The effect of Earth's rotation on mantle convection

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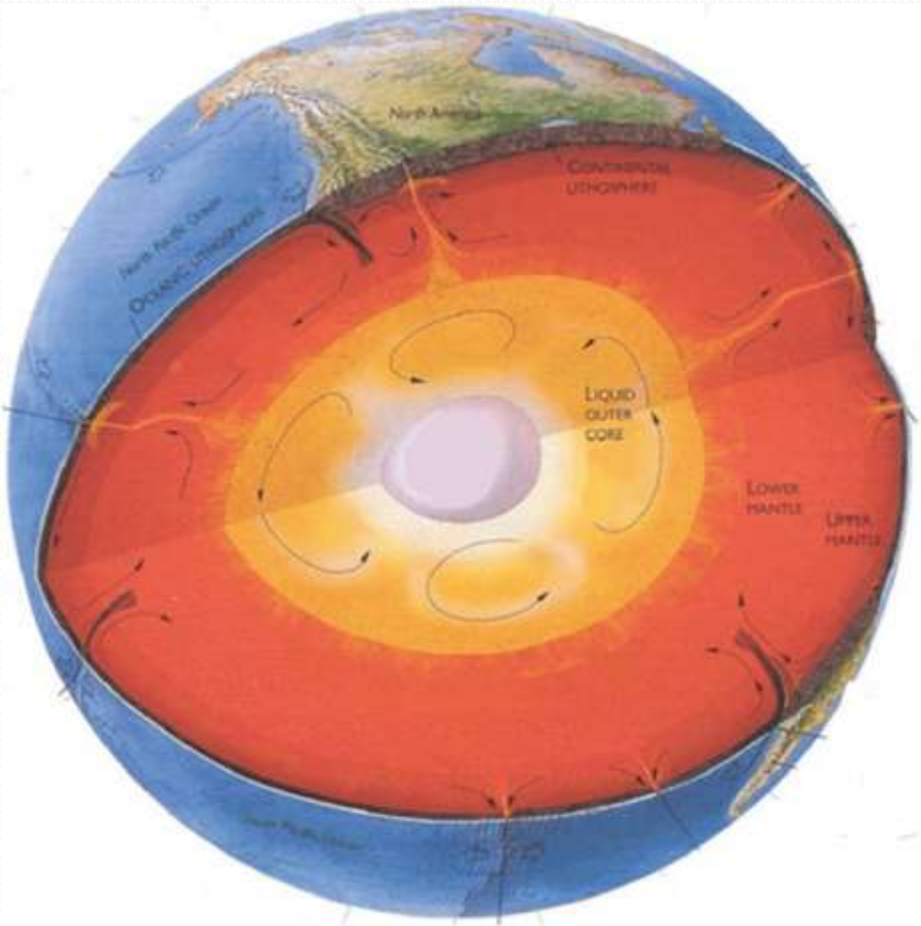
Overview of the presentation

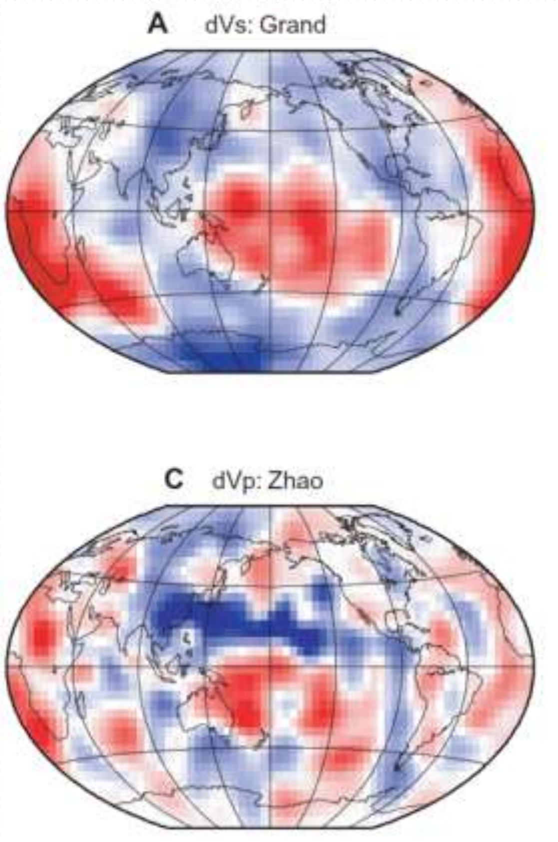
- Introduction
  - Earth’s internal structure
  - Governing equations, Centrifugal force
- First model (Diffusion)
  - Effect of the density contrast
  - Effect of the rotation
- Second model (Diffusion + convection)
- Conclusions and further plans

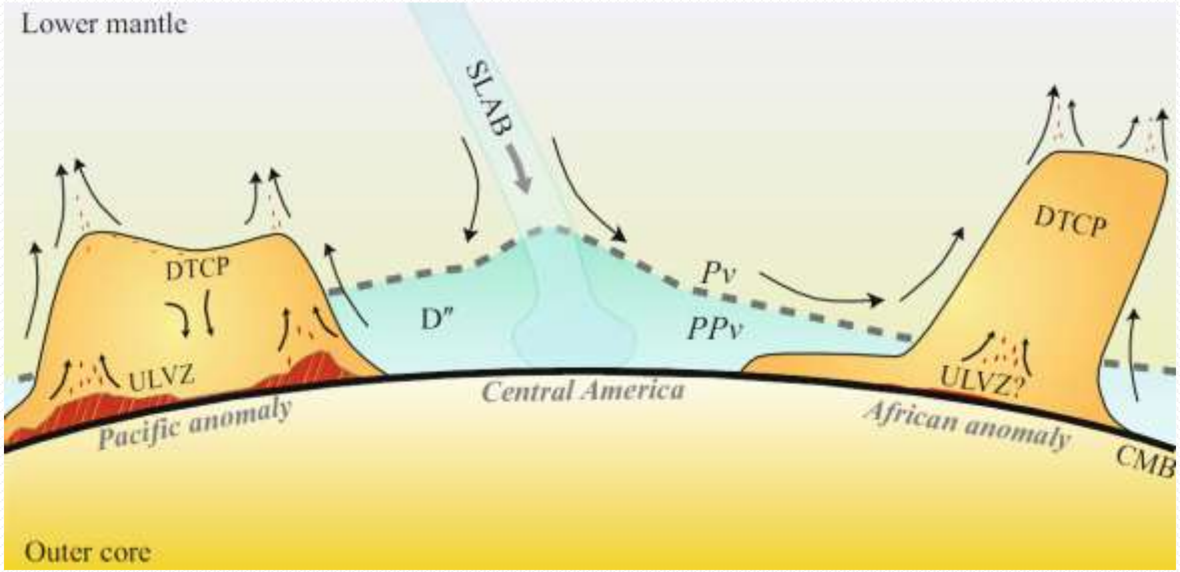
Earth’s internal structure



- Course, well separable layers
- Each layer has rather complicated structure
- Complex convectional patterns in the mantle

The mantle and the large low shear velocity provinces (LLSVP)





Governing equations

Conservation of mass

$$\boxed{\frac{\partial u_i}{\partial x_i} = 0}$$

Centrifugal force

Conservation of momentum

$$\boxed{\rho_0 \frac{du_i}{dt} = -\rho g e_i + \rho(\omega_i \omega_j - \delta_{ij}\omega^2) r_j - \frac{\partial p}{\partial x_i} + \eta \frac{\partial^2 u_i}{\partial x_j^{\,2}}}$$

Mass/Heat transport

$$\boxed{\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x_i^{\,2}} - u_i \frac{\partial c}{\partial x_i}} \qquad \boxed{\frac{\partial T}{\partial t} = \kappa \frac{\partial^2 T}{\partial x_i^{\,2}} - u_i \frac{\partial T}{\partial x_i}}$$

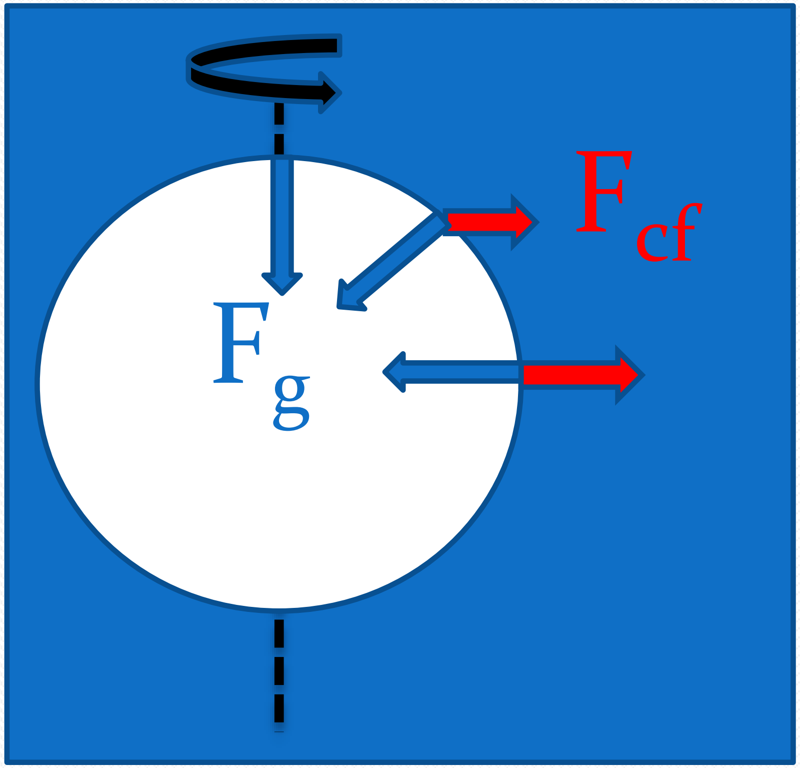
+ State equation

$$\boxed{\rho g e_i = \rho_0 (1 - \alpha \cdot \delta T + \beta \cdot c) g e_i}$$

Centrifugal force

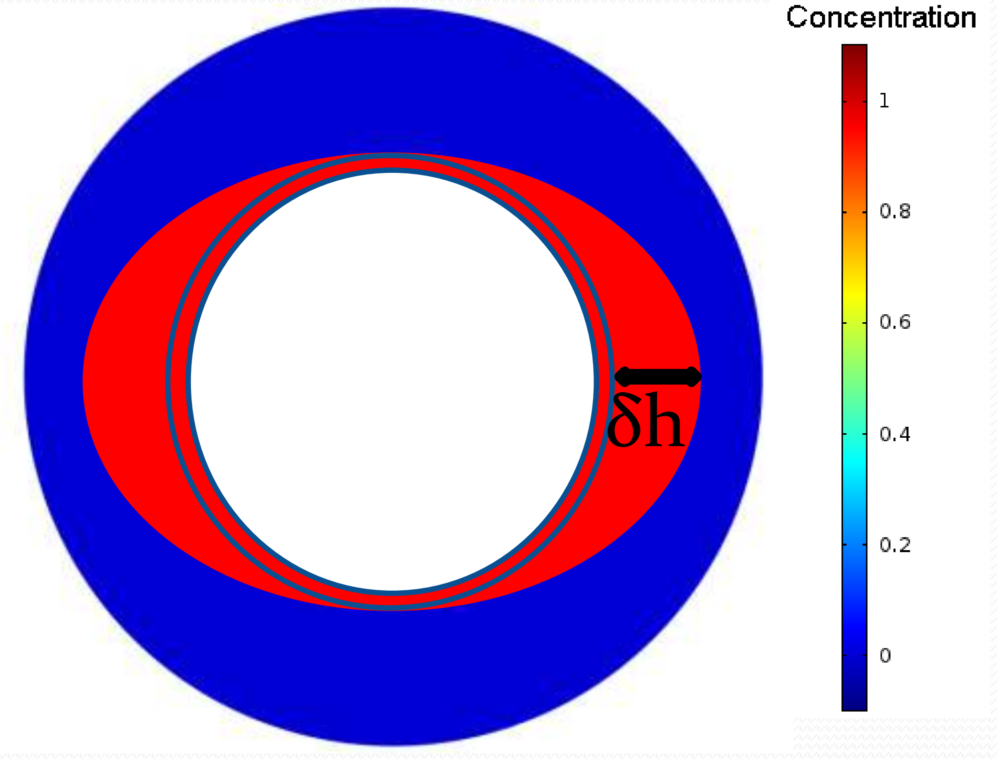
- Acts perpendicular to the axis of rotation
- It is proportional with the distance and with the square of angular velocity

How does it influence the convection in the Earth's mantle?



Modell 1

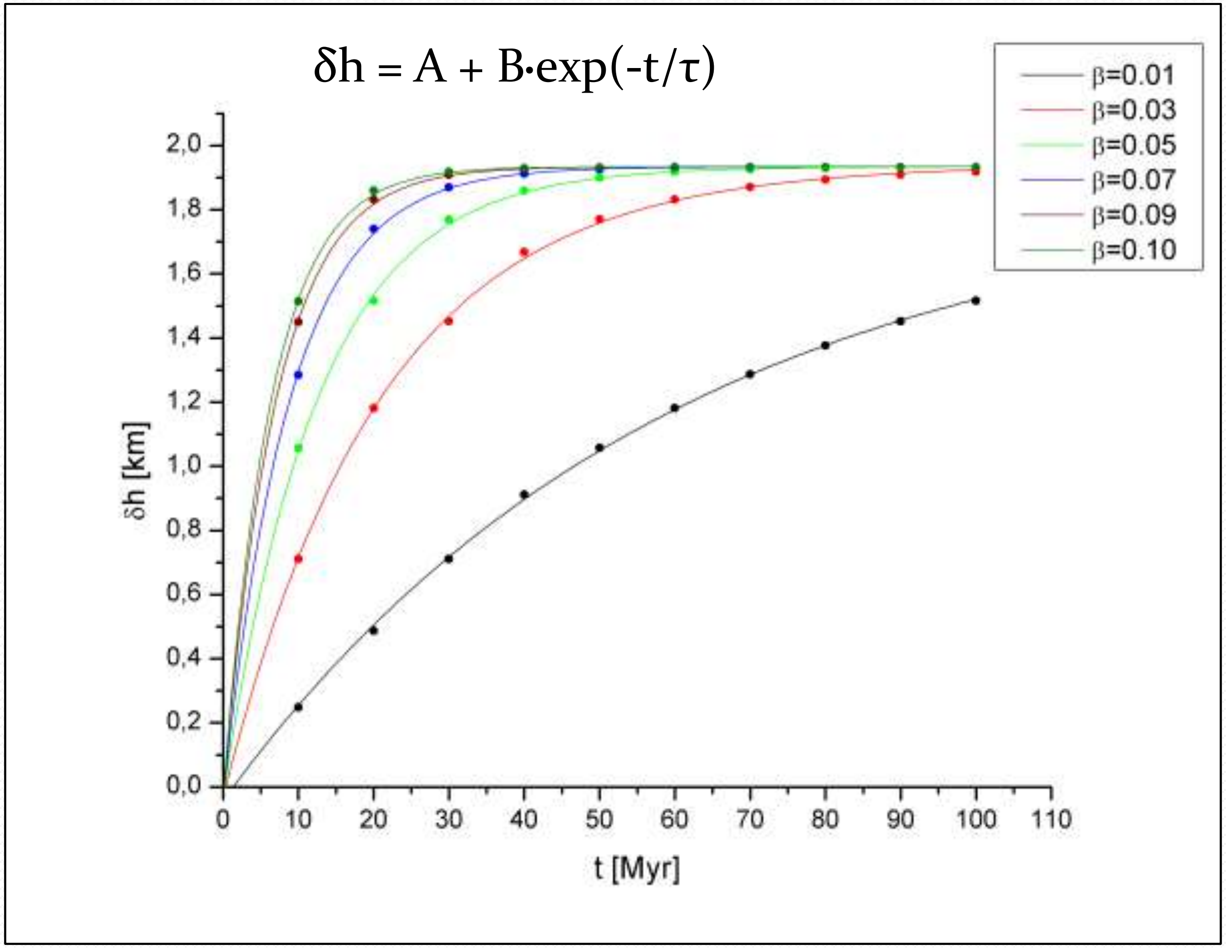
- Two-layered model without temperature difference
- The two layers differs in chemical density (parameter β carrying the relative density difference)
- The main parameter is the elevation anomaly of the dense layer



Initial condition

Effect of the density contrast

- In different models the relative density difference, β varies from 1% to 10%
- All fitted functions converges to the same value (approx. 2 km), but their characteristic times (τ) are different
- Characteristic times are inversely proportional to β

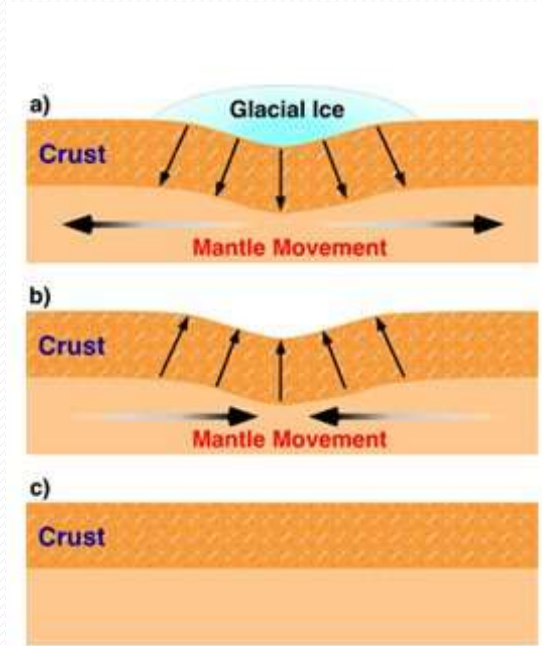


$\Omega = \Omega_0 = 7.29 \cdot 10^{-5}$ 1/s

Analogy:

- Post glacial rebound
  - Relaxation time

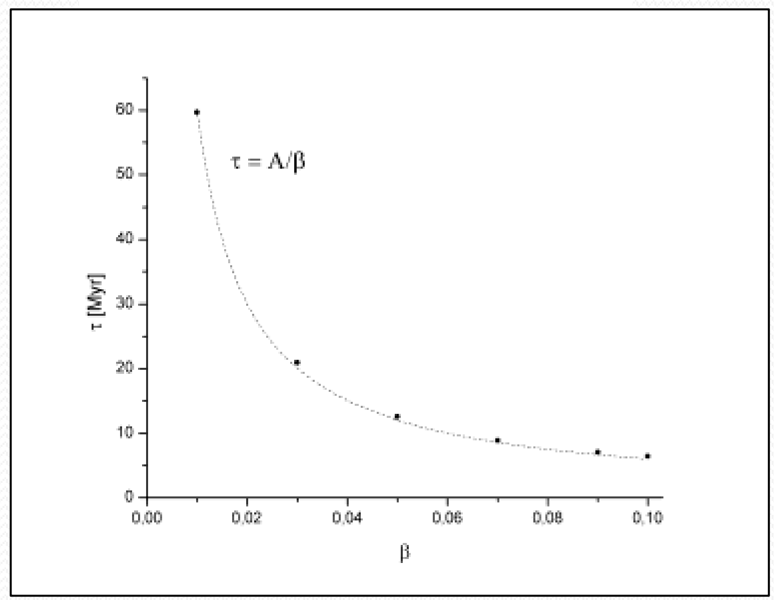
$$w(x,t) = w_0(x)\exp\left(-t/\tau\right)$$



$$\tau = \frac{4\pi\eta}{\rho g \lambda} \longrightarrow \tau \sim \frac{1}{\rho}$$

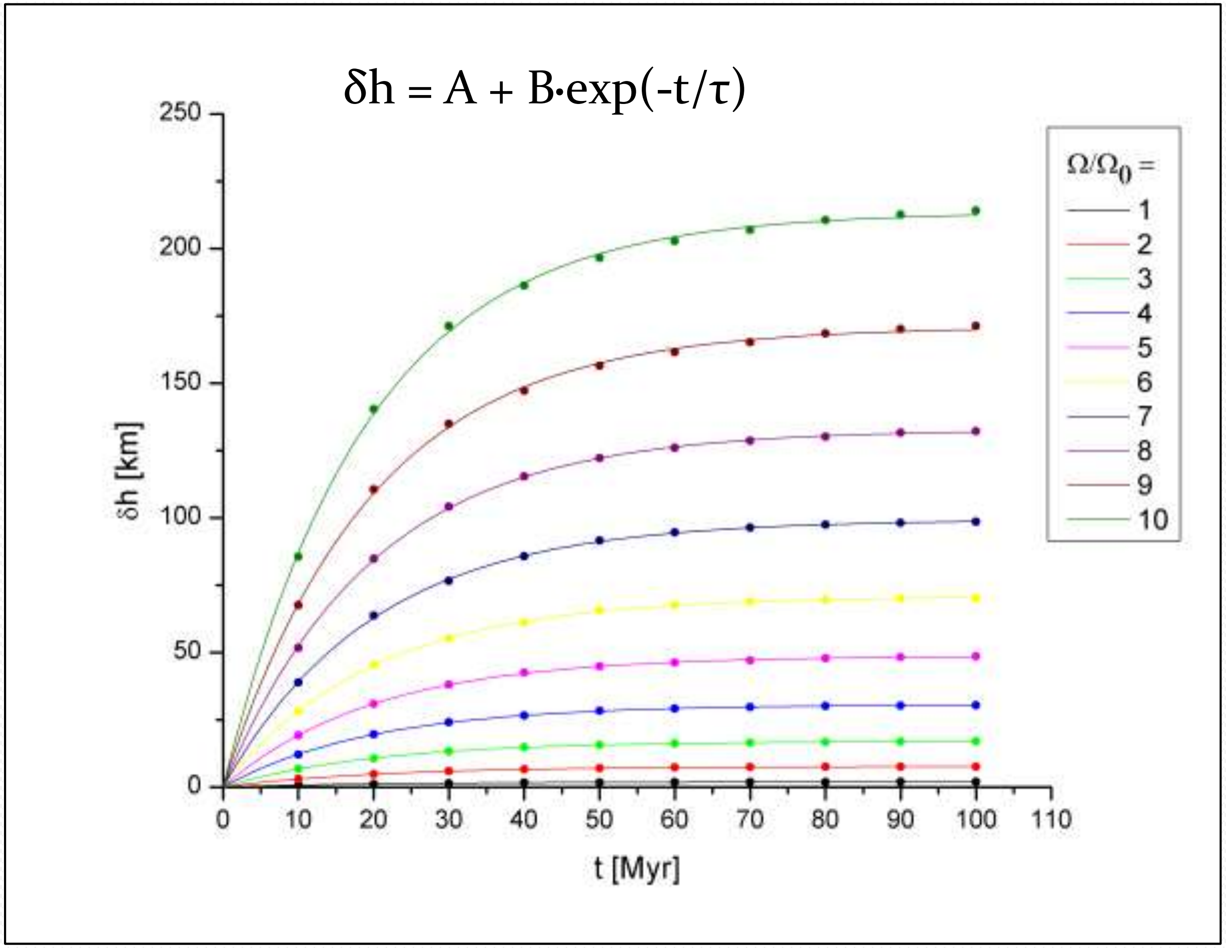
$$\updownarrow$$

$$\tau \sim \frac{1}{\beta}$$



Effect of the rotation

- Higher angular velocity larger elevation anomaly (δh)
- Elevation anomaly is proportional to the square of angular velocity
- The relaxation time does not depend on the magnitude of rotation

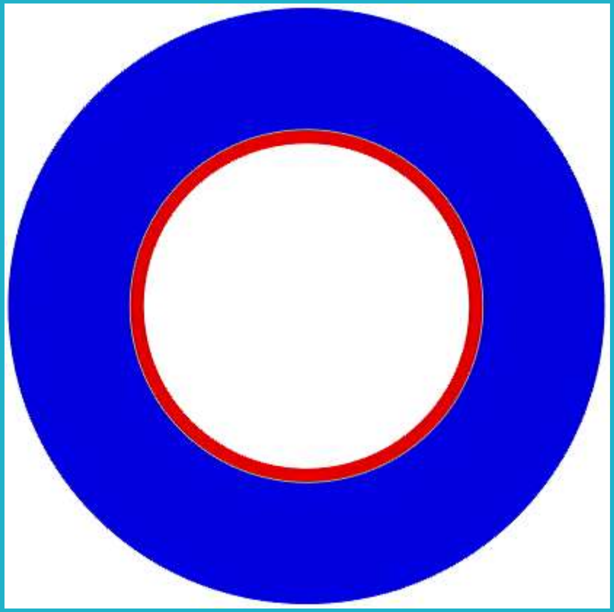


β = 3 %

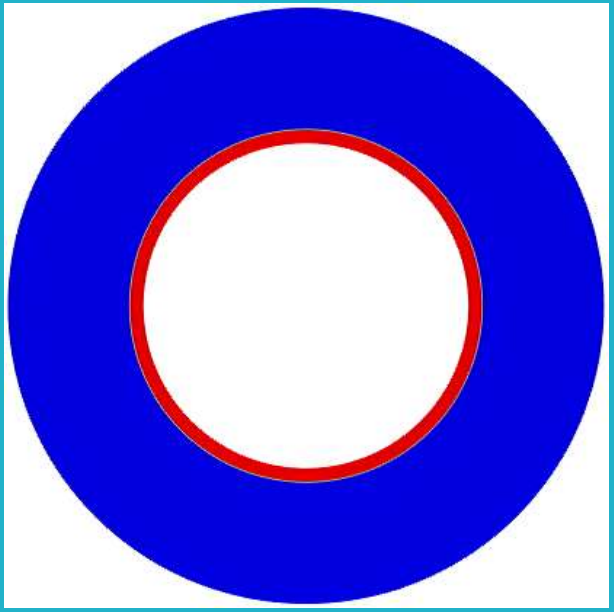
Critical angular velocity

Estimation of the angular velocity, where the centrifugal force and the gravitation force is approximately equal (at medium height):

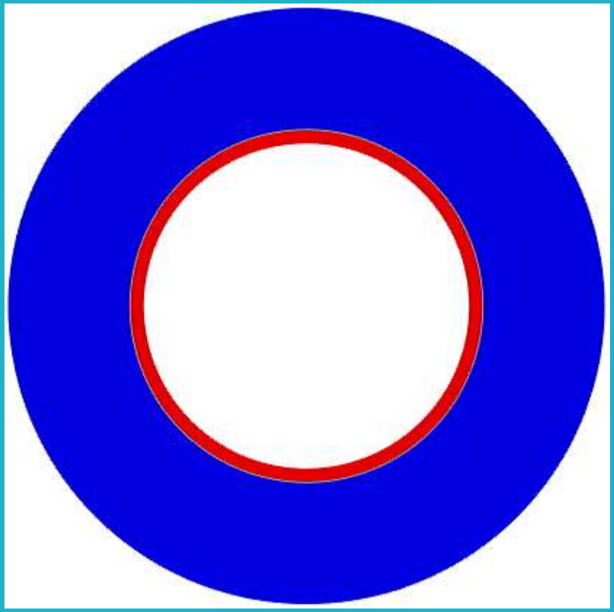
$\rho g = \rho \Omega^2 x$ $\Omega = \mathrm{sqrt}(g/x) = 1.41\ 10^{-3}\ 1/s \approx 19.4\ \Omega_0$



$\Omega/\Omega_0 = 10$



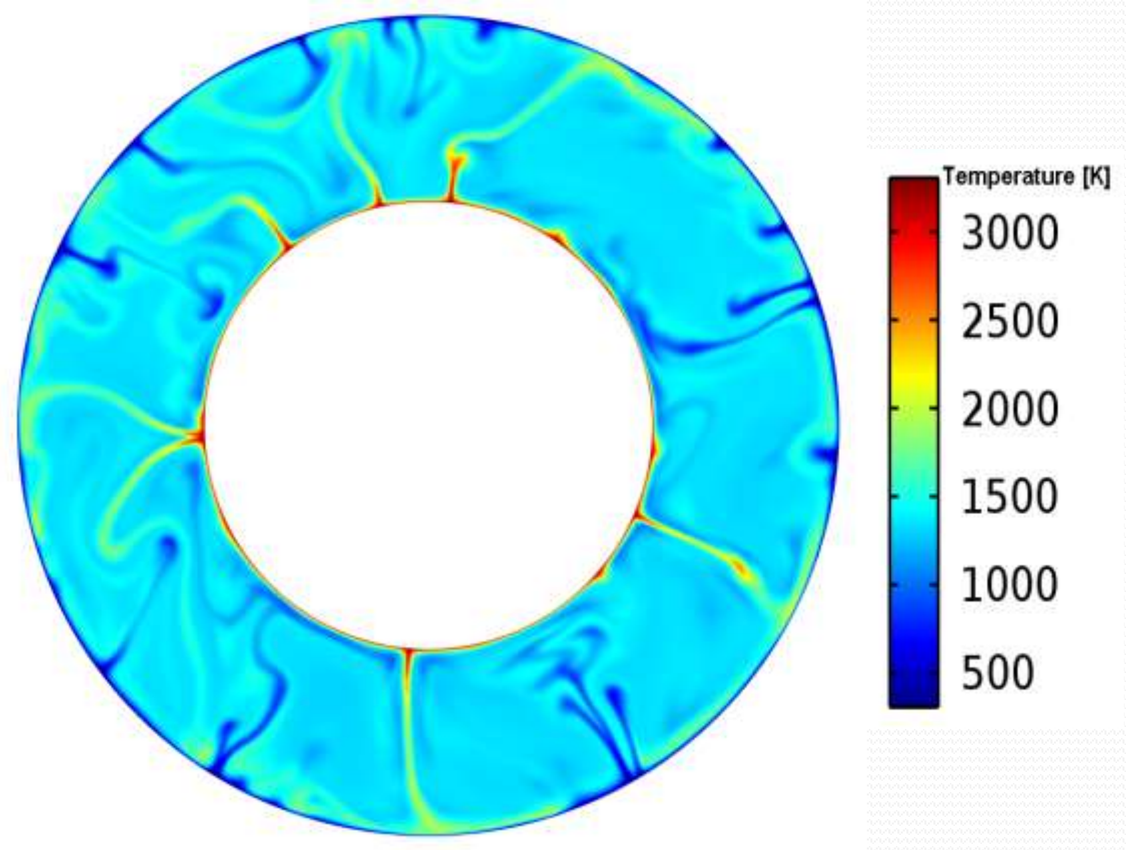
$\Omega/\Omega_0 = 19$



$\Omega/\Omega_0 = 40$

Modell 2

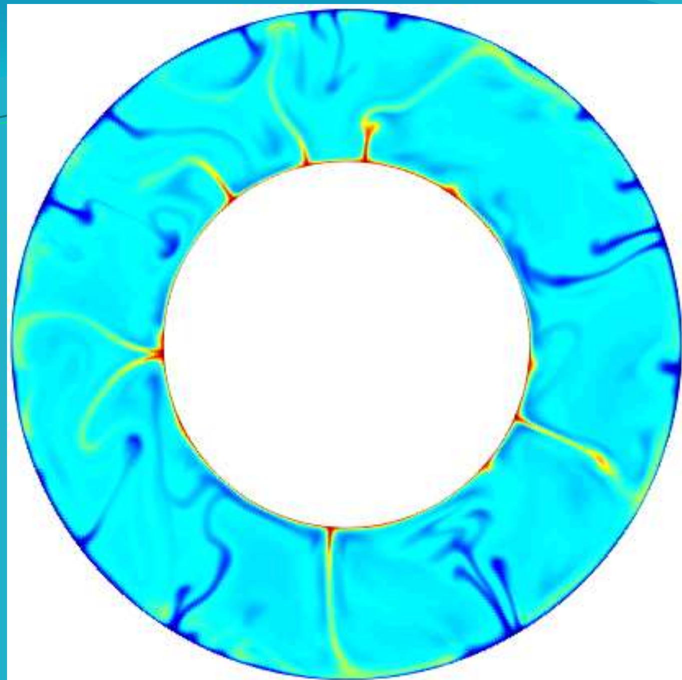
- Thermal convection in a quasi-stationary state
- Four models, one without rotation and the others with different magnitude of the angular velocity (Ω/Ω_0 = 0,1, 10,100)



Initial condition

$\Omega/\Omega_0=$

0



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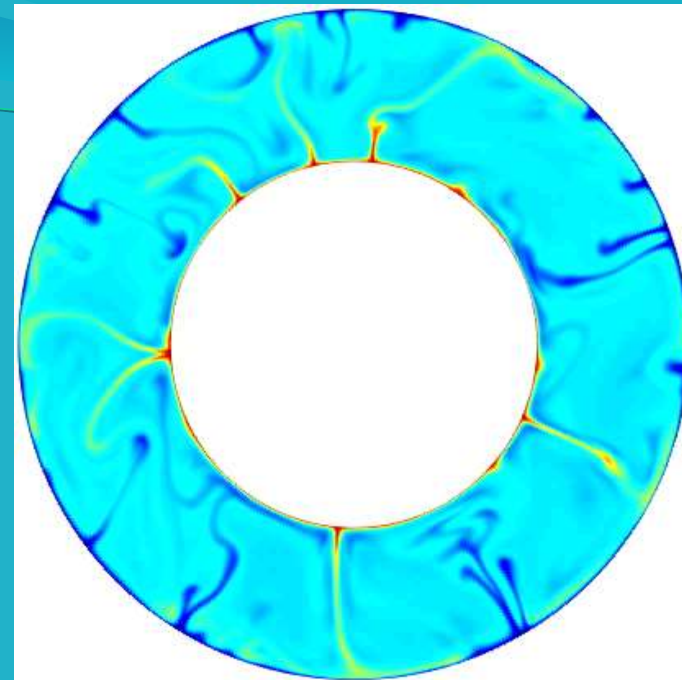

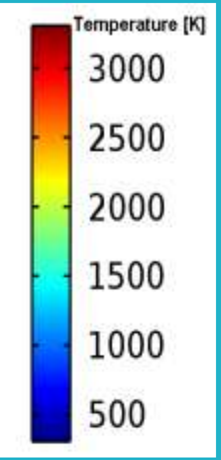

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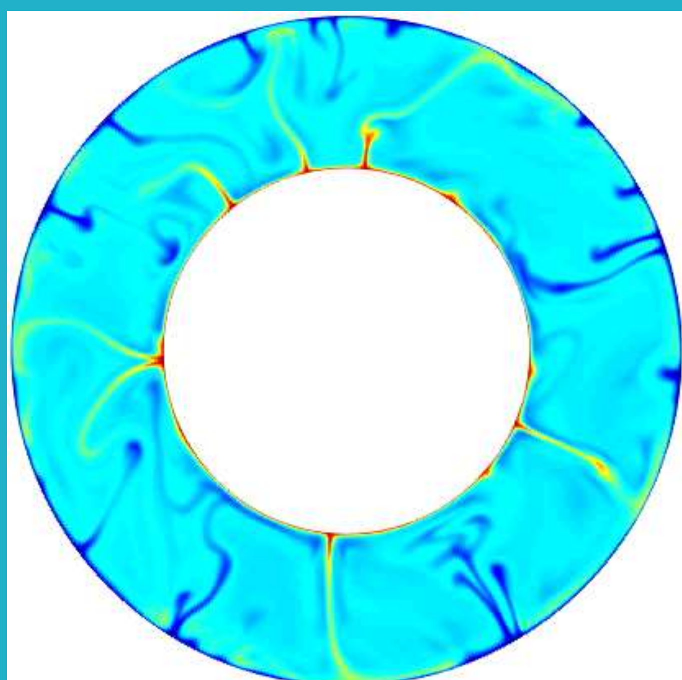
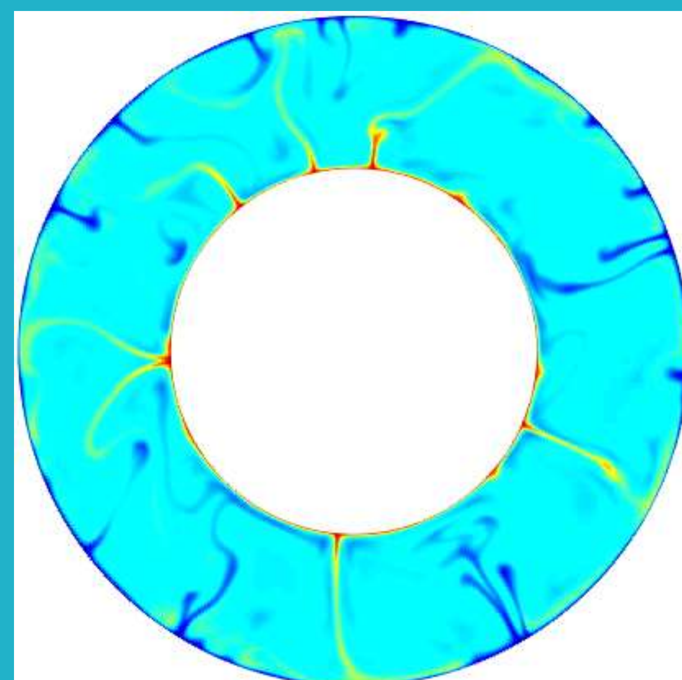
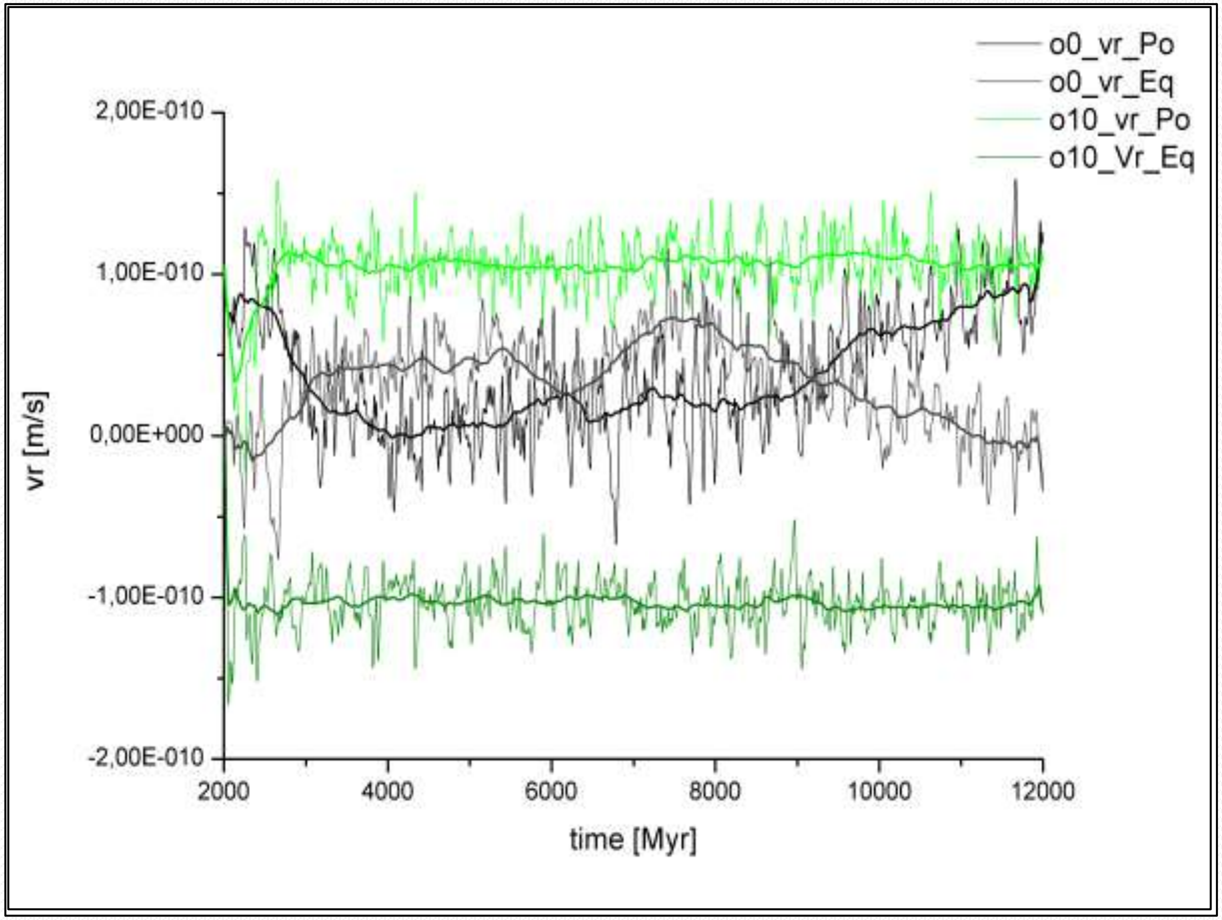


100



Angular velocity

- Direction dependent mass transport
- Different characters:
    - Ω/Ω_0=10: Increasing average temperature
    - Ω/Ω_0=100: Decreasing average temperature



Conclusions

- Deformation of the dense layer (δh) is independent of the relative density contrast (β), however the characteristic time of the deformation (τ) depends on it
- The time-dependence of deformation has exponential nature, τ is inversely proportional to β (analogy: Postglacial Rebound)
- δh is proportional to the square of rotation velocity, the characteristic time is independent of the rotation
- Lower angular velocity (Earth) has no relevant effect on the model results, higher rotation influences the system significantly

Further plans

- Further thermal convection models
- Investigation of thermo-chemical convection (thermal convection with chemical dense layer)

Thank you for your attention!