The effect of a thermal runaway on the tectonic regime of Venus

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Summary

- Venus does not feature plate tectonics, is surface temperature the reason?
- Classical hypothesis: high temperatures enhance grain growth and stabilize Venus lithosphere[1] into stagnant lid
- We test this hypothesis by 'simulating' an atmospheric thermal runaway in convection models with grain size evolution (GSE)
- These preliminary results do not support for the hypothesis, but yield new interesting questions to be explored

Methods

- We solve the equations for conservation of mass, momentum and energy using StagYY[2]
- Composite rheology (and yield stress σ_{yield})

$$\eta_{diff} = A_{diff}\left(\frac{D}{D_0}\right)^2 e^{\frac{E_{diff}+P\,V_{diff}}{R\,T}} \qquad \eta_{yield} = \frac{1}{2}\frac{\sigma_{yield}}{\dot{\varepsilon}}$$

$$\eta_{disl} = A_{disl}\left(\frac{\sigma}{\sigma_0}\right)^{-2.5} e^{\frac{E_{disl}+P\,V_{disl}}{R\,T}}$$

- Grain Size Evolution (GSE)[3]

$$\frac{dD}{dt} = \frac{k\, e^{\frac{-E*}{RT}}}{qD^{q-1}} - c\,D^2 f_G\, \sigma{:}\dot{\varepsilon}$$

- We reach steady state and then increase surface temperature (T_{surf}) 'instantly'

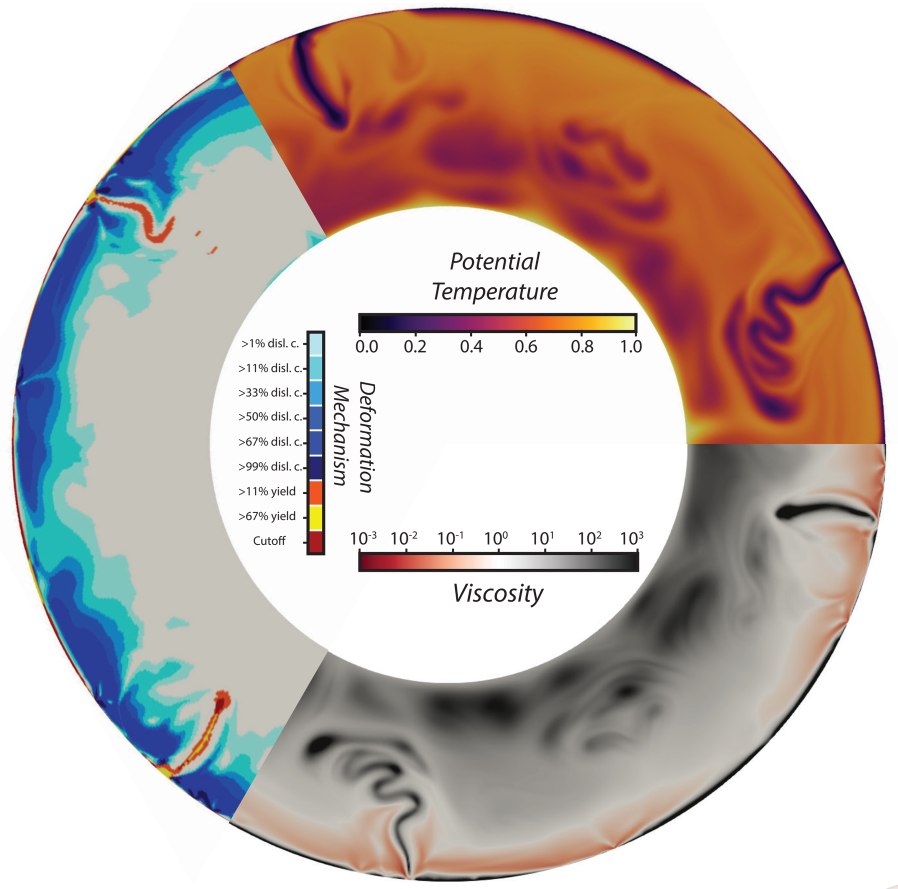
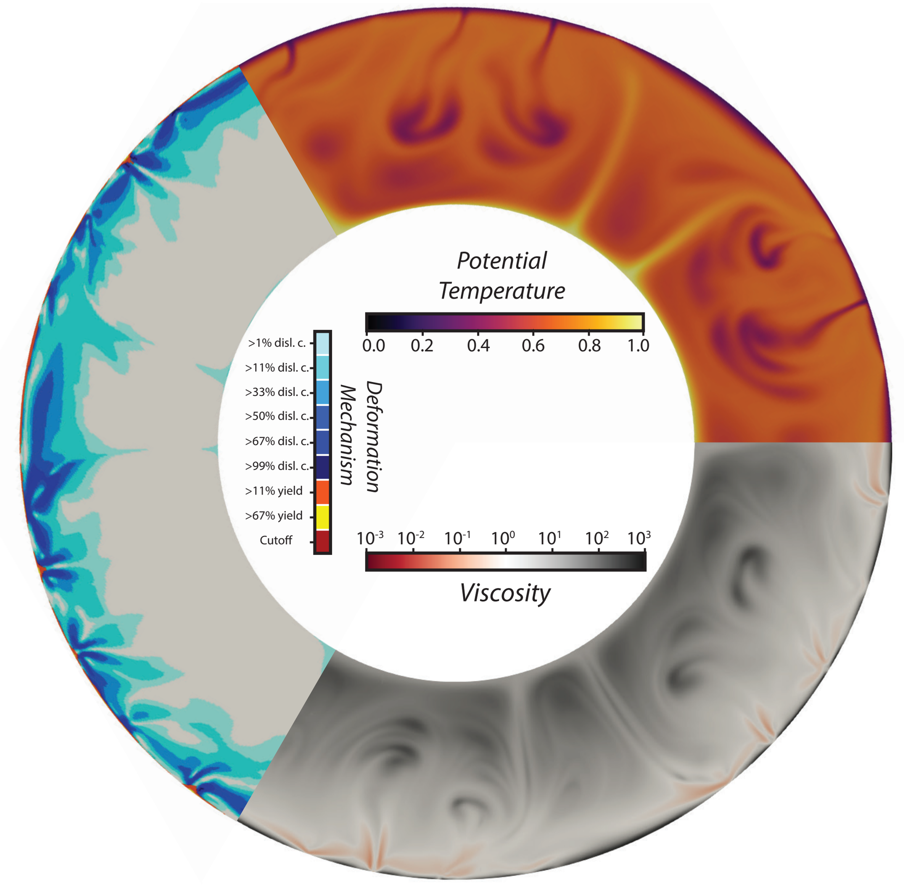


Figure 1
Snapshots of two runs with $\sigma_{yield} = 5x10^4$.

Model with ◀ $T_{surf} = 0.00$ showing subduction zones and rigid lithosphere.

Model with $T_{surf} = 0.20$ showing sluggish drips ▶ and low-viscosity lithosphere



Self consistent convection models with grain size evolution do not support a thermal runaway origin for a stagnant- or episodic-lid regime on Venus

Dislocation creep has higher activation energy than grain growth, and therefore dominates the lithospheric behavior with changing temperatures

A thermal runaway may have caused a faster cooling of the planet even at higher surface temperatures and/or non-plate tectonism (sluggish)

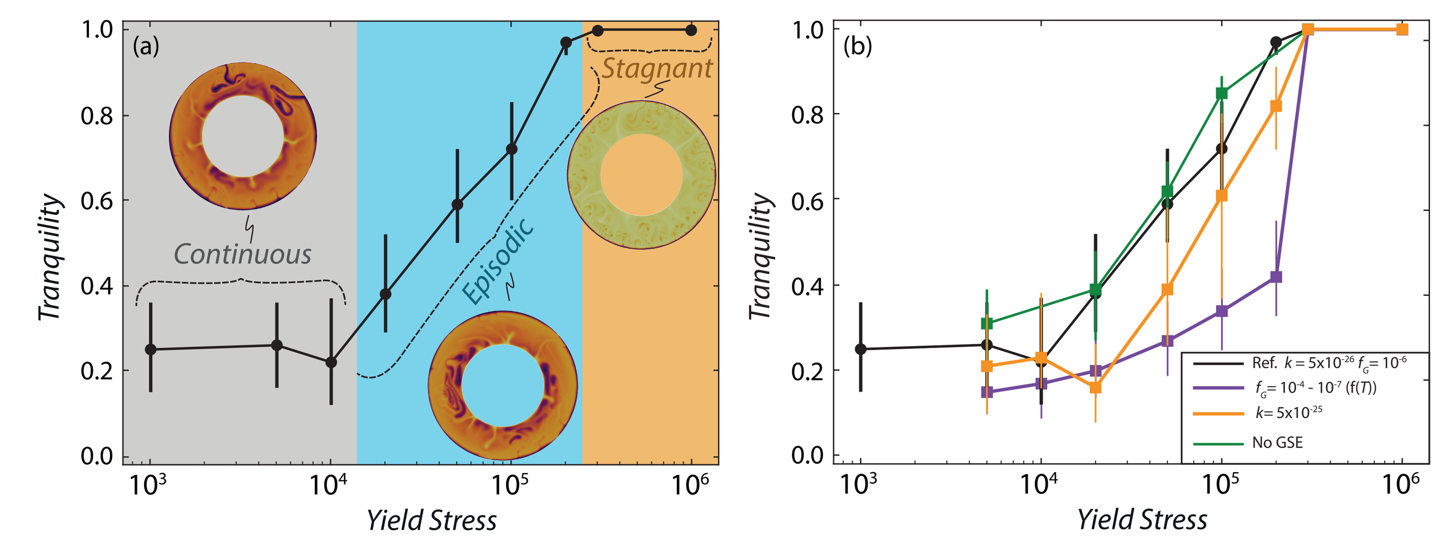


Figure 2 ▲
Tranquility vs. yield stress diagrams showing the different tectonic regimes as a function of different GSE parameters.
Note that while the mobile and episodic regimes are sensitive to these parameters, the limit between the episodic regime and stagnant lid remains unchanged.

Remaining questions

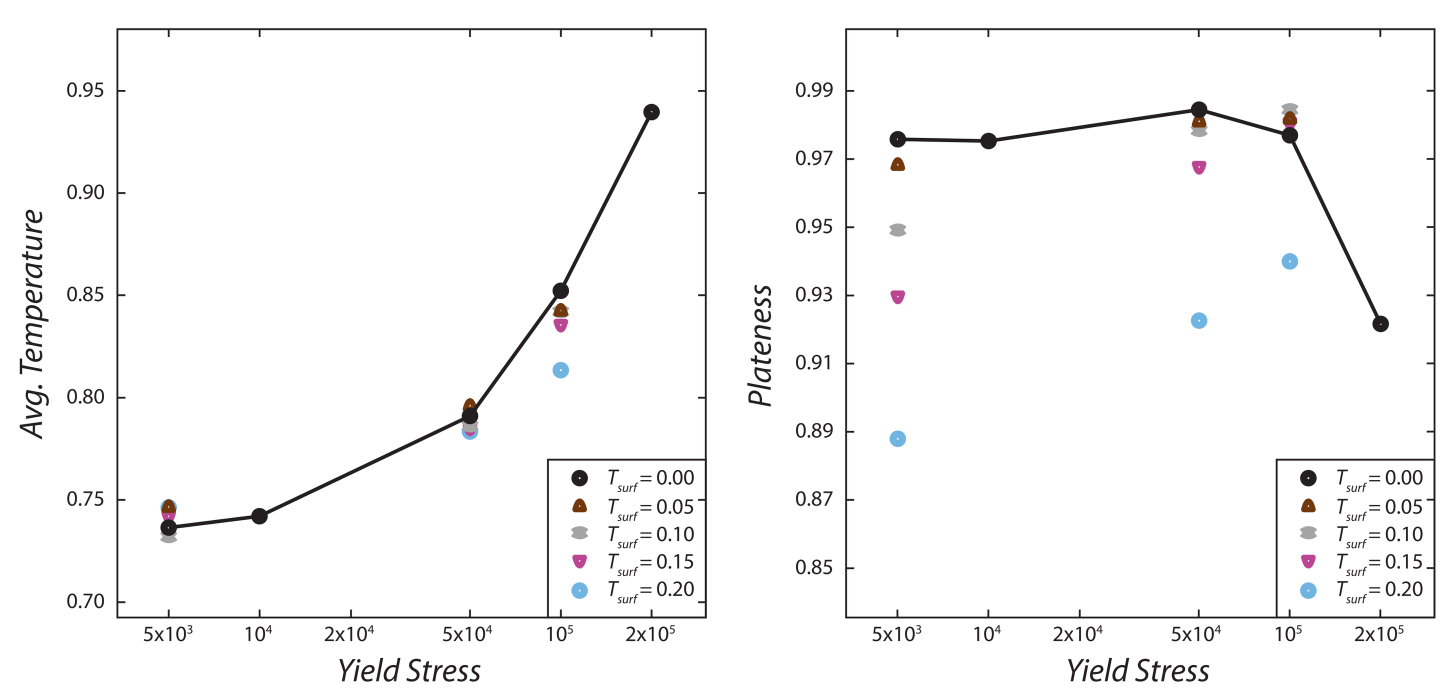
- What is and what causes the current state of Venus? and is the greater surface temperature a cause or a consequence?
- Did the planet cool more efficiently due to higher surface temperature? And what are the implications?
- What is the role of zener pinning and other rheological complexities?

References

[1]Bercovici, D., and Ricard, Y., 2014. Plate tectonics, damage and inheritance. Nature 508, 513–516.

[2]Tackley, P.J. 2008. Modelling compressible mantle convection with large viscosity contrasts in a three-dimensional spherical shell using the yin-yang grid. PEPI 171, 7–18.

[3]Rozel, A., Ricard, Y., and Bercovici, D., 2011. A thermodynamically self-consistent damage equation for grain size evolution during dynamic recrystallization. GJR 184, 719–728



◀ **Figure 3**
Average steady-state properties as a function of yield stress and surface temperature.
At low yield stresses, different surface temperatures do not result in different internal temperatures but a decreases in the plate-like behavior.
This latter effect is decreased at higher yield stresses, but an inverse correlation between surface and internal temperature is found instead.

Figure 4 ▼
Time series of average temperature for $\sigma_{yield} = 5x10^3$ (left) and $\sigma_{yield} = 2x10^5$ (right).
At low yield stresses, there is no systematic change of internal temperature with surface temperature, but this reverses at high temperatures.
Note that the cases with $\sigma_{yield} = 2x10^5$ are not in steady state and therefore not represented in Figure 3