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Interactive comment on "On the thermal gradient in the Earth's deep interior" *by* M. Tirone

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This is a useful contribution but it does not quite close the loop because the controls on the deviation from hydrostatic pressure gradients are not explored enough.

Clearly, averaged over an entire convecting system, the entropy production must match the total dissipation. Since the flow is dissipative, the isentropic model cannot be right. That is indisputable. On the other hand, averaged over the whole box it seems like the JT model must be right except within conductive boundary layers; it is interesting, then, that none of the models shown quite achieve the JT thermal gradients. The real question, for me, is: for the particular upwelling and downwelling flows embedded within the overall mantle flow, how significant is the deviation from isentropic flow? The answer depends sensitively on the viscosity structure. There are end-member cases where essentially all the dissipation in the system occurs at plate bending zones. There

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are less extreme cases where plumes and melting zones are hot and weak and so experience relatively little dissipation and require forces hardly in excess of hydrostatic to move.

The introduction of the zeta parameter, which is 1 for isentropic flow or hydrostatic pressure gradients and differs from 1 when there is a finite driving force for vertical flow, allows quantification of the deviation from isentropic thermal gradients once zeta is known. But how to compute zeta? It would be useful to contour zeta over the whole model domains shown in Figure 2 and 3 rather than just to give vertical profiles.

So, for the particular model shown in Figure 2, typical values of zeta are 0.99 in downwellings and 1.01 in upwellings. But there is no discussion of how this range of ±1% depends on important parameters like Rayleigh number or, most importantly, how different the result is in a non-isoviscous calculation. My instinct is that introduction of plate-like rheology could cause a localized region where zeta « 1 whereas the rest of the box might sit very close to (but slightly larger than) zeta = 1.

Again, for the plume shown in Figure 3, the typical value of zeta is 0.995 but how does this depend on the parameters such as boundary conditions and temperature/pressure/stress dependence of the viscosity?

Bottom line: what determines the efficiency of a convective engine, and how variably distributed are the irreversible driving forces within the overall system? This can't be addressed very well with only two representative simulations, and may therefore be a subject matter for a future, expanded study. But it requires some discussion in this study, in my opinion.

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