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Interactive Comment

Interactive comment on "The terminator "toy"-chemistry test: a simple tool to assess errors in transport schemes" *by* P. H. Lauritzen et al.

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Below the reviewer comments are in black font and author reply in blue font:

This paper presents a simplified chemistry-like interaction between two correlated tracers to test transport schemes. The authors particularly focused on the correlation properties of these tracers and the effect of monotonicity/limiters. Overall the paper is clear and well written and the test could be useful to chemistry transport development. Therefore, I don't have any objection for its publication in GMD.

We thank the reviewer for reviewing the manuscript and providing very useful comments. The revised manuscript is available in the supplement

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Specific comments:

The mathematical equations are not easy on the eye and a bit confusing whether the l in Cl is L or I. Also I don't see why one wants to use 2 or 3 letters to define a variable while one letter will suffice. The notations would be much neater and clearer if, for example, m_1, m_2 and m_3 are used for Cl, $Cl2$ and Cly, respectively.

Response: Agreed

Changes to manuscript: Notation has been been changed to X, X_2, and X_T throughout the manuscript.

Section 2. The physical meanings (i.e., mixing ratios) of the three tracers should be clearly defined in this section. The section shows lot of equations without ever saying what are these Cls.

Response: Agreed

Changes to manuscript: In the beginning of Section 2 the units of X has been clearly defined, i.e. nomenclature X describes the number density (number of molecules of compound X divided by the number of molecules of air).

Throughout the text the use of "preserve and conserve" are left somehow ambiguous and confusing as to what exactly we mean (examples: page 8772, "Another inspiration for this test is the atomic concentration is conserved."; "... conserved the total chlorine).". It would help the reader to define exactly what we mean by these words (i.e., tracer mass conservation, preserving a constant, preserving a relationship, etc...), especially in presence of the sources terms.

Response: Agreed

Changes to manuscript: This has been clarified. When talking about preservation or conservation the quantity in question is explicitly stated in the manuscript.

Section 5.3 and Fig. 5. The authors has to explain why the "default limiter" doesn't

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remove the overshoot in Cl (bottom-left corner picture). Fig. 7. The authors has to provide an explanation as to why the error in CAM-FV is around 10 times smaller than that of CAM-SE?

Response: We stated in the manuscript that an in-depth analysis of why the limiters do not preserve linear relations is up to the scheme developers. That said, we have performed some additional experiments to shed light on why CAM-SE performs as it does. Please see text below.

Changes to the manuscript: The following paragraphs have been edited/added to section 5.2:

CAM-SE does not preserve linear relations either and the errors in X_T are about an order of magnitude larger than CAM-FV. The CAM-SE limiter is optimization-based (using Least-squares) and guarantees no under- or over-shoots at the element level while maintaining mass-conservation at the element level (Guba et al., 2014). While the optimization-based limiter preserves linear relations with exact arithmetic, its present implementation in CAM-SE does not lead to such preservation (most likely due to iteration thresholds, if-statements, etc. that can be non-linear).

To further understand this behavior we have performed some tests (not shown) turning the chemistry off and advecting linearly correlated Cosine hills and linearly correlated step-functions. The Cosine hills are C^0 continuous (the function is continuous but its derivatives are not) and the limiter exactly preserves the linear relationship. For the step-functions, which are discontinuous distributions, the correlation preservation is only maintained up to $O(10^{-8})$ due to an $O(10^{-8})$ overshoot in one of the tracers. So the advection operator introduces an $O(10^{-8})$ error. The terminator chemistry constantly enforces a discontinuity in the distributions and in combination with the CAM-SE limiter, strong error growth is produced. It is beyond the scope of this paper to trace down exactly where in the implementation this error is introduced and to find a remedy. The terminator test is designed to enable scheme developers to test their scheme in

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setups that are directly relevant to some of the issues seen in chemistry application. In this particular case, the terminator test clearly exacerbates small errors in correlation preservation that may be easily overlooked in inert transport testing (such as the tests in Lauritzen et al., 2012).

Final thought: Let us denote the test's equations as follows: (a) $dm1/dt = S1(m1, m2)$, (b) $dm2/dt = S2(m1, m2)$, (c) $dm3/dt = 0$, and (d) $m3 = f(m1, m2)$. I would like to see a discussion about the over-specification of this problem (i.e., there is an arbitrary choice of how one could solve these over-specified equations set). If (d) is an important property to maintain, then one could simply solve (a) + (c) and deduce m2 from (d), instead of the approach used in the paper [i.e., (a) + (b) and check how well we achieve (d)]. I am not asking to redo the experiments with the alternative approach but a brief discussion as to why this way and not the other way?

Response: Agreed!

Changes to the manuscript: The following paragraph has been added to the end of Section 3:

We note that instead of advecting each species separately by solving the advection equations in eq:adveqs or eq:rho-phi with $\phi = \mathrm{X}, \mathrm{X}_2$, one may also choose to advect the sum X_T and one of the species, e.g. X, and then diagnose the remaining species, X_2. If the transport operator conserves a constant, which many transport operators do, then the constant sum X_T is trivially conserved if chosen as a prognostic variable. This approach is commonly used in chemistry transport models for some families of species. E.g., Douglass *et al.* (e.g., 2004) advected the sum of total inorganic chlorine and bromine to avoid spurious maxima and minima in their distributions in the stratosphere. Idealized tests to evaluate how well families of species that add up to a constant are preserved see, e.g., Lauritzen and Thuburn (2012). .

Minor comments:

Section 5.1, page 8781: There is a bit of mis-use of the word mass. Most the word "mass" in the 2nd paragraph of section 5.1 refers to "density". We should be clear that $\rho\phi$ is the tracer density and not mass [if ρ is the density of dry air and ϕ is a tracer mixing ratio (mass = $\rho\phi V$ where V is the volume element)].

Response: Text changed to avoid confusion (refer to $\rho\phi$ as tracer density).

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Please also note the supplement to this comment:
http://www.geosci-model-dev-discuss.net/7/C3590/2015/gmdd-7-C3590-2015-supplement.pdf

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