

## ***Interactive comment on “Enforcing conservation of axial angular momentum in the atmospheric general circulation model CAM6” by Thomas Toniazzo et al.***

### **Anonymous Referee #1**

Received and published: 2 January 2020

Previous work has indicated significant angular momentum conservation errors in the CAM FV atmospheric dynamical core, with consequences for aspects of the simulated global circulation such as the Hadley circulation. The manuscript replicates these errors in numerical experiments, and uses a combinations of mathematical analysis and numerical diagnostics to pinpoint the main source of the angular momentum errors as the discretization of the momentum advection terms in the ‘vector invariant’ formulation. A ‘correction’ to the momentum advection terms that make them (almost) angular momentum conserving in a zonal average, and a ‘fixer’ that enforces global angular momentum conservation are presented. The effects of applying the correction and the fixer, either individually or together, are quantified in numerical experiments.

C1

I believe this work will be of interest to the community, both to users of the CAM model and also, more widely, to those developing dynamical cores based on the vector invariant form of the governing equations. I would therefore be happy to see it published in due course. However, there are parts of the manuscript that need to be more clearly or more carefully explained. I am therefore recommending some revisions before publications.

### **Specific points**

1. The abstract is rather brief and lacking in detail.
2. Lines 18-20 are rather unclear. There are some unstated assumptions and omitted steps.
3. Line 32: Again there are several steps missing in the implied causal chain.
4. Line 69 and numerous other places: The same model resolution is sometimes referred to as ‘1.9°’, sometimes as ‘f19’, and sometimes as ‘2°’. This is confusing for the reader and makes the manuscript hard to read and follow. Please use a consistent notation.
5. Line 72: What is meant by ‘the Eulerian grid’? Surely you mean the spectral dynamical core (with Eulerian rather than semi-Lagrangian advection)?
6. It would be worth stating somewhere in the Introduction whether the FV dynamical core is exactly mass conserving. (It is rather difficult to conserve anything else if mass is not conserved.)
7. Line 138: Explain the notation in the definition of  $\alpha$ .
8. Equation (3): Is  $\lambda$  a coordinate or an index? Also, what is  $\Delta_k$ ?
9. Lines 155-156: Which ‘denominators’ are referred to? What is meant by ‘inertia’ (also line 165)?

C2

10. Line 167: What is  $\Delta p$ ?
11. Lines 179-180: What is meant by 'pure Eulerian mode'?
12. Lines 198-199: Surely you mean AM fluxes?
13. The discussion on p9 needs more detailed explanation. Line 205: which 'problem'? Equation (5): I was able to convince myself that, in the continuum limit, the right hand side reduces to the zonal mean of a zonal derivative and therefore vanishes. However, I could not manipulate the integrand into the form stated in lines 212-213. Equation (7): Some explanation is needed for the terms  $\mathcal{Y}$  and  $\mathcal{F}$ .
14. P10. The idea of substepping hasn't been mentioned until now; perhaps it needs a sentence of introduction.
15. Line 234: 'zonal momentum sink of the shallow water'; please rephrase more clearly.
16. Line 251-252: this global fixer variant?
17. Line 255: If I recall correctly, the JW06 test case has a constant pressure bottom boundary (initially) rather than a flat (constant  $z$ ) bottom boundary.
18. Line 320-321: 'only by means of momentum advection'. (Angular) momentum can be transferred over great distances by waves. Whether one considers the transfer to be by advection or by pressure forces depends on whether one takes an Eulerian or Lagrangian point of view.
19. Line 324: 'except for those specific to orographic processes'. Do you mean those parameterisations are switched off?
20. Line 384: 'equivalent temperature field'. What does this mean? Presumably nothing to do with equivalent potential temperature?
21. P23. It would be worth noting that the f09 simulation is not improved everywhere

C3

by the correction and fixer, e.g. near the South Pole, especially in the stratosphere.

22. Appendix A. After some effort I was able to convince myself that equation (A1) is correct. However, some of the terms are incorrectly described in the text. For example,  $D_L$  is the divergence of the flux of *relative* AM. Also,  $C_\lambda$  includes the tendency of the contribution of planetary rotation to AM (not absolute AM; there is no contribution from  $u$ ). But  $C_\lambda$  also includes the divergence of the flux of that contribution to the AM.

23. Appendix B. It would be worth reminding the reader that the contribution from the zonal pressure gradient has been dropped. Some more careful explanation is needed under equation (A4); if I understand correctly, the 'final' new value of  $u$  is  $u_n + \overline{\delta u}$  rather than  $u_n$ .

### Figures and tables

Fig. 1. Axis labels are too small to read when printed.

Fig. 6. Axis units cm/s/day (check what departures from SI units are permitted by GMD)

Fig. 7. Only one hemisphere is shown in each panel, presumably because the results are symmetrical about the equator. Perhaps give the reader a sentence of explanation.

Fig. 9. There is no colour bar; perhaps it has been cropped as the manuscript was put in GMD format?

Fig. 11. The right side of this figure appears to have been truncated too. Note also that the legend is too small to read when printed at normal size; I had to look at the electronic version.

Table 1. What are the percentage figures given in the table? Please give enough detail in the caption.

### Minor errors, typo's etc

Title page: Please check the initials of the last author.

C4

Line 16. Repetition: 'specific' means per unit mass

Line 18. Repetition: 'atmospheric air'

Line 48: model's

Line 61: phase 6th

Line 110: founf

Line 246: zonal wind increments are

Line 266: close to

Caption of Fig. 5: shows

Line 343: angular momentum (or AM).

Line 362: numerically

Caption of Fig. 7: 'vertical latitude-pressure profiles'; the word vertical is redundant.

Line 408: levels

Line 485: Something does not make sense here.

Line 679: applies

Line 709: shew

---

Interactive comment on Geosci. Model Dev. Discuss., <https://doi.org/10.5194/gmd-2019-254>, 2019.