Answers to Referee 2: Comparison of the fast Lyman-Alpha and LICOR hygrometers for measuring airborne turbulent fluctuations

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GENERAL COMMENTS: This is a review of manuscript amt-2017-353, "Comparison of the fast Lyman-Alpha and LICOR hygrometers for measuring airborne turbulent fluctuations". The LICOR sensors in different forms are used at automated field stations for research networks covering large temporal and spatial scales, and are well characterized. The purpose of this manuscript is to evaluate LICOR humidity sensors in a new environment, on aircraft, compared with standard Lyman-alpha hygrometers. The results show that the LICOR sensors are well suited for airborne measurements of humidity fluctuations, provided that a vibrationless environment is given, and this turns out to be more important than close sensor spacing. This is a detailed technical assessment of LICOR sensors that should be posted online for discussion in AMTD after some major revisions are made. LICOR sensors are widely used on aircraft, so validation of their performance is needed. The manuscript is an important contribution because it analyzes the environments in which the LICOR sensors perform well compared to the "gold standard" of Lyman-alpha hygrometers. appreciate the hard work of the authors to collect the field data and carefully analyze the results.

We would like to thank the referee for acknowledging the importance of the work presented in the manuscript.

What remains for the authors to do is to rewrite the manuscript with better explanation of their reasoning and conclusions.

We included more explanations in the manuscript, which take into account the comments of the referees.

The manuscript could also benefit from better English editing.

The English style has been improved by taking into account the very detailed comments of Referee 1. Several sentences have been re-written, and the grammatical and spelling mistakes have been corrected.

SPECIFIC COMMENTS: 1 I have a concern that the authors and other research groups are using LICOR sensors in an environment that the manufacturer does not recommend.

We understand that the manufacturer does not sell the system for airborne applications, as they are aware that vibrations may hamper the data. For that reason, we consider it even more important to figure out the limitations of the sensor in terms of vibrations.

Manuscript page 4, lines 9-12: The authors stated that "the manufacturer warns in the manual that the sensor should not be applied with vibrations around 150 Hz and around the harmonics". Is it possible for the authors to contact the LICOR manufacturer to get approval - or feedback from the Technical Support department - for flying a LICOR on aircraft?

Yes, we were in contact with the manufacturer, and presented the results. Some stafff members showed large interest in the investigations, however, we did not get an official statement from the company.

2 The reported experiment involved one vibration-isolated closed-path hygrometer and two non-isolated open-path hygrometers, so how do you know whether the drift and noise are due to vibration or the open-path? Are there other possible reasons for the drift (such as drift in the electronics response or internal processing?)? We operated the identical open path sensor on a platform affected by vibrations (Do128, not isolated), and on a platform with much lower level of vibrations (Helipod, carried by helicopter, without own propulsion). For the latter application, the open-path sensor performed well without any drift. This comparison allows the conclusion that the vibrations are responsible for degrading the measurements. To clarify, we added the following sentence in the conclusion section:

"Altogether, both open-path and closed-path LICOR sensors are suitable high-resolution hygrometers for airborne applications, if the vibrations are low."

3 Section 1.3, page 3, lines 14-25, describe laser hygrometers but has some gaps as listed below: 3.1) Page 3, lines 24-25 claim that "it is not possible to obtain real-time humidity data." Although the Buchholz et al. hygrometer (Buchholz et al. 2014) does not provide real-time humidity data, other laser hygrometers do this routinely (see papers such as S. B. Smith et al., JGR, 2017, R. L. Herman et al., ACP, 2017, or M. Zondlo et al.).

We added in the text:

"For large research aircraft, some specifically designed hygrometers are implemented: On the National Science Foundation Gulfstream-V aircraft, a cavity diode laser hygrometer with two absorption lines in the near-infrared is deployed with a temporal resolution of 25 Hz (Zondlo et al., 2010). On the NASA ER-2 aircraft, a specifically designed near-infrared tunable diode laser spectrometer is deployed for measuring atmospheric water vapour concentration (May, 1998), with a sampling rate of 1 Hz and 10% accuracy(Herman et al., 2017). Compared to the LICOR sensor, this tunable diode laser hygrometer can be operated much faster (up to several kHz) and with a known accuracy, providing the most precise humidity values available to date (Buchholz et al., 2013, 2014, 2016). However, this hygrometer requires extensive post processing, and at least so far it is not possible to obtain real-time humidity data. The spectroscopic sensors are experimental systems and not commercially available yet."

3.2 page 3, line 25 claims that "The spectroscopic sensors are experimental systems and not commercially available" but the Picarro and Los Gatos systems mentioned earlier are commercially available laser hygrometers that have sufficient accuracy for the science. They can also provide realtime humidity data. Yes, we agree with the referee. However, the price for a Picarro and Los Gatos sensor is much higher, and so is the weight, which makes them not so easy to use in aircraft. We changed the

text to:

"As the LICOR sensor is currently the cheapest fast-response water vapour sensor commercially available, and small enough to be easily integrated into aircraft, its airborne applications will very likely increase."

3.3 page 4, lines 10-11 claims that "... the LICOR sensor is currently the fastest and cheapest water vapor sensor commercially available" but laser hygrometers are faster than the LICOR. We changed the text to:

"the LICOR sensor is currently the cheapest fast-response water vapour sensor commercially available"

4 I find the discussion of the time resolution of the LICOR to be disorganized and confusing (Sections 2.1 and 2.2 and 3.4). I recommend that the authors should reorganize the discussion of the time response, time delay and time synchronization to one section because these are related.

We are not very happy with this suggestion. Section 2.1 generally introduces the LICOR sensors with their properties. However, the time synchronisation stronly depends on the setup in the corresponding measurement platform with the tube lengths, and distances between hygrometers and 5-hole probe. Therefore, we would prefer to discuss the synchronisation separately for each airborne carrier platform.

4.1 What is the time resolution of the LICOR instrument? Page 5, line 2, indicates that the data is "internally processing and finally provided at a maximum frequency of 20 Hz." Are the detector and electronics signal chain sufficiently fast to resolve changes in water vapor at 20 Hz?

Yes, the provided maximum frequency is 20 Hz. The internal data sampling and acquisition is fast enough. To avoid confusion, we changed the sentence to:

"The data sampled internally at 150 Hz frequency is processed and provided at a maximum frequency of 20 Hz."

4.2 Page 5, line 9: what is the response time of the Rosemount EL102 sensor? It is only characterized here as a "fast response time." How fast? We changed the text to:// "Rosemount EL102 sensor with a fast response time (100 Hz)"

4.3 Page 5, lines 25-30: How can you carry out successful fast measurements with the closed-path LICOR if there is a 250-millisecond calculated delay? Have you tested the delay? What is the residence time in the sample cell?

The delay is just a temporal offset, which can be corrected. The residence time in the sample cell depends on the air flow speed, and is taken into account in Sect. 2.2.

4.4 Page 10, line 23 and Page 11, line 25: the authors state the "Generally a temporal resolution of 20 Hz is sufficient for humidity flux calculations." It is not clearly explained how the authors came to this conclusion. Is there a reference that can be cited as evidence for this?

We included in Section 4.2 the following text:

"It can be concluded from Fig.10 and Fig.12 that the fluxes for frequencies exceeding 1 Hz are negligible for these specific flight conditions. Therefore, the sampling frequency of 20 Hz is sufficient for airborne turbulent humidity fluxes."

Furthermore, it is unclear from this manuscript whether the LICOR has an actual temporal resolution of 20 Hz (when the sampling delays and internal processing are included).

The delays are constant temporal offsets, which do not influence the capability of the sensor to provide data at 20 Hz resolution.

5) Flight figures 3 and 6 are hard to read: please consider larger font text

We enlarged the text in the figures.

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