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Interactive comment on "Revision of the convective transport module CVTRANS 2.4 in the EMAC atmospheric chemistry–climate model" *by* H. G. Ouwersloot et al.

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We thank Referee #1 for his/her comments that help to sharpen the manuscript and are glad that he/she appreciates the importance of an optimized convective tracer transport module in EMAC. Below we respond to these comments point by point and include the modifications that will be applied to the revised manuscript. Original comments are displayed in italic font.

As a general comment, Referee #1 wonders whether the modifications have a similar significant effect for tracer transport in the "real world" as is shown for academic tracers that decay exponentially with various lifetimes, mentioning that radon would be a good compound for such a quantification. Furthermore, he/she suggests to analyze how the quantified deviations in tracer transport change for different season.

First, we would like to emphasize that radon is an inert exponential decaying tracer. As such, the only difference with the employed academic tracers is the specific lifetime (3.8 days) and the emission distribution (only over soil). For a general overview, we deliberately prescribed atmospheric tracers that are not chemically produced or depleted within the atmosphere and that are not characterized by heterogeneous emissions so that the investigated effects would not become diluted by additional processes. This is consistent with similar previous comparison studies, e.g. Lawrence and Rasch (2005). In our manuscript we present a first-order evaluation of the induced differences due to the altered convective transport representation, based on lifetime. The final impact for individual atmospheric compounds under specific conditions will of course depend on many different factors, including chemistry and emission patterns, but can be investigated using the updated EMAC code in follow-up studies.

For the sake of this reply, we reran the ORG and I100 numerical experiments including ^{222}Rn. The final RMSD, calculated in the same way as described in the manuscript, is 31.306 %, which is consistent with the analysis in the manuscript.

Additionally, we chose to present differences in the yearly averaged data, since these are already very significant. In line with general statistics principles, the root-mean-square deviation is on average higher when determined using data that is averaged over shorter periods. This effect would be strongest if the RMSD would be determined over instantaneous data, even if averaged over a year afterwards. However, as shown in Table 1 this effect is also apparent if the RMSD is determined per season. In general, the RMSD per season is higher than the RMSD determined over the year, but the order remains the same. Only for radon a significantly stronger RMSD can be noticed for (mainly) the DJF season, related to its emission pattern. By showing that the applied changes in the convective transport representation in EMAC are significant for yearly averaged concentrations, we automatically demonstrate that these changes are

Table 1. Weighted root mean square deviations [%] between numerical experiments ORG and I100.

#Period	1000 s	1 hour	6 hours	1 day	2 days	^{222}Rn	25 days	50 days
DJF	8.292	12.213	30.791	44.778	42.886	42.369	11.931	7.074
MAM	8.423	12.420	31.497	46.178	44.359	37.410	11.975	7.002
JJA	8.615	12.760	32.493	48.066	46.719	31.095	12.912	7.525
SON	8.314	12.285	31.355	46.258	44.601	33.122	12.270	7.208
YEAR	8.068	11.858	29.935	43.326	41.319	31.306	11.007	6.433

significant for shorter averaging periods as well.

Major comments

It is still not clear how the sub times length is used in the model. I am not sure if I understand it correctly which can be caulated from equation (8) in Page 3122. Then the intermediate time steps will be the global time step in sub time stepes with length delta (t_sub). But the main problem is that the sub time steps will be different at each level or each location. Does the model call the CVTRANS submodel at every time step (12 minutes) steps?

The reviewer is right that Eq. (8) on page 3122, together with the given that the amount of sub time steps has to be an integer, determines the length of the intermediate time step. This is determined per column. Within each call to the CVTRANS submodel (in our case with a time step of 12 minutes), the convective transport is calculated for each horizontal position using the locally required amount of sub time steps. This will be clarified in the text by adding “For every horizontal location the convective transport in the column is calculated independently in CVTRANS using the locally required amount of sub steps.” at the end of Sect. 2.2.1.

It is mentioned that the "no nudging is applied to meteorological data during the simulation" in Line 7 Page 3125. Therefore, the results are from free running CCM simulations. However, I think it would be better to use the nudged model because you will have the same convective mass fluxes from the CONVECT scheme since the meteorological conditions are identical. That is more meaningful when you compare the results using different f_maxfrac.

The reviewer is right that this would be important if f_maxfrac would impact the meteorological conditions. However, in EMAC the CVTRANS submodel only determines the convective transport of tracers other than water. The convective transport of water is linked to the convection scheme and is therefore directly calculated by the CONVECT submodel. Since the prescribed atmospheric tracers do not interact with radiation and do not affect cloud formation, meteorological conditions are not altered between the numerical experiments. We will clarify this by including "for tracers other than water" in line 10 on page 3120.

Can you explain why there are high mixing ratio the 1day lifetime tracers in Fig1 (a) and Figure 2(a) from the standard model simulation (ORG)? It would be better to check the convective mass fluxes and/or PBL boundary layer mixing.
Why the relative mixing ratio is still high in the polar region in Figure 2b? It would be better to plot Figure 2a as a log scale in the mixing ratio, otherwise, it is hard to say why the relative difference in other plots are important.

As mentioned in the original manuscript, the timescale of convective transport is of the same order of magnitude as this lifetime. Therefore, mixing ratios are relatively high in the boundary layer.
These figures provide a general insight in the (altered) distribution of atmospheric com-

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pounds, related to the applied convective transport representation, that an analysis of boundary-layer properties would not provide.

The relative mixing ratio difference in Fig. 2b is that high over the polar region, because the original mixing ratio (Fig. 2a) is that low. A small absolute difference therefore results in a strong relative difference. As such, Fig. 2a helps to interpret Fig. 2b. Absolute differences are strongest in the lower troposphere. However, by itself an absolute difference is without meaning. For example, if given a difference of 10 ppm in the observation of a chemical species, one would always need to know the base concentration to assess its relevance. Likewise, when comparing EMAC with observations or other models these percentages are important. This is also why previous studies (e.g., Lawrence and Rasch, 2005; Tost et al., 2010) presented induced differences in the same manner.

While locally these relative differences are very important, indeed they can distort the picture of the impact on the global distribution of atmospheric compounds. In the original manuscript this is explained explicitly with the use of Figs. 1a and 2a. For an objective quantification of the change in the tracer global distribution, the RMSD calculation is introduced.

I do not quite understand the Figure 5 and “instantaneous differences can be more significant, e.g., of the order of 10% in the lowest kilometer of the atmosphere” and Figure 5. Since the only change between “altered concentrations at updraft base” and “Analytic expression at cloud base” is to apply a factor (f_trans) below 2500m or below PBL height. So I thought the big changes should at that levels. But there are large changes even at 10 or 15 km.

The factor, f_{trans}, is not applied everywhere below PBL height or 2500 m, but rather solely at the base of de updraft plume, k_b, if it is located below the top of the PBL (or between PBL top and 2500 m). However, the concentrations in the air that enters the

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plume from below are altered. Since this is the main inflow for the plume, at all levels the properties of the plume are changed. Thus all layers are affected.

This work seems to be important for the strong convection cases, therefore, the results should highlight some strong convection cases, rather than using the 1 year averaged presented here.

Indeed, the applied changes result in the most significant differences for strong convection cases. However, as explained while answering the general comment, by presenting the significant differences in 1 year averaged data we show that the impact is not just limited to such cases. Of course, a quantification of the individual induced differences for all possible time periods, locations, different chemical species and conditions is impossible. Therefore, we limit ourselves to this demonstration of the significance of the applied alterations.

Minor comments

The quality of all Figures are not good.

If the reviewer could elaborate, we could apply changes. If the problem is (only) related to the light colour of the labels and the presence of raster lines within the contour plots, we would like to clarify that these are probably due to conversion issues from high quality figures. We will take care to improve the figures' quality in the final manuscript as well. Please inform us if the reviewer dislikes the figures for other reasons.

Page 3122 Line 1, rewrite as "in the grid cells part affected by plumes".

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We will rewrite it to “The temporal evolution of the mixing ratios in the grid cells parts that are affected by the plumes is expressed by”.

Page 3126 equation (14), change it to “RMSD”

We thank the reviewer for pointing out our spelling error.

References

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Interactive comment on Geosci. Model Dev. Discuss., 8, 3117, 2015.