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The effect of resurfacing events on dynamic topography of the surface

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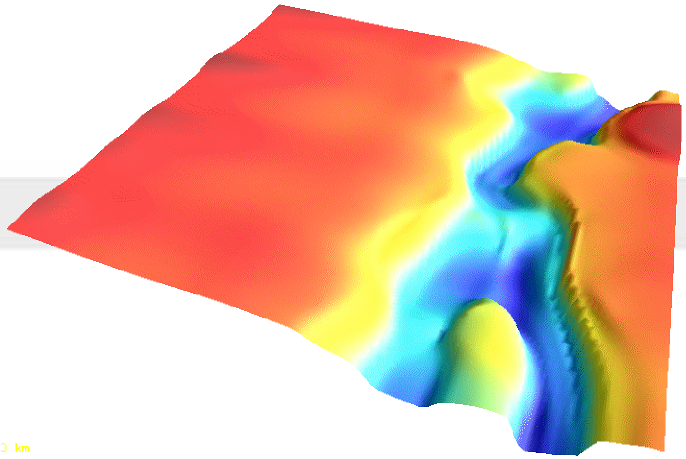

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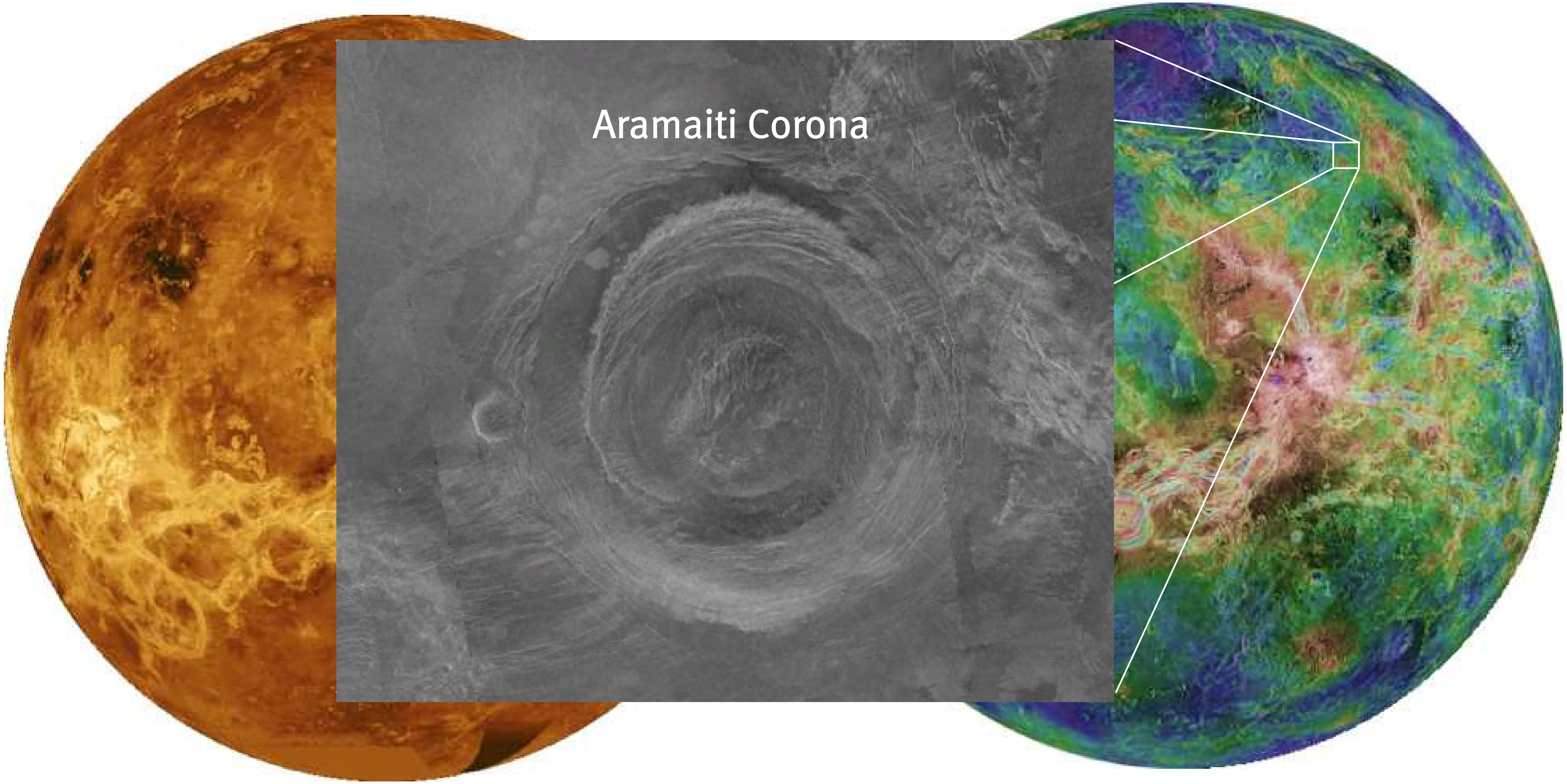
Motivation



Magellan Radar Data

Coloured Relief

NASA/JPL/USGS

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Model

Governing Equations:

$$\begin{aligned} 0 &= \nabla \cdot \underline{u} \\ 0 &= -\nabla p_d + \nabla \underline{\underline{\sigma}} + RaT\underline{e_z} \\ \frac{\partial T}{\partial t} + \underline{u}\nabla T &= \nabla^2 T \end{aligned}$$

Boundary Conditions:

- Stress-free and impermeable boundaries
- Thermally Insulating sidewalls
- Basal Heating

Model Conditions:

- Boussinesq-Approximation
- 3D-Box, Cartesian grid
- Primitive Variables

Fluid Conditions:

- Incompressible
- Highly viscous (Pr=∞)
- Viscoplastic Rheology

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Rheology

- Temperature-Dependency

$$\eta(T) = \exp\left(-\ln(\Delta\eta_T)T\right)$$

Thermal viscosity contrast

Decreasing viscosity with increasing temperature.

- Stress-Dependency

Yield Stress

$$\eta(E) = \eta^* + \frac{\sigma_Y}{\sqrt{E}}$$

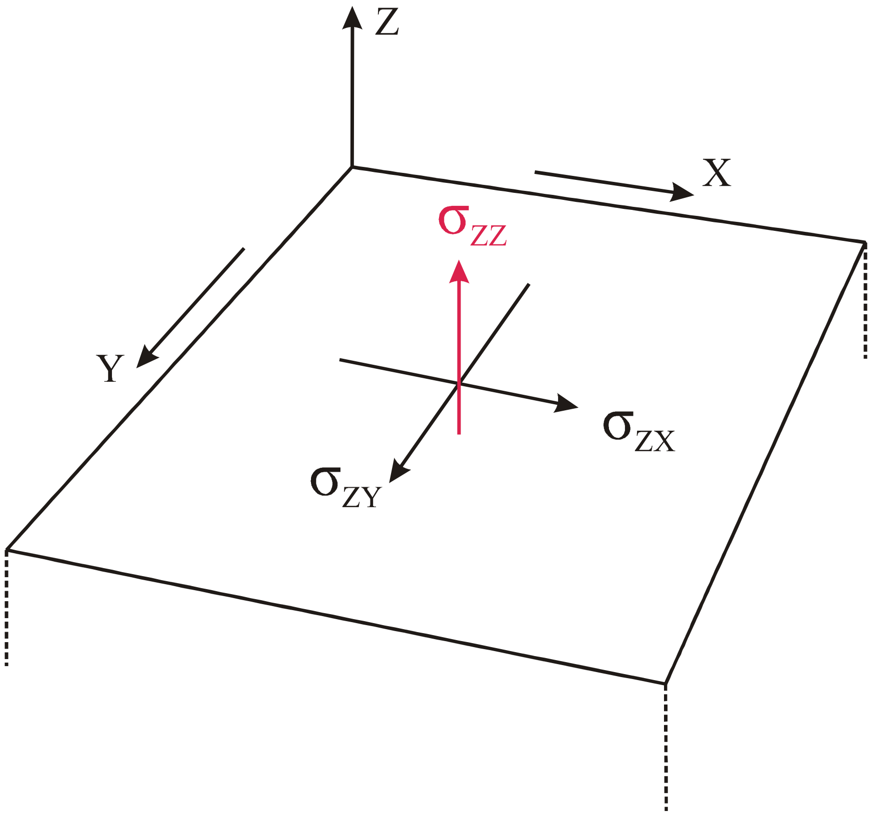
Effective Viscosity at high stresses (10^{-5})

Second Invariant of the Strain-Rate Tensor

Decreased viscosity at high stresses (plastic failure).

- Combinated in Harmonic Mean

Calculation of the Dynamic Topography



A vanishing Normal Stress ...

$$0 \stackrel{!}{=} \sigma_{zz} = p + \tau_{zz}$$

... with separated pressure components ...

$$p = p_d + \rho g h$$

... leads to a nondimensional formulation.

$$h = \frac{\alpha \Delta T d}{Ra} \left(p_d^* - 2\eta^* \frac{\partial u_z^*}{\partial z^*} \right)$$

<u>Formulation in Primitive Variables is useful!</u>

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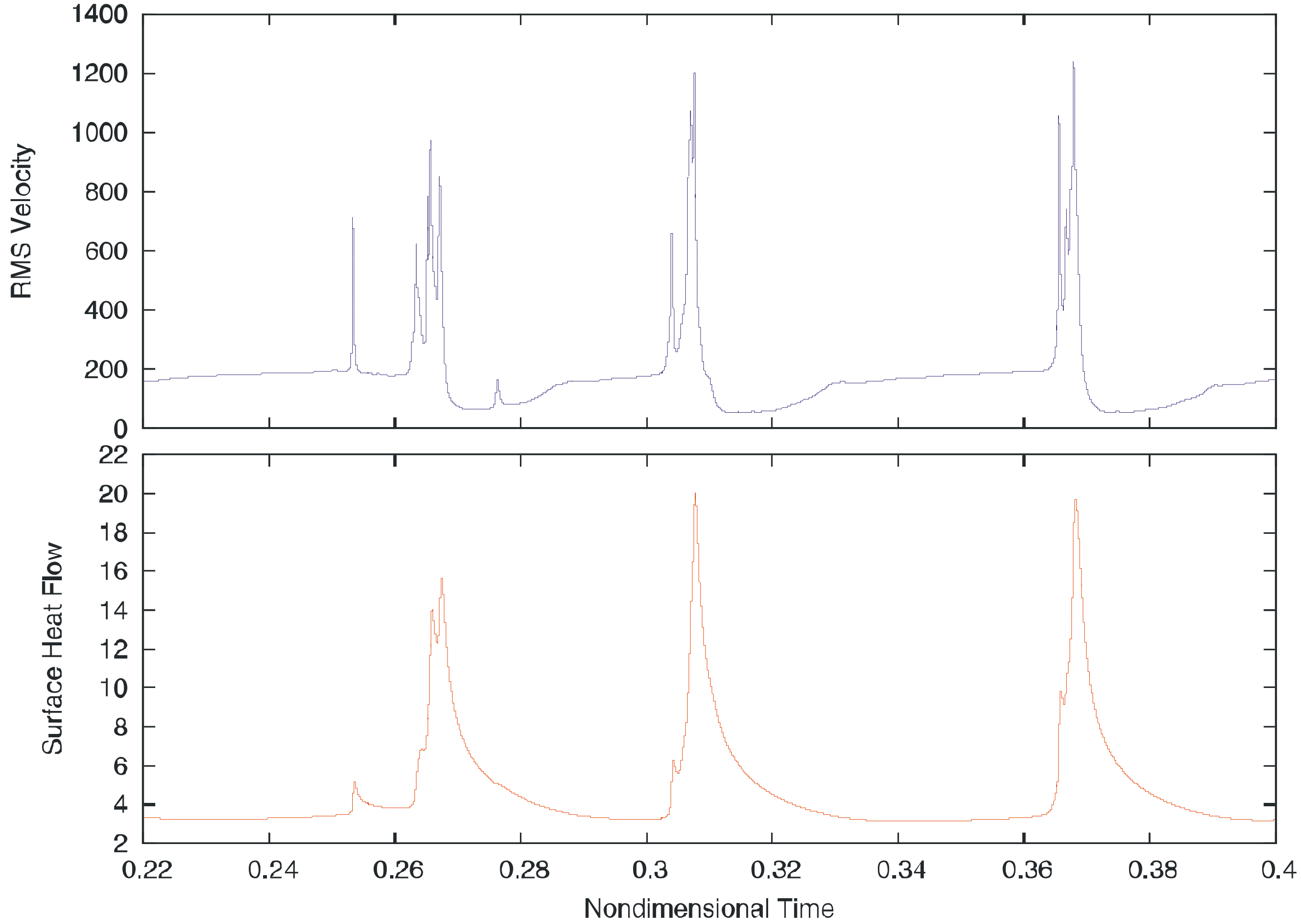
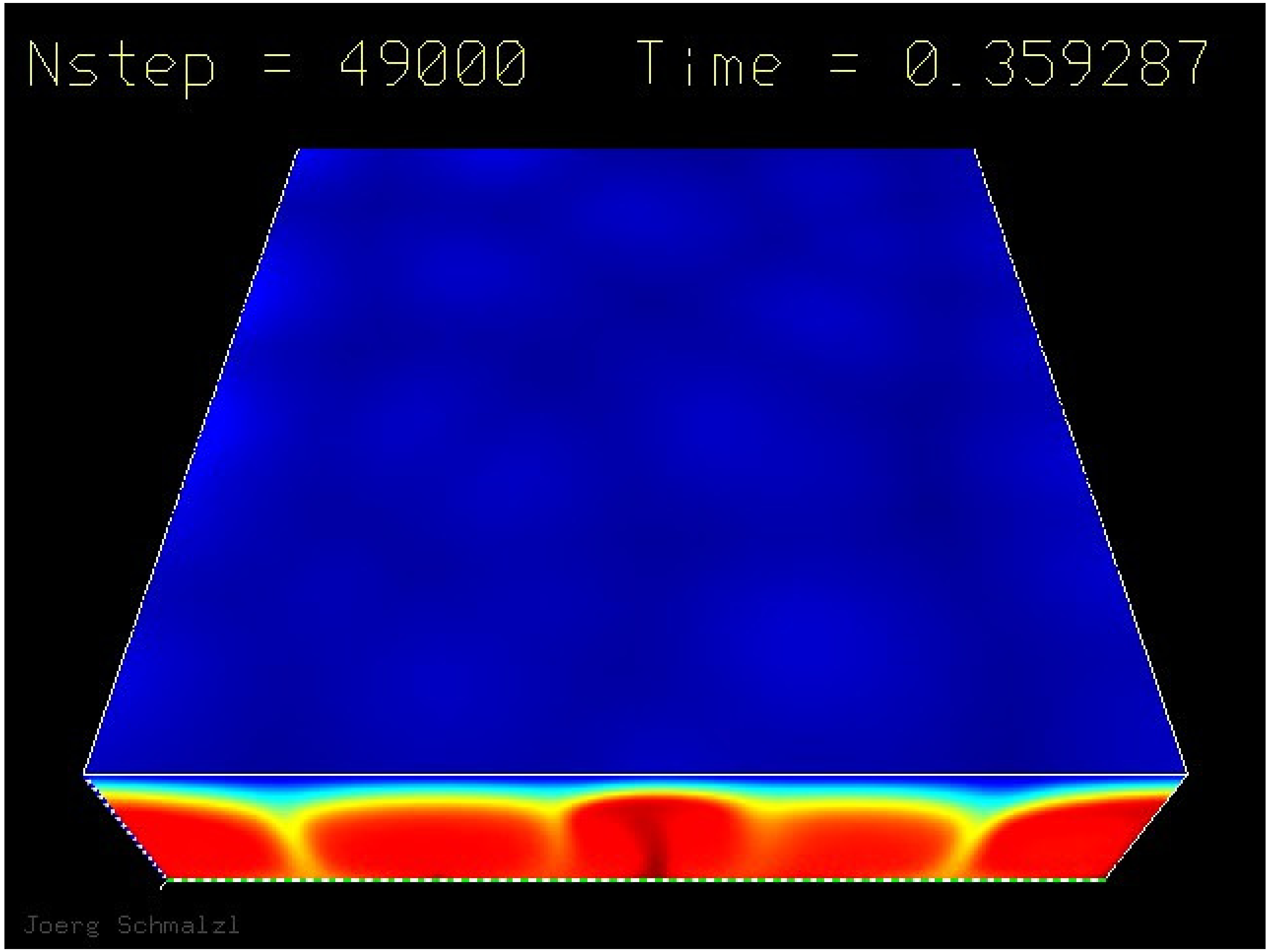
Episodic Behaviour



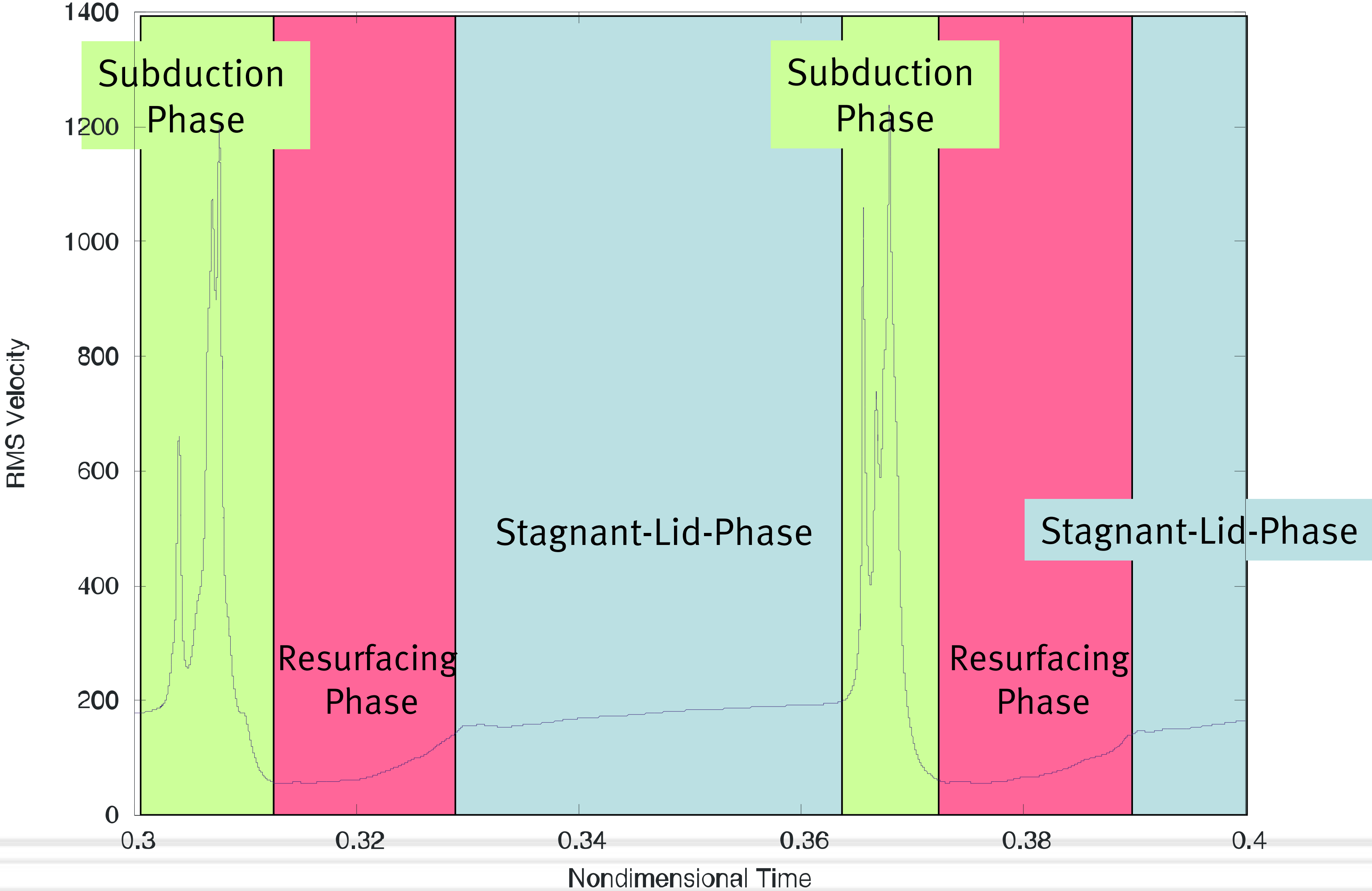
System Parameters: $Ra = 100, \Delta\eta_T = 10^5, \sigma_y = 2.0$

Resurfacing Event



Surface Velocity and colour-coded Temperature

Separated Phases



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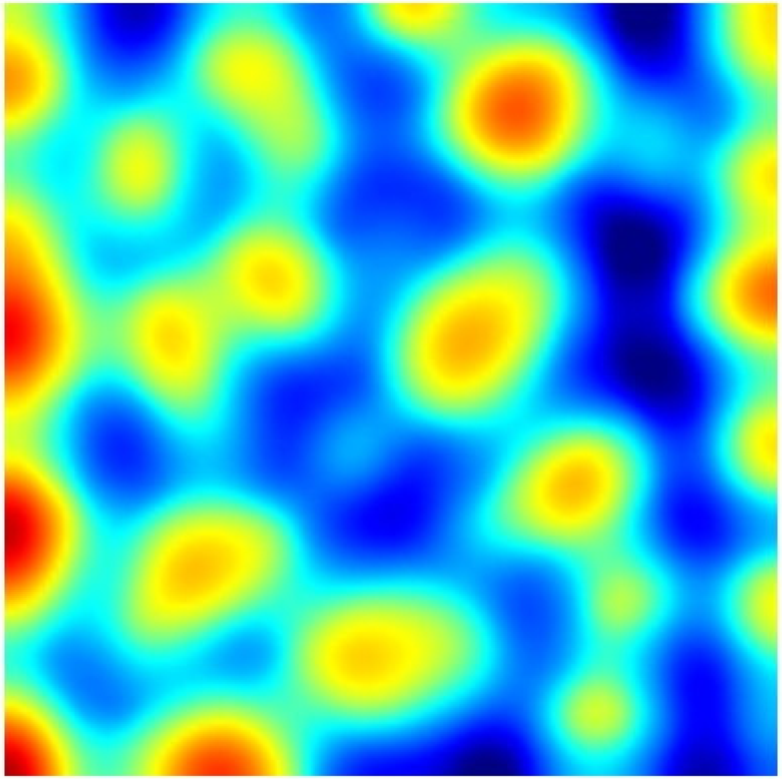
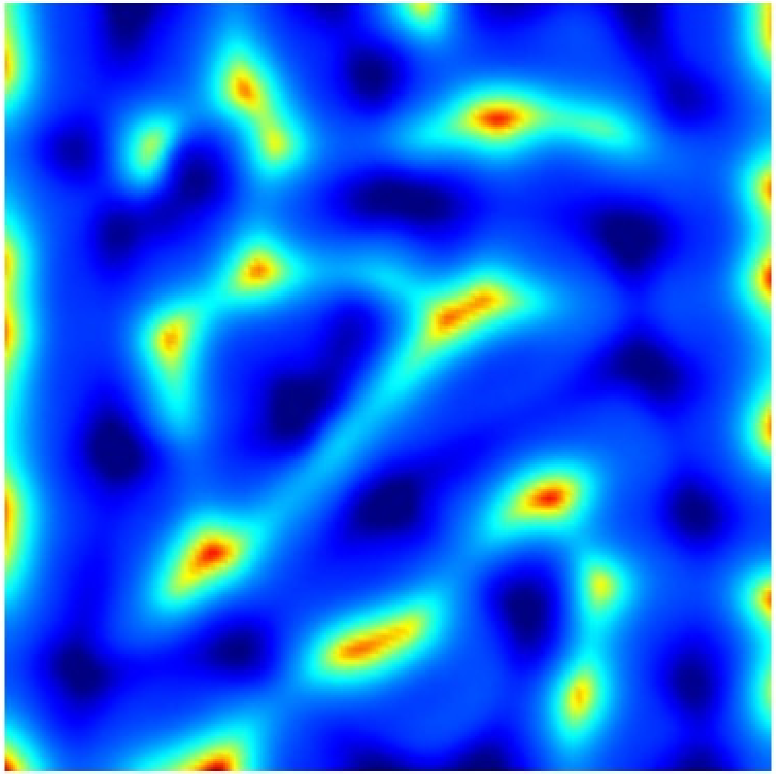
Stagnant-Lid-Phase



Dynamic Topography of the Surface



Horizontal Cross Section of the vertical component of the Velocity

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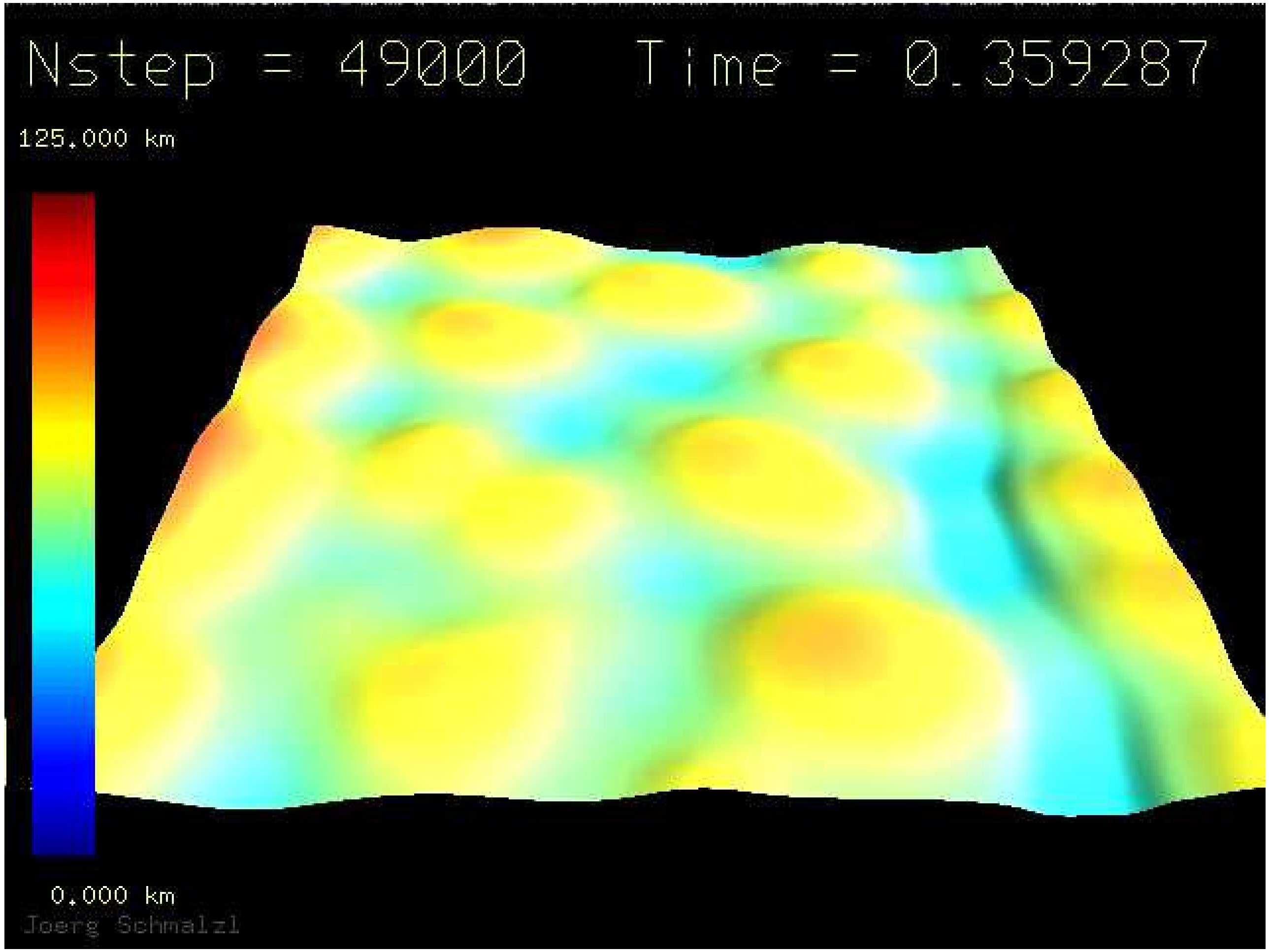
Subduction Phase



Dynamic Topography of the Surface

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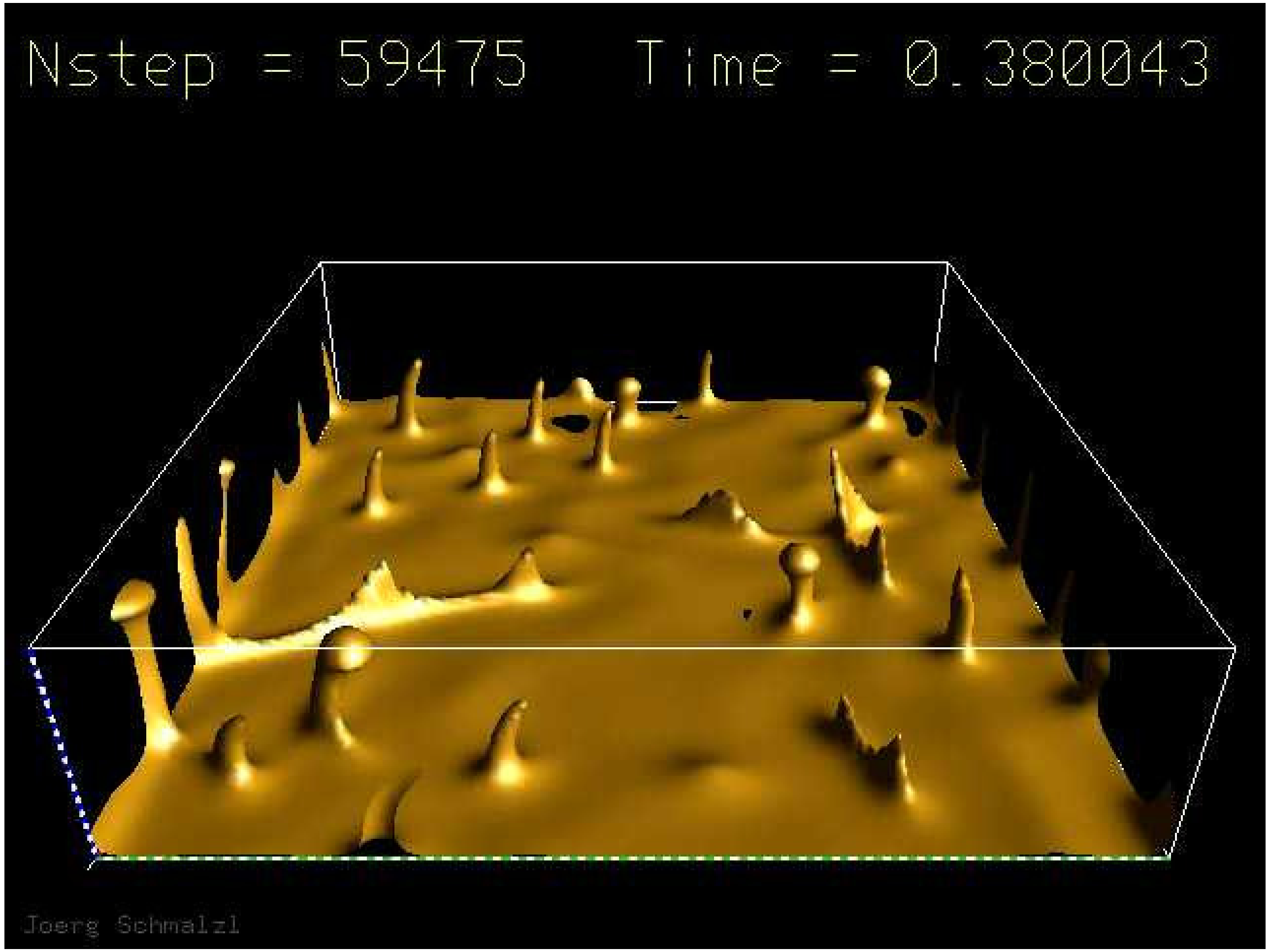
Resurfacing Phase



Temperature Isosurfaces: T=0.9

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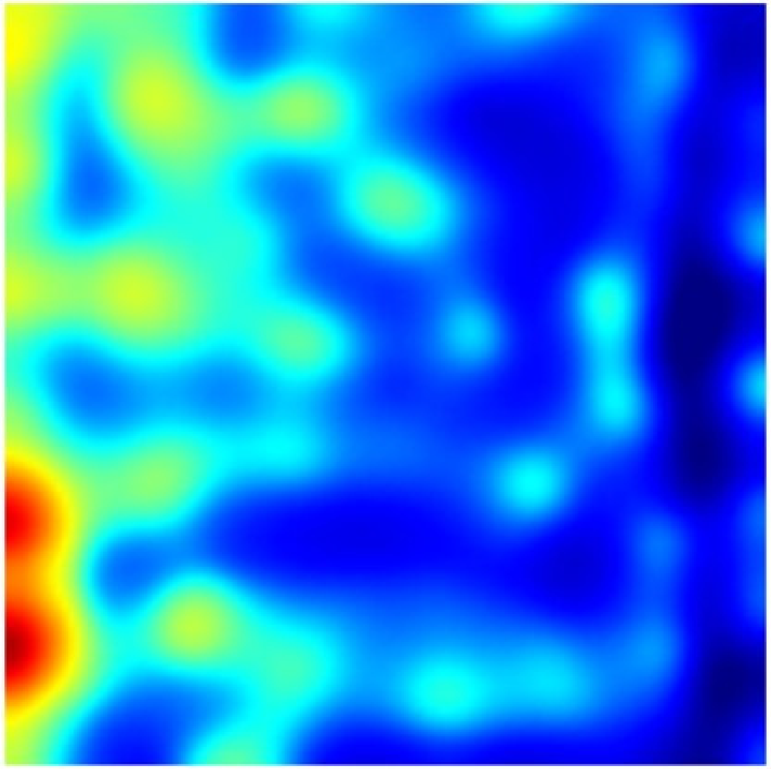
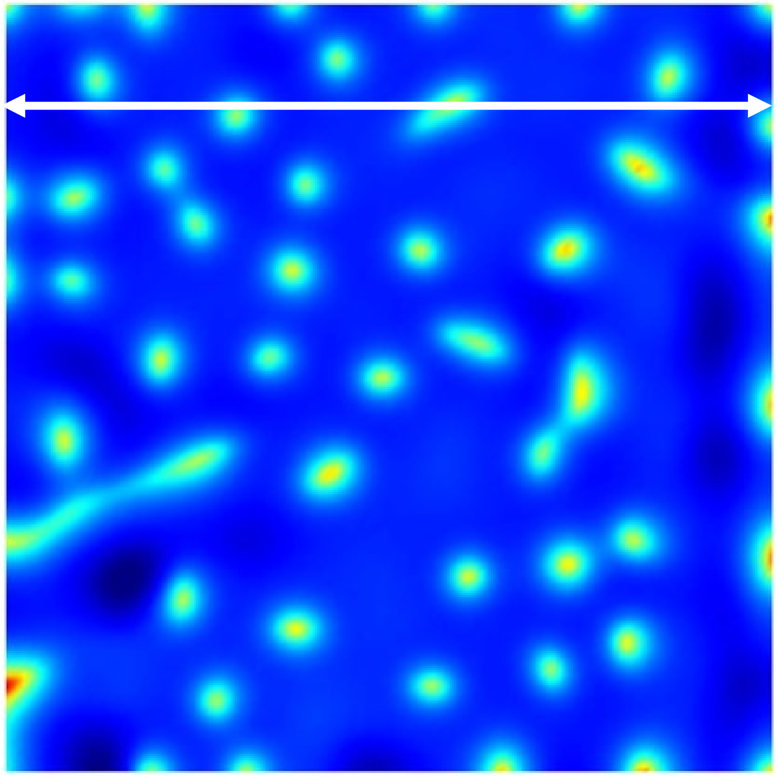
Resurfacing Phase

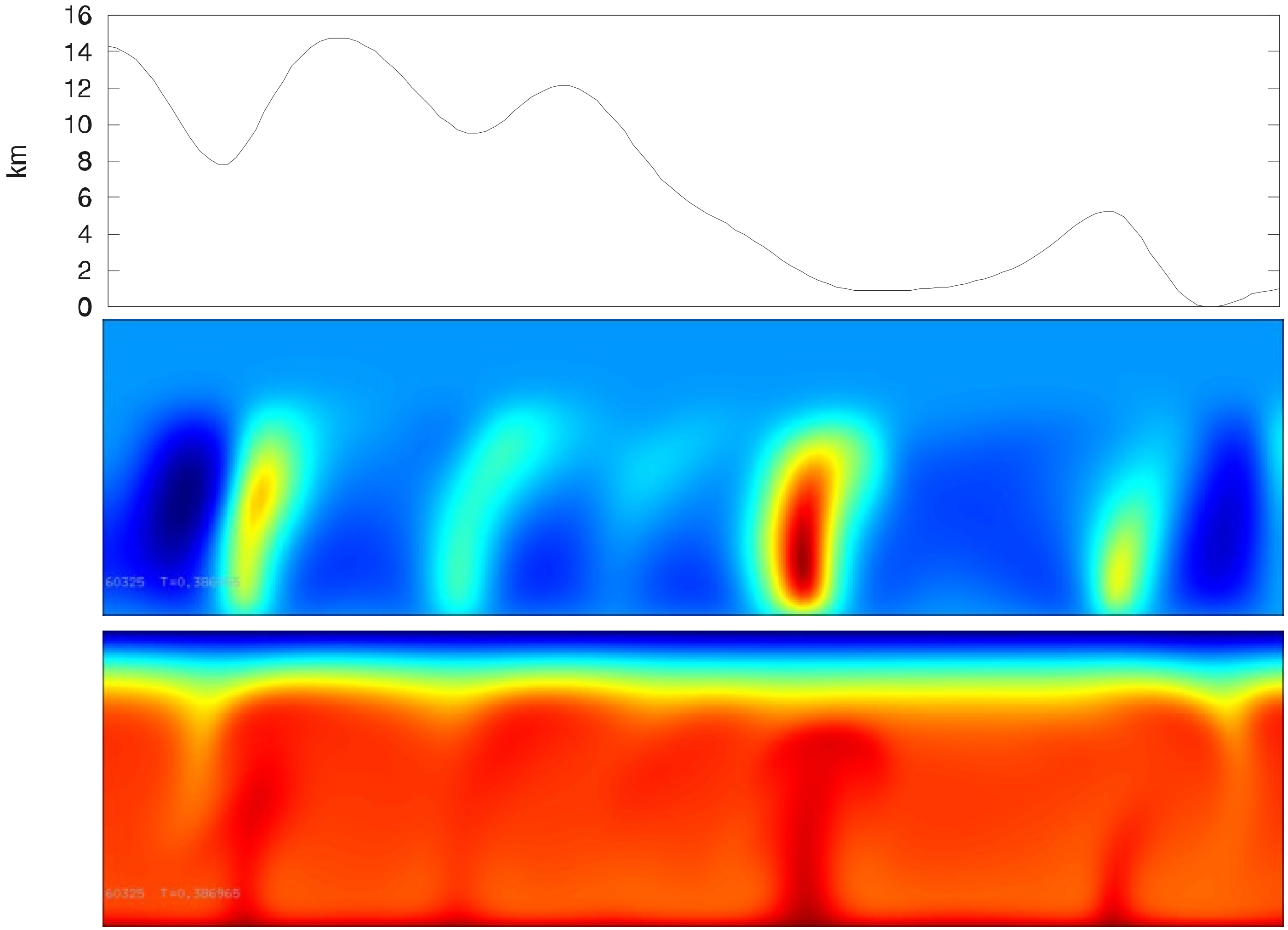


Dynamic Topography of the Surface



Horizontal Cross Section of the Vertical Component of the Velocity

Plumes beneath depressions



Surface Topography

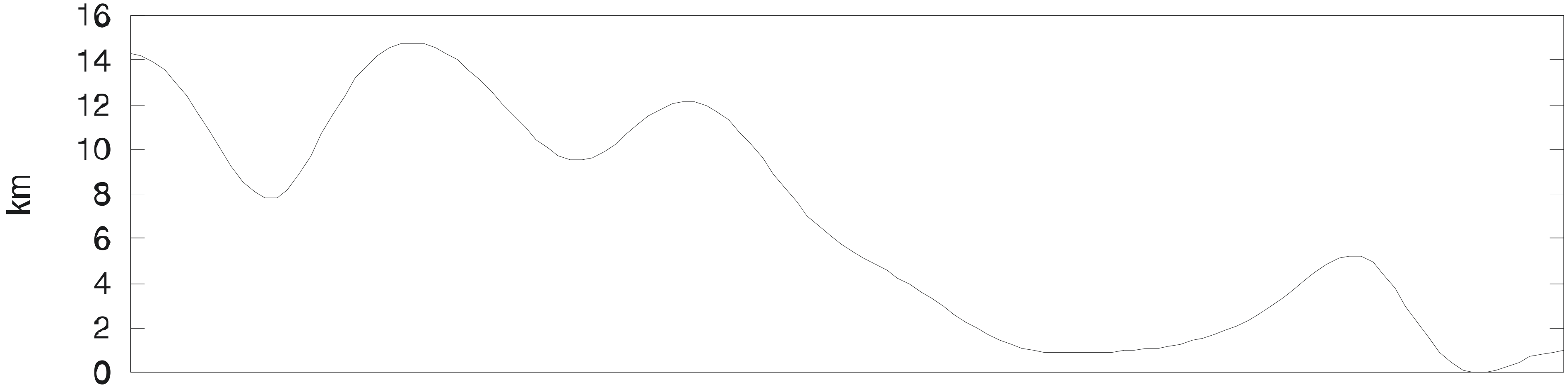
Vertical Velocity

Temperature

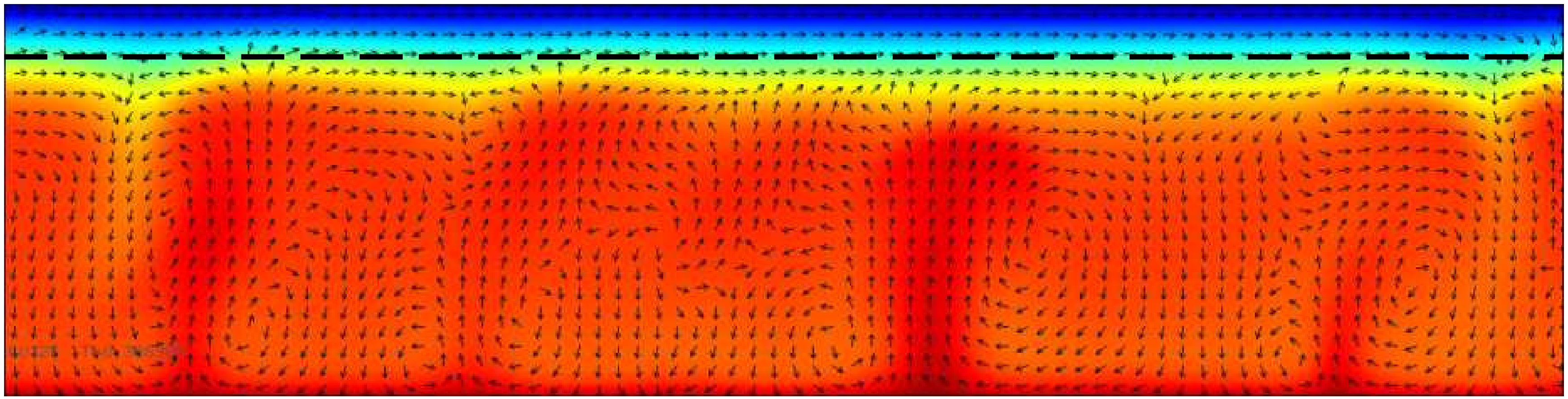
Vertical Cross Section

Min  Max

Plumes beneath depressions



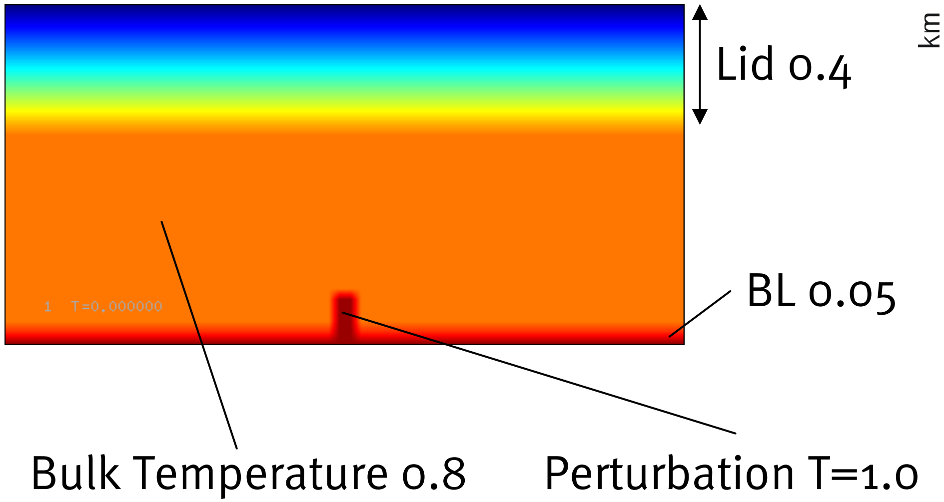
Surface Topography

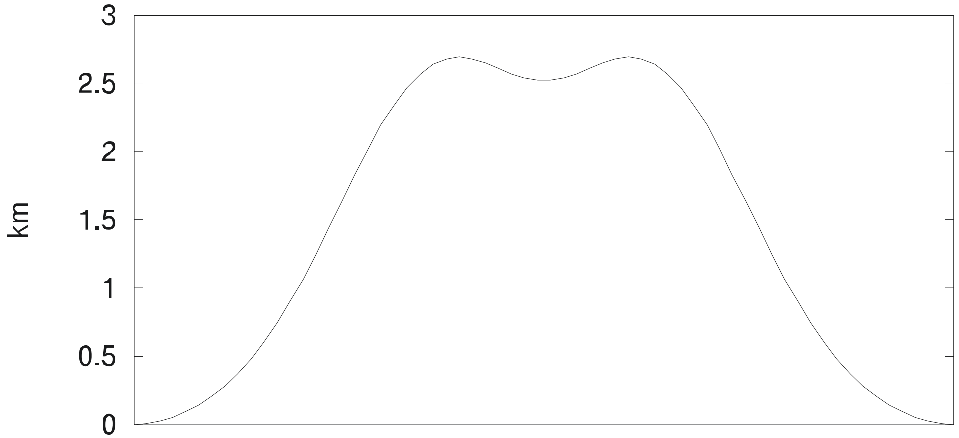


Normalized Velocity Field

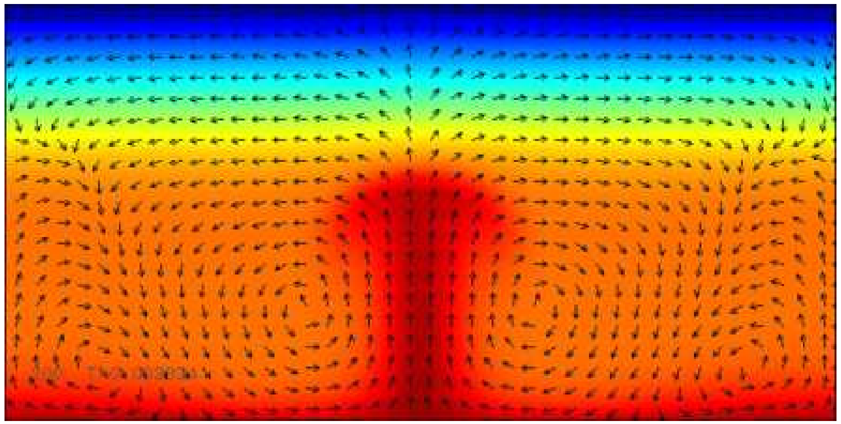
Active Formation of Depressions

Initial Conditions





Surface Topography



Normalized Velocity Field

Same Parameters:

$$Ra = 100, \Delta\eta_T = 10^5, \sigma_y = 2.0$$

Summary

- We applied a self-consistent 3D model of mantle convection with temperature- and stress-dependent viscosity.
- At moderate yield stresses the flow shows episodic global subduction events.
- Each period can be divided into three phases:
  - In the Stagnant-Lid-Phase the topography can be clearly correlated with the plumes.
  - In the Subduction Phase the topography consists of a grabenlike subduction zone and a spreading flat area of new material.
  - In the Resurfacing Phase a global correlation between plumes and topography cannot be found.

➢ It is possible that a plume is rising beneath a topographic depression.

➢ We found hints, that topographic depressions at the surface can be formed by an uprising plume actively.

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Literature

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