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Atmospheric Chemistry and Physics Discussions

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Interactive Comment

Interactive comment on "Redistribution of trace gases by convective clouds – mixed-phase processes" *by* Y. Yin et al.

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Replies to the Specific Comments:

1. The main limitations of this study are that the use of an axisymmetric cloud model, which prevents cloud developing from situations under strong environmental wind shear, and that no chemical reactions are considered for chemical species involved into the transport process. Therefore, the results obtained in this study can only be referred to as an upper limits to the gas transported.

   In this study, the maritime case differs from the continental case only in terms of the spectrum and concentration of CCN. Under real conditions the CCN composition, thermodynamic conditions, initial ice nuclei (IN) concentrations, etc. are also different between a continental and a maritime cloud.

   For initialization, a warm bubble that produced a 2°C perturbation was applied at the beginning of the sumulation. So, the cloud simulated in this study is representative of an isolated convective cloud or one of the growing cells in a more complicated convective cloud system.

The main disadvantage of an axisymmetric model is that the environmental wind shear cannot be considered and only one cloud cell could be simulated. However, under certain conditions, especially when the evironmental wind is weak, an axisymmetric model is superior to a 2D slab-symmetric model for reproducing the three dimensionality of a cumulus cloud. A comprehensive comparison between axisymmetric and 2D slab-symmetric cumulus cloud models is given by Soong and Ogura (1973).

2. In the model frozen drops are transferred to ice crystals if their radii are smaller than 100 μm, otherwise, they are transferred to graupel particles. Although difficult to justify from a microphysical process point of view, the assumption is in accord with observations that most crystals are small and most graupel particles are large. In the simulated continental case, drops remain small due to the larger drop concentration, therefore, a significant number of the drops are still small when they are lifted to the freezing level, and are frozen to ice crystals. In contrast, in the maritime case, drop growth by collision-coalesence is more efficient and many of the drops become larger than 100 μm before they are brought to the freezing level, therefore, a larger number of them are frozen to graupel particles.

   It should be noticed that the above assumption only refers to the freezing process. Other ice formation processes such as ice nucleation through vapor diffusion, contact nucleation, ice multiplication, also take place. The total production of ice crystals and graupel particles depends on all these processes. So, we can't simply say that maritime clouds tend to produce graupel and continental clouds tend to produce ice crystals.

   The assumption about what hydrometeor class is formed upon droplet freezing does affect the gas transport. In the paper we now briefly describe the importance of this assumption.

A statement of the characteristic of CCN spectra is added in the text. The maritime case has been referred to as ‘the cloud with the maritime CCN distribution’.

3. Figures 6 and 7 show the spatially integrated TOTAL species mass (gas plus all hydrometeor phases). The captions have been clarified in the text. The tracer mass in the ice phase (especially in ice crystals) is important in the anvil region.

4. We agree with the referee on this point. After expulsion from the ice, the tracer dissolves into the remaining supercooled drops. This has happened during most of the cloud lifetime. But after 64 min, as can be seen in Figures 4 and 5, there is very little liquid water left in the region above 4 km, therefore, most of the tracer expelled from ice particles is present in the gas phase. This has been added in the revised version of the text and the Barth et al. (2001) reference has been included.

5. Changing the burial coefficient from 0 to 1, the gas abundance in the outflow region reduces about 30% for a tracer with Henry’s law constant of 10^4 mol dm^{-3} atm^{-1}. This may or may not be negligible depending on your point of view (compared with a factor of 12 change caused by changing R_c from 0 to 1).

   For clarity, a more detailed description of the gas scavenging by ice particles is added. A comparison between cases C7 and M7 with cases C9 and M9 shows it is indeed true that much more gas scavenging of highly soluble tracers occurs for the C9 and M9 simulations.

   A figure is added for the different burial coefficient simulations.

   The case in Figure 9 should be C8 not C7. This has been clarified in the revised version.

6. In an axisymmetric model, two dimensions, z (altitude) and r (radial distance), are used to describe a three-dimensional cloud. The cloud volume or spatially-

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integrate mass can be calculated just based on the distributions on these two dimension, and a third dimension is unnecessary and not existing.

Because the initial total mass (spatially-integrated) of the tracer is strongly dependent on the model domain, it is not a good physical quantity to compare with that inside the cloud, instead, mass (or mixing ratio) fraction is usually used to express how much tracers are transported through the cloud (e.g., Wang and Crutzen, 1995; Crutzen and Lawrence, 2000). Therefore, in Figures 8 and 9 the tracer mixing ratio is shown as a percentage of that of the initial boundary layer value, not 'the initial total mass (spatially-integrated) of the tracer'.

More sophisticated washout calculations can be done, but our main focus is on what comes out at cloud top. We would prefer not to expand the paper in this direction.

Figures 8 and 9 have been clarified. First, 'fraction' is replaced by 'percentage'. Second, the radial distance is given for the results. The low percentage of the tracer after 60 min is results mainly from dilution due to mixing and rain-out to the surface.

Since the cloud boundaries are far enough from the domain boundaries the advection of tracers out the domain is not important. There is tracer advection into the domain from the lateral boundary in the boundary layer–this is a realistic representation of a single cloud in a large domain.

7. Both the results presented in this paper and that in an earlier paper (Yin et al. 2001 in this journal) revealed that all highly soluble gases (effective Henry's law constant larger than 10^6 mol dm^{-3} atm^{-1}) behave in a nearly identical way to each other, independent of their solubility. Therefore, the results for tracers with Henry's law constant higher than 10^9 mol dm^{-3} atm^{-1} would be similar to those for a tracer with a Henry's law constant of 10^9 mol dm^{-3} atm^{-1}.

Replies to the Technical Corrections:

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1. The sentence has been reworded based on the Referee's suggestion.

2. The time step is indicated in the text.

3. This question is not clear to us, but we guess it refers to the calculation of gas scavenging by ice particles. Therefore, a more detailed description of this calculation is given in the text.

4. Totally 11 tracers with effective Henry's law constant ranging from 0 (insoluble) to 10^9 mol dm^{-3} atm^{-1} (highly soluble) were represented.

References

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