USING SEISMIC TOMOGRAPHY TO IMAGE SUBDUCTION SYSTEMS: APPLICATIONS TO MIDDLE AMERICA AND SUNDA

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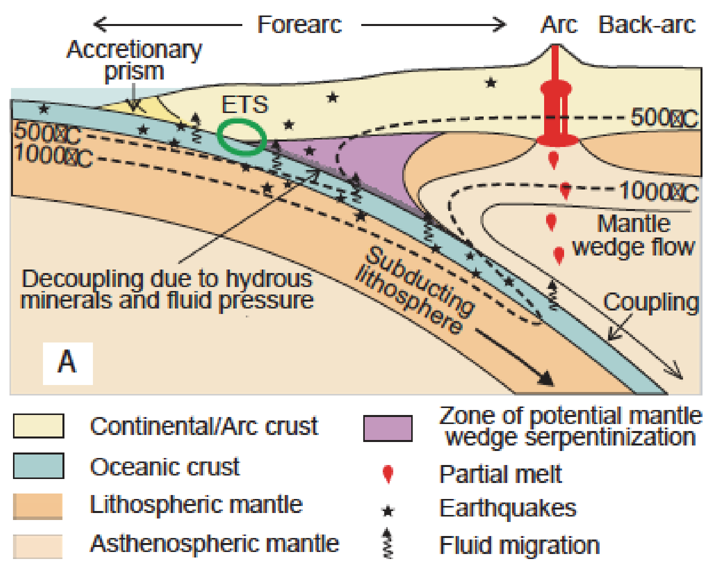
Sumatra: Jeremy Pesicek, Cliff Thurber, Bob Engdahl, Haijiang Zhang, Sri Widiyantoro

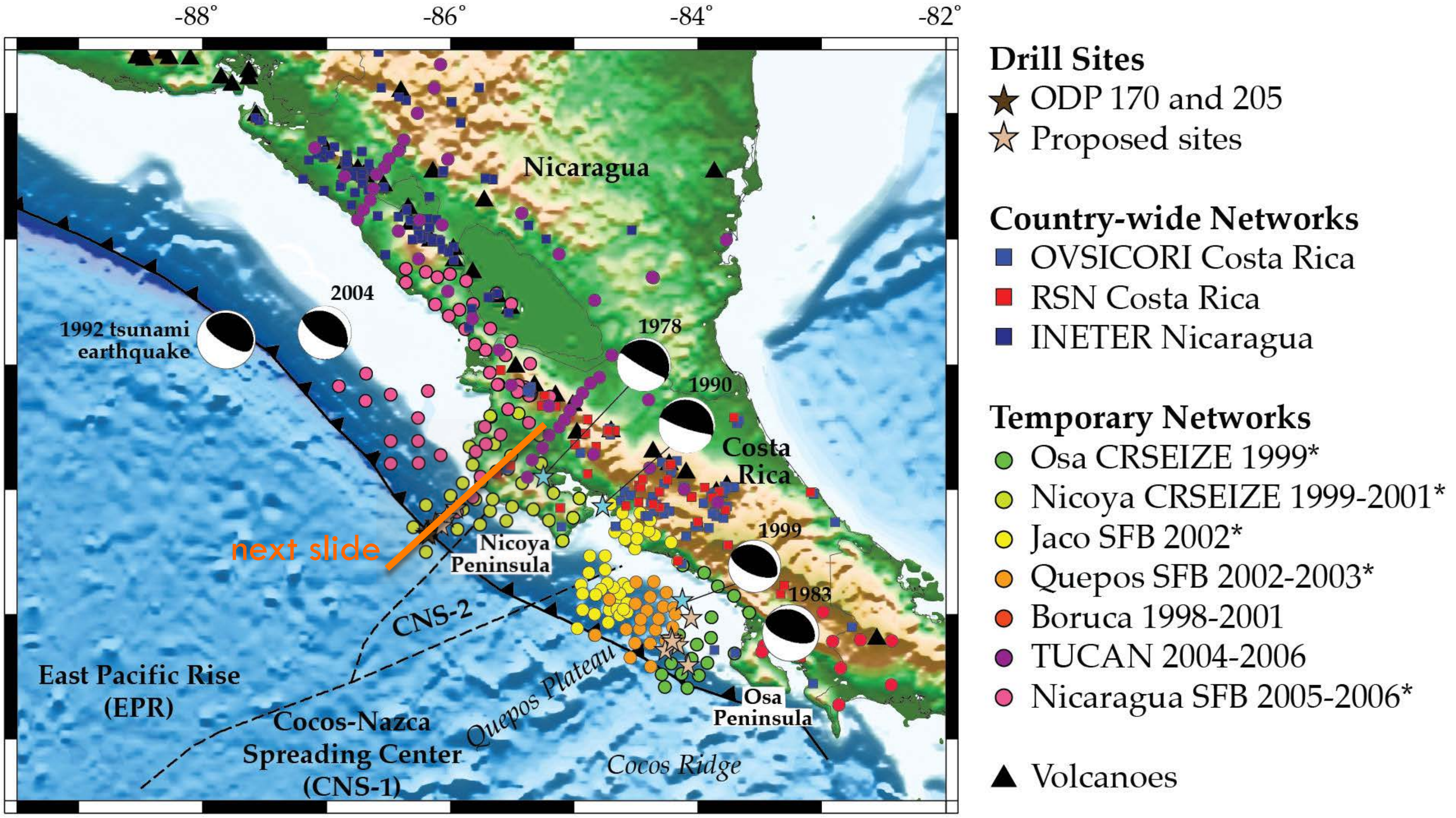
Controls on spatial and temporal seismicity and deformation patterns across the seismic cycle

- What controls magnitude, slip extent, and slip rates?
- What is the role of secondary faulting and what are the potential earthquake and tsunami hazards from earthquakes on these faults?
- How does volatile release from the subducting sediments and igneous ocean crust affect the slip behavior of the subduction megathrust?
- What is the role of serpentinization in weakening the incoming plate and the plate interface?



From GeoPRISMS SCD Science Plan

Margins Seize/SubFac Focus Site: Costa Rica and Nicaragua, MAT



Active source, current Nicoya, and experiments in the backarc or Talamanca are not shown

Summary of past and present tomography results

- Geodesy, large magnitude earthquakes, thermal constraints and microseismicity constrain different seismogenic zone “limits.”
- Updip limit of microseismicity is sensitive to changes in temperature and/or pore fluid pressure along-strike (i.e., Newman et al., 2004; Spinelli and Saffer, 2007)

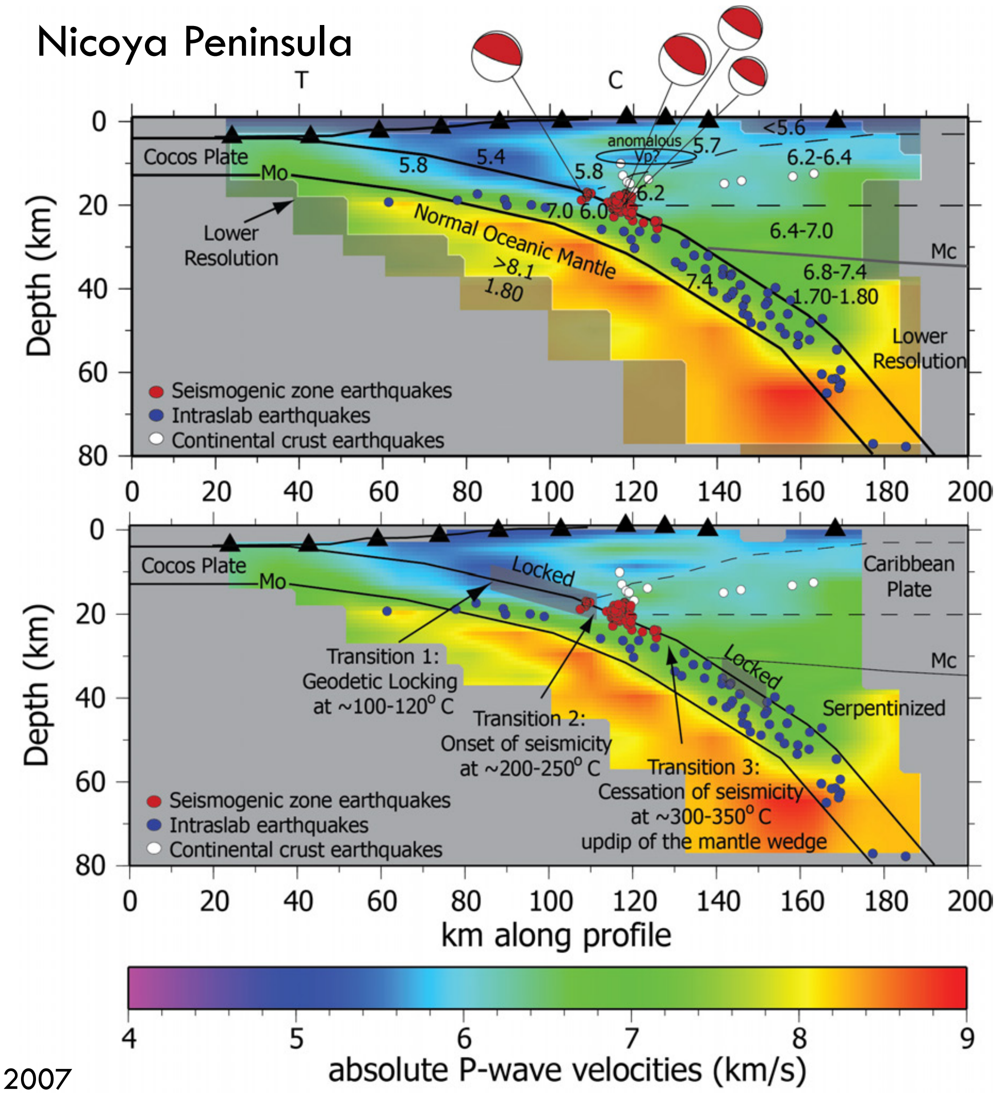


Image modified from DeShon et al. 2006; Schwartz and DeShon, 2007

- Oceanic upper mantle is serpentinized along Nicaragua, allowing for significant fluid input into the subduction system at depth (i.e.., Grevemeyer et al., 2007; Syracuse et al., 2008)

- Large-scale differences in slab and wedge velocities and hypocenter distribution along Nicaragua and northern Costa Rica suggest the upper plate plays a critical role in subduction and volcanic processes (MacKenzie et al., 2008; Rychert et al., 2008; Dinc et al., 2010; etc)

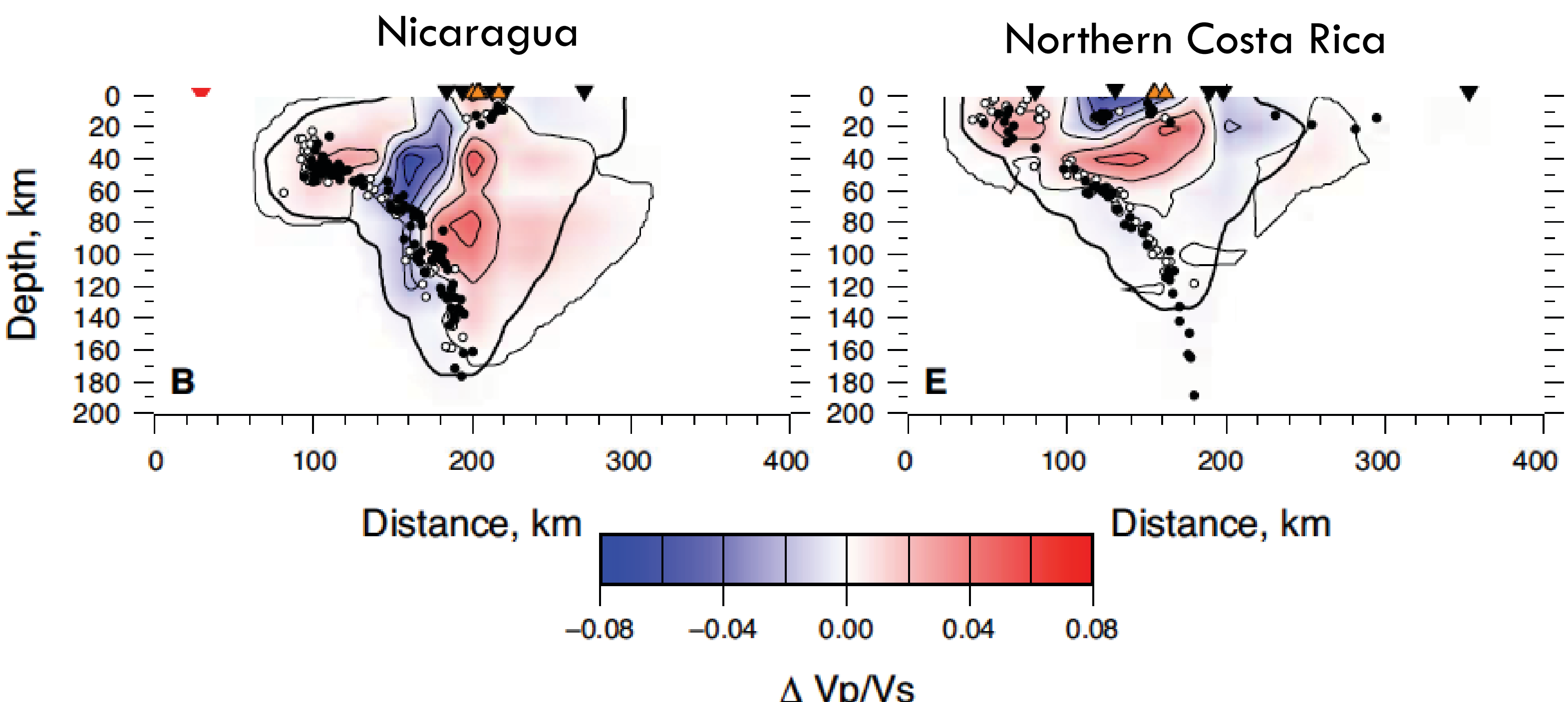
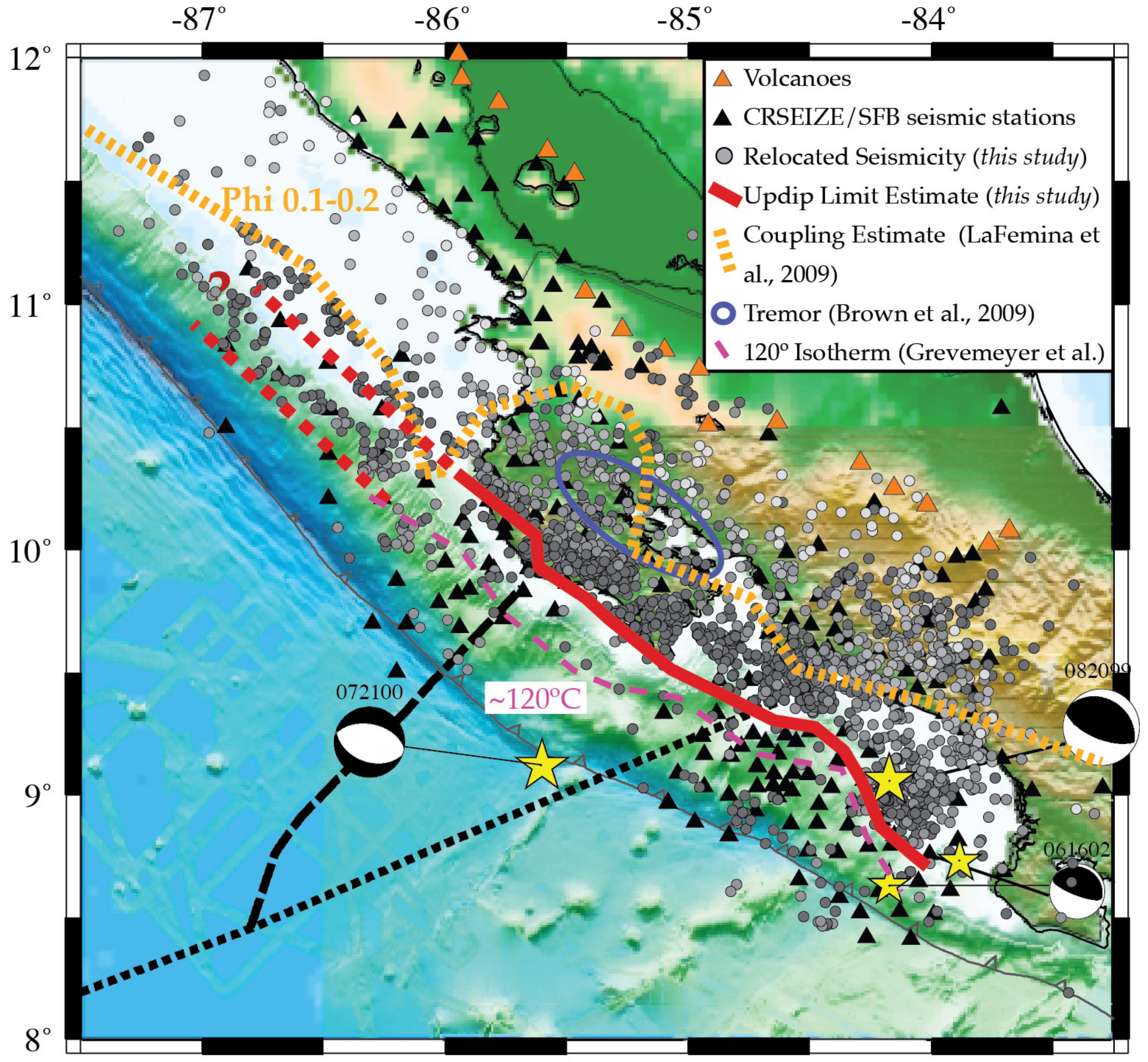
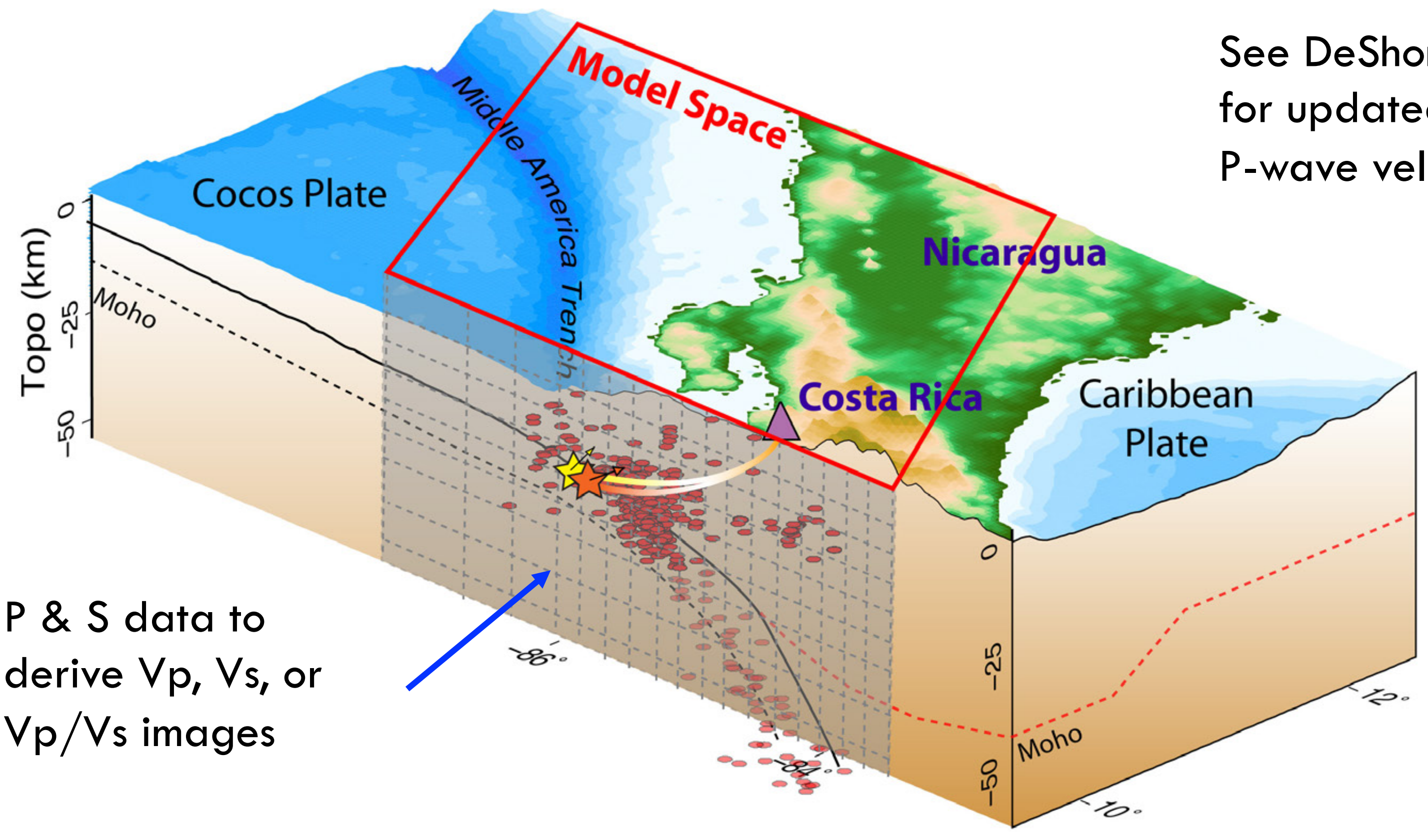


Image from Syracuse et al., 2008

- Updip limit is variable and may be closer to trench in Nicaragua
- Downdip limit may be controlled by the presence of fluids along the plate interface or serpentinization of the mantle wedge (Van Avendonk et al., 2010; DeShon et al., 2006)
- Tremor and slow slip processes have been identified at the updip and downdip edge of the seismogenic zone (Brown et al., 2005; Brown et al., 2009)



Double-Difference Tomography

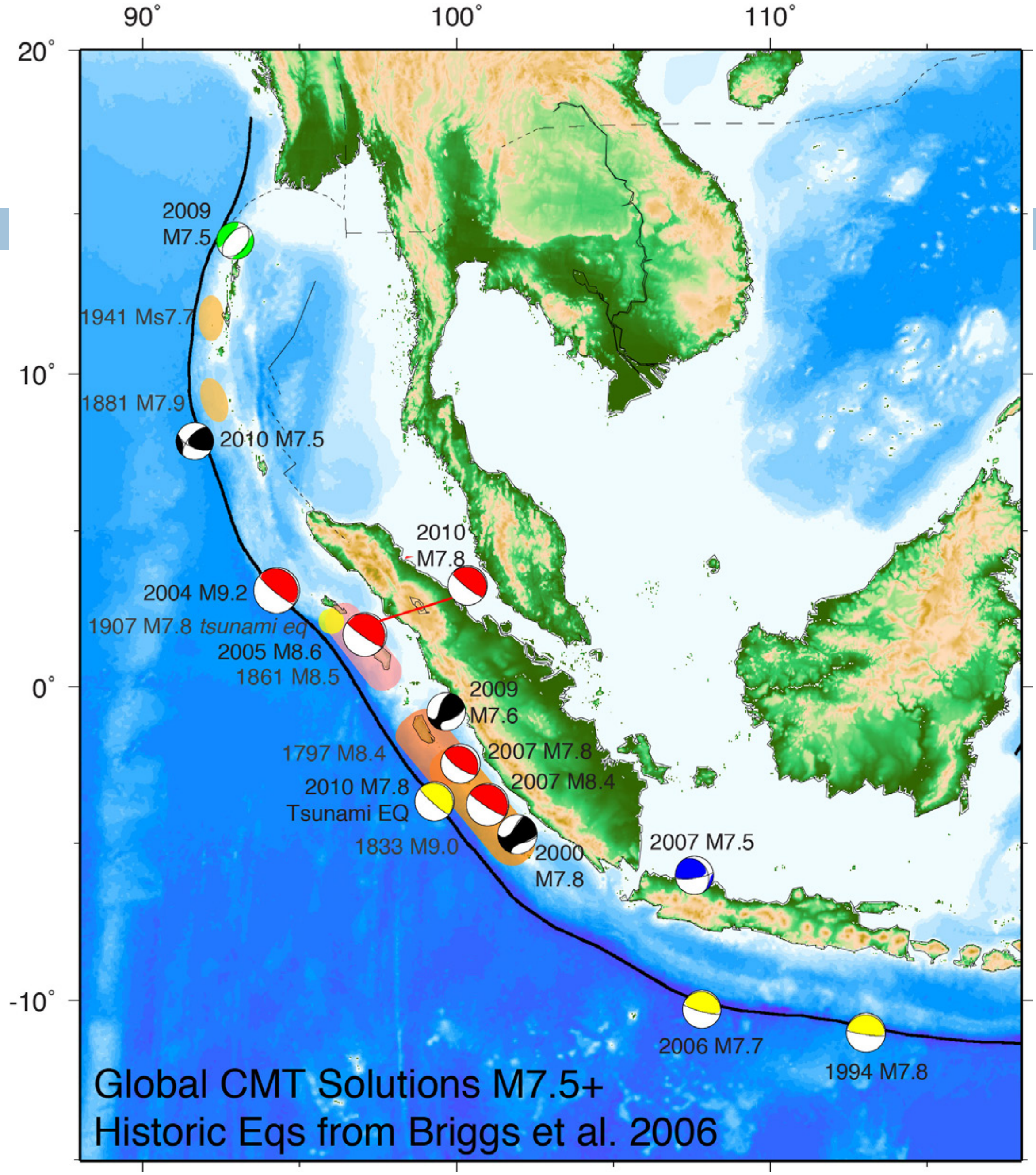


See DeShon et al. poster for updated DD-derived P-wave velocity model

P & S data to derive Vp, Vs, or Vp/Vs images

Absolute times, differential times, and waveform cross-correlation differential times

Sunda Subduction Zone

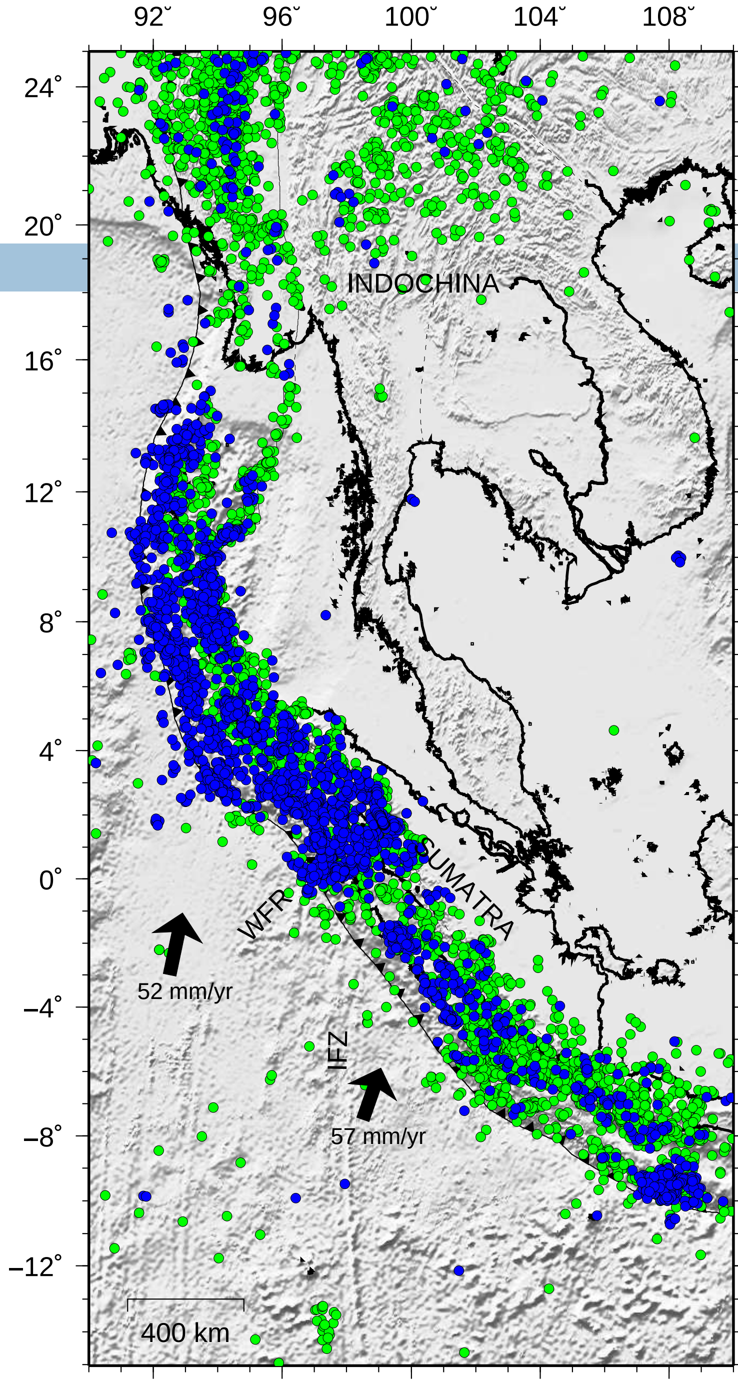


Tomography Opportunity

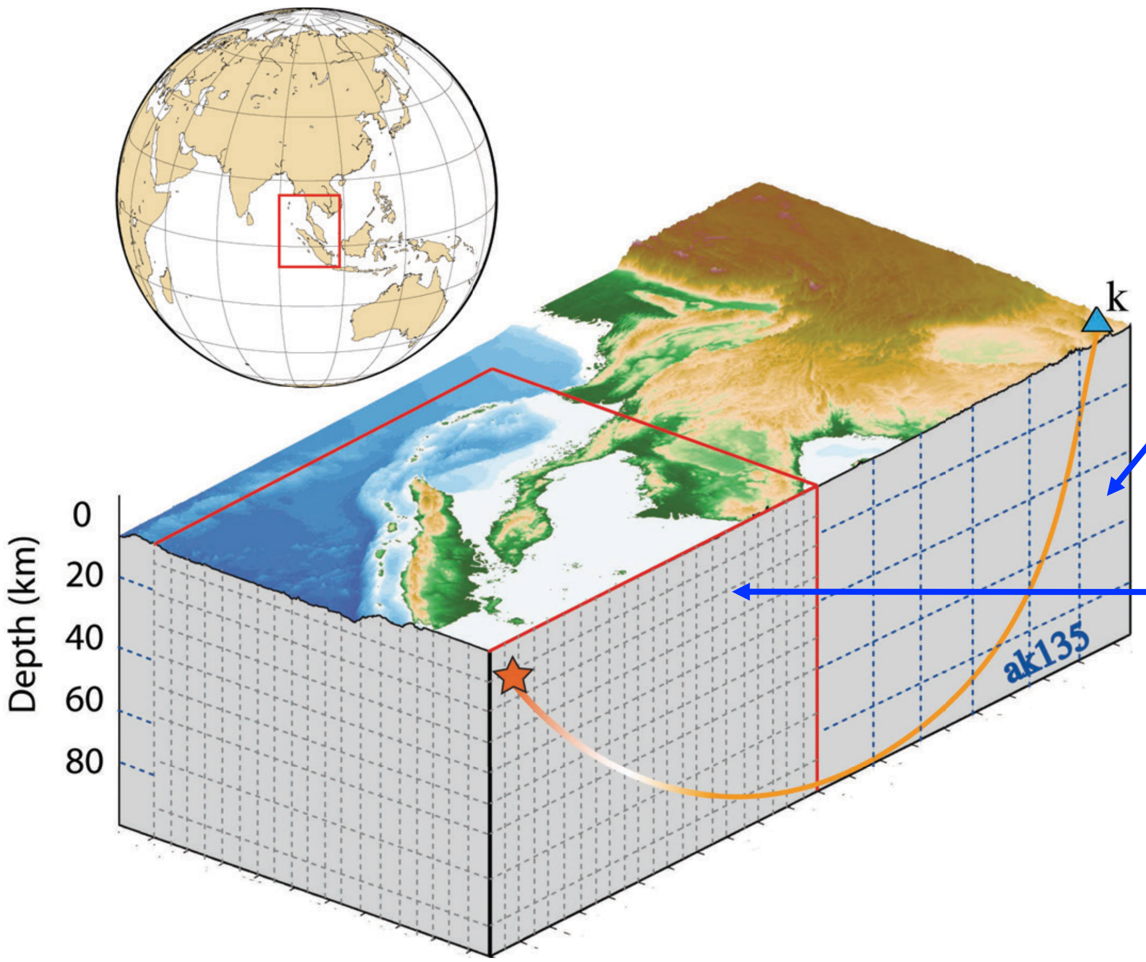
- Improved event distribution from aftershocks of the 2004 and 2005 great earthquakes

Before: **5,460 earthquakes**
- 94,529 seismic phases
- 1,706 stations

After: **3,372 earthquakes**
- 527,713 seismic phases
- 2,099 stations



Step 1: Nested Regional Tomography Method

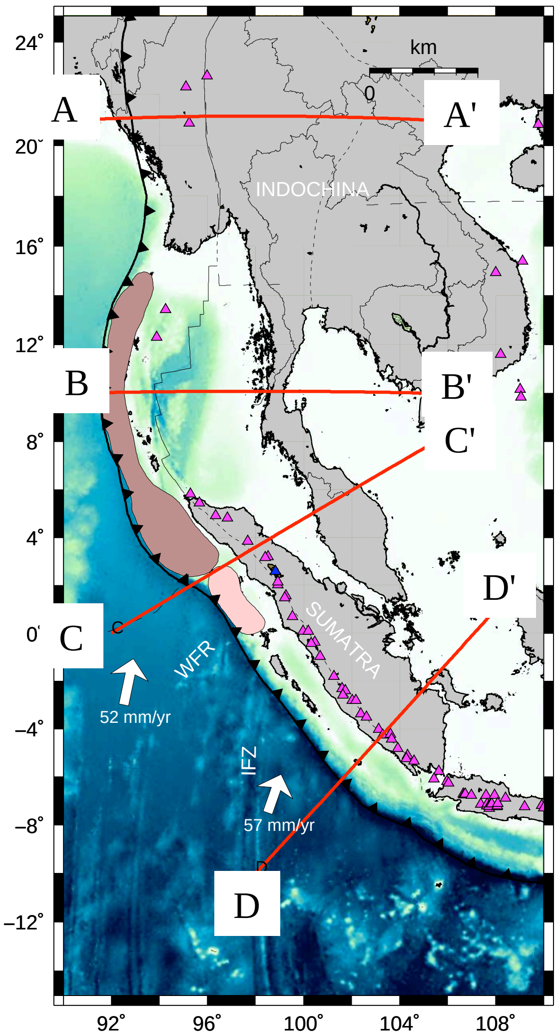


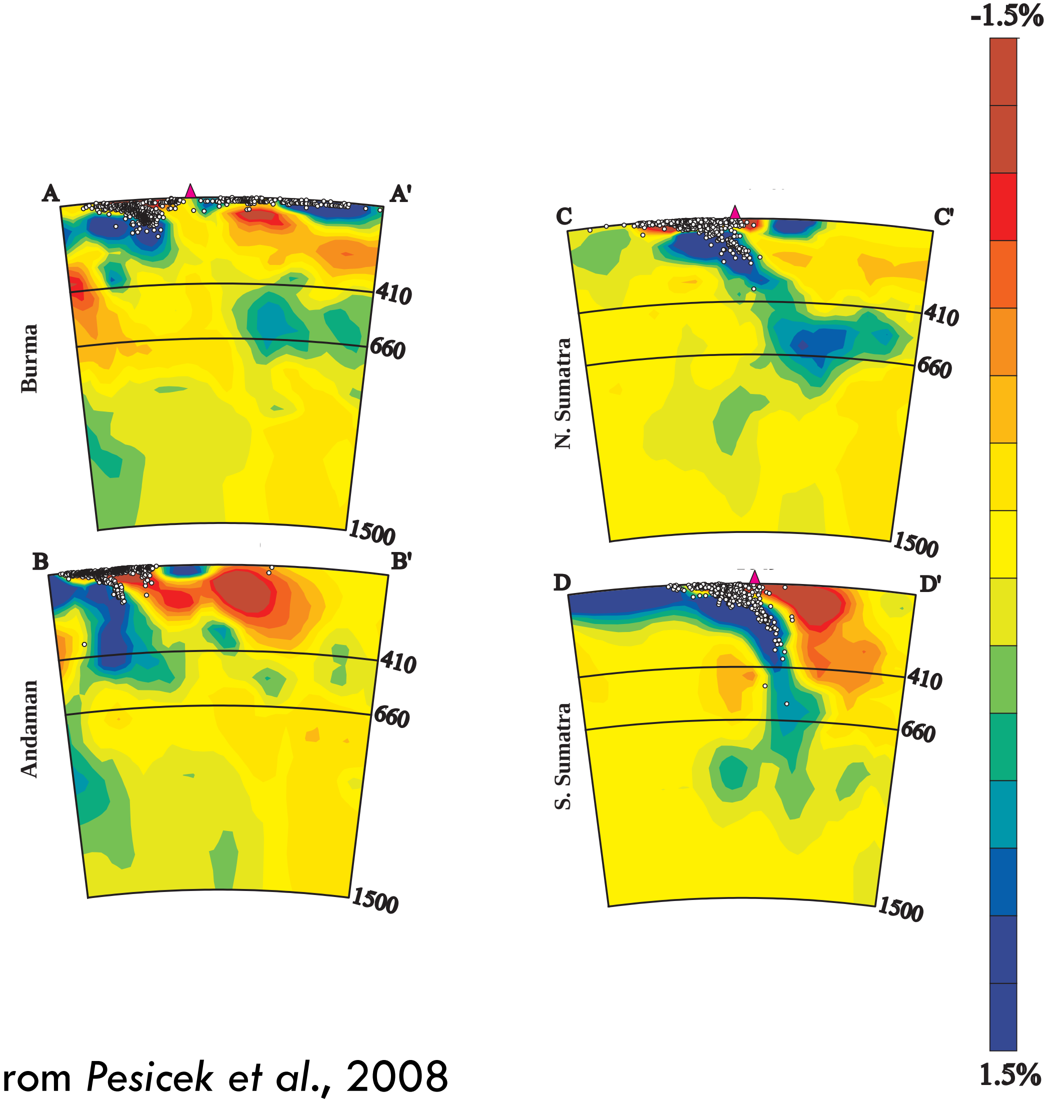
Global 5° cells
16 Layers (to 2889 km depth)

Regional 0.5° cells
19 Layers (to 1500 km depth)

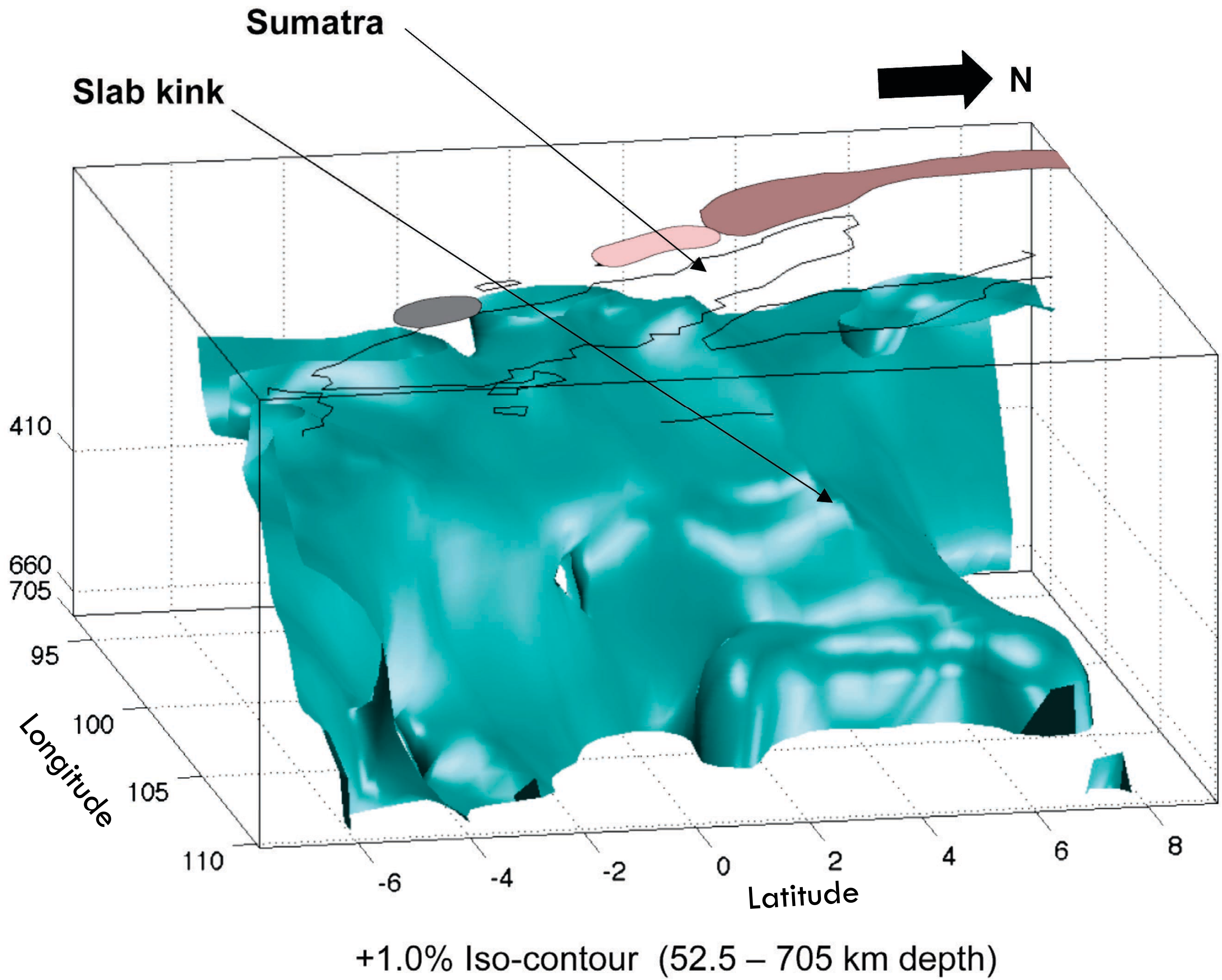
Based on Widiyantoro and van der Hilst (1996)

Single Iteration Results



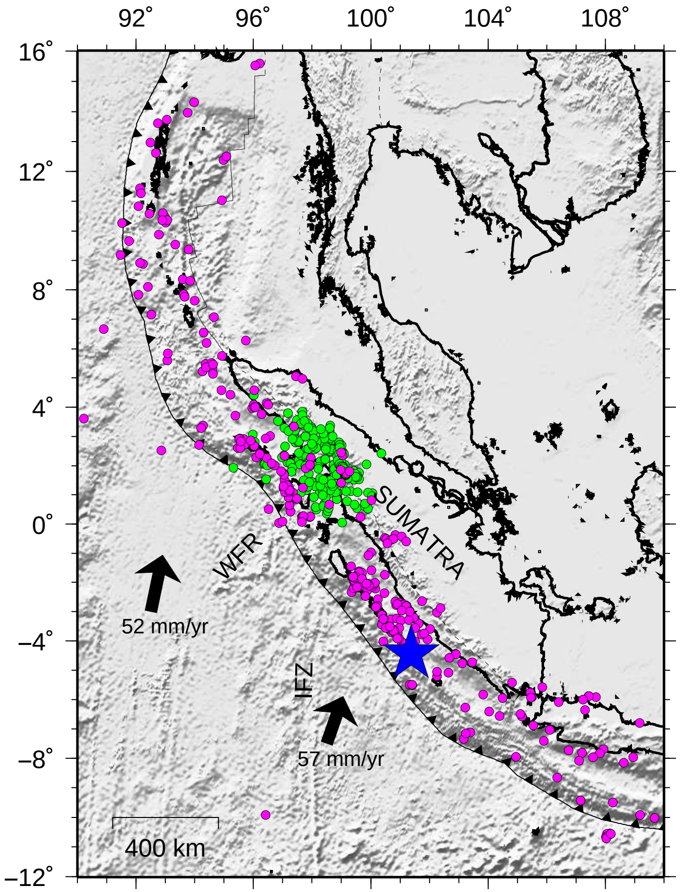


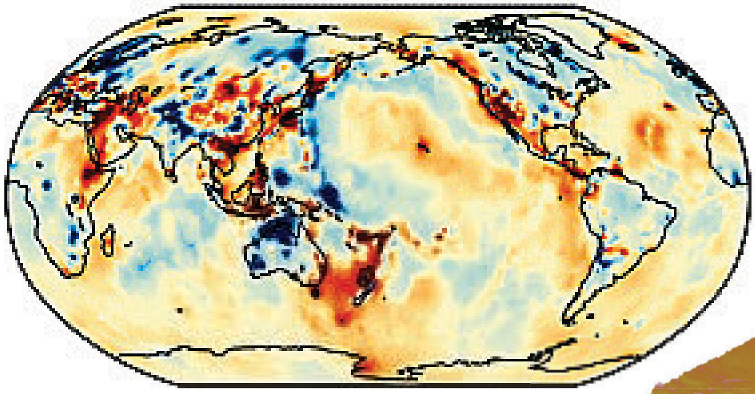
From *Pesicek et al.*, 2008



From *Pesicek et al.*, 2008

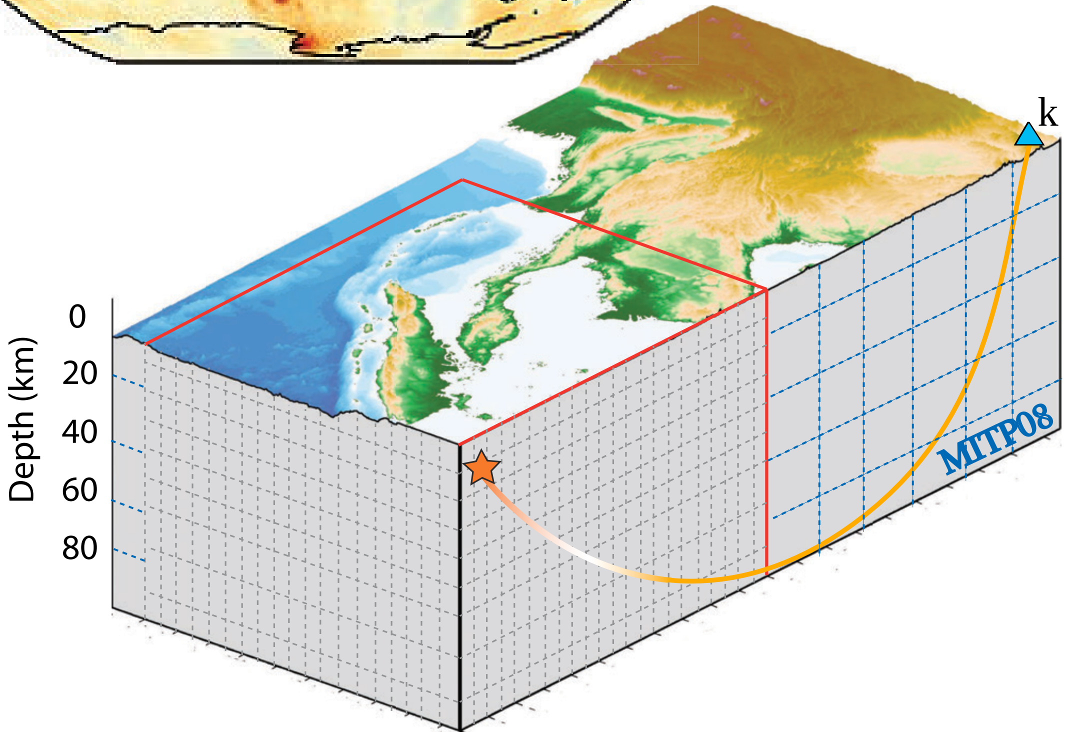
Step 2: Improving the Nested Model



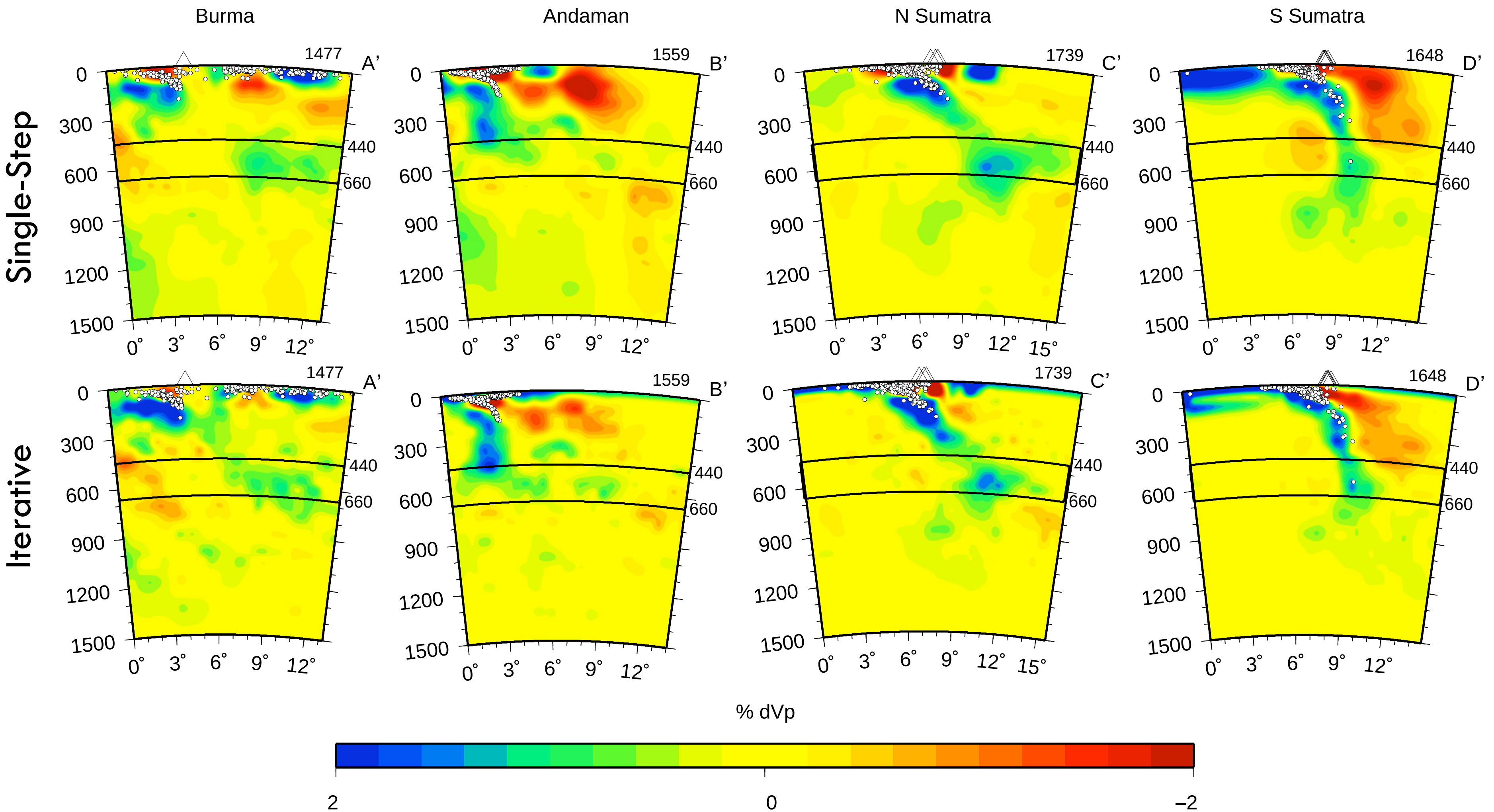


MITP08 Global *P*-wave model

(Li et al., 2008)

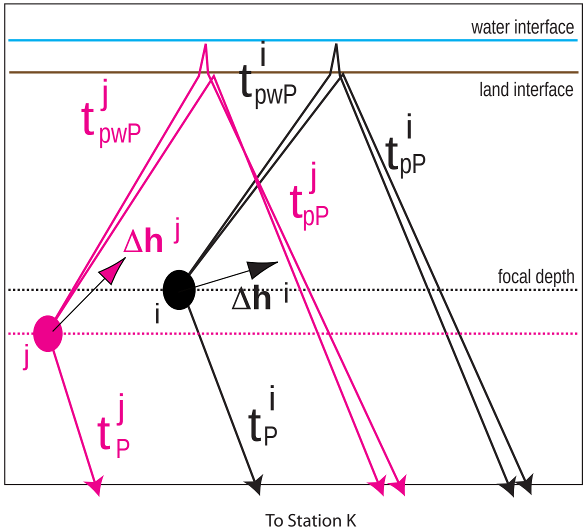


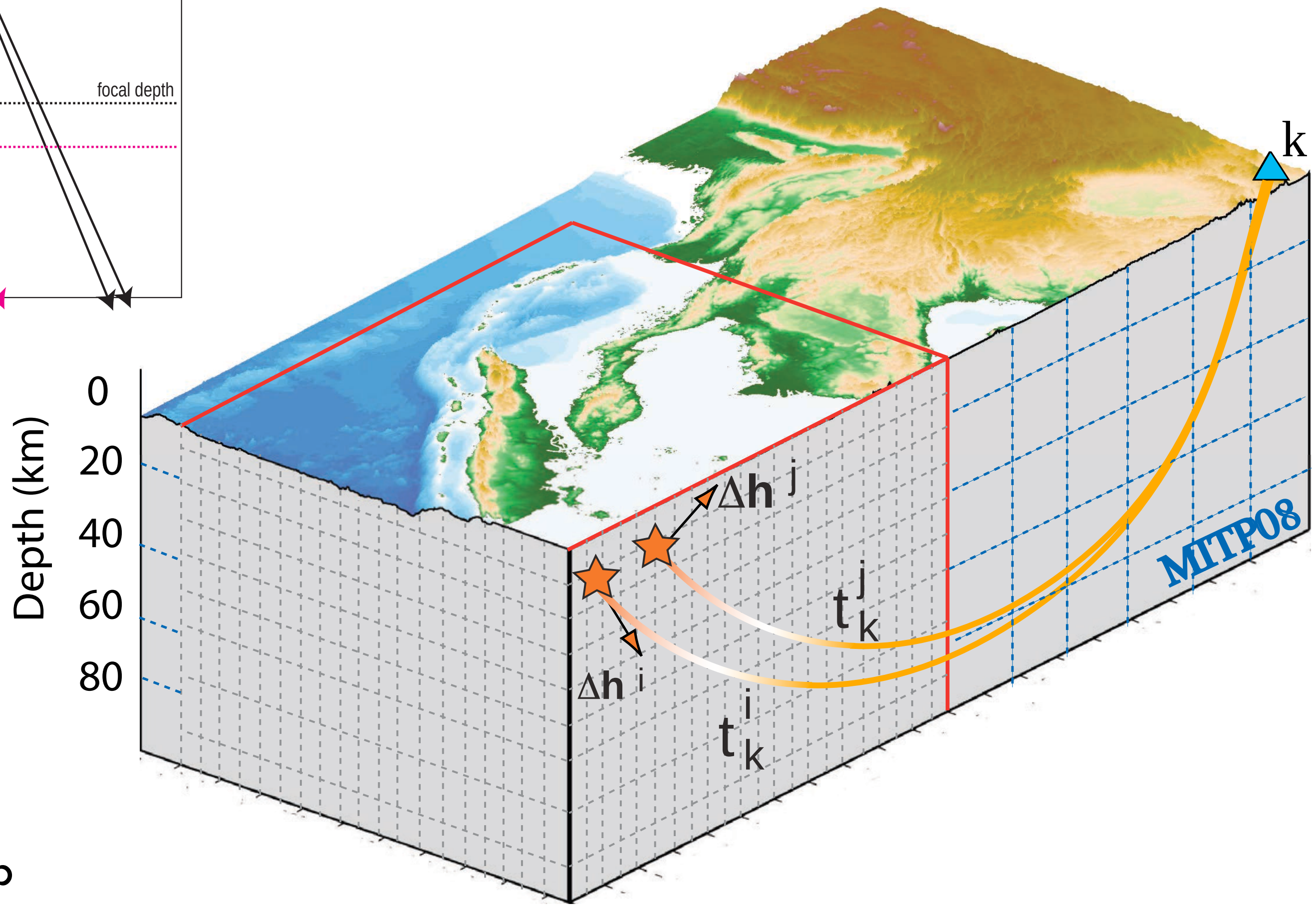
Iterative Results



From *Pesicek et al.*, 2010a

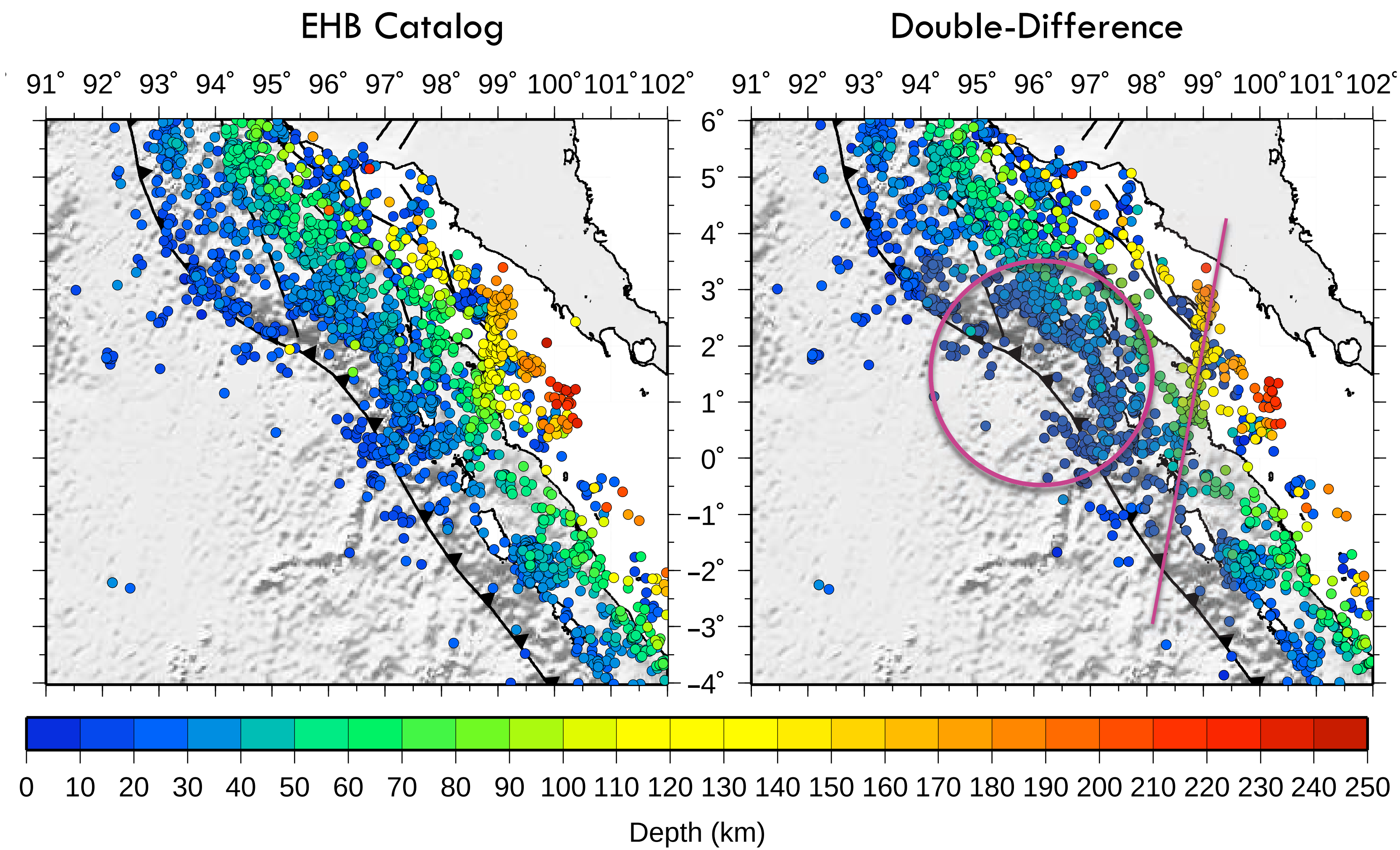
Step 3: Teleseismic Double-Difference Earthquake Relocation





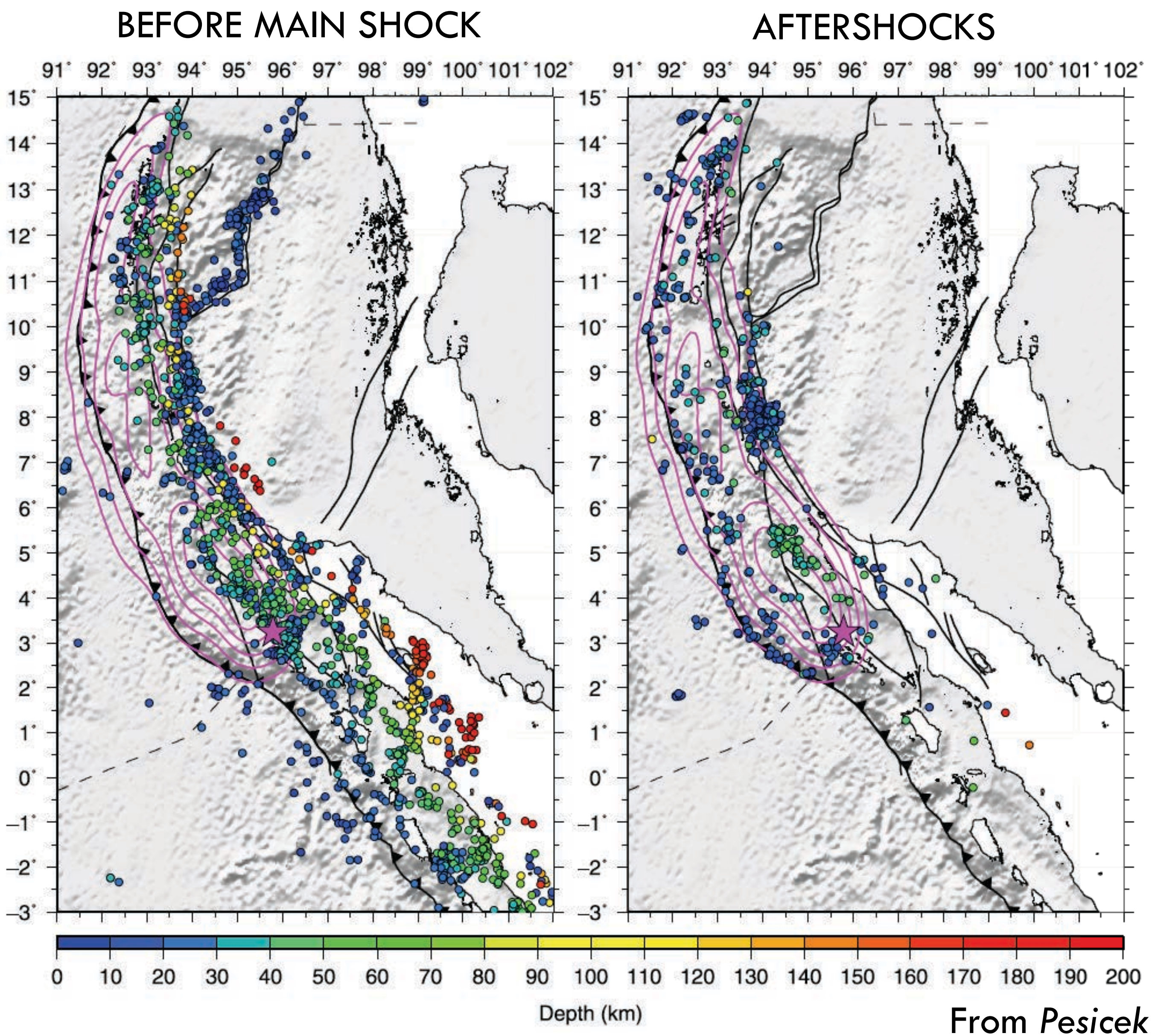
From *Pesicek et al.*, 2010b

Map view location comparison



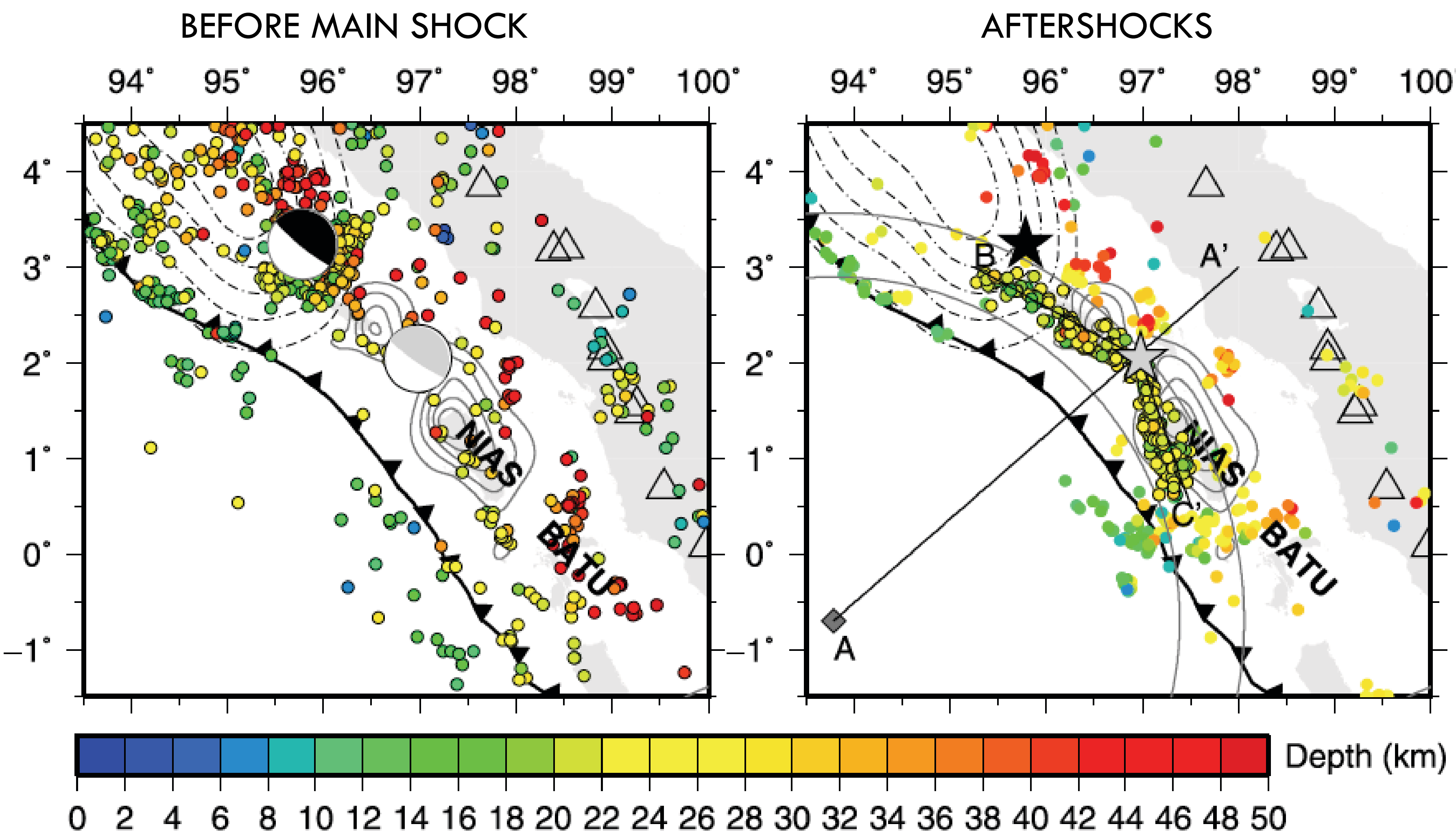
From *Pesicek et al.*, 2010b

2004 M9 Earthquake **Coseismic Slip** & Aftershocks



From *Pesicek et al.*, 2010b

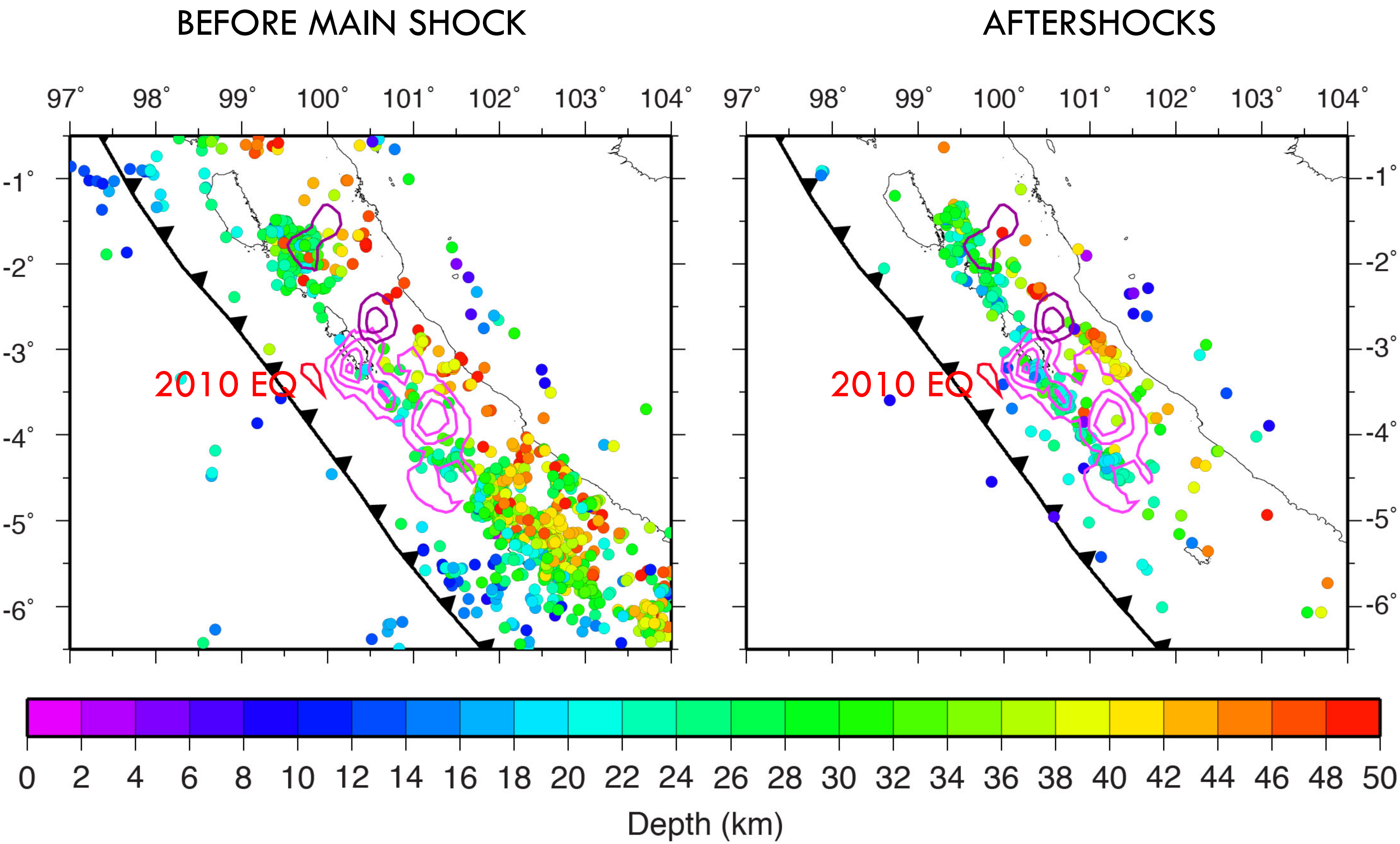
2005 M8.7 Nias Earthquake **Coseismic Slip** & Aftershocks



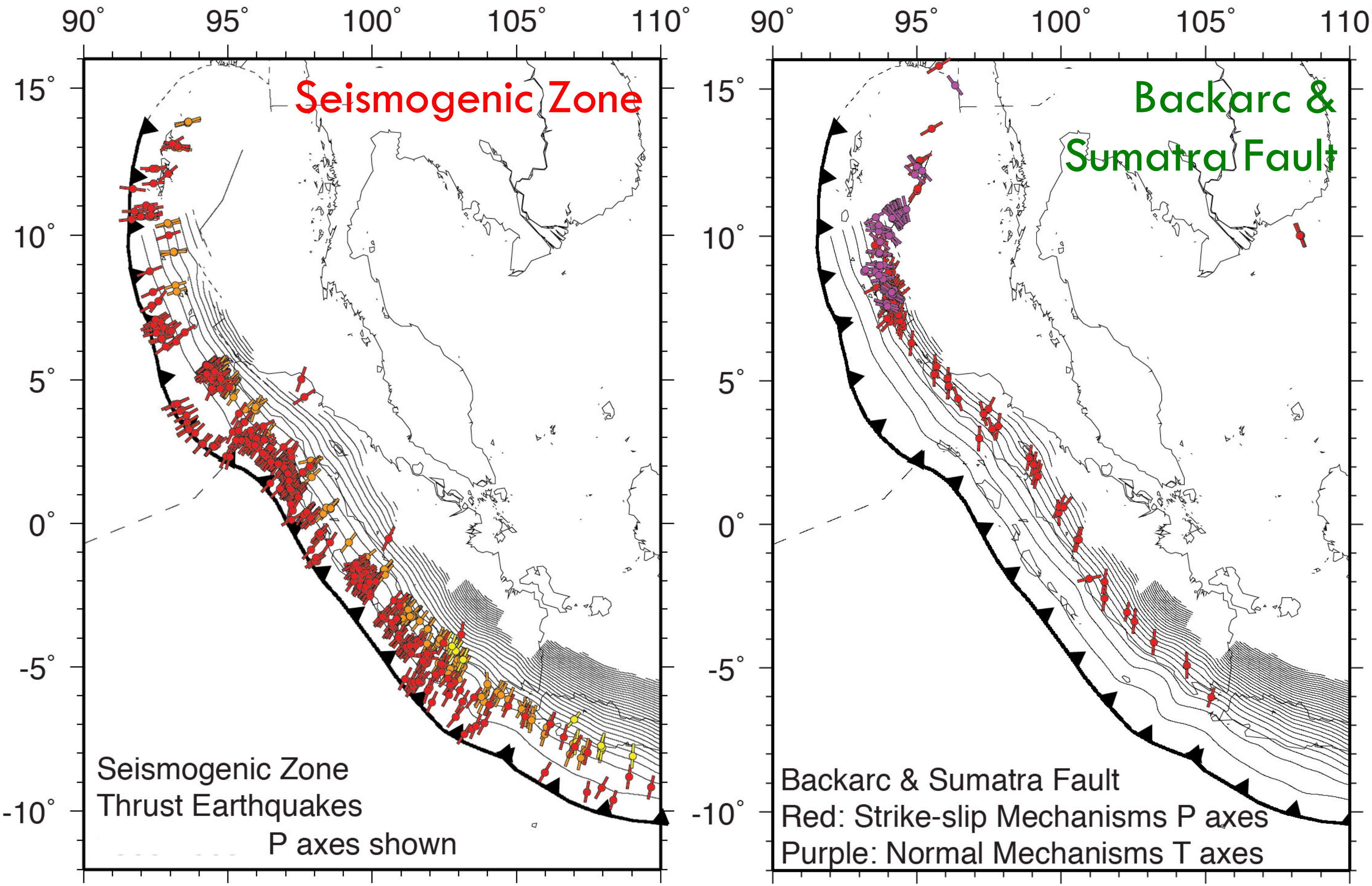
From *Pesicek et al.*, 2010b

2007 M8+ Southern Sumatra Earthquakes

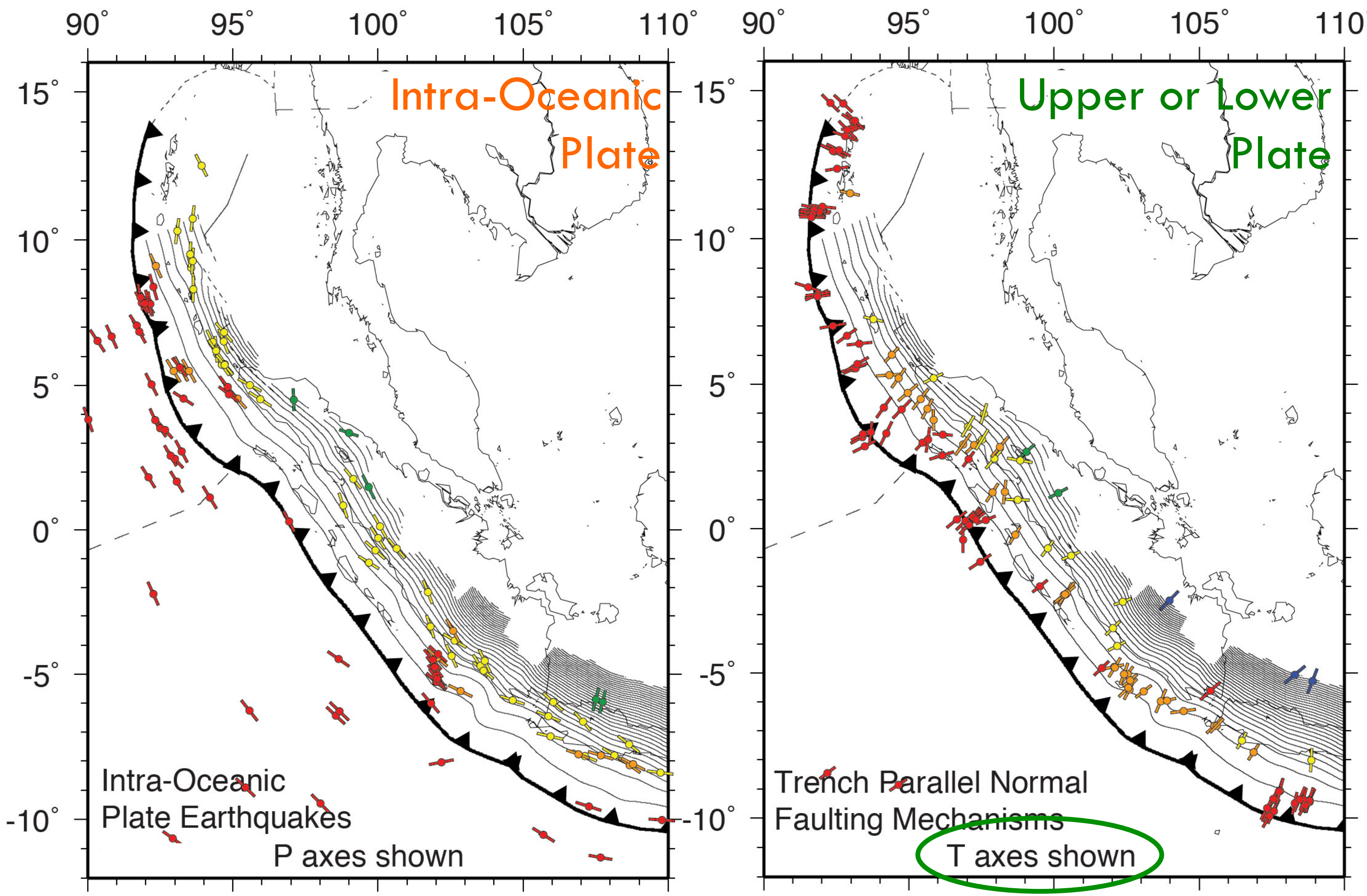
Coseismic Slip & Aftershocks

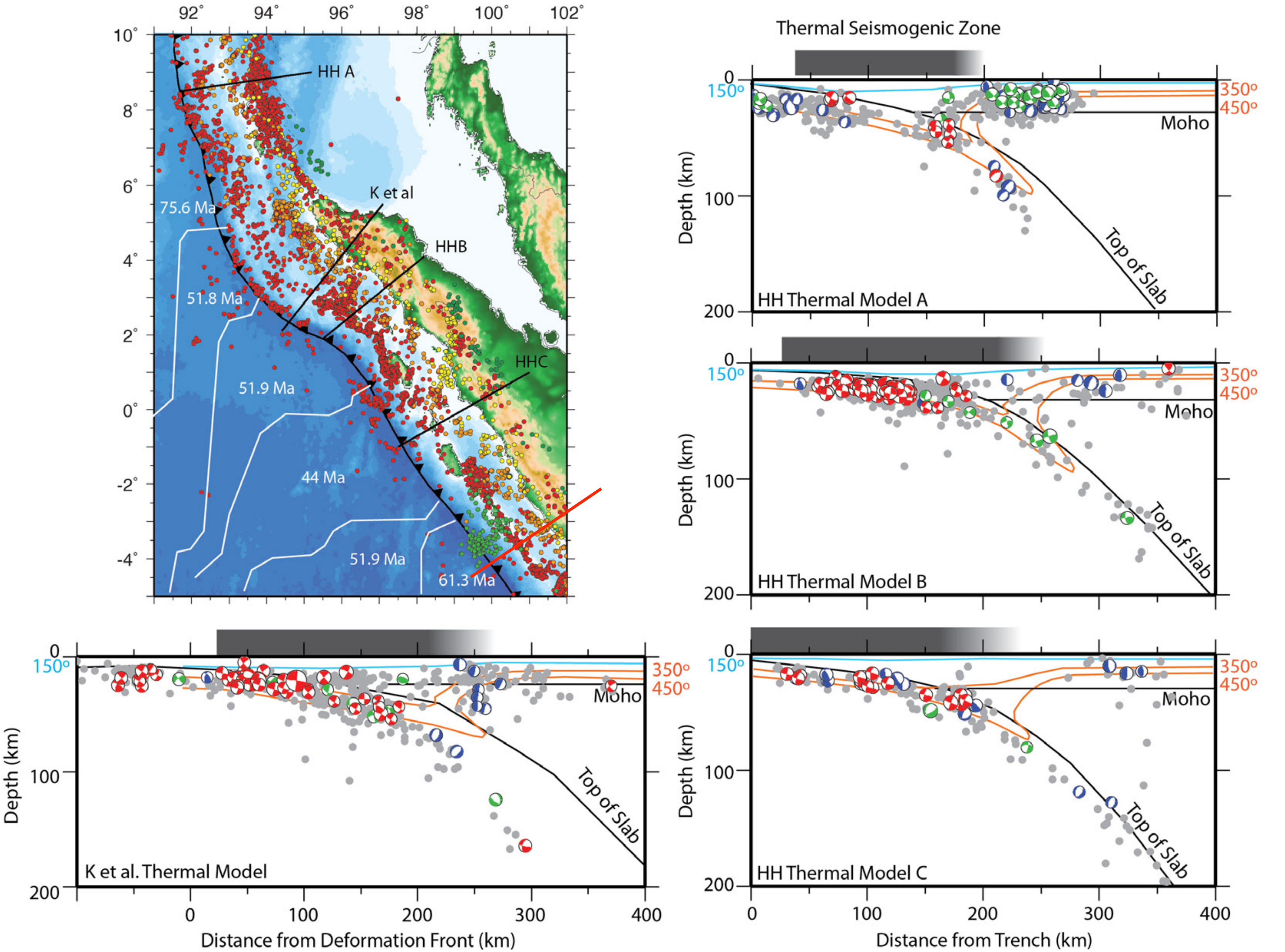


CMT solutions through 2009 at the DD locations



CMT solutions through 2009 at the DD locations

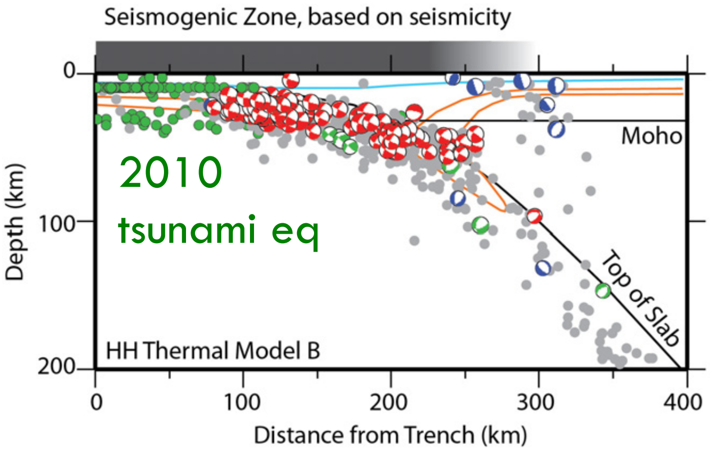


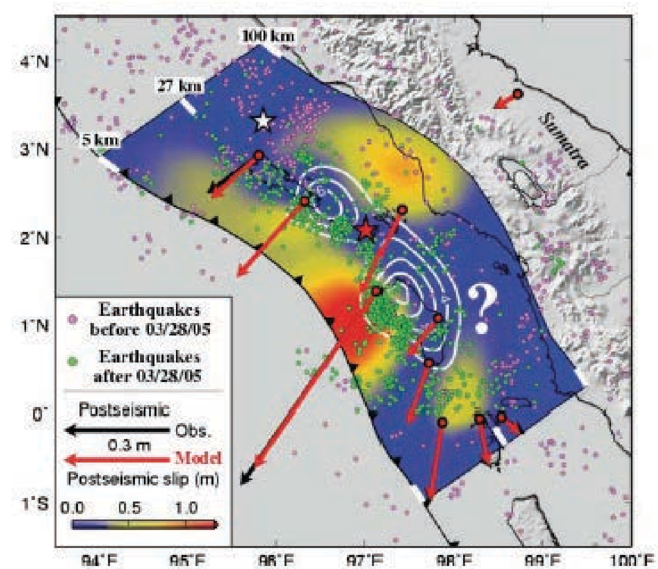


Thermal models from Hippechen and Hyndman, 2008; Klingelhoefer et al., 2010

Sunda Summary

- Clarified relation of aftershocks to fault slip
- Significant seismic features revealed
  - Investigator Fracture Zone
  - Fold in the subducting slab projecting up to Simeulue Island
- Confirmed that megathrust seismicity occurs downdip of the Moho/slab intersection and is more consistent with thermal proxies
- The potential for slip to the trench cannot be discounted along ALL of the margin





From Hsu et al., 2006

Implications for Implementation

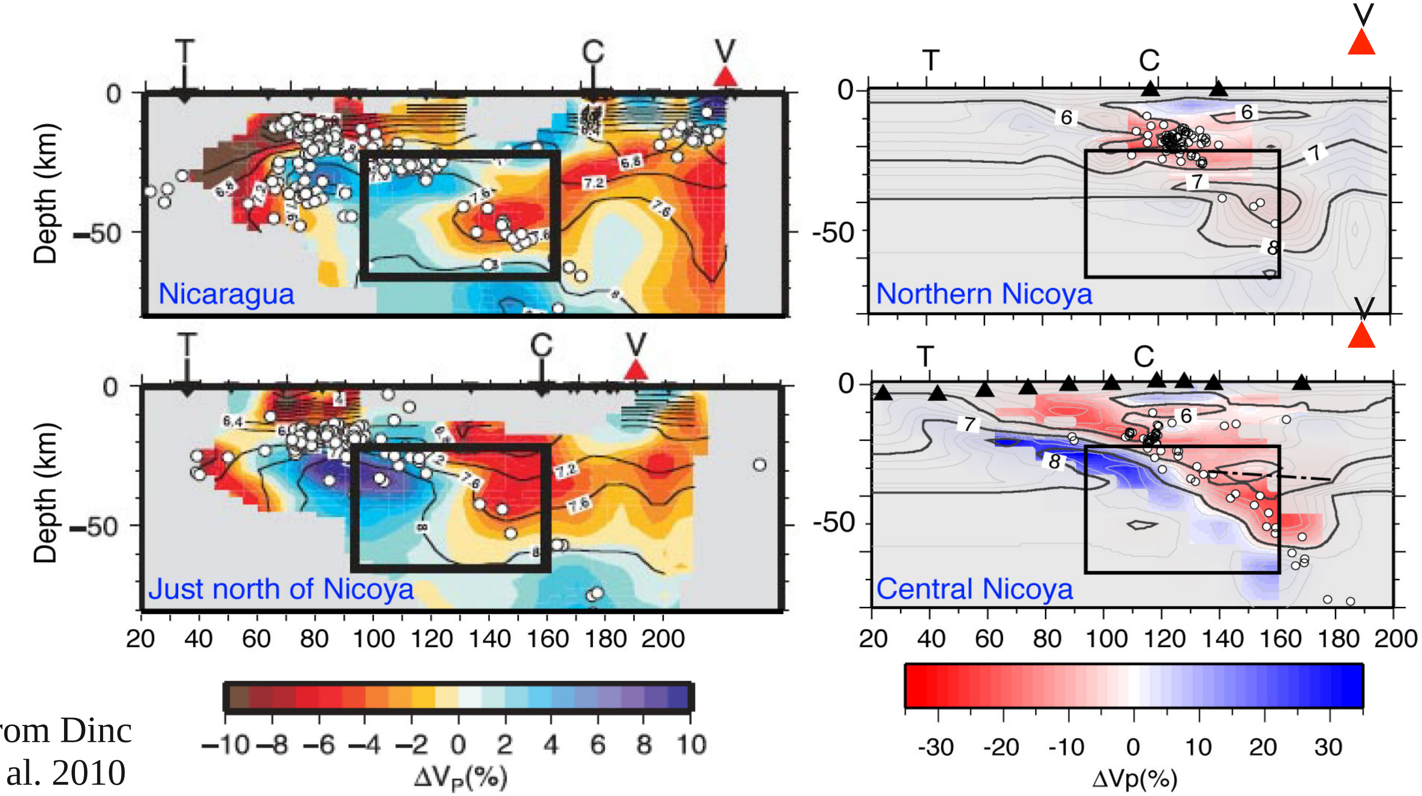
- FOCUS SITE approach is essential for some questions
  - Local data is necessary for detailed seismic images of the subduction boundary
  - Allows for better integration with other geophysical datasets
- GLOBAL STUDIES of THEMES is possible using teleseismic data
  - Continued improvements in teleseismic location accuracy allows for more thorough global studies of seismogenic zone processes, such as rupture duration
  - Plethora of great megathrust earthquakes since 2004 have potentially illuminated a broad range of subduction zone 'types' and could be studied using teleseismic data

Thank you

Outline

- Interests parallel with the SCD science plan
- Local and regional earthquake tomography with application to Costa Rica/Nicaragua
- Regional and teleseismic earthquake tomography with application to Sunda
- Conclusions

- Large-scale differences in slab and wedge velocities and hypocenter distribution along Nicaragua and northern Costa Rica suggest the upper plate plays a critical role in subduction and volcanic processes (MacKenzie et al., 2008; Rychert et al., 2008; Dinc et al., 2010; etc)



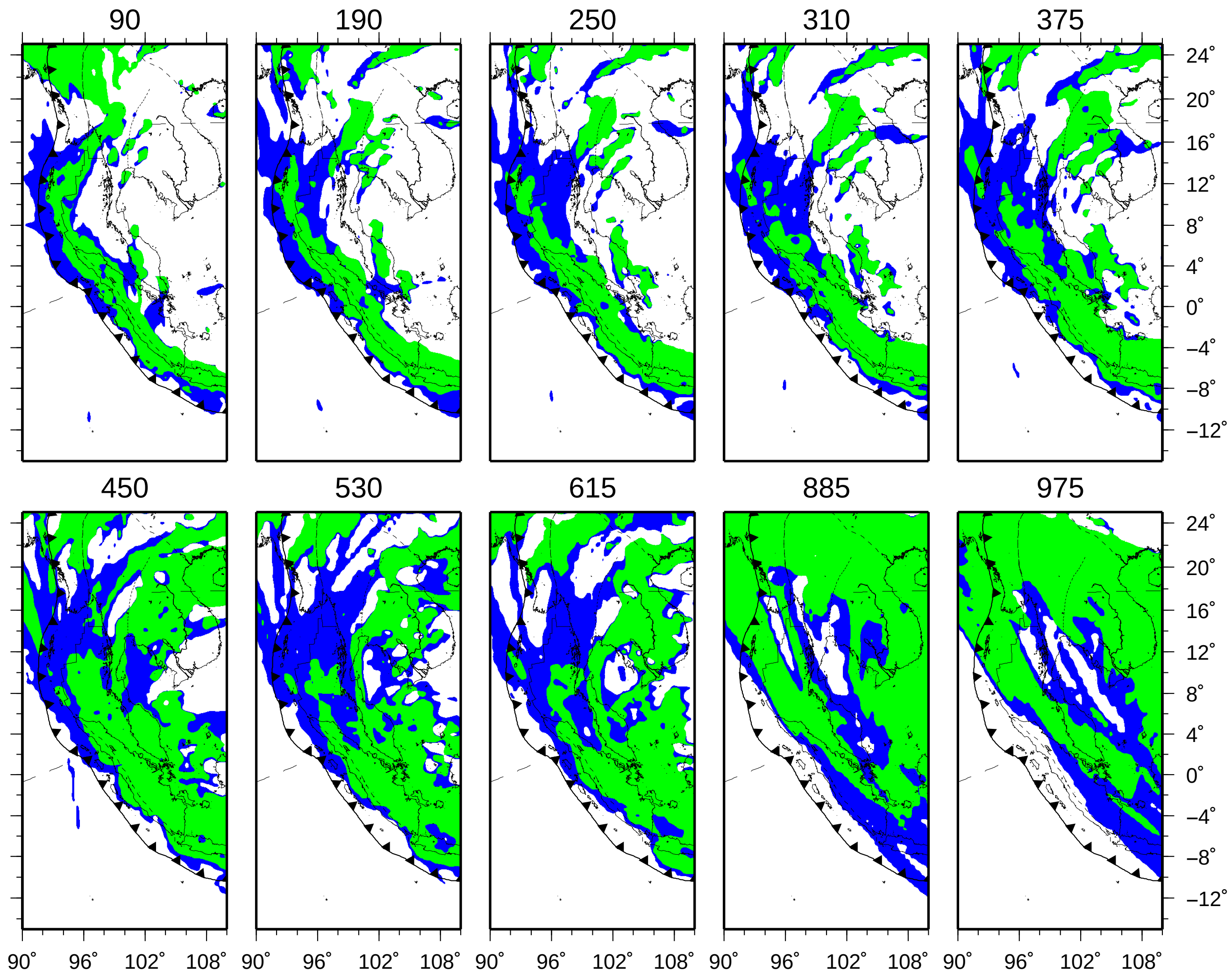
From Dinc et al. 2010

From DeShon et al. 2006

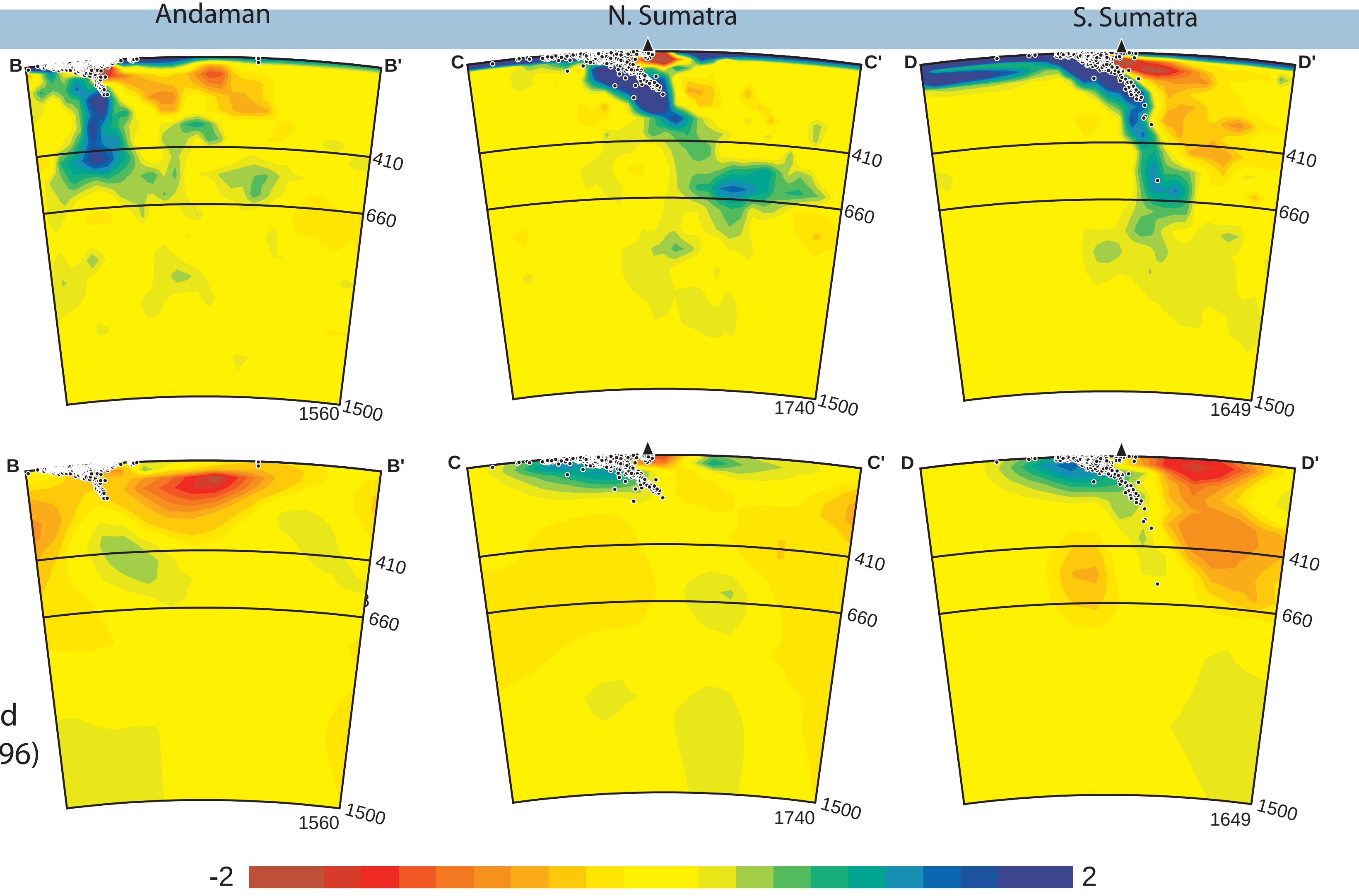
Increased Ray Coverage

Depth slices showing cells with >10,000 km of total ray length

Prior to 2004
2004 onwards

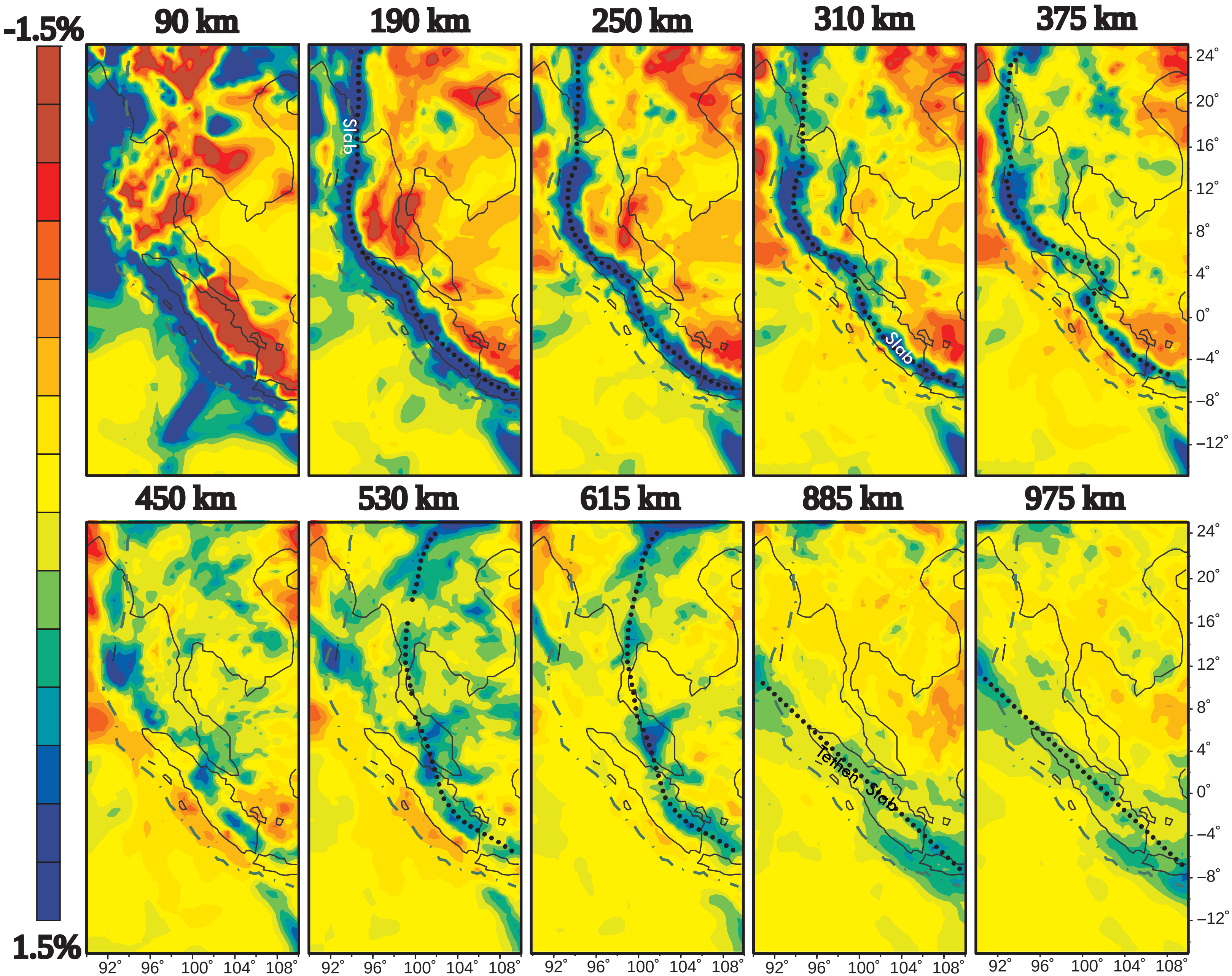


Tomography Results Comparison



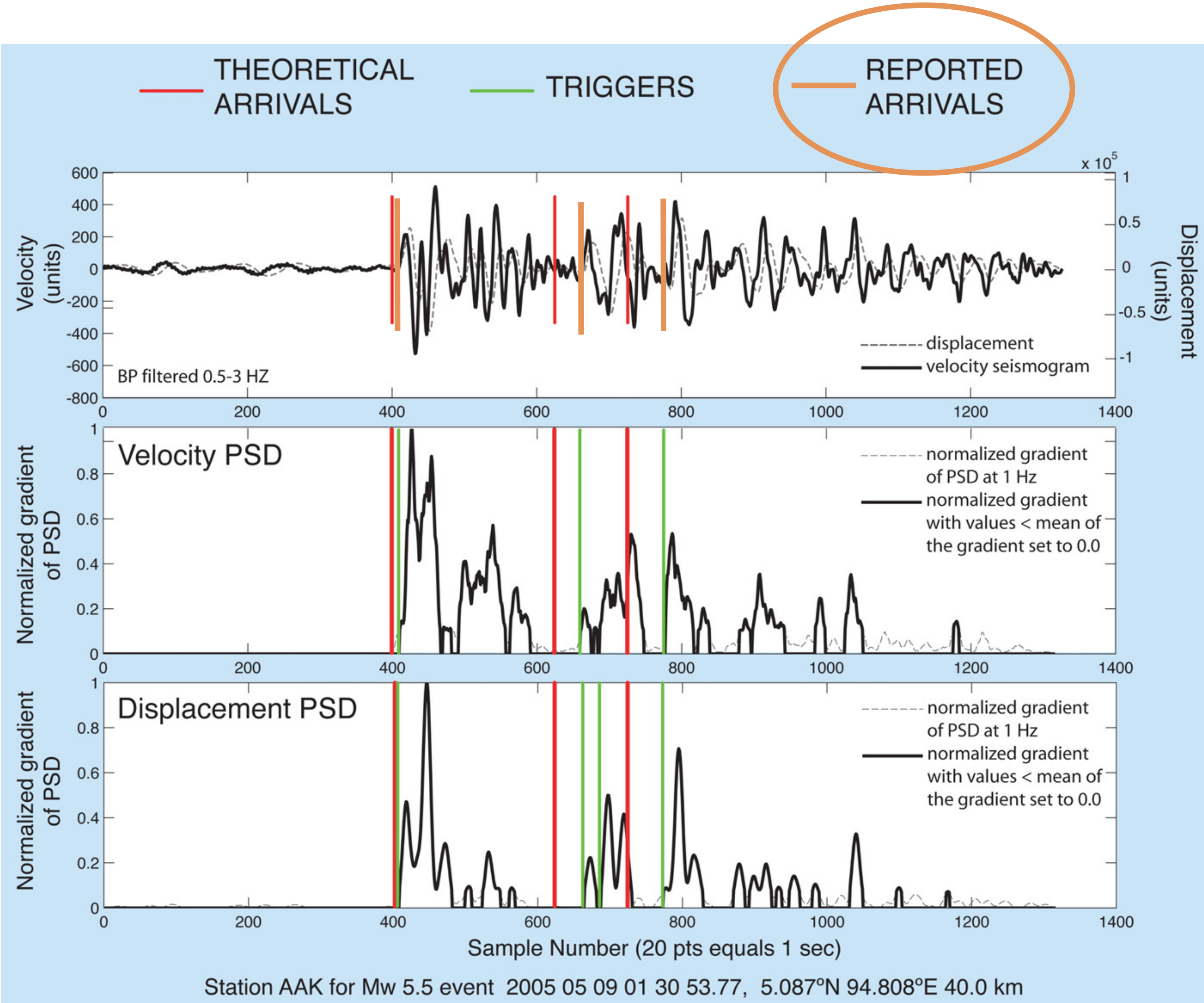
(Pesicek, 2009)

(Widiyantoro and van der Hilst, 1996)

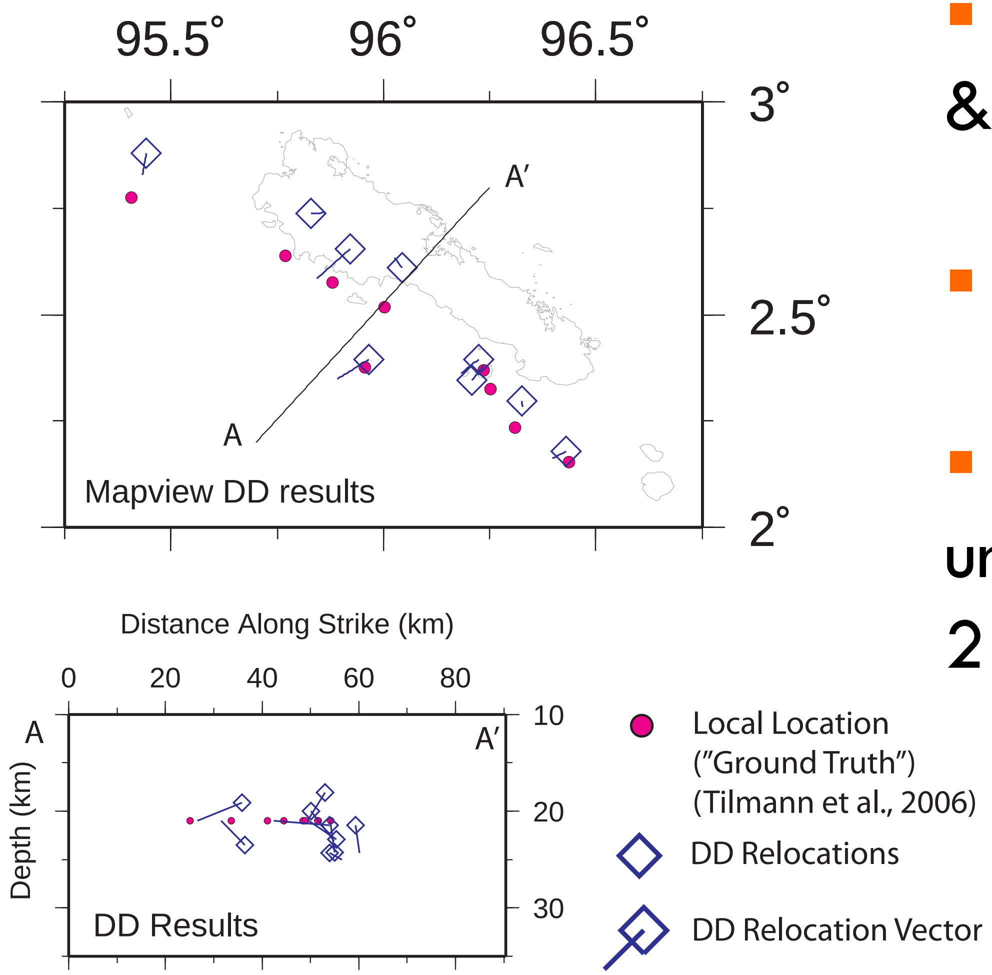


-1.5%
1.5%
90 km
190 km
250 km
310 km
375 km
450 km
530 km
615 km
885 km
975 km
Slab
Slab
Tethen Slab
24°
20°
16°
12°
8°
4°
0°
−4°
−8°
−12°
92°
96°
100°
104°
108°

Identifying Additional Depth Phases

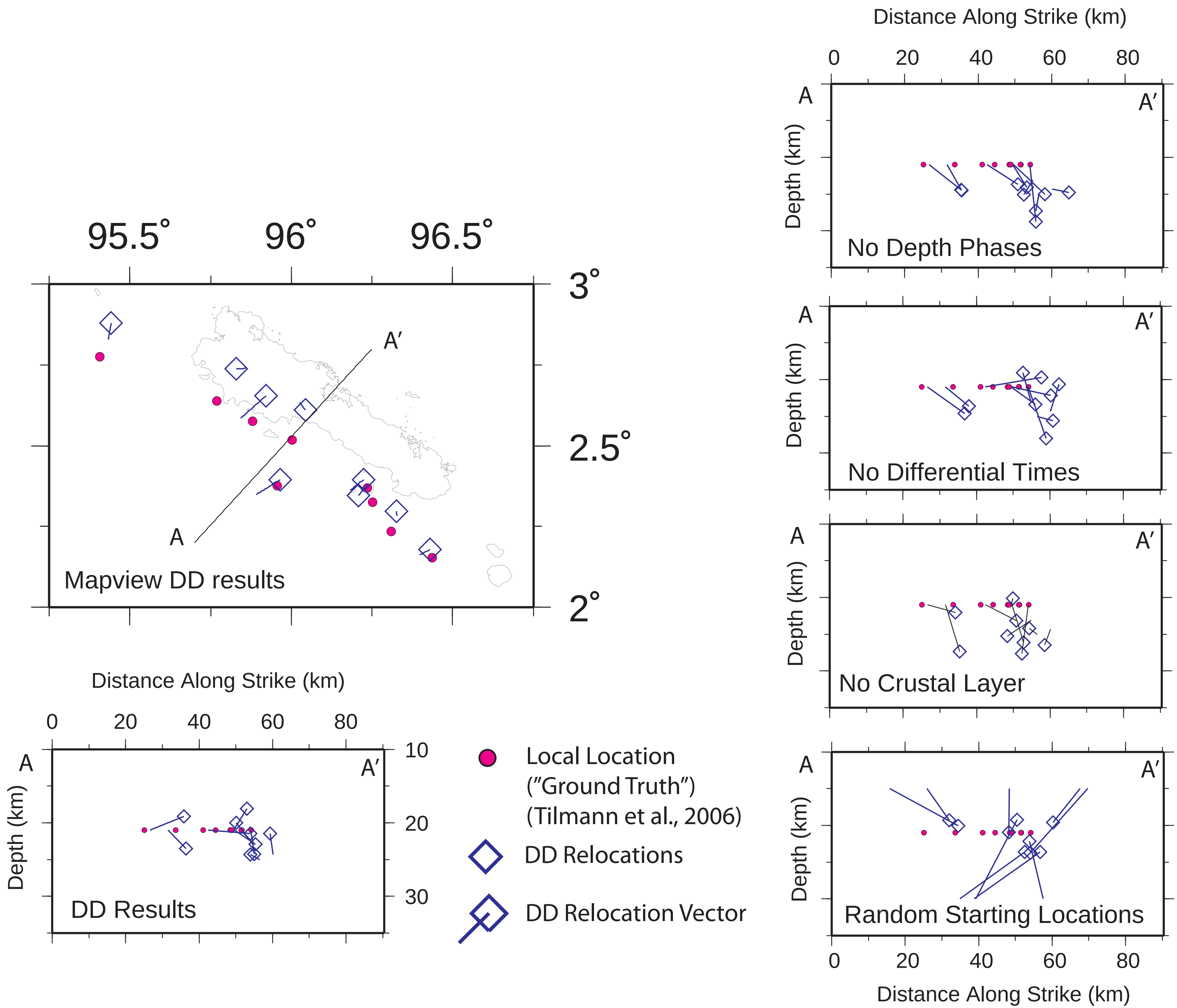


Location Uncertainties



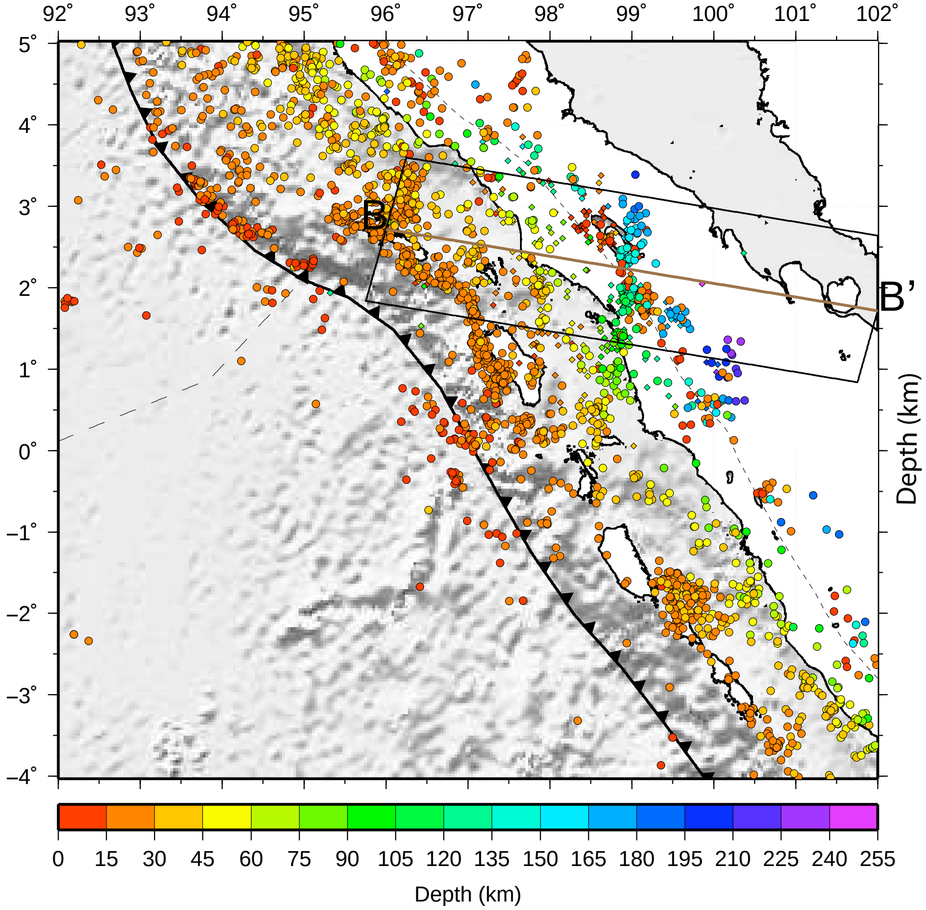
- Comparison to OBS data & jackknife tests
- ~5 km hypocenter shifts
- Reduced location uncertainties from 10 km to 2 km

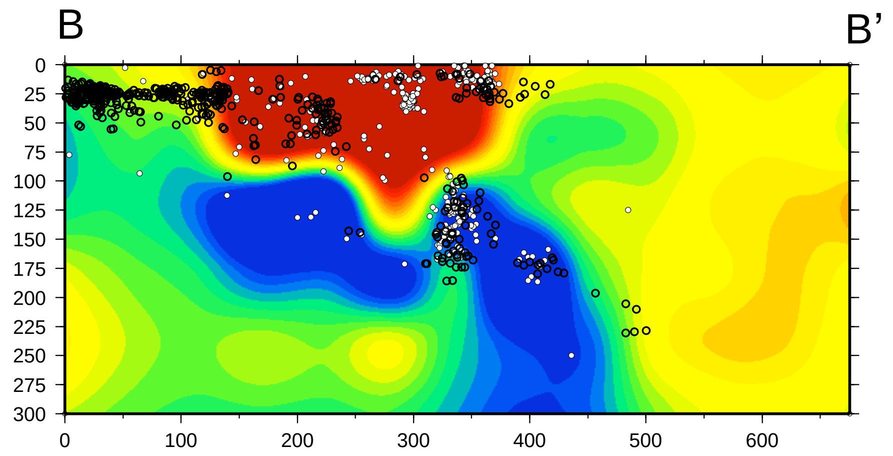
From *Pesicek et al.*, 2010b



95.5°
96°
96.5°
3°
2.5°
2°
A
A′
Mapview DD results
Distance Along Strike (km)
Depth (km)
DD Results
No Depth Phases
No Differential Times
No Crustal Layer
Random Starting Locations
0
20
40
60
80
10
20
30
Local Location
("Ground Truth")
(Tilmann et al., 2006)
DD Relocations
DD Relocation Vector

Subducting the Investigator Fracture Zone





Teleseismic DD Relocations