Anonymous Referee #2

Review of the manuscript egusphere-2026-4762, entitled « Accurate and high-resolution measurements of UTLS water vapor by balloon-borne laser absorption spectroscopy » by Brunamonti et al.

The article describes in detail a new laser absorption hygrometer, under development since several years at EMPA (Switzerland). The instrument, ALBATROSS, was test flown under small weather balloon a couple of times and has been participating to the AQUAVIT-4 intercomparison campaign (in its earlier version) in 2022.

I particularly appreciate the sections « Technical challenges » and « Flight-by-flight performance summary », detailling all sources of contamination and a step-by-step discrimantion of outgassing sources. Such issue is a longstanding challenge for stratospheric water vapor measurements. I believe this is really informative for further developments conducted by other research groups.

The manuscript is weel written, I only have a couple of questions/comments:

Authors: We thank the Referee for the positive and constructive feedback that helped us to improve our manuscript. Below are the individual comments from the Referee (in black) and the replies from the Authors (in blue). Page and line numbers refer to the revised manuscript.

Line 2, page 4 : « with a compact, monolithic segmented circular multipass cell » : What material is used for the SC-MPC ? Is it still aluminum as described in Tuzson et al., 2020 ? Did you test the optical stability (path length) in a thermal enclosure ?

Authors: The SC-MPC consists of a monolithic aluminum ring, manufactured by diamond-turning (see Graf et al., 2018; 2021). Its OPL stability against thermal expansion has not been tested in a climate chamber, but it can be derived from its material properties and was simulated using 3D-CAD calculations.

The aluminum 6010 alloy has a linear coefficient of thermal expansion of approximately 21.5 $\mu m\ m^{-1}\ K^{-1}$ between –50°C and 20°C. Assuming that the SC-MPC expands linearly along its circumference, for a change in temperature of 50 K (consistent with cell body temperature measurements performed along flight, from about +20 °C to –30°C), this corresponds to an expansion of 365 μm in circumference, resulting in a 58 μm change in radius. Multiplied by 56 reflections, this gives a total change of 3.2 mm, corresponding to about 0.05 % of the OPL. Therefore, even the maximum uncertainty associated with cell thermal expansion is negligible in the context of this study.

Note that the same aluminum SC-MPC was also used to perform cold-cell spectroscopy measurements of CO_2 isotopes down to temperatures of 150 K (Nataraj et al., 2022).

The description of the SC-MPC has been improved as follows:

"The SC-MPC consists of a diamond-turned aluminum ring with 57 individual mirror segments ($6\times6\ mm^2$) carved onto its inner surface, providing an optical path length (OPL) of 6.1 m within a 10.9 cm diameter circular geometry (Graf et al., 2018; 2021). It is highly resistant to thermal

and mechanical stress (Tuzson et al., 2020; Nataraj et al., 2022), and allows […]" (page 4, lines 3-6)

Reference: Nataraj, A., Gianella, M., Prokhorov, I., Tuzson, B., Bertrand, M., Mohn, J., Faist, J., and Emmenegger, L.: Quantum cascade laser absorption spectrometer with a low temperature multipass cell for precision clumped CO_2 measurement, Opt. Express, 30, 4631-4641, https://doi.org/10.1364/OE.447172, 2022.

Line 18-19, page 12 : Figure 3, flight F6 & F6 descent shows that there is a residual outgassing inherent to the flight chain during the end of the end that will be difficult to remove. The only option is to burst at much higher altitude so this 4 km contaminated layer does not preclude upper stratospheric measurements. This is a well-known problem, already pointed out in several papers since back in 1991 (Ovarlez, 1991) where the origin was unknown up to nowadays (Ghysels et al., 2024). In such, for scientific applications aiming to study stratospheric variability, it is highly desirable to use descent data for the analysis. It could be fair I guess to mention this in the « Flight F6 » paragraph.

Authors: We thank the reviewer for this comment. Indeed, the contamination at 24-28 km altitude in F6 ascent, due to residual desorption/outgassing effects from external moisture sources in the balloon train, is an artifact that will be difficult to remove, as it is inherently related to the balloon platform and payload geometry. However, the comparison of ALBATROSS and CFH data in this region still provides some interesting insights. We have added the paragraph below to Section 4.3 (Stratosphere) to comment on these issues and remark the importance of a careful quality-check of balloon-borne ascent data in scientific studies. A reference to Ovarlez (1991) was also added to Section 2.2, where the issue of external moisture sources is first introduced (page 7, line 7).

"*The fact that successful measurements above ~24 km altitude were achieved in the descent of F6 and not during ascent (see Fig. 3g), despite the ALBATROSS operating conditions were the same, strongly suggests that the ascent contamination originates from external moisture sources associated with the balloon train. In contrast, the corresponding CFH profile does not exhibit comparable contamination in the same altitude range (Fig. 3g), although it was flown on the same balloon as ALBATROSS. A possible explanation is the relative positioning of the intake tubes of the two instruments within the payload assembly (see Fig. 2c), with ALBATROSS directly underneath the balloon train, hence more prone to contamination compared to CFH, which was more off centred. This observation highlights the sensitivity of lower-stratospheric H_2O measurements to desorption and outgassing effects, which have been reported previously for a range of balloon-borne hygrometers (e.g., Ovarlez, 1991; Brunamonti et al., 2018; Jorge et al., 2021; Ghysels et al., 2024). It further underlines the importance of rigorous quality control, particularly for ascent data.*" (page 16, lines 21-30)

Additionally, fortunately the flights occurred while Aura LMS was still in operation : comparing your measurements (and CFH) to MLS vertical profiles (not affected by outgassing) could help demonstrating that no residual outgassing is left.

Authors: While Aura MLS was indeed operational during part of the campaign, a meaningful comparison would require dedicated treatment of spatial and temporal co-location

uncertainties, representativeness errors, and the significantly different vertical resolutions of the datasets. Such an analysis is beyond the scope of the present validation study, whose primary objective is the intercomparison with established in-situ reference instruments (CFH and RS41). We therefore refrain from including Aura MLS data in the present manuscript.

Nevertheless, please note that a comparison of all in-situ instruments operated during *the Swiss H_2O Hub* project, including ALBATROSS, against ground-based remote sensing and MLS satellite retrievals is in preparation in a separate manuscript.

Line 1, page 13 : you mention that the larger relative difference between ALBATROSS and CFH & RS 41 near 8-9 km for flight F1 and F4 is due to contamination : what is the source ?

Authors: The observed contamination is attributed to outside-cell absorption caused by failure of the in-flight purging system, as discussed in Section 4.1. The sentence was revised to clarify this point:

"*[…] where the onset of contamination due to outside-cell absorption effects at ~8–9 km leads to larger deviations.*" (page 13, lines 14-15)