

Advantages and Challenges of Increasing Complexity in Geodynamic Modeling

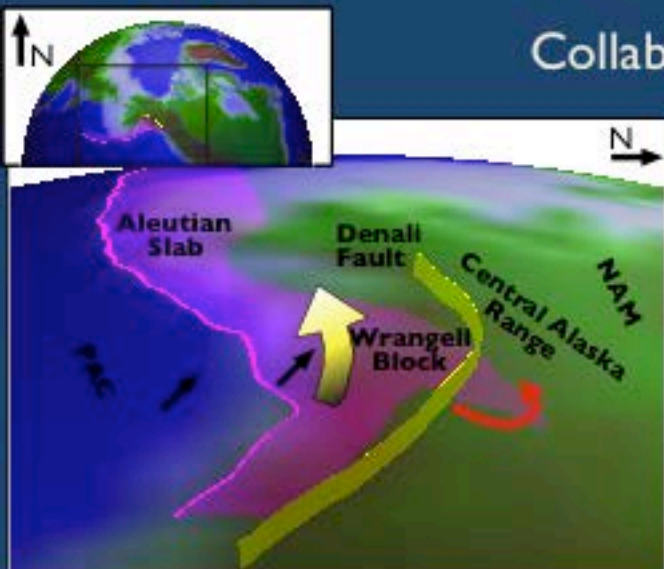
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Karen Fischer, Burak Yikilmaz, Lynn Jadamec

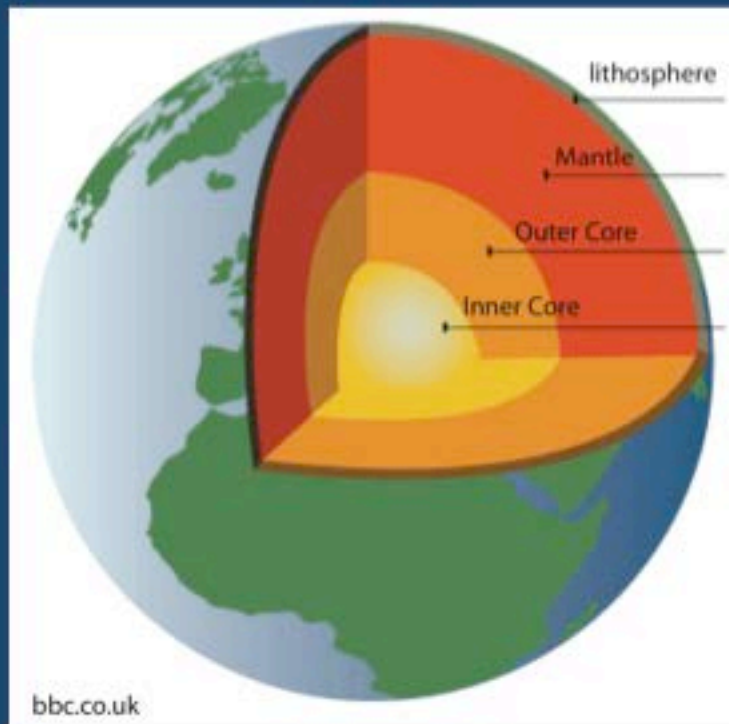
Resources: NSF, XSEDE, TACC, KeckCAVES



Outline

- Scientific Results from 3D Plate Model
- Computation and Model Runtime
- Data Incorporation and 3D Visualization
- Broader Impacts

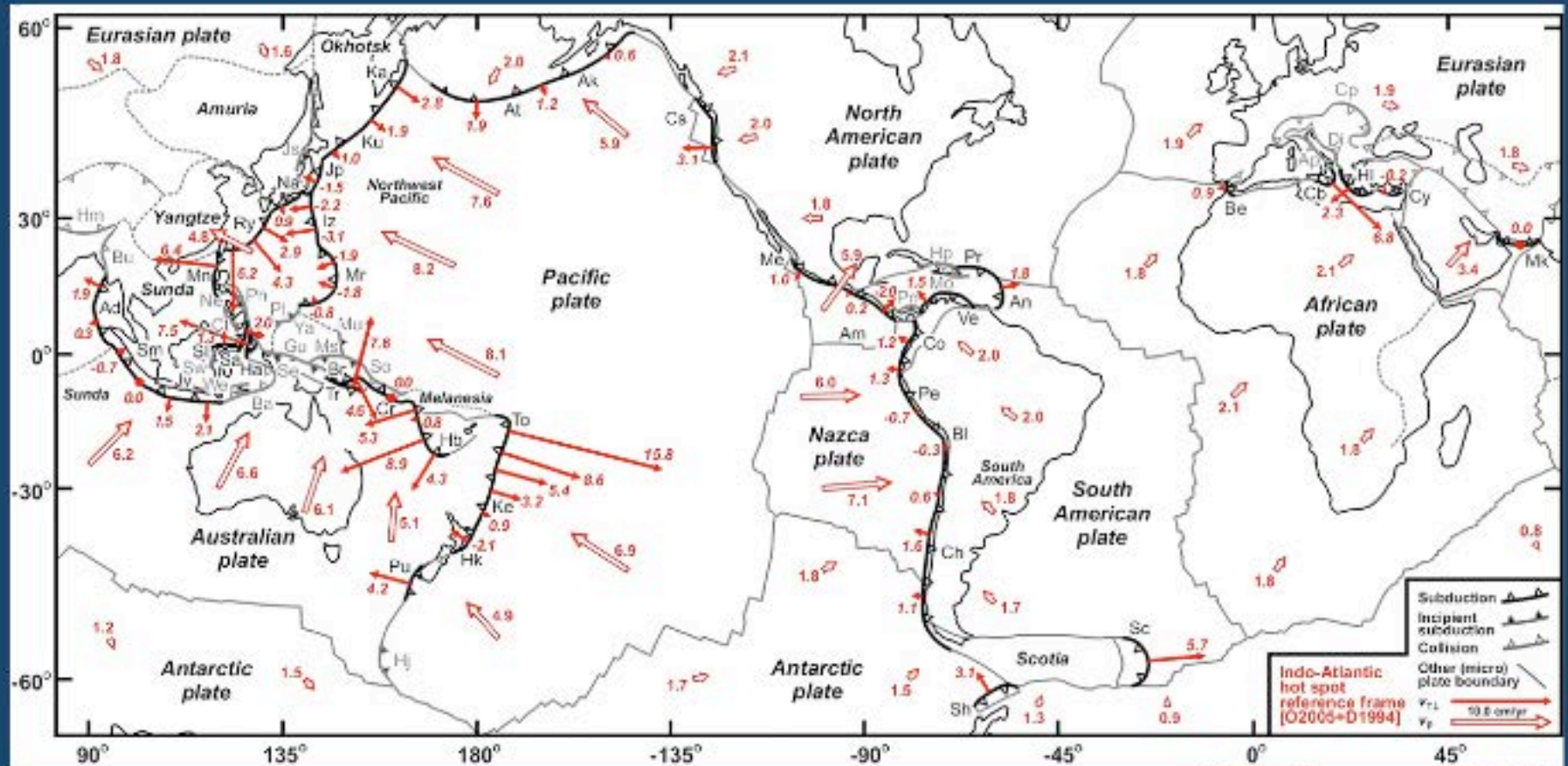
Model Earth as a Viscous Flow Problem



Viscosity of Lithosphere and Mantle range 10^{17} to 10^{24} Pa s
Typically Newtonian viscosity (decreasing viscosity with increasing temp)
Leads to decreases in viscosity with depth but laterally constant values
Solve Stokes or Navier-Stokes equations for the velocity and pressure

(Kohlstedt et al. 1995; Hirth and Kohlstedt, 2003; Turcotte and Schubert, 2002)

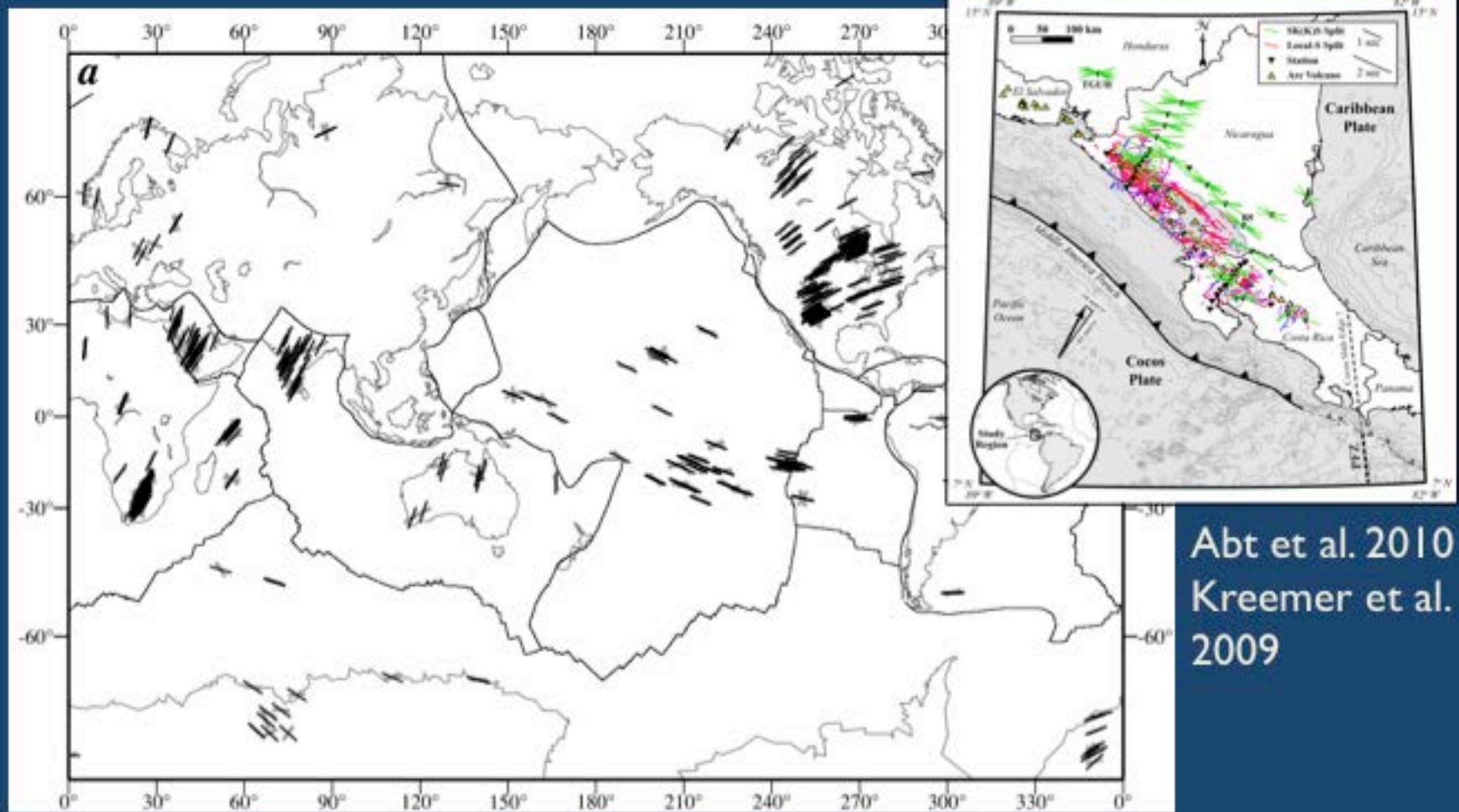
Observe Surface Plate Velocity (1-15 cm/yr)



Schellart et al. 2008

Lithosphere (outer layer of Earth) ~15 (52) 'Plates' ~150 km thick
Motion of plates on Earth's surface from GPS measurements
(DeMets and Dixon, 1999; Bird 2003; Schellart et al. 2008)

What About Mantle Underneath Plates?

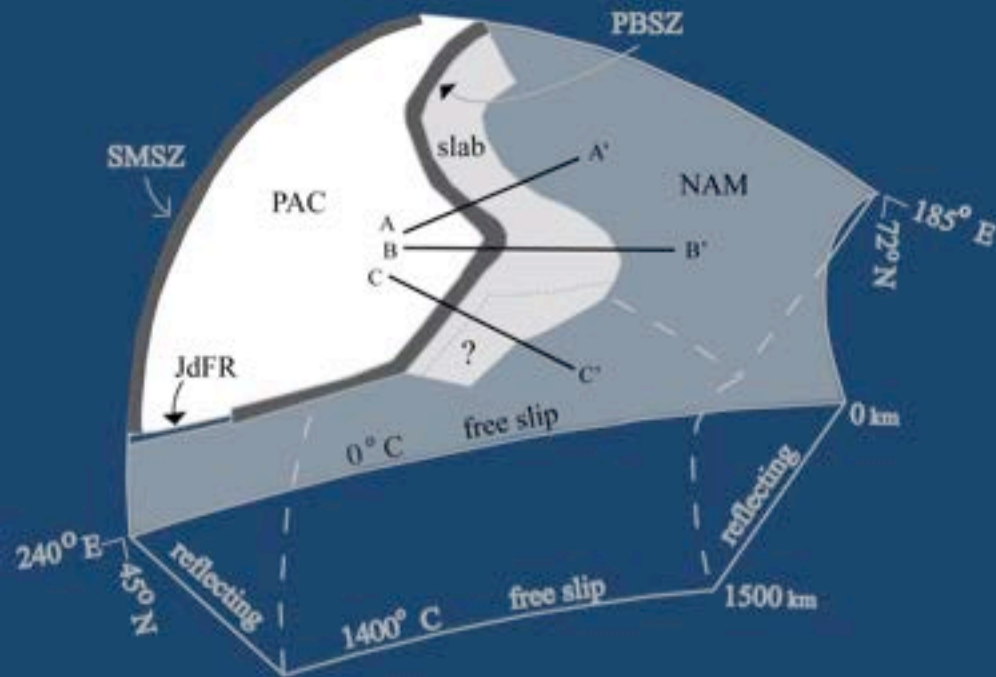


Abt et al. 2010
Kreemer et al.
2009

Infer direction of mantle flow from fast axis of seismic anisotropy
Plates-mantle coupled within oceanic plates but not at boundaries

(Fischer et al. 2000; Becker et al. 2003; Conrad et al. 2007; Karato et al. 2008; Long and Silver, 2009)

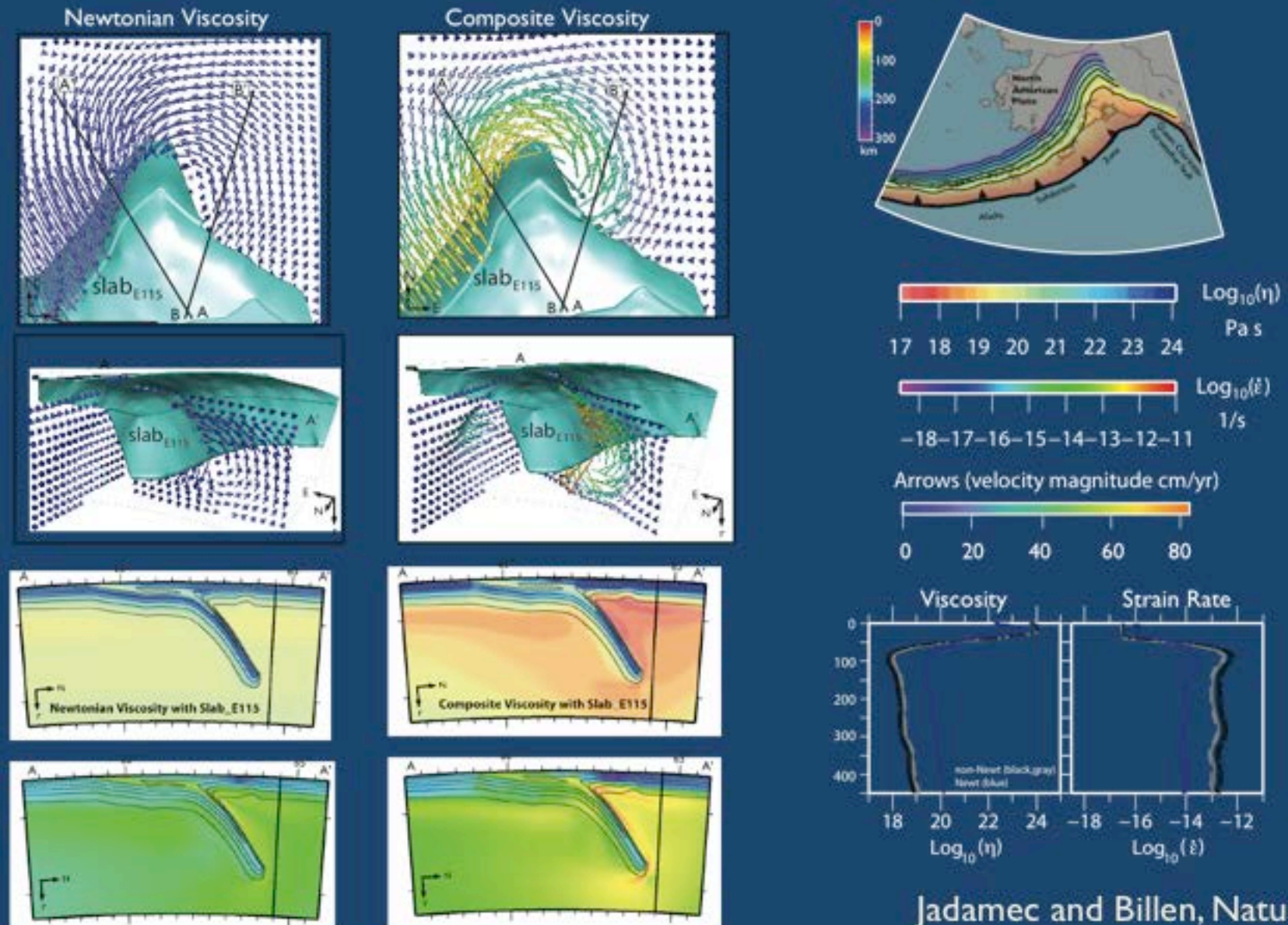
3D Geodynamic Model of Subduction Zone



Viscous Flow FEM Model

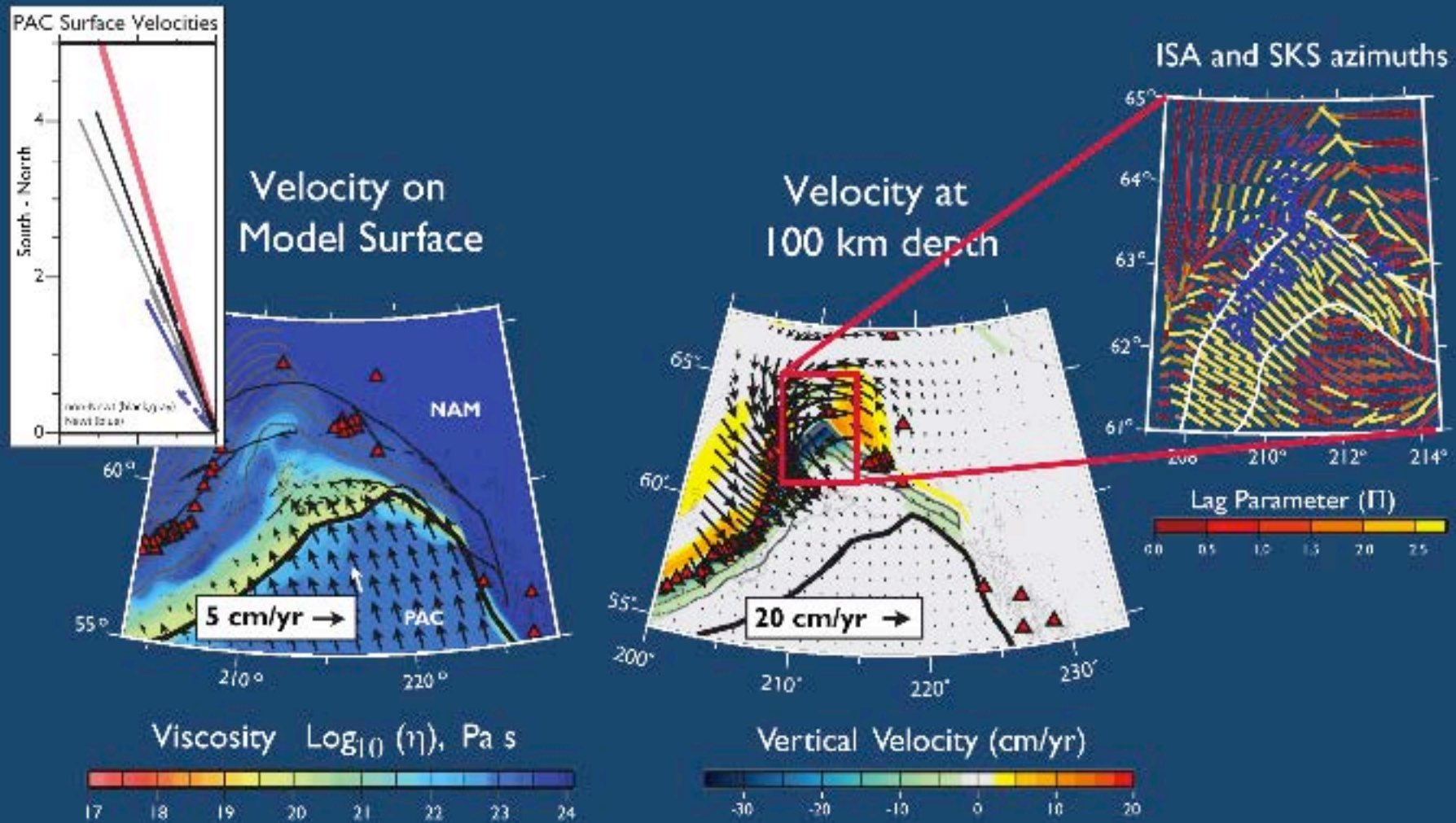
- CitcomCU (Moresi and Solomotov, 1995; Zhong, 2006)
- Solves Stokes Equations
- Use Composite Viscosity (Newtonian, Non-Newtonian with stress exponent 3.5 rock deformation experiments)
- 100,000,000 nodes
- 2.35 – 20 km resolution
- 17,000 Compute Hours/Job
- Ran on XSEDE (TACC)

Models Predict Low Viscosity and Rapid Flow



Jadamec and Billen, Nature 2010
Jadamec and Billen, JGR 2012

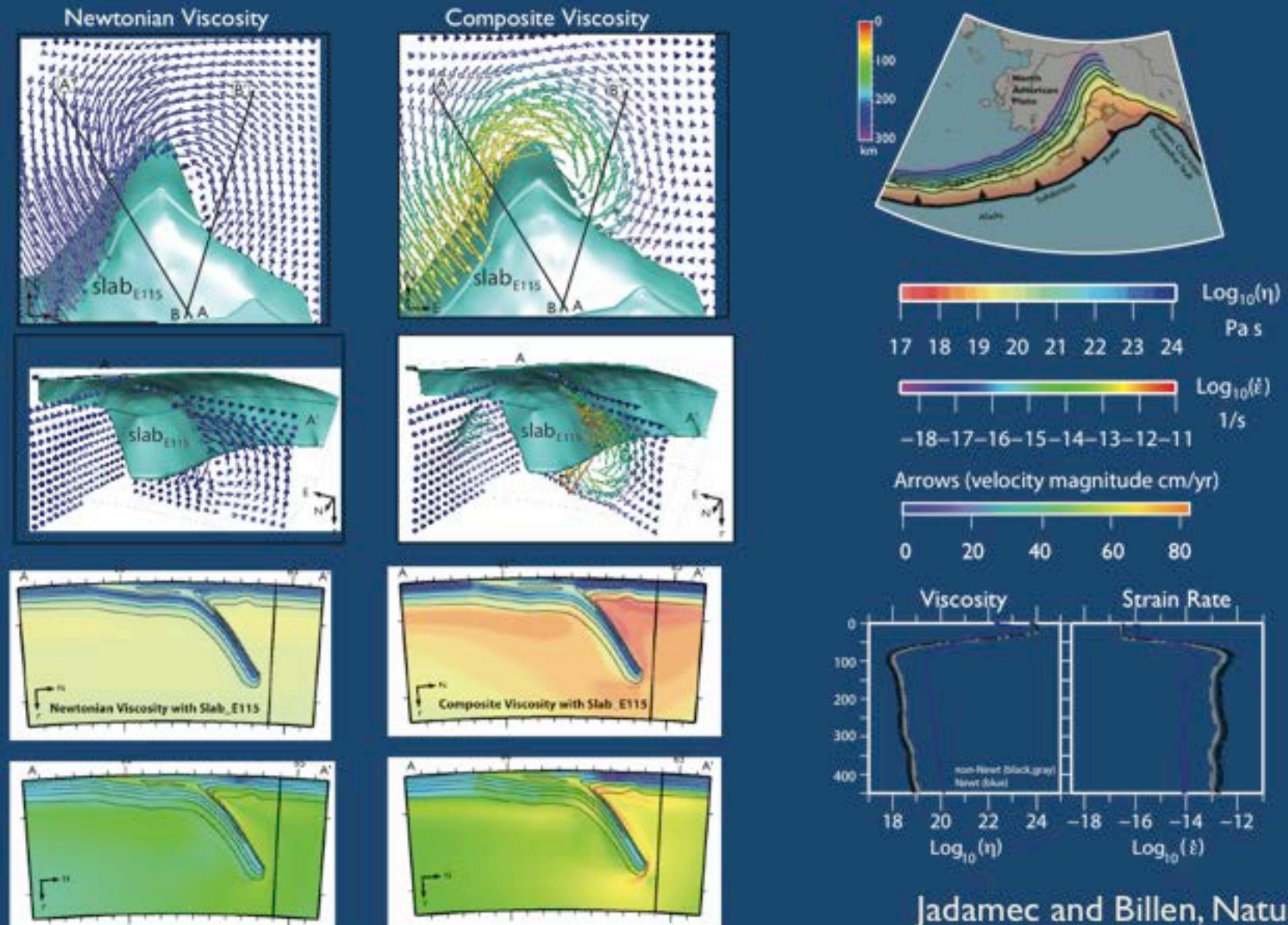
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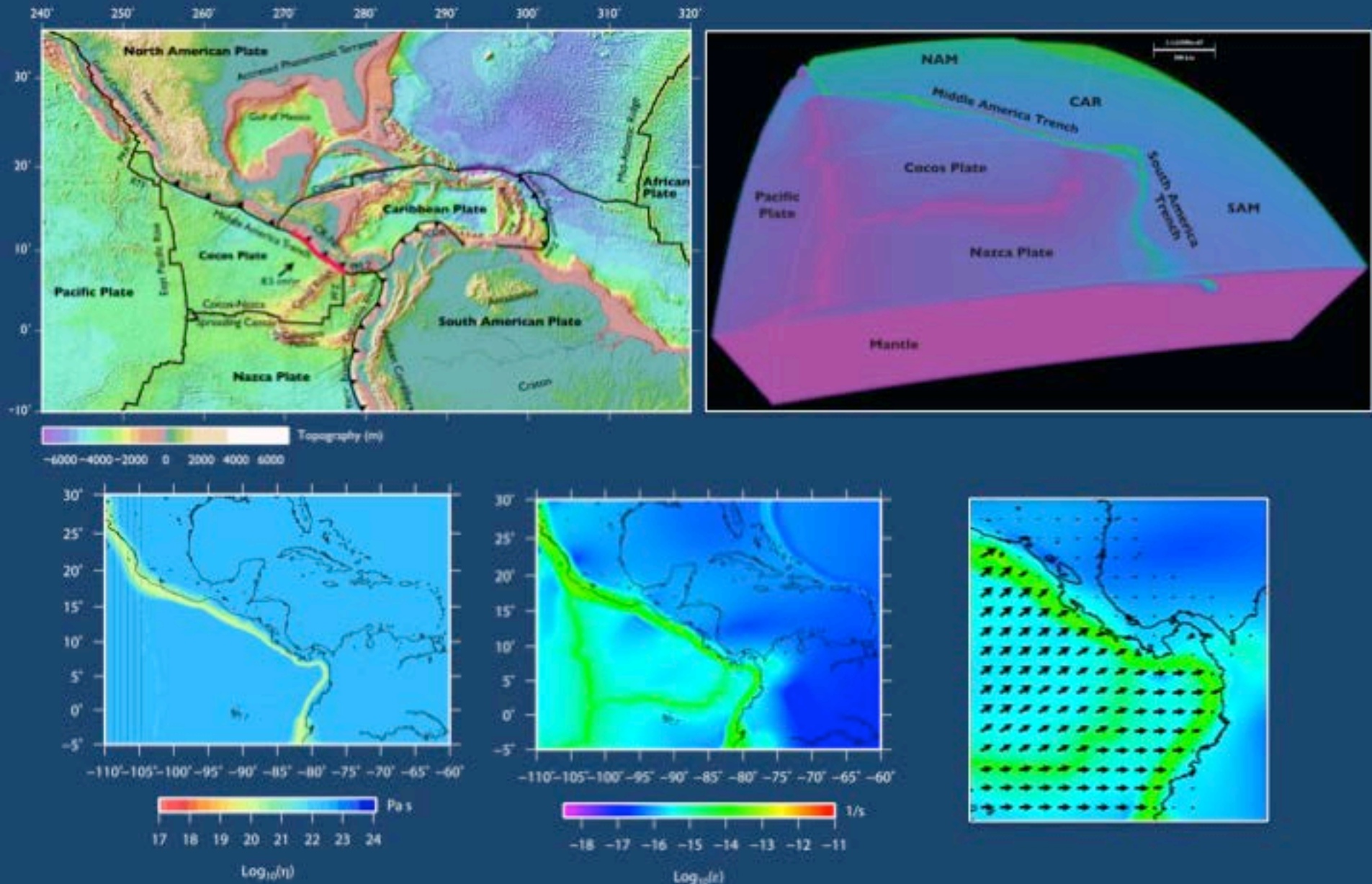
Plate Motion Constraints-DeMets and Dixon, 1999; SKS Constraints-Christensen and Abers 2010

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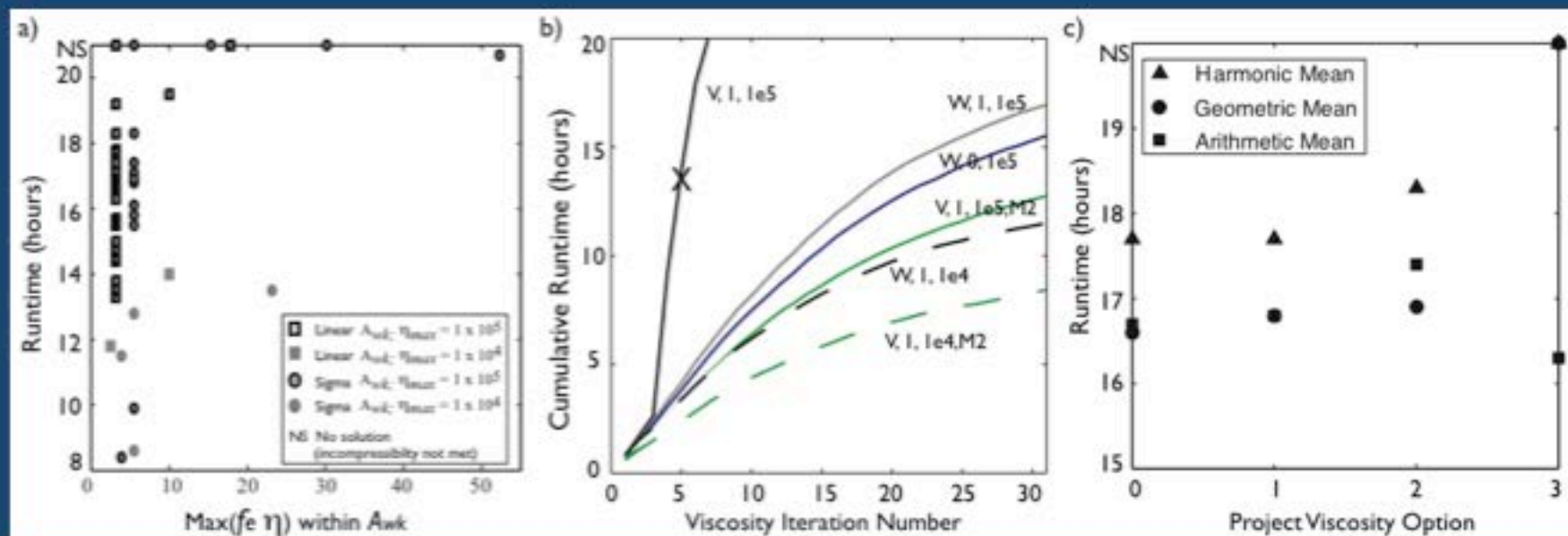
Test For Rapid Flow in Cocos-Nazca System



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Computation and Model Runtime



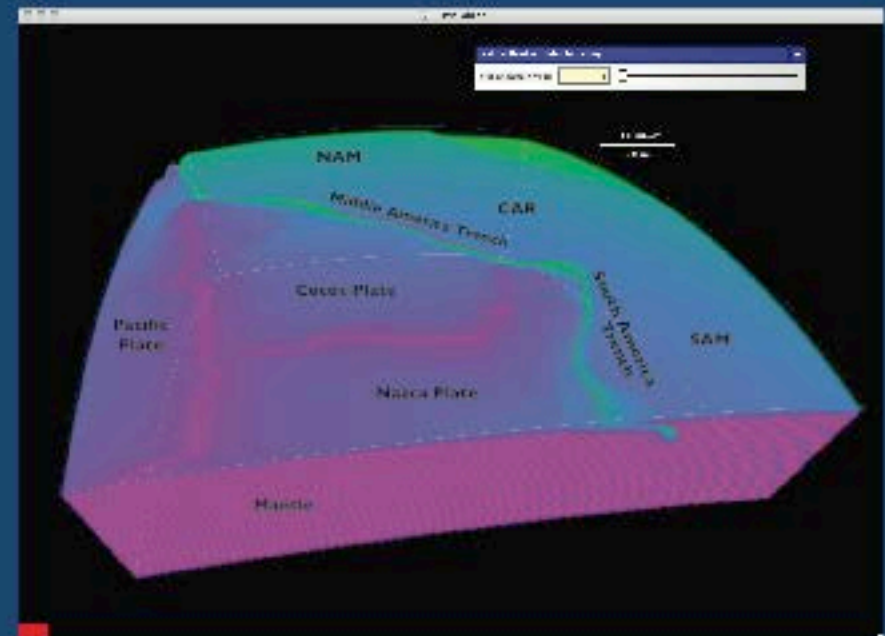
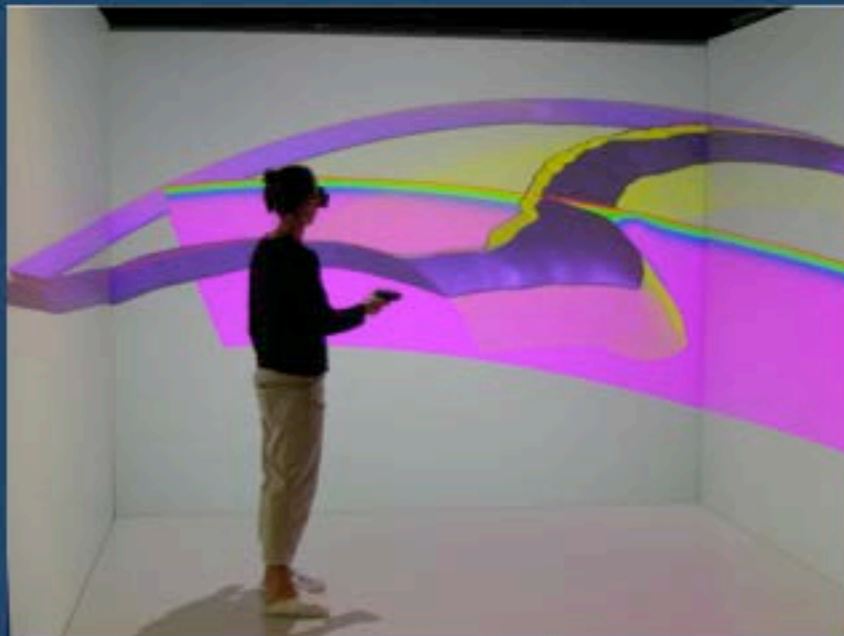
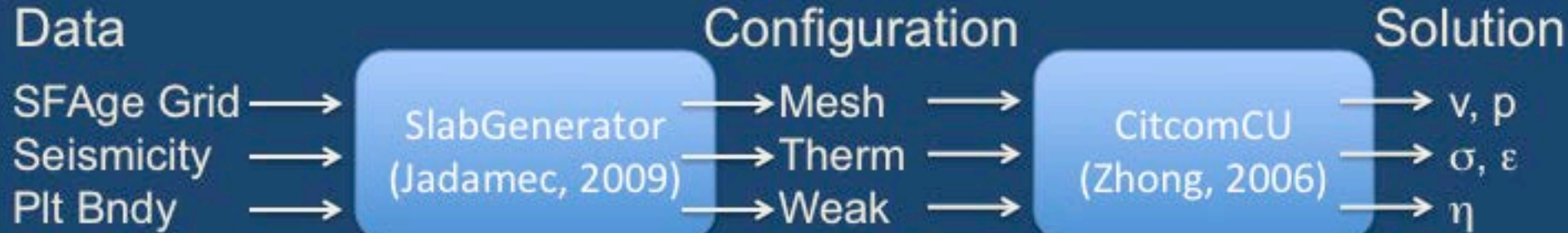
Large viscosity variations in Earth challenge for geodynamics codes (Moresi and Solomotov, 1995; Tackley, 1996; May and Moresi, 2008; Burstedde et al. 2009)

Choice of multigrid and solver parameters reduce runtime by 30%
Significant because can determine whether you can obtain a solution and, if so, whether you have the (compute) time to solve it (Jadamec et al. ACM XSEDE 2012)

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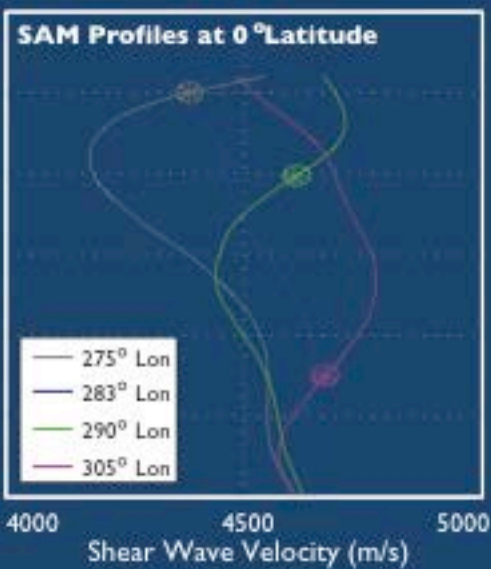
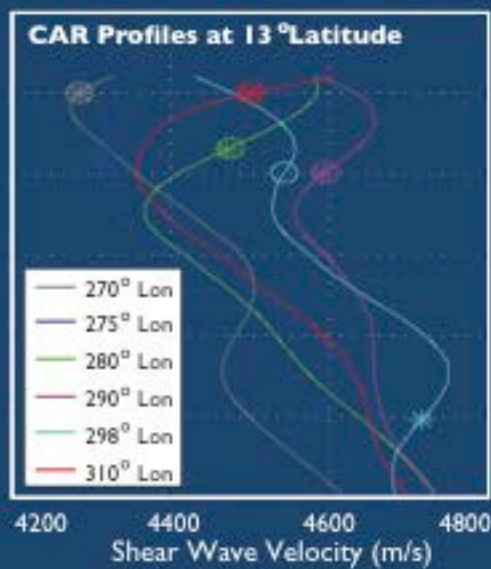
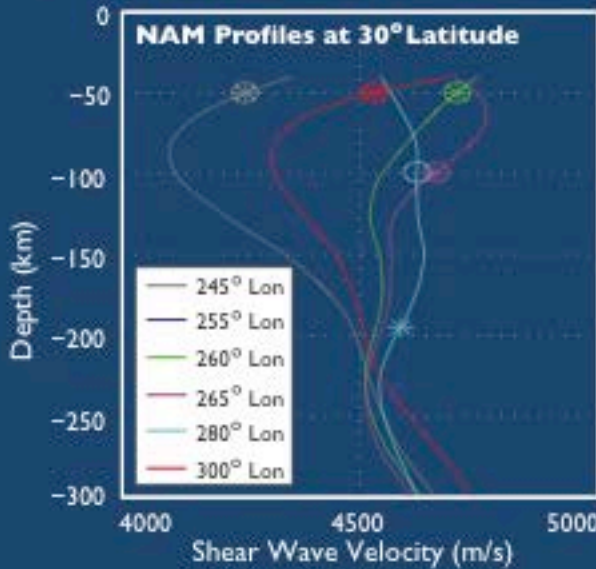
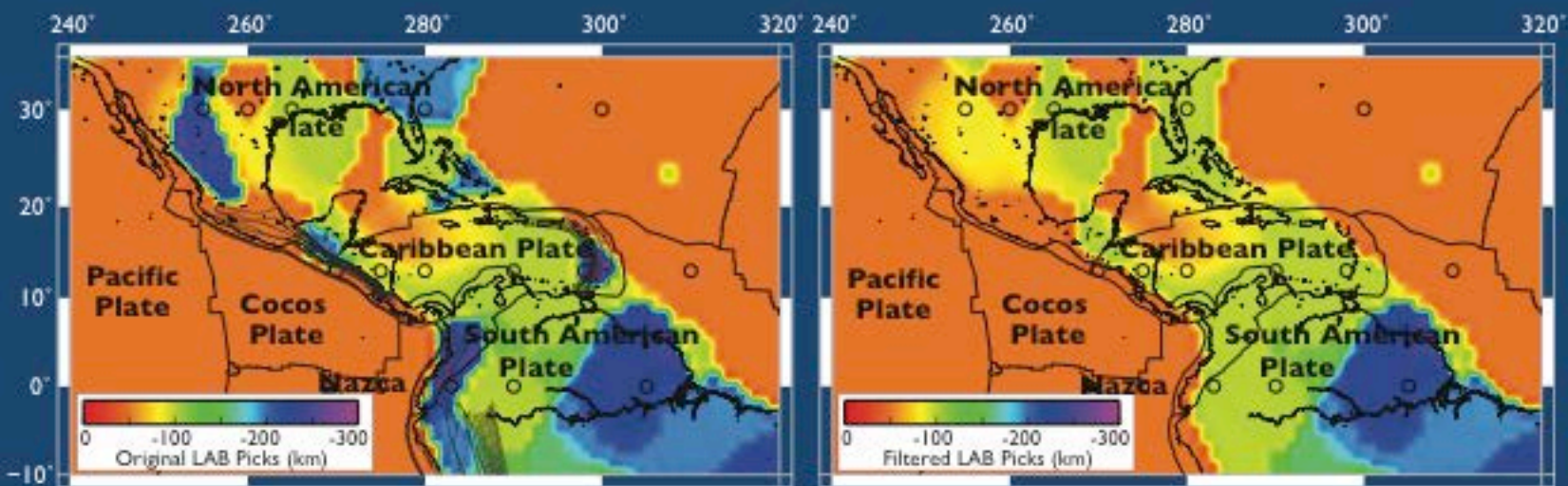
Construction and Visualization of 3D Model



Jadamec and Billen, 2010; Jadamec and Billen, 2012; Jadamec et al. 2012

Kreylos et al. 2006; Kellogg et al. 2008; Billen et al. 2008; Vanco et al. 2012

Constraints on Variable Plate Thickness



LAB depth processed from Lekic and Romanowicz, 2011; Plate Boundaries-Bird, 2003; Slab Contours-Syracuse and Abers, 2006; Gudmundsson and Sambridge, 1998

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Living with Plate Boundaries Project

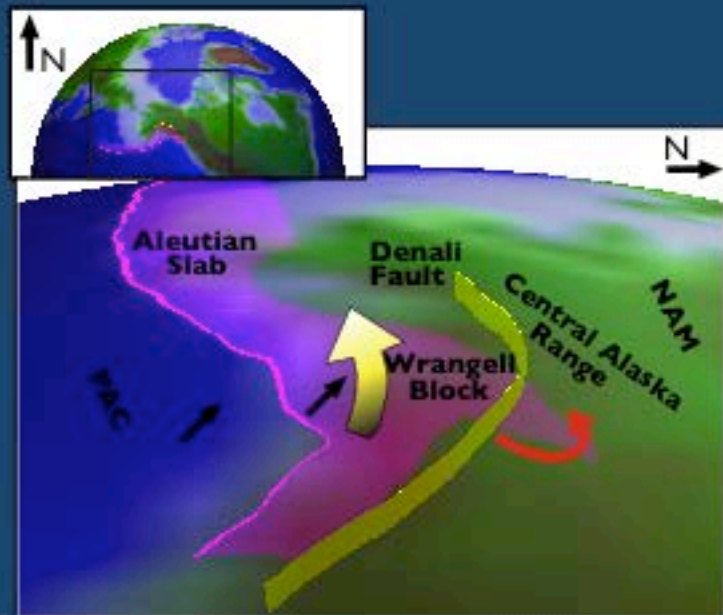


3D Renderings of Plate Boundary Configuration (Geophysics)

Painting Geomorphic Expressions of Tectonic Processes
(Strato-volcano Arenal, Costa Rica, Oil on Canvas by Lynn Jadamec)

Conclusions

- Power law (stress-dependent viscosity) decouples mantle from plates in subduction zones, leading to mantle flow rates over 10X plate motions
- Incorporation of geophysical complexity and large viscosity variations have high computational costs



- Software and Hardware to render spatial complexities and Gigabytes of data
- Bring knowledge back to general public and communicate process behind the hazards (public awareness)