

Authors' response to reviewer comments

We thank both reviewers for their time and for their many suggestions/comments, which will help improve the manuscript. We detail the responses to each of these comments in turn below.

We will also take the opportunity to improve the flow of our manuscript by dividing Section 2 into various sub-sections, and change some of the terminology used for consistency.

Reviewer #1

We note that many of these issues have been addressed prior to publication in AMT Discussions following comments made by the same reviewer during the Technical Corrections stage. Our responses to these comments reflect the changes that were made to the manuscript at this stage, and make explicit where any further changes have been made.

Main remarks/comments:

P3, 1st paragraph: The first sentence "Measuring the continuum...present in the atmosphere" is too general. For example CRDS/OF-CEAS techniques allow for measurements at room temperature and at low pressure close to atmospheric conditions. Same remark for the next sentences: equivalent pathlength with CRDS/OF-CEAS techniques can reach several hundreds of km and base lines are highly stable.

We agree that CRDS allows for measurements at room temperature (and in principle lower) and at low pressure, and have added in a statement to this effect. Room temperature is not the same as atmospheric temperature however; there are not yet (to our knowledge) measurements by CRDS of the continuum in these windows at temperatures as low as 280K, which are the atmospherically relevant temperatures we refer to here. We have changed the text to indicate that we consider temperatures below room temperature and added a further sentence to acknowledge the importance of CRDS at room temperature.

P6, L7: The authors have to specified the cutoff value for the Voigt profile and if they include or not in the continuum the plinth below the absorption lines.

This is the standard 25 cm^{-1} with the plinth subtracted from the absorption lines, as it is assumed to be included in the continuum. We have now explicitly included this information in the manuscript.

P9, Figure 3: On panel (d) the water vapour optical depth is around 0.025. This value doesn't correspond to values reported in Fig 4 and in Supplementary Material which are between 0.01 and 0.008 for the same spectral region. Can the authors clarify this?

Thank you for spotting this. This Figure was in error, due to a software bug, and has now been corrected.

P9 or P10: In addition to figures 4 and 5, a figure showing the relative contribution of the aerosols and of the continuum to the optical depth after subtraction of the line-by-line and Rayleigh contributions will be very helpful to demonstrate the importance of the aerosols optical depth knowledge.

We agree. Figure 5 has been updated with a second panel showing the relative contribution of aerosol and continuum to the combined continuum + aerosol optical depth.

P19, L17-18: ...due to the lack of laboratory measurements at atmospheric temperatures, one must assume a temperature dependence of the self-continuum. This sentence has to be reformulated as CRDS/OF-CEAS measurements of the self-continuum are available at room temperature. Why the authors did not adopt this data set instead of the extrapolated high temperature data of the CAVIAR laboratory measurements?

Even with room-temperature measurements of self-continuum, it is still necessary to extrapolate down to ~280K for our purposes. We have made this more explicit in the manuscript. We chose to use the CAVIAR-lab data since it has broad spectral coverage across all the windows, and measurements at a range of temperatures across each of these windows.

P21, L25-29: In these lines, authors discuss the two possible temperature dependences and they seem to have the same “degree of confidence” in both. This is a little bit strange as they decided to replace the room temperature CAVIAR data by the values extrapolated at 280 K from high temperature CAVIAR measurements.

Our stance on this is that there are two possible temperature dependences; given the consistency of the straight line fit through the high-T CAVIAR-lab data, we believe it is reasonable to suggest that there is possibly an issue with the low-T CAVIAR-lab data in this window, unless there is some unexpected temperature dependence. This lower temperature dependence is also consistent with the OF-CEAS data of Richard et al. It is our belief that this is likely to be a more robust estimate of the temperature dependence given the agreement between the high-T CAVIAR-lab data and the Richard et al. data. This paragraph has been reworded, and the figure caption updated with the low-temperature CAVIAR-lab data point, as we agree that it was not clear.

P24, Fig 14 (b): The data point called Mondelain et al. (2015) should not be plotted on this panel as it was obtained at 4250 cm⁻¹ and not at 4300 cm⁻¹.

Thank you for pointing out this error. This data point has been removed from the Figure.

P24, L20: The authors should mention here that the difference is due to the fact that, in one case (Vasilchenko et al) a purely quadratic function was used to fit the data considering that there was no adsorption on the mirrors and that in Mondelain et al an additional linear term was used to take into account the supposed adsorption contribution.

A sentence has been added to this effect explaining why the two do not agree within the uncertainties.

P26, L5: The authors should mention that in the 4 μm window the continuum is stronger than MT_CKD and the extrapolated CAVIAR-lab self-continuum.

This has been added.

P26, L9: The authors should add: ... a factor of 100 would be required to bring the CAVIAR-lab and CAVIAR-field self-continua into agreement, in contradiction with CAVIAR foreign continuum.

We agree that this is inconsistent with the majority of available data, and have included this rewording into the sentence.

P27, Figure 16: Several experimental points from CRDS/OF-CEAS experiments are missing in the 4 μm window (see Campargue 2016 and Richard 2017) and in the 2.1 μm window. In the 1.6 μm window the plotted data have to be replaced by the more recent measurements of Vasilchenko 2019. In Figure 16 (and also in Fig. 17), the uncertainties on the CAVIAR lab measurements are missing and have to be added.

These data points have been added to the manuscript. We have added the uncertainties in the CAVIAR-lab measurements to the plots; in the self-continuum case we scaled the uncertainties from the higher-temperature measurements using the same extrapolation. We also make clear that the comparison here is with the various Grenoble measurements at room temperature, and indicate that an additional scaling factor would need to be applied to these measurements to bring them down to $\sim 280\text{ K}$.

The next revision of the paper will include an updated uncertainty budget, with an additional term due to this extrapolation in temperature to 280 K.

P28, L 29-30: A strong affirmation is made here by considering that almost all the continuum observed in Reichert and Sussmann is due to the foreign contribution. The authors have to justify this.

We justify this based on Page 9 lines 2-4 of Reichert and Sussmann (2016), which states “the foreign continuum... is by far dominant for most spectral regions given the dry atmospheric conditions encountered in [their] data set.”. We have added extra sentences to the text to reflect this.

Specific comments

P3, L12: ...the adjustment of the water vapour...

This has been corrected.

P3, L13: in addition to additional empirical adjustments?

This has been reworded to avoid the repetition.

P3, L32: Only the reference for the foreign-continuum is given. Which self-continuum cross-section is used to obtain the estimated values given in the sentence?

The given reference (Ptashnik et al. (2012)) contains within it the estimates for the partitioning of the foreign and self-continuum based on Ptashnik et al. (2011a) and Ptashnik et al. (2012). The sentence has been updated to reflect this.

P6, Eq. (2): What means tother as there is already tother_gases in the equation?

This refers to other continua, such as the O2 and CO2 continua which are included in MT_CKD. The text now more explicitly refers to this.

P18, L13: ...self-continuum cross-section...

A "c" has been added to the beginning of cross-section to fix this.

P35, L17: The term AOD has to be defined.

The acronym "AOD" has been removed and replaced with τ_{aerosol} , to remain consistent with the rest of the manuscript.

P36, L7: Such an analysis...

The extraneous "a" has been removed from this sentence.

P36, L25: ... the water vapour self-continuum in the near-IR windows at sea level.

The hyphen has been removed.

In AMT paper supplementary:

P2: Just before equation (S12) it is written $y=mx+c$. This is misleading as in fact x equal to m in Equation (S12). Authors should replace m by b for example.

Thank you for pointing this out. We have changed the format of the linear equation from $y = mx + c$ to $y = ax + b$, to remove this confusion.

P3: Additionally, the agreement between the Langley and closure data (Figure 8)...

This has been changed.

Figure S3: Cosinus is missing in the legend of the y-axis. Moreover the angle θ is already used at the beginning of the paper to name the solar zenith angle. Another Greek letter should be used.

The cosine has been added and theta replaced with phi, to avoid this confusion.

Reviewer #2

A small adaption of the overall structure could improve the readability of the paper further. Section 3 with the results contains with subsection 3.2 a comparison with MT_CKD. Section 4 is then about the comparison with laboratory observations. Although section 3.2 is about optical depth and section 4 mostly about cross sections, it could be an advantage to lift both to the same level of sections.

We agree that the treatment of MT_CKD and the laboratory observations is inconsistent. We will therefore change Section 3.2 such that it is now its own Section (section 4).

Specific comments

P3, line 13: The authors state that “in many cases they use either version 2.5 or version 3.2” of MT_CKD. It would be helpful, if the authors could give a more specific reference or a short indicative list of some relevant cases.

We agree that including some examples with citations is beneficial here; we will include a list of various codes which use MT_CKD, mentioning the version number where made explicit in the references.

P4, line 22: How do the authors come to the conclusion that Zugspitze measurements were taken at airmass factors of ~ 6 ? Please explain this in more detail.

This number is taken from the fact that the lowest airmass factor at the surface for Zugspitze in Dec/Jan is ~ 3 , and the limit imposed by the authors indicating that only observations with airmass below 9 are used. The sentence will be changed to reflect this range of airmasses more precisely.

P5 concerning experimental setup: It remains unclear how the Microtops II sunphotometer was operated. Was this handheld device mounted on a stand/tripod? Was it mounted on a solar tracker? It would be helpful if the authors describe how it was ensured that the aerosol optical depth measurements were performed along the same atmospheric path.

The Microtops sunphotometer was operated by hand by an operator at the field site co-incident with the FTIR measurements – the lack of a dedicated solar tracker on this is potentially a source of uncertainty in the aerosol measurements. However, this is not something that we can quantify or cross-check, given the lack of measurements from another source other than the FTIR. We will include this caveat when discussing the Microtops measurements, and will add the need for better tracking of the solar disc as a suggestion in Section 5.

P9, fig. 3c: The data shown is marked as smoothed. How exactly was this smoothing mathematically performed? Is it the same smoothing about 15 cm^{-1} mentioned for the continuum on p6, line 14?

This is the same smoothing (at 15 cm^{-1}) as performed for the final analysis, which was performed using a moving average (boxcar) filter. The text will be updated to reflect this.

P10, fig. 4: In this figure the blue shading corresponds to $k=1$ and the cyan shading to $k=2$ uncertainty. There seems to be an envelope below and above the cyan shading that is colored again blue. If there is a physical meaning of it, could the authors please explain it?

These lines are there to demarcate the edges of the uncertainty limits. Given that they caused ambiguity as to their meaning, they will be removed.

P13, line 8: A suggestion for improvement is to mention the magnitude of the field-of-views of both the Microtops and the FTS.

We will now include the FOV of the Microtops and FTS within the manuscript, and point toward our discussion of the forward scattering/FOV issue on Page 13.

P16, fig. 8: Is there any reason why the Langley and closure method derived optical depths in the upper part of the figure do not cover the same region of the residual in the lower part of the figure? If possible, they should be the same

We have now updated the figure to show the residual on the same scale as the top panel.

.P19, line 4: The section title with laboratory observations fits to the lab measurements, but does not quite fit to the comparison with Reichert and Sussmann (2016) that are also included in the comparison. Their observations were field observations as the CAVIAR field data in this paper.

Section 4 (now Section 5, see top-level response to Reviewer #2 above) has been renamed to "Comparison with other observations", and the text in the first paragraph changed to reflect that we are also comparing to these field observations.

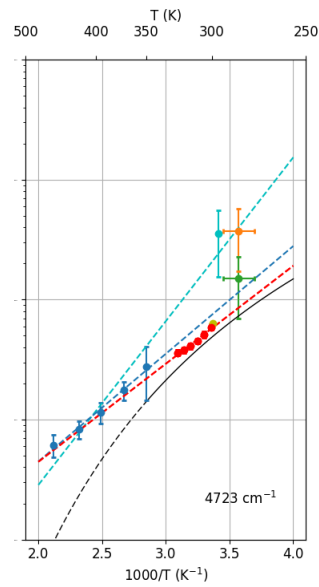
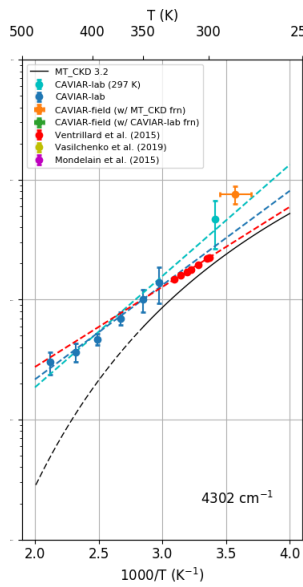
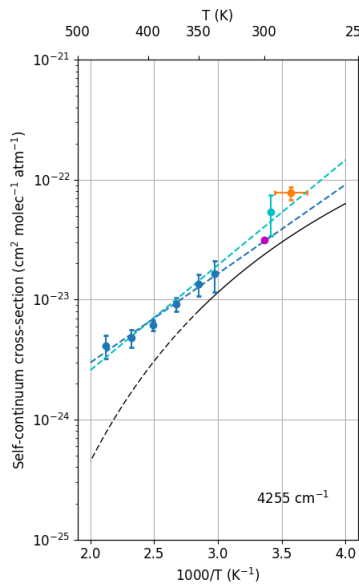
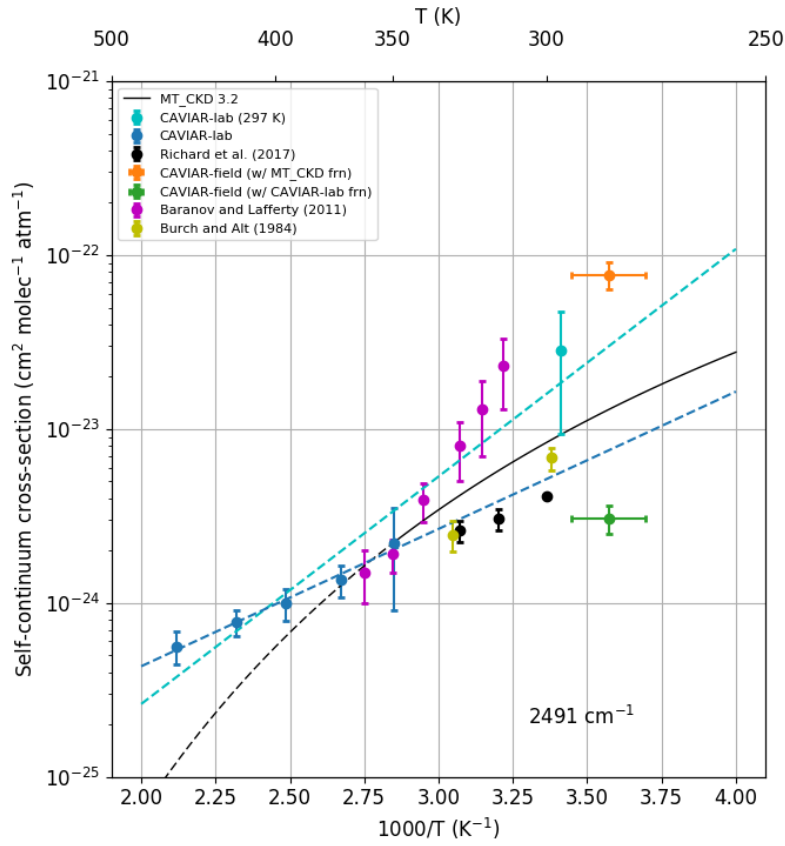
P19, line 8: The derived continuum optical depth $\tau_{\text{total}}^{\text{CAV}}$ has another naming in the following formulas, e.g. formulas (3) and (5). Additionally, the quantity $\tau_{\text{for}}^{\text{lab}}$ mentioned on P20, fig. 11 was not introduced

$\tau_{\text{total}}^{\text{CAV}}$ will be renamed to more accurately fit what is in the Figures and the Equations. Equation (4) will be updated to fix a typo, where the left-hand-side of the equation is equal to $\tau_{\text{for}}^{\text{CAV}}$ rather than the correct $\tau_{\text{for}}^{\text{lab}}$.

.P24, line 10: The authors refer to lower temperature data (cyan point and dashed line), but in figure 13 there is no cyan point and no cyan dashed line. Seemingly, this passage is from an earlier version of this paper. CAVIAR-lab (297K) should be removed from the legend in figure 13.

The version of Figures 13 and 14 used in the uploaded drafts of the paper do not include this data point and the corresponding extrapolation – this was in error. The correct versions of these

Figures are shown below – they are the figures uploaded for the original draft, but including the 297 K data in the legend. These will be included for the final version.



P26, fig. 14: CAVIAR-lab (297) is not anymore included in the figure, so it should be removed from the legend. The same applies to the caption.

See previous comment.

P29, fig. 16: At the beginning of the second line of the caption self-continuum is assumed to be the foreign-continuum.

The caption will be fixed to reflect that the CAVIAR-field self-continuum is estimated using the CAVIAR-lab foreign-continuum.

P33, fig. 17: In the caption it would be more precise, to mention that the showed data corresponds only to atmospheric windows in the mentioned region. The authors could insert “in atmospheric windows” between continuum and across.

We will now make explicit that the CAVIAR-field data corresponds to the window regions only, and use “CAVIAR-field” rather than “Langley-estimated” for consistency.

P33, fig. 17: Concerning the showed Reichert and Sussmann (2016) data, ignored is the fact that they used MT_CKD_2.5.2 model for their continuum retrieval. As the self-continuum was assumed to be consistent with the MT_CKD model a direct comparison like in this figure is challenging.

We believe that this comparison is reasonable, given we have used MT_CKD_3.2 in panel a) of this Figure to obtain the foreign continuum, and that since the foreign continuum contribution is dominant in the Reichert and Sussmann (2016) case, we believe that it is not likely to have an impactful effect on the comparison. We will add an additional sentence to the Figure caption and to the text to make clear that this is the case.

P38, line 27: Constraining the spectral coverage from 2000-7000 cm⁻¹ to 2100-6600cm⁻¹ would be more precisely .

The text will be updated to match the title and more precisely reflect the wavenumber range.

Supplement: The airmass factor definition $m = \cos \theta$ contradicts the airmass factor definition given in the paper. The Beer-Bouguer-Lambert law given here is only valid with $m = 1/\cos \theta$.

This was a typo and will be corrected.

Technical corrections

P3, line 7: remove “at” after temperature

This will be corrected to “as”.

P10, line 5: word repetition (distance 2) of approximation/approximately

This sentence will be reworded to “...which in the limit of small absorption is approximately the optical depth noise in that region”.

P12, line 9: insert vapor (or vapour) between water and continuum

This will be added.

P27, line 3: Period/full stop is missing right after “term”.

This full stop will be added.

P37, line 27, word repetition (distance 1) of aircraft

We will now reword this to remove the repetition, and also define FAAM.

P40, line 16: remove “10”, which seems to be a line number of an earlier version of this paper

This will be removed.

Supplement, P2: remove “the” in front of “account” in the third-to-last paragraph

This will be removed.

There is an inconsistency in the writing of the MT_CKD versions. Mostly the current version is named MT_CKD3.2, but sometimes the naming is with a space in front of the version number. For the future reader a coherent way of writing would be an advantage, e.g. in browsing the paper. The model’s developers are using with MT_CKD_3.2 a third way of spelling

We shall ensure that all references to MT_CKD now use the MT_CKD_ syntax, to be consistent with other literature.