

This study describes the convective exchange matrix, a new tool to analyse convective transport. and its application. The matrix is then used to study the change of convective transport in historical climate simulations, comparing (mainly) the 1980ies with the 2010s.

Overall, this is an interesting topic and well suited for ACP. However, I feel that several clarifications are needed, including the validity of the transport calculations. Please see my comments below.

### **General comments:**

#### **Section 2:**

I suggest re-ordering this section to have the model and submodel described first and then the simulation setup as the last subsection. In addition, I am surprised that the CVTRANS does not get mentioned in the simulation setup – but it is used? Additionally, the simulation setup describes the setup of the global simulations, but nothing is mentioned in the manuscript about the setup for the simulations in section 3.1, other then different versions of CVTRANS.

#### **CVTRANS and convective exchange matrix:**

Do I understand correctly, that the exchange matrix is a tool that does not itself calculate the transport but uses the transport as calculated by CVTRANS? This could be a bit clearer in the description.

Regarding section 3.1, where you only compare the exchange matrices of different versions of CVTRANS: How can you know that the transport itself is simulated well? Thus, that all your results and conclusions of the following global study are meaningful? This is a crucial point, so please elaborate.

In section 3.2 you – for the first time – mention CVTRANS 3.0. Is that the version CVTRANSnew (section 3.1) or CVTRANSturb, or yet a different version? Would probably be good to also mention version names in section 3.1 (also for CVTRANSold).

#### **Model levels:**

As model levels are arbitrary, your reader (and I) might (or do) struggle when you indicate the analysed altitude level by model level numbers. Sometimes, you provide the respective altitude in hPa in brackets, sometimes you reverse the annotation the “hPa (model level #)”, sometimes only hPa, sometimes only model level number (for example throughout the second half of page 7). Please, 1) stay consistent and 2) provide a ‘human readable’ format, like hPa. If you really want to keep the model levels in the text, than please put these into brackets. Also, when you talk about higher/lower levels, it is sometimes not clear whether you mean higher/lower in model level world or in ‘real’ world. This needs more clarity!

On lines 221-225 you make a remark on the model levels vs hPa for the global simulations. Please, to also help your reader here, provide a ‘human readable’ altitude equivalent for the whole profile, such that your reader can identify whether a certain model level might be rather located in e.g. the BL, lower free troposphere, upper troposphere, tropopause region, etc. It should suffice to at least say which model levels they “roughly correspond to”. Also here, use the ‘human readable’ format in the description of your results. At the same time, I am wondering, that e.g. in Figures 8, 9, and 10 you provide equivalent pressure levels that do not change between the figures, even though following your remark, I would have expected this?

#### **Grammar:**

Throughout the manuscript, I had to re-read several sentences as the order of the words in the sentences was mixed up (wrong sentence structure), e.g. “mostly starts/starts mostly” or the placement of the verb. I believe, a lot of text editors have a grammar check, please make use of it! I won’t correct these instances in the detailed comments.

## Detailed comments:

line 24: "... and the related scavenging"

Scavenging of what? (aerosols, tracers, ...)

line 27: "... it is a hot topic in literature"

If this is a hot topic, then I would expect more references and their conclusions in the following. However, there are basically three studies mentioned, of which only one is from the recent years (Lepore et al., 2021). However, you mainly focus only on one study (Stevenson et al., 2005). I think, the discussion around the Stevenson paper could be condensed while the introduction would severely benefit from including more references and details about the conclusions of other recent studies looking at this 'hot topic'.

line 34: "Thereby"

I think, this is not the right word, did you mean "They found that" or something along that line?

line 41: "Therefore, this study" -> 'Therefore, our study'

line 42: typo 'specifically influence'

line 42/43: check for missing commas (,).

line 68/69: shorten to "... utilising EMAC." (had been introduced in the subsection before)

line 69: "10 Pa" – Do you mean 10 hPa?

line 70: T63 – for readers not familiar with EMAC, please state what this resolution means in terms of spatial resolution (km).

lines 80-83: These are rather statements for the acknowledgements.

line 86/87: Here, you state that the convection is parameterised based on Lawrence and Rasch (2005), while in the results, you often stress the Tiedtke-Nordeng convection parameterisation. Which is used?

line 120: "A formulation following..."

Unspecific – what exact formulation? Or is there only one, then say "the formulation".

lines 122-124: "The adaptive time stepping by Ouwersloot et al. (2015) must be applied" & "Hence, we argue that adaptive time stepping should be applied"

Double! Please remove redundancy.

line 130: What is "C"?

line 132: "First, in every vertical model level (1,2,...,N)"

Please include the information about the model level ordering that follows in lines 143/144 here, to avoid confusion (e.g. otherwise the reader would think that in line 143 i should be smaller j not the other way around).

line 146: "in the electronically supplements" -> remove 'electronically'

Figure 1: I would suggest to include model level numbers (1, 2, ..., N) in the Figure to help guide the reader. You mention downdraft and large-scale subsidence in the caption, I would suggest to also include these with arrows in the schematic in the middle of the figure for completeness.

### Section 3.1

I am missing information on the simulated case. Nothing is mentioned in the simulation setup section, neither is it here (the only mention is in line 167 “for one exemplary deep convective event”). Is the case that you simulate an idealised storm, or is it a real case?

line 173: “... and subsides...” -> remove ‘and’

line 174: “The large scale subsidence together with the downdraft balance the updraft.”  
Are there no large scale upward motions in the model?

line 175/176: “This is realised by allowing the subsidence to transport mass to the model level directly below the original level only “  
Why does this make the subsidence slower?

Figure 3: Comparing to Figure 2, it seems that in some places of the figure there should be a coloured shading, e.g. around origin level 16/destination level 26-31. Maybe adapt the colour scale?

line 232: “The convective transport based on the Tiedtke-Nordeng convection parameterisation indicates typical features. “

Are these features typical for the Tiedtke-Nordeng parameterisation? How is it different for other parameterisations? Please discuss/describe. If it is not specific for this parameterisation, the sentence could be removed because of redundancy.

line 233: “reaches not” -> ‘does not reach’

line 239: a) “distinguishable increase” – increase compared to what?

b) “lowest three model levels”

Is that now level 1-3, or 31-29? See main comment on model levels.

lines 241-243: These sentences are somewhat contradictory: The upward transport to these levels has been strengthened, but at the same time these levels are only occasionally influenced by convection? Maybe better to discuss together with the matrices that separate tropics from subtropics?

line 259: “Thereby, overshooting is defined as events where the updraft mass flux reached beyond the tropopause in one column”

Thereby is probably not the right word. Do you mean that the Tiedtke-Nordeng scheme defines overshooting like this? Is that definition consistent with the definition of overshooting in Wu et al. (2023), which you compare to in the following? As convective overshooting does not only happen at the tropopause, definitions might differ and thus, would need to be discussed here.

line 273: “The upward transport has decreased...”  
Repeat what you are comparing.

line 275: “Less deep updraft convective mass fluxes...”  
Do you mean ‘Fewer occurrences of ...’?

Figure 6 (caption): “colors” in the caption of Fig. 5 you use ‘colours’, please check consistency of the usage of British vs American English throughout the manuscript.

line 314: “A similar picture...” Similar to what? Actually, I have the impression that the whole sentence is not necessary and can be removed.

line 319: “ The downdrafts shift to higher origin levels. “

Here, I am not sure what you refer to with ‘higher levels’ is it higher model level numbers (so lower levels in the atmosphere) or higher in the sense of altitude in the atmosphere? See also major comment on model levels; I would strongly suggest using a notation that goes from low levels at the ground to high levels at altitude.

line 329: remove ‘although’

line 329/330: “A shift of the downdrafts“  
A shift from where to where?

Figure 11/line 349: Do I understand correctly, that you identify transport from the boundary layer to the upper troposphere based on the transport that happens within one 12min time step? Is that not too short? I would think, that the BL to UT transport happens on time scales of about 30min (e.g. Thompson et al., 1997), so that would be 2-3 time steps in your simulation. Thus, you would underestimate the transport if only using one time step?

lines 357-360: Why are too high precipitation rates an indicator for overestimated convective transport?

line 449: “... convection reaches further...” -> reaches ‘higher’

lines 454-459: Here, you compare updraft speeds as studied by Del Genio et al and mass fluxes. These are not directly comparable, as for the calculation of the mass fluxes you need to take into account the updraft width/area (or area fraction). Did you check whether this also changed?

line 462: “high altitude levels” -> Would be good to stick to the UT/LS notation to make clear what exactly you identify as high altitude here.

line 466: “... at lower temperatures as the colder point tropopause...”  
Did you mean ‘at the cold point tropopause’?

line 470: typo CVTRANS

line 470/471: I suggest to swap the two sentence parts (before/after the comma) to start the conclusions more general.

line 471: “Thus”

I don’t think, thus is the right word here – do you want to say that you take CVTRANS a step further (further to where?) because you apply it?

line 473/474: “(2) In addition, the entrained air into the downdraft can be directly detrained in the same level of the downdraft comparable to the proceed concerning the updraft.”

I don’t understand what you want to say here, please rephrase.

line 475: “more realistic handling of the turbulent mixing”

I am not a 10% convinced here. At the end of section 3.1 you even state that “the transport to the upper troposphere by CVTRANSturb is not efficient enough”. How do infer, that your setup results in a more realistic handling of turbulent mixing? In fact, I only see the differences between the CVTRANS versions described (in section 3.1), but no discussion about which version provides the most realistic treatment anywhere in the manuscript.

That relates to my comment on CVTRANS version, which version do you refer to in the conclusions, which version do you use in the global simulations, which versions are CVTRANSold/CVTRANSnew/CVTRANSturb?

line 476: “redistribution OF air masses”

line 478: “... disentangled from the other processes.”

What are ‘the other processes’? If you write ‘the’, you have to be specific.

line 483/484: Remove “Respectively”

line 484: replace model level notation. A lot of people read the conclusions before the main manuscript, thus, they will not understand which altitude you are looking at.

line 486: “smaller mean transport” -> ‘weaker mean transport’

line 489: “ first insights in “ -> insights into

line 490: “becomes emerging” -> emerges

line 490: “climate change open the path for higher but in total less upward transport” -> climate change opens the path for stronger but in total weaker upward transport

line 491: “Furthermore, this study...”

Do you really mean ‘this study’, or ‘the convective exchange matrix’?

Supplement:

Figure S1: I think this figure is extremely helpful and should thus be included into the main manuscript, including a good description of the figure in the main text.

I think, that “Very small to zero transport” in the figure is already an interpretation of simulations you run, while it should rather describe the potential process – which would be (in the style as you describe the updrafts) “extreme downdrafts”. Also, what about upper level downdrafts?

## *References:*

Thompson, A., Tao, W., Pickering, K., Scala, J., and Simpson, J.: Tropical deep convection and ozone formation, Bull. Amer. Meteor. Soc., 78, 1043–1054, doi:10.1175/1520-0477(1997)078<1043:TDCAOF>2.0.CO;2, 1997