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Review of the manuscript „The TropoPause Composition TOwed Sensor Shuttle (TPC-TOSS): A new airborne dual platform approach for atmospheric composition measurements at the tropopause“

by Bozem et al.

Reply to referee #1

We appreciate the kind words on our manuscript and thank the referee for the constructive comments and proposed suggestions. These helped to improve the manuscript. We will answer to all comments of referee #01 below point by point. Referee comments are given in standard, answers in red, and changes to the manuscript in blue font.

This is a nice manuscript describing the use of a novel sensor package that is towed behind an aircraft on a cable. Case studies that demonstrate the use of this technique in the tropopause region where there can be very significant but transient structures that produce strong vertical gradients are presented. The manuscript is well written and generally clear, and the subject matter is appropriate for publication in AMT. Minor revisions are needed to address a few questions, correct technical issues, and provide additional information.

1) Table 2: Please provide a column for instrument uncertainties at the stated sampling frequency. I believe the SkyPOC particle size range is misstated; Bundke et al report a lower detection limit of 0.25 µm.

Thank you for the suggestion. In Table 2-4 an additional column was added stating the uncertainty of the respective instrument where applicable. Thank you for pointing out the wrong size range. This was a typo, the correct lower detection limit is 250 nm. The text in the table was changed accordingly.

2) Section 3. At some point here I would like a brief discussion of how the cable system works and how far the TPC-TOSS module can be lowered. What is the total cable length and the typical vertical separation? This is evident only in graphs. What is the range of deltaZ (or cable length) that could be used safely? Alternatively this could go in Section 5.1.

Following the suggestion of both reviewers we added the following paragraph about the handling of the winch and TPC-TOSS as well as wire length in section 3:

The TPC-TOSS is attached to a winch under the right aircraft wing that is equipped with a steel wire of a maximum length up to 4 km. The pilots operate the winch to release the drag body to the desired wire length and retract it after the measurements. For certification reasons the operation of the winch is only allowed below 25000 ft (7.6 km) while the maximum flight altitude with the TPC-TOSS deployed is 41000 ft (12.5 km). During the TPEX I flights with the TPC-TOSS a wire length of 3000 ft (914 m) was used. The main reason for not using a longer wire length was the military controlled restricted air space with a maximum side length of 50-80 km in which we were only allowed to fly with TPC-TOSS due to safety constraints. The small area resulted in multiple turns during aircraft operation. Based on the experience from earlier campaigns in the same airspace, the chosen wire length was a compromise between a maximum reachable vertical distance between Learjet and TPC-TOSS and safe and feasible Learjet operation (Klingebiel et al. (2017, and references therein). With this wire length a vertical distance between Learjet and TPC-TOSS of 152 ± 8 m was reached during stable flight conditions (no turns or climbs/descents). The maximum range of vertical distance was between 95 m and 220 m including turns and altitude changes. Further details on the relative position of TPC-TOSS and Learjet are discussed in Sect. 5.1.

In Sect. 5.1 we added the following for more details on the relative position between Learjet and TPC-TOSS.

Line 437 ff.: Due to the limited operational area, the wire rope length was set to 914 m as mentioned in Sect. 3. This resulted a horizontal distance between TPC-TOSS and Learjet of 877 +- 3 m on average during undisturbed flight conditions (no turns and no climb or descent). The resulting vertical distance was on average 152 +- 8 m.

Line 444 ff.: The lateral distance between TPC-TOSS and Learjet was on average 89 +- 8 m based on flight F10.

3) Line 214. Change to, "the addition of insulation to protect the instrument by maintaining temperatures above 0 degrees C." Is this an arbitrary temperature limit or would the ozone instrument still function at colder temperatures? I ask because tropical missions near the tropopause might see much colder temperatures than this (if ~13-14 km altitude could be reached).

We changed the text accordingly. With the “cold weather upgrade” provided by 2BTech, which we applied, the lower limit of the operating temperature range for the ozone instrument is -20°C. We aimed at keeping the temperature inside the instrument above freezing point to avoid any ice formation. Notably, the TPC-TOSS instrument had to be switched on under cold environmental conditions since it was not allowed to have the TPC-TOSS powered while attached to the Learjet. Insulation helped to reduce the cooling rate of the ozone monitor before switching it on 15-30 min after takeoff.

4) Figure 6b. What is the standard deviation of the Gaussian fit? This would inform as to total instrument variance.

The standard deviation of the Gaussian fit is 1.6 ppbv and is thus on the order of the noise determined with regular calibrations in the field. We added the following sentence to the discussion of Fig 6b:

The standard deviation of the gaussian fit amounts to 1.6 ppbv and is on the order of the instrument noise determined in the previous section.

5) Line 343. Surprising use of imperial length units. I thought this was strictly a problem in the U.S.!

Thank you for the hint. We added the length in SI units.

6) Line 354 "peeks" -> "peaks" and line 302 "week" -> "weak".

Correct. We changed it accordingly

7) Line 382 "Atomizer" -> "atomizer"

Correct. We changed it accordingly

8) Line 395. Reference to Fig. 17 before Fig. 12. Generally figures need to be cited in order. You could place the bin diameters as vertical lines in Fig. 11b instead, if you prefer. This might help see how they span the range of compositions. Except, see the next comment below.

We removed the reference to Fig. 17 at this place, as this reference might anyway be misleading, because Fig. 17 does not show the exact new bin scheme but only a size distribution within the new bin scheme.

9) Fig. 11. There is a substantial (~20%) shift in diameter from the manufacturer's calibration, consistently for both instruments. It's not clear if this correction has been applied when the new wider bins were created. I'm not sure of the reason for creating the wider bins, other than some way to represent the range of possible sizes. It may be better to calculate a low-refractive index calibration and a high-refractive index calibration (by calibration, I mean relationship between channel number and calibration diameter for each calibrant), then a medium-refractive index calibration as the default value. Uncertainty bars would then span across the low- and high- refractive index cases and you could still use the full 99-channel resolution of the UHSAS. I'm not sure what the wider bins gains you since using that method a central bin diameter is assumed and only one size distribution, with no uncertainty range, comes out. Uncertainty ranges might be more useful than grouped wider bins.

The shift in diameter from the manufacturer's calibration to our calibration measurements has been taken into account before adjusting the bin schemes.

We performed a low-refractive index and a high-refractive index calibration: The low-refractive index calibration was done with glucose and the high-refractive index calibration with PSL. We chose to reduce to fewer and wider bins according to an earlier study using exactly this UHSAS-A instrument (Mahnke et al., 2021, ACP). Here, we did not just group the bins together, but we also looked at the statistics to account for the data within the 10% and 90% percentiles. Further, we think that the readability of size distributions is easier with a reduced number of size channels compared to a large number of size bins with individual uncertainties.

We added the following text to section 4.5.1:

We use these calibration measurements, including the shift in diameter and the individual size calibrations for different refractive indices in order to introduce a new bin scheme. Here, we assign the particle signals to less and broader bins to account for the different refractive indices of the particle types. More precisely, we convert the measured 99 bins into 9 bins of quasi-logarithmic spaced channels. This method is also used in an earlier study using this UHSAS-A instrument by Mahnke et al. (2021). For the reassignment to the new bin scheme, we analyze all individual size calibrations and the corresponding particle diameters of the measured size distributions. Furthermore, the new bins are defined to include all data between the 10 % and 90 % percentile of the measured diameters to account for the uncertainties caused by the different refractive indices.

10) Fig. 13. There are some surprising size-dependent counting efficiency differences between units here, which pass without much comment. ~30% is a big counting difference (i.e., 350 nm). What is going on? Any ideas?

We agree that these differences are unexpected. We are not sure what has caused them, but they could be due to imperfect gain stage calibration combined with laser misalignment, resulting in reduced sensitivity in this size region. The laser had to be replaced before the campaign and, as the official support for the UHSAS-A has been discontinued by the manufacturer, the new alignment was carried out to the best of our ability. We added the following sentence in the discussion of Fig. 13:

The discrepancies in the range between 300 and 500 nm are unexpected, and there is no clear explanation for them. It may be a combination of imperfect gain calibration and slight laser misalignment causing the undercounting of particles at the UHSAS-A

11) With PSL, when you are comparing numbers do you just integrate the PSL peak, or are you counting additional surfactant/contamination particles in the smallest bins (assuming no DMA is used for the PSL calibrations to remove the smaller contaminant particles)?

For all measurements including PSL, we used the DMA to remove contaminant particles. For all number concentrations we integrated over the region around the selected size peak for all calibration substances.

12) Line 417. The yaw angle (alignment with respect to the local wind vector) of -147 degrees must be an error. I might believe -1.47 degrees.

We used the wrong term since we refer to “heading” here, as also shown in Fig. 14. The text was corrected accordingly.

13) Fig. 16. What is the shading on this plot?

The shading in figure 16 denotes the total uncertainty of the shown parameters calculated from individual uncertainties of measured parameters used to derive for example ozone and Theta gradients (lower panel in Fig. 16). The caption was changed accordingly:

The shading in all three panels denotes the total uncertainty of the shown parameter consisting of individual measurement uncertainties of the respective parameters. For ozone related quantities the uncertainty is much smaller than the observed variability and thus hardly seen on the figure.

14) Line 483. Two periods after "cabin".

Correct. We changed it accordingly.

15) Figure 17. I don't find log-log size distributions very useful. Of more interest (at least to me) would be how well the integrated number, surface, volume, and effective radius agree. These are the parameters governing CCN activity, heterogeneous chemistry, extinction and mass transport, and remote sensing retrieval, respectively.

See reply to 16.

16) If data need to be plotted on a log axis, it implies that the parameter is not normally (Gaussianly) distributed. Thus standard deviation, which assumes Gaussian statistics, is not valid and is meaningless in describing the statistics. A geometric standard deviation might be better here. (But I would prefer linear plots of N, S, and V vs log diameter instead.)

We chose the log axis in order to see also smaller numbers in the particle diameters. However, we agree with your comment and according to your suggestions we added N, S, and V as linear plots vs. log diameter.

17) The lateral and fore-aft spacing of the TPC-TOSS is mentioned in Section 6, but of more importance is the vertical spacing, which is not mentioned.

As stated for point (2) we added more information on the vertical spacing in Sect. 3. We further added the information on vertical spacing in Sect. 6 and modified the sentence as follows:

TPC-TOSS was positioned between 95 and 220 m below, up to 900 m behind and up to 100 m lateral to the aircraft during flights.

18) Please make sure that all figures are plotted using colors and/or symbols that would allow a person with a color vision impairment to distinguish the different parameters. There are two such scientists in my close acquaintance and it can be a struggle for them.

We checked and modified figures to our best ability to account for a color vision impairment. In case further changes are necessary we will modify the figures accordingly.

References:

Mahnke, C., Weigel, R., Cairo, F., Vernier, J.-P., Afchine, A., Krämer, M., Mitev, V., Matthey, R., Viciani, S., D'Amato, F., Ploeger, F., Deshler, T., and Borrmann, S.: The Asian tropopause aerosol layer within the 2017 monsoon anticyclone: microphysical properties derived from aircraft-borne in situ measurements, Atmospheric Chemistry and Physics, 21, 15259–15282, https://doi.org/10.5194/acp-21-15259-2021, 2021.