## ***Final author response to reviewer comments***

We thank all reviewers for carefully reading our manuscript and for the detailed feedback aimed at helping us to improve the manuscript further. Below we address the concerns raised point by point and group some points since they are related to the same questions.
Gratefully and with best regards.

***1.***

***What is the role of the laser line width itself? Can it be neglected?***

The line width of the DFB diode laser is in the range of 1 MHz ($10^{-5}$ - $10^{-6}$ $cm^{-1}$) and therefore negligible for typical atmospherically broadened absorption lines (width 0.1 - 0.01 $cm^{-1}$).

***Frequency noise, in particular associated with back reflections into the laser, can cause significant line broadening. that might affect the shape of the absorption line***

The diode laser is a single mode fiber coupled DFB diode laser with an optical isolator. Further the numerical aperture of the single-mode fiber and the very small effective area of the fiber end face further suppress possible reflected light very effectively. Feedback into the laser therefore has not been seen under any conditions.

***2.***

***As the author state, the purpose of the HAI instrument is to measure water vapor in its various phases (gas, liquid, solid).How do cloud particles affect the determination of pressure from the line shape?***

Cloud particles can scatter and absorb the laser light. But in contrast to the narrow absorption line of the water vapor (0.1 - 0.01 $cm^{1}$) all condensed water phases show only very broad spectral features which do not create structured absorption which could interfere with the water vapor. Broadband losses thus are corrected very effectively via the baseline determination process. The active acquisition time slice of our TDLAS scan is only 1.35 ms. Thus slowly variable absorption by could particles is kind of “frozen” over the timespan of a laser scan and therefore relatively easy to correct for. In addition we record and save all TDLAS spectra as raw detector scans, which are then later evaluated with the most up-to-date and most appropriate spectral fitting model. During this process we also check (and correct) every single scan for excessive disturbances by broadband absorption.

***3.***

***Upwind antenna, other inlet systems and the outside White cell itself modify the air-flow and cause turbulence. How does this affect the measurements?***

This is correct. The basic idea is to use the data of HAI’s pressure measurements to explore and validate the accuracy of the CFD-model, which is currently under development at the research center of Jülich. The CFD models allow vice versa then a quite comprehensive view on the flow field around the aircraft. Important to keep in mind is, that the HAI instrument is located directly in the first row of inlet-systems on the HALO aircraft, so that no other inlet or antenna is upstream of HAI. This avoids unwanted turbulences so that the basic flow is quite laminar.

***4.***
***During SPURT HALO was deployed in the UT/LS region on both sides of the tropopause. Unfortunately the analysis presented here is restricted to rather high water vapor concentrations (larger than approx. 150 ppmv) yielding large signal to noise ratios. It would be interesting to show also results based on low H2O concentrations (less than 50 ppmv), that are more typical for the tropopause region. I also assume that the stated total uncertainty 5.1 % is only valid for a rather large SNR. What is the uncertainty closer to the detection limit?***

The HALO campaigns in which HAI was installed were TACTS, ESMval and ML-CIRRUS. The TACTS campaign was mainly in the stratosphere with several dives to low levels, the ESMVal more in the upper troposphere. The HAI open-path cell is designed for the water vapor measurements in the entire range of the atmosphere, but not primarily, as we wrote in the paper for pressure measurement. We agree that for pressure measurements higher signal to noise ratios are necessary. It's not an easy task to give an equation between uncertainty and $H_2O$ concentration, since many factors have to be taken into account. To clarify that a bit, we showed in the paper both, calculations for "laboratory" and "flight" conditions. If we discuss for example just the lowest concentration (4 ppmv) we found during the TACTS campaign a few situations, where uncertainties of 10% can be physically based augmented, but there are other situations (e.g. high background light from sun radiation) where no pressure evaluation can be performed. So to sum up: The lower the water vapor concentration the more effort is needed to assess every single scan for the possibility of an accurate pressure evaluation. But on the other hand it is of course possible to develop a dedicated TDLAS pressure spectrometer on many other molecules. For a dedicated pressure TDLAS it could be better to use sensing molecules which are more evenly distributed in the atmosphere like $CO_2$, $O_2$, or $CH_4$.

***5.***
***Minor remark: Considering Fig. 9 and 10, does the correlation in Figure 10 represent the data in Figure 9? If yes, how well is the performance over the whole TACTS campaign, given the fact, that the spectroscopic pressure seems to be always higher than the MMP as stated on page 4795?***

Yes that's right. We did similar evaluation on other flight situations where we see similar results. Since HAI is a completely new instrument, our focus is in the future to combine CFD simulations and TDLAS evaluation to improve the overall performance and uncertainty of the whole HAI instrument, and to simplify a respective automated evaluation of the pressure measurements. Finally when e.g. the CFD-corrected temperatures are used during the evaluation, we can get a more accurate view on the pressure deviations in many flight conditions and can separate them hopefully to different influences. It is very challenging to derive highly accurate pressure data to discuss several hPa pressure deviations in a pressure filed with a basic pressure of several 100 hPa, since this is in the foreign broadening just 1% (!) relative contribution.

*6.*

***Section 2.1 to 2.2, esp p. 4780, line 13-16 / Figure 1: A more detailed description of HALO would be helpful since no reference exists for this instrument. Sections 2.1 and 2.2 have been published in detail by the authors (and others) whereas HALO has yet to be described in any detail. Figure 1 is generic to any laser-based measurement and serves little purpose.***

In order to offer the complete basics of the DTLAS sensor we would like to have this in the manuscript.

***I recommend including a more detailed schematic of HALO itself – a short summary of its design/components (e.g. how large is the pylon, what is the pathlength, how long of a fiber is needed, how far the pressure sensor is mounted above fuselage and below the optical cell; what are typical detector signal voltages in-flight).***

A new schematic has been added instead of the photo to improve this.

***The photo of Fig. 6 was helpful but is really tiny – more general information is needed.***

The photo was replaced by the schematics.

***For example, I had a hard time understanding about the "rectangular" pressure sensor (MMP) and why it would have lower pressure. I certainly understand how the airflow rapidly goes around the pylon and thereby decreases the pressure, but then a square interface in that flow should cause RAM pressure and increase it. I clearly don't understand the geometric design, and these matters are important in interpreting the data – or at least need clarity to those unfamiliar with the HAI pylon/instrument.***

A new schematic has been added instead of the photo to improve the description of the necessary pressure components.

***I understand a full instrument paper for HAI is forthcoming, but given that it isn't available to the community, some general information is needed for this manuscript to stand alone.***

This paper is meant to describe a general concept and the possible performance of an open path, optical pressure sensor. Hence, the focus is not the HAI-Instrument itself. The optical pressure measurement is an additional benefit of HAI, but was not an original design target. HAI is a also much too complicated to explain the treatment of the water vapor evaluations here in detail. If we would try this would (in our view) lead the focus too far away from the main topic of this paper. So we ask for the reviewers understanding that a full description of HAI is far beyond the scope of the paper. Nevertheless we add a few more details to better explain the location of the sensors used in this paper. We also will remove the photo and replace it with two schematics which will better describe the location of the different pressure sensors and their components relative to the air flow and the optical path.

*7.*

***End of section 2.5: Can the authors quantify how clouds/optical disturbances would increase the width and hence pressure uncertainty? What are typical detector signals in-flight, and how often do they get to a value in which the pressure retrieval would be affected (e.g. if a typical voltage is 5 volts, then how does the SNR change at 1 volt, 0.5 volts, and 0.1 volts – perhaps only quote the lowest 10% of signal strengths or some other relevant matter – but the authors probably have some idea on this).***

The first question about disturbances is quite similar to the one (2) above. The typical peak to peak detector currents are in the range (peak-to-peak) 0.1 mA, but that is not the limitation. Our fit approach takes into account the water vapor absorption line and the synchronous broadband background radiation as well as the spectral broadband losses for every single TDLAS scan, the transmission losses and the background radiation can be corrected quite efficient. The limitation results from a lower absorbance due to lower water vapor concentration in the gas flow through the sample in combination with for example interference structures (fringes) or to strong background radiation e.g. by direct sun light on the detector. This one of the main advantages of the way we evaluate the data. We save every single spectrum and can decide afterwards which level of uncertainty for the evaluation of a single pressure (or concentration) value is achievable. So for example for $H_2O$-concentration levels above 50 ppmv nearly all spectra can be used for pressure determination.

***8.***

***p. 4793, line 9: Because select people cite a number out of context, I would emphasize here again that the detection sensitivity is only for the 1.4 micron channel and the 2.6 micron channel has higher sensitivity for water vapor. This is especially true since there is no HAI paper yet, and people may be desperate to quote a published number (even if that is not the point of this paper).***

As this paper is focused on the evaluation of the line width and not the line area we prefer not to extensively discuss the concentration resolution of the HAI spectrometer, however we will include in the paper the following sentence:

*„The presented line width evaluations are exclusively targeted on the determination of the pressure and not the gas concentration. Due to the large dynamic range of the water concentration the resolution would also strongly depend on flight height and thus is not easy to state in a single performance parameter. However, preliminary results of a concentration evaluation of the 1.4µm open-path HAI signals yielded at flight heights with 300 ppmv water vapor to a precision of 1.3 ppmv (1σ) at 0.2 seconds response time. These early evaluations also indicate for the 2.6µm path a preliminary precision of 0.2 ppmv (1σ) under equal conditions. "*

***9.***

***p. 2795, line 7-9: solar radiation isn't quantified at all – can the authors bracket a typical solar signal or variance in the background radiance from their existing flight data (e.g. a circle over a clear sky ocean)? Does it typically change the detector signal by 1%, 0.1% or ???***

As written above the background emission (e.g. sun) is corrected for every single scan (i.e. 240 times per second). The solar radiation depends on the angle between aircraft (cell, mirror, detector) and sun. So in some flight tracks the background light amounts to a few to 10% of the total, in other more extreme cases the sun light is 4x stronger than the total laser radiation detected. Generally due to the way how we correct each individual spectral scan this is the vast majority of all cases not a problem and does not affect the evaluation on the level of accuracy we are currently stating. The limitation is the signal to noise ratio (max absorbance to residual structure) and as a typical number (depending on the structure of the residual) for high $H_2O$-concentrations that can be SN of several 1000 and, for low $H_2O$-concentrations, down to single digit SN levels. At very low SN levels it has to be decided case by case if the structures allows a pressure determination or not. But as we wrote in the paper HAI is originally not designed for pressure measurement. The pressure measurement is just an added, very useful feature. For a dedicated pressure sensing TDLAS we would probably pick another molecule like $CO_2$, $O_2$, or $CH_4$ which does not show the large dynamic range of water vapor, which leads sometimes to difficulties to determine overall uncertainty of the pressure measurements.

***10.***

***Fig. 3 caption: Use "Example" or "Select" instead of "exemplary". Fig. 7 caption and elsewhere: "It has to be kept in mind that the gas flow is passing through the open-path cell at approximately 900 km/hr". This has been mentioned numerous (six) times in the text and doesn't need to be repeated continually (once at the start, or to really emphasize a key point later, perhaps). High speed aircraft work is hard, no one will argue this – but the continual references distract from the work. Fig. 8: The atmospheric science community of AMT will not be surprised that H2O measurements for the troposphere need to be on a log-scale – so an exclamation point isn't necessary.***

Good points, we will revise the text.

***11.***

***Can the authors in the conclusions make any extrapolations to expected performance (improvement) of the pressure measurement at high altitudes (P<200) due to the higher SNR of the 2.6 micron line? Is there hope for measurements in the 130-200 hPa range with accuracies of <3% (note a 9 hPa offset at 130 hPa is getting large). Overall, the paper will provide a benchmark for optical pressure sensing on airborne aircraft and also provides means for future improvements (using a gas with steady concentrations like CH4, N2O, or CO2 – though probably not possible on HALO due to other constraints). I enjoyed reading this immensely and found it innovative.***

That's an interesting, but not easy to answer question. Currently, the 2.6 µm HAI overall performance is not (yet) significantly better than the 1.4 µm. This is caused by the fact that the 2.6µm components are so much less developed than the 1.4µm ones. All components like fibers, fiber coupling, fiber connectors, laser, and detectors are a bit to a lot worse than the 1.4 µm standard telecom technology. It is thus an open question how fast 2-3µm developments by our group , any other research groups or industry will allow to take advantage of the stronger line strength of the fundamental bands. In principle, the 2.6 µm line could allow pressure measurements in the lower pressure range, if some parts will be replaced by better commercial or new developed optical components.

However, if high resolution pressure measurements are necessary for the CFD-validations in the lower pressure range (= lower atmospheric $H_2O$-concentration range, see answered questions above) e.g., a dedicated pressure sensing spectrometer should e.g. use fibre-coupled 2 µm lasers to determine the pressure at the quite steady target molecule $CO_2$. This would allow to get rid of all the self-broadening and especially variable signal-to-noise issues. We would expect that use of a steady target molecule should lead to an overall uncertainty below 2% in the full pressure range of the atmosphere. This however would also ask for improved, high-accuracy spectral data including temperature dependence.

Another (but more costly to integrate) alternative would be to go even further in the infrared where compact MIR (QCL or ICL) laser spectrometers e.g. for $CO_2$ with a simple and short single open path of 10 -20 cm could yield a much higher absorption and thus a significantly better S/N. If the demand for high speed optical pressure measurement is that high, than that would definitively be one way to go.

We included some of the above remarks on a dedicated pressure TDLAS sensor in the improved manuscript.