Rwenzori Mountains
Western Branch, 5200m

Plume Dynamics and Surface Uplift

Role of Mantle Flow on Rifting in East Africa

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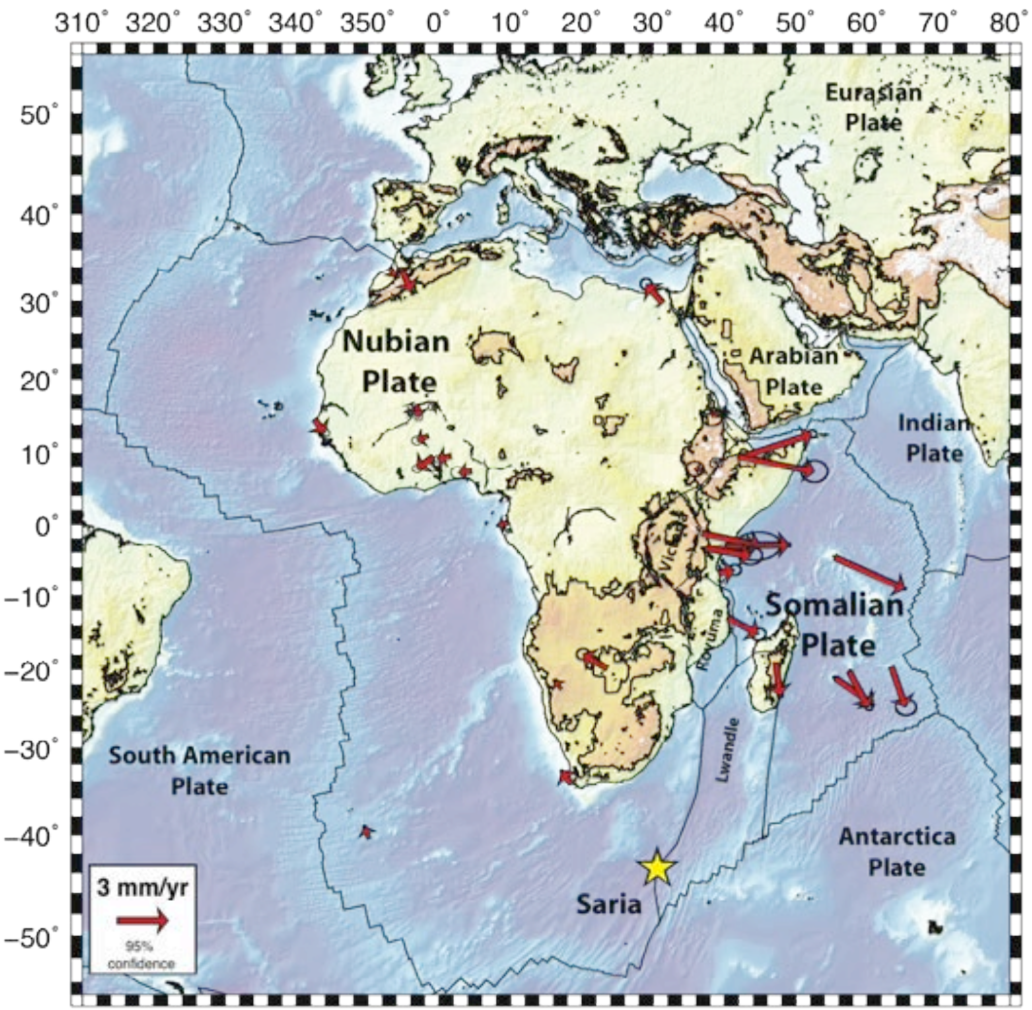
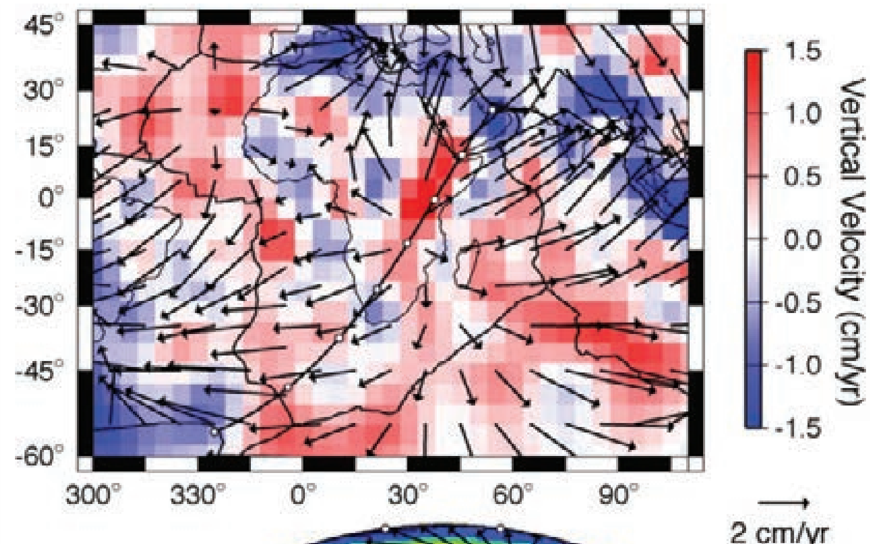
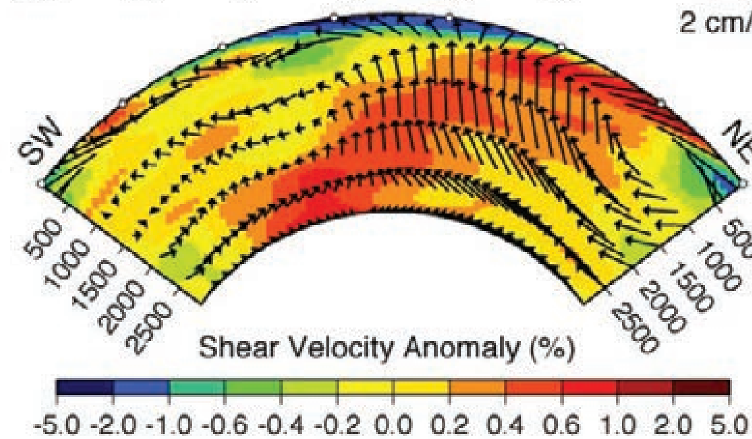
25 October 2012

Dynamics of the East African Rift?



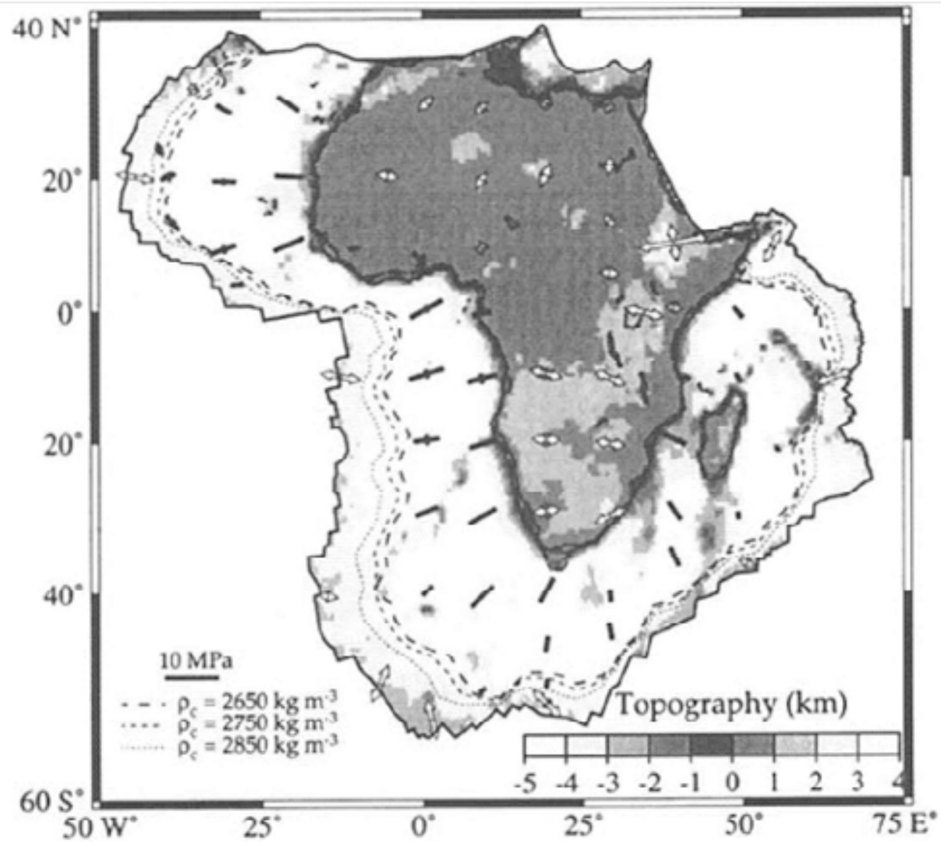
Behn et al, 2004



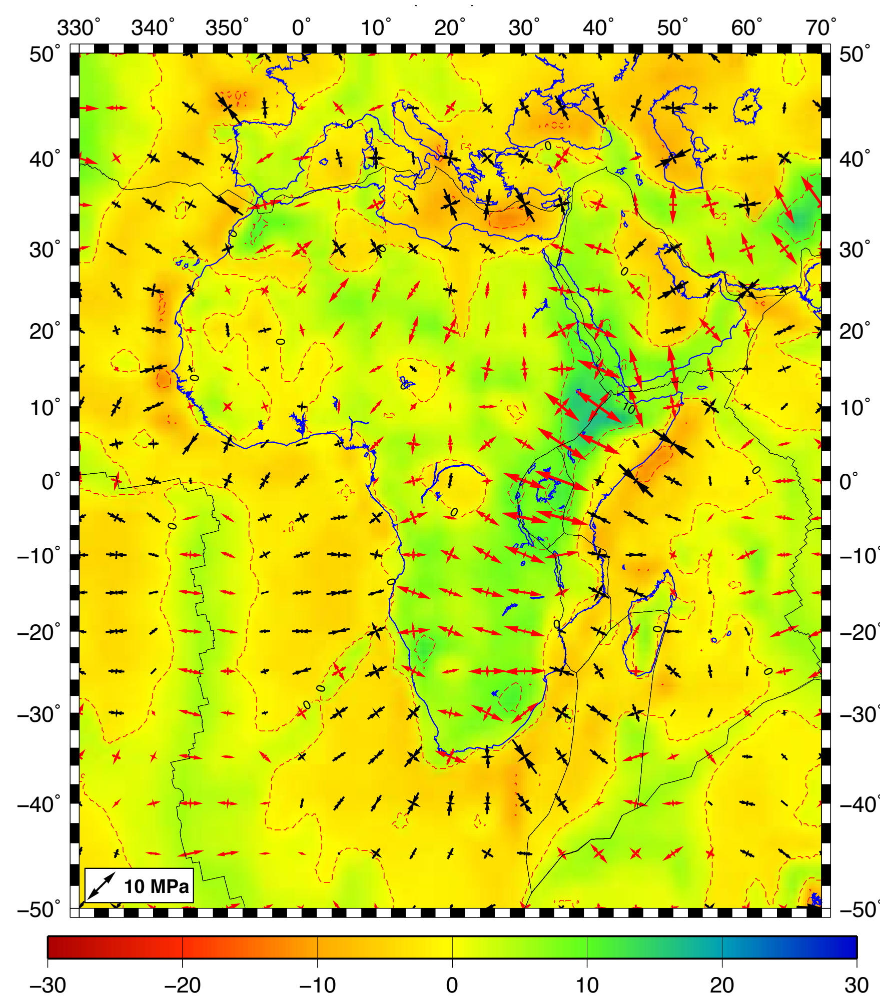


Risema et al, 1999

Dynamics of the East African Rift?



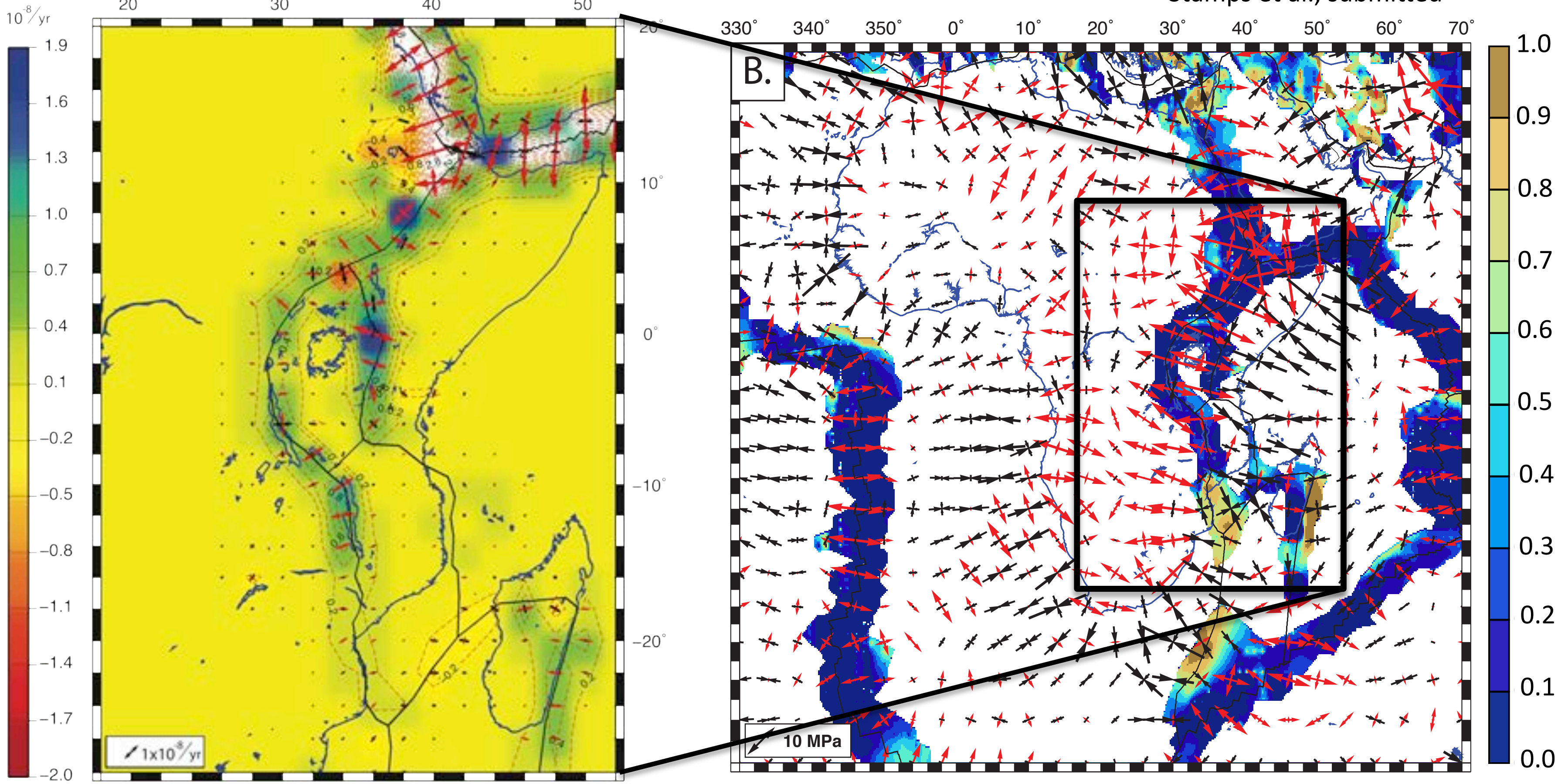
Coblentz and Sandiford, 1994



Stamps et al., 2010

Dynamics of the East African Rift?

Stamps et al., submitted



Strain Rate Field

Dynamic Topography + Basal Shear Stress

The Model

DRIVING EQUATIONS

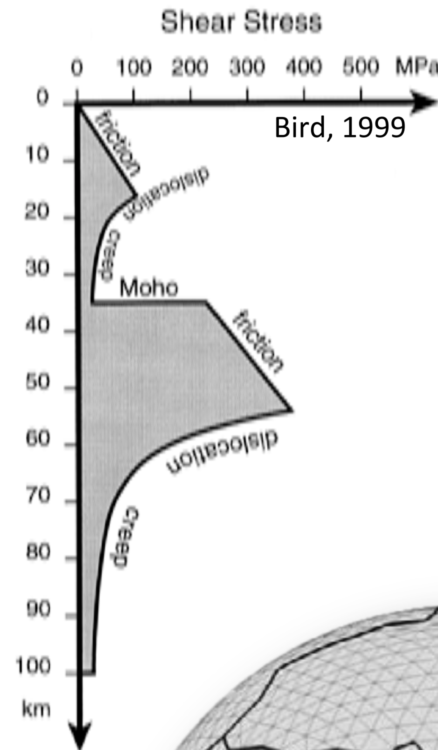
- instantaneous momentum balance

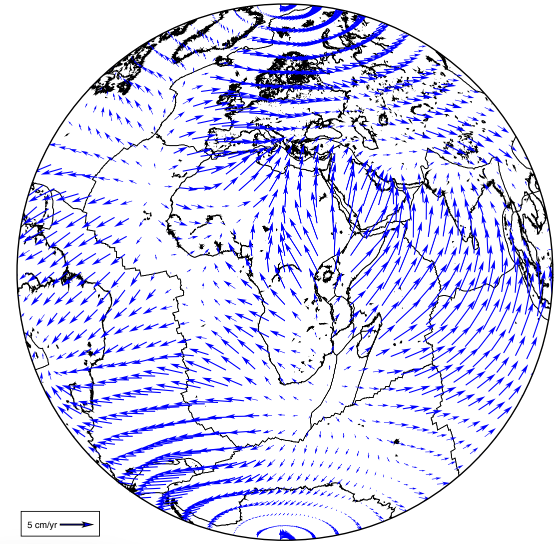
BOUNDARY CONDITIONS

- gravitational potential energy
- mantle flow (several models)
- or no mantle flow

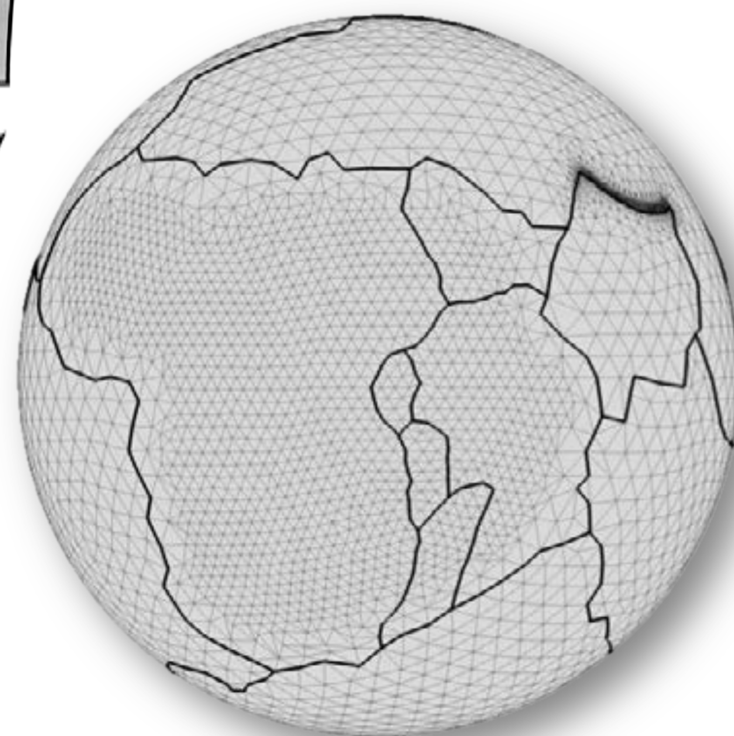
CONSTITUTIVE RELATIONSHIPS

- friction / brittle regimes
- dislocation creep / ductile regimes

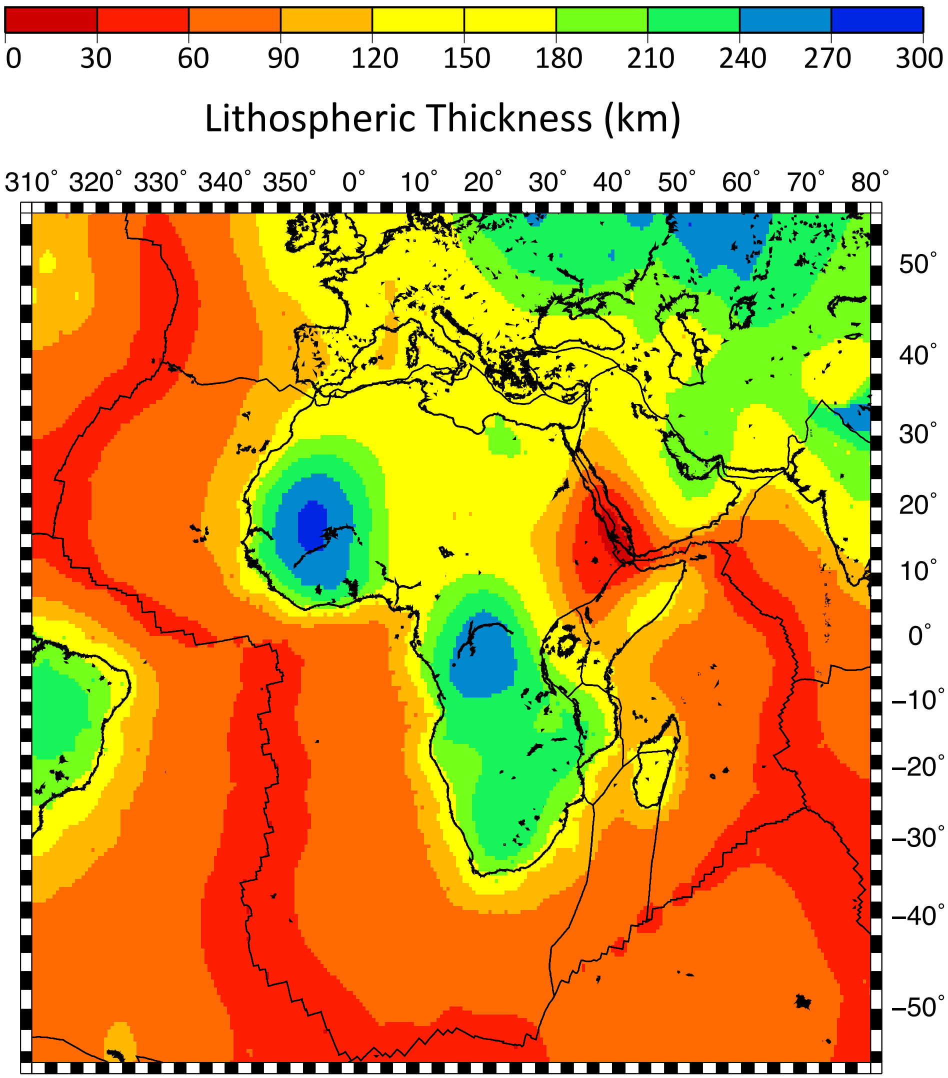




Buiter et al., 2012



The Model



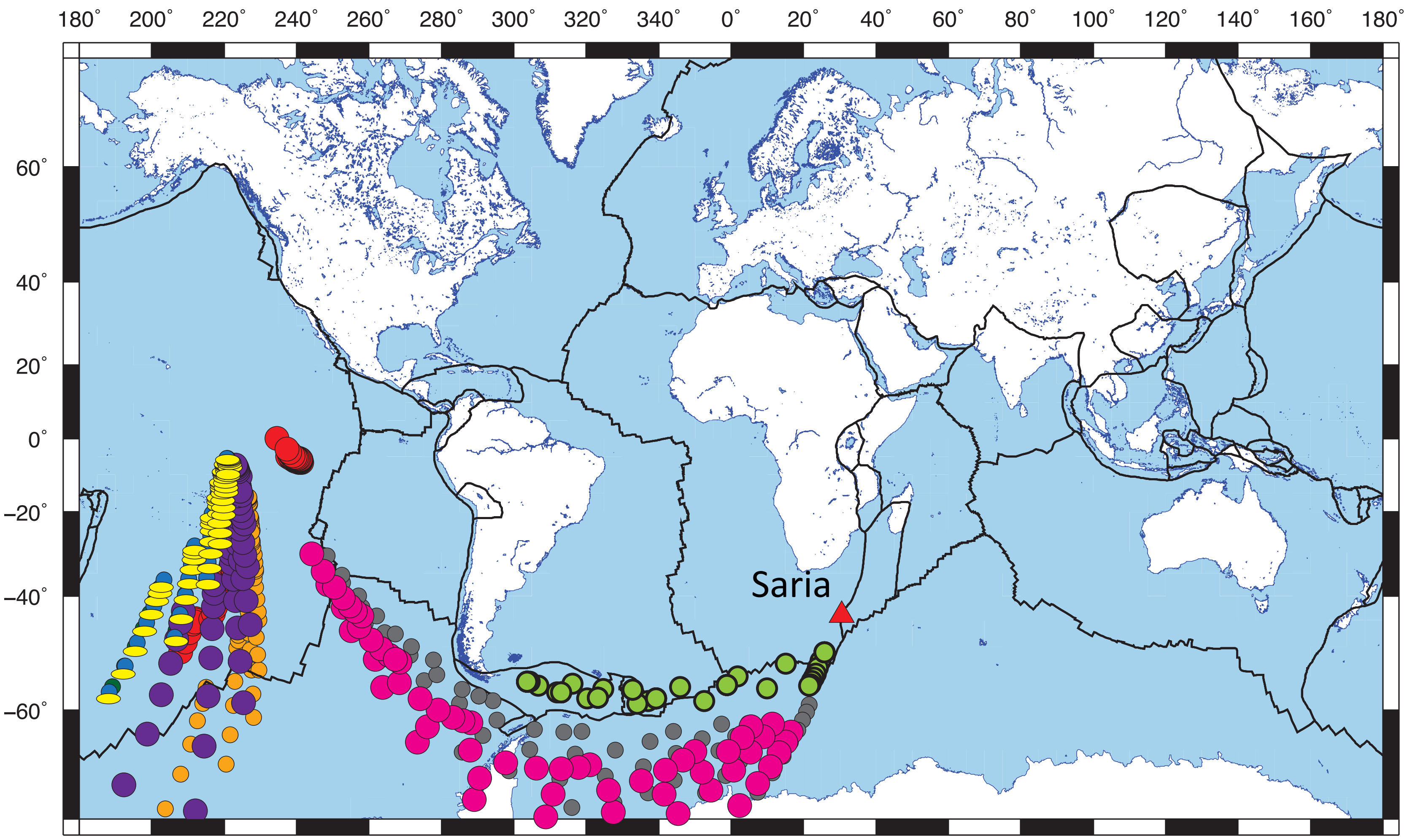
RHEOLOGY

- Brittle and viscous regimes
- Rheological parameters on quartz and olivine constrained by experimental results (Kirby, 1983; Ranalli, 1995)

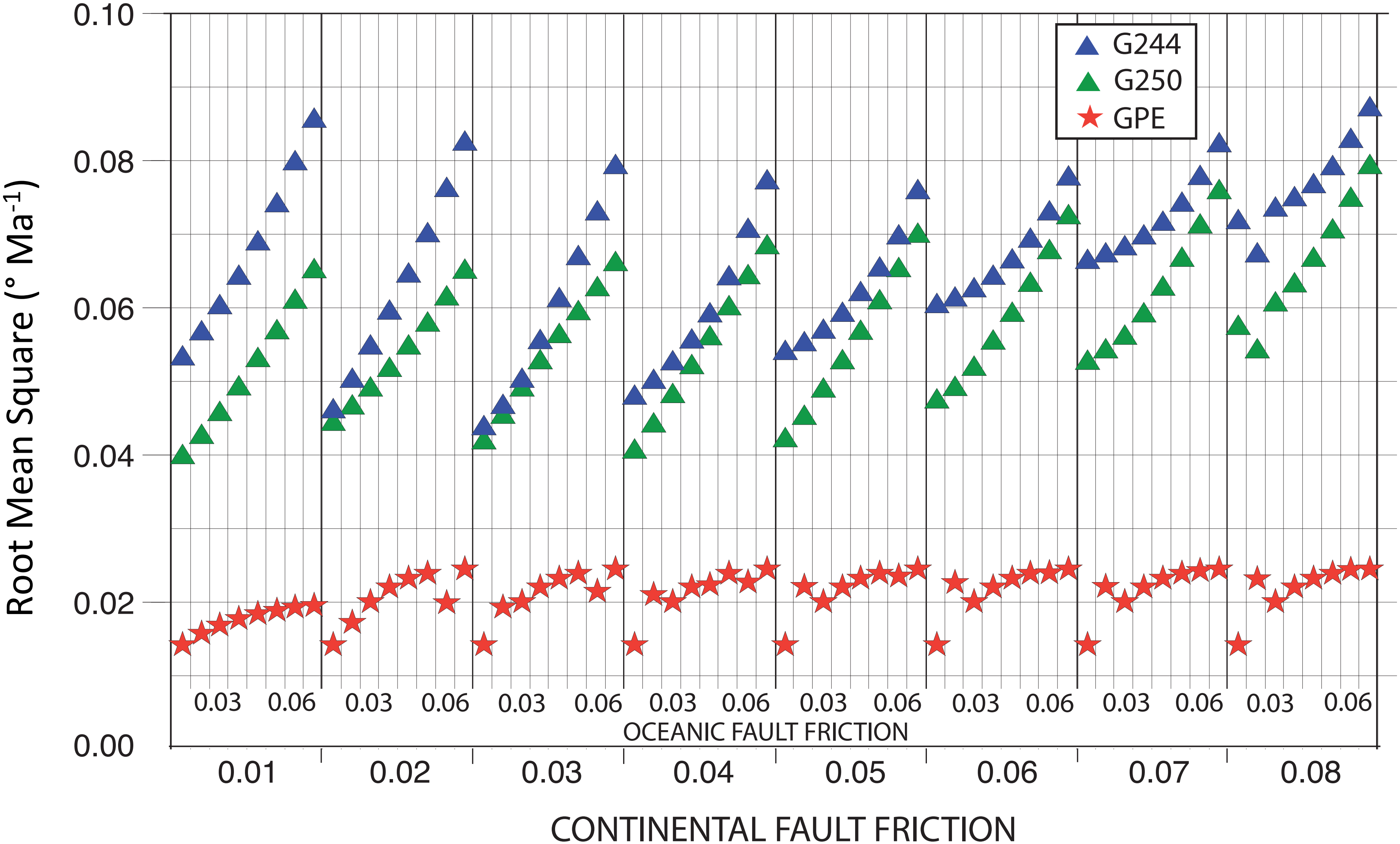
LITHOSPHERE STRUCTURE

- ETOPO5 topography
- CRUST2.0 crustal thickness (Bassin et al., 2002)
- Heat-flow interpolation
- Variable geotherm
- Major cratons are evident

Results: Nubia-Somalia Euler Poles



Results: Root Mean Square



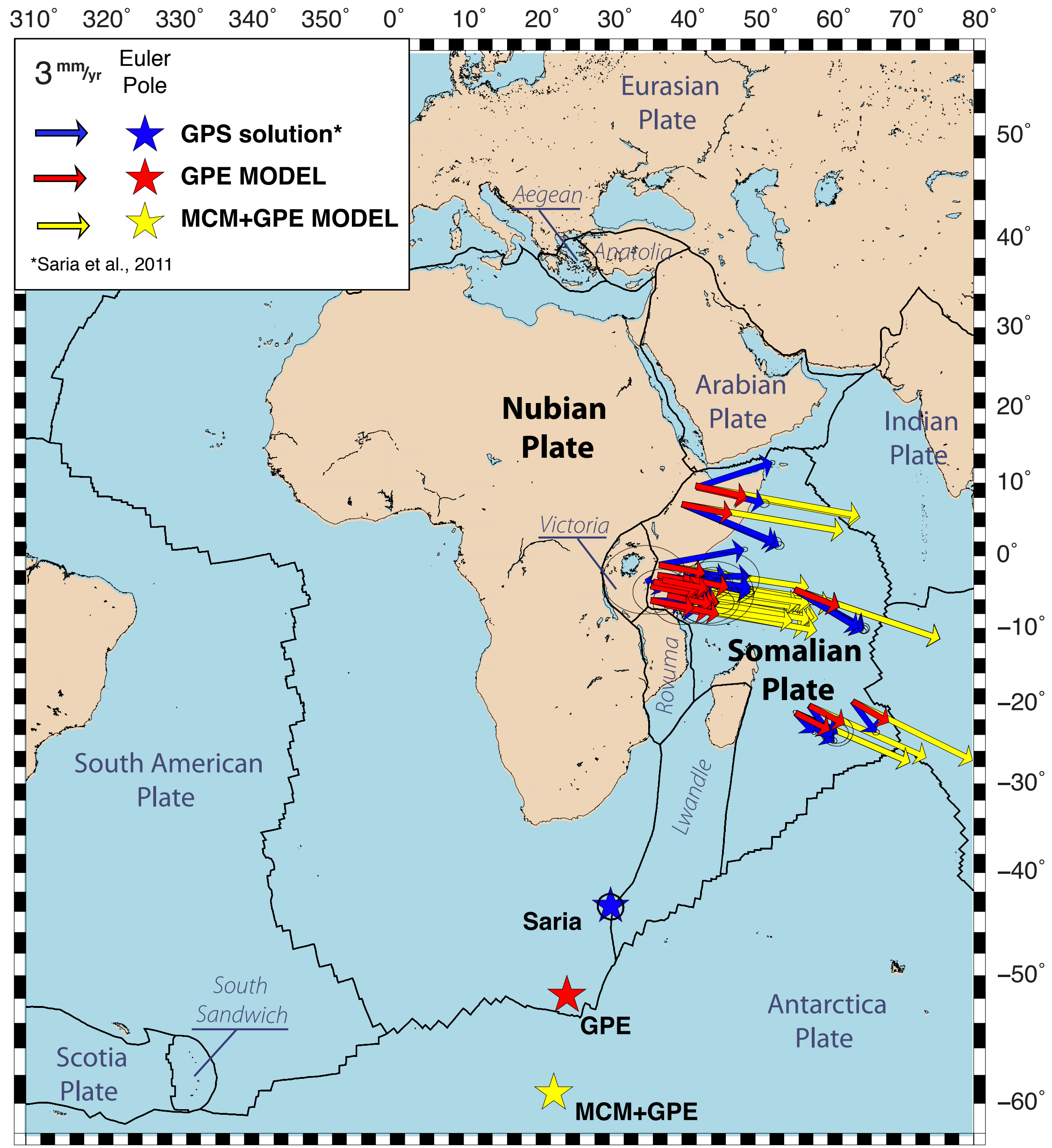
Best Models

GPE

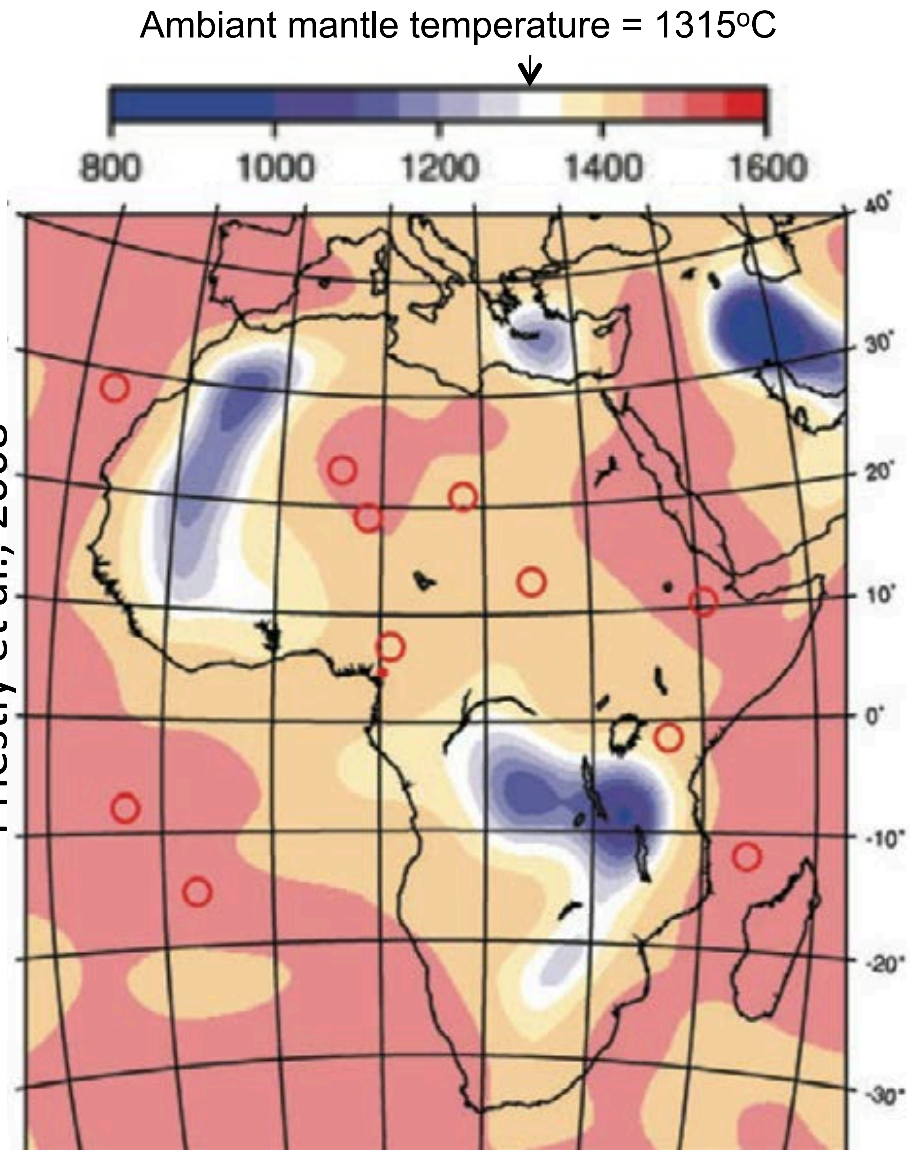
- Mantle resists plate motions
- Mantle flow velocities set to zero
- Basal shear stress = 0.02-0.04 MPa

GPE+MANTLE

- Schuberth et al., 2009
- 250 km depth
- Basal shear stress = 0.04 – 0.08 MPa



Sub-lithospheric decoupling layer?



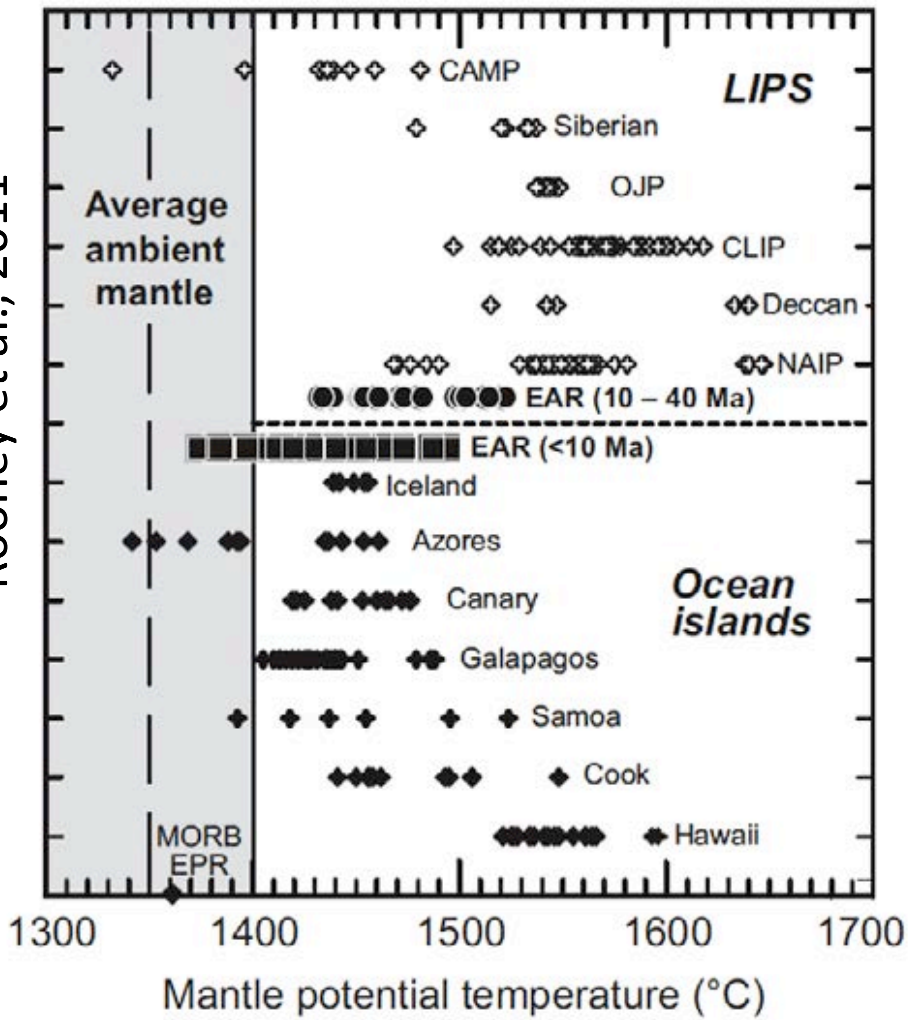
Priestly et al., 2008

175 km

- Priestley et al. (2008):
  "At 175 km depth, most of the African mantle is marginally cooler than the surrounding oceanic mantle"

Sub-lithospheric decoupling layer?

Rooney et al., 2011



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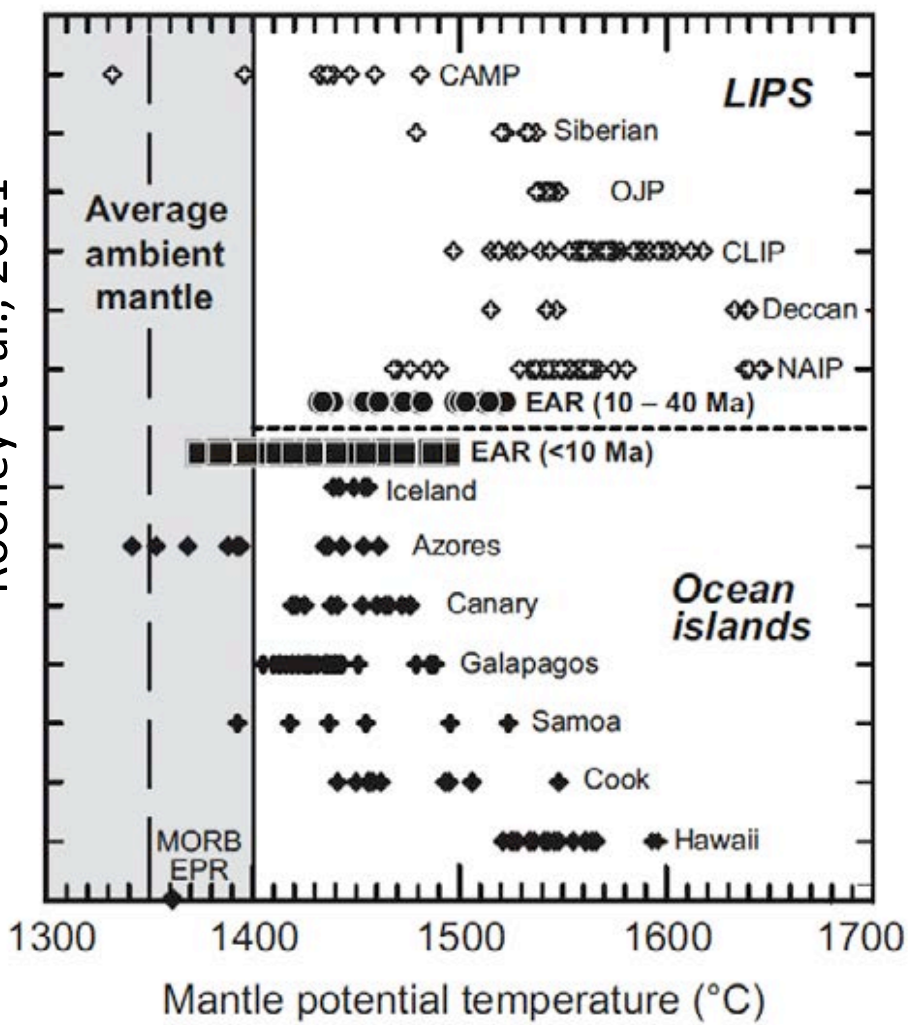

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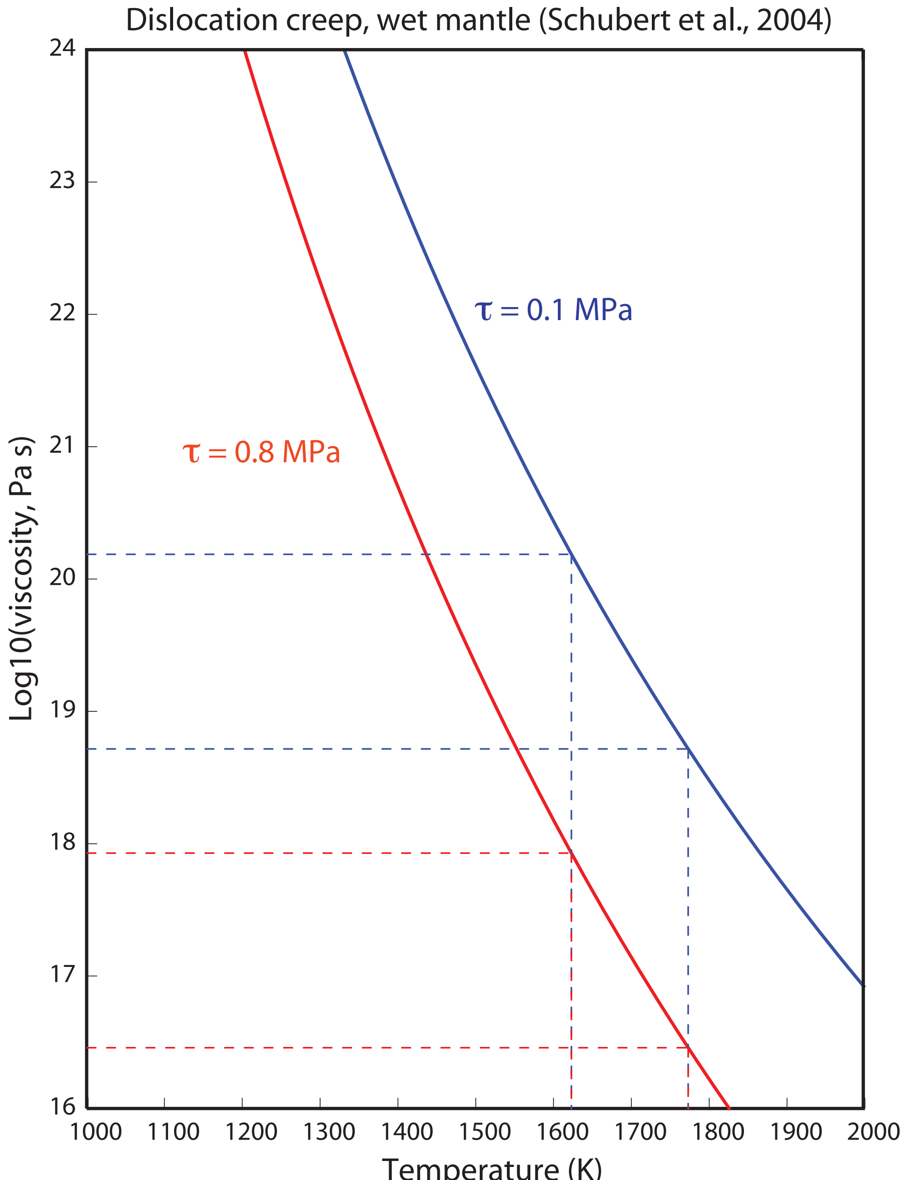

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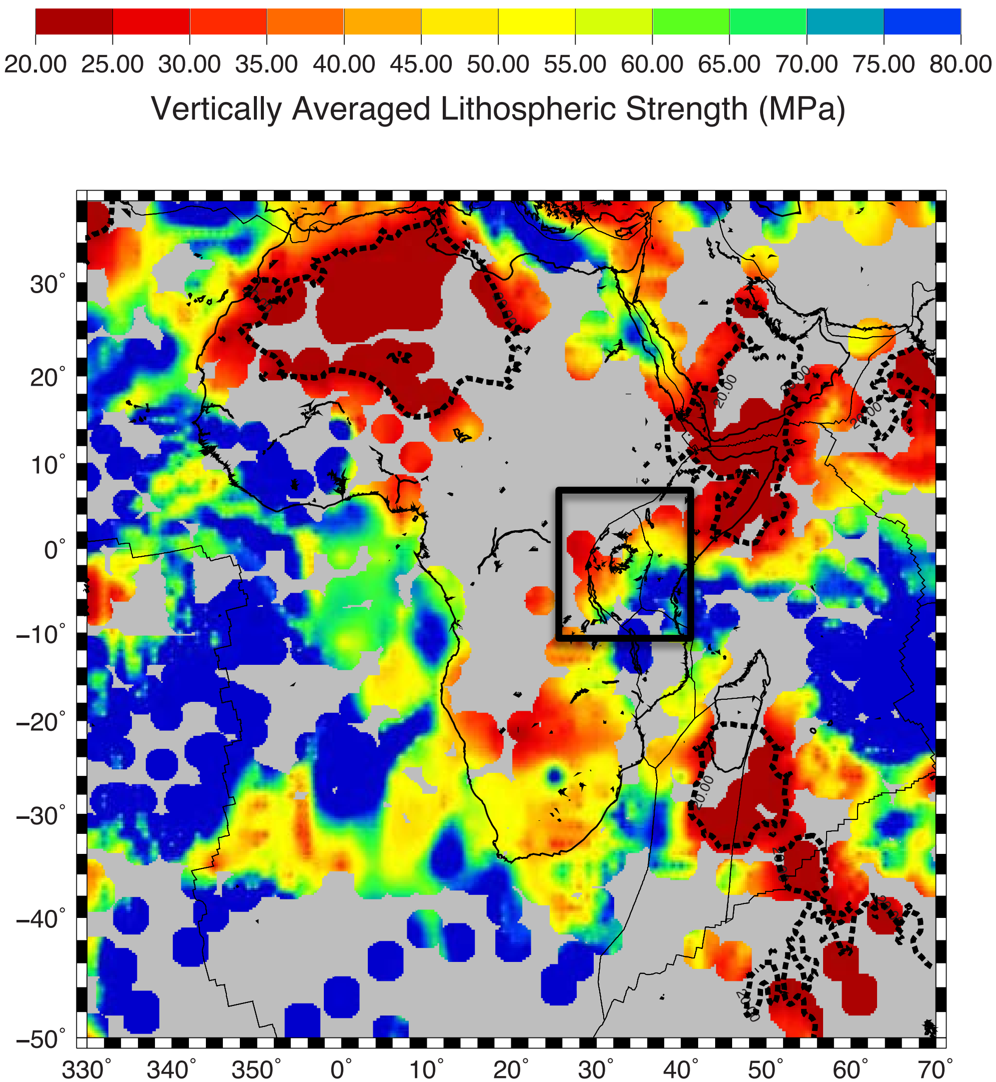
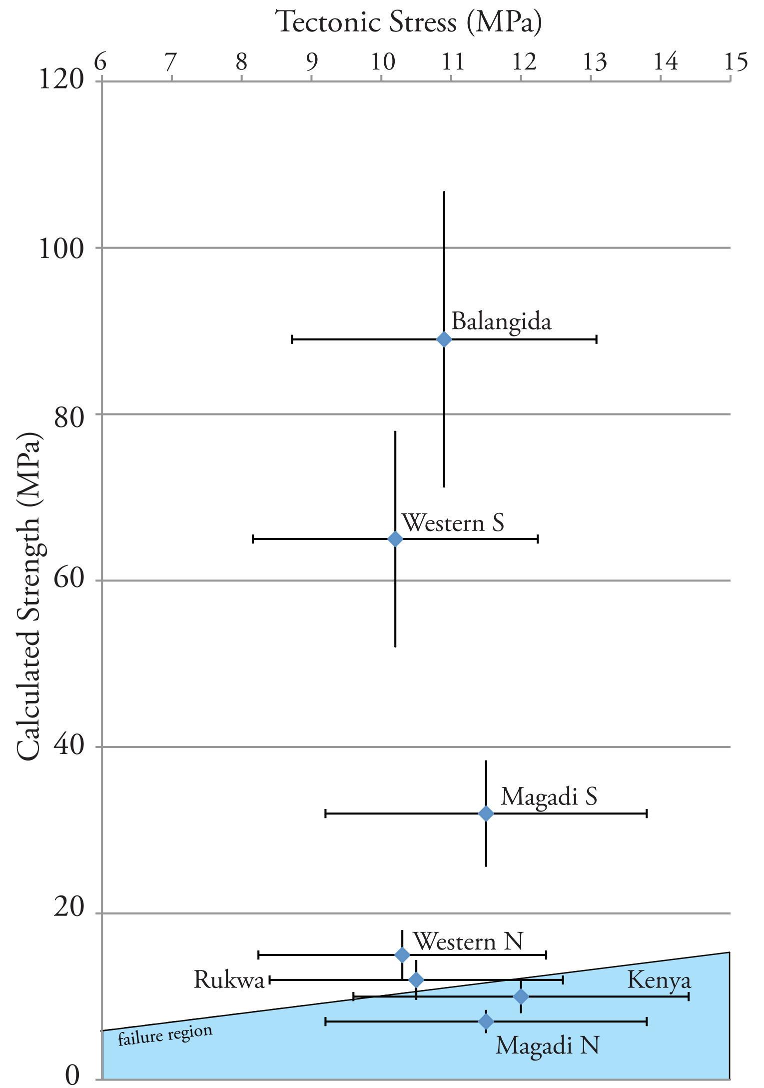
- 100° ΔT→ decrease in viscosity 1 order of magnitude

Strength of the Lithosphere





Conclusions and Open Questions

- Present-day Nubia-Somalia divergence across the EAR is well explained by buoyancy stresses caused by eastern+southern Africa's dynamic topography – a result of African Superplume.
- Buoyancy stresses are large enough to oppose the resistance of a passive (static) mantle – a convective mantle efficiently coupled with the lithosphere would cause divergence at a rate much faster than observed: African lithosphere is largely decoupled from the underlying large-scale mantle flow.
- This decoupling may be explained by a reduced viscosity of the sub-lithospheric mantle due to excess temperature and volatile caused by heat advection from the African Superplume.
- **Problem**: tectonic forces still insufficient to initiate rupture of a "normal" continental lithosphere
  - Does its strength reside entirely in its crust – either intrinsically (e.g., *crême brulée* model) or as a result of thermal erosion of the mantle?
  - Are other processes locally decreasing lithospheric strength (magmatic intrusions, convective removal of upper mantle, ...)?

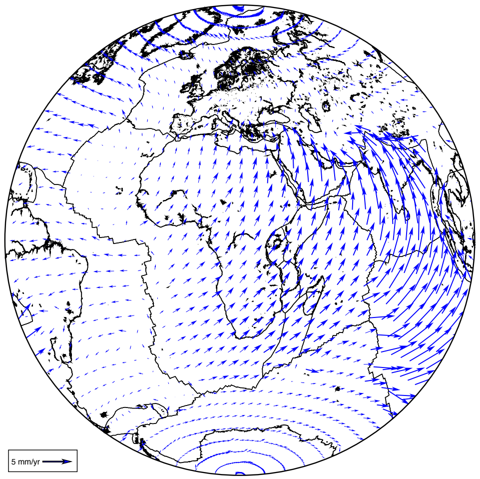
Additional material

mantle flow fields

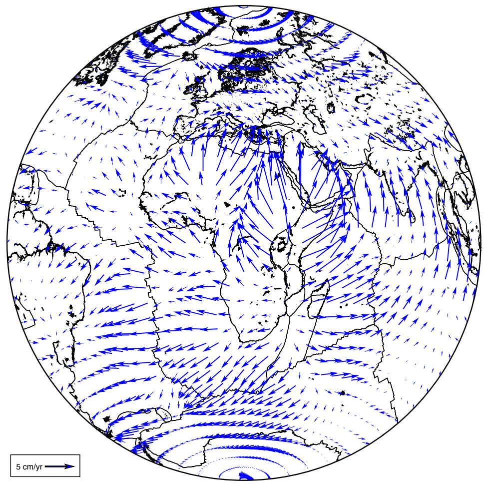
wet gabbro layer (Karato, 2012 model)

mantle temperature fields

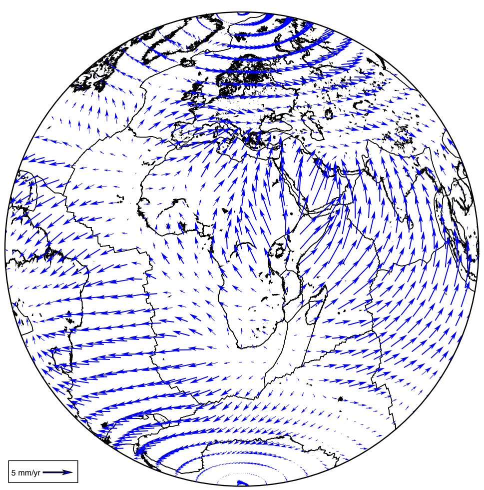
The Model



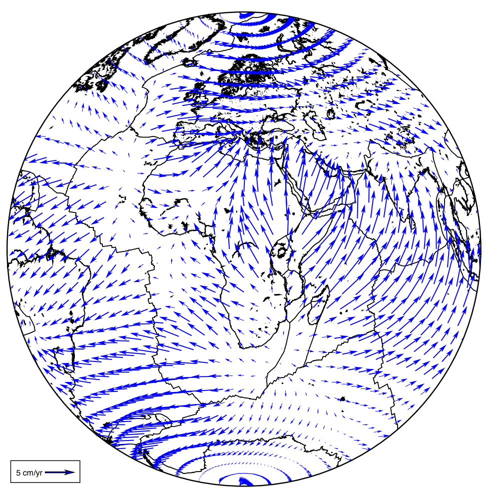
Schuberth et al., 2009



Forte et al., 2010



Steinberger & Calderwood, 2006



Buiter et al., 2012

4 example mantle flow models tested

MANTLE FLOW MODELS

- Tangential velocities
- Buiter et al., 2012; Steinberger and Calderwood, 2006; Schuberth et al., 2009
- Cratons and no-craton models
- 212.5, 220, 244, 250 km depths
- Viscosity is 10^{19} & 10^{21} Pa.s

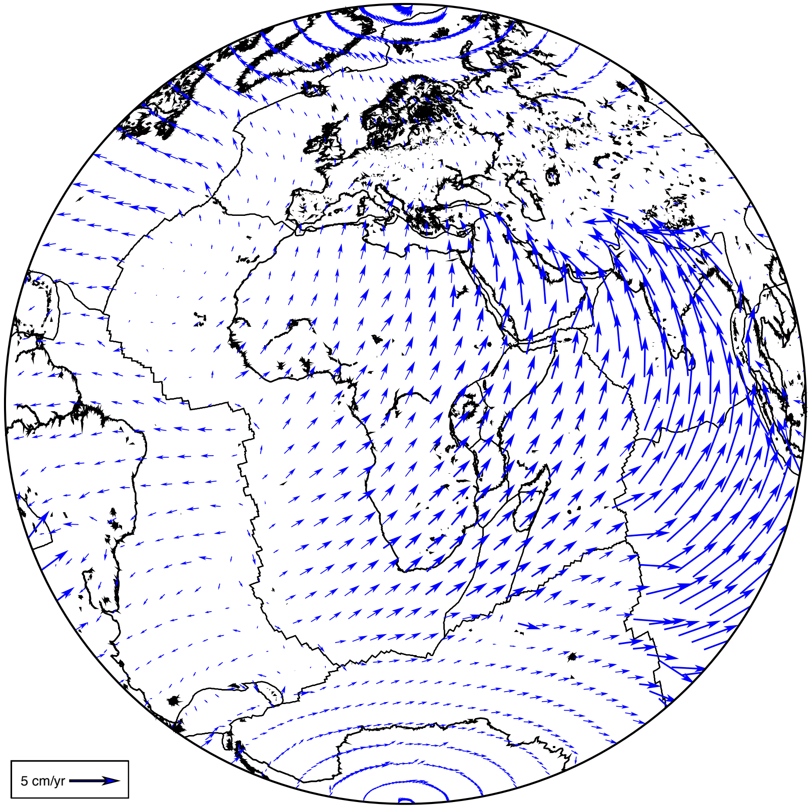
COUPLING MECHANISM

- Assume viscous coupling, hence no deformation between base of lithosphere and depth of tangential velocities

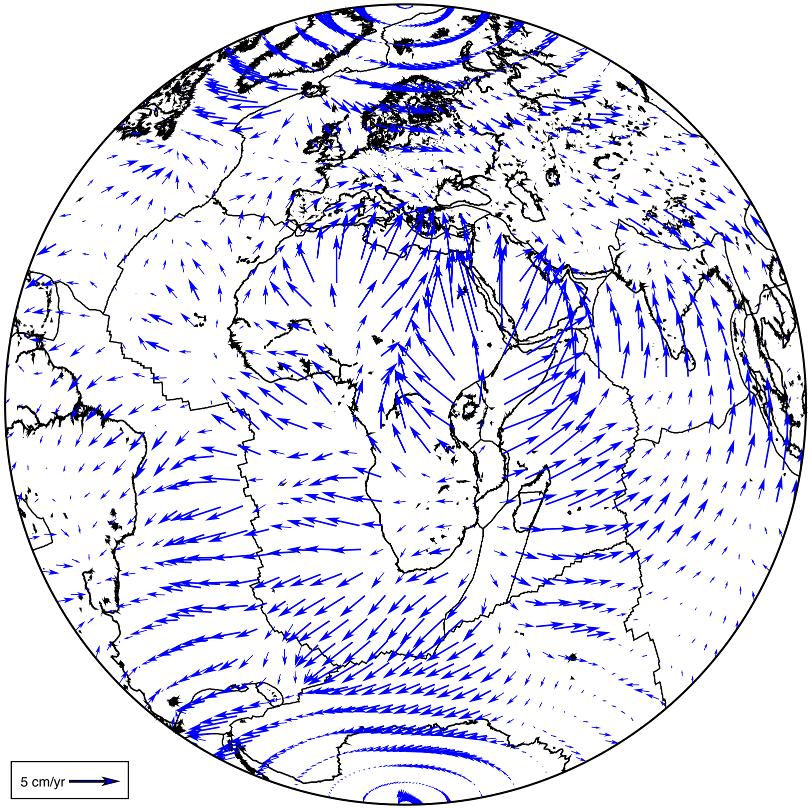
$$\left[\frac{\partial}{\partial x}\left(\frac{V_{mantle} - V_{node}}{d}\right)\right]\eta$$

Mantle Flow Fields

Schuberth et al., 2009
250 km depth

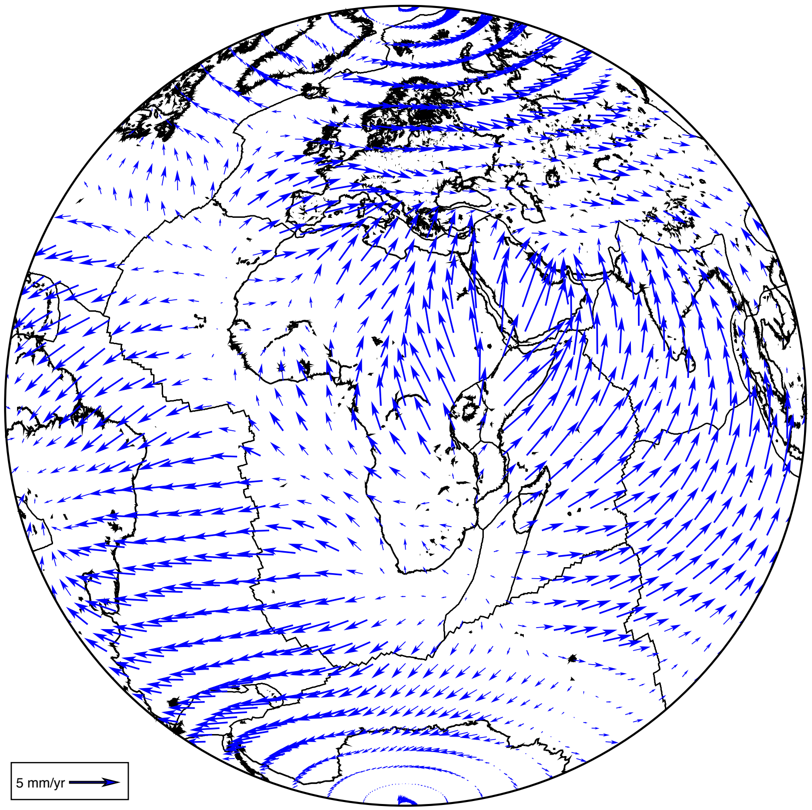


Forte et al., 2010
212.5 km depth

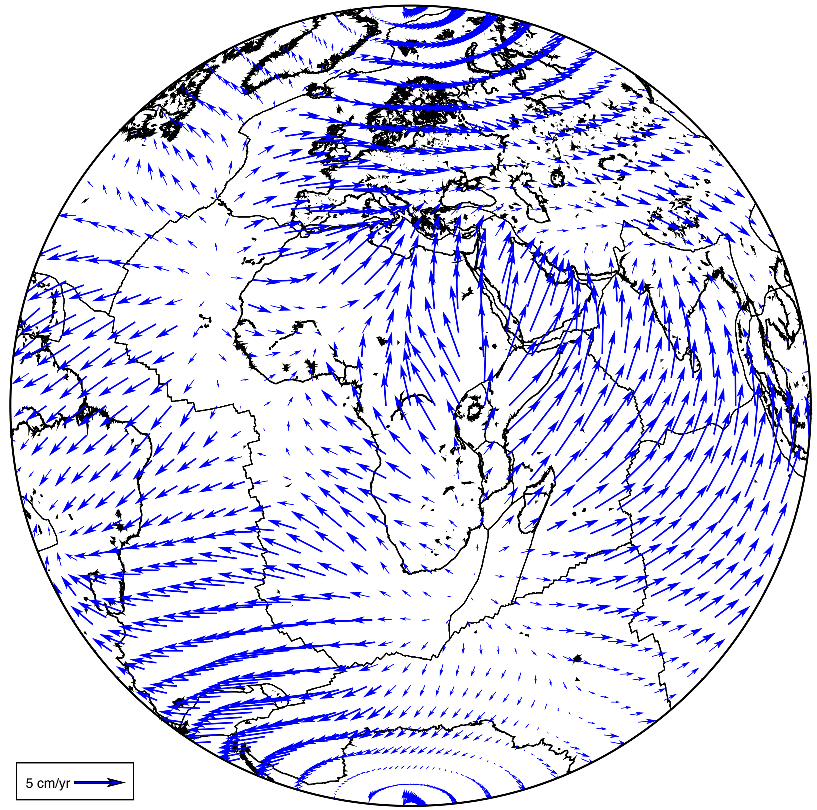


Mantle Flow Fields

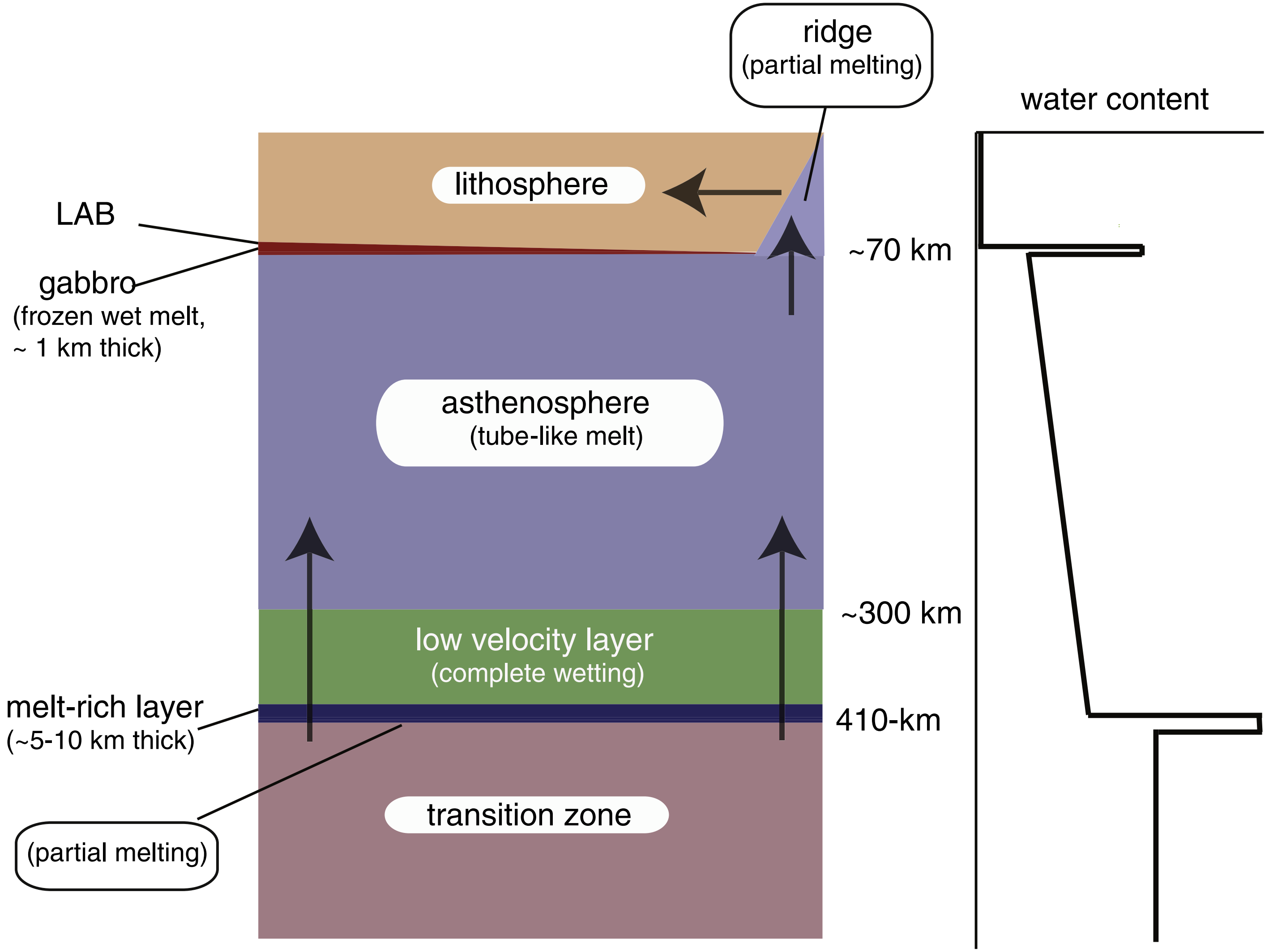
Buiter et al., 2012
220 km depth

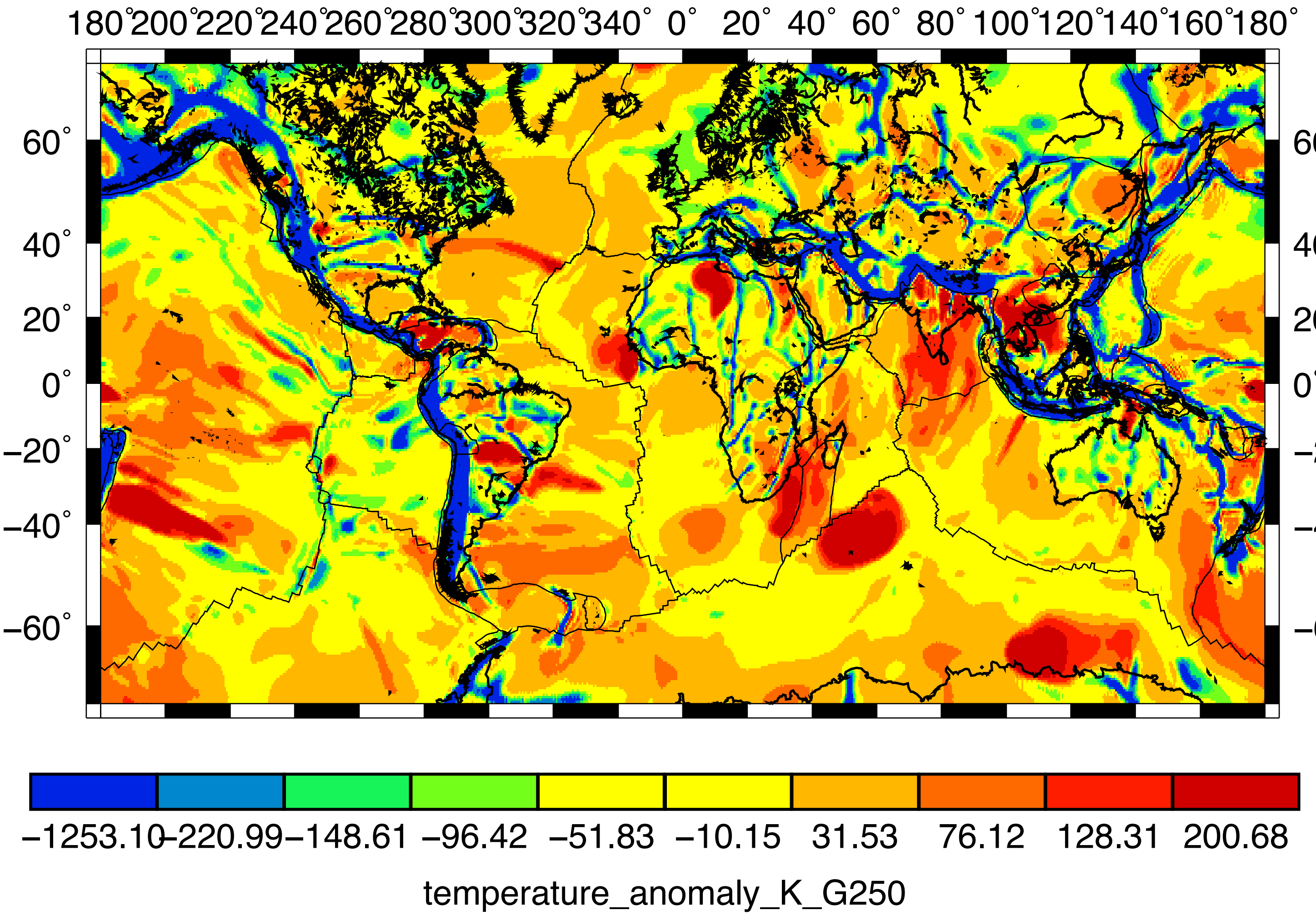


Steinberger and Calderwood, 2006
220 km depth

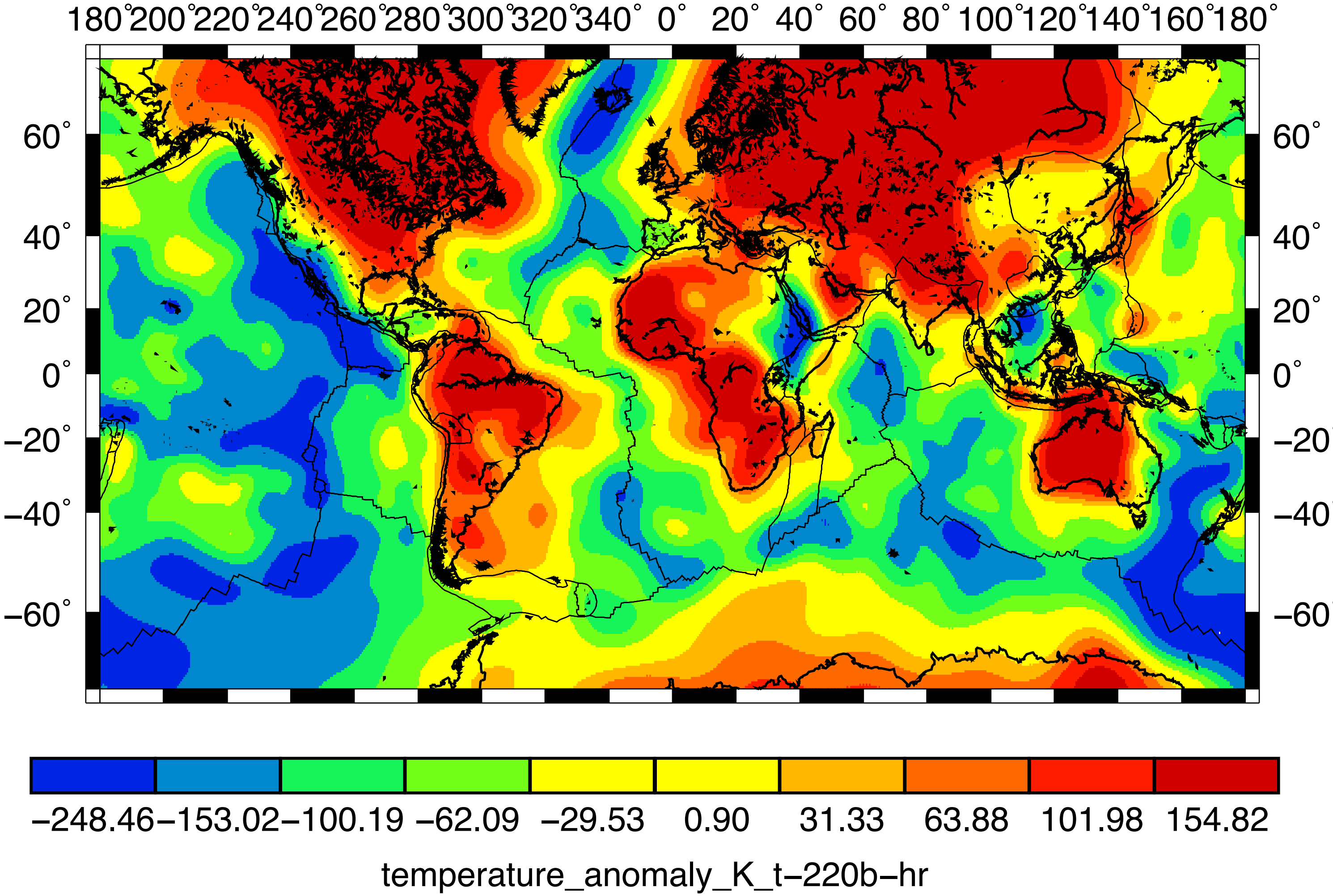


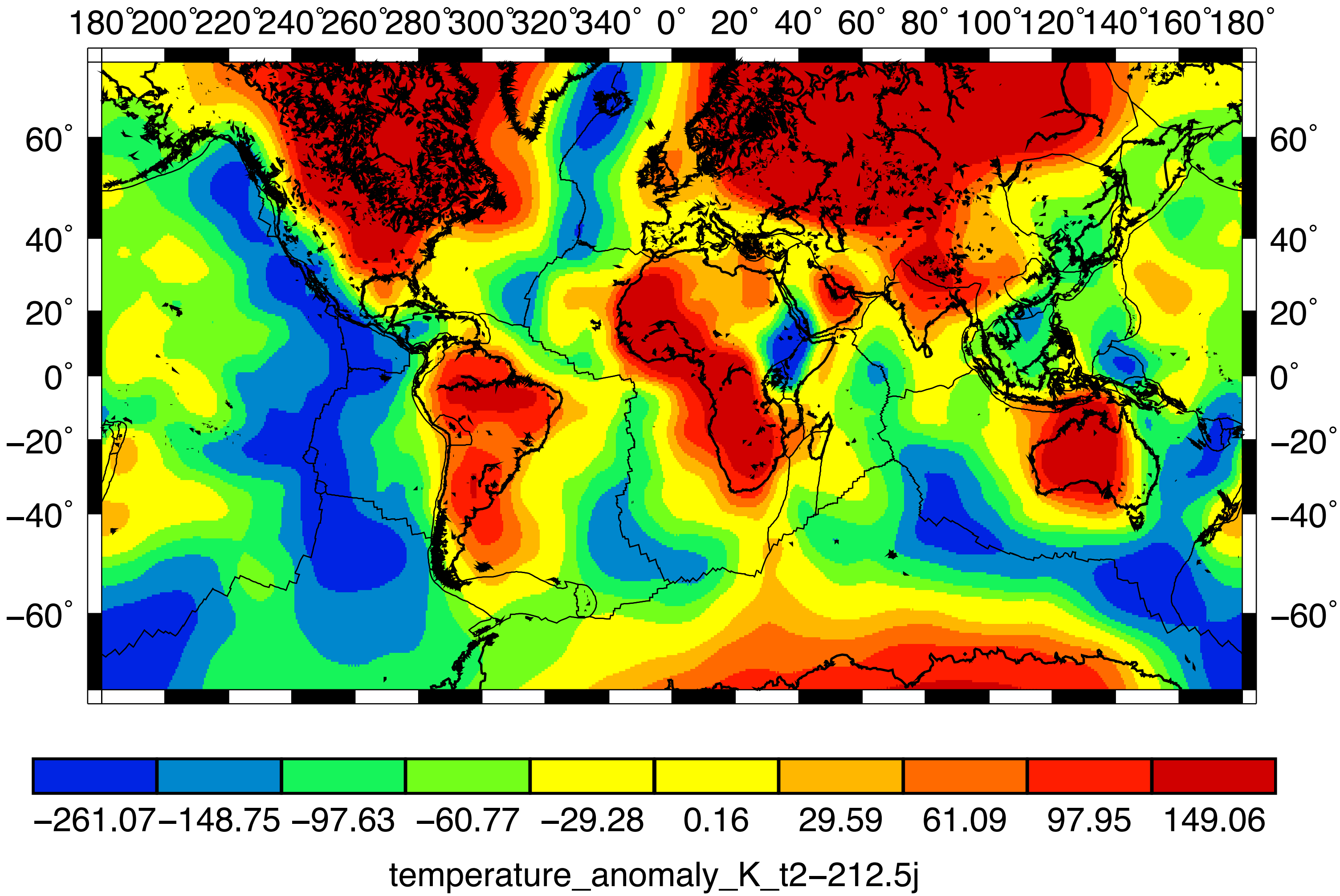
Karato, 2012 Model for Decoupling





180° 200° 220° 240° 260° 280° 300° 320° 340° 0° 20° 40° 60° 80° 100° 120° 140° 160° 180°
60° 40° 20° 0° −20° −40° −60°
−1253.10 −220.99 −148.61 −96.42 −51.83 −10.15 31.53 76.12 128.31 200.68
temperature_anomaly_K_G250


180° 200° 220° 240° 260° 280° 300° 320° 340° 0° 20° 40° 60° 80° 100° 120° 140° 160° 180°
60°
40°
20°
0°
−20°
−40°
−60°
−248.46 −153.02 −100.19 −62.09 −29.53 0.90 31.33 63.88 101.98 154.82
temperature_anomaly_K_t−220b−hr


180° 200° 220° 240° 260° 280° 300° 320° 340° 0° 20° 40° 60° 80° 100° 120° 140° 160° 180°
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temperature_anomaly_K_t2−212.5j