Exoplanet interiors

In this exercise, you will test the vigour of mantle convection under different planetary conditions using a simple model. Load this website and answer the following questions:

Source: https://ian-r-rose.github.io/interactive_earth/thermochemical_hires.html

1. The “mantle” in this model is initialised in a nearly stable state. After about 15 seconds, it will become unstable and you will start to see upwellings (light colours) and downwellings (dark colours). What variable does colour represent here?

2. The Rayleigh number, Ra, is a unitless quantity that measures how vigorously the system is convecting. For Earth’s mantle, Ra ≈ 10^7. Decrease the Ra of the system by scrolling down. At what value of Ra do the upwellings and downwellings stop moving chaotically? Explain why this does not mean the mantle has stopped convecting. *[Hint: try generating a hot spot or cold spot and see what happens.]*

3. Below a critical value of Ra ≈ 10^3, convection stops and heat travels by conduction. Get the mantle below this critical Ra. Based on the colour map, how do you know convection has virtually stopped?

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4. We can calculate Ra as:

$$\mathrm{Ra} = \frac{\alpha \rho g \Delta T d^3}{\kappa \eta},$$

   where α is the thermal expansivity of the material in K^{-1}, ρ is its density in kg m^{-3}, g is the gravity at the surface in m s^{-2}, ΔT is the temperature contrast across the layer in K, d is the depth of the convecting region in m, κ is the thermal diffusivity in m^2 s^{-1}, and η is the dynamic viscosity in Pa s. Assume for simplicity that α, ρ, κ, and η are material properties of mantle rock that are constant across different planets. From this information, compare an exoplanet's convective vigour to Earth's if:

   a. the exoplanet has a larger radius than Earth.

   b. the exoplanet has the same total radius as Earth, but a larger iron core (Mercury is an example of a planet with a very large ratio of core to mantle).

   c. the exoplanet is many billion years older than Earth and as such has gradually lost most of its primordial heat.

5. Would you rather live on a planet with a radius half as small as Earth's or twice as large, and why?