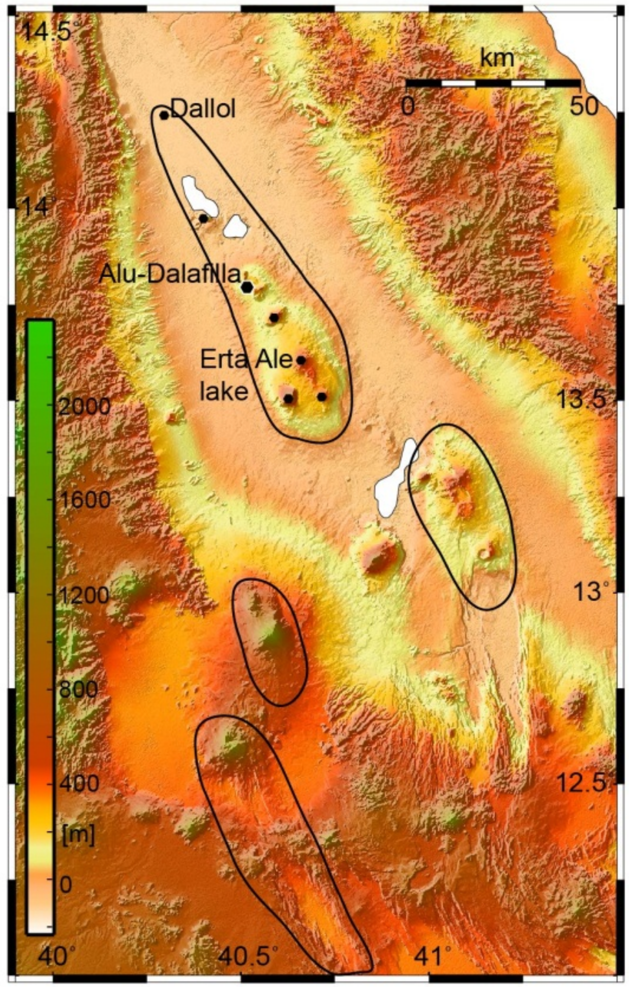
Topography and Stress in the African Continent: a mantle dynamics perspective



Carolina Lithgow-Bertelloni, University College London; Paul Silver, DTM Carnegie Institution of Washington

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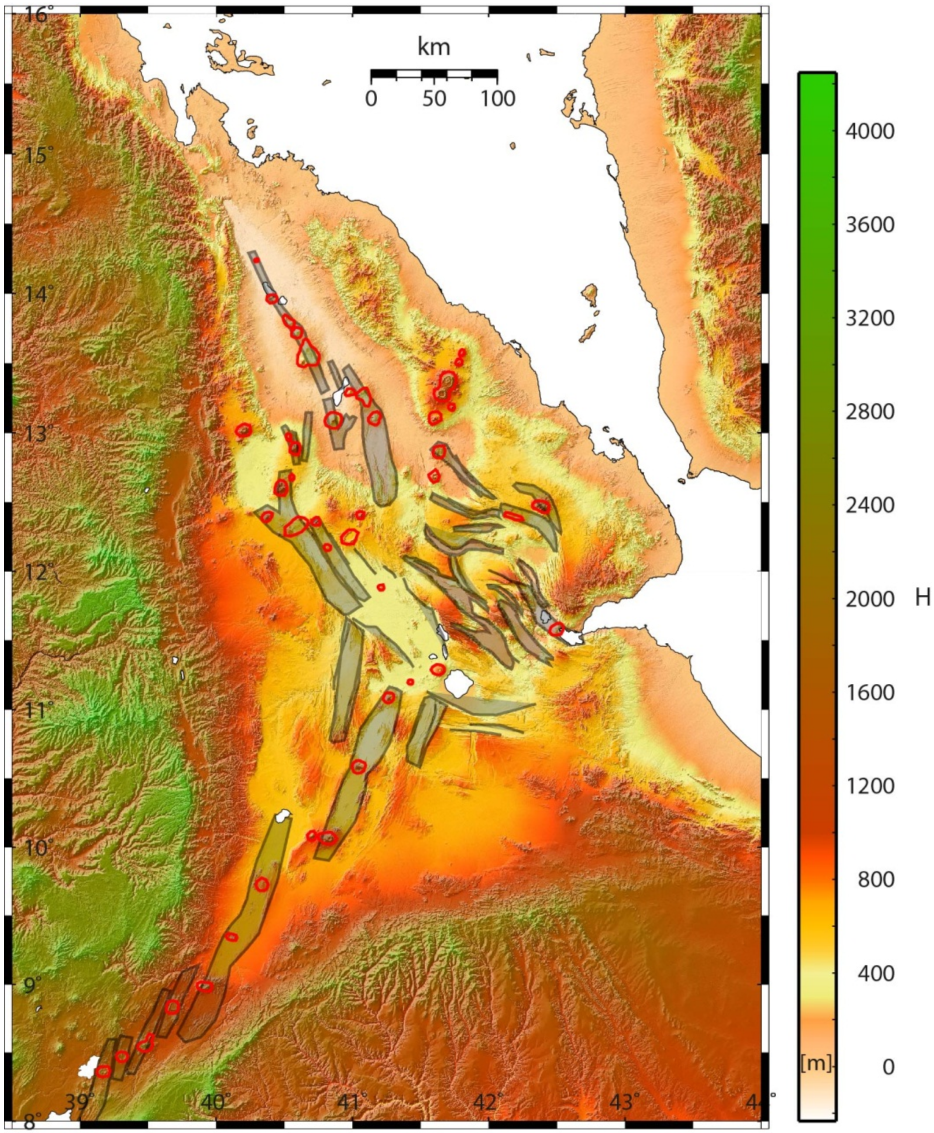

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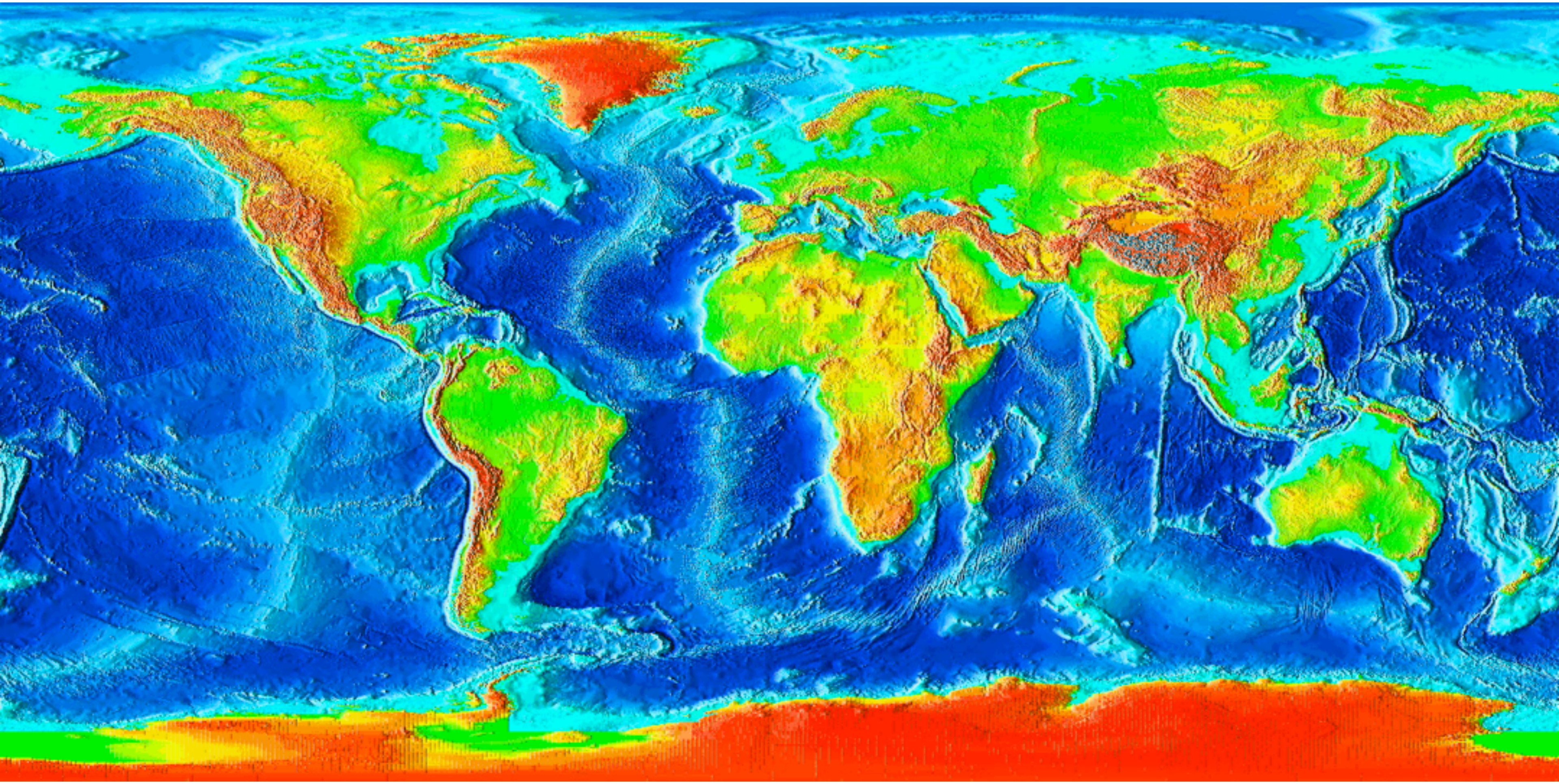

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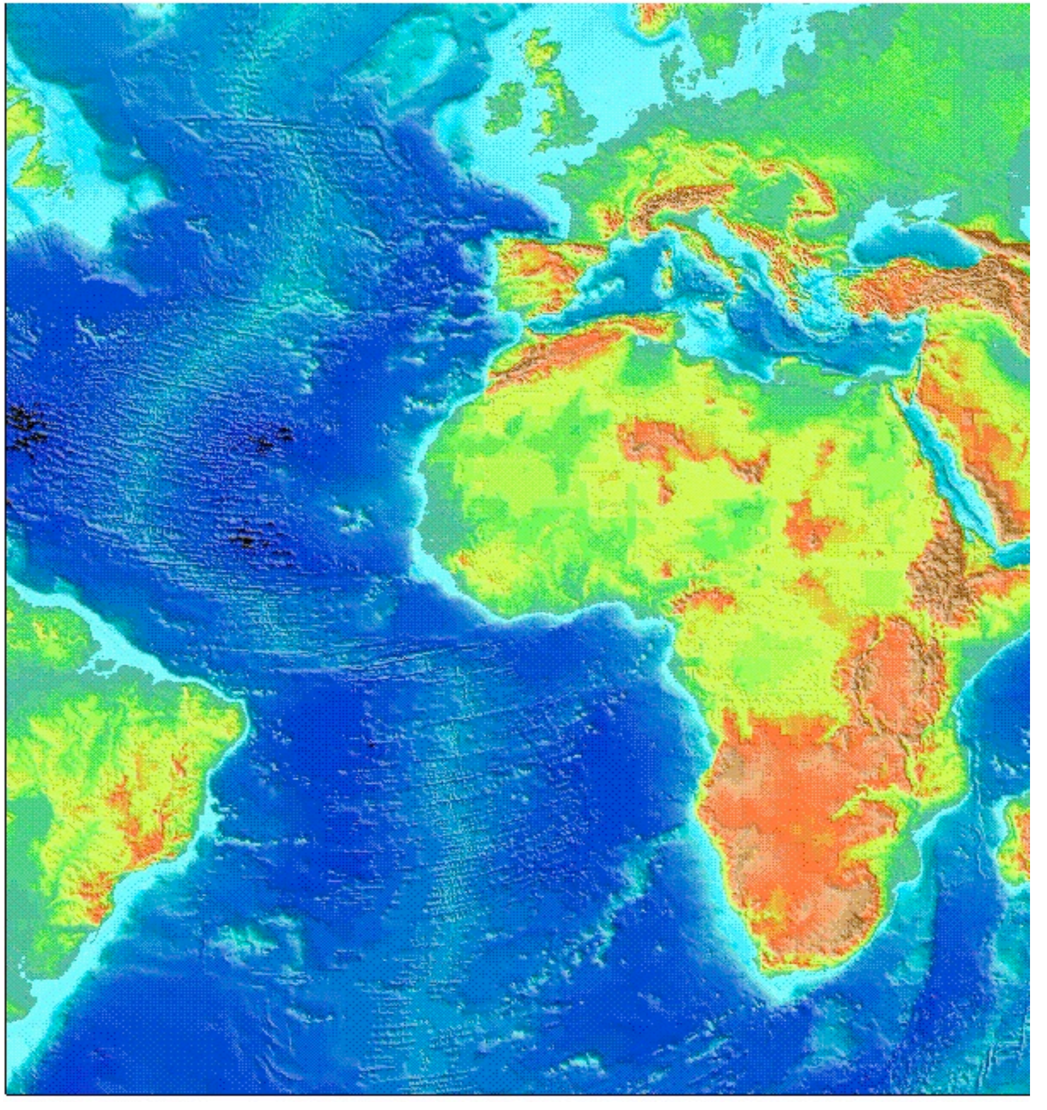
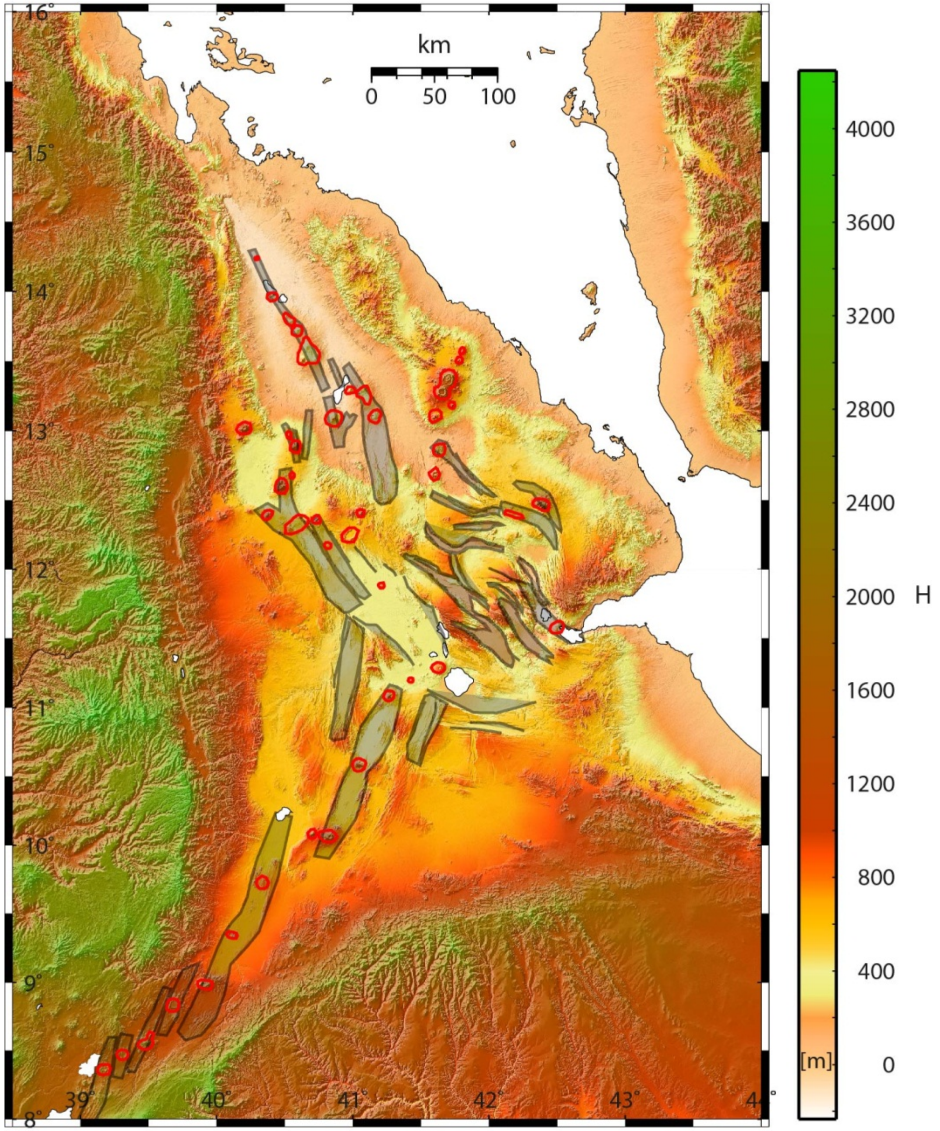


Carolina Lithgow-Bertelloni, University College London; Paul Silver, DTM Carnegie Institution of Washington

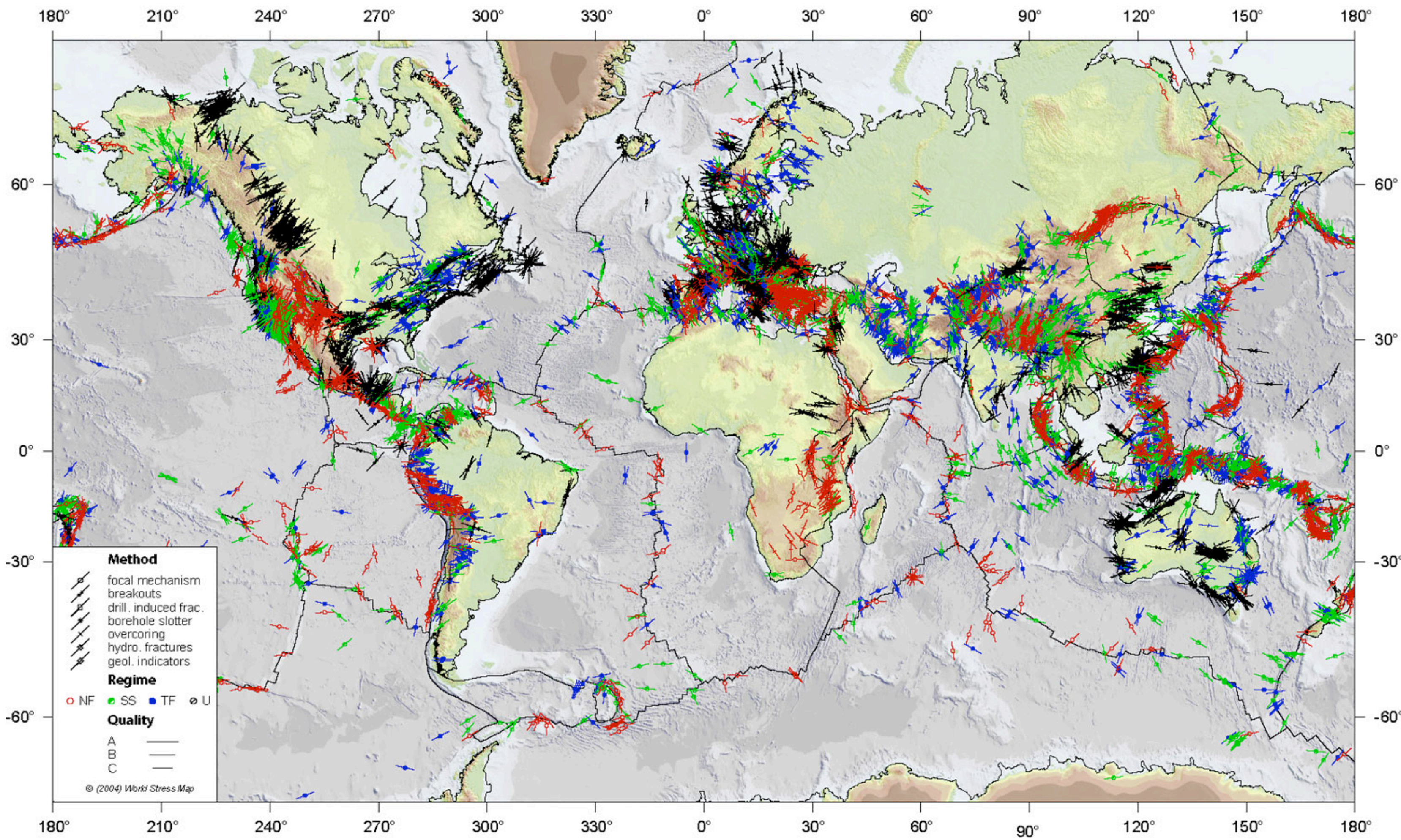
Rifting



km
0
50
100
16°
15°
14°
13°
12°
11°
10°
9°
8°
39°
40°
41°
42°
43°
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
[m]
H

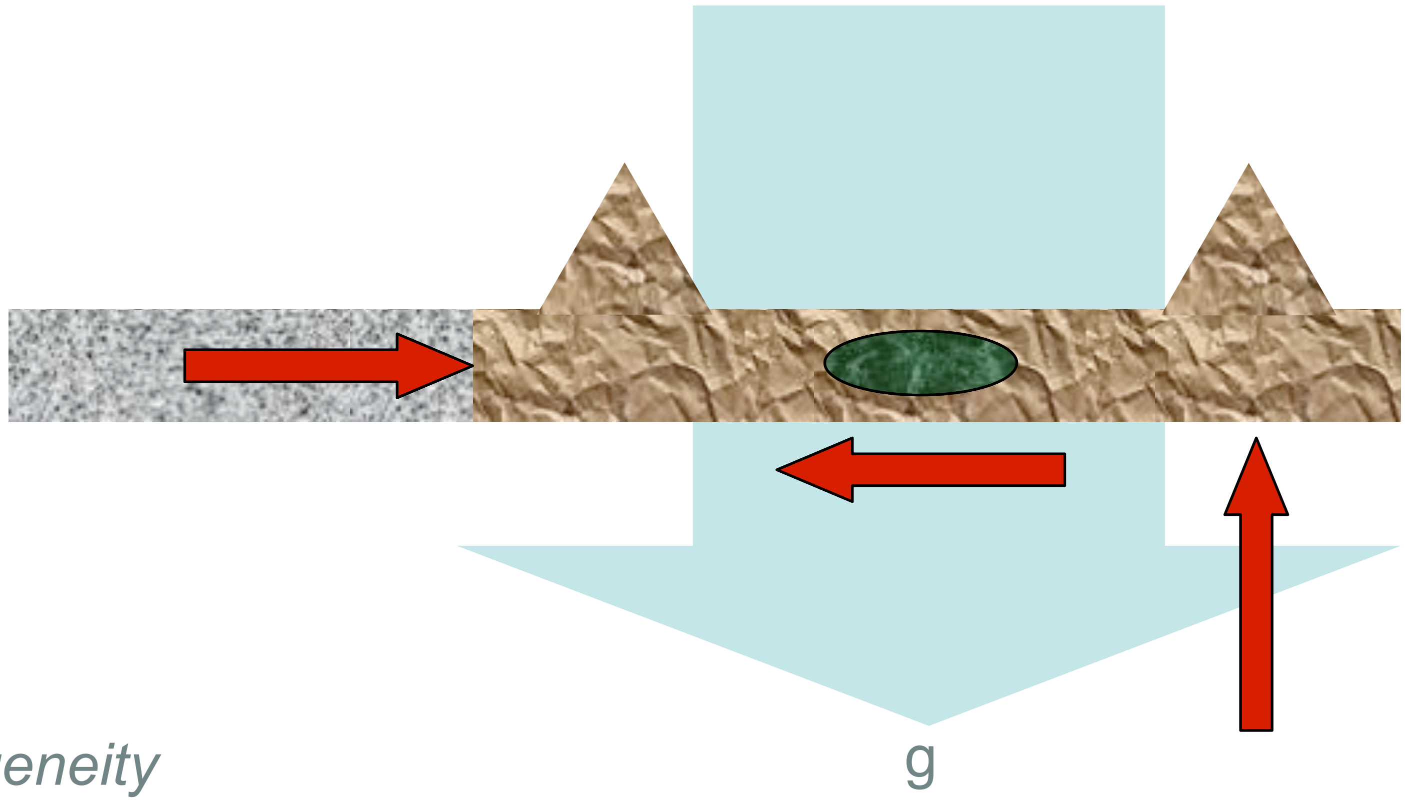
Observations of Lithospheric Stress

Contributions: Mantle Stresses; Crustal Heterogeneity



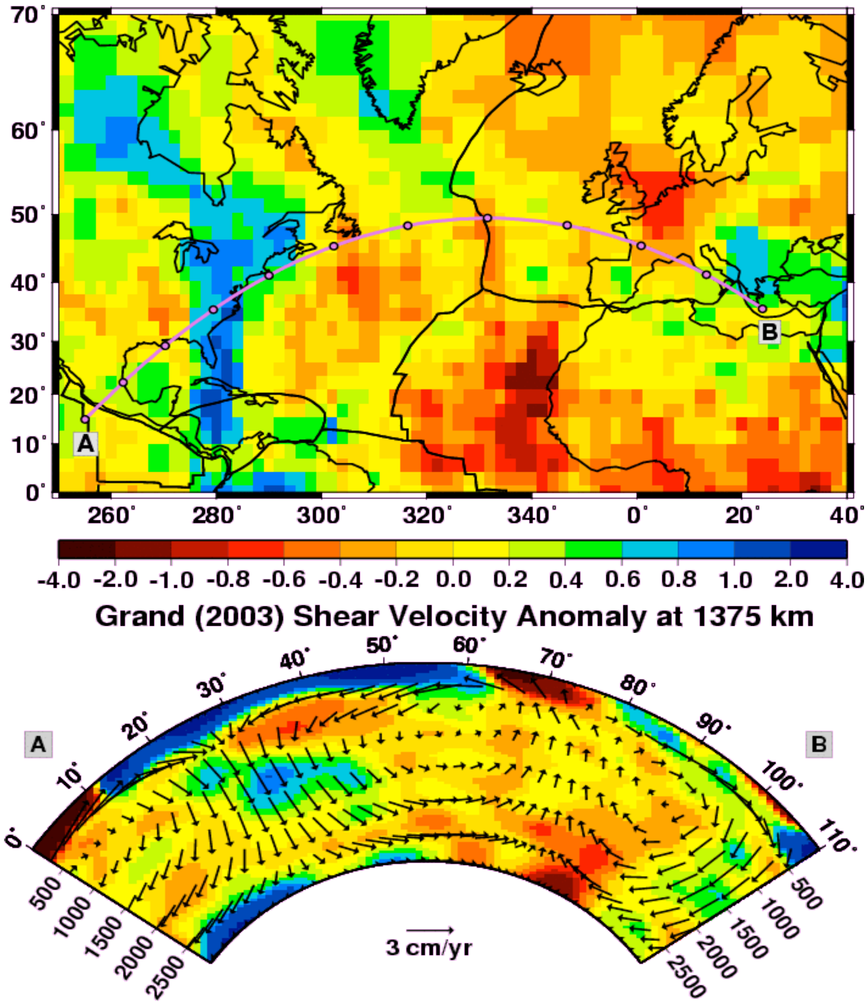
[*Reinecker, J., Heidbach, O., Tingay, M., Sperner, B., and Mueller, B.*, 2005]
(available online at www.world-stress-map.org)

Sources of Stress



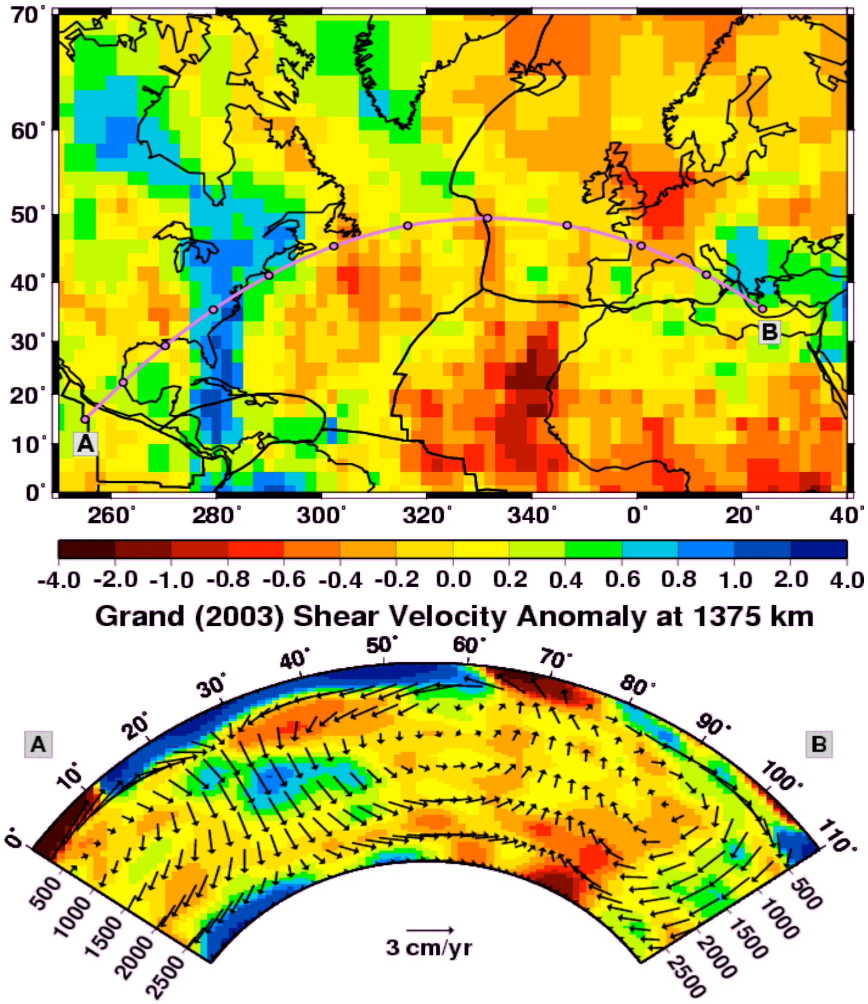
Inhomogeneity
Topography
Edge Tractions
Basal Tractions

Computing Mantle Flow



[*Conrad et al*, 2004]

Computing Mantle Flow



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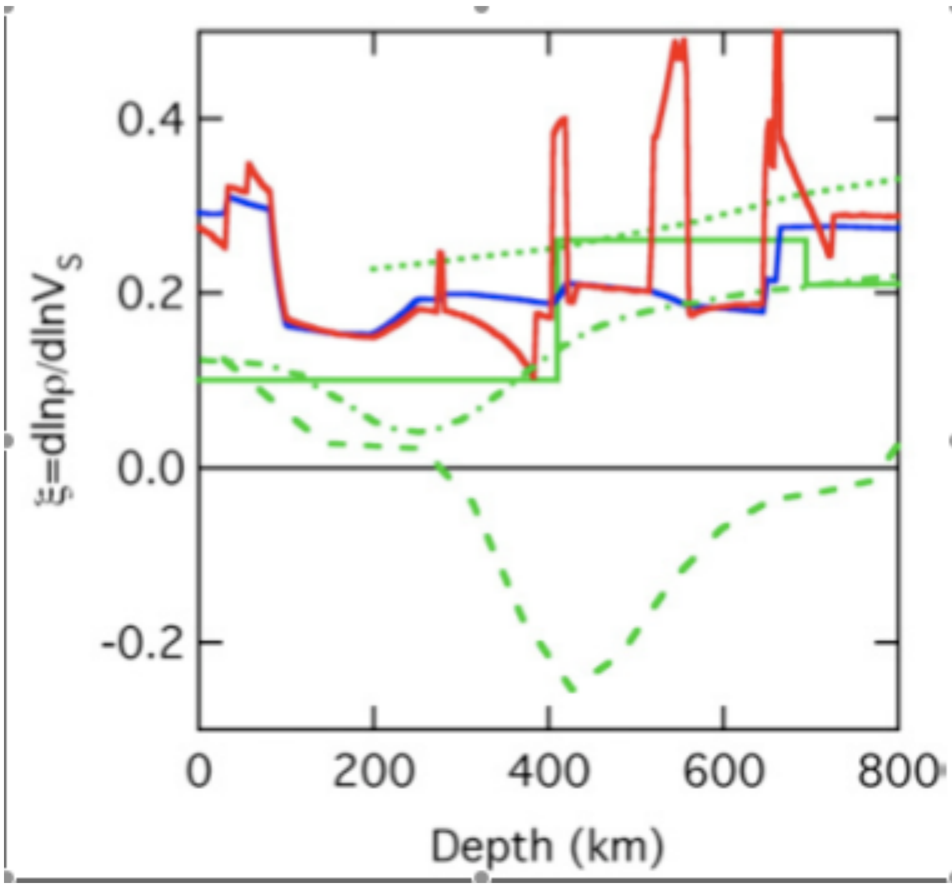
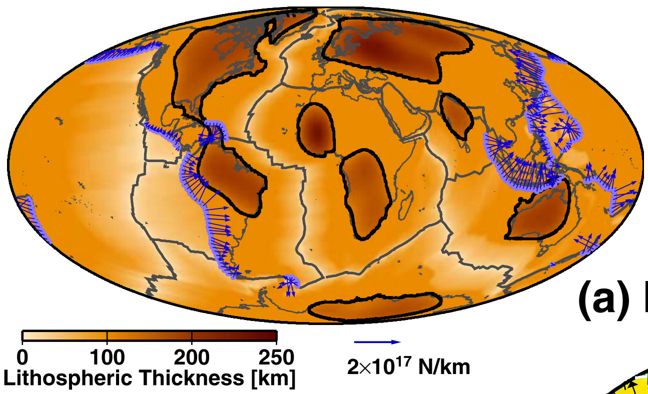
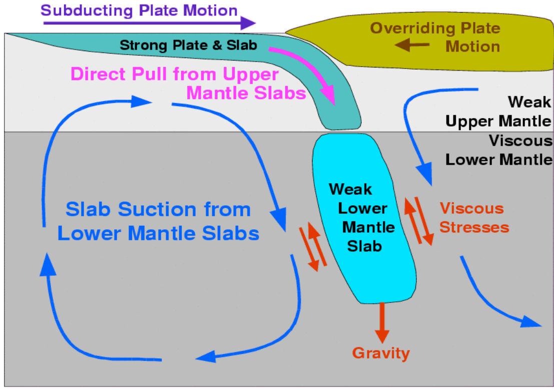


[*Stixrude and Lithgow-Bertelloni*, 2007]

Plate Driving Forces





[*van Summeren et al., in press*]

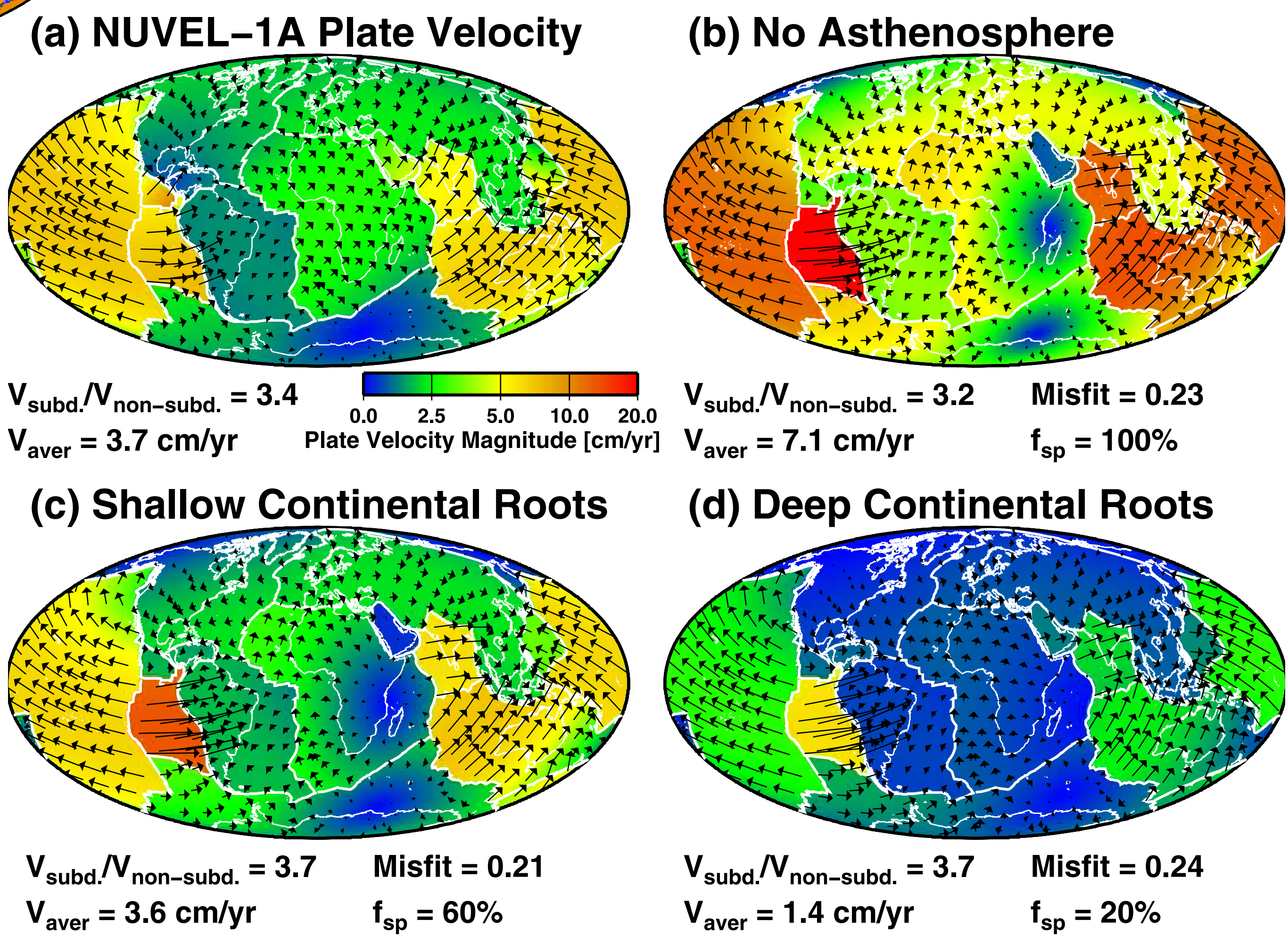
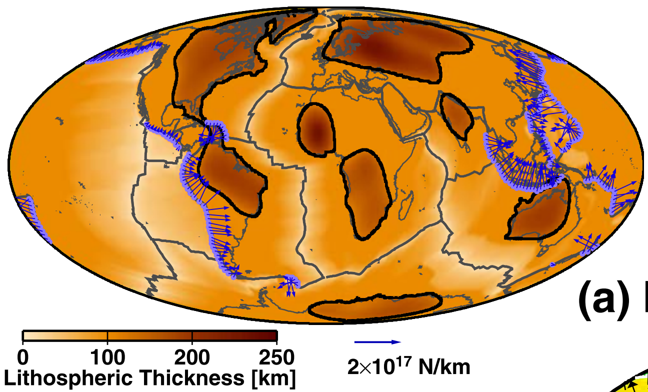
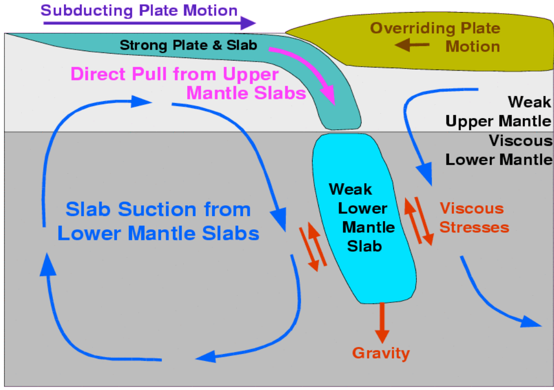


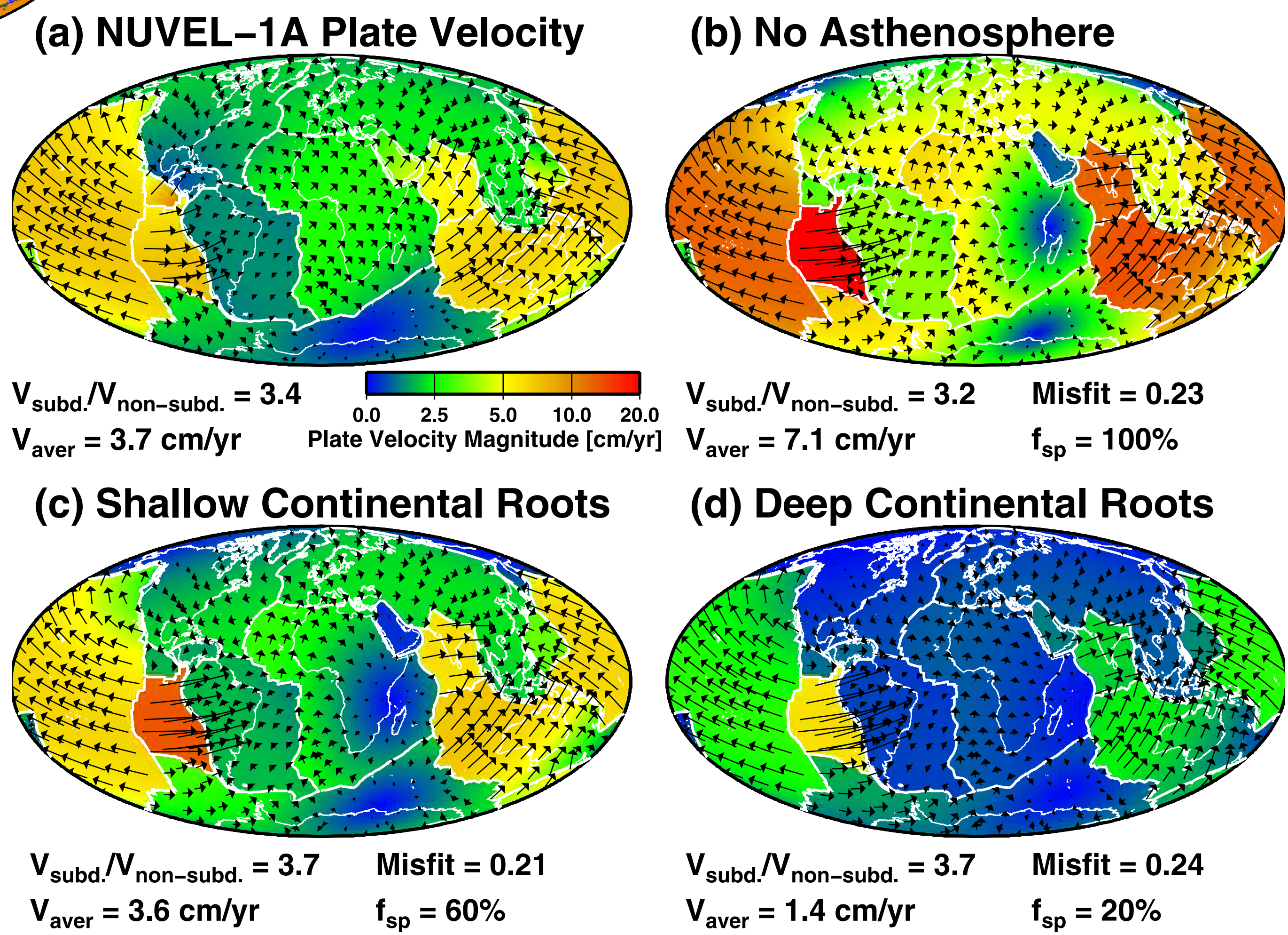
Plate Driving Forces



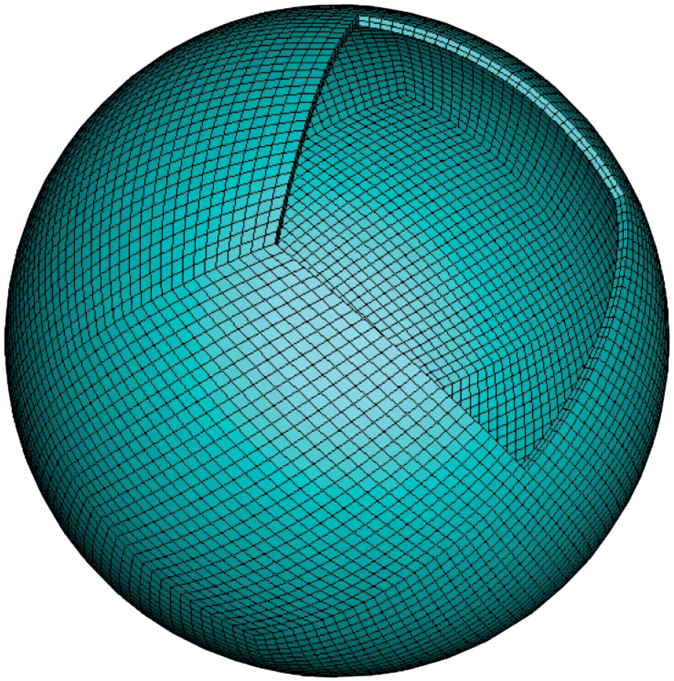
Slab Pull from Upper Mantle Slabs
Slab Suction from Lower Mantle Slabs
Shallow Roots and Global Asthenosphere

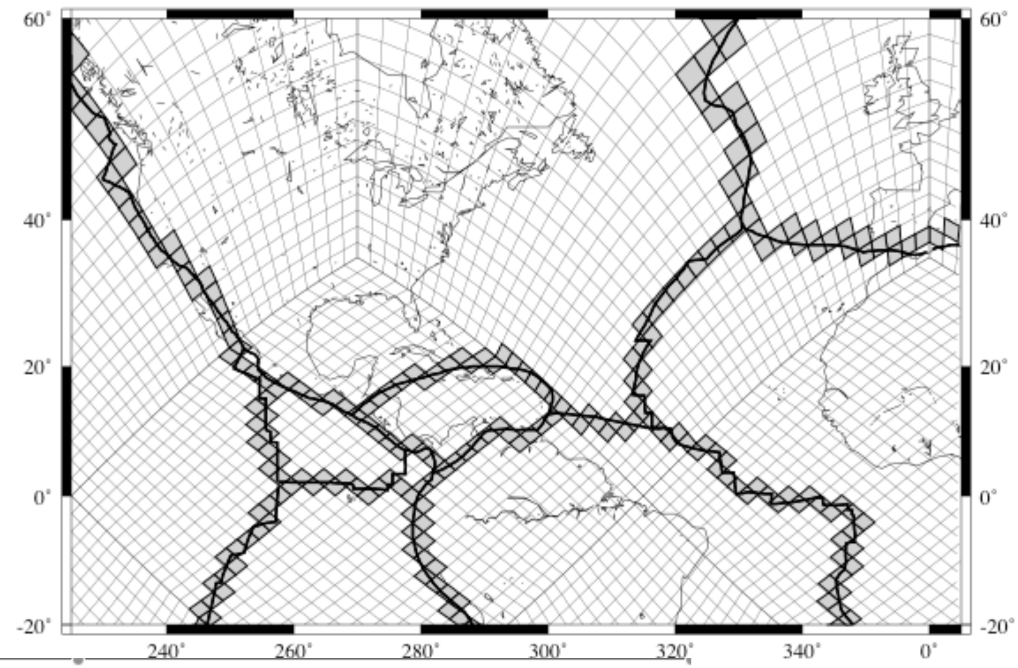


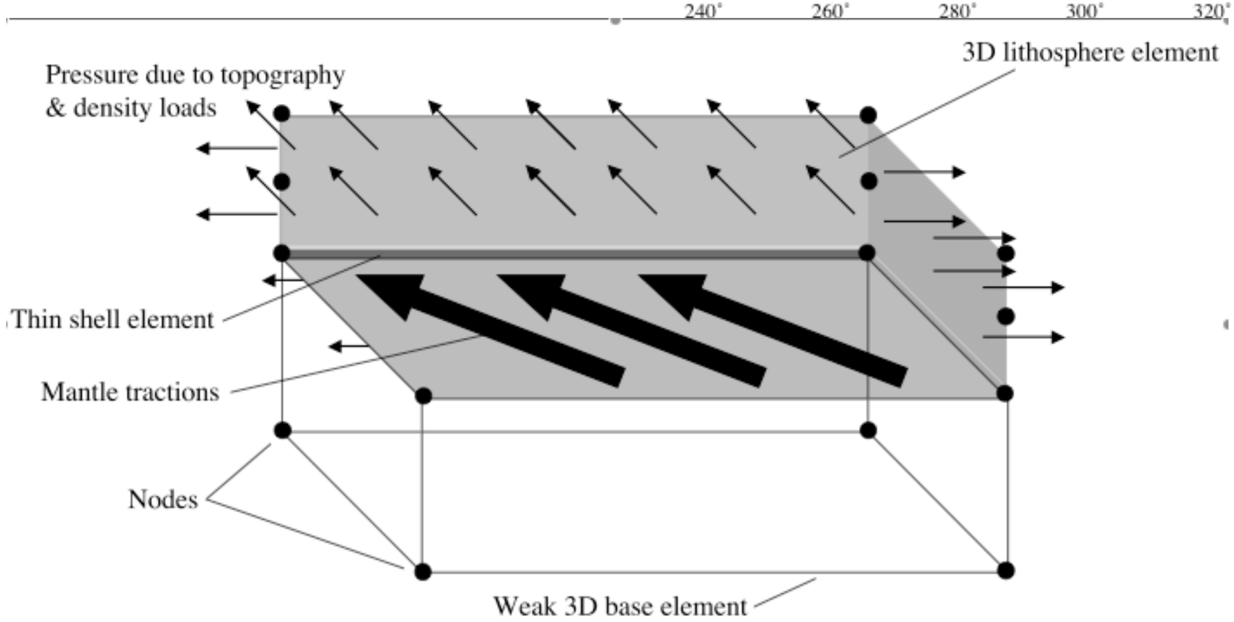
[*van Summeren et al., in press*]



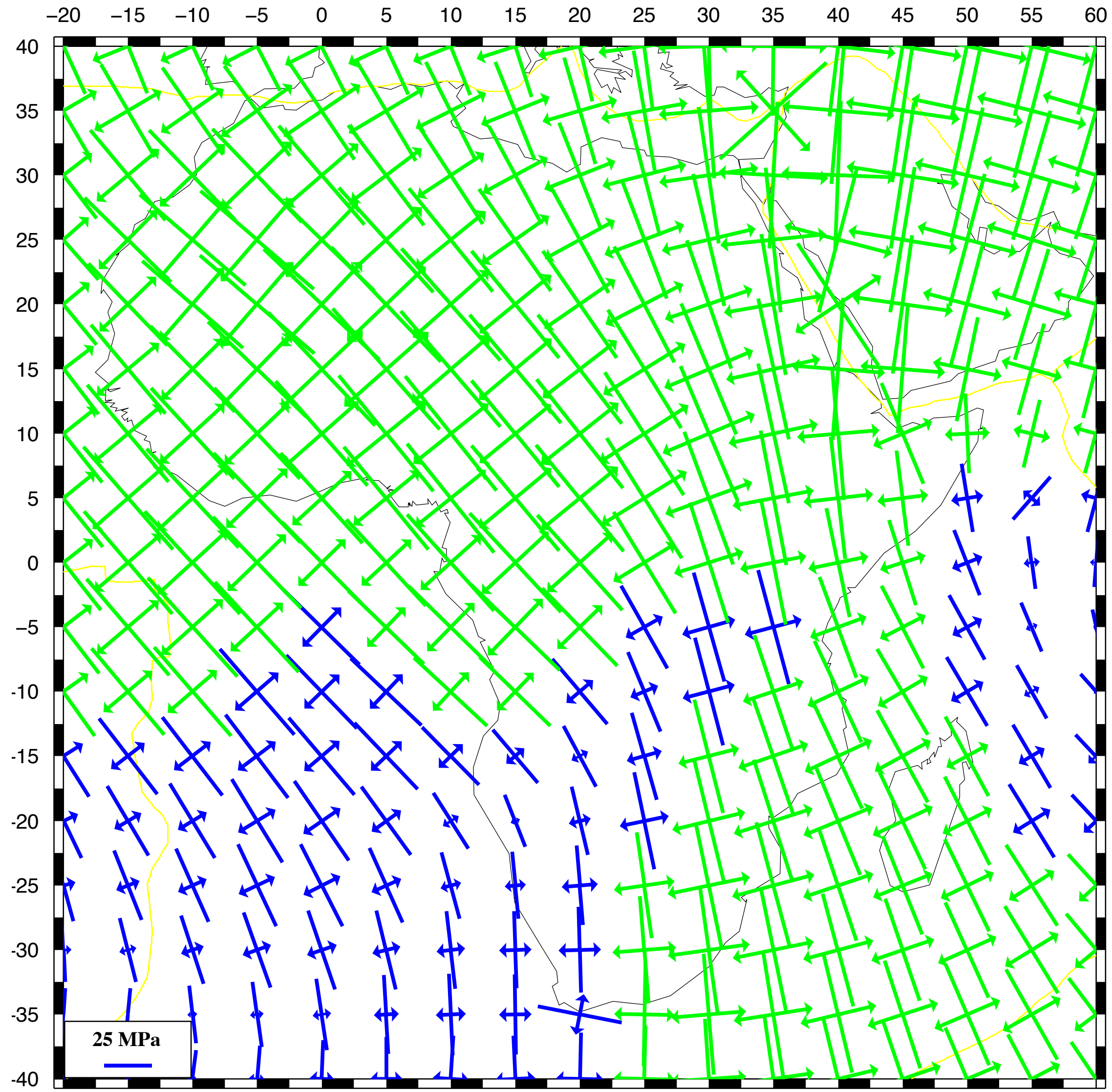
Modeling the Lithosphere



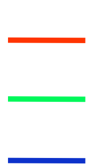




Horizontal Tractions

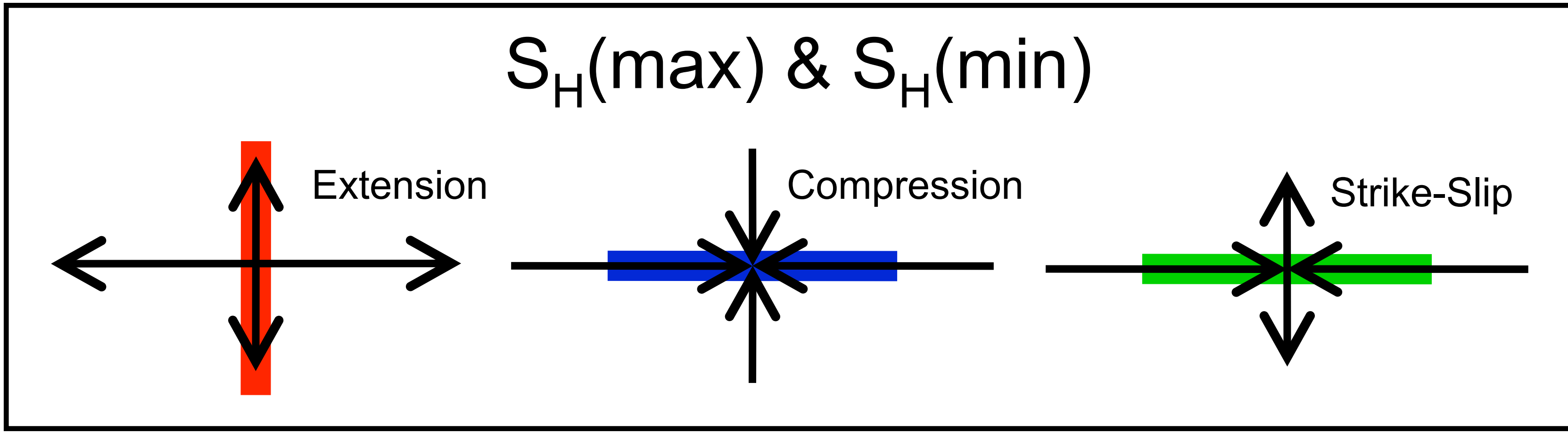


REGIME



[*Lithgow-Bertelloni & Guynn*, 2004; *Naliboff et al.*, 2009]

Horizontal Tractions



REGIME

- Normal
- Strike-slip
- Thrust

[*Lithgow-Bertelloni & Guynn*, 2004; *Naliboff et al.*, 2009]

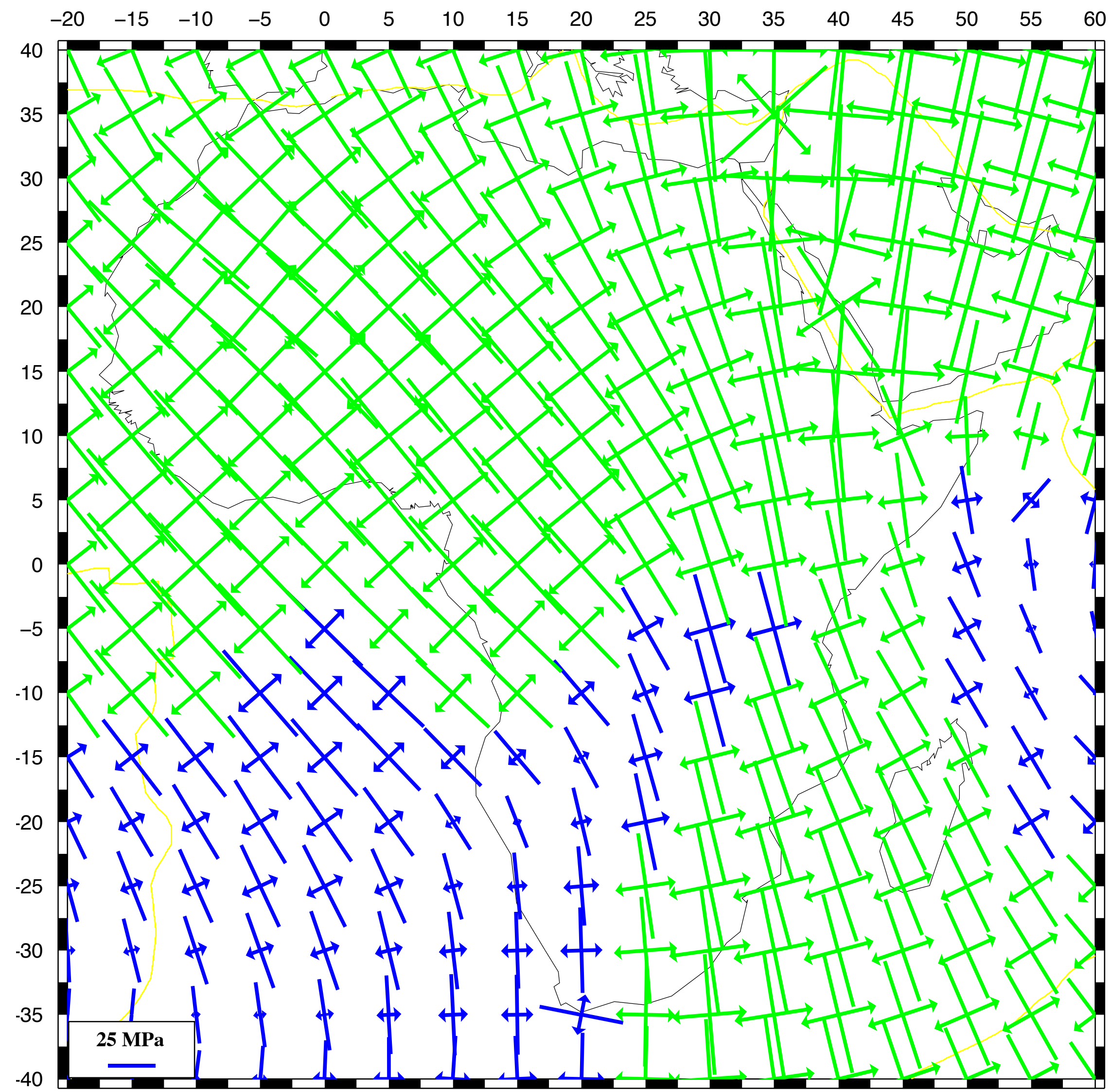
Horizontal Tractions

REGIME

Normal

Strike-slip

Thrust



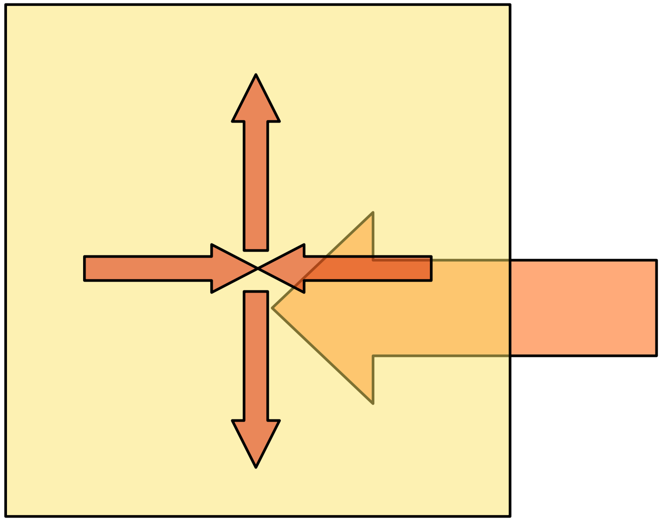
[*Lithgow-Bertelloni & Guynn*, 2004; *Naliboff et al.*, 2009]

Stresses due to Basal Tractions

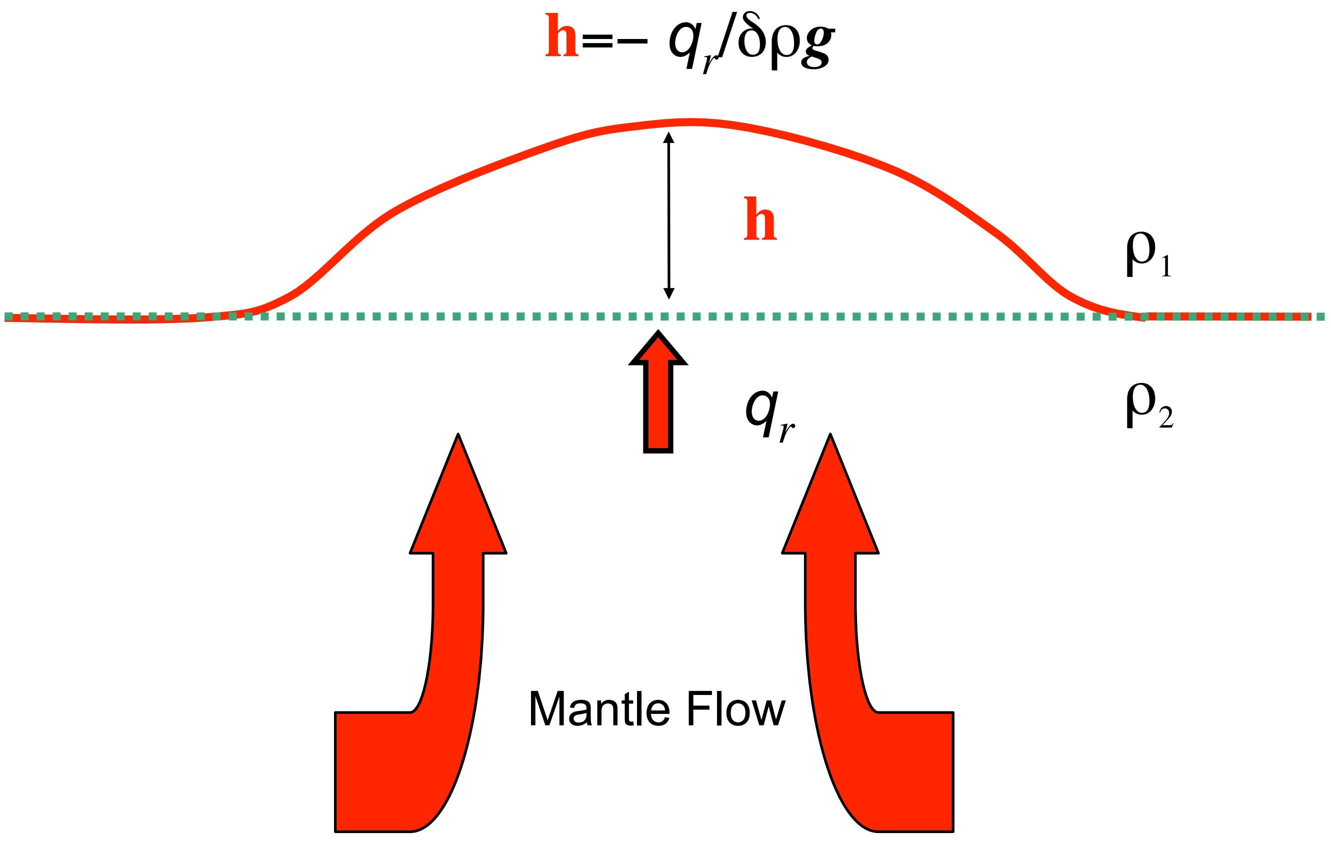
$$\frac{\partial}{\partial\theta}(N_{\theta\theta}\sin\theta)+\frac{\partial N_{\theta\phi}}{\partial\phi}-N_{\phi\phi}\cos\theta+q_{\theta}R\sin\theta=0$$

$$\frac{\partial}{\partial\theta}(N_{\theta\phi}\sin\theta)+\frac{\partial N_{\phi\phi}}{\partial\phi}+N_{\theta\phi}\cos\theta+q_{\phi}R\sin\theta=0$$

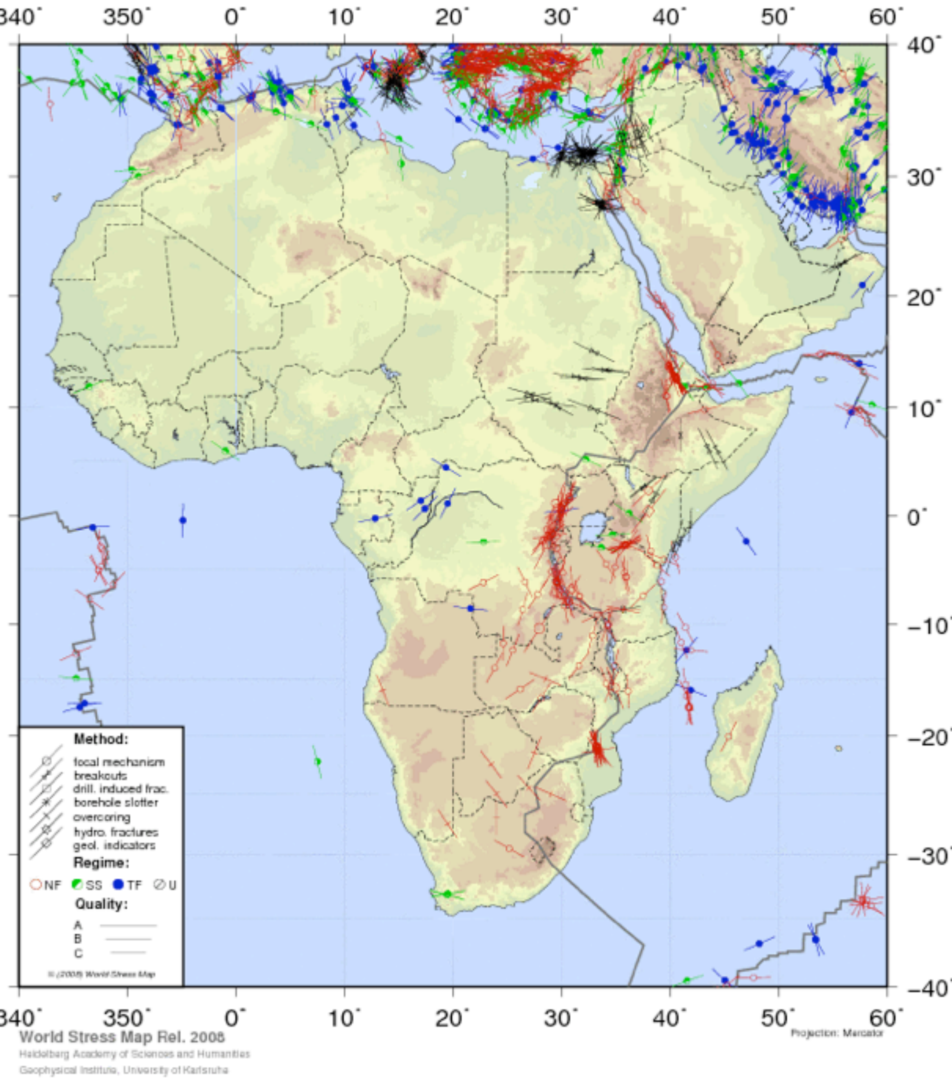
$$N_{\theta\theta}+N_{\phi\phi}+q_{r}R=0$$

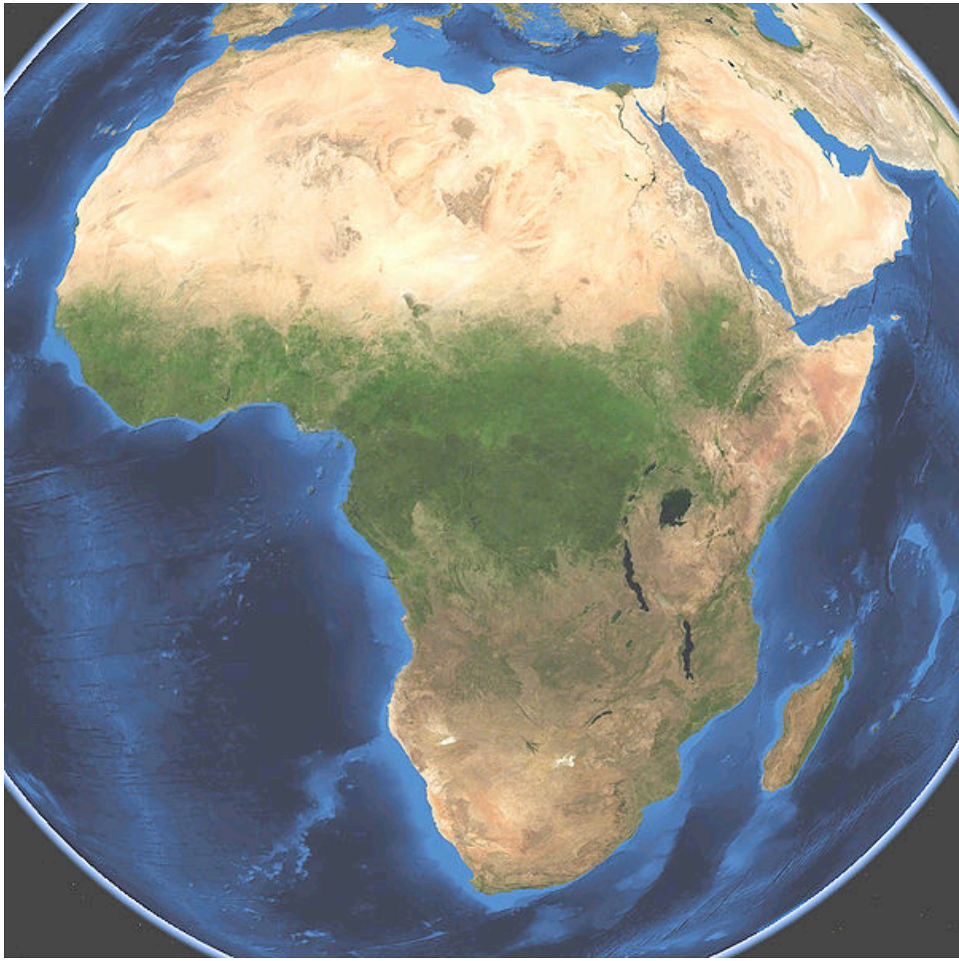


Dynamic Topography



Dynamic Uplift and Extension

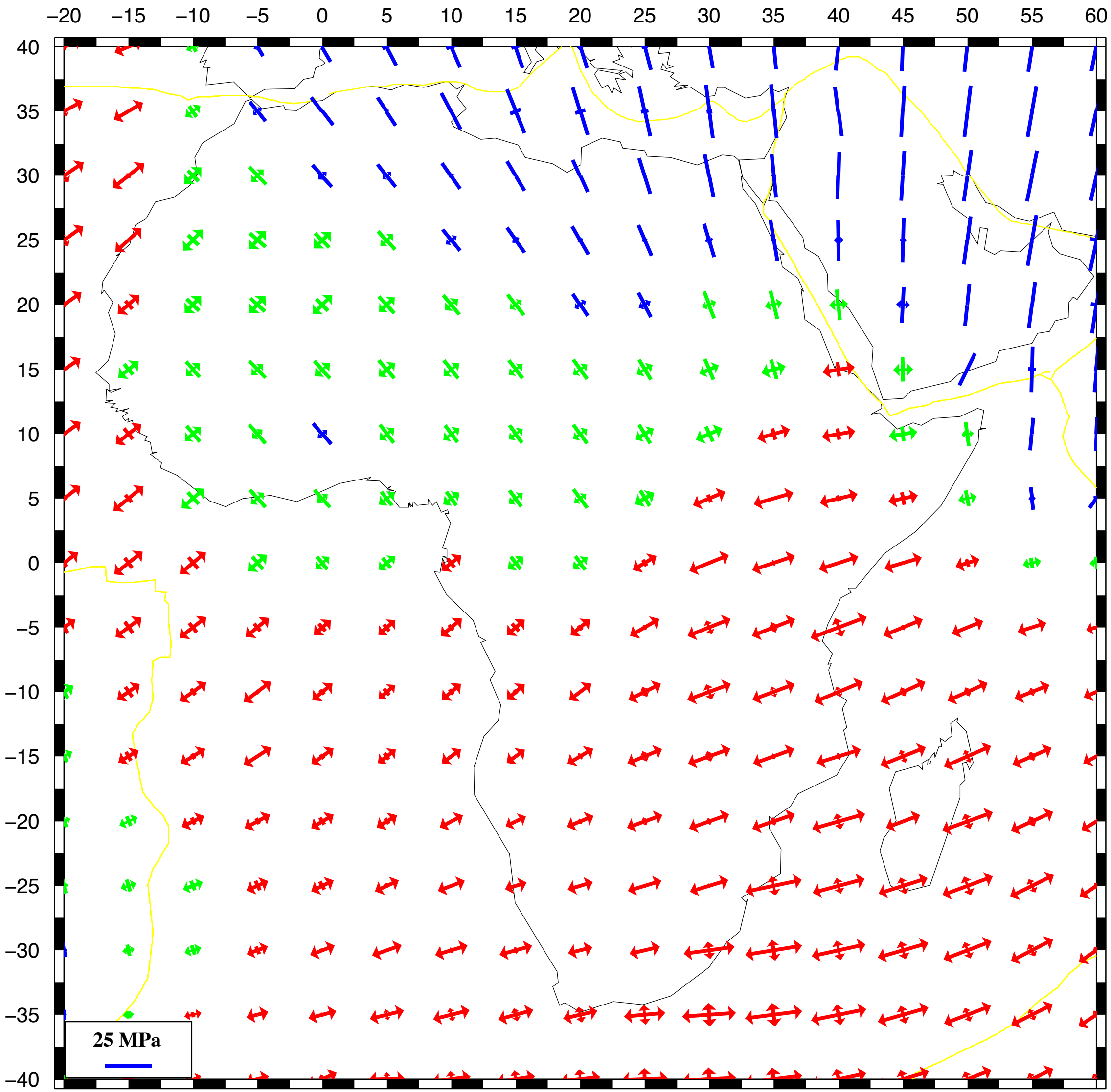




Radial Tractions

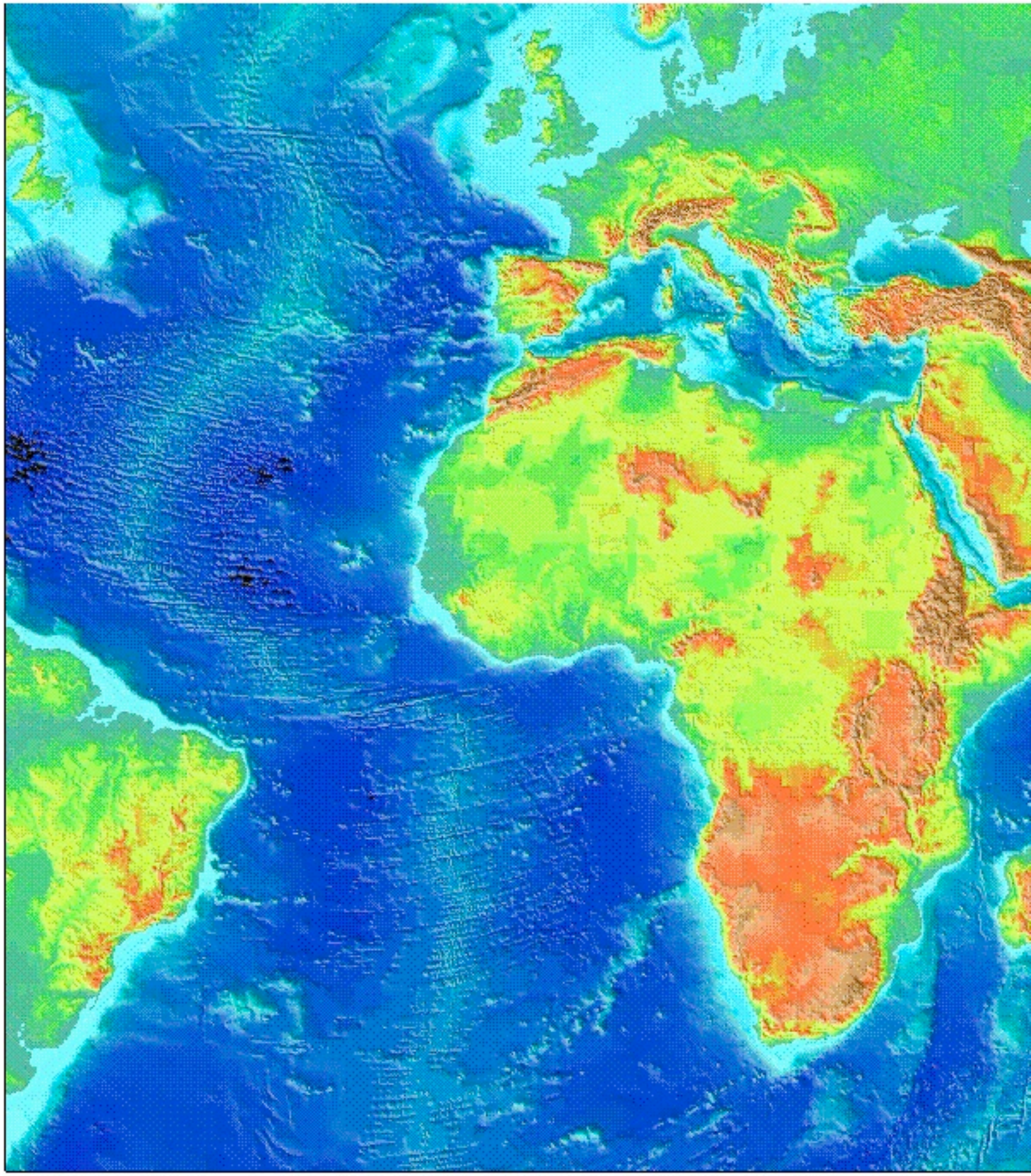
REGIME

Normal
Strike-slip
Thrust



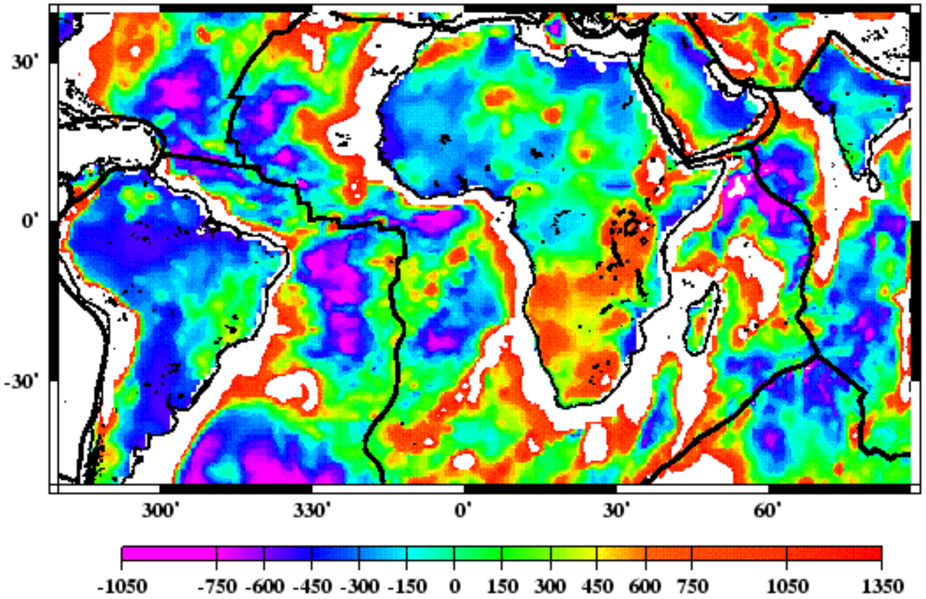
[modified from *Naliboff & Lithgow-Bertelloni, submitted*]

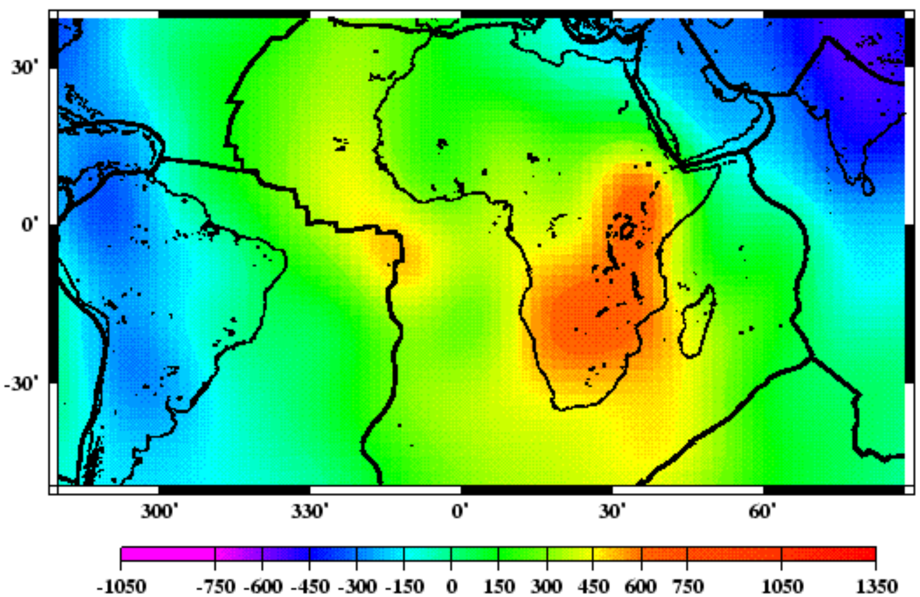
Southern Africa



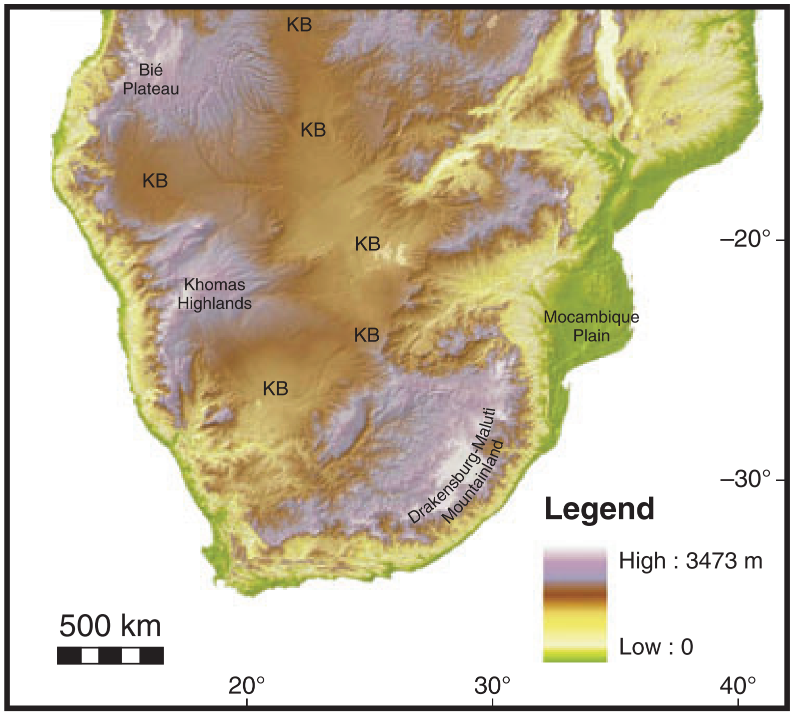
[*Lithgow-Bertelloni & Silver*, 1998]

Southern Africa





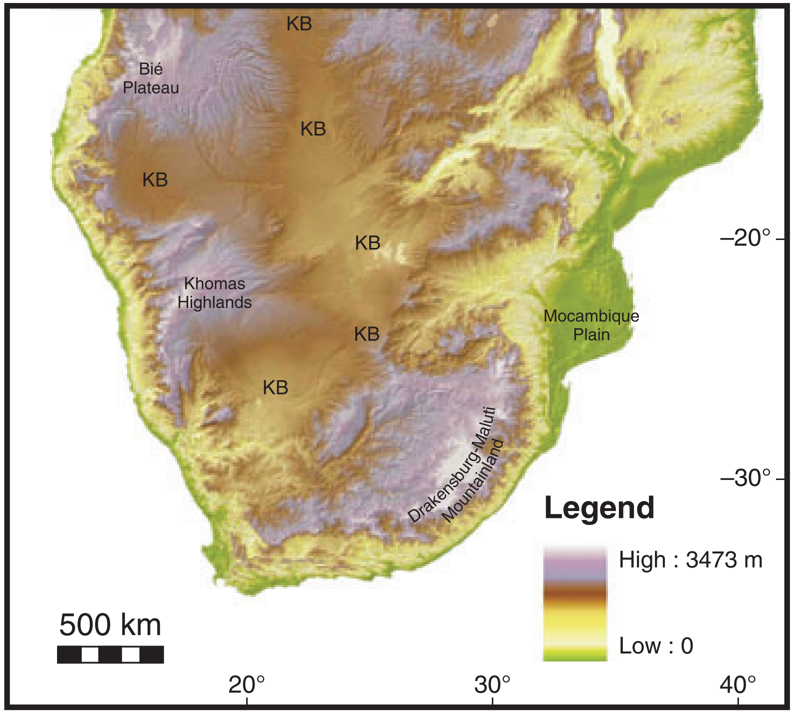
[*Lithgow-Bertelloni & Silver*, 1998]



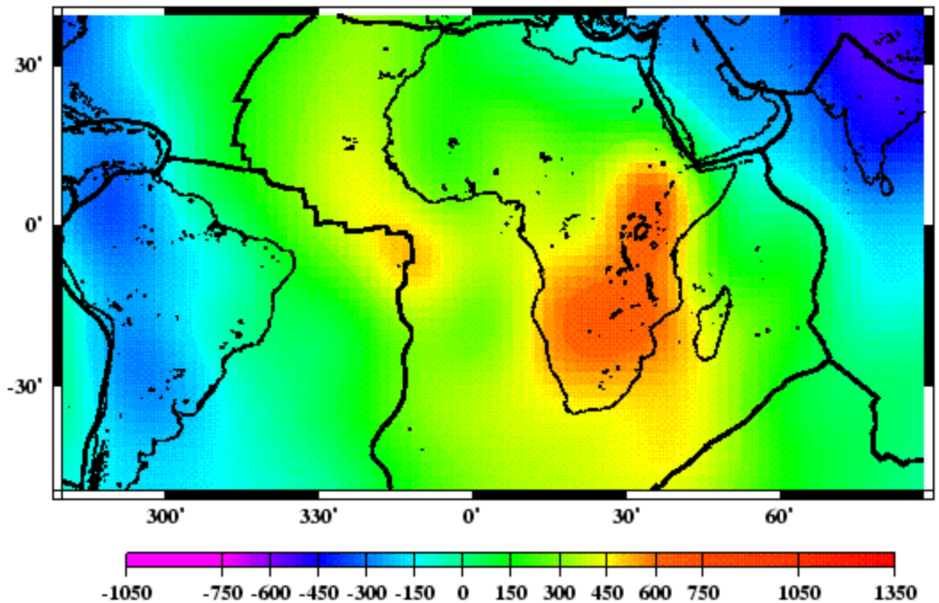
[*Moore et al.*, *2009*]

[*Lithgow-Bertelloni and Silver*, 1998]

But when we look more closely...?

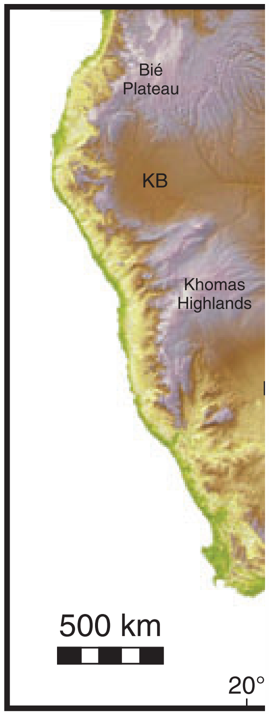


[*Moore et al.*, *2009*]

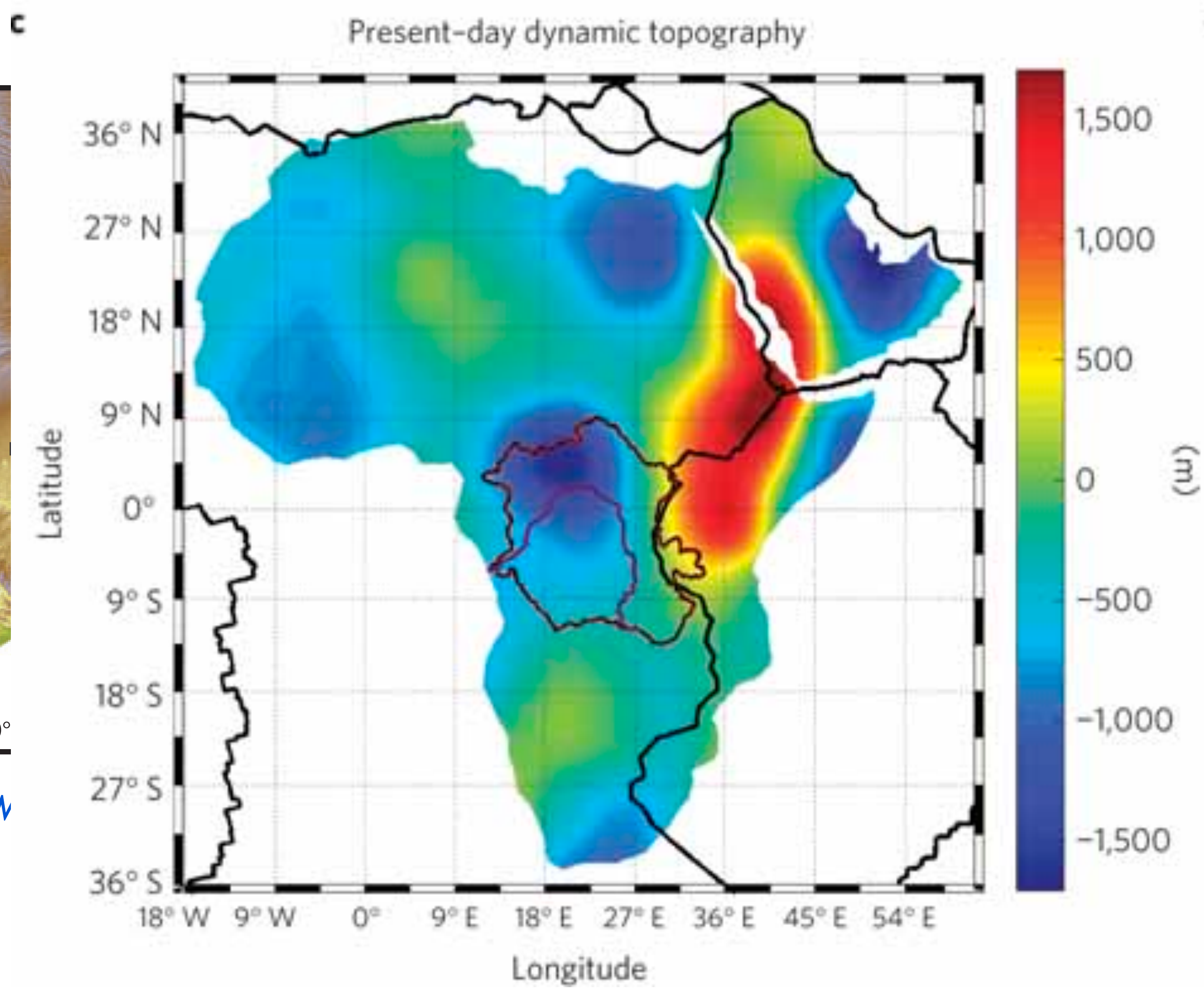


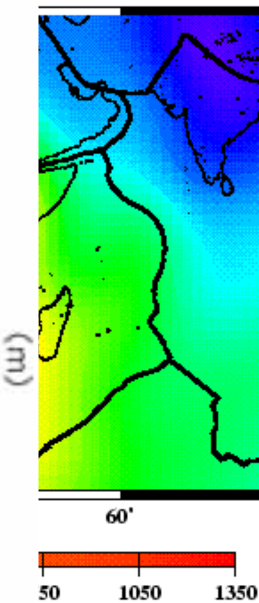
[*Lithgow-Bertelloni and Silver*, 1998]

But when we look more closely...?



[*M*



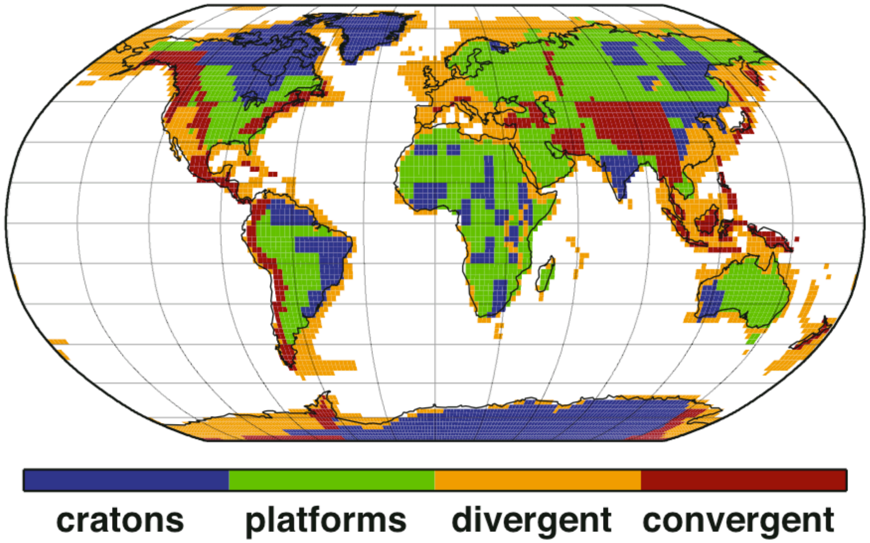


er, 1998]

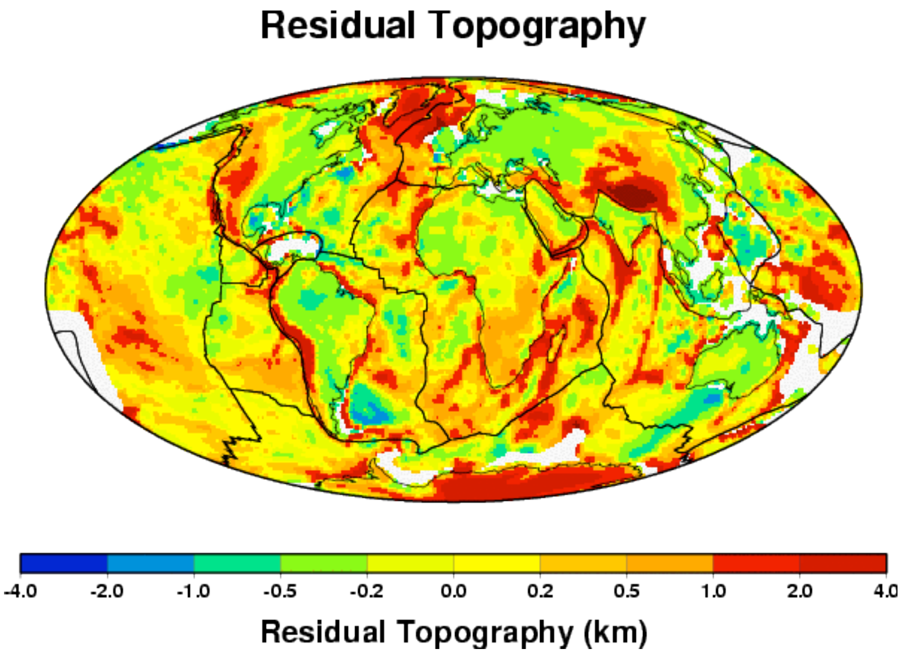
[*Moucha and Forte*, 2011]

“Observed” Dynamic Topography?

“Observed”= Residual = Total - Isostatic



[*Lithgow-Bertelloni and de Koker, in revision*]



Given observed topography determine isostatic contribution:

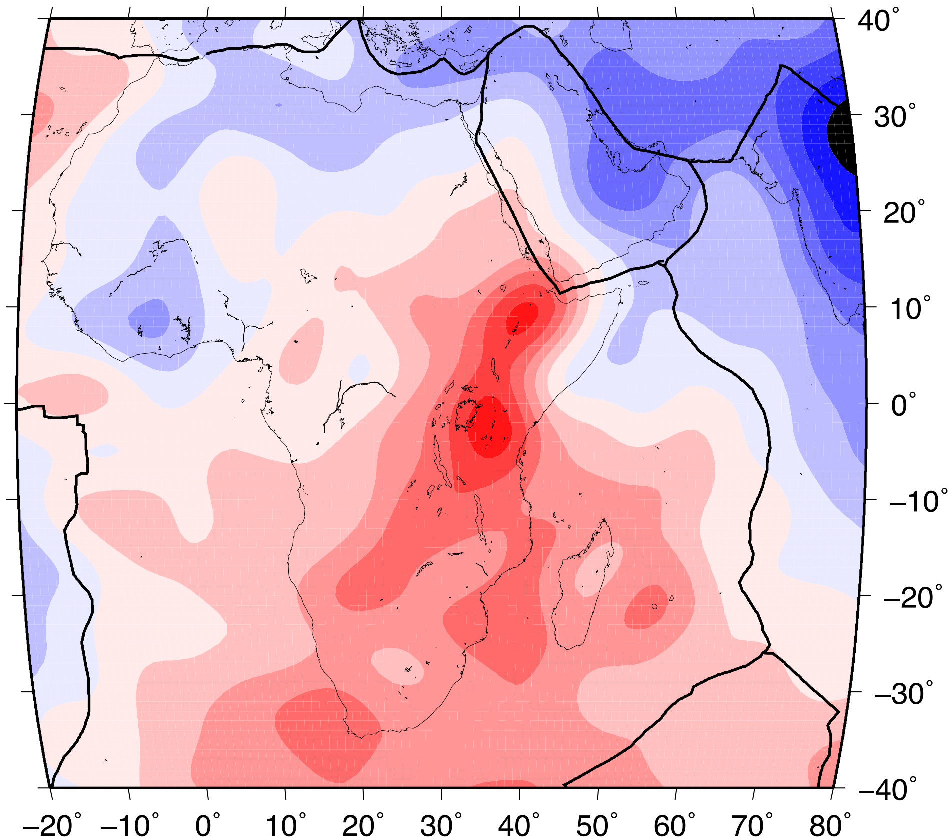
Oceans-Isochrons + Half-space cooling or plate model+ sediments

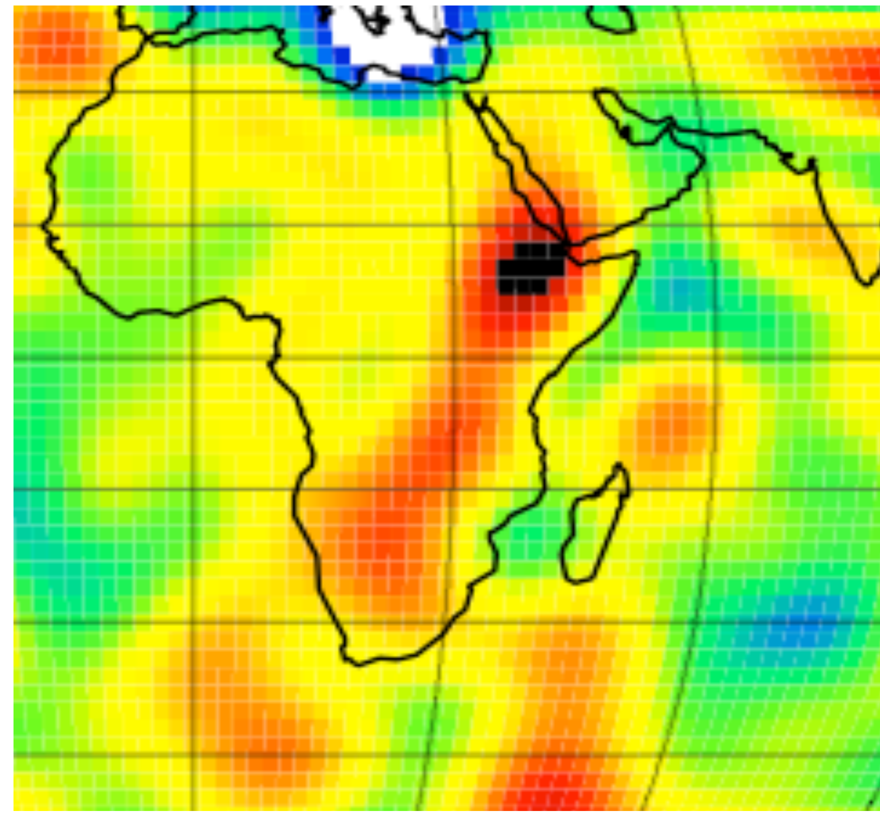
Continents-CRUST 2.0 + lithospheric mantle (depleted and undepleted)

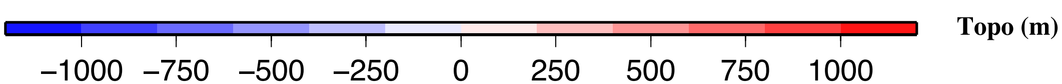
Lithospheric mantle densities computed [*Stixrude & Lithgow-Bertelloni*, 2011]

Thicknesses determined by matching spherically averaged P at 350 km to PREM

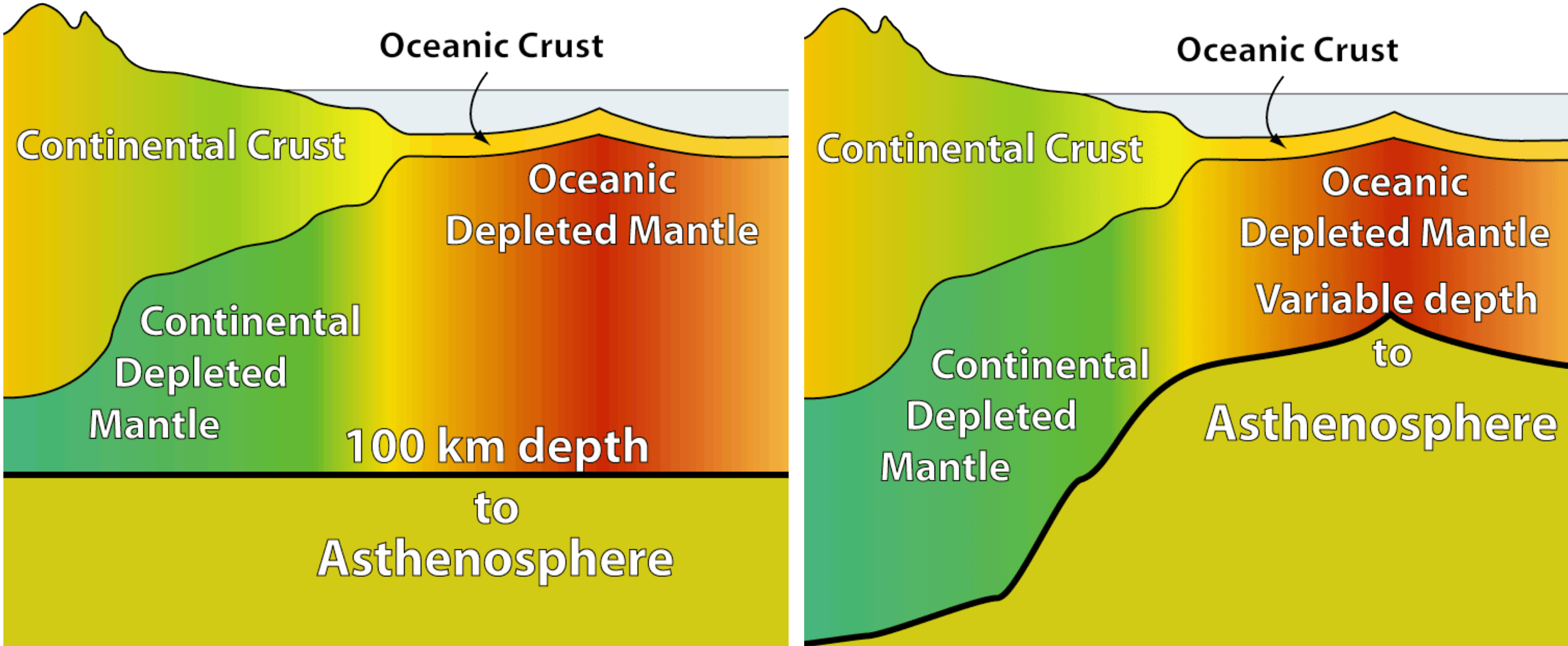
Dynamic Topography from S40RTS







Topography and Lithospheric Structure



$$\frac{\partial \bar{\tau}_{ij}}{\partial x_j} = \frac{\partial \bar{\tau}_{zz}}{\partial x_i} - \frac{\partial \Omega}{\partial x_i}$$

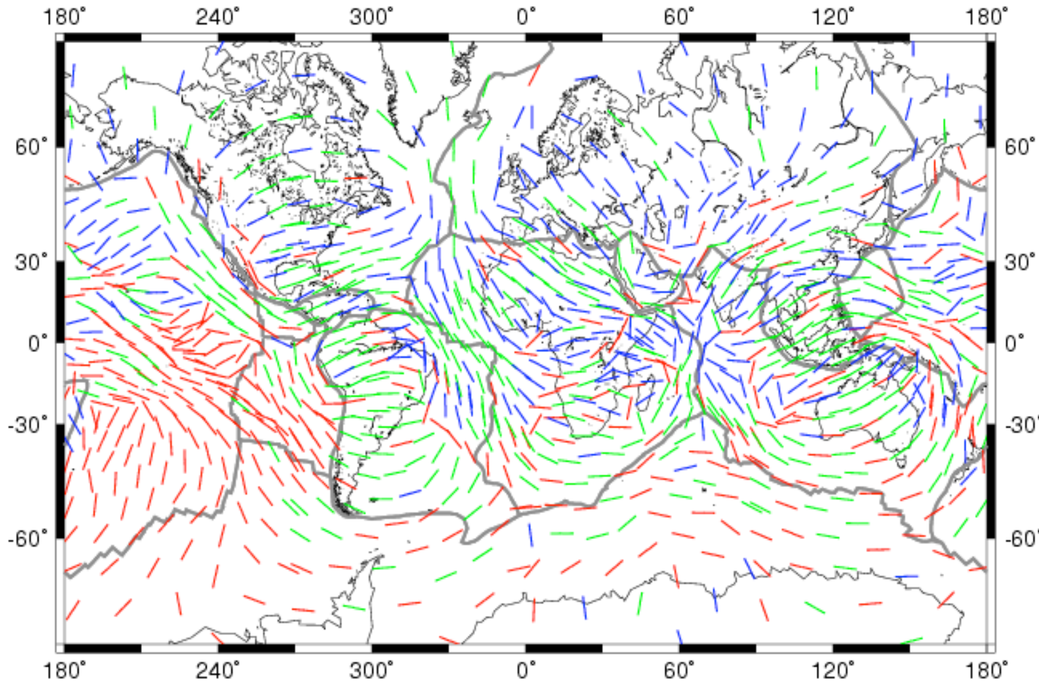
[*England and McKenzie*, 1986]

$$\Omega = \bar{\sigma}_{zz} = \frac{1}{L+h}\int_{-L}^{h} \sigma_{zz}\, dz = -\frac{1}{L+h}\int_{-L}^{h} dz \int_{z}^{h} g\rho(z')\,dz'$$

Crustal Contribution

-CRUST2.0

Fit to observations (Variance Reduction)
Azimuth-42%
Regime-46%



REGIME

Normal
Strike-slip
Thrust

[*Lithgow-Bertelloni and Guynn*, 2004]

Crustal Contribution

-CRUST2.0

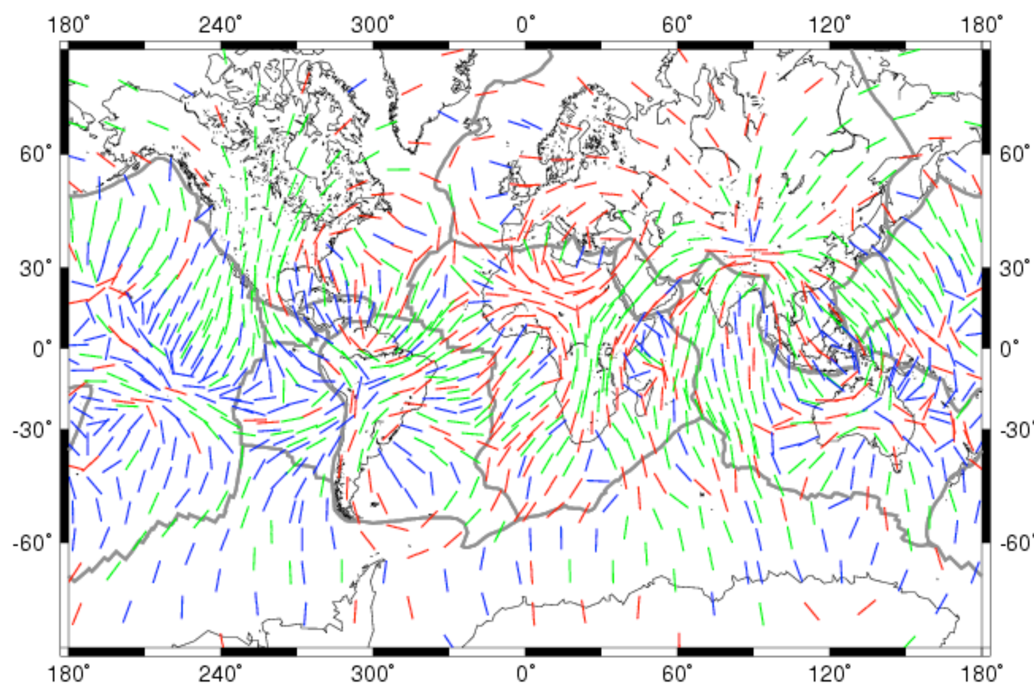
Fit to observations (Variance Reduction)
Azimuth-42%
Regime-46%

-CRUST2.0 (Pratt Compensation)

Fit to observations (Variance Reduction)
Azimuth-20%
Regime-39%

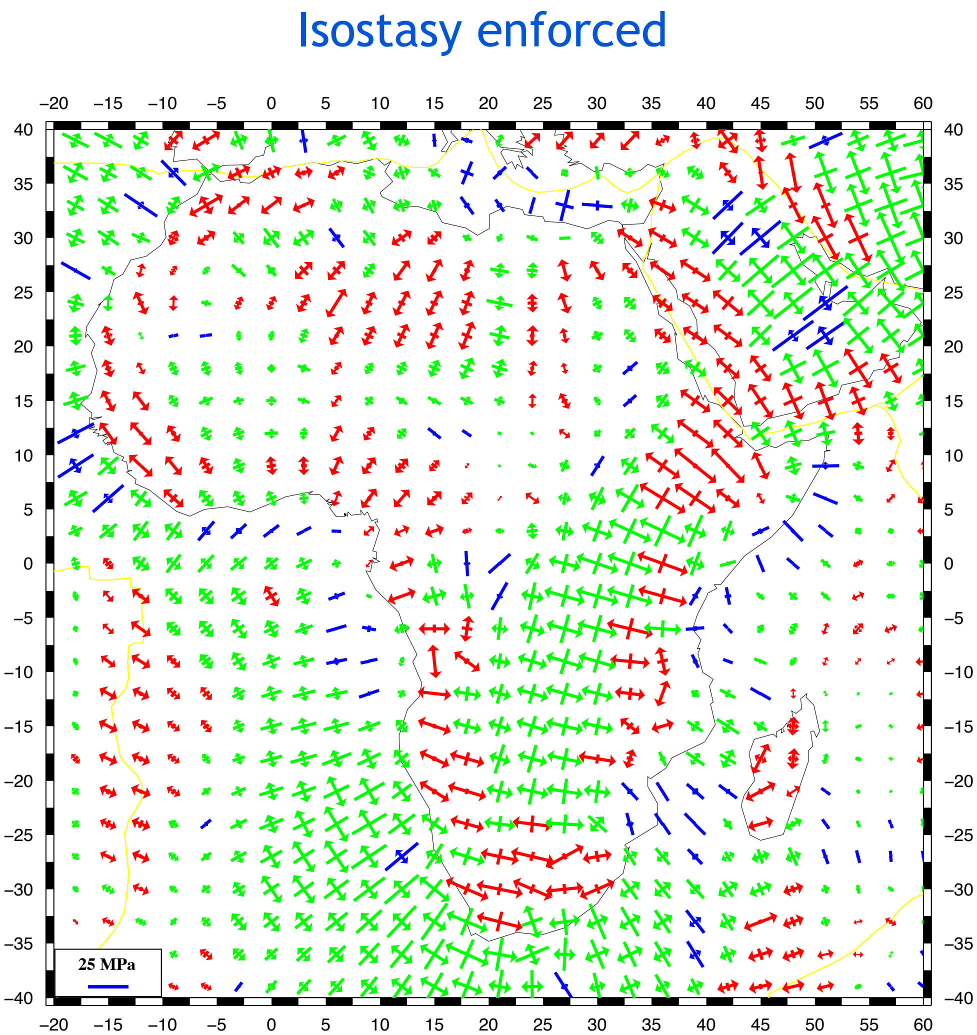
REGIME

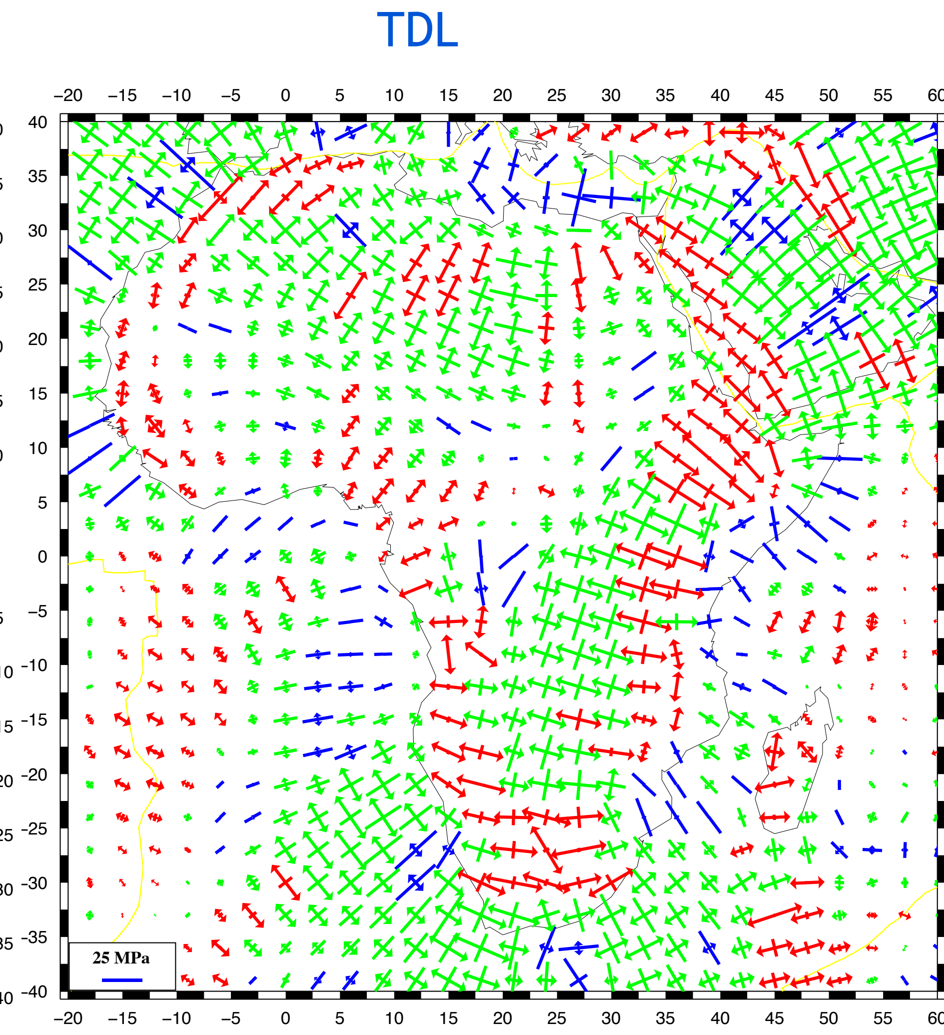
Normal
Strike-slip
Thrust



[*Lithgow-Bertelloni and Guynn*, 2004]

Effects of Lithospheric Structure





[modified from *Naliboff*, *Lithgow-Bertelloni et al.*, 2011]

Primary Results and Implications

What do we see?

-lithospheric heterogeneity and dynamic topography dominate the stress signal in Africa
-horizontal mantle tractions are large... but do not match stress patterns, how to decouple?
-Lithospheric structure assumptions CRUCIAL both in density and rheological structure!
- Choice of mantle density heterogeneity also matters

What does it mean?

-Africa strongly coupled to mantle flow via radial tractions (i.e. dynamic topography)
    -lateral variations not crucial
    -lateral, vertical variations in lithospheric (crustal?) rheology, probably very important
-Dynamic topography very important to explain African topography, but what is the right mantle structure?

What do we need to do?

-Complete crustal, lithospheric structure needed
-Better representations of lithospheric and mantle rheology (crustal...)
-temporal evolution of stress field