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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Technical Note: Adjoint formulation of the TOMCAT atmospheric transport scheme in the Eulerian backtracking framework (RETRO-TOM)" *by* P. E. Haines et al.

D. Henze (Referee)

daven.henze@colorado.edu

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1 Overview

The manuscript by Haines et al. presents an adjoint of the TOMCAT chemical transport model, RETRO-TOM. The paper does a nice job of investigating different treatments of transport and transport adjoints. Several issues discussed here are germane to many studies using adjoint of chemical transport models, if not more broadly transport models in general, such as the impacts of flux limiters and the treatment of advection adjoints. The writing is clear, the paper is well organized, and the content is appro-

priate for an ACP technical note. As a fellow adjoint model developer, I have some very detailed comments below. Of these, the only broader concerns are that another paper on an adjoint of TOMCAT was just published, and it should be discussed here. Also, I really like the formulation they have presented, as it makes an important step towards addressing a long-standing challenge in this field. However, the ultimate choice of adopting this approach over others could be discussed with a bit more balance, considering that flux limiting capabilities and using specific advection schemes may be important in other cases.

2 Comments

- This work doesn't mention the recent paper by Wilson et al. in GMD, 2014, on a different adjoint of the TOMCAT model. Clearly these were developed independently, but some discussion and comparisons should be made. For example, Wilson et al. choose a fully discrete adjoint approach for their transport. Their sensitivity evaluations and inverse modeling tests seem quite adequate. How does this thus impact the conclusions of the current work with regards to potential errors when not adopting their recommend Eulerian backtracking framework?
- 1482.7: It's not very clear here what "accuracy" is referring to, please clarify. Same issue in 1484.20, 1491.12
- 1483.17-20: Other disadvantages, as pointed out in works such as Hourdin 2006, Henze 2007 and Hakami 2007, are that the AFD approach for nonlinear advection algorithms leads to undesirable results for sensitivity analysis (i.e., non-physical negative sensitivities) and that the AFD approach for nonlinear advection algorithms could even lead to poorer performance for optimization (Gou and Sandu, 2011).

- 1485.14: Wilson 2014 also presents a nice assessment of their transport adjoint for TOMCAT using a reciprocity test.
- 1485.20: I'm pretty sure most of this discrepancy is from the nonlinear aspects of the advection in GEOS-Chem. Also, I wouldn't call the differences we noted between finite difference sensitivities (which reflect what we would have obtained were there a discrete adjoint of the advection scheme at the time) and the continuos adjoint sensitivities an "error". They were inconsistencies, for sure, but as mentioned earlier we saw that the inconsistencies were desirable, and even advantageous for inverse molding (Gou and Sandu 2011). Same comment with regards to the reference on line 19 to the discrepancies noted in Henze 2007.
- 1493.25. Why not just checkpoint the density field, rather than recalculate the transport for density between the forcing times? Perhaps it's worth noting that in GEOS-Chem adjoint we also checkpoint the evolution of the pressure field computed by the online CTM dynamical calculation at points between the assimilated meteorology, for similar reasons as described here. We only need to checkpoint the surface pressure, then we recalculate the 3D density, so it's fairly economical.
- 1487: For the sake of comparison, you might also show the equation that results from the non-density-weighted inner product derivation. It's very obvious to me how your new equation is different and better, but it may not be to others less familiar with this issue.
- 1488: I like how the reconstruction of the cost function from the adjoint sensitivities is described elegantly through Eq. 7.
- 1497.15: It wasn't clear to me what was happening in this test. Reversing the order of operations – what does this correspond to exactly? Is this equivalent to FDA?

- By implementing the Prather transport scheme, how consistent is the CTM transport with the transport used for the dynamical core of the assimilation model? This was the main reason for not changing the advection scheme when implementing the adjoint of GEOS-Chem, as the forward model community had a lot of misgivings about mixing and matching assimilated meteorologies with different advection schemes. So while the Prather scheme is potentially very accurate, running it with meteorology generated from a GCM using a different transport scheme might lead to some inconsistencies that are difficult to diagnose.
- 1500.16: And Henze 2007, Hakami 2007, Gou and Sandu 2011.
- 1500.26: This may well be your view, but we've been fairly successful at applying GEOS-Chem adjoint (with flux limiters turned on, using the continuous advection adjoint) to a range of inverse modeling problems. I recognize it is a compromise, and I think we end up spending more time iterating than otherwise, but clearly it isn't "nearly-impossible" as you suggest. It seems more like a trade-off, especially in light of the potential issue described above and the accuracy that is sacrificed when not using flux limiters. So a bit more balanced discussion would be appreciated here.
- 1501.2 and 1503.20: I disagree that advection without flux limiters would be equivalent for these species. Flux limiters help preserve peaks even when the background concentrations are not zero, just smooth relative to the peak being advected. This is often the case for O_3 and CO (think biomass burning plume), and even CH_4 and CO_2 for high resolution simulations (which include strong point sources, or time varying sources).
- 1501.7: It wasn't clear to me what the temporal extent of the source was used here, but the worst case would be a very short one (one time step). Also, I don't believe the impact of the response function was discussed. One may consider the shape of the sensitivity plume being advected, and how that is driven by the

definition of the response function. A response corresponding to a single isolate measurement will impart a very difficult plume of sensitivities to advect, whereas the forcing from global daily satellite observations would be much more smooth.

- 1501.25: This is an interesting conclusion. But another way to view these results is that the difference between the flux limited and non-flux limited simulations is accuracy that you are sacrificing in order to adopt the symmetric Backward Eulerian scheme with the Prather method.

3 Corrections

- 1482.3: model,
- 1482.5: moments),
- 1482.6: symmetric, suggesting
- 1482.20: 2006),
- 1483.1: No need for the word linear to be italicized (it's not latin etc.).
- 1483.21-22: Here and throughout, there is no need for the quotation marks around the model name or in reference to the dynamical core.
- 1486.2: 4.3), respectively
- 1495.11: RETRO-TOM,
- 1501.2: N_2O