Report on 'The importance of vertical resolution in the free troposphere for modeling intercontinental plumes' by Zhuang et al.

This paper presents a discussion of numerical diffusion in solving tracer transport problems with some theoretical analysis and numerical calculations. It is argued that vertical resolution is, in current models, often more of a problem than horizontal resolution in avoiding excessive diffusion and plume dilution. Increasing vertical resolution should be given higher priority than horizontal resolution when trying to optimise the results achievable with a given computational resource.

General comments:

The topic is of importance, the paper is well written and well argued, and the simulation results appear credible and useful. However there are a number of aspects where there are alternative perspectives and it would be useful if the paper could reflect some of these. I have described these 'perspective issues' below. The authors may or may not agree with these issues. This is fine, but, either way, there would be benefit in discussing the issues and/or in providing further arguments for their own view point which might convince readers with a different view point. I also have some specific comments which are not to do with perspective. In terms of clarity and presentation, the paper is excellent and I have suggested very few technical corrections.

Comments on perspective:

Suppose we have a specified velocity field and we are trying to compute the tracer field. Over time the tracer plume will be stretched into thin filaments. Imagine that one has a high resolution simulation which resolves all the features in the tracer at a given time. The best low resolution description could (arguably) then be obtained by averaging the high resolution field to the lower resolution. This low resolution description will not preserve the peak volume mixing ratio. Hence one could argue that seeking to maximise VMR or minimise numerical diffusion is not really the right thing to do; one should seek the right amount of diffusion for the resolution used. Page 12, lines 11-16 go some way to acknowledge this situation but it could be reflected better in other parts of the paper. E.g. page 13, line 10 'the best possible simulation would preserve the entropy'. In practice maximising VMR or minimising diffusion or entropy gain are likely to be OK because it's hard to have too little diffusion without numerical schemes which generate unsatisfactory solutions (loss of monotonicity, negative concentrations), but a little more discussion would be useful (and also see next comment).

In real flows (with molecular diffusion, no matter how small) the filamentation will cascade down to very small scales and eventually be smoothed out by diffusion. Hence, although it's correct to say advection preserves VMR, this doesn't apply to real flows without qualification and hence the relevance of the statement could benefit from some discussion (see page 4, lines 9-11 and page 11, lines 20-22). Also if one allows resolution of small scales in the tracer but doesn't add in smaller scales in the driving flow field, this is like the viscous-convective k^{-1} spectral range in turbulent flows when the molecular diffusivity is much less than the viscosity (see e.g. Monin and Yaglom, Statistical Fluid Mechanics, vol 2, p436, where the tracer is temperature). This can lead to less diffusion than would occur if the smaller velocity scales were present and to rougher tracer fields. (k^{-1} decays slower with increasing wave number than the standard $k^{-5/3}$ inertial subrange). So perhaps this is a situation where one could have too little diffusion (see page 15, lines 30-32) and too much small scale structure in the tracer field.

Mathematically it's nice to think of having a well defined tracer problem (an advection or advection-diffusion problem with a specified flow field) which one tries to solve more and more accurately as computing power increases. This seems to be the authors perspective in places. However it's probably more useful to change the problem by resolving more of the driving flow field. The comment immediately above reflects this to some extent, but one can also resolve qualitatively different features such as convective updrafts and, eventually, boundary layer turbulence. Here the physics is different, vertical velocities may be larger, and a more isotropic grid may be appropriate. This is relevant to the various discussions of $\Delta x/\Delta z$; for example on page 8, A and B may be similar in size at high resolution. On page 11, line 6, 'offsets the gains' seems to imply that the authors think the increased resolution of small scale eddies is a backwards step (presumably judged by the narrow target of minimising diffusion). However the simulation may well be better overall, and the material can't diffuse far because these new eddies are small, so the large scale distribution of the tracer shouldn't be affected much.

Other specific comments:

Page 1, line 18: I'm not sure 'dissipate' is the right word. 'Disperse' might be better. The former suggests loss of mass rather than spreading out and dilution. Of course mass loss is not impossible if mass conservation isn't satisfied but I'm not sure that interpretation is intended here. See also page 12, line 32, page 13, line 20, page 14, line 28 and figure 4 caption ('plume decay'). I have a similar comment with 'Preserve the plume' (page 10, line 17) and 'subsides' (page 11, line 15). The material is preserved but it's dispersed and diluted, and presumably the authors don't mean subside in the sense of moving down towards the ground. (I guess they might actually mean subside as the plume does spread downwards. It's slightly curious that nothing mixes up to higher heights within the troposphere. But this is likely to reflect this case only rather than generic behaviour.)

Page 3, lines 13-18: I think '(native)' means the resolution of the driving flow. If so then it would be good to say what was done at lower resolutions – hopefully the driving flow was smoothed rather than applying one grid point value over a larger area where it may be unrepresentative. Also I'm not sure what a '2-D horizontal plume' is in this context. Does this mean concentration is independent of height and depends only on x and y?

Eqns 19-21: While this is indicative, it's based on the idea of a coherent smoothly varying plume. In reality, once the plume is broken up into filaments with a lot of small scale structure, the second order derivatives will be dominated by the small scales, not the large scales which are characterised by L and H.

Page 8: This argument would not work if one was considering 3-D isotropic turbulence. Here one would expect $k = 2$ (or at least the power of Δx would be twice the power of Δz – both would have a CFL related increase), but it doesn't make sense to make Δz smaller (or bigger) than Δx. Why does the argument go wrong for this case? One explanation for this is that perhaps one should replace (23) with $D = \max(A\Delta x, B\Delta z)$, consistent with page 8 lines 29-30, or replace it with $D = A\Delta x + A\Delta y + B\Delta z$, treating x, y, z on an equal footing. I think the authors either need to use one of these more balanced forms of D (with minor changes in the conclusions) or provide more justification for their choice.

Page 10, line 27 to page 11, line 3: It might be better to initially leave the description of λ in words and not introduce $\partial u/\partial x$ (see fig 2 caption too) only to redefine it in (28). More importantly, stretching is not in general aligned with the local flow. One can add a uniform flow (Galilean transformation) in any direction without altering the stretching properties of the flow. The values are only used qualitatively however, so it's probably OK to use this as an indication of stretching.

Technical corrections:

Page 9, line 27: Should 'initialize' be 'run' or 'calculate'?

Page 11, line 8: 'Large scale vertical wind speeds' might be better. The values are too small for convective updrafts or boundary layer turbulence.

Fig 7 caption: 'straight lines' should be 'solid lines'.