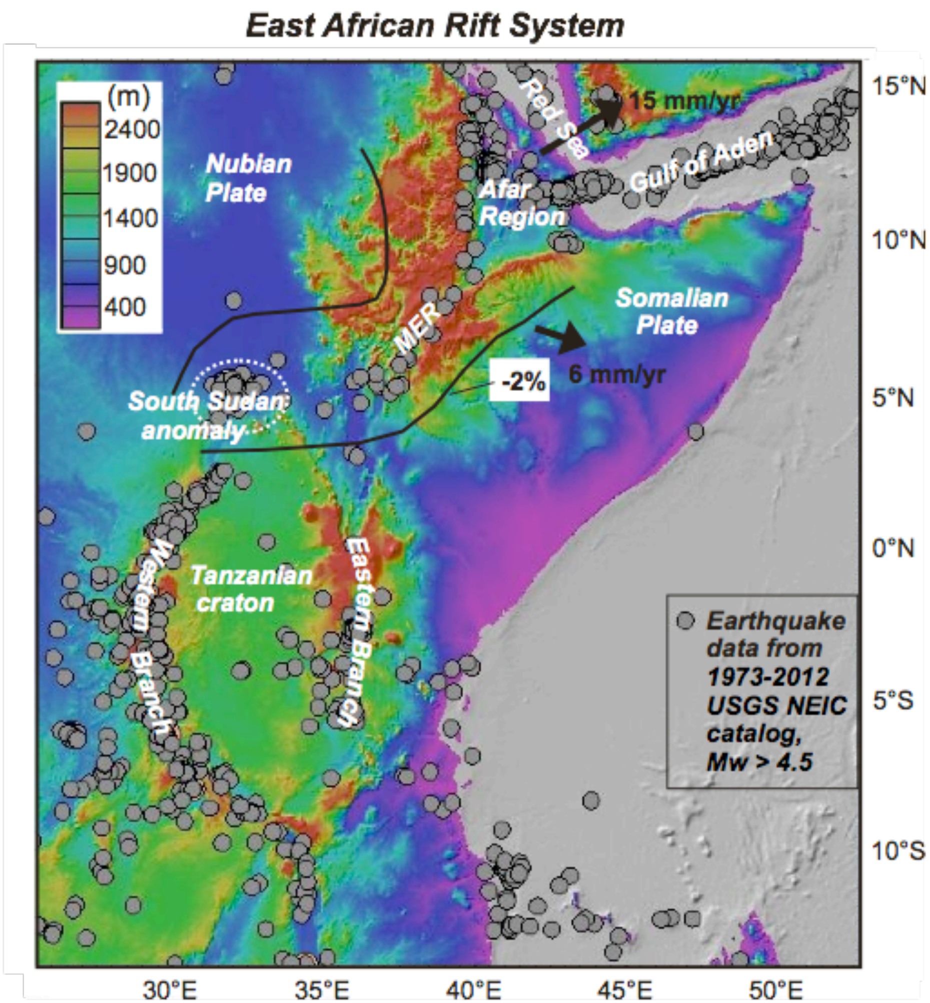
3D S-wave velocity model from joint inversion of surface waves and gravity observations

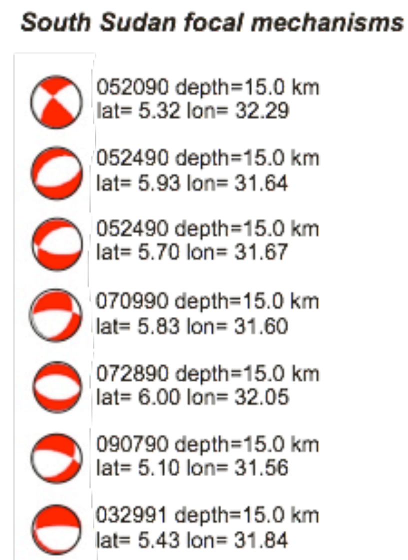
Case Study II: East Africa Rift System and geodynamics



3D S-wave velocity model from joint inversion of surface waves and gravity observations

Case Study II: New rift branch? – important geodynamic implications





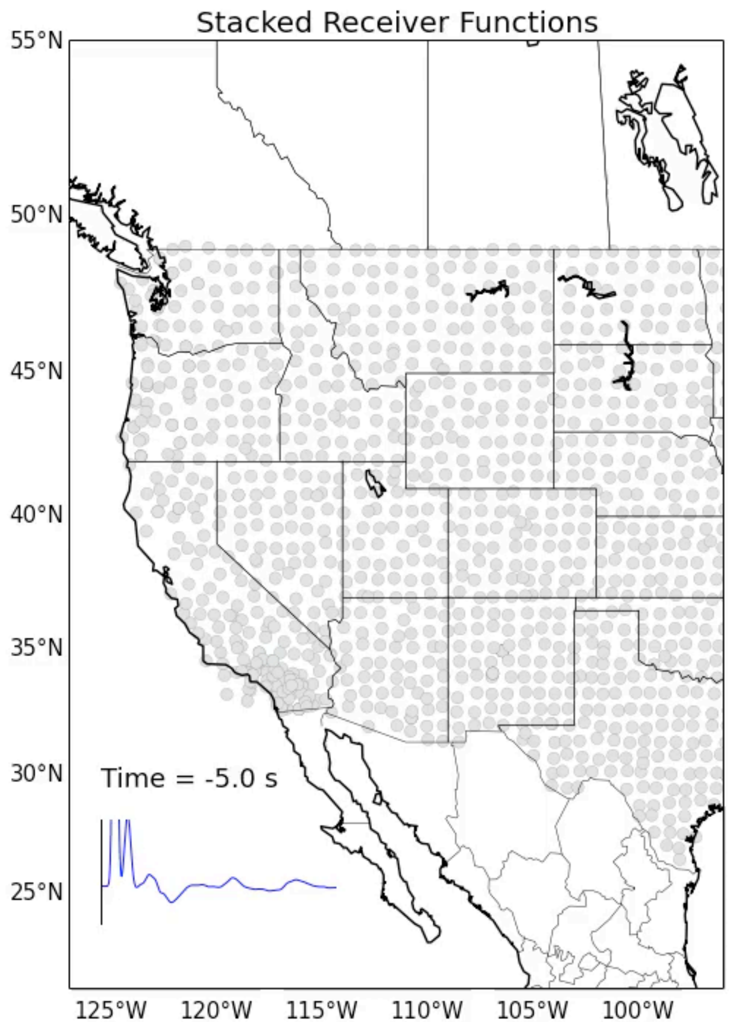
We propose:

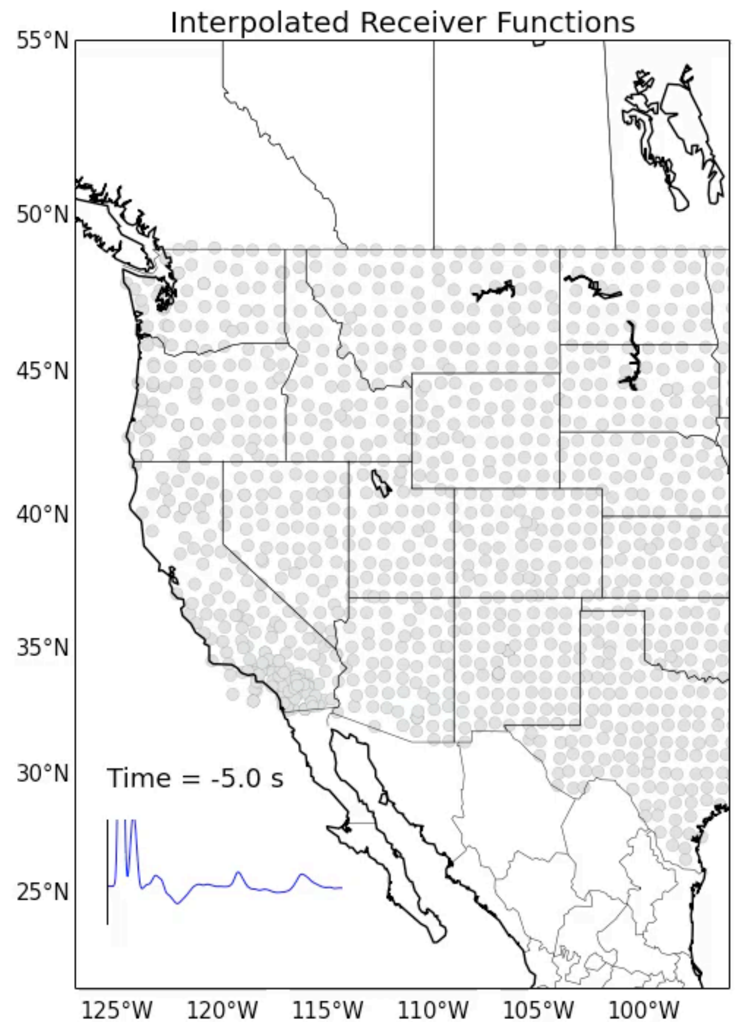
Nascent rift branch or old rift reactivation?

(Maceira et al., G3 in review)

Case Study III:
Western USA – Unprecedented Data Sets

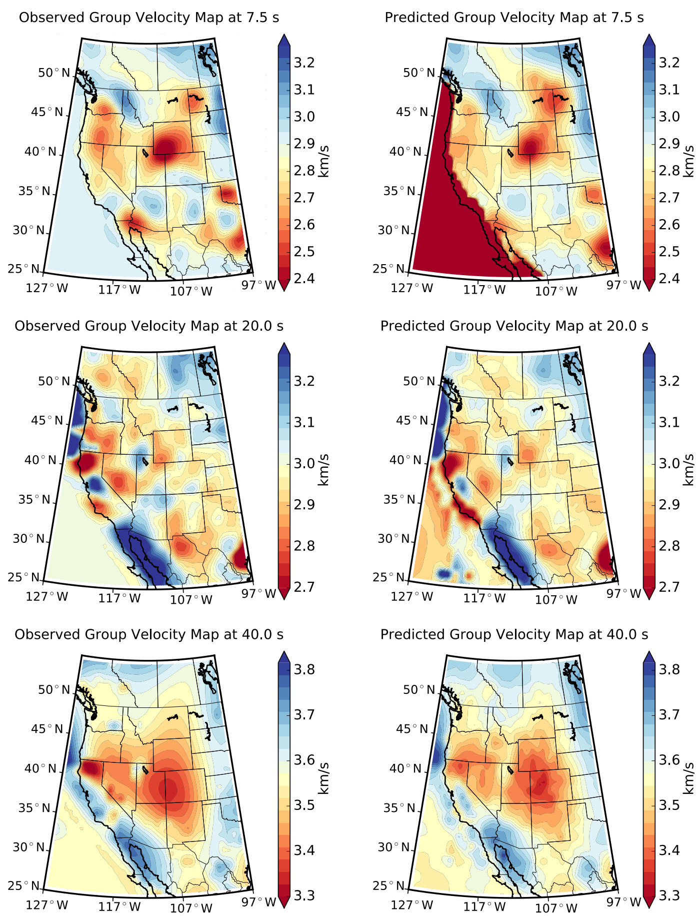
Case Study III:
Western USA – Exploring dense coverage opportunities

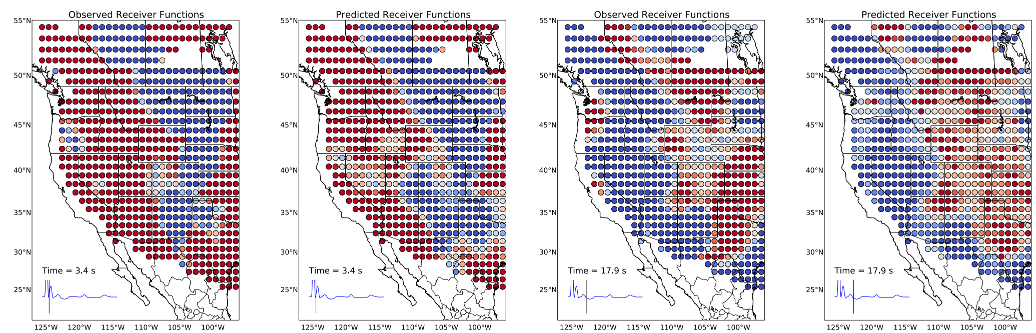


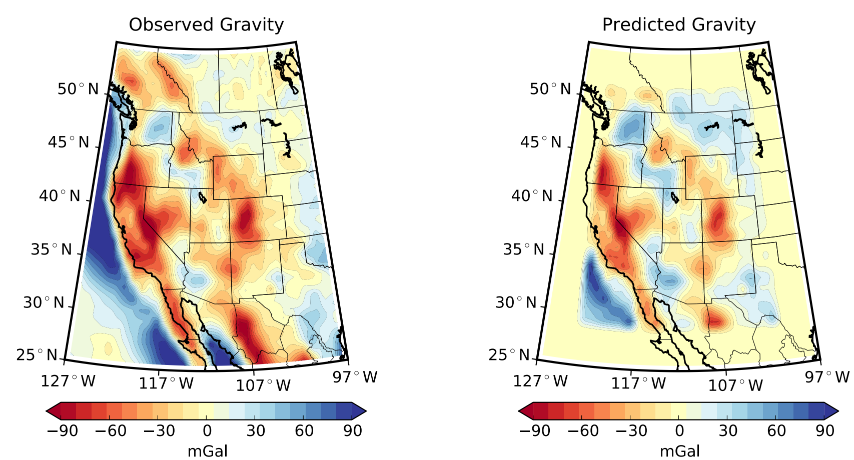


Case Study III:

First continental-scale application of joint inversion of surface waves, receiver functions & gravity







Successful!!!

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Case Study III:
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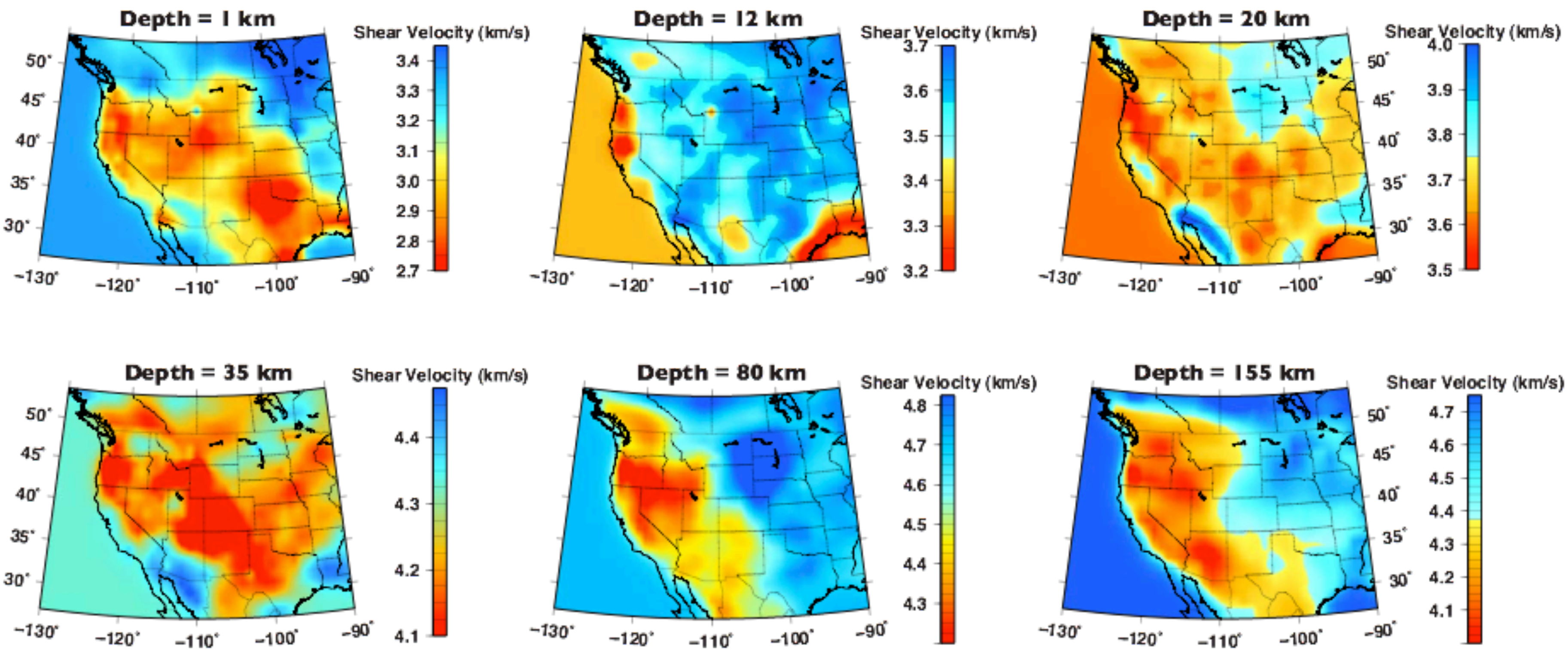

Models are consistent and smooth

– perfect a priori models for full waveform tomography.

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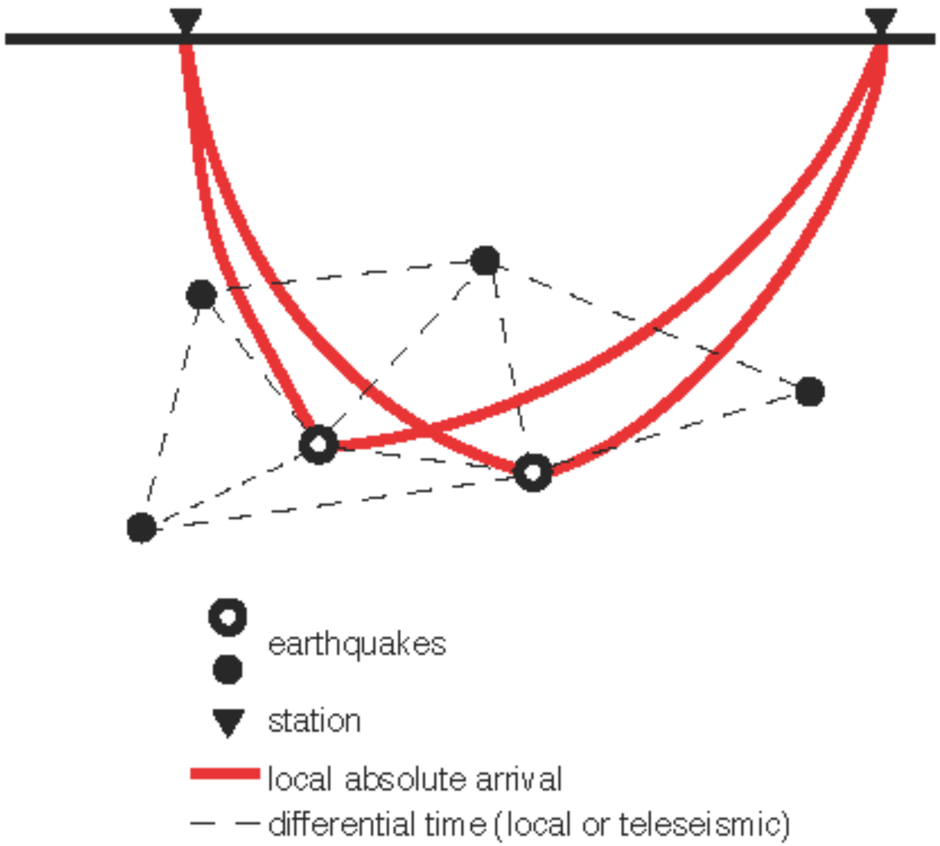
2006
PSU

2001-02

Herrmann
Computer Programs in Seismology
P Receiver Functions + Surface Wave Dispersion
SLU

LANL pioneers again:
Adding body waves travel times

For two events recorded at the same station



we can define the "double difference"
(Zhang and Thurber, 2003)

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Adding body waves travel times

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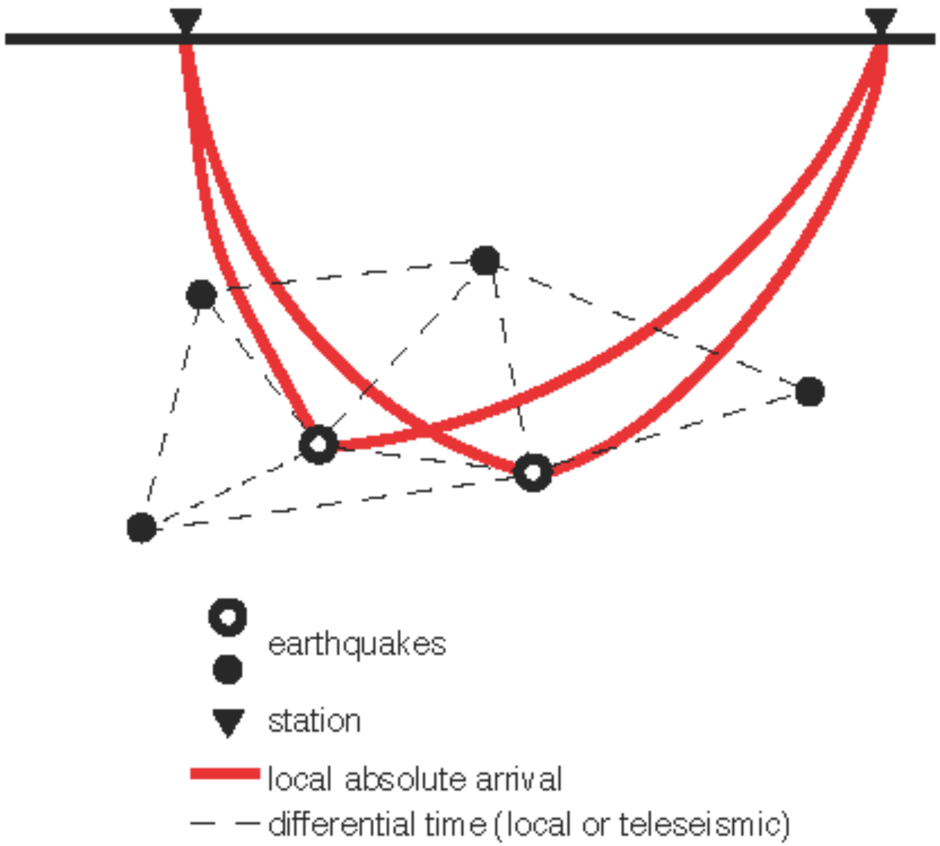


we can define the "double difference"
(Zhang and Thurber, 2003)

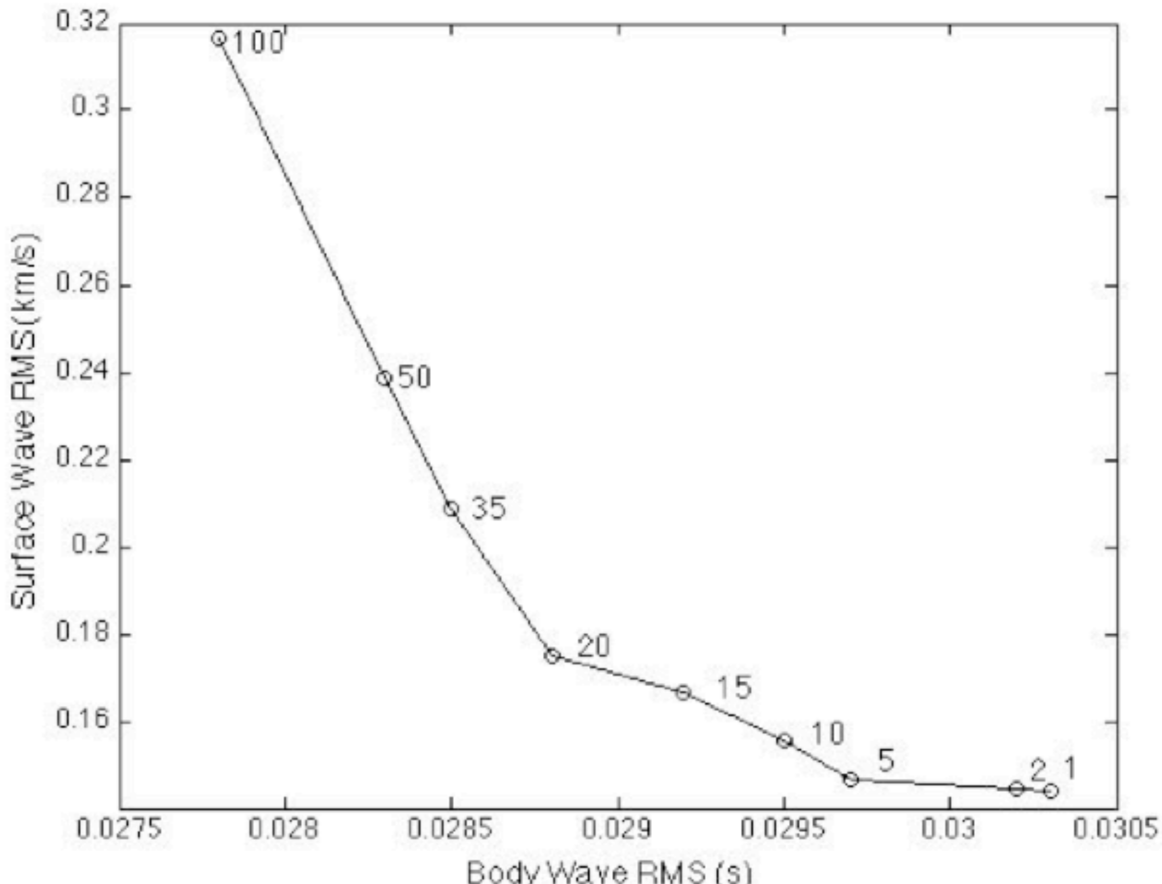
Absolute and differential times

- structure near source region is resolved at finer scale by differential data
- structure beyond source region is resolved by absolute data

Regional scale version tomoFDD

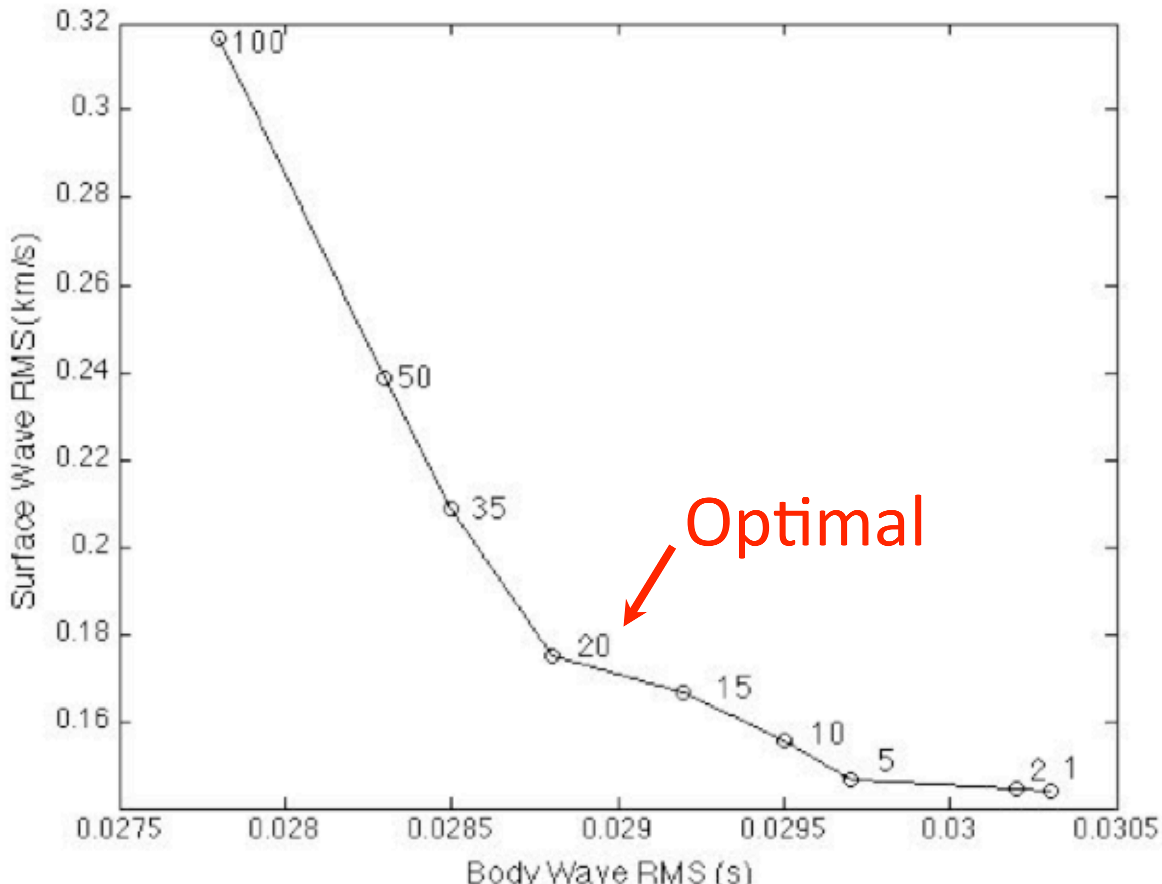
- considers sphericity of the earth
- finite-difference ray tracing method is used to deal with major velocity discontinuities

Case Study IV: First ever simultaneous joint inversion of surface wave dispersion and body waves travel times



Zhang et al. (2014)

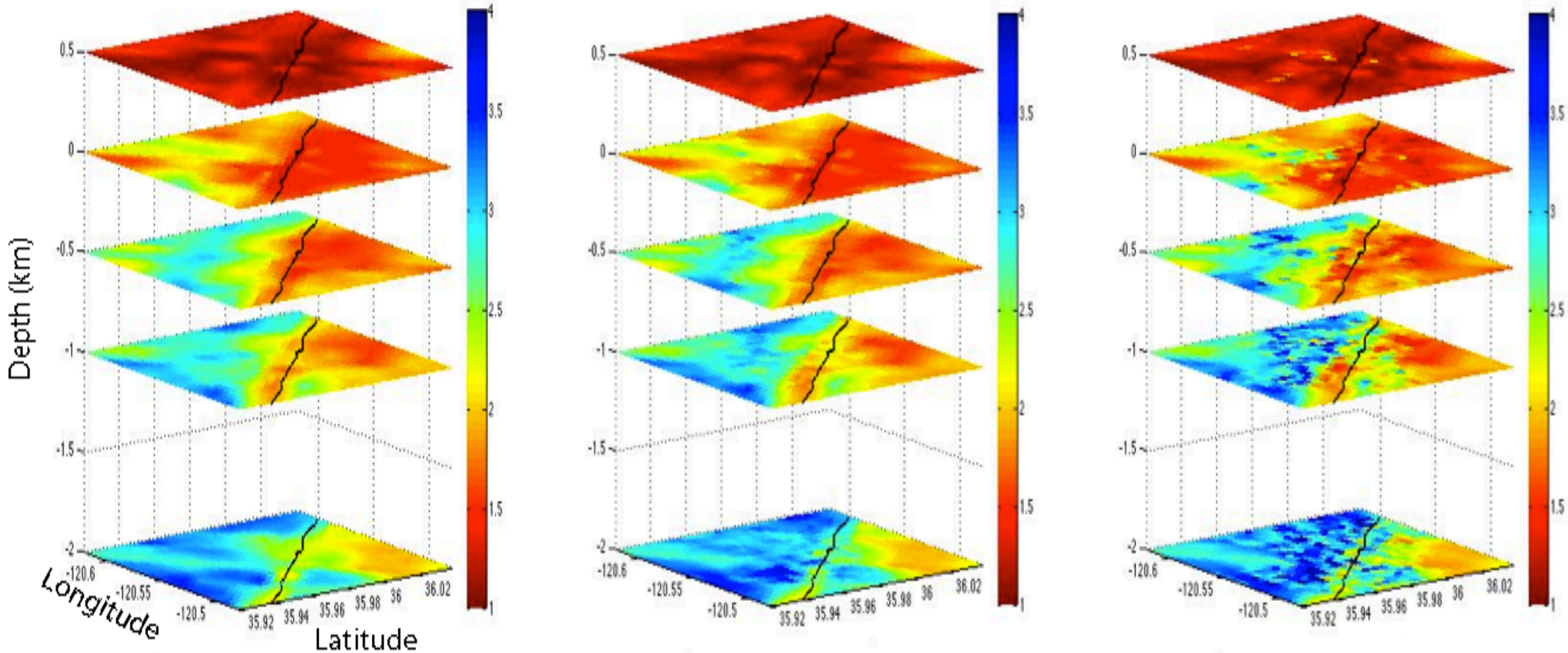
Case Study IV: First ever simultaneous joint inversion of surface wave dispersion and body waves travel times



Zhang et al. (2014)

Case Study IV: Parkfield: Application to LOCAL scales!

Relative Weight=2 | Relative Weight=20 | Relative Weight=100



Mainly surface waves – too smooth of a model

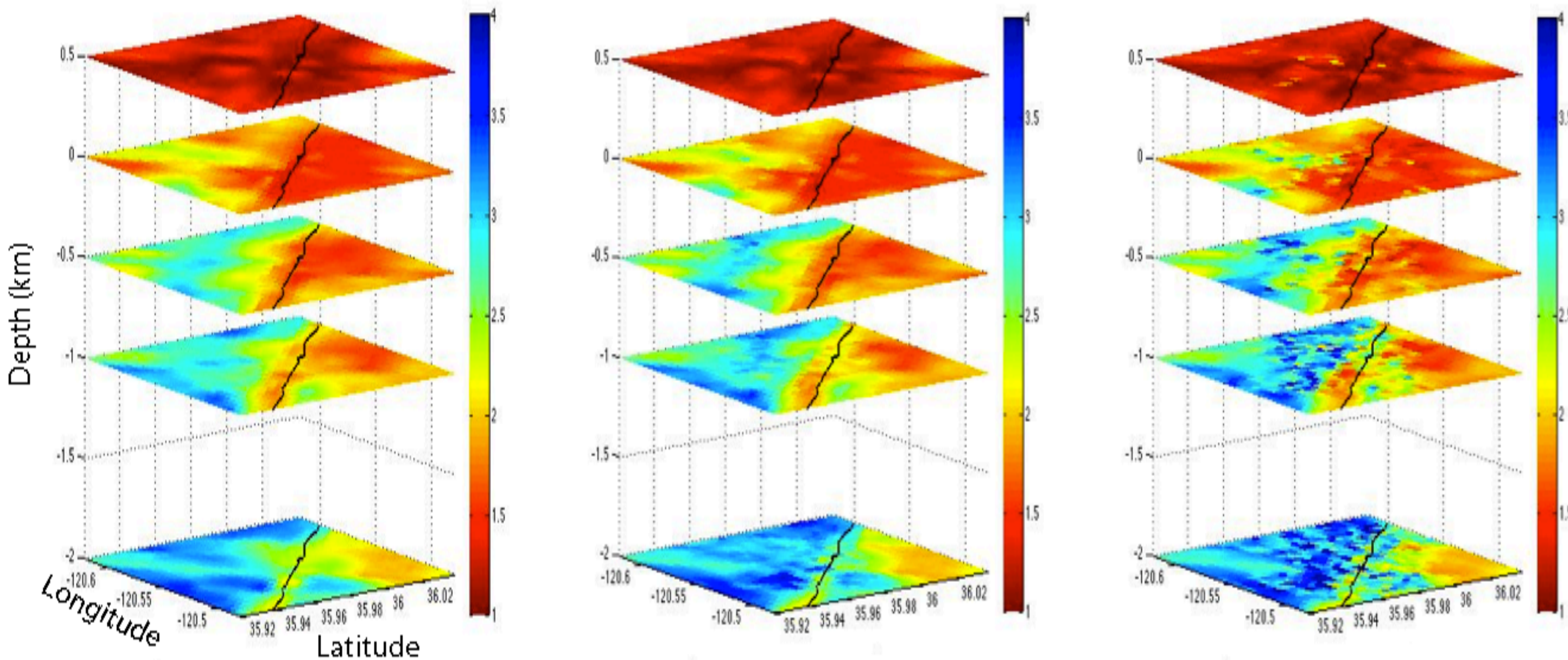
Optimal weight – better Earth model

Mainly body waves – fitting high frequency noise

Zhang et al. (2014)

Case Study IV:
Parkfield: Application to LOCAL scales!

Relative Weight=2 | Relative Weight=20 | Relative Weight=100



Mainly surface waves – too smooth of a model

Optimal weight – better Earth model

Mainly body waves – fitting high frequency noise

Zhang et al. (2014)

Adding gravity to local scale - CHALLENGING!!!

Ellen Syracuse (new LANL Director's PD)

Conclusions

- LANL pioneers advanced multivariate inversion techniques for Earth seismic structure modeling at continental (USA) and local scale (Parkfield).
- Successful application for reducing surface wave magnitude Ms threshold and detecting smaller events (Tarim basin case study).
- New models hint to new geodynamical and tectonics interpretation (EARS case study).
- Potential use for surrogate measurements in areas without access to seismic signatures (application to local scale).

Near Future

- Challenges:
  - Improve joint inversion methodology (surface waves 2-step process; uneven illumination).
  - Extension of present methodology to local scales.
- Needs:
  - Independent validation of 3D geophysical models.
  - Uncertainty Quantification
    - Reduce location error
    - Informed decision making