Review of “Accurate humidity probe for persistent aviation-contrail conditions” by Christoph Dyroff et al., MS No.: egusphere-2025-3972

Summary:

This manuscript reports on a humidity sensor for the application of persistent aviation contrail conditions (i.e., humidity levels so high that contrails of condensed ice will remain persistent and not evaporate). It presents a novel optical design featuring optical fibers and a short-path absorption path. Two nearly identical prototypes are compared to each other (the only difference being electronics). The two prototypes show good agreement with each other over a large range of water volume mixing ratios.

Overall:

Overall, this manuscript is well-written and appropriate for the scope of AMT, presenting a new sensor prototype to measure humidity from aircraft. The title, abstract, presentation, use of language, and references are all good. The novelty of this sensor is both low-noise performance and optical design (optical fibers and a short-path absorption path). One issue is that the manuscript is lacking a connection between the scientific motivation of accurate humidity measurements at aircraft cruising altitudes and performance requirements for parameters including but not limited to: the desired range of water volume mixing ratio, pressures, temperatures, time resolution, accuracy and precision.

Another issue is that the description is not complete enough for subject matter experts to assess this new sensor. The manuscript is missing important details in the description of the instrument design and operation (the flow system), electronics, spectroscopic fitting, data processing, experimental validation, and how the results relate to the performance requirements. If the authors provided more details, then this would be an important contribution to the scientific literature. I recommend that this manuscript should be considered for publication only after substantial revisions to provide more details as addressed in the science comments below.

General comments:

1. First, early in the paper, the connection is not described between persistent contrails and the detailed range of water mixing ratios, pressures, temperatures expected. All that is said is that the “relevant H2O range below 200 ppm” is appropriate (page 15, line 274 and

repeated elsewhere). This is missing detail such as: what is the lower limit of H_2O mixing ratio expected in contrail-producing regions? What accuracy of measurement is required for this application of predicting persistent contrails? What is the spatial scale in the atmosphere of high humidity / low humidity regions that would drive a requirement of how fast measurements need to be? For instance, are 1-Hz measurements sufficient?

2. What are the performance requirements for sufficiently accurate water measurements at aircraft cruising altitudes? Specifically, what is the requirement measurement dynamic range of water volume mixing ratio, pressures, temperatures? What are the required time response, accuracy and precision?

3. Given that there are existing commercial instruments (WVSS-II and IAGSO ICH) and scientific-grade TILDAS hygrometers, what is the motivation for developing a new humidity probe? How is this probe novel? This not made very clear, but it is implied in the abstract that the novelty is single-mode optical fiber (and two channels). Could the authors please state why is the novelty important (compared to existing state-of-the-art sensors) for this application of measuring humidity in persistent contrail-forming conditions?

4. For the readers, it is important to know hardware details, including material of the optical cell, and what electronics were used.

4a. In the lab measurements presented in this manuscript, what pressures and temperatures were used? Were these measured? Pressure and temperature are essential inputs into fitting spectra (as the water mixing ratio is dependent on them).

4b. If these prototypes were deployed in an aircraft, how would design change? H would the air be sampled on an aircraft? How would the sensor be packaged? What would be the pressure and temperature in the sample cell? How do gas control, temperature and pressure control affect the measurements?

Specific Comments:

5. Spectroscopy: page 3, line 57-58: "an isolated absorption line of H_2O". It is important to the readers to know specifically which H_2O line? What is the wavelength of the isolated line? Can you show a synthetic spectrum of the expected absorbance versus wavenumber (or wavelength) (for the sensor pathlength)? Can you give some rationale for why this particular water absorption line was selected?

6. Detail is lacking on optical cell, such as the pathlength, how the detector is mounted. Specifically on page 3, line 65, "The beam is aligned through a pinhole target onto a detector at 300 mm." Is this (300 mm) the optical pathlength?

7. In the Spectroscopy section, pages 4 and 5, can you provide more spectroscopic details, such as:

7a. In lines 88-89: please clarify how the baseline spectrum is used to normalize the sample spectrum. E.g., does this provide the incident/background intensity for the absorption calculation? Is it possible that trapped water in the laser diode or baseline detector could cause the low bias in the accuracy measurements (section 3.2)?

7b. In lines 106-107: what is the motivation for the two different electronics in prototypes 1 and 2? Are there pros and cons of the different implementations?

7c. In line 111, "2666 Hz (334 Hz)": why were these scan rates selected for prototypes 1 and 2?

7d. How many scans are averaged? Are scans fitted in the electronics or in software?

7e. What is the sampling rate?

7f. In line 114: how is 50 seconds of spectral averaging (followed by 10 s of averaging baseline) relevant to airborne measurements? Can the prototypes deliver 1-Hz data at the required accuracy and precision? (see comment #1 above)

7g. In line 103 "Upon pre-averaging of the spectra, they were fit in TDLWintel" and line 118 "we recorded spectra on the device and then fit them offline using the same fitting engine" – can you please say more about how the spectra are fitted? How many spectra are "pre-averaged"?

8. Page 5, lines 121-122: "glass rod" – please call this an etalon.

9. Page 6, lines 130-134: discussion is completely lacking on how the spectroscopic absorption line is fitted. Can you please say more? Are you using the Beer-Lambert Law? How is pressure broadening treated?

10. Page 6, line 133-134: "the noise is low enough to not significantly affect the overall measurement uncertainty" – this raises several questions:

10a. What is the uncertainty of the spectral line strength (and other properties) for the water absorption line selected?

10b. If noise does not significantly affect the overall measurement uncertainty, what is the dominant factor contributing to overall measurement uncertainty?

10c. Please provide more detail about how the electronics achieve exceptionally low noise? Please quantity the noise on the spectra.

11. Page 7, Figure 5 caption: what are the details of this data? Which data went into making this plot? Can you please define the acronym ADEV (please say "Allan Variance").

12. Figures 7, 8,10, 13: this manuscript jumps back and forth between ppm and "ppbv times 10^3". For better clarity, please consistently plot in the same units, ppmv.

13. Section 3.5 – how would the additional attenuation affect the accuracy and precision of the low-ppm measurement regime? It would also be valuable for the reader to have quantitative information on incident power limits for linear performance.

14. Figure 3: Consider adding etalon peaks to subplot to show how the peak locations translate to wavenumber curve

15. Figure 7 and Figure 9 show the quick response time of the instrument in lab setting with the test configurations. Could you comment on the cadence / delay times expected when integrated with an aircraft and the associated sampling system?

16. Will the sensors still be non-temperature controlled when integrated on aircraft? How will the range of temperatures and rapid fluctuations in temperature affect the instrument hardware and spectroscopic fitting?

17. Section 3.5: Please elaborate on how the non-linearities affect the accuracy and the detection limits mentioned.

18. Page 15, Line 278-280: Please provide details of all items listed: "spectroscopic fit, including the laserdependent tuning rate, the baseline characteristics as well as position and width of the fit." How do these contribute to the accuracy?

Editing Comments:

1. Please check grammar. Several commas are missing where needed.

2. Consistently use ppmv (not ppm or ppbv) and define ppmv the first time as "parts per million by volume".

3. Page 10, line 201: replace "is" with "in".

4. References: please cite references in consistent EGU format.