Integration of seismology, geodesy, and mantle dynamics for grand challenge Earth science problems

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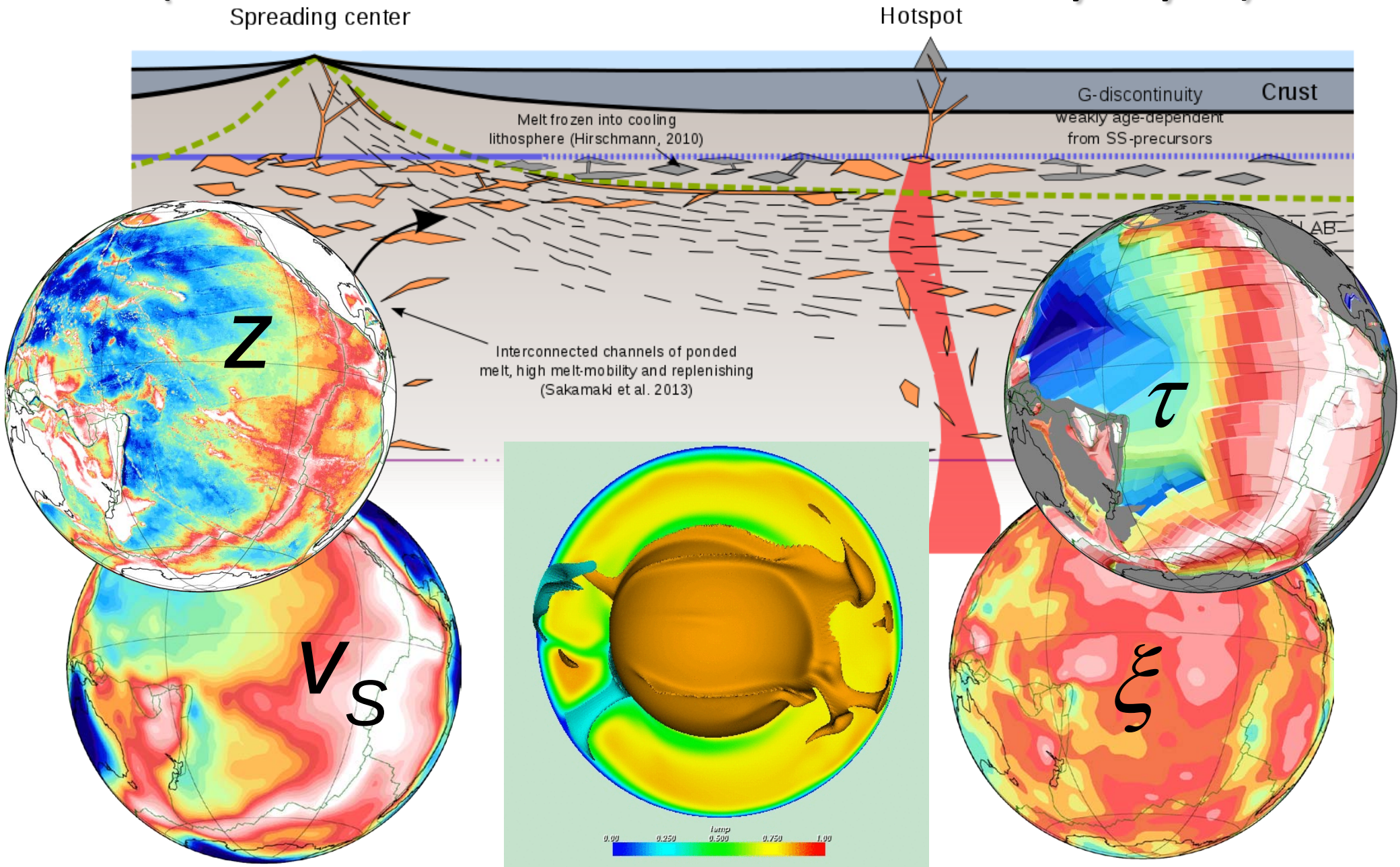
Workshop on Future Seismic and Geodetic Facility Needs in the Geosciences

Leesburg VA

May 4, 2015

Oceanic system: Reference model, no more?
(Plate tectonics = thermal boundary layer)

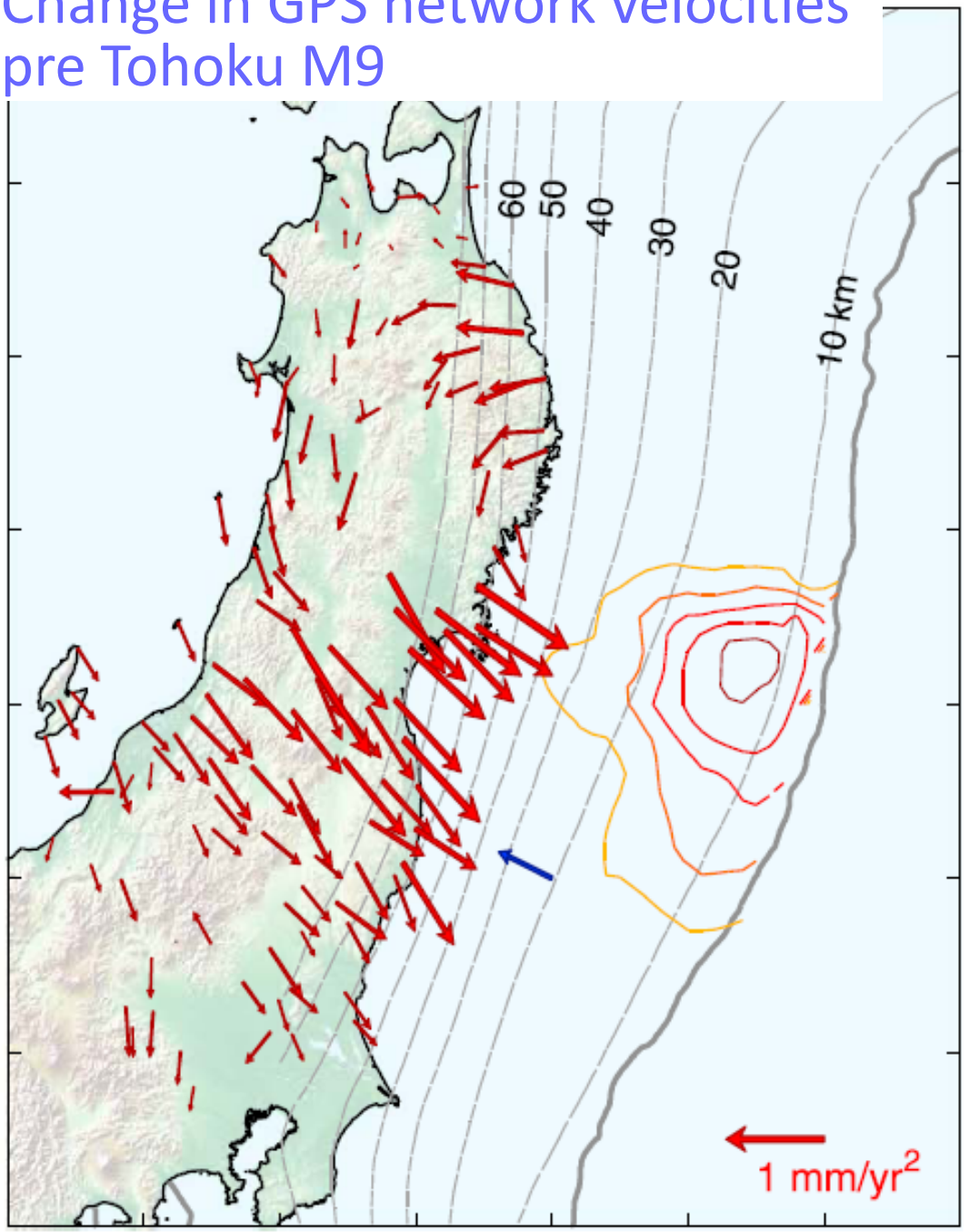


Auer et al. (in prep.)

Subduction: Transients in tectonic loading at megathrusts

- constitutive law for faults?
- plate boundary evolution?
- strain localization?
- hazard assessment?

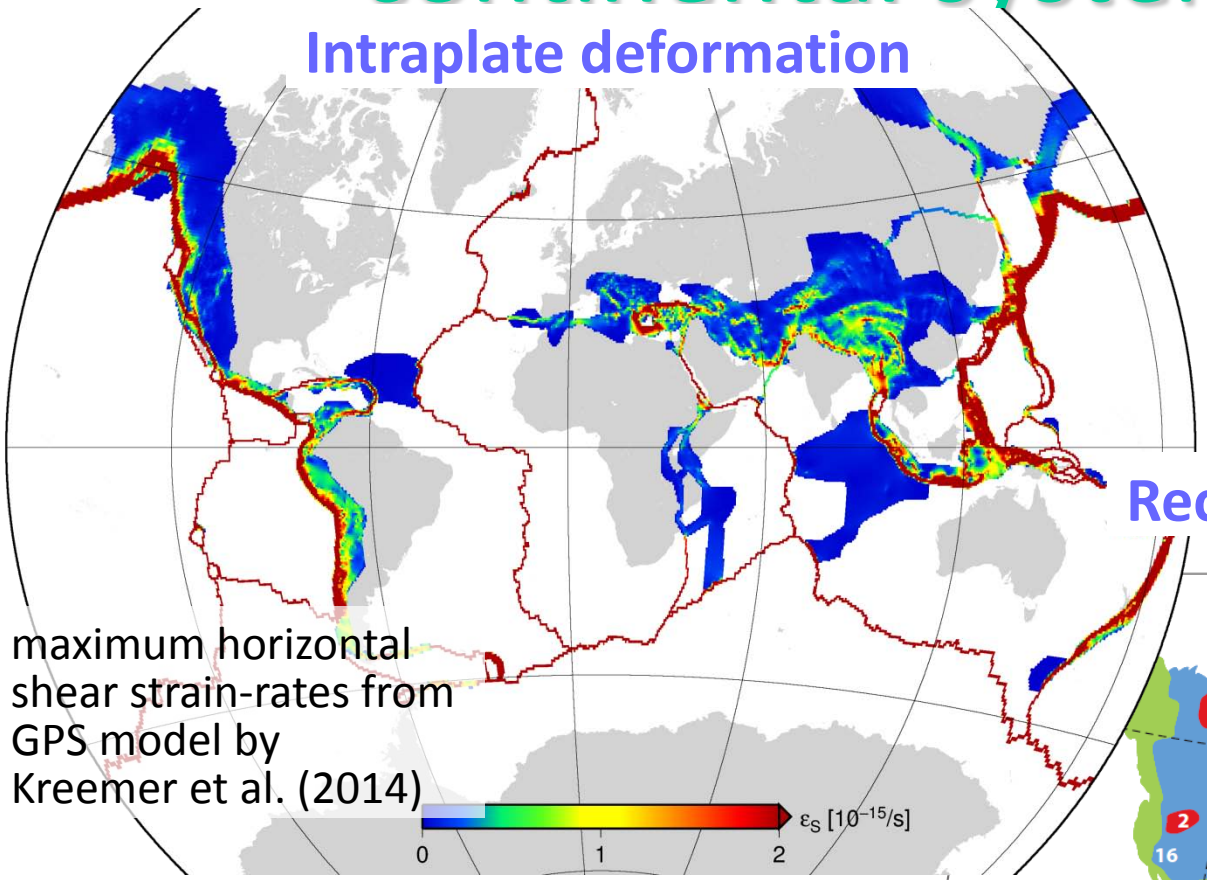
Change in GPS network velocities pre Tohoku M9



Mavrommatis et al. (2014)

Plate tectonics 2.0 has to explain continental system dynamics

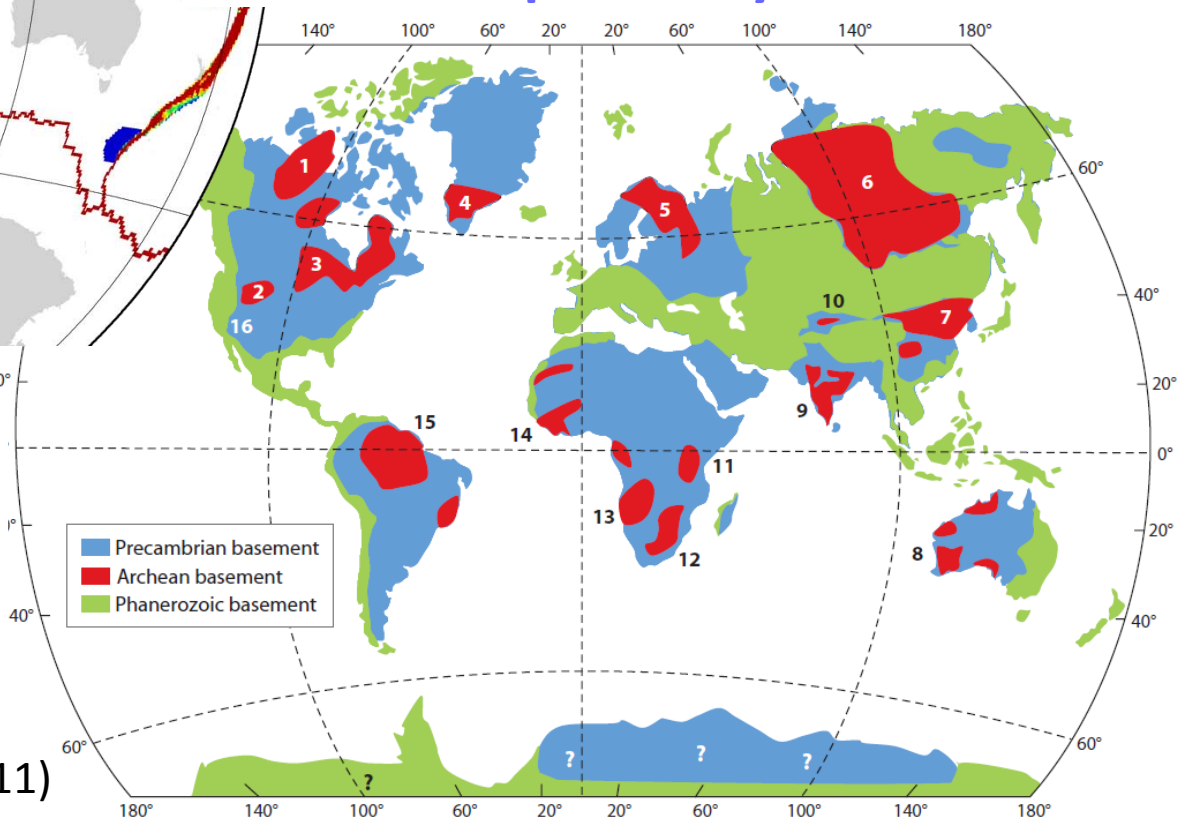
Intraplate deformation

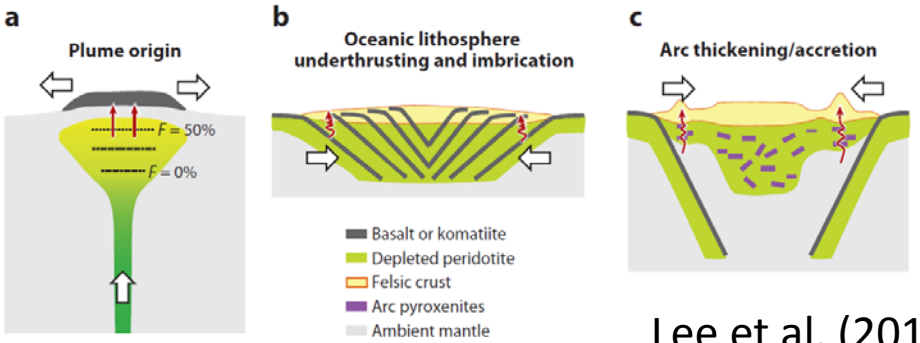


maximum horizontal shear strain-rates from GPS model by Kreemer et al. (2014)

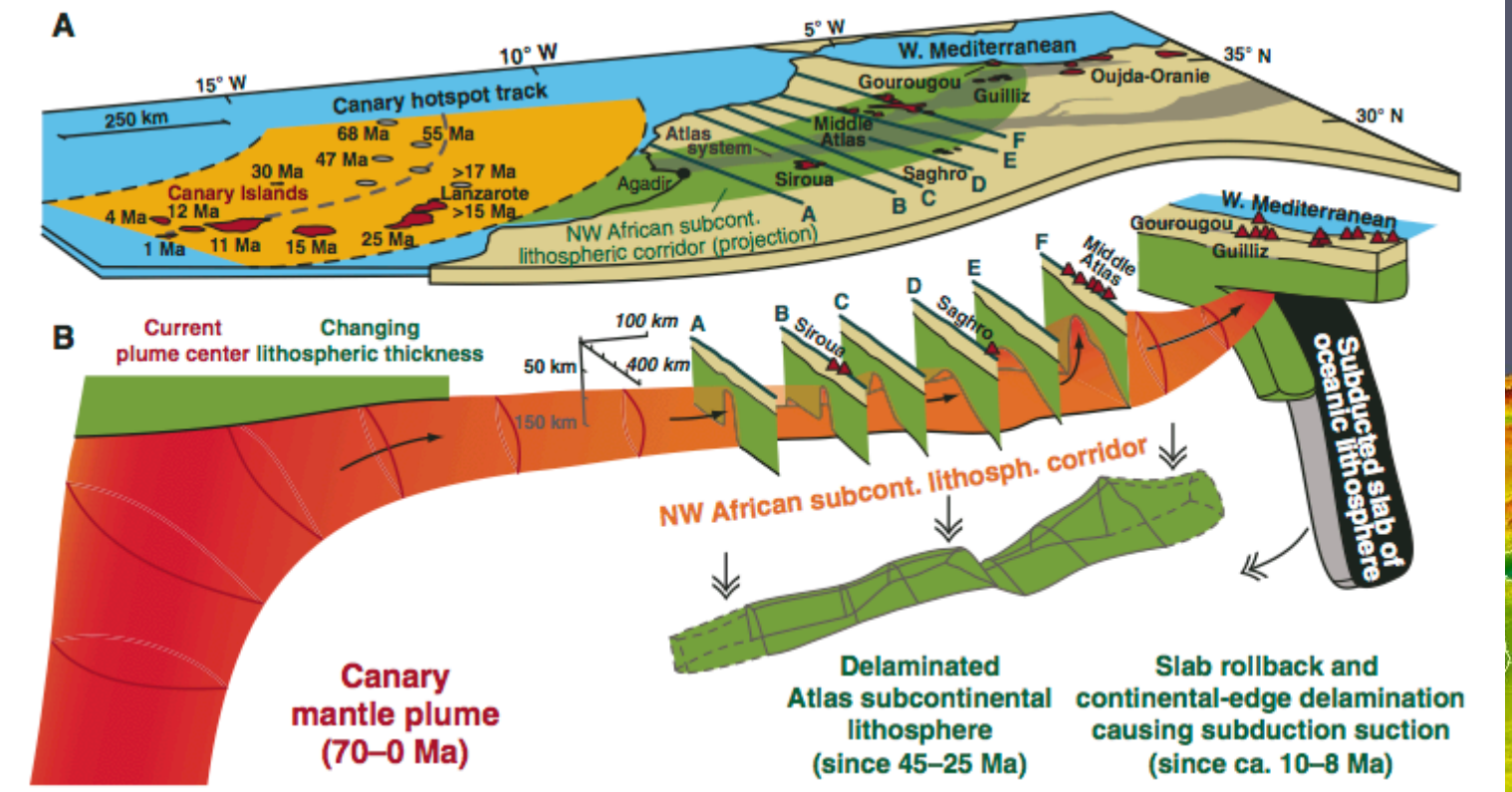
- Link surface deformation (present and past) to deep mantle dynamics

Recorder of planetary evolution



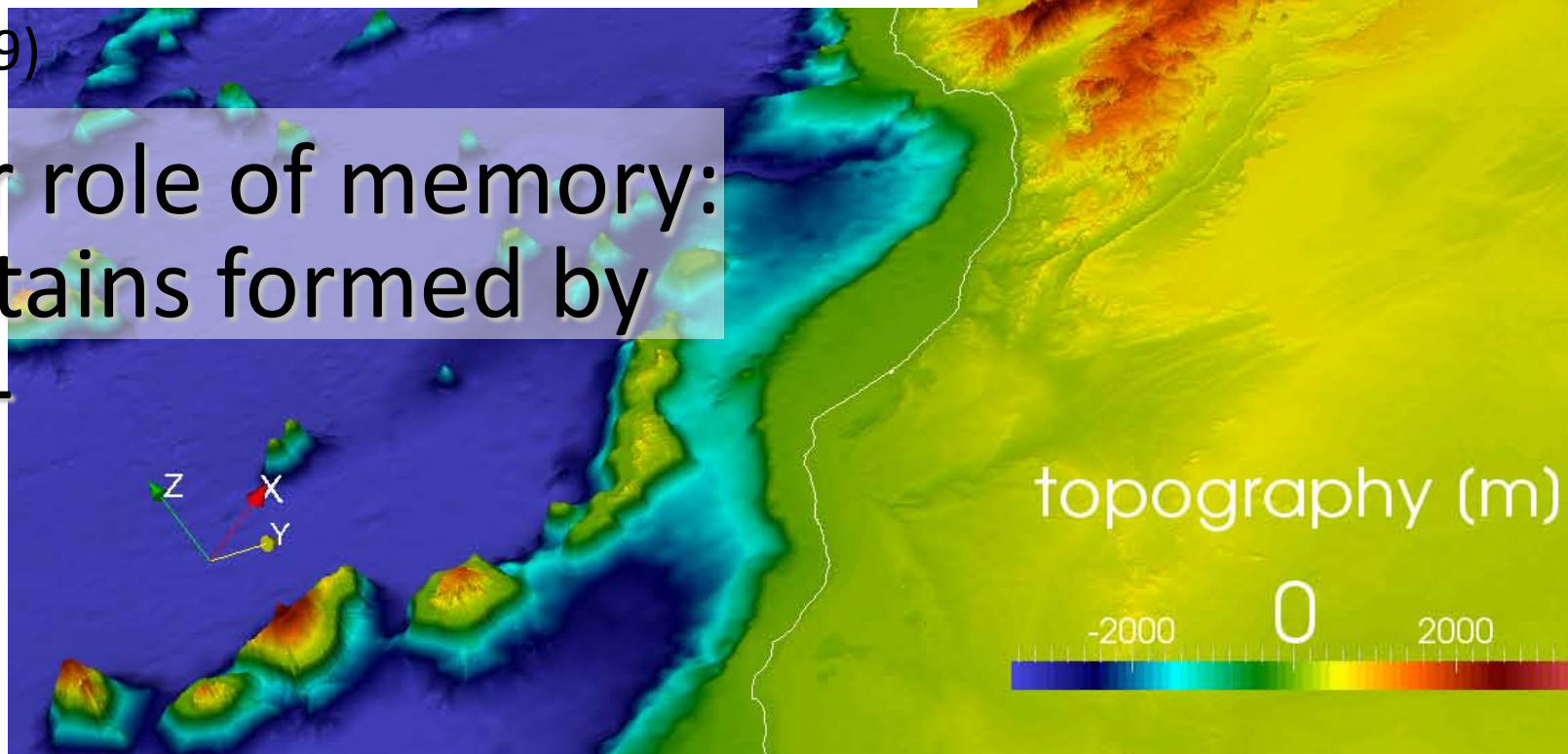


Lee et al. (2011)

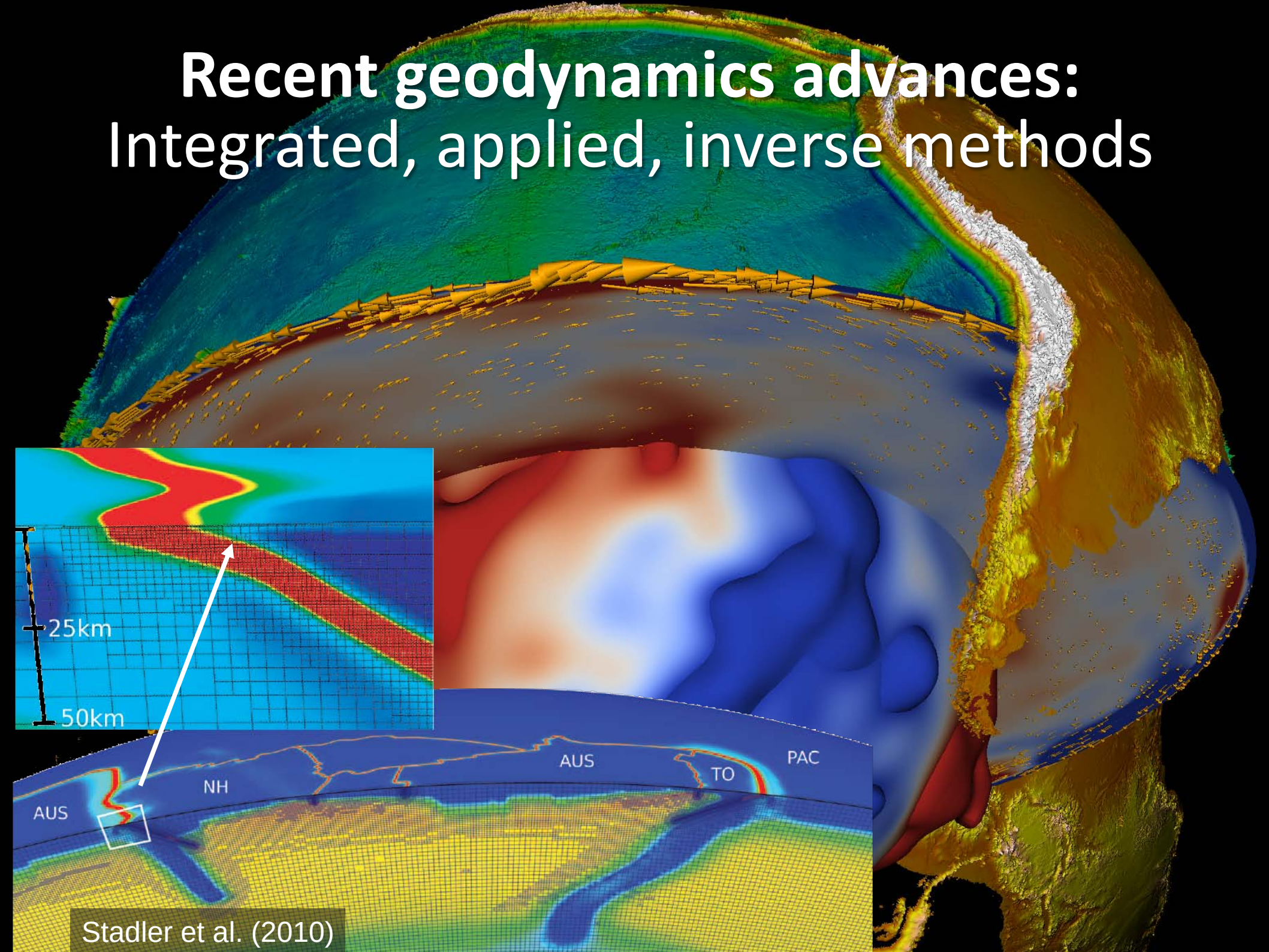


Duggen et al. (2009)

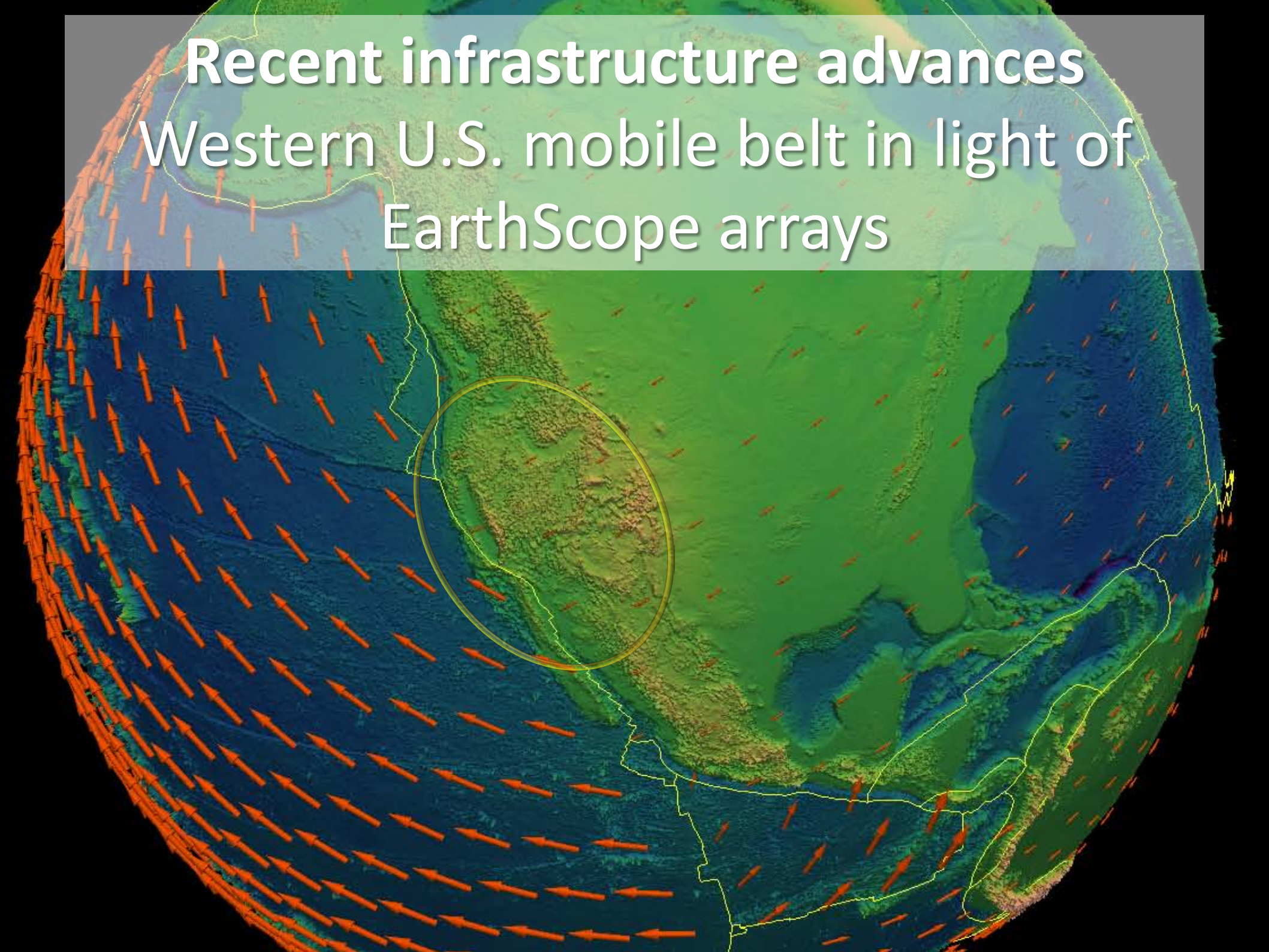
Example for role of memory: Atlas mountains formed by slab-plume-continental plate interaction



Recent geodynamics advances: Integrated, applied, inverse methods



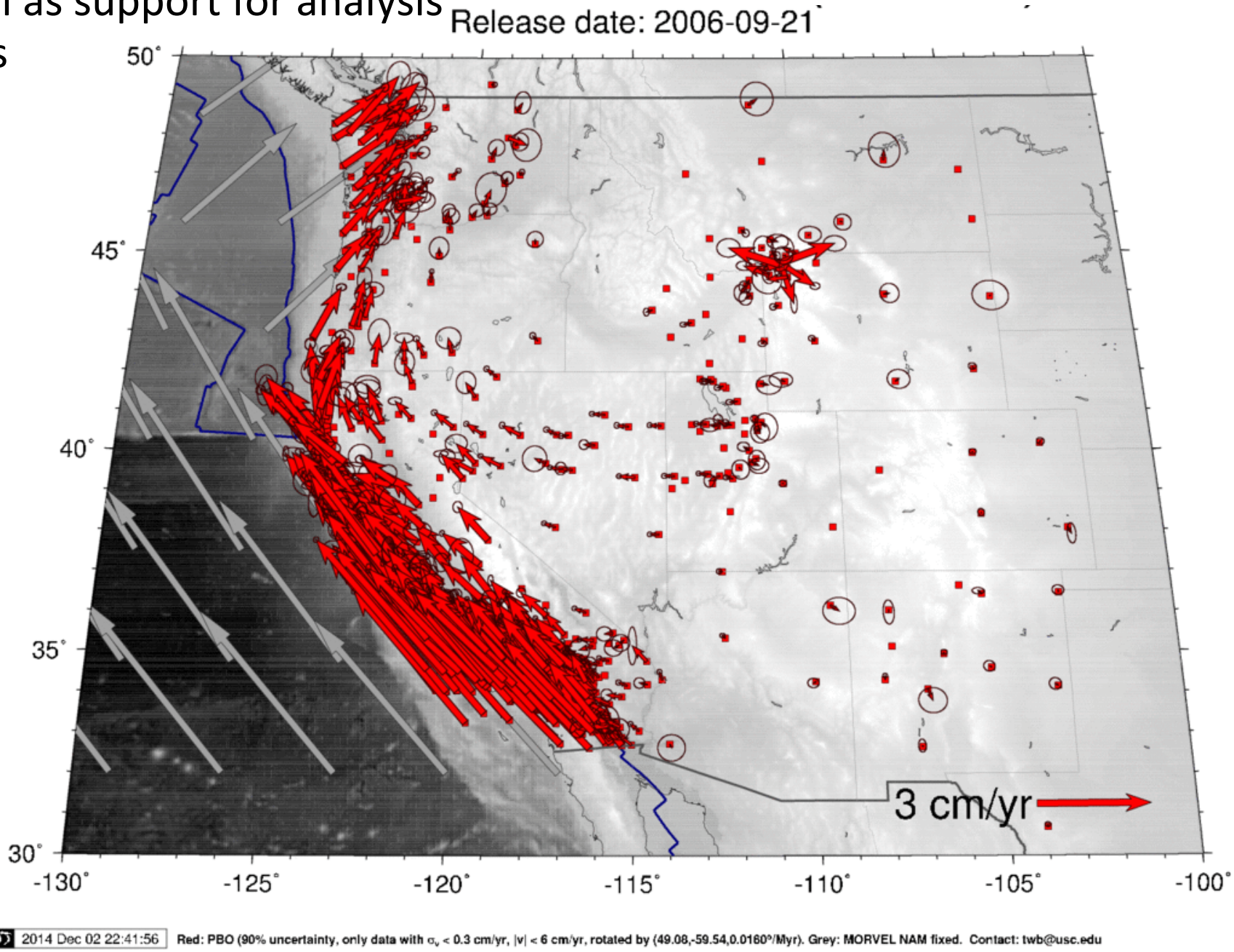
Stadler et al. (2010)


Recent infrastructure advances
Western U.S. mobile belt in light of EarthScope arrays

Sustained operations

- Key for seismology and geodesy as well as support for analysis efforts

PBO



SAVANI

Auer et al. (2014)

old model

SAVANI, l > 12

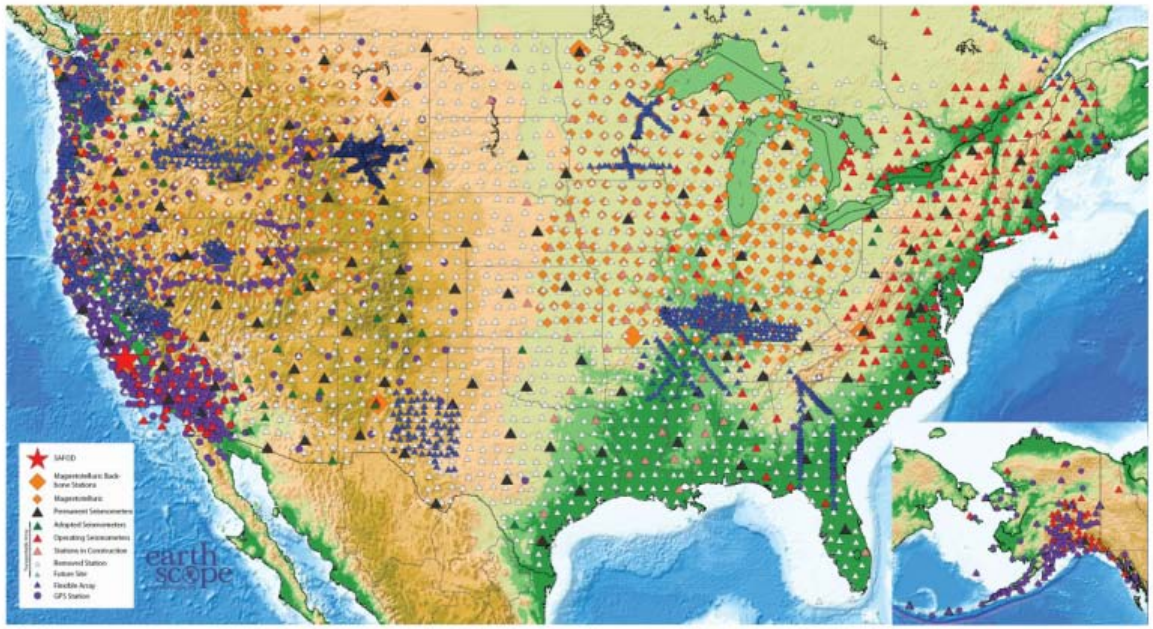
full model

short wavelength

seismic shear wave tomography maps at 200 km depth

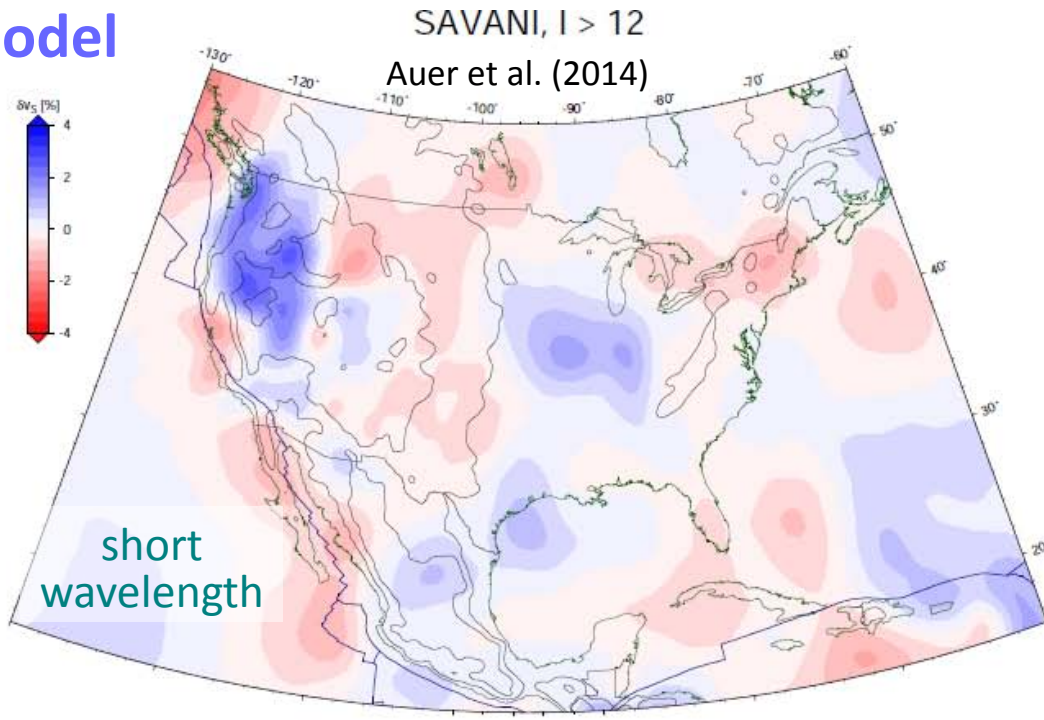
Pre USArray tomography

EarthScope Stations Status as of April 2015

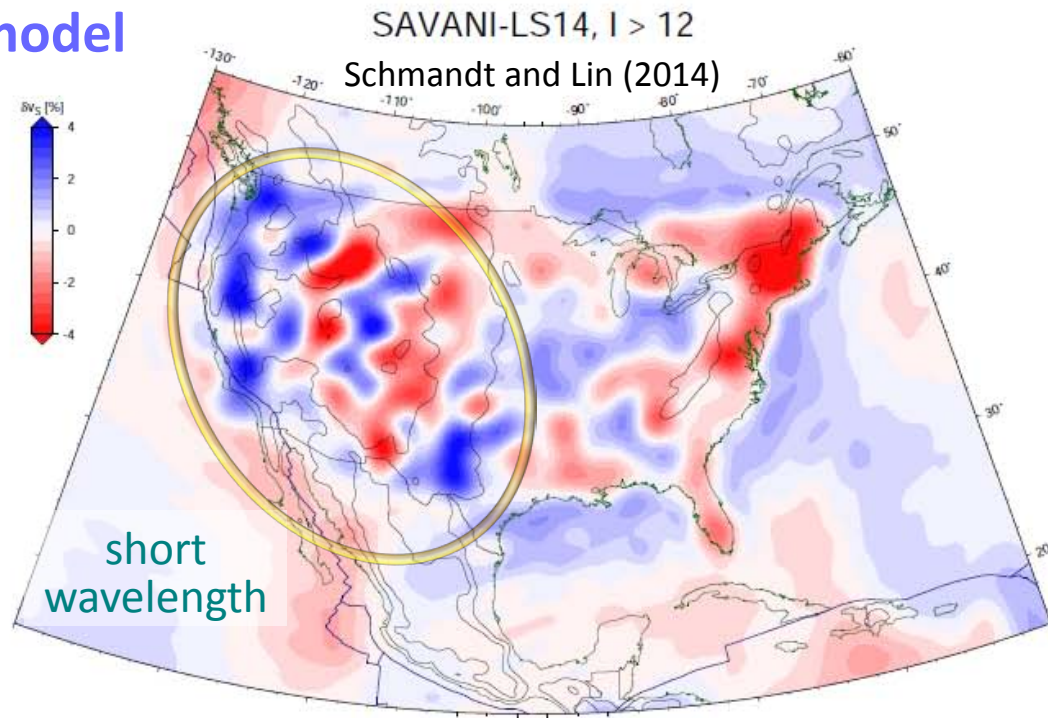


seismic shear wave tomography maps at 200 km depth

old model

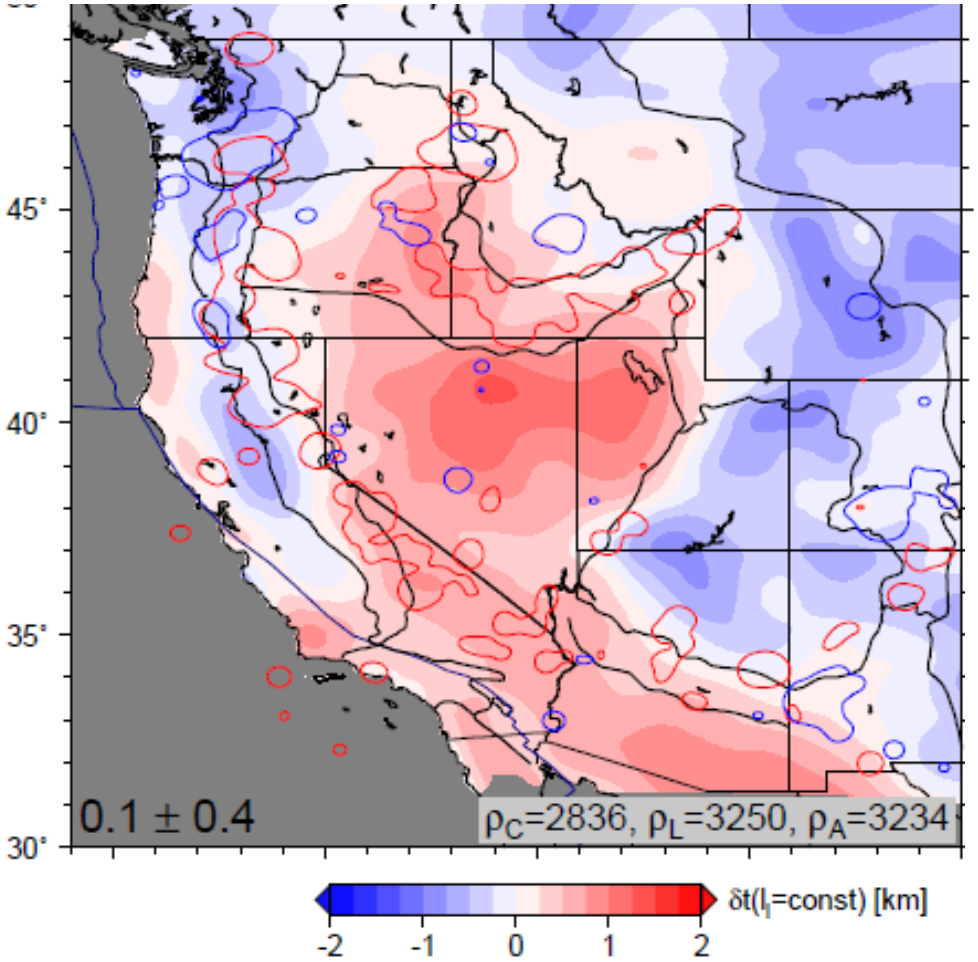


new model



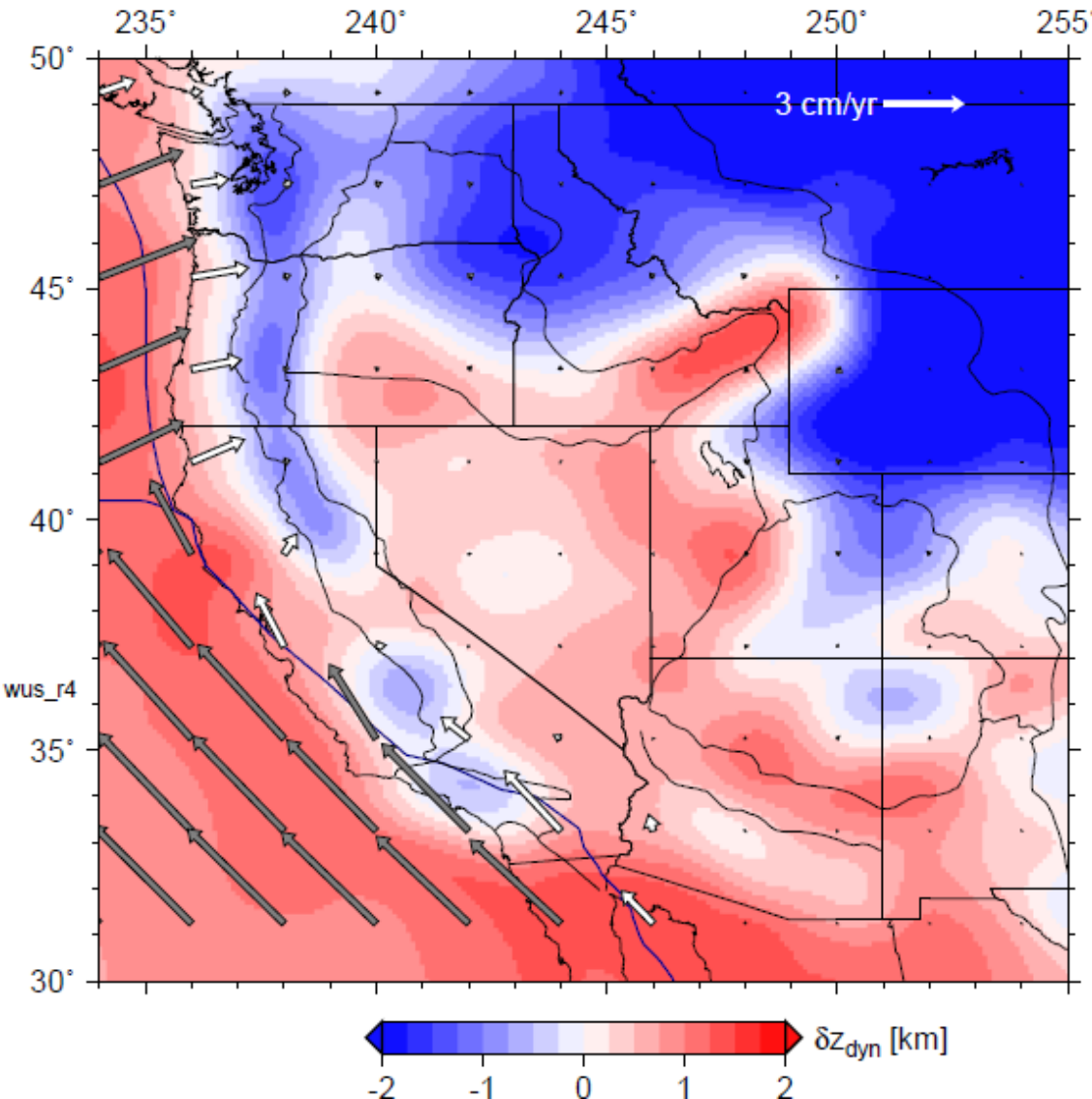
- Construct variable resolution, global shear wave models
- Include global network information and surface wave data in regional studies

residual topography



Still sorting out what this all means: Match between residual and dynamic topography

mantle flow predicted topography

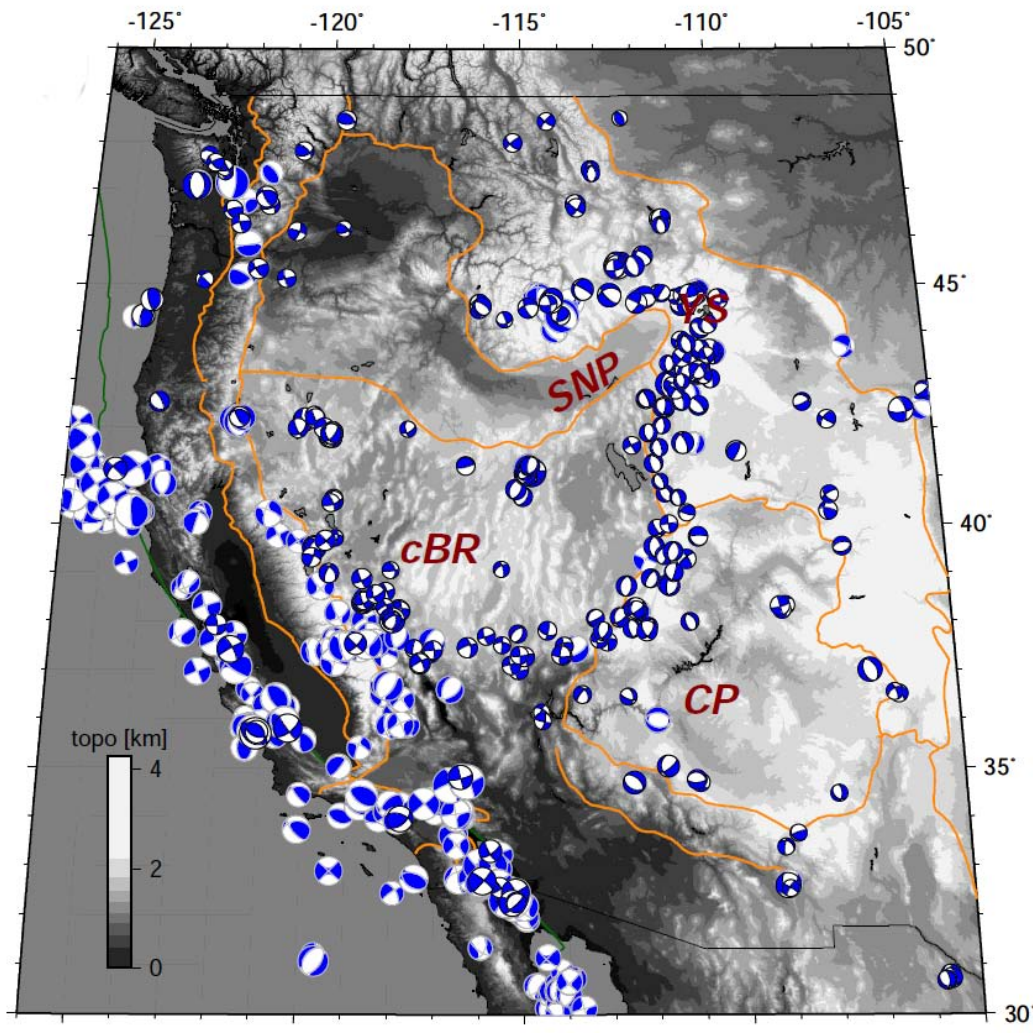


→ mantle flow induced "dynamic" topography matches non-isostatic residual

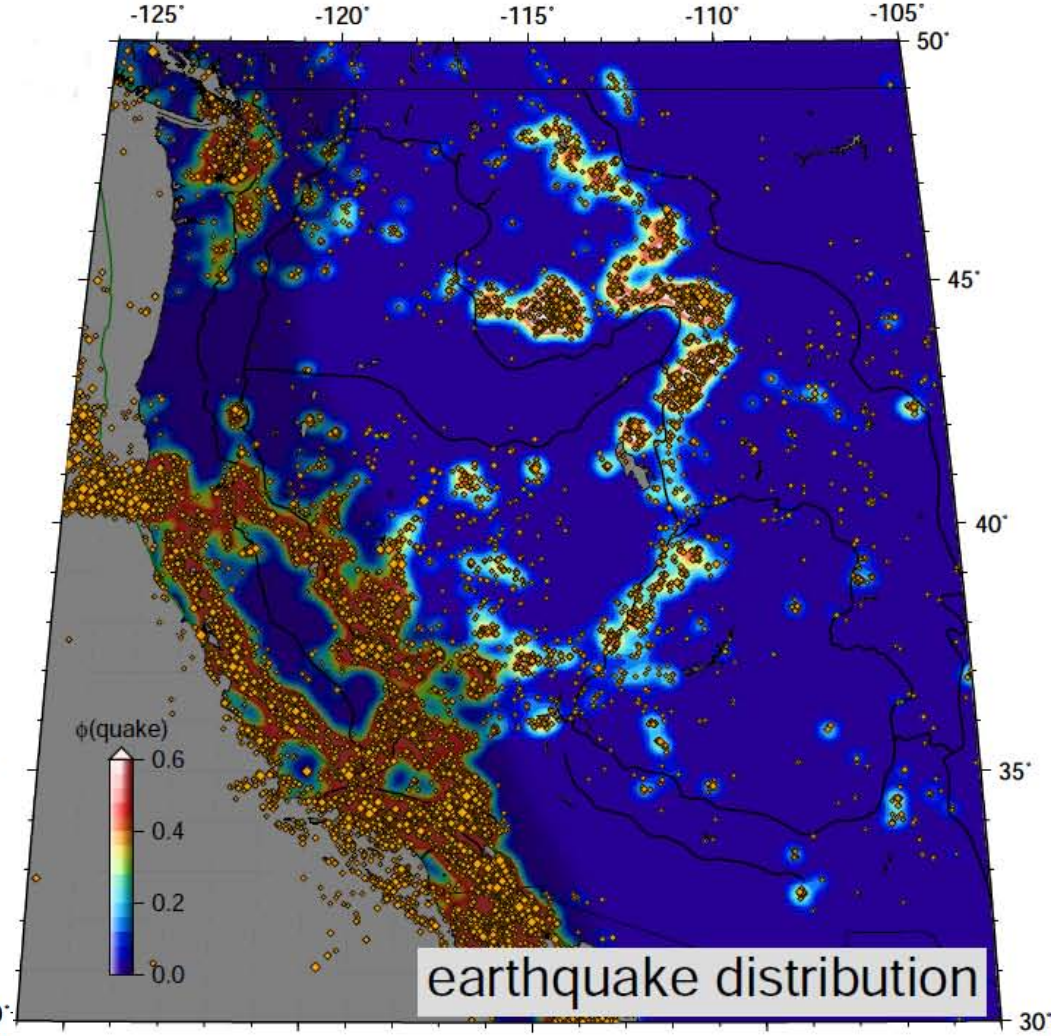
→ Composition, radial anisotropy, or remaining *uncertainty in crustal models* causing complications

Becker et al. (2014)

One continental dynamics question: Origin of intraplate seismicity?

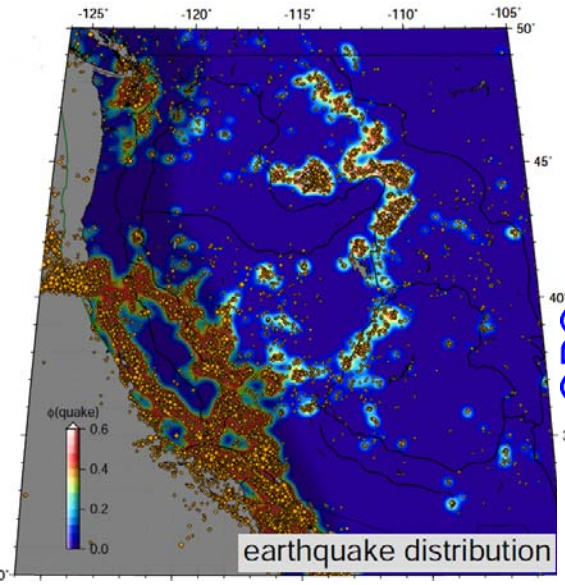


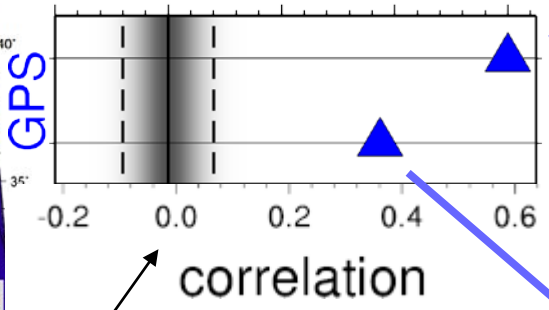
gCMTs and SLU catalog



ANSS and Engdahl catalog events, smoothed seismicity

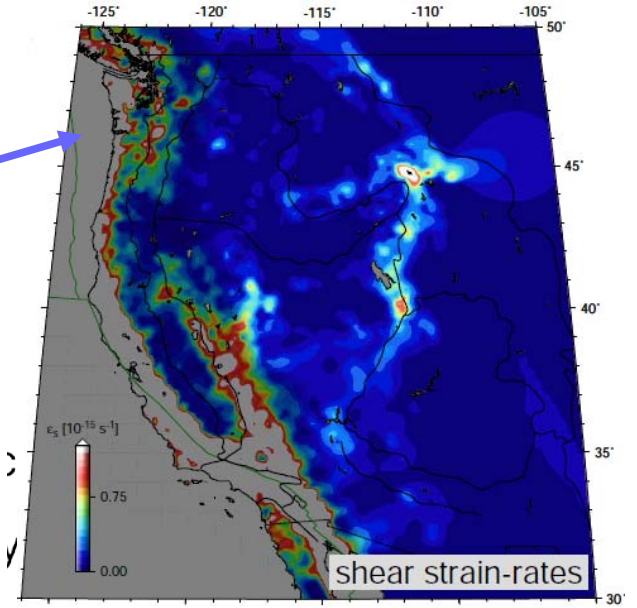
Correlation



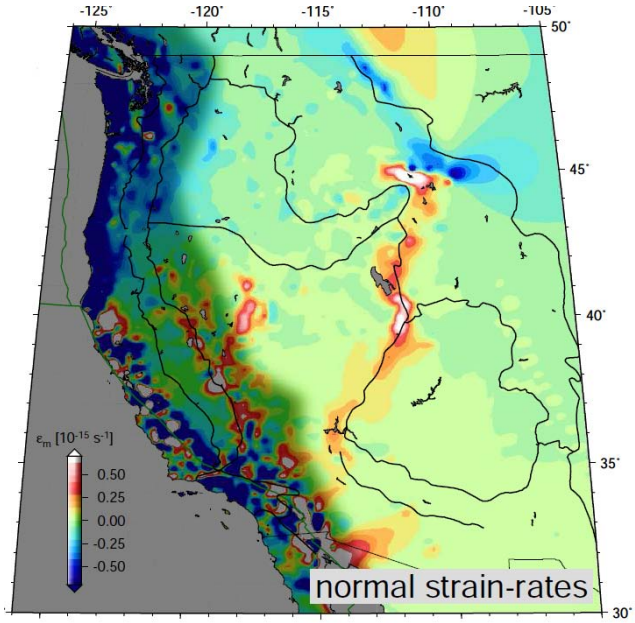


if outside gray,
~98% significant

with seismicity
away from plate
boundary



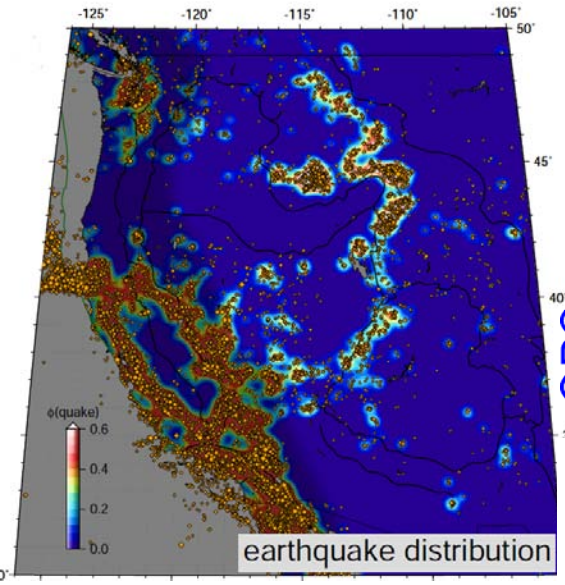
GPS geodetic
strain-rates from
Kreemer et al. (2014)

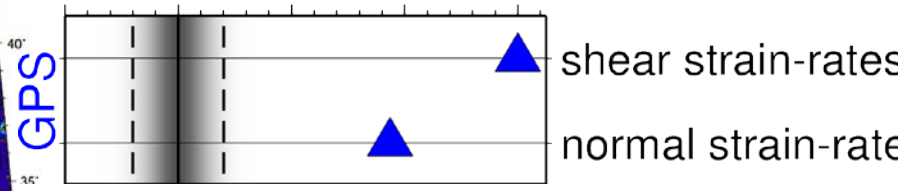


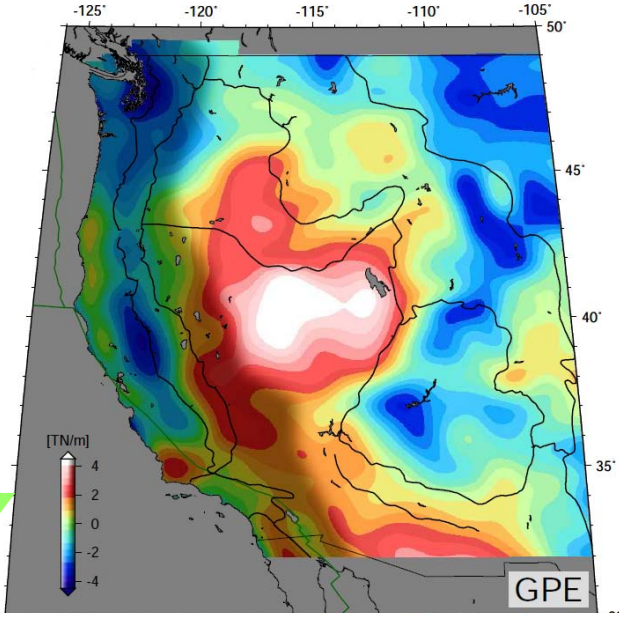
- kinematic constraints from GPS based crustal deformation model match seismicity
- not too surprising, but good baseline, and indicates little aseismic deformation

Becker et al. (submitted)

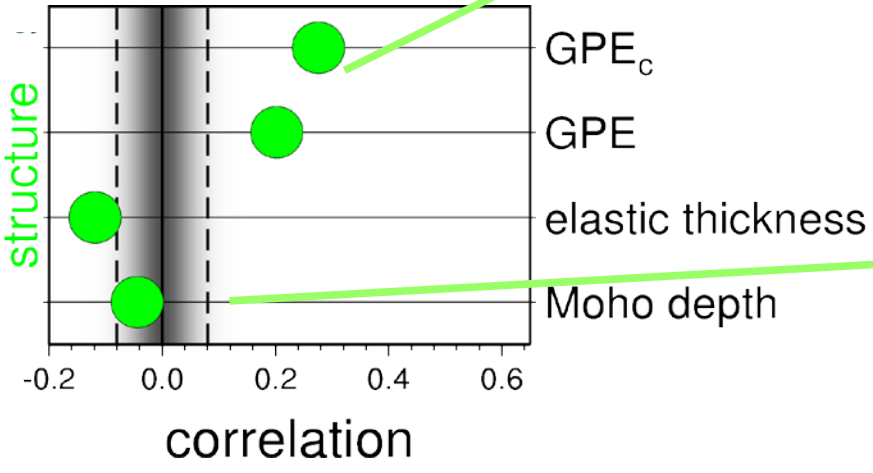
Structure as an explanation?



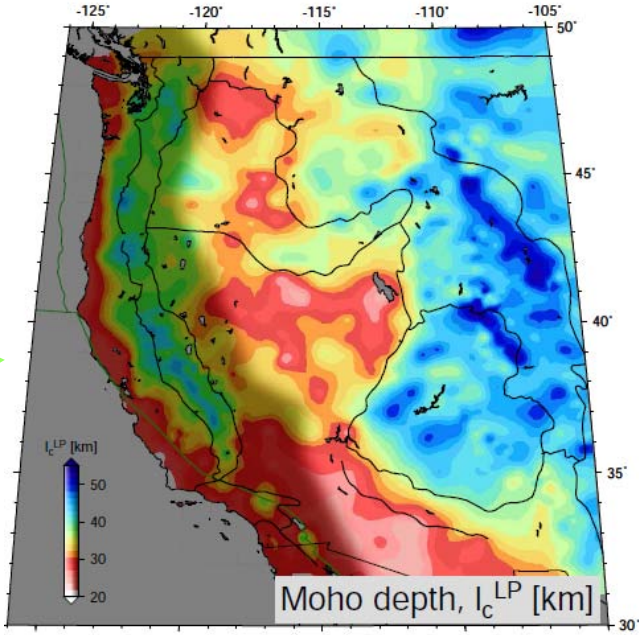




- gravitational potential energy (GPE) variations will lead to loading stresses
- structure of lithosphere may matter

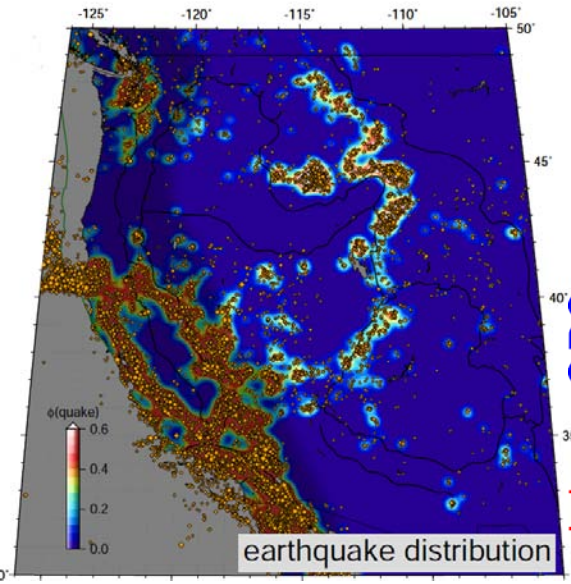


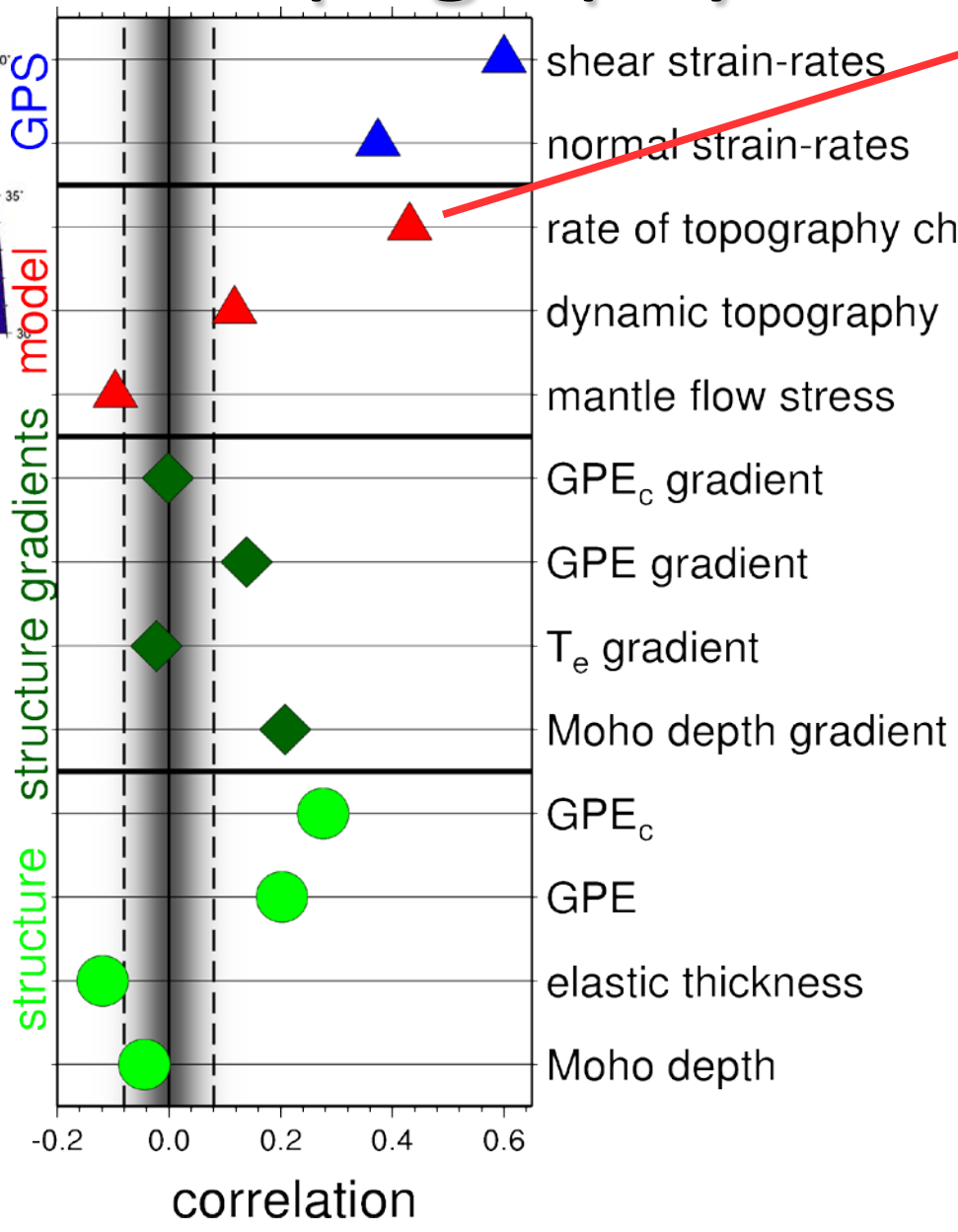
with seismicity away from plate boundary

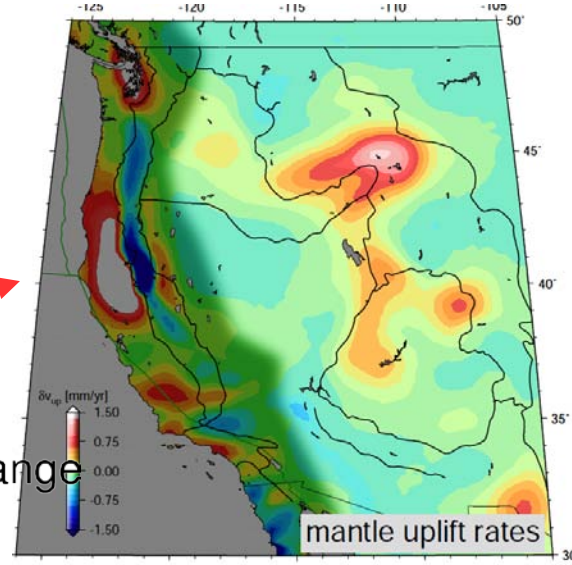


Becker et al. (submitted)

Change in dynamic topography!







→ temporal change in vertical stressing from mantle flow correlates with seismicity

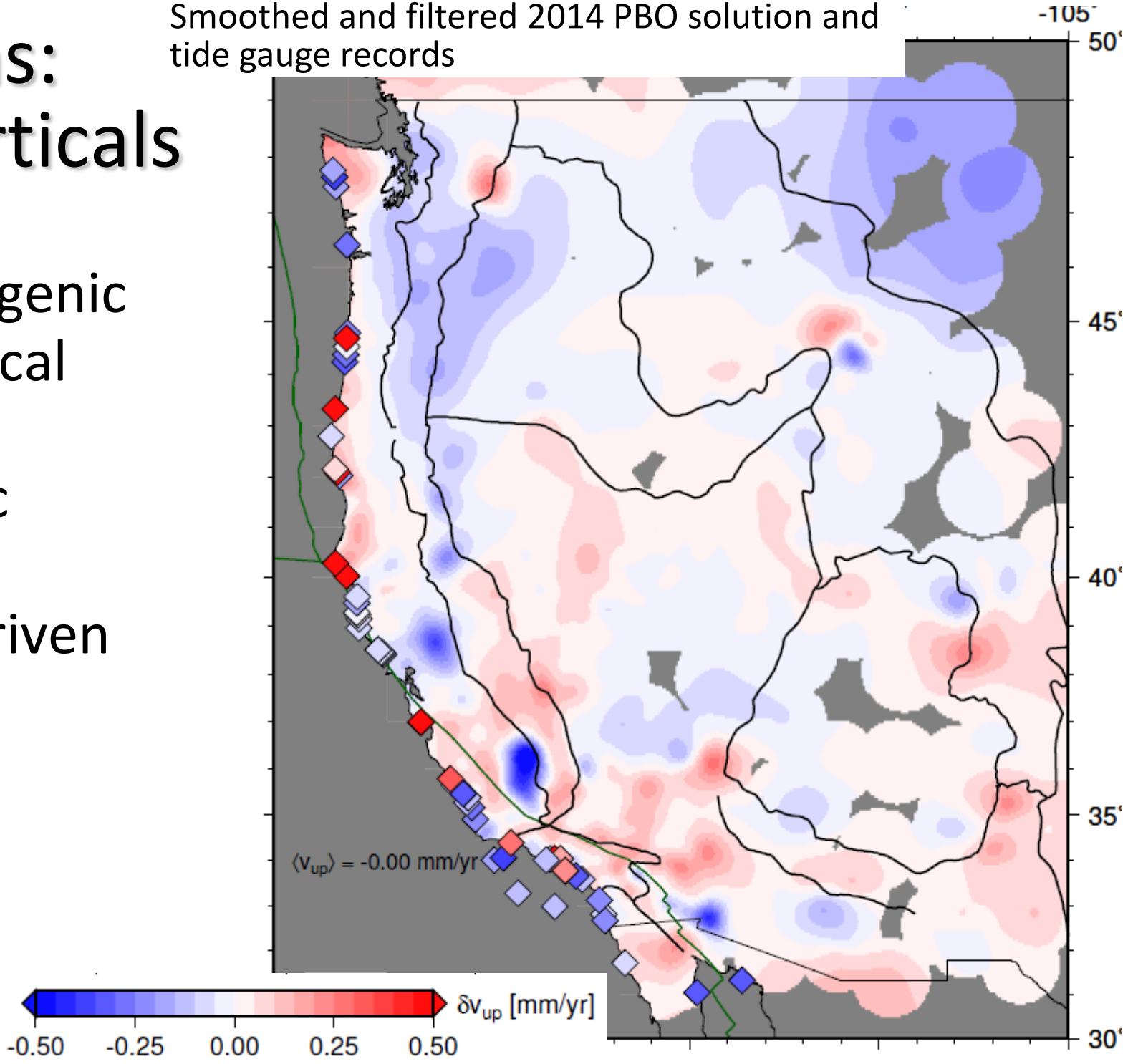
with seismicity away from plate boundary

Becker et al. (submitted)

Questions: (GPS) verticals

- anthropogenic
- hydrological
- erosional
- magmatic
- tectonic
- mantle driven

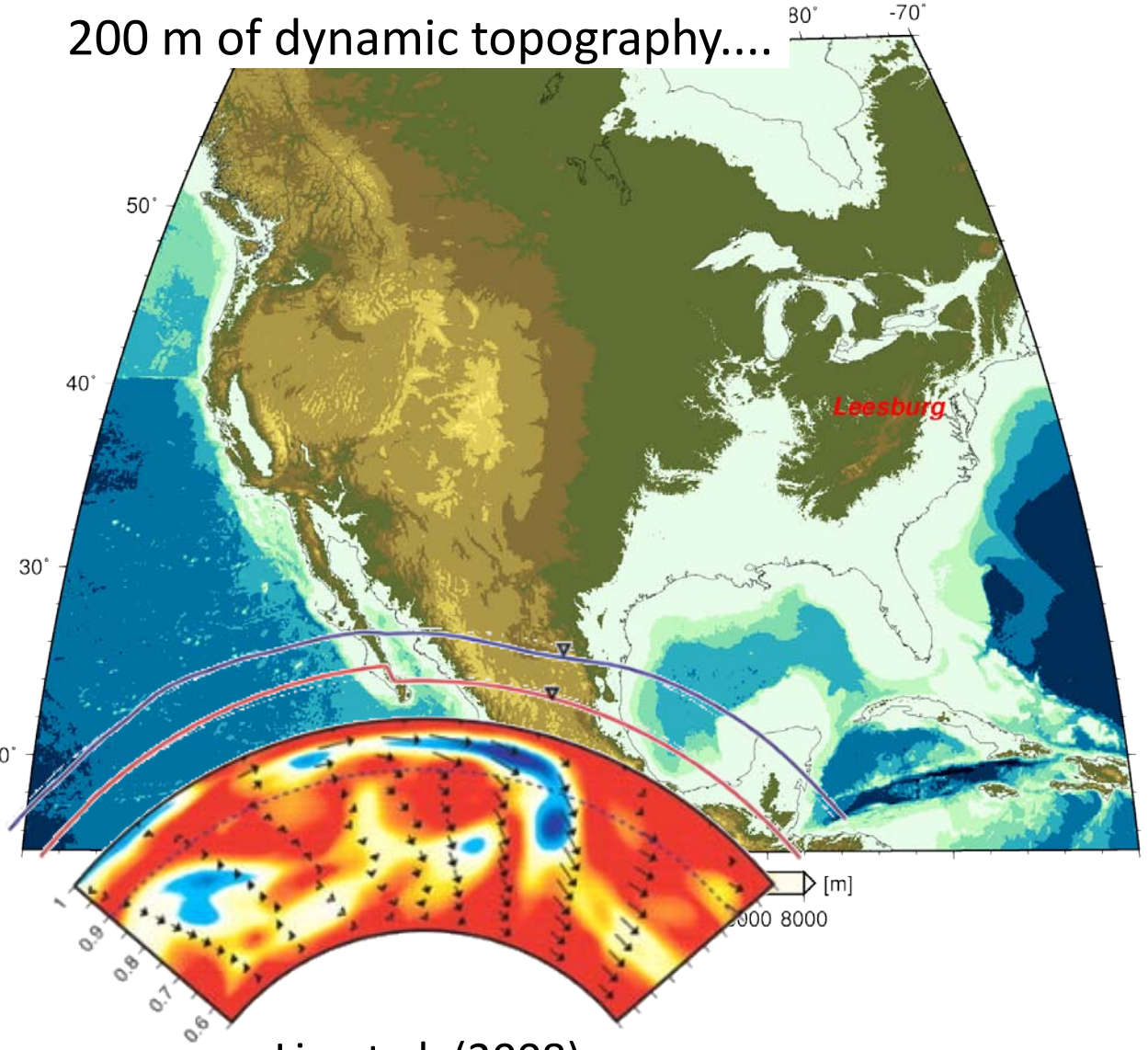
Smoothed and filtered 2014 PBO solution and tide gauge records



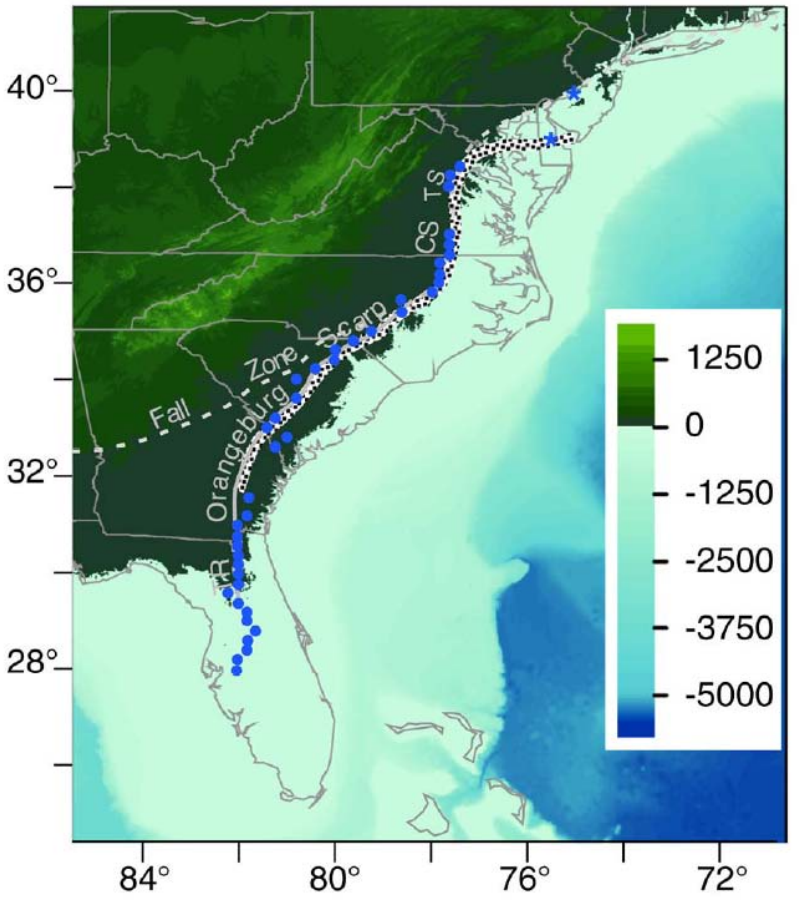
Becker et al. (in prep.)

Evolution of topography, example of **solid Earth – surface interactions**

200 m of dynamic topography....

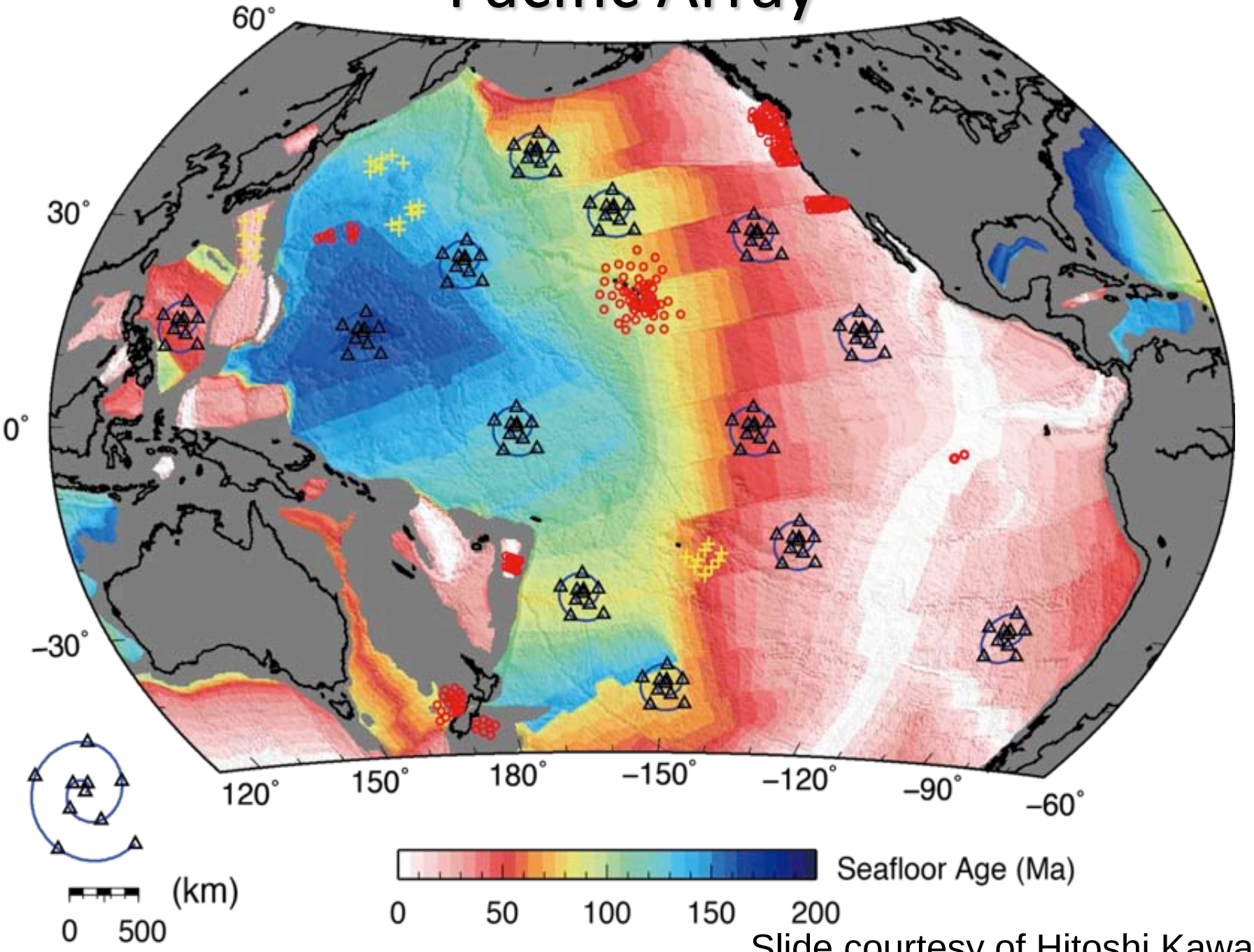


Liu et al. (2008)



Rowley et al. (2013)

Moving forward: Pacific Array

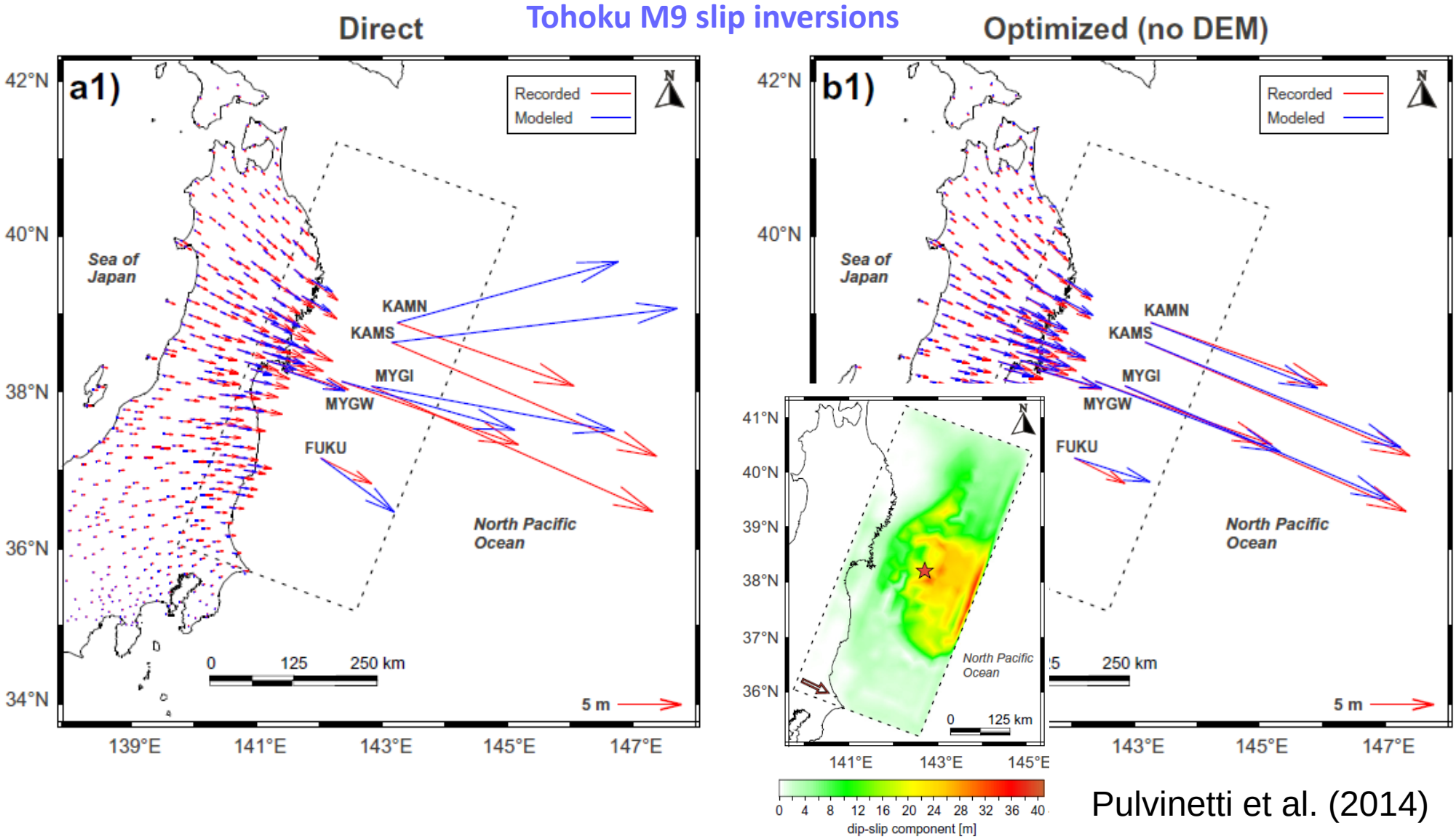


Slide courtesy of Hitoshi Kawakatsu

Moving forward:

Seafloor observatories (seafloor “GPS”, cables, cf. Japan)

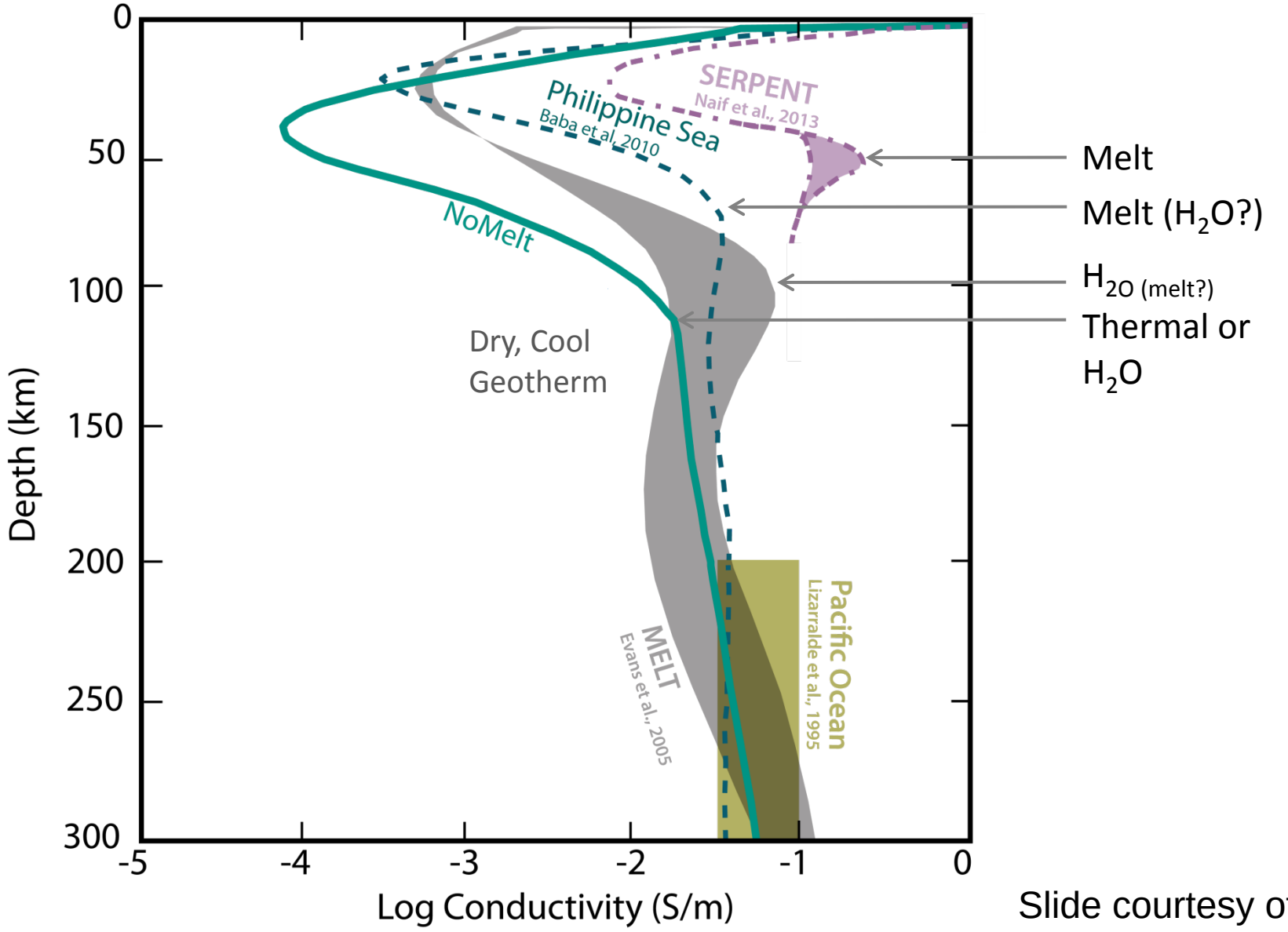
Tohoku M9 slip inversions



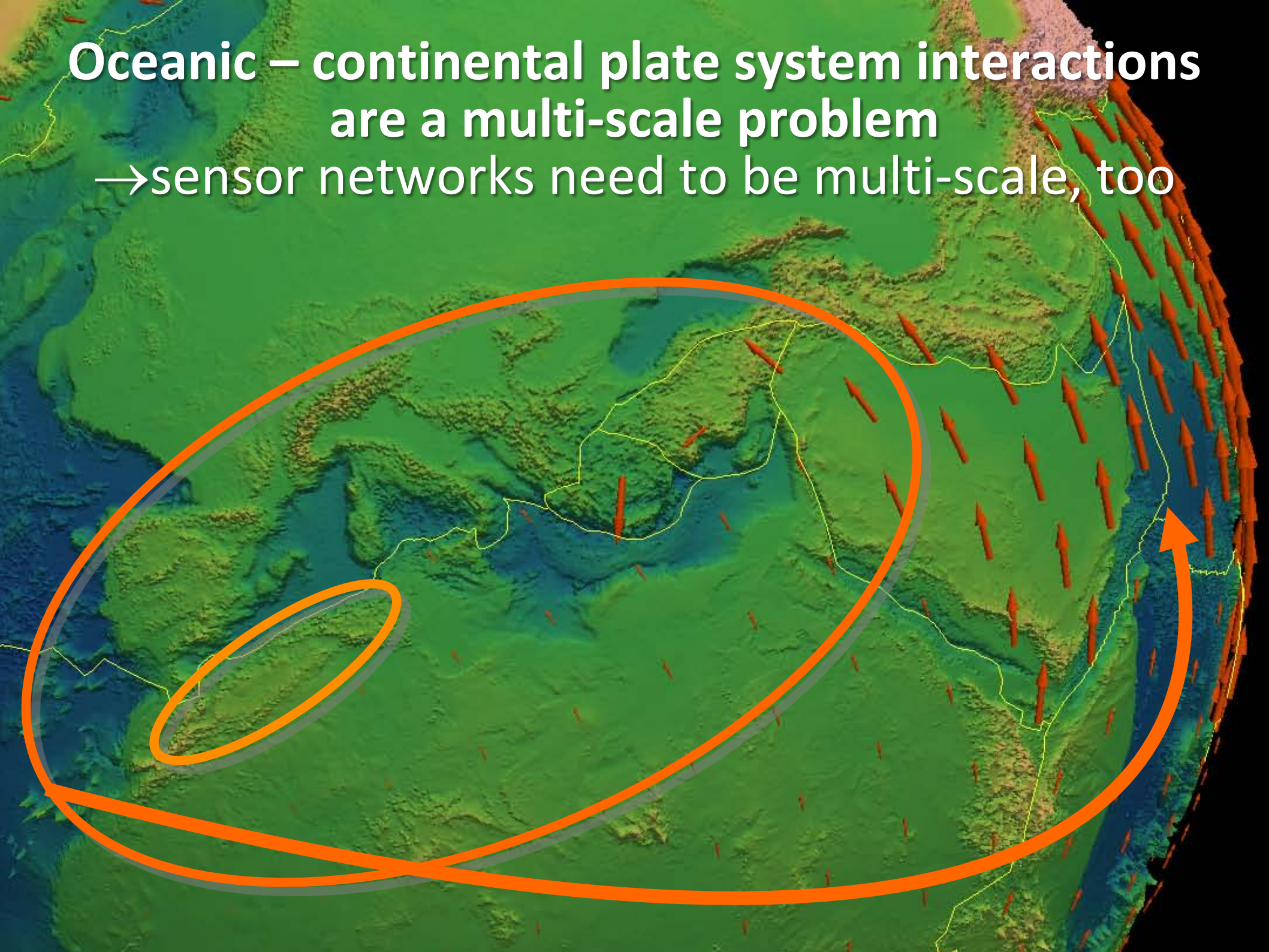
Pulvinetti et al. (2014)

Moving forward:

Joint sensor networks (seismic, MT, GPS, …) and inversions



Slide courtesy of Rob Evans

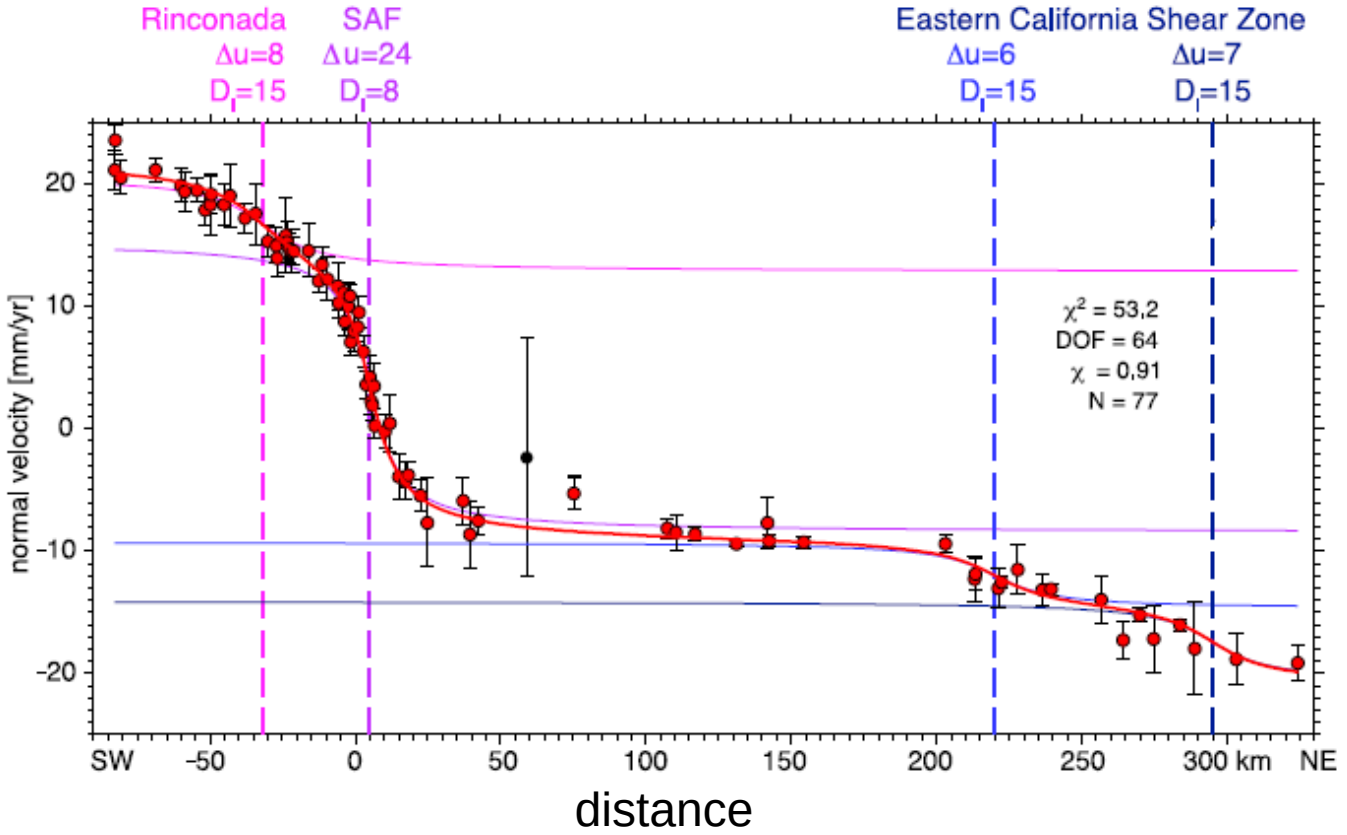

Oceanic – continental plate system interactions
are a multi-scale problem
→sensor networks need to be multi-scale, too

Moving forward:

Densification (more data is always better...)

- GPS, InSAR and dense seismology across faults
- Intermediate-period seismometer deployments for crustal structure (passive-active)
- ...

Carrizo plane GPS profile



Moving forward:

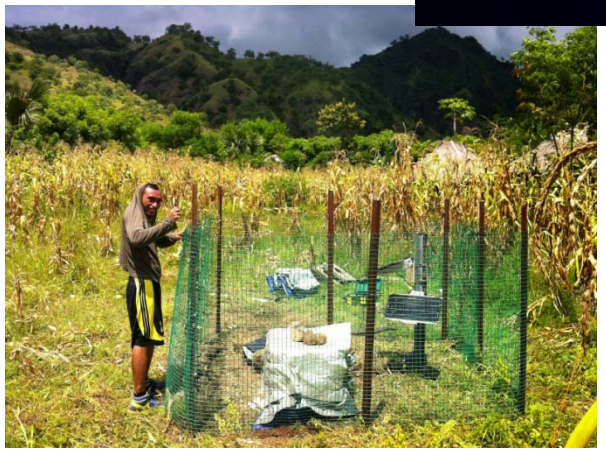
Community models

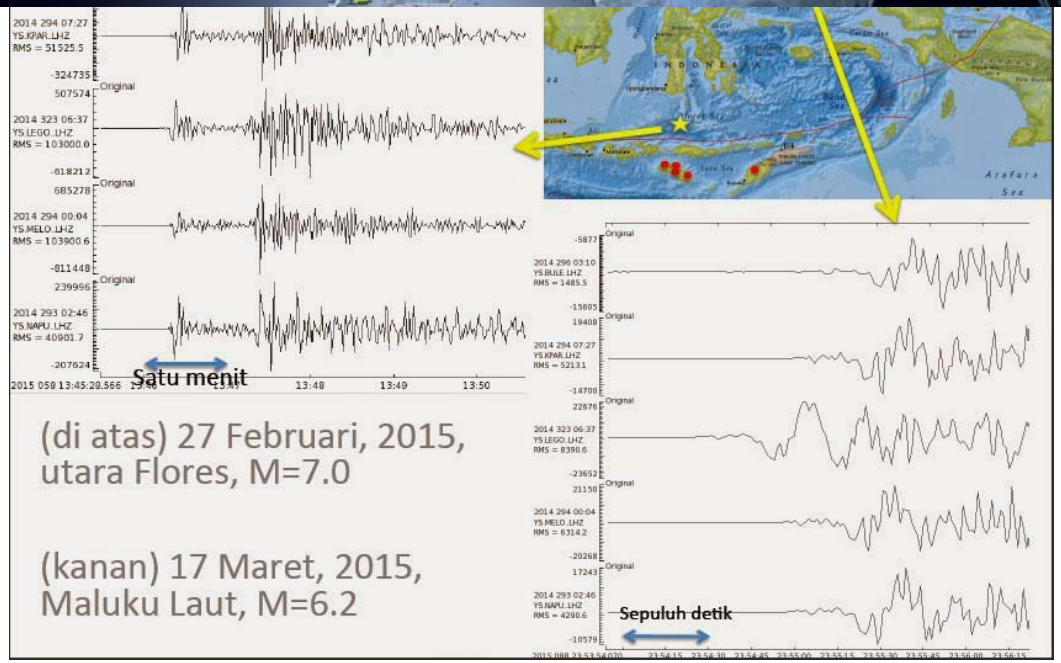
- Flavors:
  - Crustal velocity and strain-rate model
  - Crustal structure model
  - Lithospheric model
  - Mantle model
  - Rheology model
- Error bars! (...)
- Geodynamic models
  - Even if micro-scale is poorly constrained, utility in integration
  - The path is more important than the goal (cf. SCEC Community Stress Model)
- Open, collaborative data sharing
- Open, collaborative method sharing
- Reproducible and entirely published workflows

Moving forward:

Synthetic data libraries for hypothesis testing

shakemovie.princeton.edu





(di atas) 27 Februari, 2015, utara Flores, M=7.0

(kanan) 17 Maret, 2015, Maluku Laut, M=6.2

Moving forward:

A community computing facility

- Problems:
  - Solid Earth may be falling behind when it comes to high performance computing
  - Our scientific problems are unique (mixed determined, data gaps, assimilation challenges,...) and require different flavors of methods, making knowledge transfer from other fields tricky
  - Access to resources is a concern for many
- Solution?
  - Dedicated solid Earth machine or allocation
  - Driven by science community
    - Rally around *solid Earth* grand challenge questions

Moving forward:

People

- interdisciplinary community building
- interdisciplinary education
- addressing method gaps
- facilitation of collaboration