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# *Interactive comment on* "On the sensitivity of 3-D thermal convection codes to numerical discretization: a model intercomparison" *by* P.-A. Arrial et al.

**P.-A. Arrial et al.**

parrial@ucdavis.edu

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Thank you very much for your helpful comments and corrections. We answer to your comments in order:

Specific comments:

1) This is a very interesting comment. Indeed, we did not extensively describe and compare the dodecahedral stationary pattern between methods before the transition. As you observed in figure 8, the RMS velocity matches perfectly at a Rayleigh number of 7000. The same comparison and observation can be done with other Rayleigh numbers and parameters (Nusselt numbers, average temperature). We suggest adding the



following text and table in page 2044 line 14:

*In all cases of the Ra in Figure 9, the dodecahedral convection pattern is initially observed and stationary. This pattern is identical in both methods, whether one considers its geometry, the convergence of RMS velocity, average temperature or Nusselt Numbers before the transition (Tab. 1).*

**Table 1.** Comparison between computational methods RBF and CitcomS for the dodecahedral stationnary pattern at various Rayleign number. For CitcomS and a Ra=2000, the dodecahedral pattern does not satisfy stationarity to estimate parameters value

| | $\langle T\rangle$ | | $\langle V_{rms}\rangle$ | | $Nu_t$ | | $Nu_b$ | |
|---|---|---|---|---|---|---|---|---|
| Ra | RBF | CitS | RBF | CitS | RBF | CitS | RBF | CitS |
| 2000 | 0.2723 | - | 8.45 | - | 1.889 | - | 1.889 | - |
| 3000 | 0.2521 | 0.2535 | 12.97 | 13.07 | 2.411 | 2.413 | 2.411 | 2.422 |
| 4000 | 0.2403 | 0.2414 | 16.67 | 16.76 | 2.768 | 2.768 | 2.768 | 2.777 |
| 5000 | 0.2322 | 0.2331 | 19.93 | 20.01 | 3.043 | 3.042 | 3.043 | 3.052 |
| 6000 | 0.2261 | 0.2271 | 22.89 | 22.98 | 3.270 | 3.269 | 3.270 | 3.280 |
| 7000 | 0.2213 | 0.2223 | 25.62 | 25.65 | 3.465 | 3.465 | 3.465 | 3.476 |
| 8000 | 0.2174 | 0.2183 | 28.19 | 28.31 | 3.638 | 3.638 | 3.638 | 3.650 |
| 9000 | 0.2141 | 0.2151 | 30.62 | 30.74 | 3.794 | 3.793 | 3.794 | 3.807 |
| 10000 | 0.2112 | 0.2123 | 32.93 | 33.07 | 3.937 | 3.935 | 3.937 | 3.951 |

2) We do think that the current results are reliable. Results show a really good match for the cubic and five-cell steady states and the stationary dodecahedral pattern. We point out that when models are close to the transition, the destabilization can be influenced by the the discretization scheme of the method. As a reply to the first referee, we added a supplementary description of the destabilization of the dodecahedral pattern for CitcomS (see response to referee 1). We agree that the two methods mostly agree at some point and we modified the conclusion to make precise this point: page 2048, line 17

*As a general observation, both methods show a good match on the cubic and five* *cell steady state patterns, and even for the stationary dodecahedral pattern before the transition. However, we hope that the above in depth computational study strongly illustrates how numerical discretization can impact both the resulting patterns of convection as well as the transitional states that occur.*

At this time, RBF method has not incorporated variable viscosity. We did not explore the sensitivity of these models to temperature dependent-viscosity. We know that this kind of viscosity is probably going to modify the geometry of the final convection patterns and could possibly improve the stability of the dodecahedral pattern, for example. Reese et al, 1999 (Phys. Earth Planet. Int.) used a dodecahedral initial condition with a temperature dependent viscosity and investigated various viscosity ratios. However, the authors did not state the length of time integration. The results suggest that this pattern can reach a steady state with a variable viscosity. However, as the RBF method showed, the dodecahedral pattern can look steady but is actually destabilized to a lower order of symmetry. It would be really interesting to investigate the behavior of the models with variable viscosity. For Rayleigh number higher than about $2 \times 10^5$, models become strongly time dependent, entering a turbulent regime, where symmetry is completely lost. Thus, at such high Ra, it is impossible to highlight the influence of numerical discretization on the resulting patterns of convection.

Technical corrections: 1) Indeed, the reference of (Moresi and Solomatov, 1995) would be better as a Citcom reference. We move this reference to the next line. Page 2038, line 18: *Developed from the software Citcom (Moresi and Solomatov, 1995; Moresi et al., 1996), a code structured for 3D Cartesian geometry, CitcomS employs an Uzawa algorithm to solve the momentum equation coupled with the incompressibility constraints (Ramage and Wathen, 1994).*

2) The labels in the image are correct and we modify the caption according to it.

*Fig5. Time trace of (a) the outer Nusselt number and (b) the RMS Velocity* <u>*for Ra=70000 and $\delta = 0.08$ with CitcomS and $\delta = 0.09$ with RBF.*</u> *Both methods con-*



*verge to an unsteady oscillating axisymmetric pattern dominated by the $\ell = 2$ mode (see Fig. 4).*

3) The figure order is modified to follow the citation order. Thus the figure with Nusselt number and RMS velocity time traces becomes figure 9 and the figure with the final convection patterns for the dodecahedral test case becomes figure 10.

4) In the caption the references to the final convection pattern need to be shifted from (b-d) to (c-e). The new caption is:

*Fig. 12. Time traces of the evolution of the average temperature as a function of the parameter at Ra = 7000 for (a) the RBF-PS model and (b) CitcomS.* <u>*(c–e) show the final convection patterns for each of these models with (c) $\gamma = 0$, (d) $\gamma = 0.5$, and (e) $\gamma = 1.0$.*</u>

5) We added “to” before “highlight” on line 13, page 2047

6) We changed “finite volume“ to “finite element” on line 16, page 2047.

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