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Atmospheric Chemistry and Physics Discussions

Interactive comment on "A quantitative analysis of grid-related systematic errors in oxidising capacity and ozone production rates in chemistry transport models" *by* J. G. Esler et al.

J. G. Esler et al.

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The authors would like to thank the anonymous reviewers and Prof. Prather for their constructive comments. Our replies and the consequent revisions made to the paper are set out below on a point by point basis.

Reviewer 1 ———-

Reply to general comments:

The extent to which model resolution may affect mean ozone production efficiency is an important issue for atmospheric modellers, and has not previously been addressed in the three-dimensional modelling context. See for example, von Kuhlmann (2001, http://www.mpch-mainz.mpg.de/ kuhlmann/rvkdisshtml/node10.html) for an alternative

introduction to the background of the problem we consider, which clearly emphasises the need for an investigation of this type.

The studies of grid-generated diffusion in the numerical analysis community, as far as we are aware, involve test case analyses of initial value problems for passive tracers (e.g. Petersen et al., 1998, J. Geophys. Res., 19253–19259) or chemical tracers with lifetimes comparable to advection time-scales. By contrast, our paper is concerned specifically with the mean model concentrations of species (OH) or quantities (P(O_3)) that are in photochemical steady state (PCSS) equilibrium, that is they are associated with extremely short chemical lifetimes. Errors in mean P(O_3) (or mean ozone production efficiency ϵ_N) and OH are thus particularly sensitive to (and arguably dominated by) model errors in correlations between species rather than errors in their mean concentration, and these correlations are inevitably disrupted by mixing on the model-grid scale. The hypothesis tested in our paper is that the change in P(O_3), ϵ_N, OH etc. due to the change in correlations between species associated with a direct degradation of the model grid explains a significant proportion of the change in modelled P(O_3), ϵ_N, OH etc. associated with an actual change in model resolution. This is tested by comparing PCSS calculations with data from high and low resolution experiments to PCSS calculations with degraded high resolution data.

Whilst they are obviously extremely important in evaluating new numerical advection schemes, we do not see that the analysis of the type of short-time advection-chemistry test cases that we are familiar with in the numerical modelling literature are directly relevant either to our hypothesis or its test as described above. However, since our knowledge of the numerical modelling literature may be incomplete, we would greatly appreciate being directed towards the references of any relevant or interesting material from this field.

Reply to Specific Comments: Resolution of Emissions

In all global chemistry transport modelling to date, emissions data has

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been available at significantly higher horizontal resolution than that of the model grid. This resolution is usually at least $1^\circ \times 1^\circ$, see for example the 'EDGAR' and 'GEIA' websites from which most of the TOMCAT emissions are derived (http://arch.rivm.nl/env/int/coredata/edgar/v2/ , EDGAR, http://geiacenter.org/data/overview.html, GEIA). Emissions are diluted directly into model grid cells, so it is the resolution of the model grid, rather than the emissions data that is the limiting factor in all of the experiments described.

Use of term 'systematic' when referring to grid-based errors.

We describe 'systematic' grid-based errors to be in the error in PCSS quantities when the high resolution fields or observations are degraded on to a low resolution grid. We therefore mean something quite specific by this term. To make this clearer in the paper we have added the following sentence in the introduction 'Throughout this paper, we will use 'grid-related systematic error' to refer to the error introduced in calculated chemical quantities when precursor species are degraded from high to low resolution.'

Vertical resolution:

We agree that vertical resolution is another important issue, but it is much more difficult to isolate chemical changes from other differences when the vertical resolution is changed, e.g., convection parameterization, STE.

Reviewer 2 ———-

(1) Re: Figure 2 and the associated discussion: We are unsure what the reviewer means by 'Figure 2 and associated comments miss the point that P(O_3) is not a linear function of concentrations'. After all, the second panel of Figure 2 clearly shows that P(O_3) is a nonlinear function of [NO_x]. We also write 'Note that the quantities plotted also depend nonlinearly on the concentrations of other species, which may modify the simple picture presented below, but the primary nonlinearity in each case is with respect to NO_x.' The point of Figure 2 is to make a simple illustration of how the

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nonlinear dependencies can cause total ozone production to change under mixing even while all the precursor species are conserved.

(2) The smoothing function given by equation (3) is intended as a crude model of the effects of artificial diffusion introduced by the advection scheme. It is certainly possible that it overestimates the amount of numerical diffusion due to the better advection schemes, and to ensure that it did not seriously alter our results we repeated our calculations with both a less diffusive operator, and without using an operator. In both cases our qualitative results were unchanged with just a small shift in the position of the curves in Figure 4. The operation (3) does have a predictable effect on tracer spectra, reducing spectral power at the highest wavenumbers (corresponding to the grid-scale) and leaving spectral power at low wavenumbers relatively unchanged. Numerical diffusion typically has the same effect.

(3) This is an important point, and quite crucial for ozone, but it is much more difficult to isolate chemical changes from other differences when the vertical resolution is changed, for example the parameterization of convection or the rate of stratosphere-troposphere exchange.

(4) We certainly agree with the reviewer's point that undersampling of fluctuations in the vertical winds can lead to spurious model diffusion in the vertical. This can be minimised in isentropic models (e.g. SLIMCAT) by using diabatic velocities, but it is not usually possible to do this in tropospheric models that include the ground. Vertical velocities in TOMCAT are derived from the convergence and divergence of the horizontal wind field as provided by ECMWF operational analyses, and ECHAM4 is relaxed towards ECMWF analyses as described on page 2542.

M. Prather ———-

(1) A caveat has been added to the discussion surrounding Figure 3 to the effect that on flight 13 (shown in Figure 3a) the aircraft encounters unusually high variability at tropopause level. Note that Figure 4 illustrates results calculated from all SONEX

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flights, not just the one shown in Figure 3a. It is probably true that there is a bias towards encountering large variability during the SONEX flights overall, which is why we include the caveat 'Arguably, the marine flights (triangles) are more representative of the midlatitude UTLS as a whole' in the discussion surrounding Figure 4. (Marine flights are defined as those that do not encounter high-NO_x air.)

(2) On page 2546 line 11, we have amended the text to read 'or whether the differences must be due to other systematic changes in transport, or systematic changes in the parameterisation of convection, turbulent mixing or the source of NO_x due to lightning.' and on page 2548 l. 27 we have added 'Changes in STE may occur as one consequence of grid-related error in transport, which is not isolated by our experiments.' Both these changes serve to emphasise the point that we do not claim to have isolated the grid-related transport error, nor have made undue assumptions about it.

(3) We have changed the latitude range of the percentage difference plots from -80° to 60° (July) to -70° to 45° to mask regions of low OH and P(O_3).

(4) A table summarising results for July and January has been added in place of Figure 9.

(5) We think it important to make the point that other considerations may be more important than grid-averaging in other models, and the ECHAM4 section serves to illustrate this, providing what we think is an interesting contrast to the TOMCAT analysis.

Interactive comment on Atmos. Chem. Phys. Discuss., 4, 2533, 2004.