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Atmospheric Chemistry and Physics Discussions

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Interactive Comment

Interactive comment on "Contribution of mixing to the upward transport across the TTL" *by* P. Konopka et al.

Anonymous Referee #1

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General Comments

This article addresses a difficult issue that has been the subject of much recent research: the mechanisms that contribute to transport of mass from the tropical troposphere into the stratosphere. The authors use the unique CLaMS Lagrangian model to investigate the transport of tracers subject to advection and mixing. The model has been extended into the troposphere using a hybrid vertical coordinate. The authors show that in the CLaMS model the parameterisation of mixing is essential for transporting mass upwards from the average level of deep convective outflow into the tropical stratosphere. However, much more work is needed to demonstrate that mixing is the main mechanism in the atmosphere and that the mixing depends on the resolved flow in the same manner as represented by CLaMS. There are many ad-hoc features of the mixing parameterisation and more work is required to justify the scheme and its choices of parameters. The model is “evaluated” by comparing aircraft observations of ozone from a few flights in the TTL with simulations of ozone as a passive tracer, with and without mixing. The comparison is impressive, but qualitative, and it requires a leap of faith to assume that vertical transport across the TTL is dominated by shear-induced mixing. The aircraft dataset is not sufficient to assess the model's ability to simulate the long-term average vertical transport.

This paper would only be suitable for publication in ACP with major revisions addressing the model formulation of mixing and vertical transport and an assessment of its realism.

Specific Comments

1. Section 2.1: In the formulation for the vertical coordinate I was surprised that $\eta = p/p_0$ rather than p/p_{surf}. With the latter definition, the coordinate is terrain following and would simplify the lower boundary condition to $\dot{\zeta} = 0$ at $\eta = 1$.

   Another option would be to use an isentropic coordinate everywhere which is more natural for partitioning diabatic from adiabatic processes. Why did you choose this hybrid coordinate for a Lagrangian model?

2. Section 2.2: This section is the weakest in the paper. It needs to be re-written.

   The value of α from Haynes and Anglade (1997) refers to the aspect ratio in physical space L/H. However, you appear to be applying it directly to set the layer thickness $\Delta\zeta = \alpha r_0$ where ζ is a modified potential temperature with units of Kelvin. This in this definition α has dimensions!

   Also the specific entropy (as defined in Holton) $S = c_p \ln(\theta/\theta_0)$. By multiplying by density you convert to entropy per unit volume. I don't see that the discussion of “information content” is at all relevant in this context.

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If the argument you are looking for is that model layers have equal volume on average, then you require $\Delta z = (\sigma/\rho)\Delta\theta$ is constant ($= \alpha r_0$) where $\sigma = -(1/g)dp/d\theta$ and ρ is the mass density (in physical space).

3. Section 2.3: The convection does not have to be "organised" in the sense of an MCS in order to contribute to resolved scale ascent associated with latent heat release.

4. Figs.3 and 5: The arrow points to a structure that is clearly part of a mid-latitude baroclinic cyclonic system and not an MCS. This is a poor example for illustrating the influence of "convection" since the ascending flow in this system will be dominated by resolved scale ascent along the warm conveyor belt that is seen wrapping round cyclonically.

5. You must be more careful with discussion of Fig.4. The Eulerian mean $\dot{\zeta}$ velocity is not dominated by "convectively driven transport". Since $\zeta \approx p$ in the troposphere there is a large component associated with adiabatic eddy transport that produces the Ferrel cells. These cells do not appear if an isentropic coordinate is used down to the ground.

6. Section 2.4: The mixing formulation appears arbitrary, especially in the vertical. What justification is there for the choice $D_v = \Delta z^2/4\Delta t$? It is the critical value for an explicit scheme for diffusion with time-step Δt to be numerically stable but there is no physical relevance. There is no dependence on vertical shear. Presumably your criterion for mixing depends only on the horizontal rate of separation of trajectories? How is information on the vertical shear used? A much more thorough backing is required for the mixing formulation.

7. Section 4: It is not correct to describe the process in Fig.6 as an "unstable jet bifurcating into two branches". It is usually described as Rossby wave breaking.

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8. Section 6: the end of this section and Fig.14 highlight a major problem. Although, mixing is a major contributor to vertical transport in CLaMS, there are many potential problems associated with changing vertical coordinate and the switch to θ where radiative calculations are used to find $\dot{\theta}$ rather than continuity. A much more thorough investigation of the model is necessary and even then demonstrating the relevance to the atmosphere would be difficult. For example, if you use a θ-coordinate at all levels (or just increase p_r) how do the vertical velocities and the residual change?

   It was interesting to see Fig.13c which shows virtually no BL tracer above 360K even after 3 months. Trajectories integrated using continuity in pressure or hybrid pressure-sigma coordinate would indicate much more vertical transport. Therefore in CLaMS it appears that the trajectories are constrained to be far more adiabatic. The calculation of $\dot{\theta}$ and its temporal and spatial variation is a crucial issue. Even uncorrelated noise in $\dot{\theta}$ would be sufficient to create a diabatic random walk resulting in transport into the stratosphere. However, if the modelled $\dot{\theta}$ does not vary much in time or space then this walk maybe artificially limited. Equally it is often argued that the random walk is likely to be too strong when using vertical velocity from continuity. The question is whether this random walk dominates transport associated with turbulent mixing in the atmosphere. More work is required to diagnose in detail what happens in CLaMS and to relate it to suitable observations in the atmosphere if they exist.

Technical Comments

1. Abstract: Expand TTL to tropical tropopause layer in first mention.
2. The abbreviation AP for “air parcels” is unusual and seems an unnecessary distraction. I would recommend removing the abbreviation everywhere.
3. Section 2.3: You refer to Fig.7 erroneously (should be Fig.3).

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4. I believe that the ECMWF were using 4D-VAR in 2005.
5. Sections 4 and 5 would be better renumbered as 3.3 and 3.4 to indicate that they concern the “validation of CLaMS”.

Interactive comment on Atmos. Chem. Phys. Discuss., 6, 12217, 2006.