THE LIFE TECTONIC

devl

IGPP

Convection (part 4):

Compressible mantle convection

Concepts for today

- Compressible formulation for MC
- Effects of compressibility
  - on convective planfrom/structures
  - on energetics of the convection (additional heating / cooling terms)
- Feedback between temp-dep visc & compressibility
- Bullen's Parameter

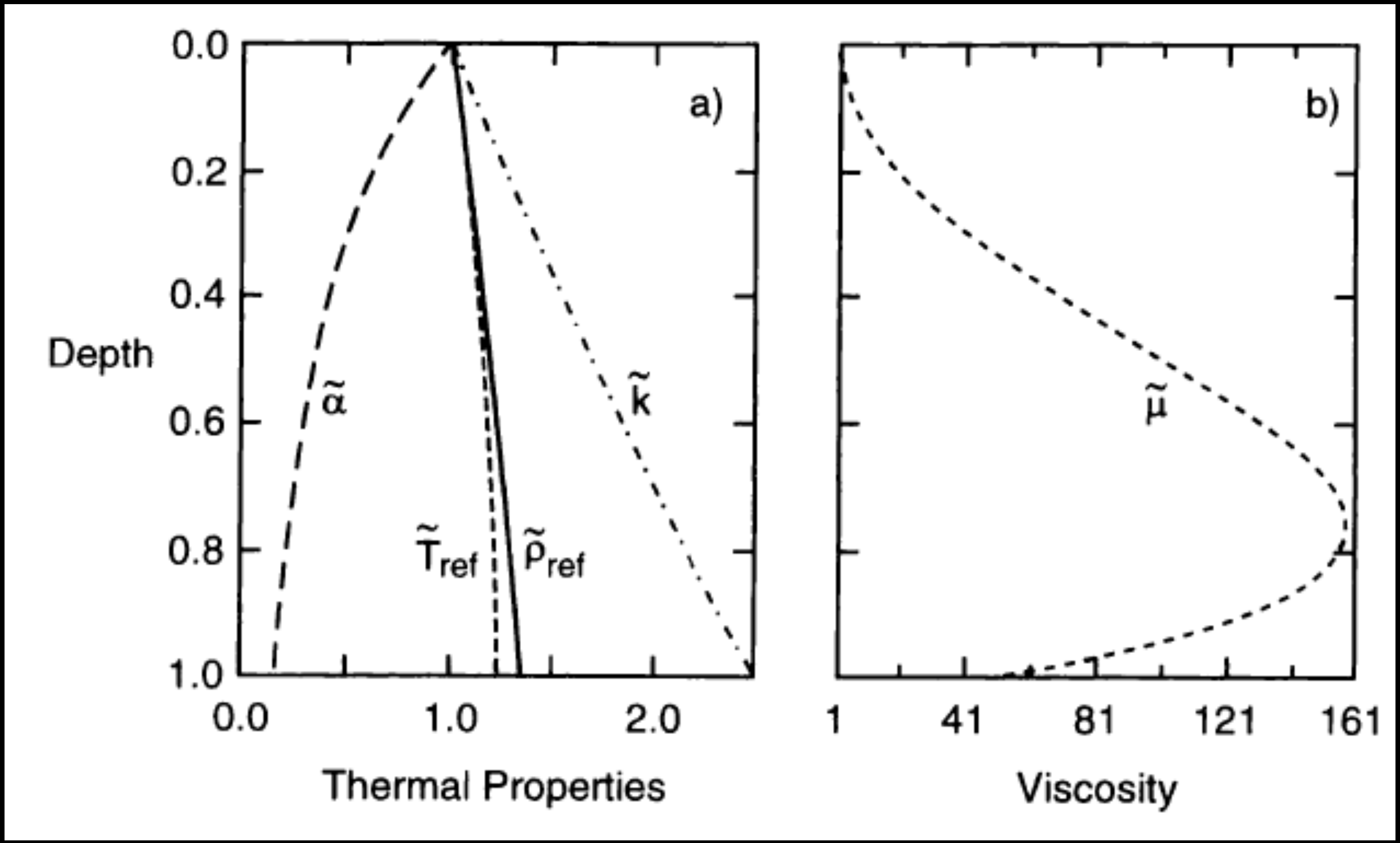
Additional references

- *Mantle Convection in Earth + Planets*
  Schubert, Turcotte, and Olson (2001)

- King et al., *GJI,* 2010

Depth-dependent material properties

- **Material transport properties are depth-dependent**
  - **including: thermal expansivity, thermal conductivity, viscosity**



Zhang and Yuen, PEPI, 1996

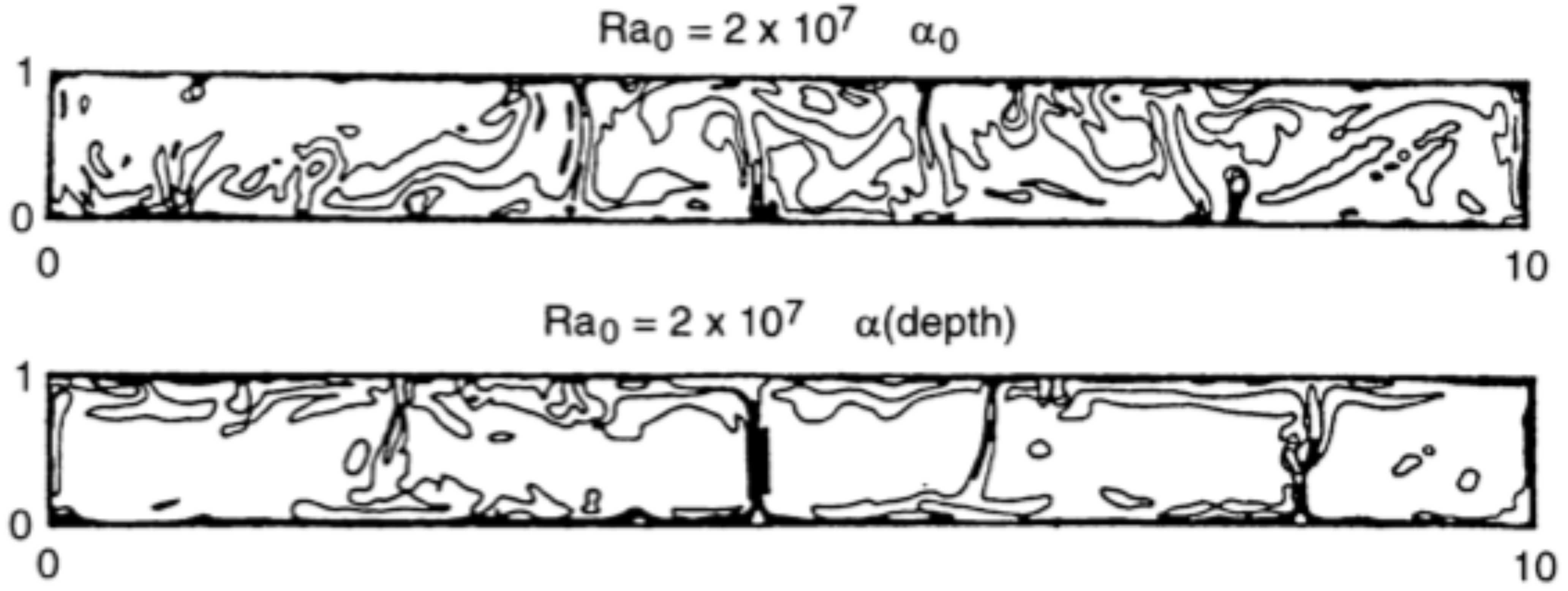
Depth-dependent material properties

- Material transport properties are depth-dependent
  - including: thermal expansivity, thermal conductivity, viscosity
  - effective Ra decreases with depth

$$Ra = \frac{\rho_r^2 \alpha_r \Delta T_r c_p g_r L^3}{\eta_r k_r}$$

Depth-dependent material properties

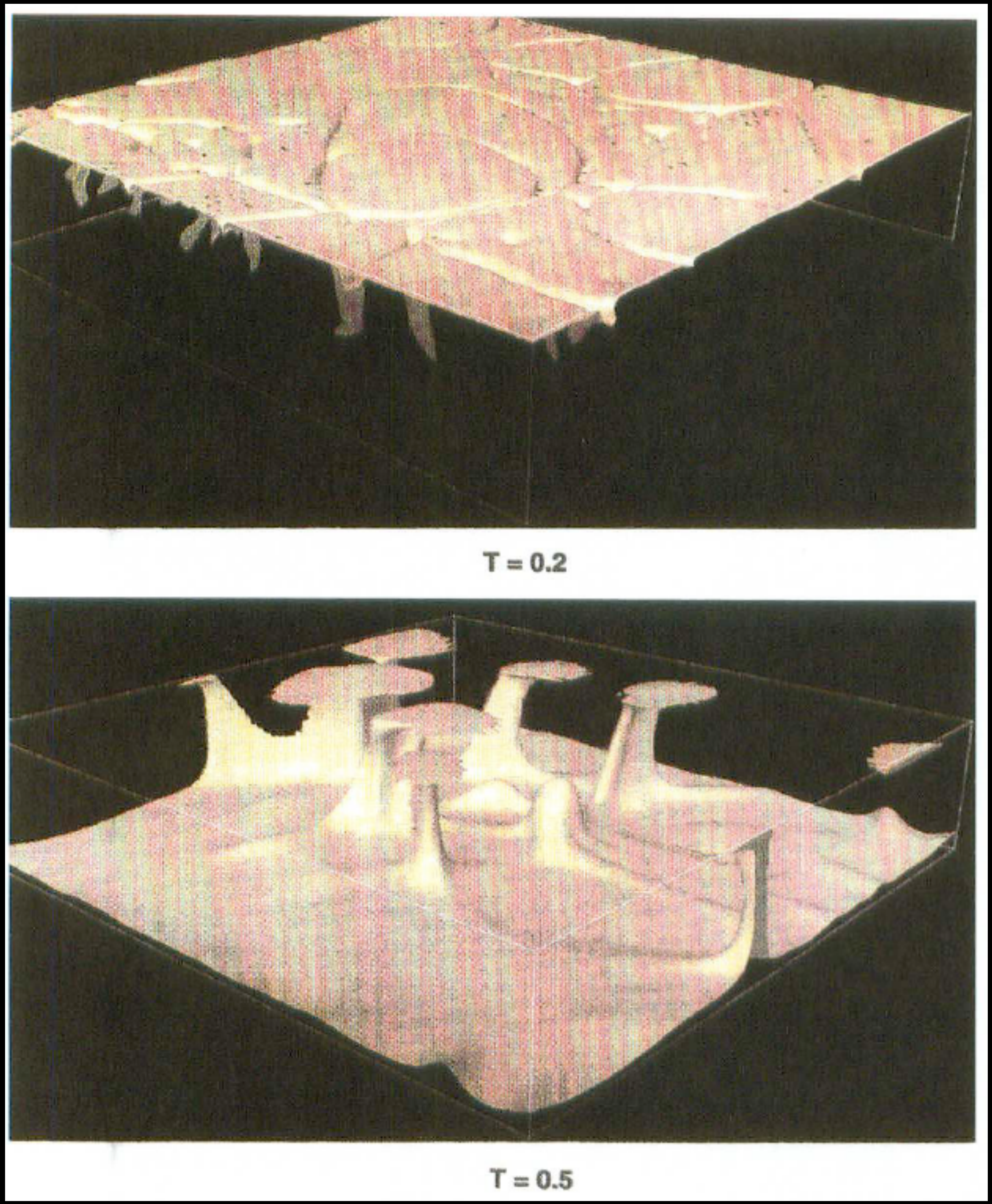
- **Material transport properties are depth-dependent**
  - **including: thermal expansivity, thermal conductivity, viscosity**
  - **effective Ra decreases with depth**
  - **creates asymmetry between upwelling and downwelling structures**



Hansen et al., Phys Fluid, 1993

Effect on convective instabilities

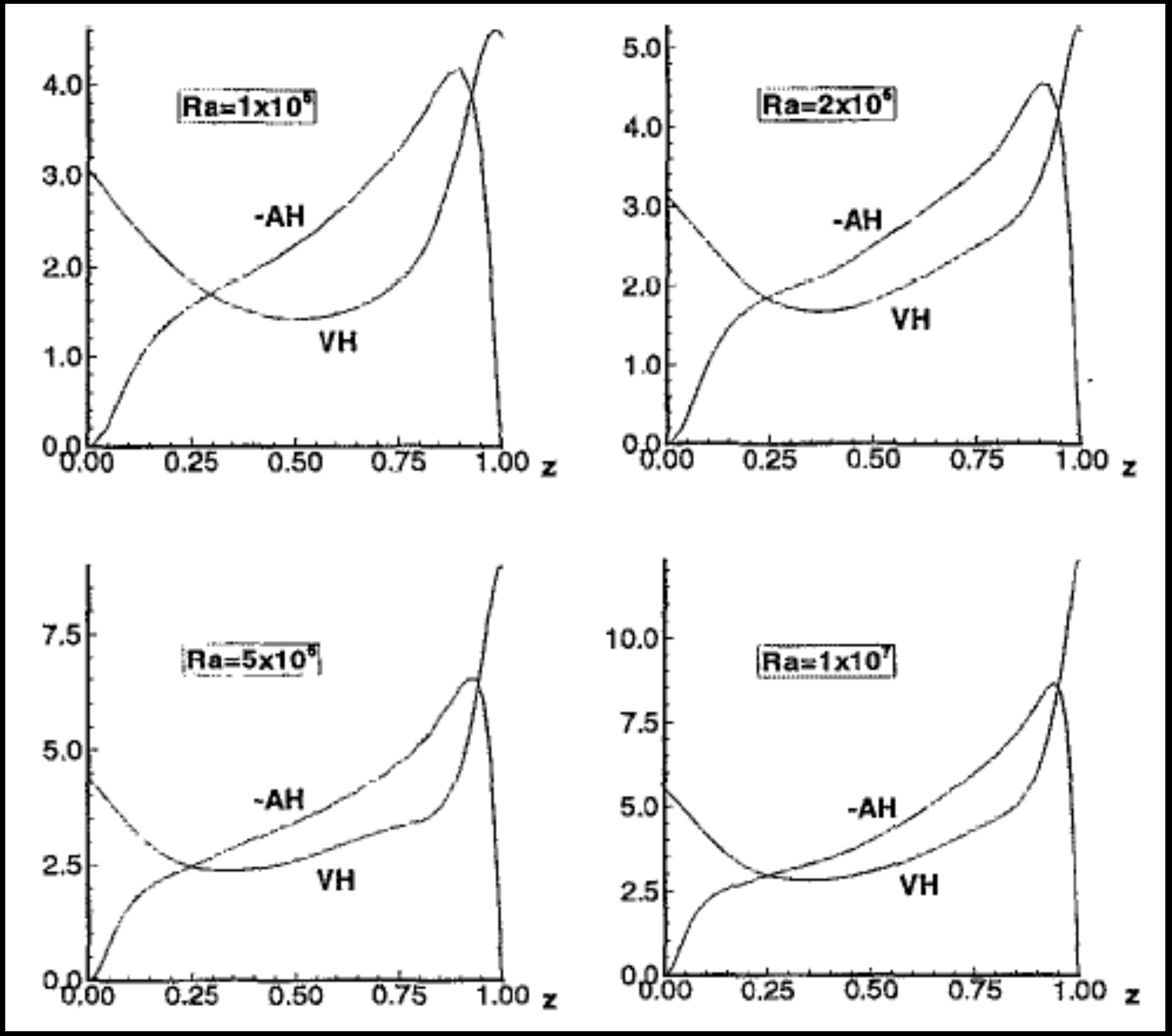
- **Convection in upper mantle has smaller-wavelength features and more chaotic**
- **Lower mantle structures are more organized and less time-dependent**



Balachandar et al., Phys Fluid, 1993

Additional heating terms

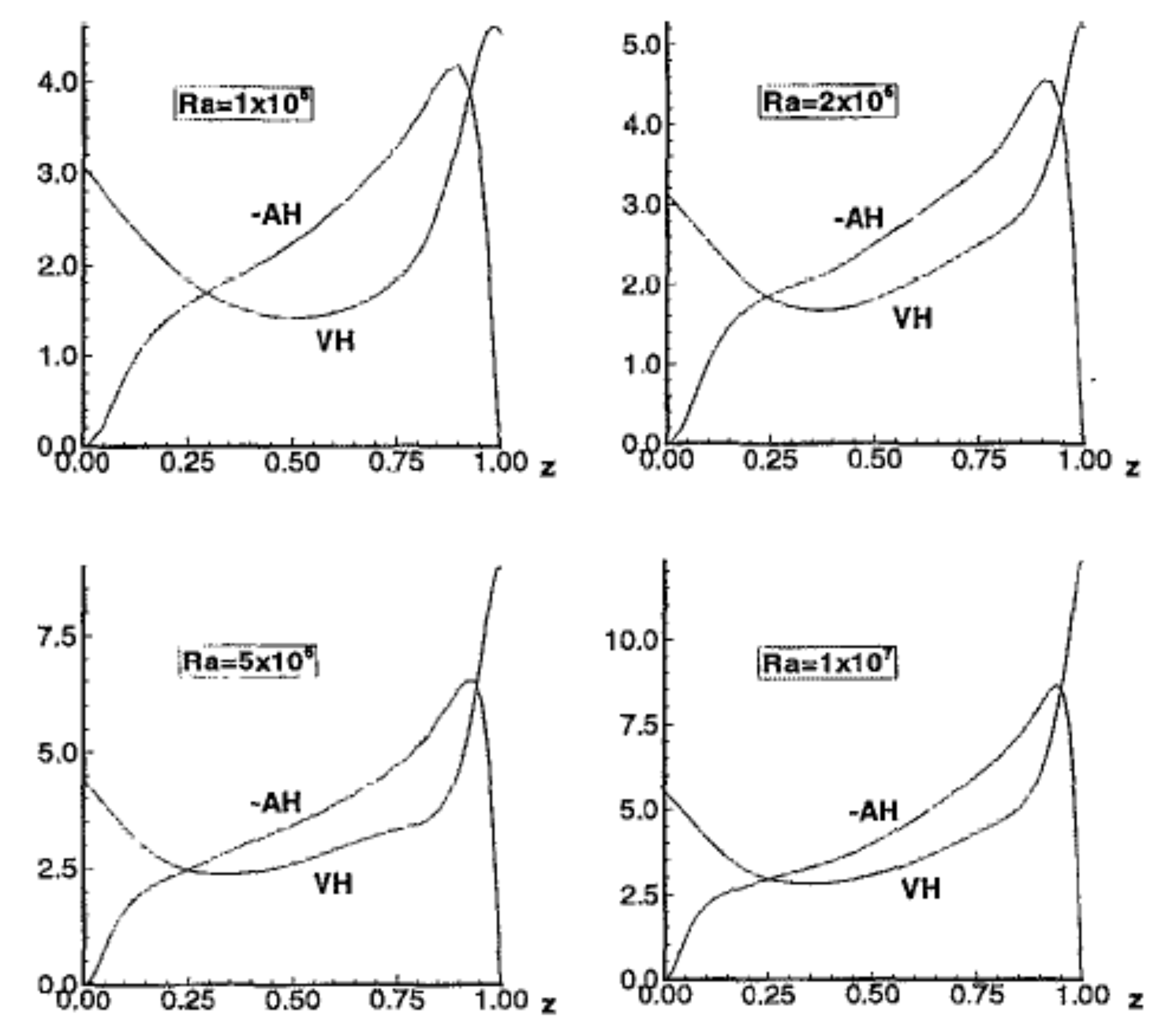
- **Viscous Heating**
  - **always a source of heat**
  - **largest heating rates at boundaries**



Balachandar et al., Phys Fluid, 1993

Additional heating terms

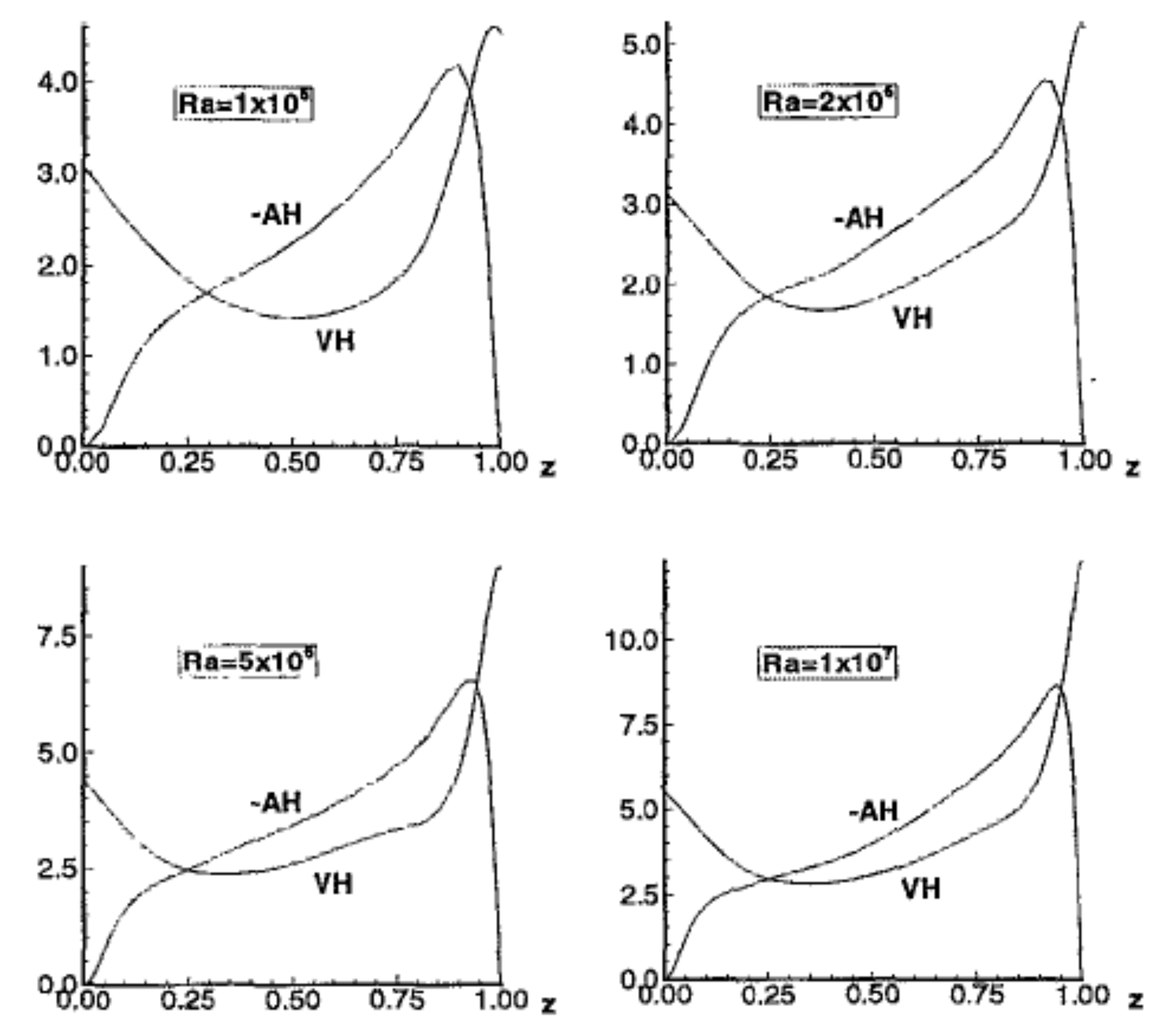
- **Adiabatic Heating**
  - **effect increases with depth**
  - **asymmetric effect:**
    - **sinking slabs compress & heat, rising plumes expand & cool**
    - **magnitude of cooling > heating because T in plumes > slabs**
  - **upwellings have viscous heating and adiabatic cooling (competing)**
  - **downwellings have viscous heating and adiabatic heating (reinforcing)**



Balachandar et al., Phys Fluid, 1993

Additional heating terms

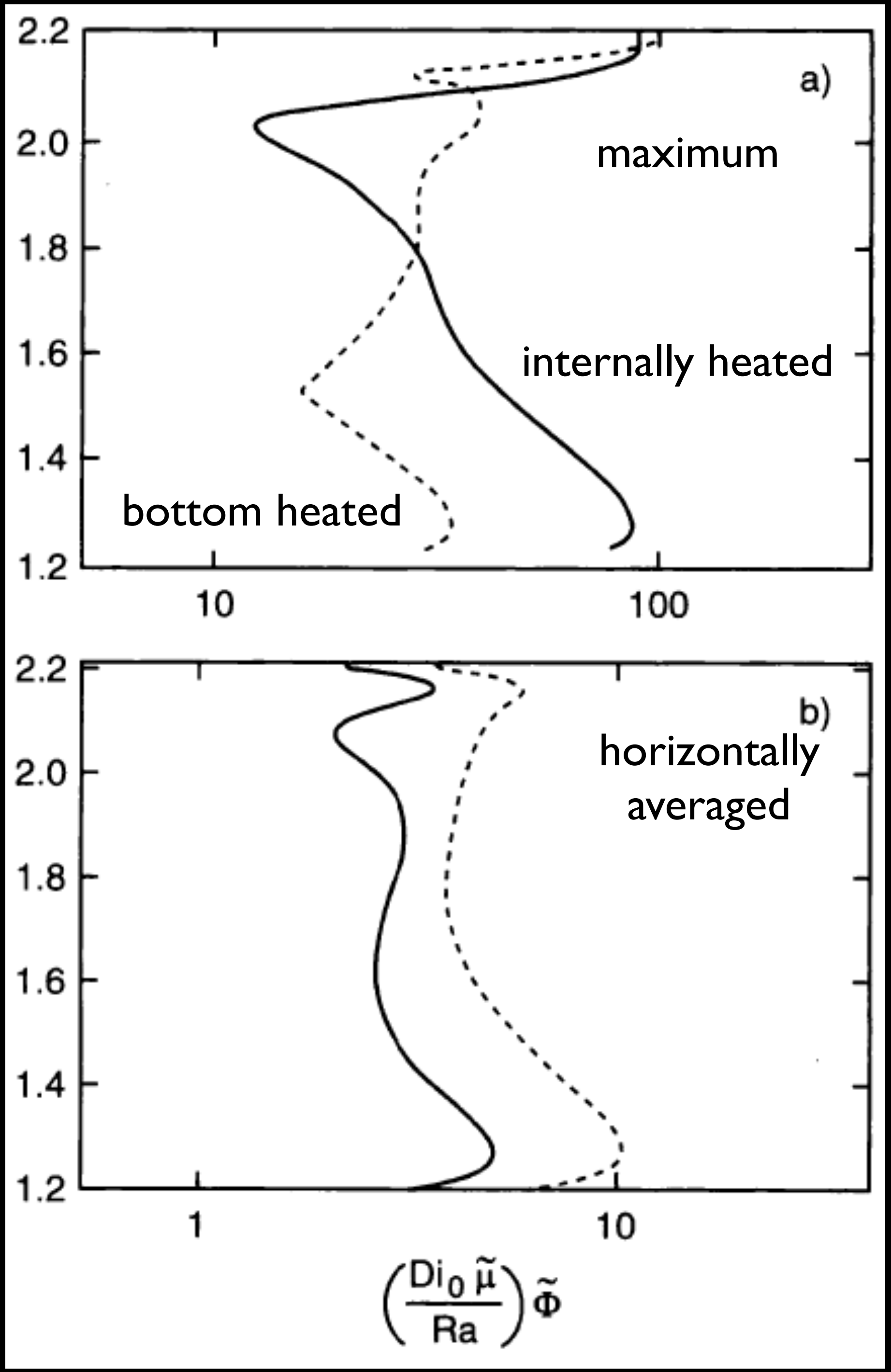
- increasingly important at higher Ra (note change in y-axis scale)
- net effect of cooling lower mantle (looks ~ an internally heated mantle)



Balachandar et al., Phys Fluid, 1993

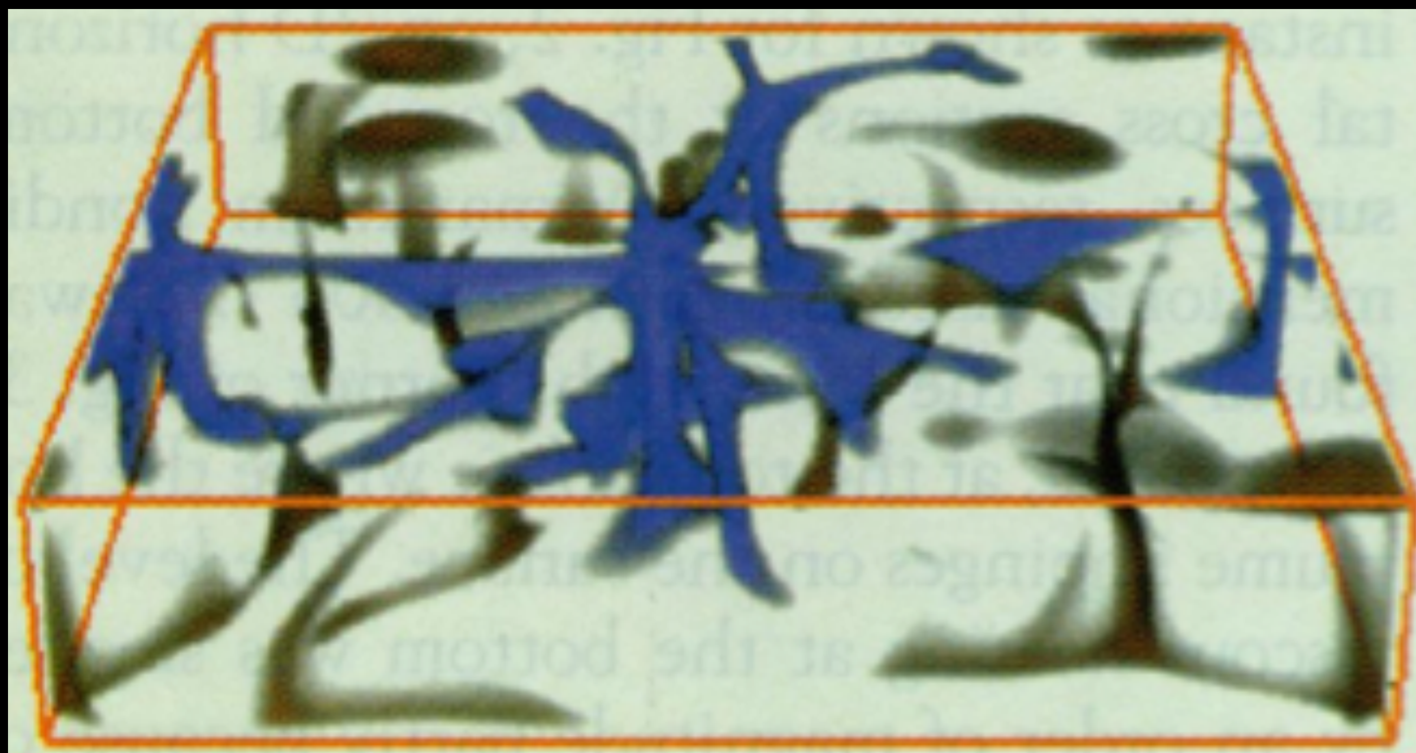
Feedbacks between effects

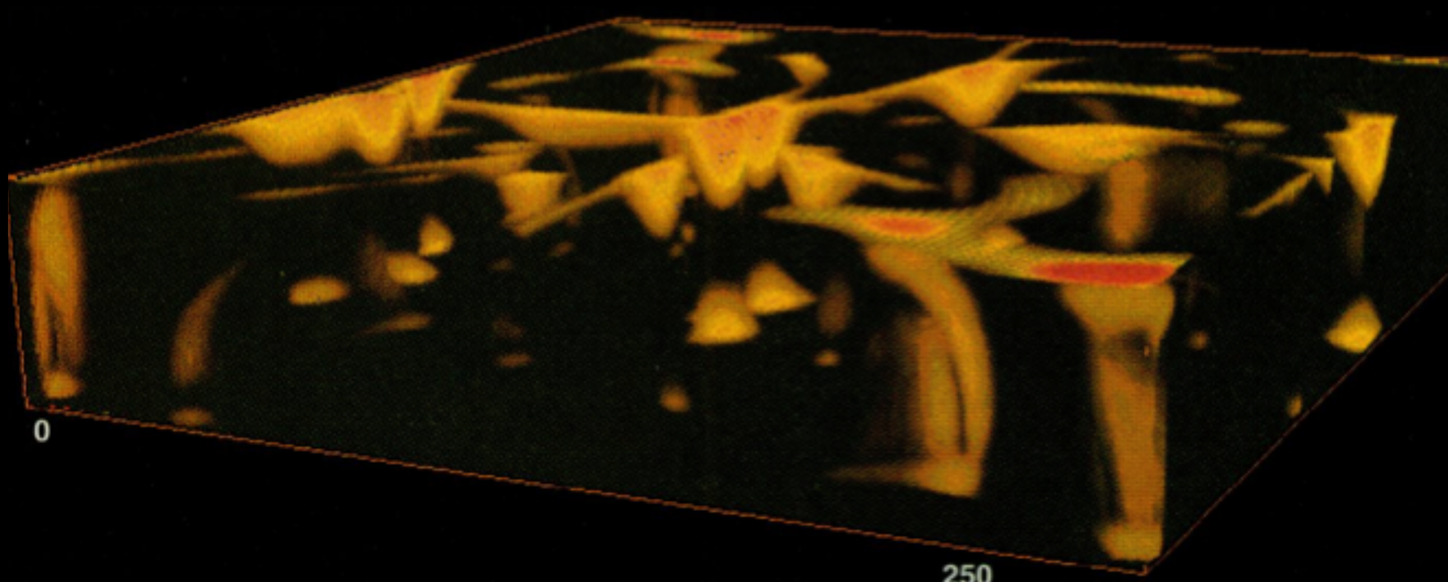
- **Positive feedback between viscous/ adiabatic heating and temperature-dependent viscosity**
- **Viscous heating raises temperature --> viscosity decreases --> strain-rate increases --> viscous heating increases, etc...**
- **Maximum feedback occurs in narrow downwelling regions near surface (i.e. surrounding slabs)**
- **averaged viscous heating rates are as large as radiogenic heating**
- **stronger in bottom heated models**

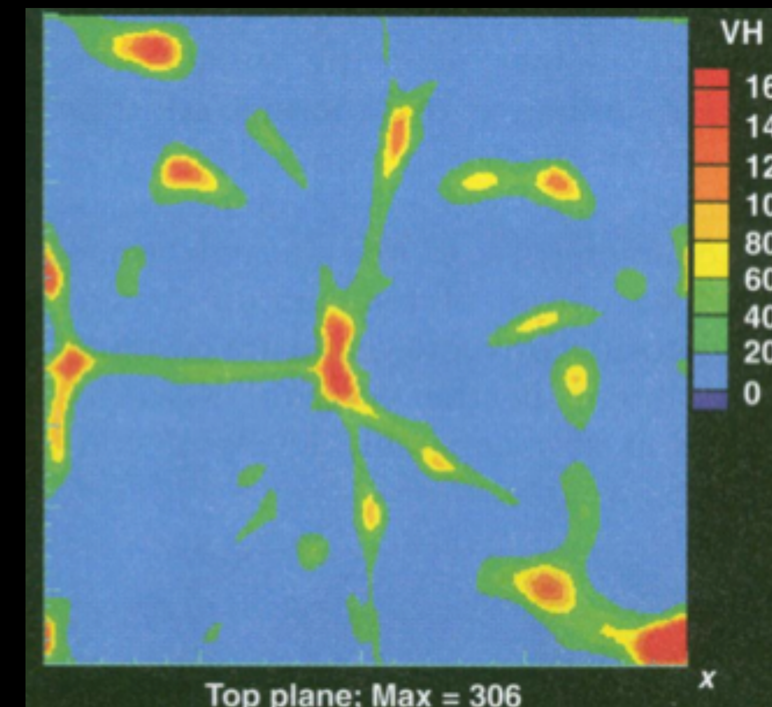


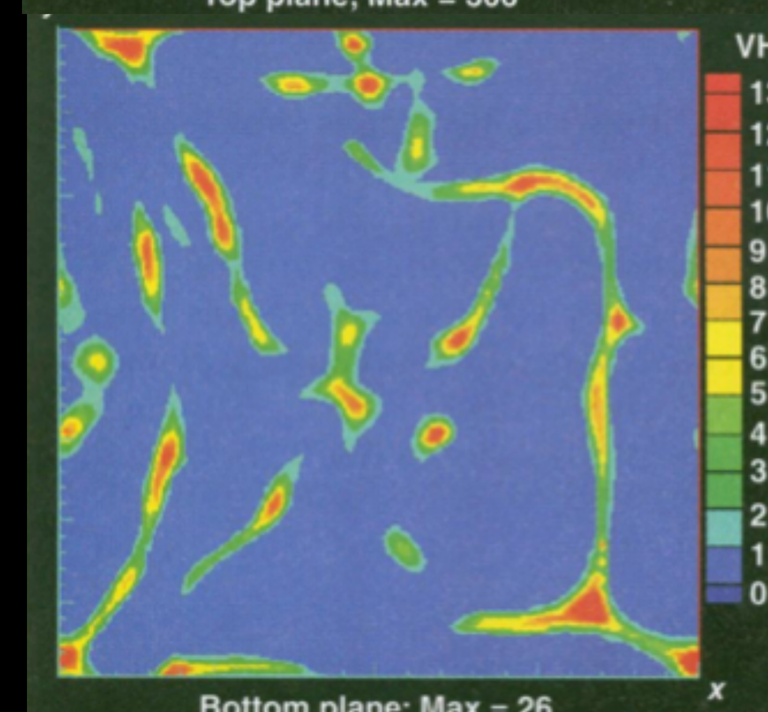
Zhang and Yuen, PEPI, 1996

Feedbacks between effects









Balachandar et al., Science, 1995

Bullen's parameter

- **Adams-Williamson's equation**

$$\frac{\partial \rho}{\partial z} = \underbrace{\frac{\rho g}{\phi}}_{\text{adiabatic density gradient}} \underbrace{- \alpha(z)\rho\left(\overbrace{\frac{\partial T}{\partial z}}^{\text{geotherm}} - \overbrace{\frac{\alpha(z) g T}{c_p}}^{\text{adiabatic temp gradient}}\right)}_{\text{non-adiabatic density gradient}}$$

Bullen's parameter

- **Adams-Williamson's equation**

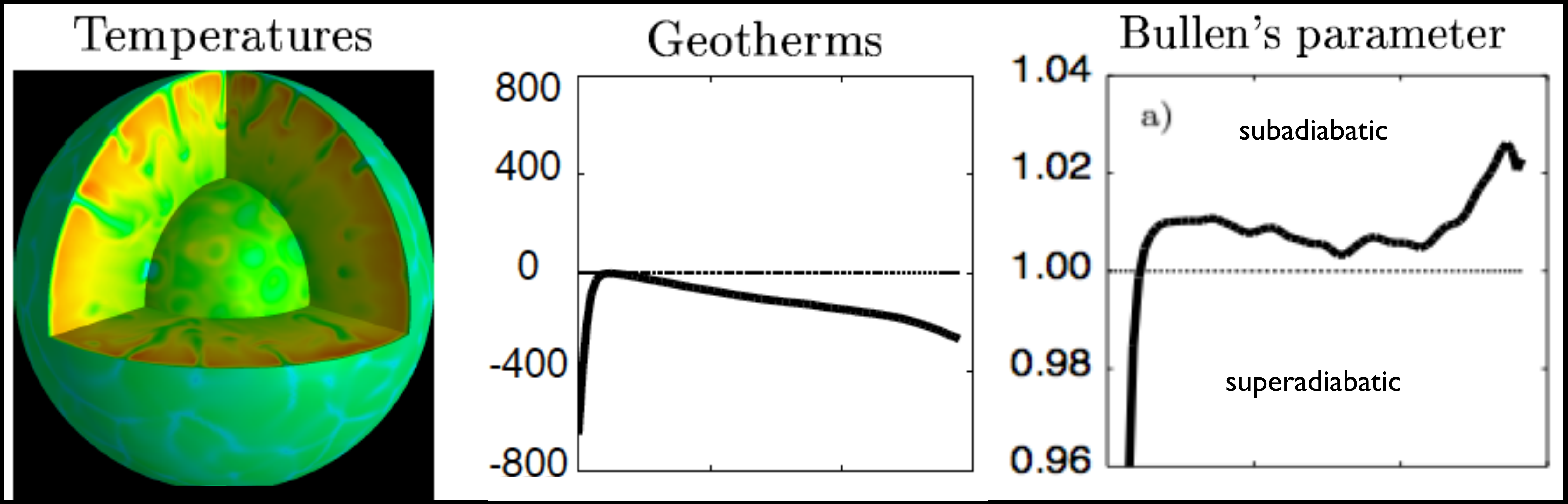
$$\frac{\partial \rho}{\partial z} = \underbrace{\frac{\rho g}{\phi}}_{\text{adiabatic density gradient}} - \underbrace{\alpha(z)\rho\left(\overbrace{\frac{\partial T}{\partial z}}^{\text{geotherm}} - \overbrace{\frac{\alpha(z) g T}{c_p}}^{\text{adiabatic temp gradient}}\right)}_{\text{non-adiabatic density gradient}}$$

- **Bullen's parameter (measure of non-adiabaticity)**

$$\Psi = 1 - \frac{\alpha(z)\phi}{g}\left(\frac{\partial T}{\partial z} - \frac{\alpha(z) g T}{c_p}\right) = \frac{\phi}{\rho g}\frac{\partial \rho}{\partial z}$$

Is the lower mantle adiabatic?

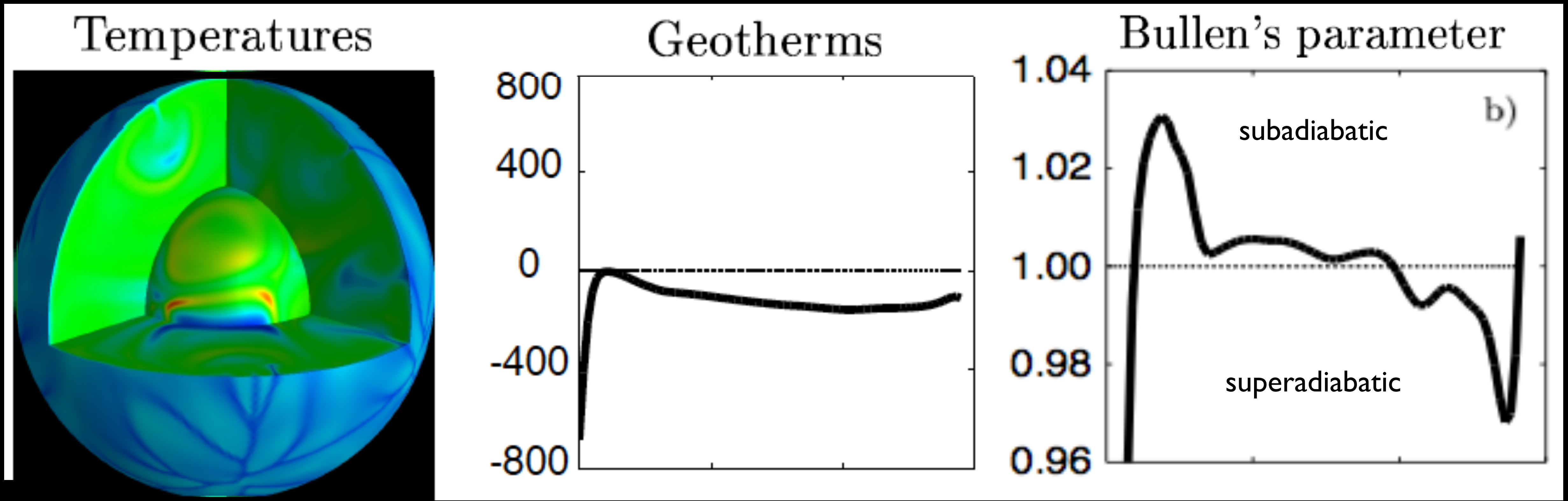
- **isoviscous, compressible, internally heated mantle at Ra = 1.1 x 10^8,**
- **lower mantle subadiabatic**



Bunge et al, GRL, 2001

Is the lower mantle adiabatic?

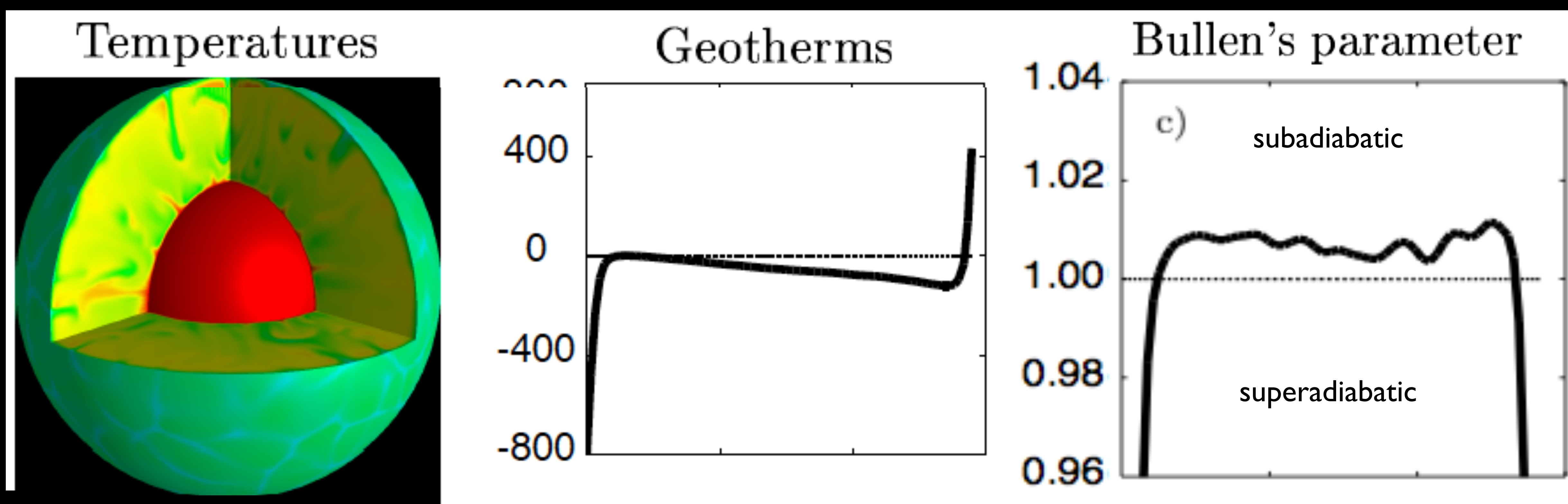
- isoviscous, compressible, internally heated mantle at Ra = 1.1×10^8, lower mantle 40x more viscous
- lower mantle superadiabatic



Bunge et al, GRL, 2001

Is the lower mantle adiabatic?

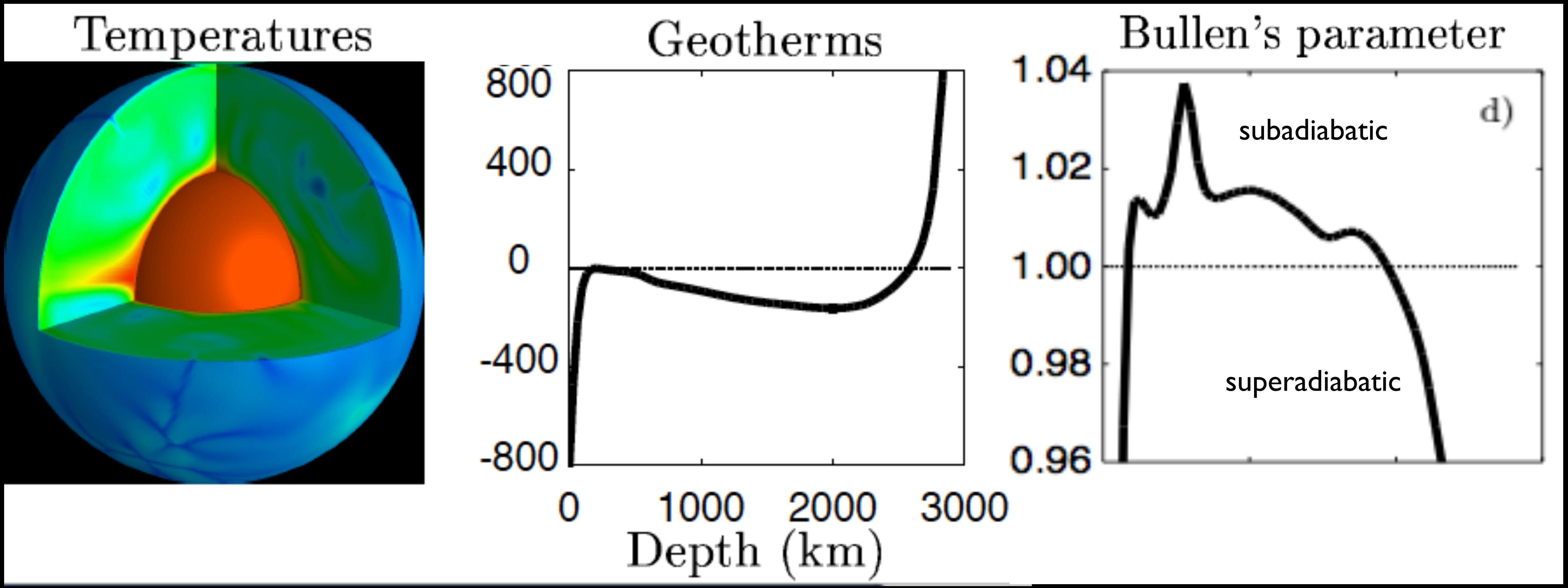
- isoviscous, compressible, bottom heated mantle at Ra = 1.1 x 10^8
- only boundary layer is superadiabatic



Bunge et al, GRL, 2001

Is the lower mantle adiabatic?

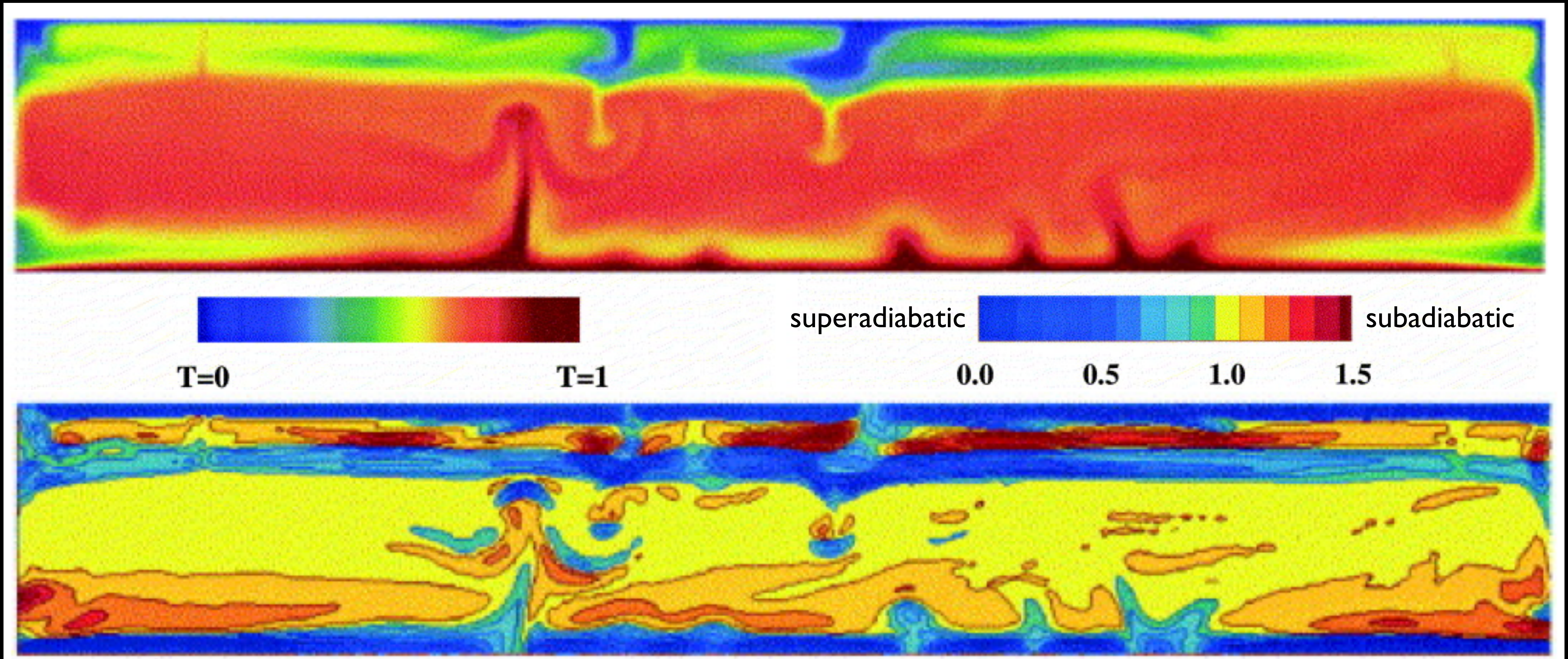
- isoviscous, compressible, bottom heated mantle at Ra = 1.1 x 10^8, lower mantle 40x more viscous
- lower mantle superadiabatic



Bunge et al, GRL, 2001

Is the lower mantle adiabatic?

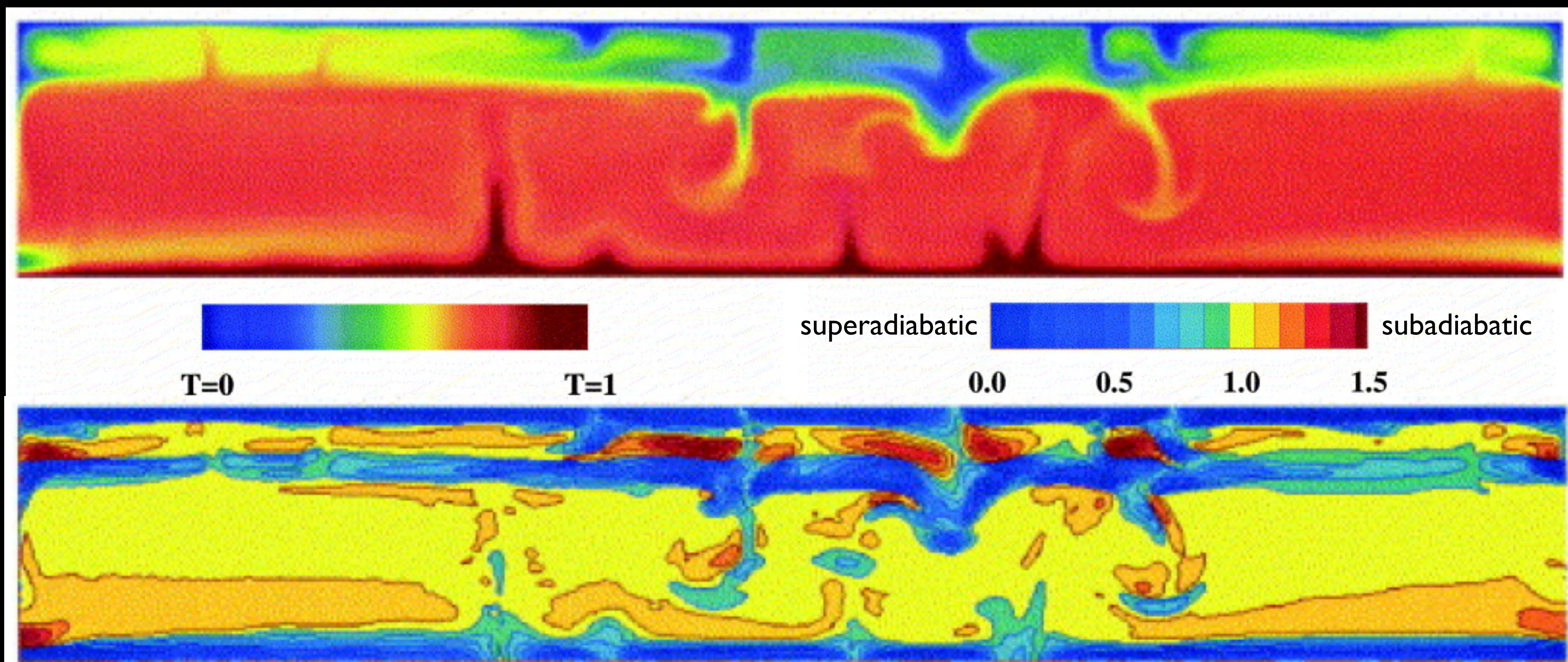
- **Temperature and corresponding Bullen's parameter from compressible mantle convection**



Matyska and Yuen, EPSL, 2002

Is the lower mantle adiabatic?

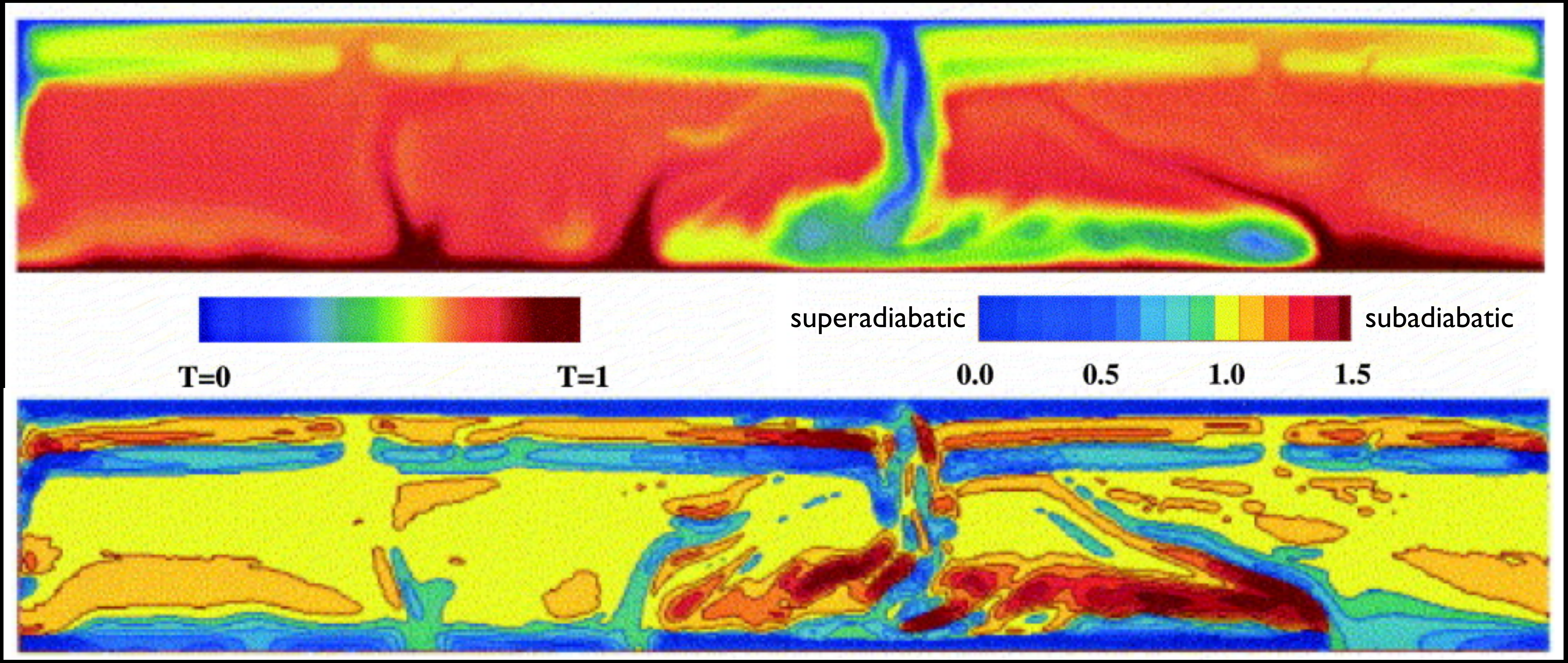
- **Temperature and corresponding Bullen's parameter from compressible mantle convection**



Matyska and Yuen, EPSL, 2002

Is the lower mantle adiabatic?

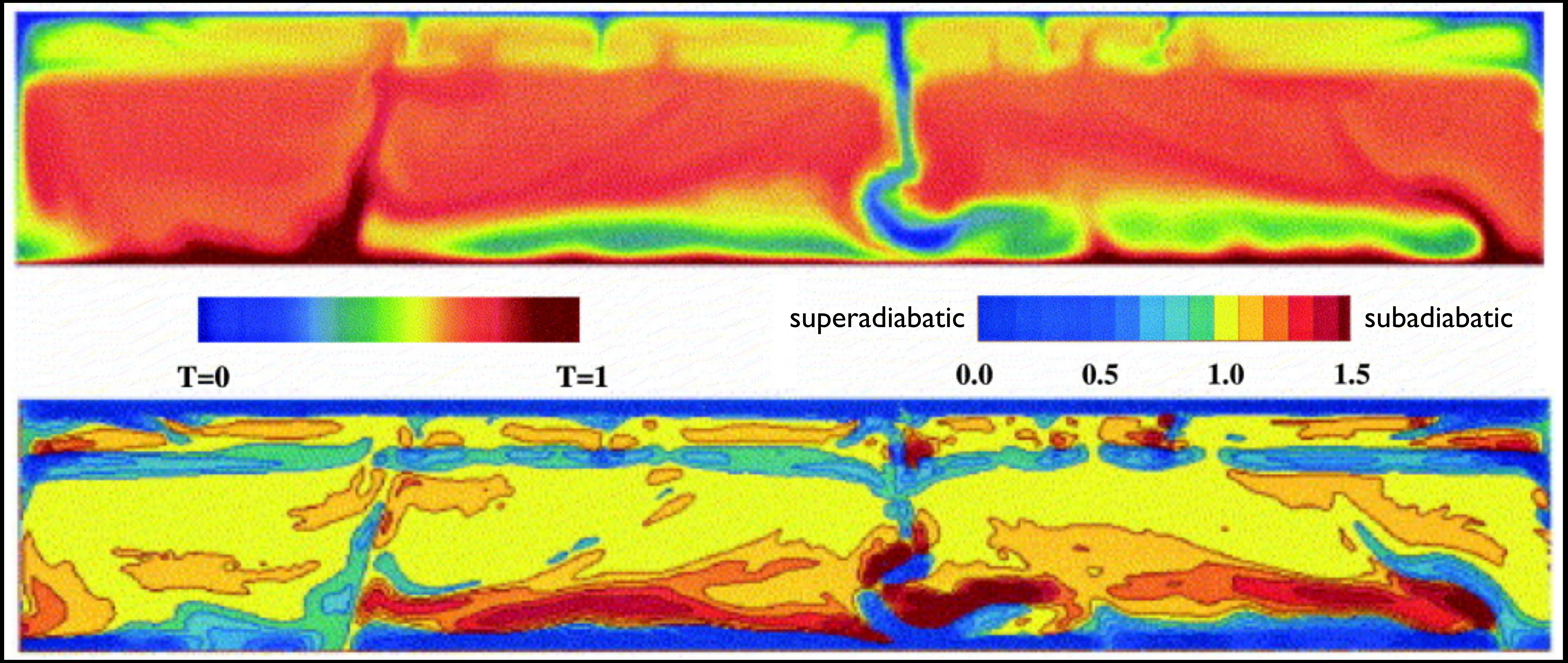
- **Temperature and corresponding Bullen's parameter from compressible mantle convection**



Matyska and Yuen, EPSL, 2002

Is the lower mantle adiabatic?

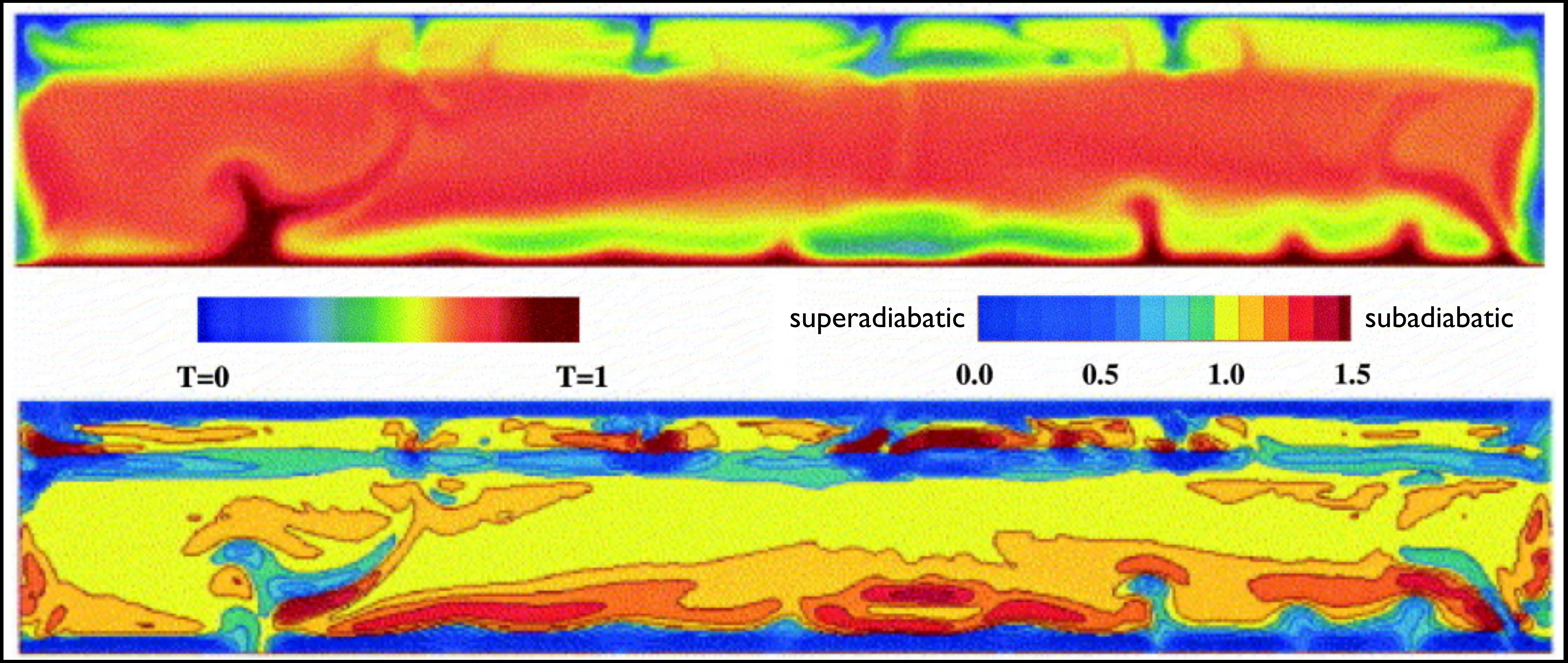
- **Temperature and corresponding Bullen's parameter from compressible mantle convection**



Matyska and Yuen, EPSL, 2002

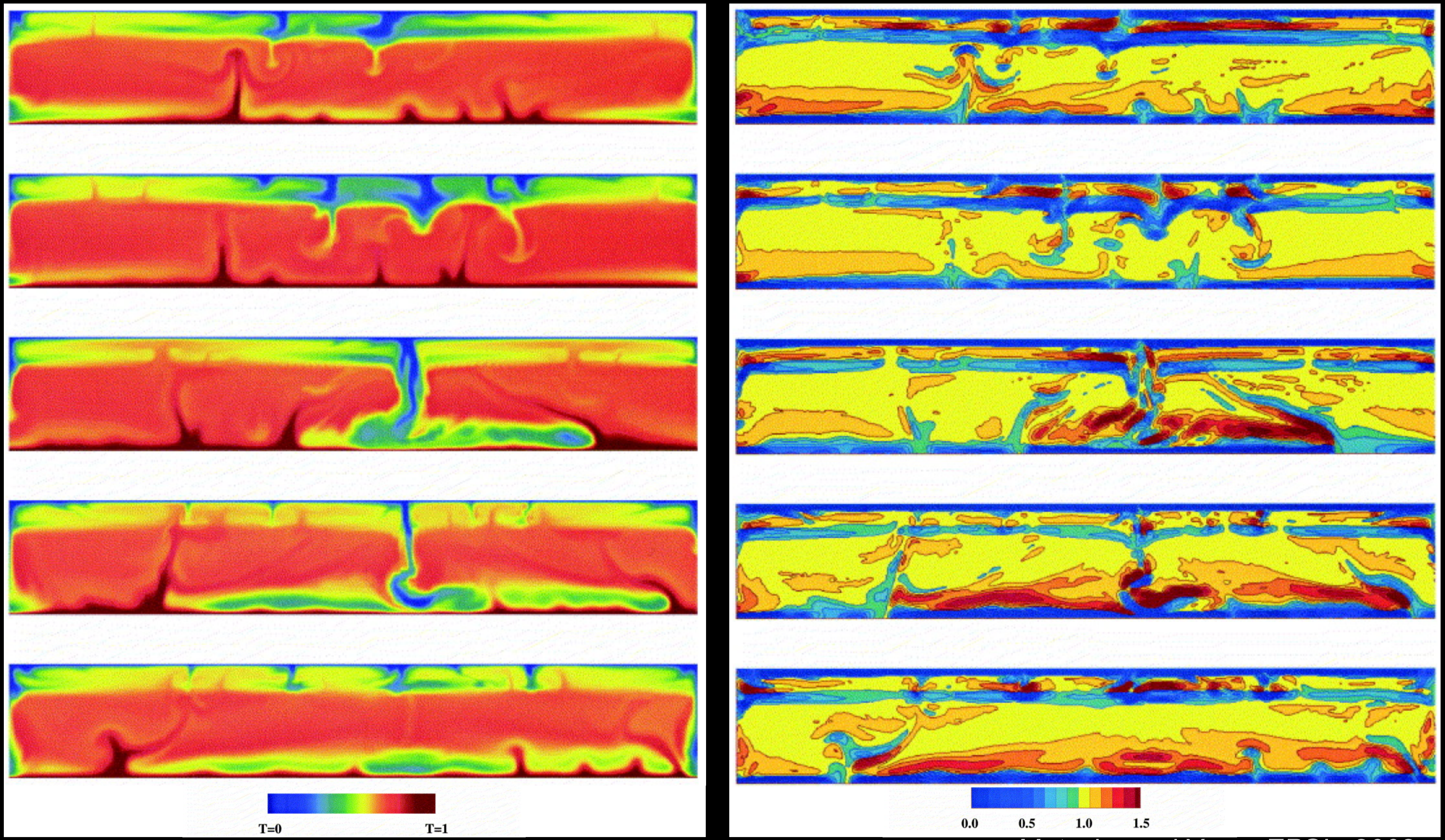
Is the lower mantle adiabatic?

- **Temperature and corresponding Bullen's parameter from compressible mantle convection**



Matyska and Yuen, EPSL, 2002

Is the lower mantle adiabatic?



Matyska and Yuen, EPSL, 2002

THE LIFE TECTONIC

www.thelifetectonic.com

Thank you! Questions??