

Interactive comment on “Downscale cascades in tracer transport test cases: an intercomparison of the dynamical cores in the Community Atmosphere Model CAM5” by J. Kent et al.

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C791

Response to reviewer 1

The author's would like to thank reviewer 1 for their helpful comments. Below is a response to each comment:

“General Comments”

The aim of our paper is to assess the ability of the transport schemes in CAM5 to solve the transport equation for the under-resolved case. We discuss the behaviour of the schemes with respect to the L2 error norm and to the tracer variance, and we also explain the reason for this behaviour is due to the type and strength of diffusion either from the truncation error of the numerical schemes (in the cases shown, usually due to limiters) or due to explicit hyper diffusion. We do comment that some, but not too much, diffusion is required for an accurate solution, but, as the aim of the paper is to investigate transport in CAM5, we do not go into more detail about what makes a ‘good’ scheme for this problem.

1. “Avoid using the denomination ‘dynamical core’ because the tracer advection is independent of the dynamics of the model. Here the the velocity is not predicted, thus the flow is not ‘dynamic’ but prescribed.”

We appreciate the reviewer's comment that the velocities are prescribed and therefore not ‘dynamic’. However we use the term dynamical core because i) these tests are specifically designed for transport algorithms in dynamical cores, and ii) part of the paper is to intercompare the transport schemes available in the different dynamical cores of CAM5, and therefore the transport scheme is named after and part of said dynamical core. However, we have made it clearer in the revised text that the velocities

C792

are prescribed and therefore these are not 'dynamic' tests.

2. "Please explain more clearly what you think is a physical mechanism for tracer diffusion? Or: What is the physical motivation for diffusion?"

As the tracers are stretched below the grid scale they cannot be properly represented on the grid, and tracer variance is transferred downscale from the resolved to unresolved scales. On the grid this is a diffusive process; we can't represent scales that are finer than the grid, so the tracer must be diffused to fill the grid cell. We have edited the text to make this clearer in our paper.

3. "Distinguish the phrasings 'diffusive' and 'dissipative'. Dissipative means that entropy is produced, see Lauritzen Thuburn 2011, QJRMS .It would also be instructive if the entropy is taken as a measure of mixing. One advantage (which is shared with the tracer variance) is that entropy diagnostics does not need the 'true' solution (see the mentioned paper)."

We have included the entropy as a measure of mixing. We compare the high-resolution solution averaged to the coarse grid with the results from the schemes on the coarse grids. We have plotted this against time (see figure). The results are very similar to the use of tracer variance and strengthen our conclusions about the schemes on the coarse grid, that they i) need to dissipate tracer variance at the grid scale (this is shown by the entropy produced by the reference solution averaged to the coarse grids), ii) are all more dissipative than the reference solution.

4. "I doubt that tracer variance is conserved in the strict sense if molecular diffusion would be included. Connected to that is the question: What means 'all the scales'
C793

(page 1789)? Stricly speaking 'all the scales' would mean that you compute a DNS where even the molecular diffusion is a resolved process. This is impossible for a global model."

We agree that tracer variance is not conserved if molecular diffusion is included, however we are working from the transport equations that assume that molecular diffusion is not included. We have clarified the text to highlight that molecular diffusion is not included in the equations, and that 'all the scales' effectively means a solution to the continuous transport equations (without molecular diffusion).

5. "Why do you need a filling algorithm for the first order upwind scheme and the van Leer MC scheme? They should not generate negative values at all by definition (besides machine truncation errors)."

In 1D both van Leer and PPM should not produce negative values, however, these schemes can produce negative values when used with a 'split' method such as the Lin-Rood scheme (which is used by CAM-FV). For this reason the filling-algorithm is used for these schemes. The 1st-order scheme does not produce negative values even when used with the Lin-Rood scheme and does not need the filling algorithm.

6. "(most interesting) Why do you think that the LW-scheme is non-dissipative? How can you prove this? The LW-scheme possesses diffusive and dispersive terms. Can you explain more why the LW-scheme seems not to dissipate tracer variance? Are there perhaps compensating effects of dispersion and diffusion?"

The Lax-Wendroff scheme is dispersive to leading order truncation error, although higher order terms are indeed diffusive. This can be shown using modified equation

analysis: e.g. for the Lax-Wendroff scheme for 1D advection the leading order error is given as

$$\frac{\partial q}{\partial t} + u \frac{\partial q}{\partial x} = -\frac{u\Delta x^2}{3!} \left[1 - \left(\frac{u\Delta t}{\Delta x} \right)^2 \right] \frac{\partial^3 q}{\partial x^3} \quad (1)$$

The next error term is $O(\Delta x^3)$ and contains a $\frac{\partial^4 q}{\partial x^4}$ term. For this reason the dispersion terms dominate the diffusion terms, and therefore the LW scheme cannot sufficiently dissipate tracer variance.

The diffusion and dispersion in Lax-Wendroff is also discussed in Rood (1987), which states 'The amount of diffusion in this scheme is the minimum amount to stabilize the Euler scheme' and '[LW] is not as diffusive as the donor cell but because of dispersion generates ripples that follow the distribution.'

We have stated in the revised text that Lax-Wendroff is predominantly dispersive (i.e. not diffusive to leading order error).

7. "Tracer variance must be dissipated to avoid the accumulation of tracer variance at the grid scale: Fig 4 shows increasing tracer variance at some places, especially for coarse resolutions: Why? Is it because of the aggregation of the reference solution to the coarse grid?"

Yes, this is due to the averaging onto the coarse grid. We have noted this in the revised text.

8. "What means 'whether a numerical scheme has accurately modelled the subgrid

C795

term' ? One can measure 'how' accurate, but 'whether..' seems undefined."

We agree and have changed the text to discuss 'how accurate' and not 'whether the scheme has modelled the subgrid term'.

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C796

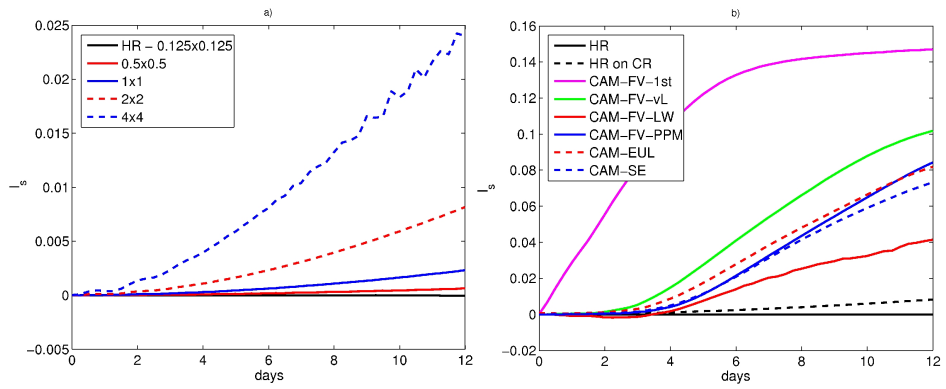


Fig. 1. Entropy diagnostic for the reference solution averaged onto the different coarse resolution grids (left), and for the transport schemes in CAM, for test 2.