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Atmospheric Measurement Techniques Discussions

Interactive comment on "Dual channel photoacoustic hygrometer for airborne measurements: background, calibration, laboratory and in-flight inter-comparison tests" *by* D. Tátrai et al.

Anonymous Referee #1

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The manuscript submitted by David Tátrai et al. is an instrument paper detailing the measurement of water vapor from research aircraft by the use of a tunable diode laser in a photoacoustic configuration. The manuscript is clearly structured and systematically describes the experimental configuration, calibration procedures and intercomparison with other instruments. The performance of the instrument and the photoacoustic technique described here is largely evaluated through laboratory and airborne intercomparisons. Good agreement is seen during blind intercomparisons between facility instruments and the photoacoustic instrument at the Environmental Simulation Facility

(ESF) chamber.

One of the strengths of this paper is the presentation of aircraft intercomparison data with the Fast In-Situ Stratospheric Hygrometer (FISH) instrument. The FISH instrument has a well-known heritage, has seen widespread use in the field and has been involved in international intercomparisons with other established hygrometers. It is unfortunate, as the authors point out, that due a variety of logistical and external factors that a direct and comprehensive intercomparison data set with FISH was unable to be collected during the aircraft campaign. Systematic differences in the sampling inlets are suggested to account for the deviation from ideal behavior in the one-to-one evaluation (cross plot) with FISH. Additionally, an intercomparison with the WS-CRDS at mixing ratios below 50 ppmv was unable to be performed. While general agreement is seen between the instruments at higher mixing ratios, the challenge and uncertainty associated with making aircraft measurements of water vapor at low mixing ratios is not ameliorated.

The manuscript and the photoacoustic instrument presented here clearly falls within the scope of this journal. The methods used are appropriate and the results are of interest. I recommend the paper for publication in AMT. I do have a few major comments, technical comments and minor corrections that I would like to see addressed before final publication.

1 Major Comments

The issue of accurate measurements of water vapor is important to the community and in this regard this manuscript is considered scientifically relevant. Given the critical importance of water vapor to the climate system, cloud formation, and stratospheric chemistry, coupled with the unique challenges of accurately measuring water vapor, particularly at the low concentrations reflective of the upper troposphere/lower strato-

sphere, the inclusion of a discussion describing the motivation for an instrument with such specifications as presented here would be welcomed.

While the paper is clearly structured, sections (Sects. 2.2.4 & 3.1) that deal with the determination of the VMR could use additional clarification. Specific comments related to this issue can be found in the technical comments below. The calibration method itself is clear, however, in general, the extraction of the VMR from the multi-dimensional calibration surface would benefit from additional description and clarification.

2 Technical Comments

- **Section 2.1:** PA cell acoustic resonance frequency is sensitive to temperature, therefore the cell is temperature stabilized to 318.0 ± 0.1 K. What is the sensitivity of PA signal, at constant water vapor mixing ratios, to changes in temperature? Specifically, can the uncertainty in measurement derived from the measurement uncertainty of the temperature of the PA cell be evaluated and discussed?

  Can the authors describe (and/or include a figure) the specific timing characteristics of the laser waveform. The wavelength of the online peak position is stated as being at 1392.535 nm, what is the offline wavelength? What waveform is used to dither between online and offline positions? At what frequency is the online/offline dithering performed?

  Given that a single absorption line is used and the PA instrument can span 5 orders of magnitude, are there are any issues (e.g., non-linearities) encountered due to saturation of the absorption line at high WV VMR?

  Can the authors comment as to why the PA cells are not maintained at a constant (reduced) pressure. While burdening the experimental setup and gas handling systems with additional complexity, this would ease calibration and VMR calculation requirements.

- **Section 2.2.2:** What determines the switching point of the SM switching algorithm? Specifically, when does SM switching occur? What type of hysteresis control is applied to prevent rapid switching when rapidly changing WV VMRs are encountered?

- **Section 2.3:** What is the equilibration time when using the calibration system. Specifically, what is the equilibration time for the calibration system in response to pressure changes at constant saturator temperatures. Presumably the temperature of the saturator cannot be held constant using the warm-up method described here, yet I'd expect that the equilibration time for pressure changes would be much faster than changes in the temperature of the saturator and effectively rendering it constant. Additionally, how is the calibration system evaluated as being equilibrated? Please comment.

- **Section 2.5:** The temporal resolution of the instrument to sudden changes in relative humidity is stated as being 2 seconds in duration. This includes effects from both the PA cell and the inlet system. Is this the same inlet system as used during airborne measurements? If not, what is the response time of the instrument in an aircraft configuration?

  What are the instrumental specifications (e.g. precision & accuracy) of the WS-CRDS system? Please include this information in the paper.

- **Section 3.1:** In general, the relationship between calibration at constant pressure and the multi-dimensional calibration surface used to derive VMR (i.e., Figs. 3 & 4) can be expanded upon.

  What is the PA signal offset between the two cells?

- **Figure 4:** It is not clear that a unique solution to VMR can be derived from the calibration surface at pressures approximately less than 150 hPa.

It's also unclear in Fig. 4 as whether both SM or only one are represented by this figure. Can the SM be explicitly stated in the figure?

- **Figure 5:** Above 1500 ppmv a systematic offset between the ESF and WaSul-Hygro is seen. Can this be explained? It appears that this occurs near the switching of SM in both subplots (~1500 ppmv).

- **Figure 7:** Does the corresponding cross plot (Fig. 5B) draw from the same dataset as the flight time comparison (Fig. 5A)? It's unclear as to why WS-CRDS values below 20 ppmv are seen in the correlation plot but in the time series plot minimum WS-CRDS values are ~50 ppmv.

- **p.6362, l.17:** `The amplitude of the acoustic signal at the frequency of the modulation of the light source usually determined by using lock-in signal processing technique is proportional to the concentration of the light absorbing molecules (McDonald and Wetsel, 1978).`

  This sentence is difficult to follow, it contains a lot of information and is a key point towards how concentration can be derived from this technique. Consider rewriting for clarification.

- **p.6364, l.10, 20:** The upper limit of WVMR is set by the combination of the temperature of the gas handling system and the PA cell. This should be clearly stated in the text. Condensation on the walls of the gas handling system would manifest as a pronounced increase in uncertainty in measured water vapor mixing ratio. Given that the gas handling system has coarser control than the PA cell, it effectively limits the upper limit of the VMR that can be achieved.

- **p.6365, l.16:** `As most of the setup (controlling electronics, laser) are common for the two cells small differences between the VMR values in the sampling lines are expected`

`to be measurable more accurately with the presented system rather than using separate systems for each sampling line.`

Expand on this statement (e.g., systematic errors and instrumental offsets are minimized with such a configuration).

- **p.6367, l.16:** The PA cells are held to $\pm$1 hPa accuracy. What is the calibration uncertainty that can be attributed to this?

- **p.6367, l.19:** `Thanks to an overpressure reduction tube, which is long enough to avoid back diffusion of water vapor from ambient air and installed to eliminate the non-synchronizability of the MFC-s just before the saturator ...`

  What is meant by the *non-synchronizability of the MFC-s*?

- **p.6370, l.2:** `The inlets of the PA cells were again joined together ...`

  Consider rephrasing this statement for clarity (e.g. During the campaign the PA cells were configured to simultaneously sample water vapor from a single backward facing aircraft inlet.).

- **p.6370, l.7:** Explicitly write type of Rosemount housing (e.g. Rosemount True Air Temperature (TAT) housing . . .).

- **p.6370, l.8:** `For the Wasul-Hygro the flow was provided by a pump ...`

  Describe location of pump (e.g. downstream of PA cell).

  Can the authors provide a make and model number of the pump or state the vacuum pump's throughput or pumping speed?

- **Section 2.5:** `From the FISH dataset all measured values above 350 ppmV had to be neglected.` Can an explanation be provided for why FISH data where WVMR > 350 ppmV had to be discarded?

  How was the presence of clouds determined?

  Can the authors state the amount of suitable data (e.g., 5 hours) and under what general conditions (e.g., upper trop., lower strat., continental mid-latitude, near convection) the intercomparison data was collected?

- **p.6371, l.13:** `The dependences are very similar for the two cells. It can be clearly seen that the use of the simplifying assumption of VMR independent sensitivities (as done previously, Szakáll et al., 2006) would lead to highly inaccurate VMR determination.`

  These statements seem to contradict one another.

3 Minor Corrections

- **p.6363, l.24:** `which is placed into a 19" 3U ...`

  Explicitly write units (i.e. 19 inch)

- **p.6366, l.6:** `The change in the SM makes it possible to extend the upper limit of the measure range to 30 000 ppmV.`

  Fix typo: measure → measurement.

- **p.6366, l.11:** `This extends the measurement range with at least an order of magnitude but above about 85000ppmV water vapor starts condensating in the PA cell or in the sampling line.`

  Fix typo: condensating → condensing.

- **p.6366, l.17:** `The lower the pressure is, the narrower the water vapor absorption lines are, and consequently the wavelength stability of the laser becomes a more and more critical issue.`

  Consider a less idiomatic statement (e.g. the wavelength stability of the laser becomes an increasingly critical issue.).

- **p.6382, fig.5(A):** Fix typo on top figure label – `Sensitivity Mode swittching point`: swittching → switching.

  Fix typo in abscissa label – `time (fracture of day)`: fracture → fraction.

- **p.6367, l.14:** `and a reduced pressure stabilizer was assembled around WaSul-Hygro.`

  Fix typo: was assembled around *the* WaSul-Hygro.

- **p.6367, l.18:** `milled into a 12 cm x 12 cm x 6 cm cooper block ...`

  Fix typo: cooper → copper.

- **p.6367, l.24:** `during one and a half day) warms up ...`

  Fix typo: day → days.

- **p.6369, l.16:** `During the campaign before and after each flight FISH was ...`

  Add commas to offset clause: During the campaign, before and after each flight, FISH ...

- **p.6369, l.27:** `During the campaign it was compared against the calibration stand used to calibrate FISH ...`

  Fix typo: stand → standard.

- **p.6370, l.4:** `[SS] tube having outer diameter of 1/8" and ...`

  Fix typo: tube having *an* outer ...

  Explicitly state units: 1/8 inch.

- **p.6372, l.5:** `respectively with horizontal line indicated ±5 % limits.`

  Fix typo: indicated → indicating.

- **p.6373, l.10:** `Besides the performance parameters discussed above in details it is important to note ...`

  Fix typo: details → detail.

- **p.6373, l.14:** `That is why a new controlling electronics is just being developed which besides the significant size reduction will be capable for real-time ...`

  Consider changing sentence to read: That is why new controlling electronics are being developed which, besides the significant size reduction, will be capable of real-time VMR calculations ...

Interactive comment on Atmos. Meas. Tech. Discuss., 7, 6359, 2014.