Response to review – RC1

General informations:

Changes in the manuscript are highlighted with dark red. *Italic* written text is the citation of the reviewers. Blue written text is the response of the authors. Longer text passages additionally included in the manuscript are highlighted with red. The revised version of the manuscript will be uploaded.

Review of anonymous Referee #3

Remark: „*The authors present a study of humidity effects on filter-based absorption measurements. These effects may be important with UAV-based (low-power filter-based) absorption measurements where flight durations are relatively short and so the drone may not spend a lot of time at a fixed altitude. These are some interesting experiments, and the authors nicely explain the theory of absorption measurements. I have not seen a lot of papers about the TAP, so this could have been a useful contribution. However, I have several concerns with this manuscript. It is not clear to me that the authors understand the instruments they use or what the data are telling them. Some key points are listed below:*"

Response:

We thank for the review. The reviewer focuses on UAV measurements. Though other applications for the STAP are available like in helicopter-borne and tethered balloon platforms. Ongoing we will address the key points of the reviewer point by point:

Key point 1: "*The TAP has a reference filter measurement, where the particle-free air downstream of the first filter is exposed to a reference measurement. This could explain why the TAP shows a lower response to humidity changes, and possibly why the sign of the effect is opposite that of the mini-Aeth. However, the authors fail to mention this crucial design difference.*"

Response:

Thanks for the comment. We totally agree that we forgot to mention that crucial difference in design. To determine the absorption coefficient, the MA200 also uses a reference spot through which no air flow is passing through. Therefore, *rh* changes have a larger impact for this instrument than for the STAP in which the reference spot downstream the sample spot is exposed to RH changes as well. We updated the sections 2.2.1 and 2.2.2 to provide a more detailed look into the design of the instruments. The sections are as follows:

"2.2.1 Single Channel Tri-color Absorption Photometer (STAP)

The Single Channel Tri-color Absorption Photometer. This photometer detects light intensities behind two quartz-fiber glass filter (PALL LifeScience, Pallflex Membrane Filters Type E70-2075W) at three wavelengths (450, 525 and 624 nm). On the first filter, the sample filter, the light attenuates due to deposited particulate matter. The second filter, the reference filter, is located downstream the sample filter and allows blank filter reference light intensity measurements.

By default, the particle light absorption coefficient is determined internally using 60 s averages of the raw intensity measurements for both filter spots. Therefore, in Eq. (5) *I(t)* is defined as:

$$I(t) = \frac{I_{\mathrm{smp},\lambda}}{I_{\mathrm{ref},\lambda}}, \tag{7}$$

where I_{smp} and I_{ref} is the intensity of light at the certain wavelength λ behind the sample (smp) and blank reference (ref) filter, respectively. Nevertheless, all raw measurements are recorded with a time resolution of 1 Hz allowing a recalculation of σ_{abs} at this time resolution. The volumetric flow is set to one liter per minute (lpm). According to the manual, at an internal averaging interval of 60 s, the measurement uncertainty is specified to 0.2 Mm^{-1}. The spot diameter is ~4.8 mm which leads to a sample area of A_{spot} ~1.75e-5 m^2.

2.2.2 MA200

The second instrument used here is the microAeth® MA200 is a small sized (13.7 x 8.5 x 3.6 cm; 420g), absorption photometer measuring the attenuation of light at 5 wavelengths (375, 470, 528, 625, and 880 nm; 625 nm are investigated in this study) due to deposited particulate matter on a PTFE filter band.

Similarly to the STAP, the MA200 detects light intensities behind a sample and reference spot. The particulate matter samples on a sample spot with 3 mm diameter leading to a sample area of A_{spot} ~0.71e-5 m^2. The reference spot of same area allows for blank filter measurements. M_{eBC} is determined under the assumption that the change of attenuation is proportional to the deposited eBC mass. The measurements were recorded with a 1 Hz time resolution. With the DualSpot® technology the instrument is able to reduce uncertainties related to loading effects up to 60 % (Holder et al., 2018) but was not functioning at the time of the experiment.

Holder et al. (2018) reported that the measurements are slightly depending on *rh* and *T* of the aerosol sample. However, they observed concentrations of up to 7 mg m^{-3}, at which the observed dependence on humidity and temperature did not influence the measured values significantly. Furthermore, they used another version of the instrument (MA350), which may react differently to changes in humidity and temperature."

Key point 2: "*The effects due to humidity changes are *temporary*. This is shown by the rise in absorption followed by a return to normalcy. The authors try to explain the initial changes by speculations about physical phenomena, but the measurements return to that shown by normal, unaffected conditions even as the RH remains high. The water film or beads would not disappear if the humidity remains constant.*"

Response:

Thanks for that comment. We totally agree that the effects are temporary. But, the main focus of this paper is to highlight these temporary changes, since they are important, especially when a high temporal and spatial resolution is needed. The focus of our study is not on measurements with a long averaging time.

Indeed, the beads would not disappear. But after the filter equilibrates after humidity changes there is no change of the optical properties (attenuation) of the filter medium. Since only change of the attenuation of two subsequent measurements is important for the measured particle light coefficient a constant relative humidity has no effect on the measurements.

Key point 3: "*A lot of the manuscript focuses on 60-second average measurements. The typical flight time of a UAV is 30 minutes, maybe two hours maximum. At the short end, 60-second averages are not very useful. At the top end, the instrument has time to equilibrate at a particular altitude to wait out any RH effects.*"

Response:

Thanks for that comment. Indeed, for some applications the averaging period is too long. However, the 60-second averaging part of the paper, was intended to qualitatively describe the observed effect. The reaction of the instruments is also shown on a one second time base in Figure 3. These are important to resolve the effect of fast relative humidity changes which is necessary results to develop a correction scheme for the *rh* effect. Equilibration is not intended within this paper, since boundary layer physics, especially in the transition zone of mixing layer and free troposphere, do not allow for equilibration. Also measurements in clouds can be characterized by a fast changing relative humidity. Anyhow, we updated the manuscript by including Figure 3 to show the behavior of both instruments at 1 Hz time resolution in dependency of the *rh* change rate d*rh*/d*t*.

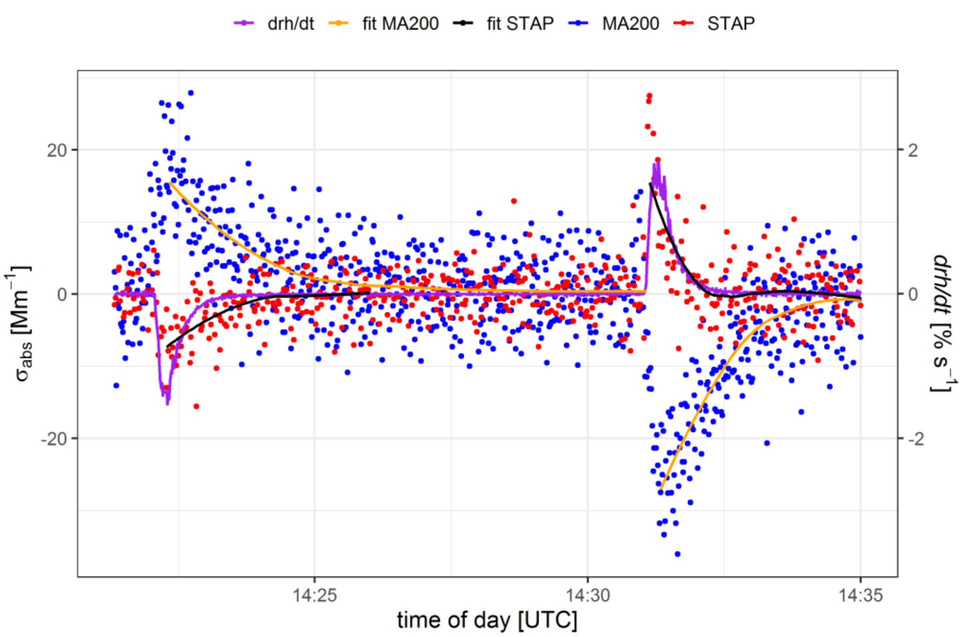

Figure 1: 1 Hz raw data of σ_{abs} at 625 nm measured by the MA200 (blue points) and recalculated at 624 nmSTAP200 (red points), the smooth fit through the measurements (orange and black), and d*rh*/d*t* (purple line).

Key point 4: "*The authors present an experiment showing that a dryer reduces the observed RH effects, but don't seem to understand or at least fail to explain why - the dryer likely reduces RH at the filter, so the effect on measured absorption should correspond to that at lower RH. This is seen by the similarity in slopes between the non-dryer and with-dryer cases. A key analysis would be (a) measuring the RH post-dryer; (b) comparing the effect at the post-dryer RH (say 90% pre-dryer, post-dryer 55%) to that at the same non-dryer RH (55%).*"

Response:

Thanks for that comment. We refer to anonymous referee #4 (RC2 supplement) that section 3.3 only describes that a dryer dries humidified air and recommends to omit this section. We therefore removed the section from the manuscript.

Key point 5: "*The authors compare the dry-to-wet and wet-to-dry changes without considering whether these changes are of the same magnitude both ways. There could be hysteresis effects, similar to particle hygroscopicity.*"

Response:

Thanks for that comment. We refer here to the scatter plot figures (Fig. 5 and 7 in the new manuscript) which clearly shows the dependency to the sign of the *rh* change. Obviously, the magnitudes are the same for both cases, at least on the basis of the used averaging period which might include a possible hysteresis effect. We clarified within the manuscript and added the sentence "As shown in Fig. 4, the magnitude of the deviation due to positive or negative changes in humidity is approximately the same for each device in terms of magnitude." at the end of Section 3.1. The sentence "Similar to the clean case, for both instruments, drying and humidifying the sample stream to the same extent resulted in a deviation of σ_{abs} with the similar magnitude." was added at the end of Section 3.2.1 and at the end of section 3.2.2 we added: "Overall, the magnitude of the deviation of σ_{abs} was independent of the sigh of humidity change for both instruments.".

Key point 6: "*The filter loadings and changes in RH considered here are ridiculously high. See for example doi:10.5194/amt-6-2115-2013; figure attached. RH changes are more gradual and Bap values are much, much lower, which suggests that we will not see the high spikes reported here (except maybe in biomass smoke plumes). The high filter loadings used here (~50 microg/m3) are likely exacerbating any effects.*"

Response:

Thanks for that comment. We agree, the filter loading concentrations are high. Anyhow, the loading periods where very short, and the attenuation due to loading with soot was never below 0.52 (extreme case), but the majority was above 0.74 which is a reasonable value for multi used filters or measurements in polluted conditions. Additionally, the filter loading concentrations cannot exacerbate the observed Considering *rh* change rates, we agree, especially in the case for 1 second average periods the change rates were pretty large. Anyhow, we also presented cases with change rates of -1.42 to 1.09 % s^{-1} which can be observed under real atmospheric conditions. Furthermore, since the observed points lying on the same line with a constant slope over all considered *rh* changes it is a satisfying assumption that the slope is also valid for very small *rh* changes resulting in smaller bias. To point out that the filters were loaded before the humidified sample airstream was collected by the instruments we added: "Two main setups were used to investigate the effect of changes in real humidity. In the first, the filters of the devices were unloaded and the instruments collected a particle free airflow with adjustable relative humidity to examine the pure filter effect. In the second, the filters of the devices are loaded to a certain degree and afterwards they sample particle-free humidified air which accounts for the combination of both effects, the pure filter effect and the effect induced by the hygroscopic behavior of the particles." as second last paragraph in Section 2.3.

General point 1: "*There are other minor issues, and the manuscript needs an once-over by a native English speaker.*"

Response:

Thanks for that comment. We read over the manuscript and changed some unclear sentences. We refer here to the supplemented revised version of the manuscript in which all changes are documented.