Interactive comment on "The impact of overshooting deep convection on local transport and mixing in the tropical upper troposphere/lower stratosphere (UTLS)" by W. Frey et al.

Anonymous Referee #3

We'd like to thank the reviewer for his/her comments. Please find a point-to-point reply below, the referee's comments are typeset in bold italic, our replies in normal font.

General comments:

...

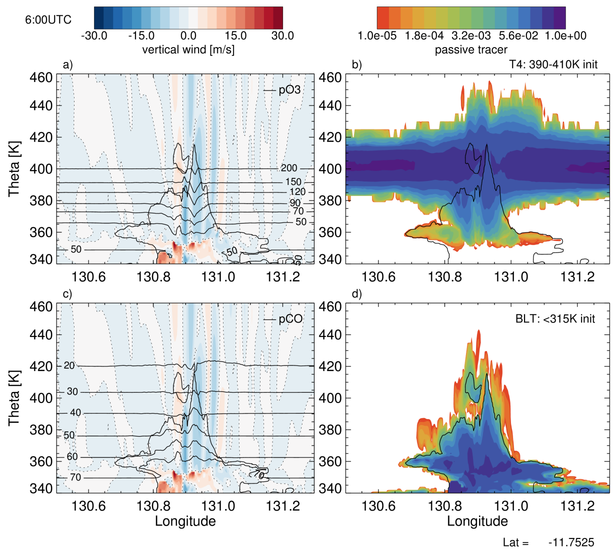
Specific Comments:

page 1050, line 29: "... the Thompson scheme produced the smallest Hector." This sensitivity discussion is great, as information on sensitivities is helpful to the community. So, I don't find anything wrong with your discussion, but I recommend some added clarification. First, what do you mean by "smallest"? I infer from the following sentence that "smaller" refers to the depth and magnitude of the convective turrets. Are there additional "smaller" traits, or is that the extent of what you meant to convey? You also mention that NSSL performed "slightly better" than the Morrison scheme. Can you be more specific about what fields in particular were "better"?

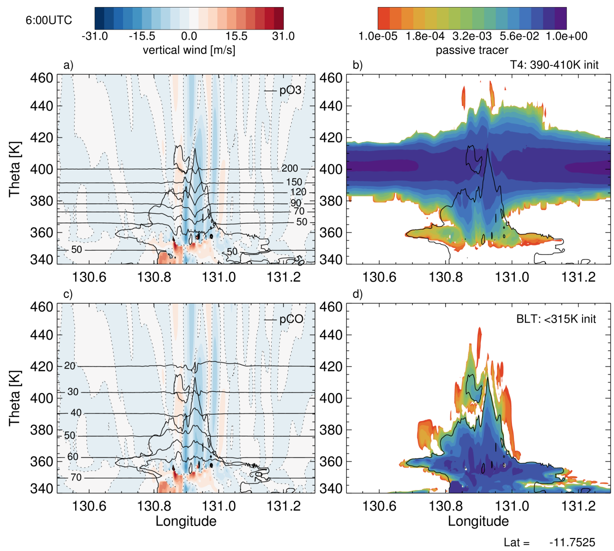
> Reply: For the comparison we used the ice content of the simulated clouds to infer the development and vertical extension of the clouds, as well as the extent of the anvil. Furthermore, we were mainly comparing maximum altitude reached by the cloud turrets and timing of the convective cells/overshoots, which we compared to aircraft and CPOL radar observations. All comparisons were based on simulated storms in domain 4; domain 5 was added only after conclusion of this comparison, and only run for the NSSL microphysics scheme due to the computational cost.
>
> While the maximum altitude reached by the simulated Thompson cloud was about 17km, Morrison reached about 18.5km, and NSSL about 19.5km (cf. aircraft measurements between 18-18.7km - not necessarily reaching to the top of convection - and CPOL radar 19km). Also in the horizontal, the Thompson scheme achieves the smallest spatial extent, followed by Morrison, and the largest diameter is reached by the NSSL scheme.
>
> Timing: While the Thompson and Morrison storms started developing at about the same time, the Morrison clouds reach higher at an earlier time, and on the other end dissipate less quickly than the Thompson clouds. The NSSL scheme achieved an even better timing, starting convection 30min earlier than the Morrison scheme. This scheme achieves the best agreement respective timing compared to the timeframe given by the CPOL observations.
>
> Actually, we also tested the WDM6 scheme, which however did simulate clouds that only reached about 10km altitude, which is why we did not mention this. Following your comment we decided it could be worth mentioning this as well in the revised manuscript version.
>
> Thus, we rephrased the text as follows:
>
> "In addition to the NSSL microphysics, the WDM6, Thompson, and Morrison two-moment schemes (Lim and Hong, 2010; Thompson et al., 2008; Morrison et al., 2009) were tested. While Thompson, Morrison, and NSSL all simulated Hectors with clouds reaching high into the TTL, convection in the WDM6 scheme just reached up to 10km. From the remaining three, the Thompson scheme produced the smallest Hector in horizontal and vertical extension. Morrison and NSSL simulated higher vertical wind speeds (about 8–10ms^{-1} higher) and higher reaching turrets, also producing overshooting into the stratosphere, as observed. The NSSL scheme achieved slightly larger horizontal and vertical extent than the Morrison scheme. While the timing is similar for the Thompson and Morrison schemes, the NSSL scheme showed a better timing by about half an hour. Thus, overall, the NSSL scheme performed best, and was chosen for the rest of the study."

Figures 7-11, 13-14: As stated in "General Comments", I think you've done a great job with the figures in this article, but I need some clarification on the figures that use potential temperature as an axis. Some sort of interpolation to potential temperature surface would need to be performed, as the potential temperature surfaces are not planar when the storm is active (figure 12). You need to explain how this was done, as the method of interpolation would impact your results. Also, gravity waves, particularly near the overshooting tops, often cause near vertical isentropes (figure 12). How did you deal with these vertical isentropes when converting to potential temperature coordinates?

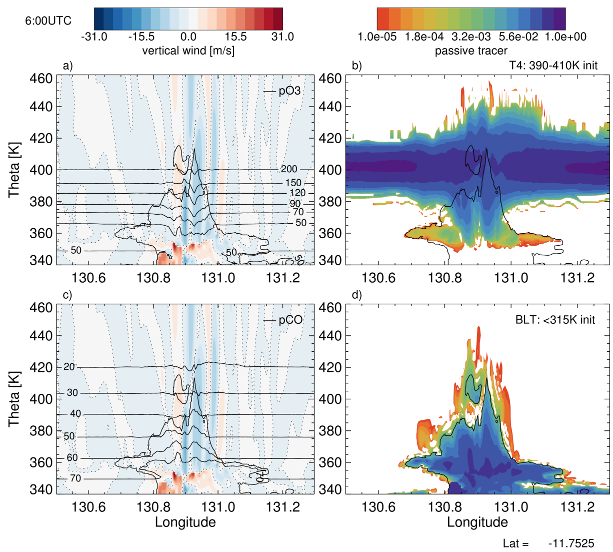
Reply: To regrid data onto the potential temperature, we did vertical interpolation for each lot-lan grid point column onto a regular potential temperature ordinate. The plots in the manuscript use linear interpolation, though using other interpolations does not make a major difference. Below we show a few examples based on Fig. 9 (i.e. at a time where almost vertical isentropes occurred) using different interpolation methods. It shows that the basic conclusions remain unchanged.



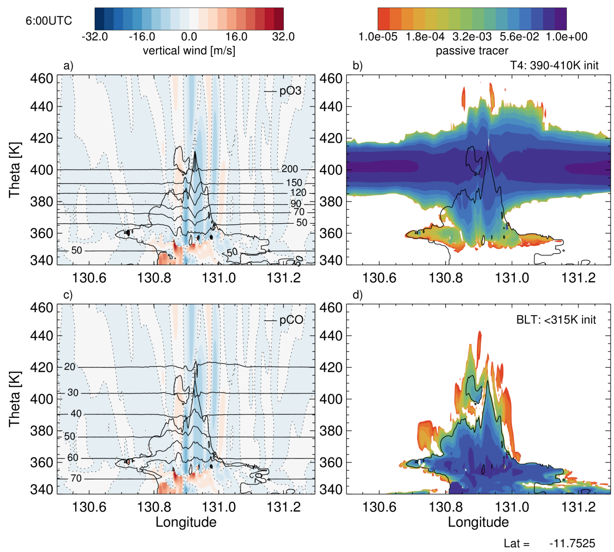
original/linear



quadratic



lsquadratic



spline

At near vertical isentropes the interpolation might lead to smoothing of the gradients, thus, the real changes may actually be larger than displayed in the plots. We added a footnote to the reference to Fig. 7: "Linear interpolation has been applied in the vertical to regrid data onto a regular potential temperature ordinate (Fig. 7-11, 13, 14). Care should be taken interpreting the figures when isentropes are near vertical. However, different interpolation methods lead to almost identical results."

Figure 11: Are you able to show any later times? The storm is still active at 6:00, and this figure shows there are still some changes in the tracer perturbation fields from 6:30 to 7:00. At what time is the transport profile fixed? I.e., at what time are there no longer parcels with positive/negative buoyancy?

Reply: From inspection of the cloud development, we infer that convection becomes inactive at around 7:00UTC. We do include 7:30UTC in Figure 11 now: Some further changes are still obvious, however, these are presumably caused by other processes as horizontal advection.

We add the following text: "Convection becomes inactive at around 07:00UTC, however, some further changes to the in-cloud tracer profiles may occur, presumably due to horizontal advection or other lateral inmixing processes not related to convection."

page 1062, lines 25-26: The sentence that begins with "However, this moistening …" reads very oddly. Having a "however" and a "but" in the same sentence left me confused about what you were trying to say here.

Reply: Replaced "but" with "instead".

Technical Corrections:

page 1045, line 24: "...cloud turrets were performed, which..."

page 1048, line 6: I think there is an extra "the" in this sentence. "Therefore, 3 arc-seconds..."

page 1054, line 18: "...model identifies mixing, Fig. 12 shows..."

page 1066, line 11: "...altitude of the layer..."?

page 1066,line 12: "...can actually lead to both hydration and..." (no comma)

Reply to Technical Corrections:
We applied all corrections as suggested.

References:

Lim, K. S. S. and Hong, S. Y.: Development of an Effective Double-Moment Cloud Microphysics Scheme with Prognostic Cloud Condensation Nuclei (CCN) for Weather and Climate Models, *Mon. Weather Rev.*, 138, 1587-1612, 2010

Morrison, H.; Thompson, G. & Tatarskii, V.: Impact of Cloud Microphysics on the Development of Trailing Stratiform Precipitation in a Simulated Squall Line: Comparison of One- and Two-Moment Schemes, *Mon. Weather Rev.*, 137, 991-1007, 2009

Thompson, G.; Field, P. R.; Rasmussen, R. M. & Hall, W. D.: Explicit Forecasts of Winter Precipitation Using an Improved Bulk Microphysics Scheme. Part II: Implementation of a New Snow Parameterization, *Mon. Weather Rev.*, 136, 5095-5115, 2008