Review of "The importance of vertical resolution in the free troposphere for modelling intercontinental plumes" by Zhuang et al.

This paper discusses the importance of vertical resolution relative to the horizontal resolution. The authors claim that there exists an optimal grid resolution ratio of 1000 between horizontal and vertical resolution.

The statement that the often used approach of increasing the horizontal resolution alone is insufficient for an optimal solution has been made before, also by the same authors. Also, as the authors themselves point out, optimal grid resolution ratios not too dissimilar to what is stated in the manuscript have been suggested before. This study is extension to previous work in that it aims to theoretically derive an optimal grid resolution ratio and to support the findings by performing idealised simulations with the GFDL-FV3 global dynamical core. Though not ground breaking the manuscript could be published after revisions as outlined below.

The paper makes very bold statements that are not widely valid and applicable since the findings are much more model, case and resolution dependent. This needs to be acknowledged and discussed more widely.

For increasingly higher spatial resolutions that approach convection permitting or even convection resolving scales, an aspect ratio of 1000 wouldn't make much sense since the resolved dynamical features become more isotropic compared to a model where most of the vertical motions is on the subgrid scale.

For a plume with an aspect ratio of 1000 (and flow ratios in the same order) as used here it is not surprising that a grid with the same aspect ratio provides an optimal solution.

A validation with a real event would be limited by an incomplete knowledge of the atmospheric state. Only with a perfect knowledge of the atmospheric flow that drives the tracer transport the presented argument holds.

Advection is not the only time step limiting process. Gravity waves, for example, pose a much stronger constrain. Since in global models the vertical resolution is higher than the vertical resolution (even if smaller than an aspect ratio of 1000) the numerical treatment is usually not the same for the vertical and the horizontal. GFDL-FV3 is an extreme example since it is not even Eulerian in the vertical. Although this is mentioned in section 3 this should already be mentioned at the beginning of section 2 since GFDL-FV3 is already discussed in section 1. Even then GFDL-FV3 doesn't fit the description of an Eulerian chemical transport model for which the theoretical analysis is performed in section 2. GFDL-FV3 is a full dynamical core with tracer transport so that the analysis in section 2 only applies to this model if aspects of predicting the flow are ignored. However, a more accurate prediction of the flow with increasing horizontal and/or vertical resolution is key for the interpretation of results in section 4. Appendix B is important but it shows similar numerical diffusion properties only for the transport, not for the dynamical core as a whole if I understand correctly.

Volume mixing ratio is usually defined as tracer mass per unit volume and is thus not preserved in a non-divergent flow as stated. However, mass mixing ratio (the tracer mass per total mass) is. According to the figure labels, the authors define volume mixing ratio as tracer volume per total volume. This is only equivalent to mass mixing ratio for gaseous tracers, not for particulate tracers, like aerosols. To my knowledge, GFDL-FV3 solves for the tracer mass per unit dry air.

I would have expected that section 4 confirms the optimal grid resolution ratio of 1000 but it does not. Since section 4 only focuses on error metrics for the tracer transport without including computer time, unsurprisingly, the case with the highest horizontal and vertical resolution produces the best results. At the highest resolution the aspect ratio is below 1000 (dx/dz=25km/80m=312.5) so that simulations with higher vertical resolution would be needed to be able to prove the point of section 2. Only for C48 do the performed simulations significantly exceed an aspect ratio of 1000. Simulations with higher vertical resolution at higher horizontal resolution are needed to prove a relationship based on equation (25).

The initial conditions chosen for the test case are discontinuous at the plume edges. No matter what the spatial resolution, the grid well never resolve the transition between inside and outside plume. Thus, this test case cannot converge. It should still be possible to test the relationship for an optimal grid ratio as derived in section 2 but it would have been better to consider a test case that can numerically converge.