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A benchmark comparison of numerical topography:

what are suitable sticky air parameters?

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NGU Norges geologiske undersøkelse

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Motivation

- So far in usual Eulerian numerical models of mantle convection:

  - vertically fixed free slip upper boundary

    with

  - traction-derived dynamic topography

    but

  - no “real” topography (i.e. bending of lithosphere)

➡ sticky air approach

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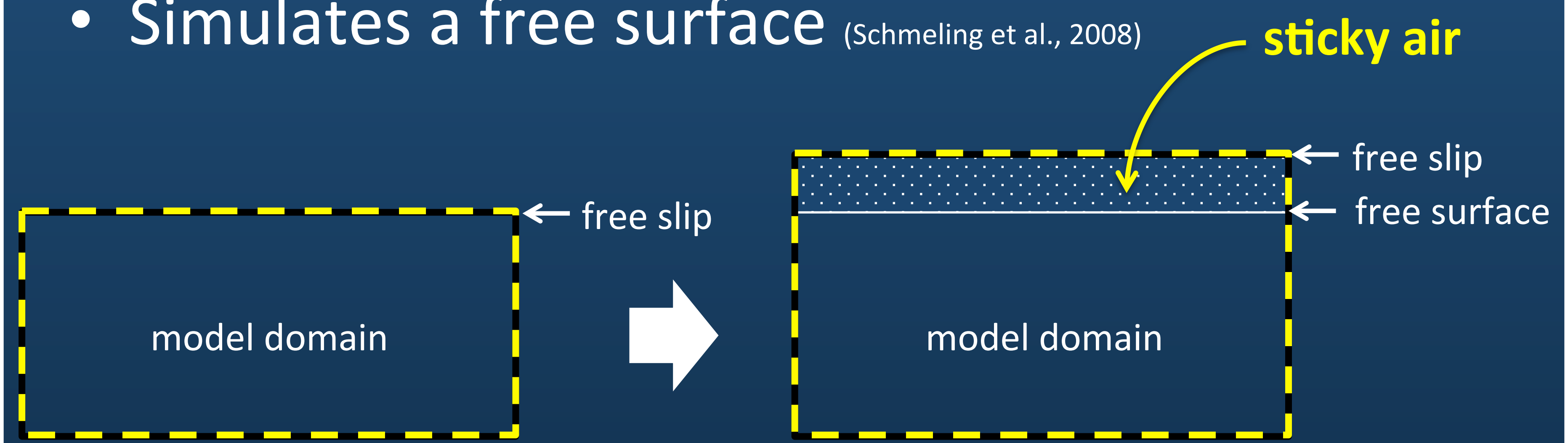
Motivation

"sticky air"

- "Low" viscosity, zero density layer

  ($\eta_{st} \approx 10^{19}$ Pa·s, $\rho_{st} = 0$ kg/m^3)

- Below a free slip top boundary
- Simulates a free surface (Schmeling et al., 2008)



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Motivation

- It is important to choose the sticky air parameters wisely:
    - Computation time
    - Physical accuracy

- Need for guidelines for suitable sticky air implementation

➡ analytics & benchmark

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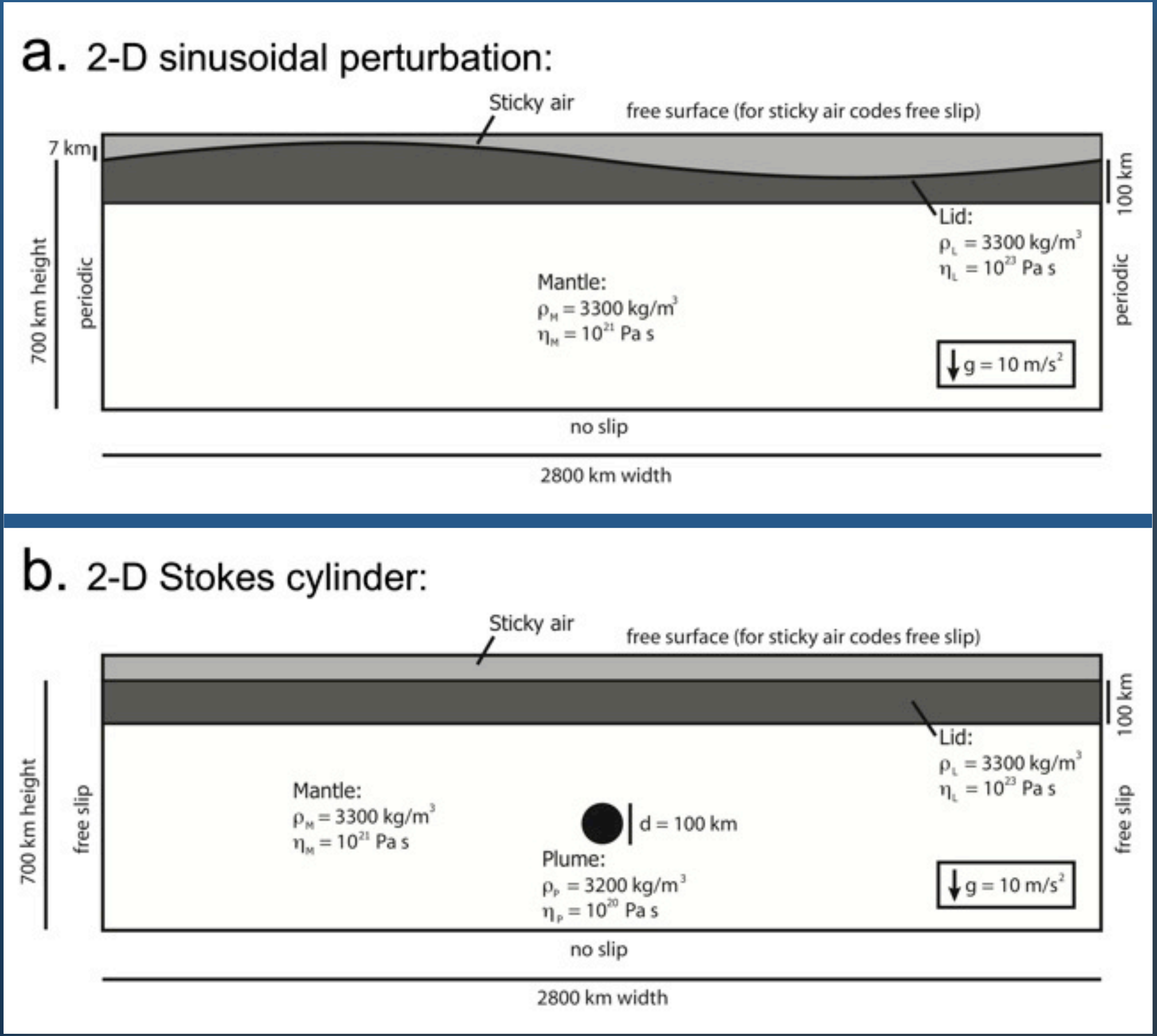
Methodology: model setup

2 cases:

Topography decay

Analytical solution available!
(Ramberg, 1967)

Rising plume



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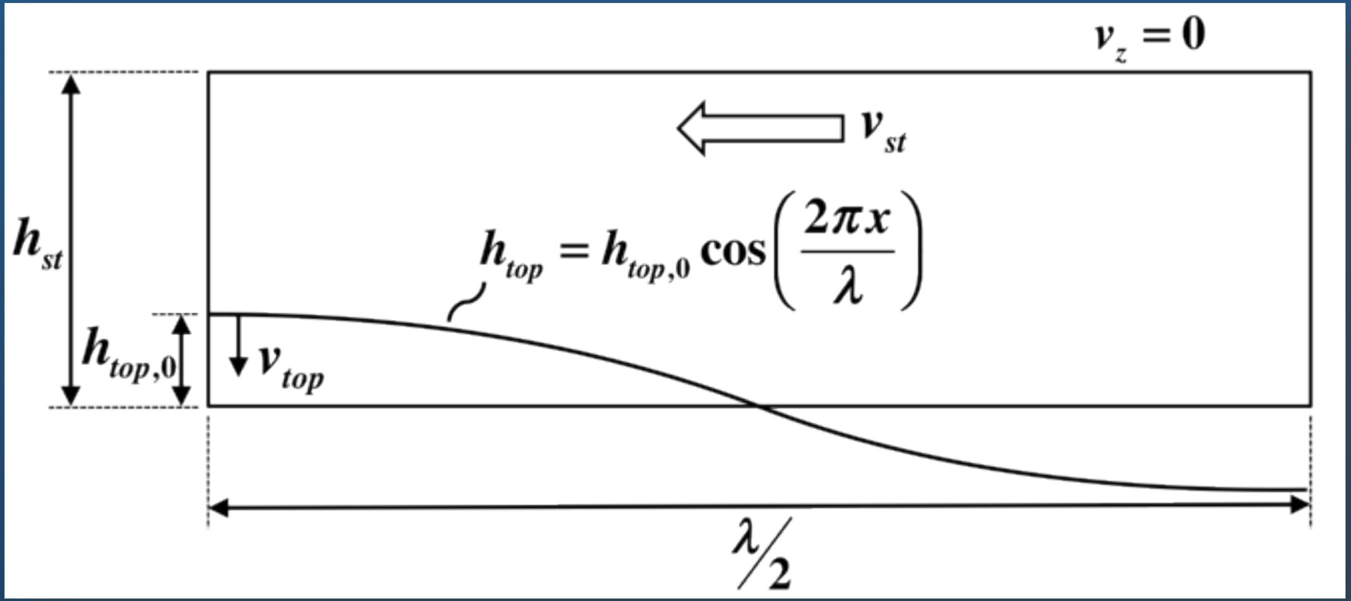
Methodology: analytics

- Free surface conditions from channel flow



Traction free surface if: $\boxed{C << 1}$ (i.e. h_{st}=thick; η_{st}=low)

A

$$C_{\max} = \frac{3}{2\pi^3}\left(\frac{L}{h_{st}}\right)^3 \frac{\eta_{st}}{\eta}$$

Isostatic relaxation time

B

$$C_{Stokes} = \frac{1}{16}\frac{\Delta\rho}{\rho}\left(\frac{h_{model}}{h_{st}}\right)^3 \frac{\eta_{st}}{\eta}$$

Stokes time scale

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Methodology: numerics

Numerical codes:

	Code	Upper boundary:
FEM	• MILAMIN_VEP (Golabek, Kaus)	free surface
FEM	• SULEC (Buiter)	free surface / sticky air
FEM	• UNDERWORLD (May)	sticky air
FDM	• FDCON (Schmeling, Orendt)	sticky air / free slip
FDM	• I2VIS (Duretz, Gerya)	sticky air
FDM	• STAGYY (Crameri, Tackley)	sticky air

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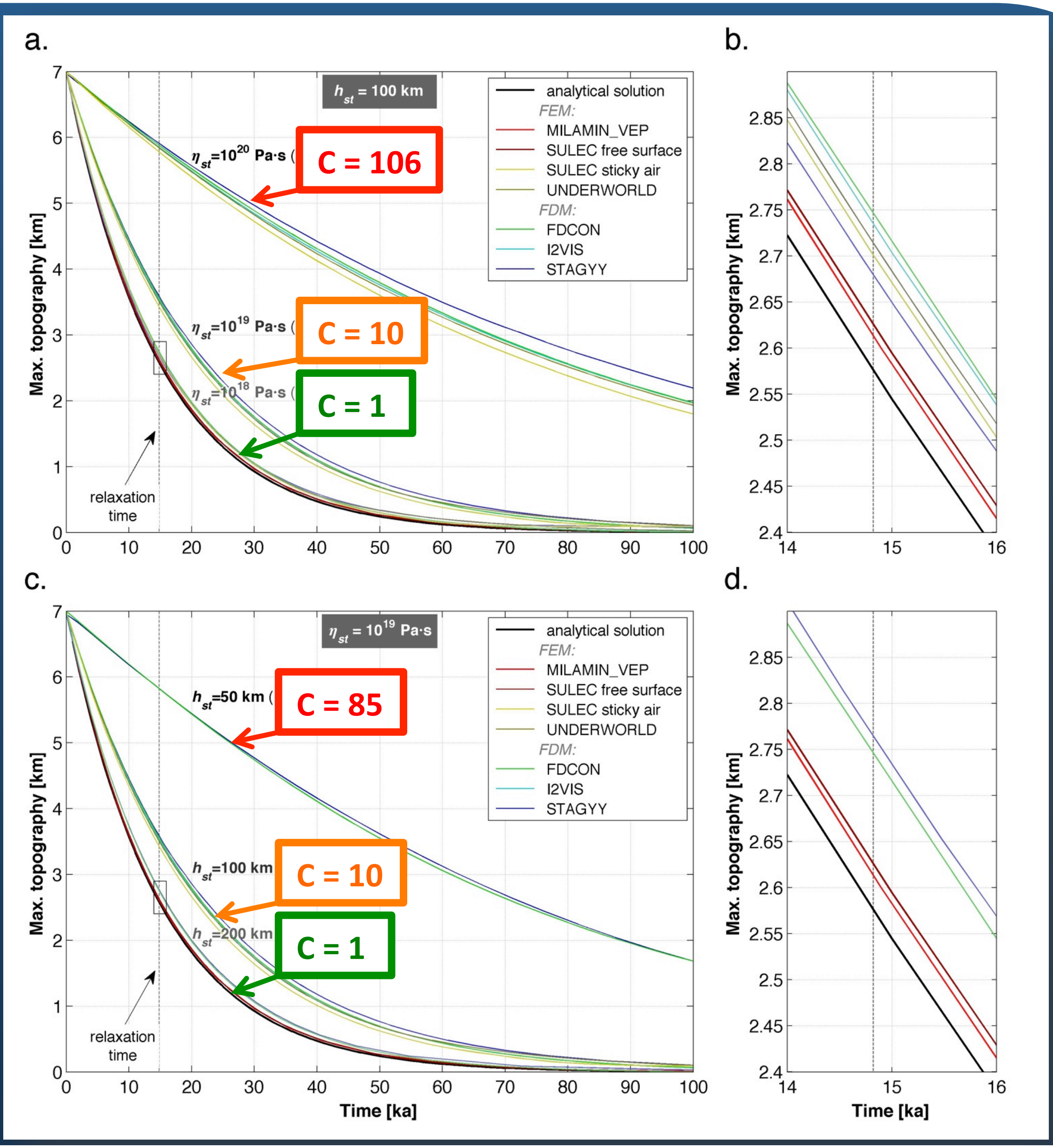
Results: Case 1

$$C_{max} = \frac{3}{2\pi^3}\left(\frac{L}{h_{st}}\right)^3 \frac{\eta_{st}}{\eta}$$

Change in viscosity:

Change in thickness:



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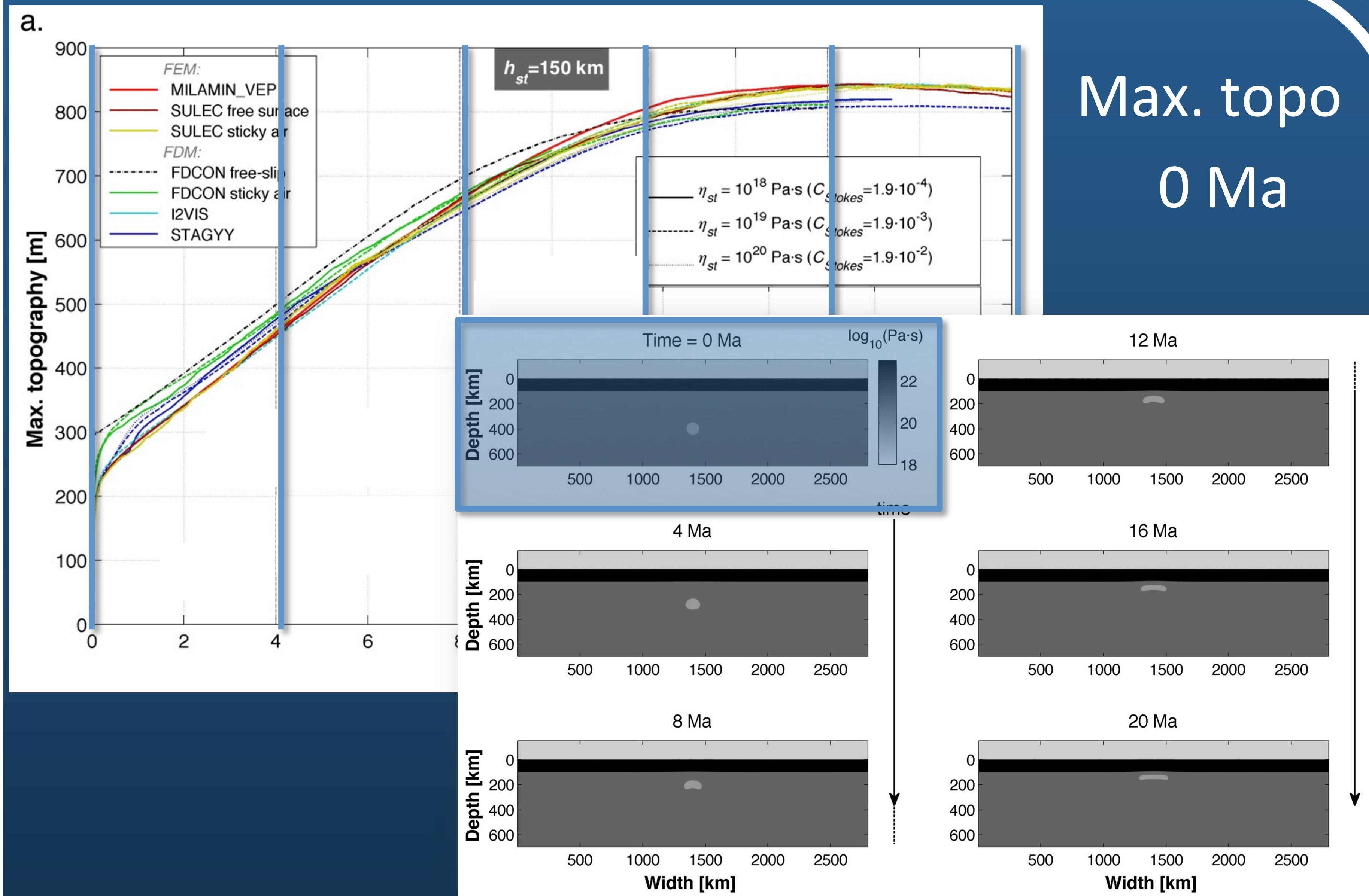
Results: Case 2



Max. topo

0 Ma

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Results: Case 2

h_{st} = 150 km, variable viscosity

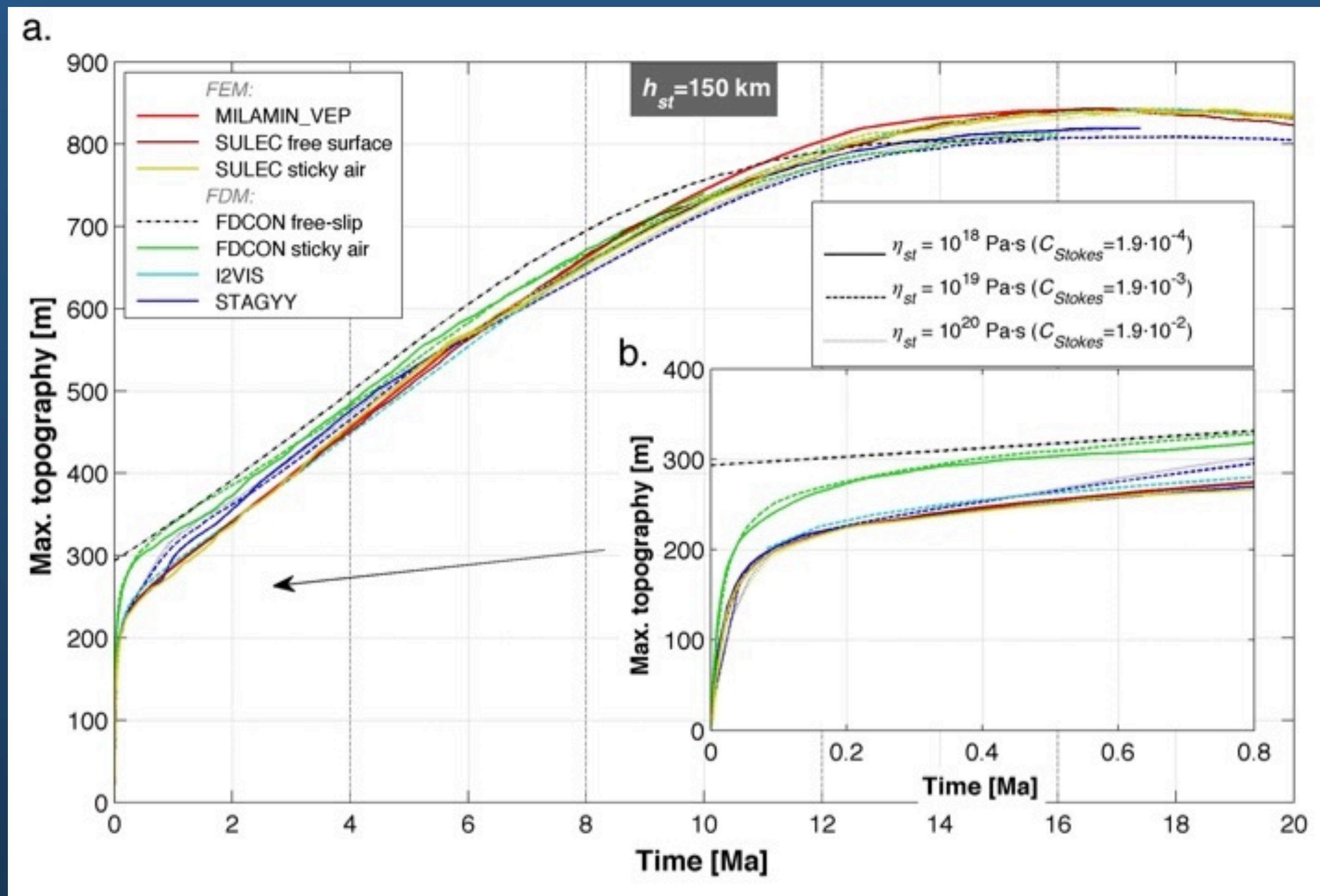
True free surface

vs.

Free slip

vs.

Sticky air



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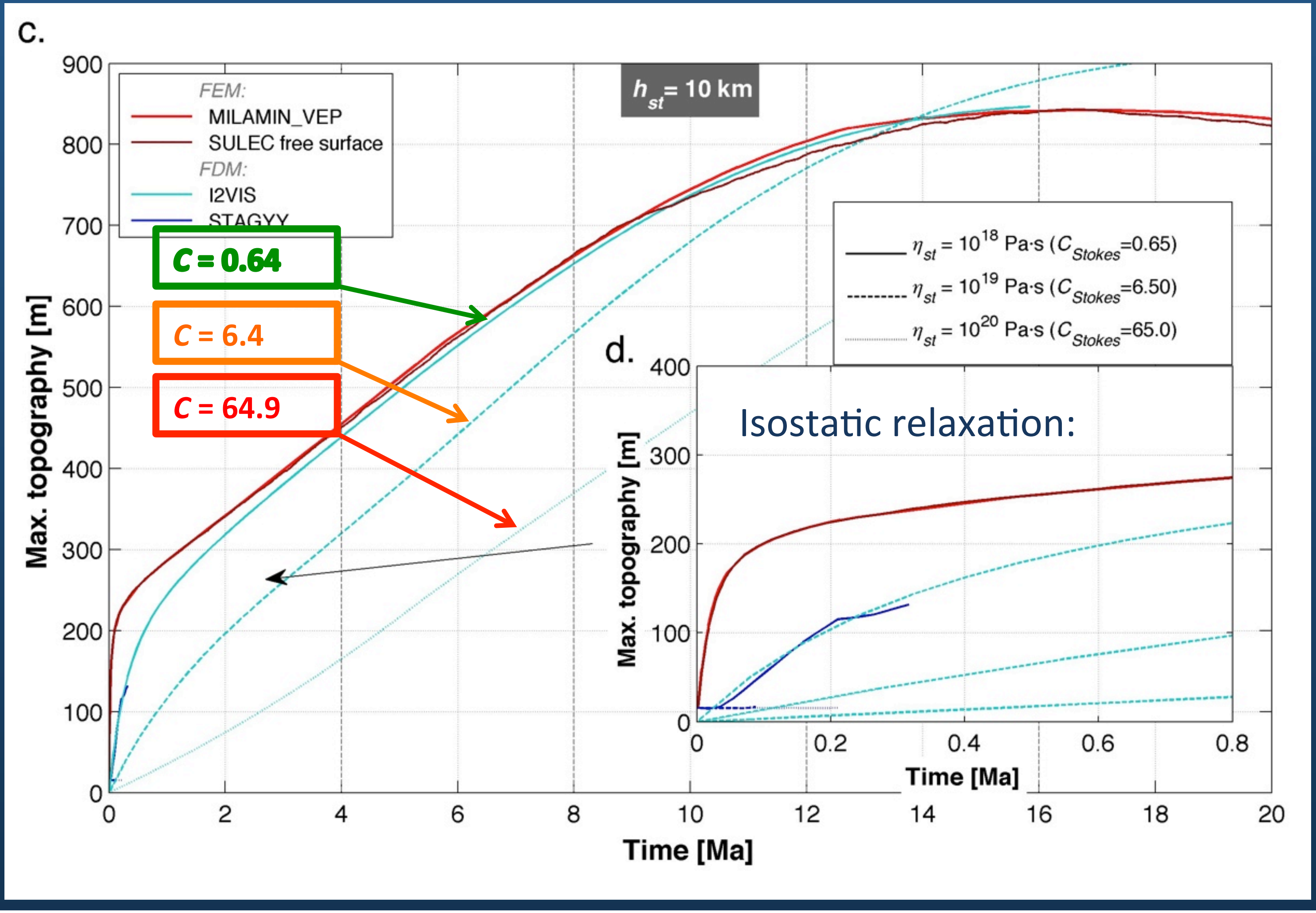
Results: Case 2

- Analytical prediction: $C_{Stokes} = \frac{1}{16}\frac{\Delta\rho}{\rho}\left(\frac{h_{model}}{h_{st}}\right)^3 \frac{\eta_{st}}{\eta}$



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Results: Case 2

- Short-term vs. long-term geodynamics

  - Isostatic relaxation: $C << 0$

$$C_{\max} = \frac{3}{2\pi^3}\left(\frac{L}{h_{st}}\right)^3 \frac{\eta_{st}}{\eta}$$

10^{18} Pa·s ⟷ 100 km

10^{19} Pa·s ⟷ 220 km

10^{20} Pa·s ⟷ 470 km

  - Stokes setup: $C << 0$

$$C_{Stokes} = \frac{1}{16}\frac{\Delta\rho}{\rho}\left(\frac{h_{model}}{h_{st}}\right)^3 \frac{\eta_{st}}{\eta}$$

10^{18} Pa·s ⟷ 25 km

10^{19} Pa·s ⟷ 60 km

10^{20} Pa·s ⟷ 130 km

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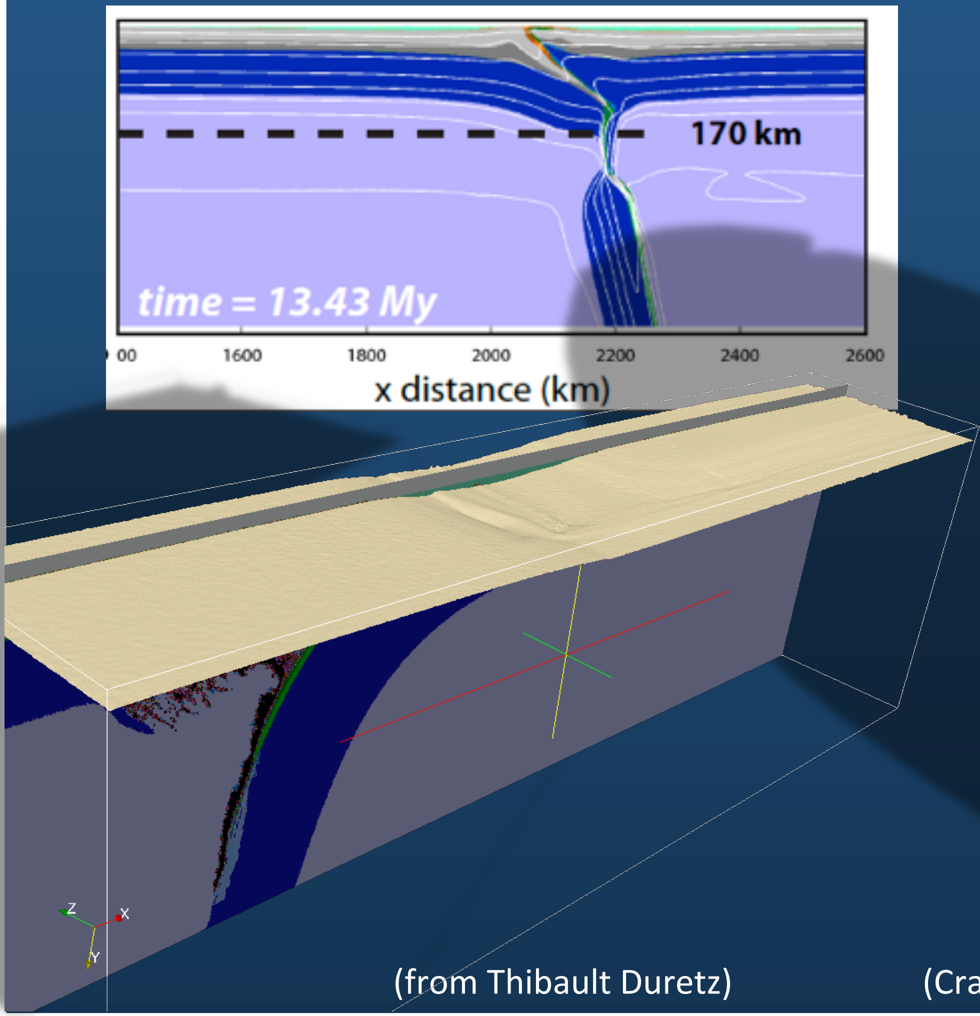
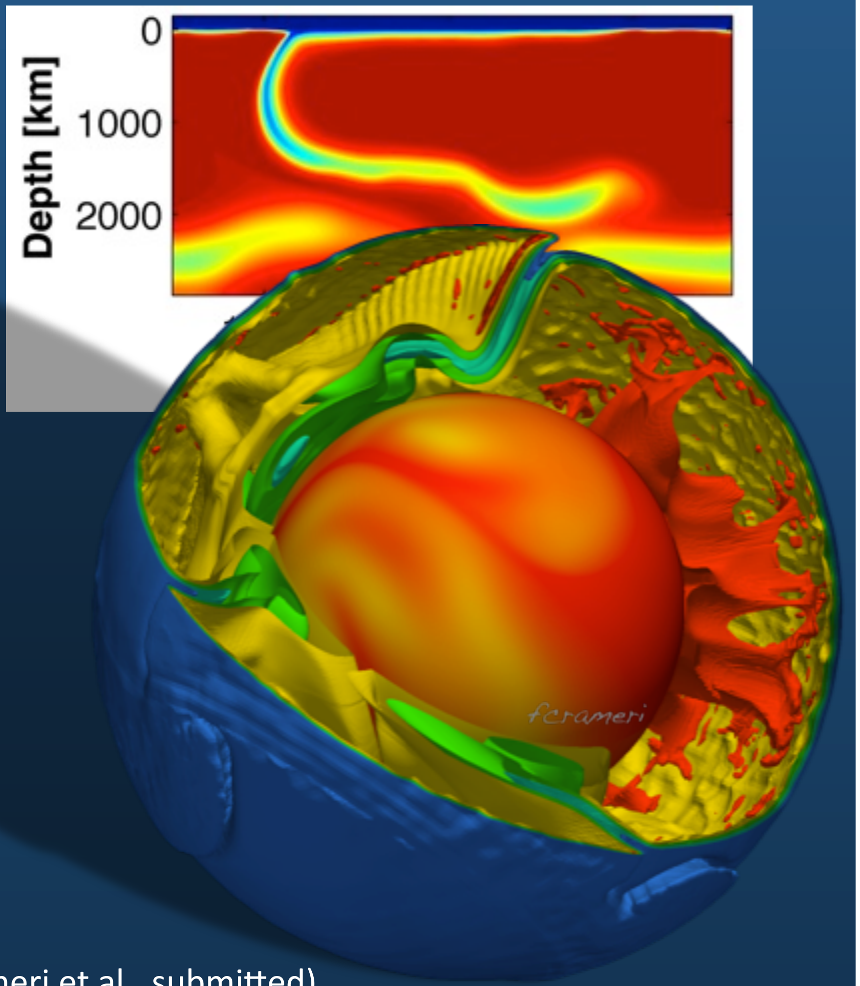
Applications

- More complicated geodynamical models:





(from Thibault Duretz) (Crameri et al., submitted)

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Conclusion

- Before running a model think about dominant driving term (estimate of max. velocity in model).
- Check the analytical condition *C* for isostatic or long-term geodynamics with your model parameters.
- Set sticky air properties wisely!

  So that $(\eta_{st}/\eta_{ch})/(h_{st}/h_{ch})^3$ is sufficiently small.

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