Atmos. Chem. Phys. Discuss., 6, S6800–S6808, 2007
www.atmos-chem-phys-discuss.net/6/S6800/2007/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "The role of the retention coefficient for the scavenging and redistribution of highly soluble trace gases by deep convective cloud systems: model sensitivity studies" *by* M. Salzmann et al.

M. Salzmann et al.

Received and published: 14 February 2007

We appreciate the comments and the criticism by this referee and we thank the referee for pointing out that the time and domain averaged cloud mixing ratios for the ARM A LSF run in Fig. 4 showed unrealistic values in a layer close to the surface (see comment below).

Referees #4 and #5 indicated difficulty accepting the use of artificial tracers in this study. Such tracers are applied in several studies on which this one builds; however, we apparently directed the text too much towards those who have been involved in these previous simulations, and clearly need to provide a better discussion of the motivation and interpretation.

In the revised version of the manuscript, we added the following sentences in Section 6:

“The specific set of idealized tracers and bubbles for the initiation of convection in this study were partly chosen in order to obtain results comparable to previous studies regarding the role of the retention coefficient, and partly based on experience from budget analysis of sensitivity runs including photochemistry. Though these idealized tracers do not correspond exactly to any single specific tracer, artificial tracers like these have frequently been used in previous studies to provide information which is applicable to a wide range of real trace gases which have similar key qualities. More detailed discussions of this connection are found in Crutzen and Lawrence (2000).”

Referee #4 criticizes that the conclusions of this study are based on very specific model assumptions. We, on the other hand, consider the finding that the simulated transport of the released tracers strongly depends on the model setup (bubble vs. LSF) an integral part of our results, although the original intent of this study was to learn something about the effects of different types of storms. Bubbles have also been used to initiate deep convection in earlier cloud resolving case studies investigating the role of the retention coefficient, and a large part of our knowledge regarding the role of the retention for tracer transport is based on the results from these previous cloud resolving case studies.

We believe that this paper contributes a number of novel and important aspects to the discussion regarding the role of the retention coefficient for tracer transport. The finding that the sensitivity towards the retention coefficient very strongly depends on assumptions regarding on the shape of the initial profile and the model setup is one of our key results. To our knowledge, neither of these sensitivities has been investigated in previous studies. This is probably the first study in which results from various runs were compared, and the first study investigating the influence of larger cloud systems on soluble tracer transport. While one might qualitatively anticipate some differences be-

ACPD
6, S6800–S6808, 2007

tween the cases and the model setups, we did not expect to find nearly opposite results when comparing the runs with isolated storms initiated by a bubble to the cloud system resolving runs. The release of tracer from freezing hydrometeors provided an efficient transport pathway to the upper troposphere only in our bubble runs (as expected based on previous studies in which bubbles were used to initiate deep convection) but not in the LSF runs. We think that the results from this study will be important for future research regarding the role of the retention coefficient. We agree, however, that further studies are needed to better understand the general role of the retention coefficient. Therefore, in the revised manuscript, we changed the title from:

“The role of the retention coefficient for the scavenging and redistribution of highly soluble trace gases by deep convective cloud systems: model sensitivity studies”

to:

“Model sensitivity studies regarding the role of the retention coefficient for the scavenging and redistribution of highly soluble trace gases by deep convective cloud systems”

Furthermore, we emphasized the need for further studies in the abstract.

The referee stated that “comparisons for the effects of different convective initiation processes are ambiguous because they are based on arbitrary choices for the initiation of convection and tracers, model domain and analysis time”. However, the large qualitative difference between the bubble runs and the LSF runs does not depend on the analysis time as indicated by the time series in Fig. 5 of the original manuscript (Fig. 7 of the revised manuscript) and by Table 1. Furthermore, the dependence on the initial profiles and on the model setup has been discussed in much greater detail than was the case in earlier cloud resolving studies investigating the role of the retention coefficient for tracer transport. Fig. 4 of the original manuscript (Fig. 6 of the revised manuscript) mainly illustrates the large qualitative differences between the runs regarding the released tracers. Until now, no agreement exists among modelers regarding domain sizes and analysis times to be used in such studies, and a similar

ACPD

6, S6800–S6808, 2007

EGU

figure was shown in the pioneering cloud resolving model study regarding the role of the retention coefficient by Barth et al. (Note that Barth et al. chose to show averages over a sub-domain).

“Results for this simulation appear not be consistent with the results from other cloud resolving models or observations for this case”:
We appreciate that the referee has pointed this out. The high time averaged near-surface hydrometeor mixing ratio in the ARM A LSF run are an artifact due to spurious condensation occurring prior to the onset of deep convection. The first 18 h have been removed from Fig. 6 of the original manuscript (Fig. 8 of the revised manuscript) and the reason for this is discussed in Sect. 5. As already mentioned in our initial reply regarding this issue, we would like to point out that we had done additional simulations, some of which for brevity are not mentioned in the manuscript. In particular, we find that our results regarding tracer transport and scavenging for the ARM A LSF case are robust (i.e., same qualitative and very similar quantitative conclusions) for
-a 2-D run with 250 m constant vertical resolution (in this run spurious condensation during the first hours does not occur)
-a 2-D run in which the original Lin et al. (1983) microphysics scheme was used, which is also part of the standard WRF model.

Specific comments:

The description of the microphysics scheme was extended and a schematic regarding the processes in the scheme (Fig. 1 in the revised manuscript) was added. Section 5 regarding the role of the microphysical processes was extended and Fig. 12 regarding rain formation was added.

Section 3 was re-arranged and extended in a revised version of the manuscript. It now contains a sub-section for each of the runs.

Page 10781: Additional information regarding the vertical resolution was included for the ARM A and the STERAO case. The increased resolution in the ARM A LSF run resulted in an earlier onset of deep convection which is in better agreement with observations. Regarding the average transport and scavenging of soluble tracers, increasing vertical resolution towards the surface does not qualitatively change the results in the ARM A LSF run.

Same page: A motivation for re-initializing tracers in the LSF runs is presented in Sect. 3.1 of the revised manuscript:

“The rationale for re-initializing the tracer fields is to compensate for the lack of large scale processes and chemistry acting on the tracers and to obtain a set of results for different time slices. Re-initialization was previously applied by Lu et al. (2000) in cloud system simulations of tracer transport.”

and the implications are discussed in Sect. 4:

“Note that in the ARM A LSF runs the re-initialization coincides with times of minimum simulated deep convection (Fig. 2 and Fig. 3c). In the TOGA COARE runs, the six time slices yielded qualitatively similar results for the dependence of the transport of the highly soluble tracers on the retention coefficient (not shown), indicating that the results are on the whole not particularly sensitive to the time of the re-initialization.”

Note also that re-initialization can be avoided in multi-day cloud resolving studies including chemistry (Salzmann et al., 2004, Salzmann, 2005). For the purpose of the present study, doing so would, however, further complicate the manuscript without obvious advantages.

Different diagnostic times: see above (reply to general comments).

Same page: The idea behind setting H_L = 1×10^6 mol l^{-1} atm^{-1} is to mimic “highly soluble tracers”. The following sentence has been added to better explain, what is meant by this: “A preliminary sensitivity run assuming even higher Henry’s law coefficients yielded very similar results, in agreement with Barth et al.(2001) and Crutzen and Lawrence (2000)”.

ACPD

6, S6800–S6808, 2007

Interactive Comment

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

EGU

Comment regarding page 10783:
We agree that the usefulness of the bubble approach for studying the role of the retention coefficient is almost certainly somewhat limited. Nevertheless, bubbles are still a common way of initializing cloud resolving models, and they have been used in previous studies investigating the role of the retention coefficient for tracer transport. Based on a comparison between the ARM A LSF and the ARM A BUB case we suggest that using bubbles to initiate deep convection may result in an over-estimate of the influence of the retention coefficient on the vertical transport of highly soluble tracers. It can not be ruled out, however, that under certain conditions similar storms could develop regardless of the initiation method. The following sentence was included in Sect. 3.2.1 of the revised manuscript: “A few sensitivity runs starting from other initial profiles based on observations during the 4-day ARM A episode yielded even shorter lived storms (not shown).”

Comments regarding page 10784:
Regarding different diagnostic times in Fig. 4 of the original manuscript please see above (reply to general comments).

Same page: In the paragraph starting on line 10, page 10748 of the original manuscript, we do not suggest that there is a problem with the approach by Crutzen and Lawrence (2000). Instead, we argue that we can qualitatively reproduce the results of Crutzen and Lawrence (2000) and the results of Barth et al. (2001). This paragraph was extended in order to clarify this point. It now reads as follows:

“Based on the ratios $\alpha=\overline{\mu}_s/\overline{\mu}_i$ of soluble to insoluble tracer average mixing ratios in the upper troposphere after modeled deep convection, Barth et al. (2001) have suggested that global models such as the one used by Crutzen and Lawrence (2000) may underestimate the transport of highly soluble tracers to the upper troposphere. Crutzen and Lawrence (2000), however, investigated the transport of soluble tracers with a surface source (similar to T1), while the initial profile specified by Barth et al. (2001) is identical to T2. Fig. 7 and Table 1 show that for T1 α is generally very low, in agreement with

ACPD
6, S6800–S6808, 2007

Interactive Comment

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper

EGU

Crutzen and Lawrence (2000), who calculated mixing ratios of highly soluble tracers in the mid- and the upper troposphere to reach 5% or less of that of an insoluble tracer. For T2, on the other hand, α is much higher, which is in line with the result of Barth et al. (2001), who found that upper tropospheric mixing ratios of highly soluble tracers were reduced by 40–60% within a sub-domain of the STERAO simulation. (Note that especially for T2 the ratios generally depend on domain size, since they depend on the ratio of cloudy area to cloud free area.) Barth et al. (2001) mention a number of points why their results and the results of Crutzen and Lawrence (2000) should not be compared directly. Fig. 6 and Table 1 indicate that one can attribute the large difference in α noted by Barth et al. (2001) primarily to the use of different initial/boundary conditions in the two studies."

Same page, same paragraph: Note that the point in this paragraph is not that different initial/boundary conditions can cause different efficiencies of tracer transport. The point is that using an initial profile like in Barth et al. (2001) can be expected to lead to different values of α than using an initial profile like the one of Crutzen and Lawrence (2000) because of non-zero background values in the upper troposphere, pretty much independent of tracer transport efficiency. Consequently, the results by Barth et al. (2001) do not suggest that global models such as the one used by Crutzen and Lawrence (2000) generally underestimate the transport of highly soluble tracers to the upper troposphere.

Comment regarding page 10785:
Please see the comment above regarding the high amount of cloud water below 2 km in the ARM A LSF run. The maximum graupel mixing ratio for all ARM sub cases (A, B, and C) in the models compared by Xu et al. (2002) varies by more than a factor 3 between ∼0.01 and ∼0.035. We simulated a maximum graupel mixing ratio of ~ 0.05 for sub case A only, which also yielded by far the highest maximum precipitation rates in the model comparison by Xu et al. (2002). A relatively high graupel mixing ratio is most likely related to the relatively low density of graupel assumed in the microphysics

ACPD
6, S6800–S6808, 2007

scheme (see discussion in Sect. 5).

Comment regarding pages 10785–10786:
The difference between the bubble and the LSF runs was attributed to differences in the inflow region based on Fig. 4 and on Fig. 7 showing that cloud water in ARM A LSF exists mainly in the inflow region. (The latter also holds for TOGA COARE, not shown). However, while revising the manuscript it was found that thin clouds similar to the "arcus clouds" in the ARM A LSF run also form in parts of the STERAO storm which we failed to notice earlier. In the revised manuscript, the location of the cross section in Fig. 8 (Fig. 11 of the revised manuscript) was moved, so that this can be seen. Fig. 12 of the revised manuscript indicates that the simulated formation of rain at low altitudes may play a role for the efficient uptake in the LSF run (see also discussion in Sect. 5 of the revised manuscript). While this is very plausible, it is, however, difficult to prove, and further studies are needed. In the revised manuscript, the need for further studies is indicated in the abstract.

Comment regarding page 10789: One of the basic conclusions of the study is indeed that there may be a problem with the bubble approach which is still widely used. Compare our reply to the comments regarding page 10783.

Comments regarding page 10790: See above.

References

Barth, M. C., Stuart, A. L., and Skamarock, W. C.: Numerical simulations of the July 10, 1996, Stratospheric-Tropospheric Experiment: Radiation, Aerosols, and Ozone (STERAO)-Deep Convection Experiment storm: Redistribution of soluble tracers, J. Geophys. Res., 106, 12 381–12 400, 2001.

Crutzen, P. J. and Lawrence, M. G.: The impact of precipitation scavenging on the transport of trace gases: A 3-dimensional model sensitivity study, J. Atmos. Chem., 37, 81–112, 2000.

ACPD

6, S6800–S6808, 2007

Interactive Comment

Lu, R., Lin, C., Turco, R., and Arakawa, A.: Cumulus transport of chemical tracers. 1. Cloud-resolving model simulations, J. Geophys. Res., 105, 10 001–10 221, 2000.

Xu, K.-M., Cederwall, R. T., Donner, L. J., Grabowski, W. W., Guichard, F., Johnson, D. E., Khairoudtdinov, M., Krueger, S. K., Petch, J. C., Randall, D. R., Seman, C. J., Tao, W.-K., Wang, D., Xie, S. C., Yio, J. J., and Zhang, M.-H.: An intercomparison of cloud-resolving models with the Atmospheric Radiation Measurement summer 1997 Intensive Observation Period data, Q. J. R. Meteorol. Soc., 128, 593–624, 2002.

Interactive comment on Atmos. Chem. Phys. Discuss., 6, 10773, 2006.