Reply to Anonymous Referee #1

August 29,2025

Dear Reviewer,

We sincerely thank you for your thoughtful and constructive review of our manuscript “HoloTrack: In-Situ Holographic Particle Tracking of Cloud Droplets.” We greatly appreciate the positive assessment of the instrument’s design, evaluation, and potential impact on cloud microphysics research. The comments and suggestions helped us further improve the clarity and utility of the paper. Below, we address each comment in detail one by one. Below, reviewer comments and question appear in *blue* and our responses are shown in black.

Review of "HoloTrack: In-Situ Holographic Particle Tracking of Cloud Droplets"

Overview of the Paper: *This manuscript presents HoloTrack, a novel, fully autonomous instrument for the in-situ measurement of cloud microphysical properties. The primary innovation of HoloTrack is its ability to perform three-dimensional particle tracking by capturing pairs of holograms at a high frequency (25 pairs/sec). This allows for the direct measurement of individual cloud droplet velocities in addition to their 3D position, size, and shape. The authors provide a comprehensive description of the instrument's mechanical, optical, and electronic design, as well as its automation systems. The paper's strength lies in its thorough performance evaluation, which includes a maiden test flight on the Max Planck CloudKite (MPCK) platform, static tests using a calibrated "CloudTarget," and a series of detailed wind tunnel experiments. These evaluations quantify the instrument's detection efficiency, velocity measurement accuracy and uncertainty, and the aerodynamic influence of the instrument's body on the sample volume under various yaw angles. The work represents a significant technical achievement and provides a powerful new tool for advancing the experimental understanding of cloud microphysics, turbulence, and droplet dynamics.*

General Recommendation: *The paper is well-written, the instrument is thoughtfully designed, and the performance evaluation is extensive and convincing. It is a substantial contribution to the field of atmospheric measurement technology. The conclusions are well-supported by the presented data. The manuscript is nearly ready for publication.*

I recommend this paper for publication after minor revisions. The revisions suggested below are intended to clarify a few points, which will enhance the paper's impact and utility for future users of this technology.

Comments:

(C1): Table 1 (page 10): Two instruments are listed under the heading "Planned but not operational." To enhance clarity, consider naming the subsection: "Future Instrumentation"—to clearly indicate that they were not part of the current test configuration.

(A1): We thank the reviewer for this helpful suggestion to improve clarity. We have renamed the subsection of the table to “Future Instrumentation” according to your suggestion to indicate these instruments were not part of the test configuration.

(C2): Line 111: For unambiguous interpretation, please state explicitly which side of the windows the measurements refer to (e.g., "interior-facing" or "exterior-facing").

(A2): We thank the reviewer for pointing out this ambiguity. We refer to the exterior-facing sides of the windows. We have reworded the sentence to “The exterior-facing side of the camera window is at reconstructed z = 2.5cm and the exterior-facing side of the laser window at z = 22cm.” to clearly indicate that anything between 2.5cm and 22cm can be considered the actual sample volume.

(C3): Line 165: For clarity, consider labeling the holograms as H_1 and H_2 instead of A and B. The use of A/B within the sentence structure may cause confusion.

(A3): We thank the reviewer for this helpful suggestion. We have replaced the A/B labels with H_1 and H_2 not only in line 165 but for consistency also throughout the manuscript including legends of Figures and already introduce this naming convention in the introduction and the new Figure 1 for clarity.

(C4): Line 170: Please clarify why the second exposure (B) must be exactly 14 ms. Is it not possible to wait 13.9 ms and then use an exposure time of 0.1 ms instead?

(A4): We thank the reviewer for pointing out this ambiguity. We have revised the text to clarify that the second exposure H2 must be $t_{H2} \approx t_{rd} - \Delta t$, where Δt is the time interval between the two exposures. For particle tracking velocimetry, Δt is typically small compared to t_{rd}, making $t_{H2} \approx t_{rd} \approx 14$ms a good approximation. This revision makes the statement both more correct and complete.

(C5): Figure 6: For consistency and easier referencing, use (a), (b), (c) to label the panels.

(A5): Following the reviewer’s suggestion we have added A,B,C to the panels in Figure 6 and added it wherever panels of Figure 6 are referred to in the text.

(C6): Line 275: Please specify the distance between the instrument and the balloon. Additionally, address whether the balloon has any potential influence on the measurements (e.g., wake effects, thermal interference, shadowing)

(A6): We have added the information about the distance between balloon and instrument as well as information about the intended mounting option for future flight in line 289 of the revised manuscript: “For the maiden flight, HoloTrack was attached with a line about 3 m below the keel of the lower Helikite, which results in a distance of 6 m to the balloon for ease of operation (see Figure 5 A). The hanging point is approximately 6.5 m downstream of the balloon edge. Hence, the wake does not reach HoloTrack as long as the pitch angle of attack is smaller than approximately 45°. As demonstrated in Figure 6, in the test flight the standard deviation of the pitch angle was only 10° with a mean of 0°. While even in this configuration the effect of the balloon is minimal, in future flights HoloTrack can be hung on a line directly from the tether at arbitrary distances below the balloon e.g. 10 m to 1000 m (as shown for WinDarts in Chávez-Medina et al., 2025).
In addition, we want to note that previous measurements with a different instrument (Advanced Max Planck CloudKite or MPCK[+]) have shown comparable turbulence dissipation rates for both belly and keel mounting (directly below the balloon and 3 m below), indicating that turbulence is likely not affected by the balloon even when the measuring instrument is closer to it than in the HoloTrack maiden flight. Dynamic pressure field distortions, however, can influence the mean velocity, which is why future deployments will consistently use a tether mount further away from the balloon than in the maiden flight, as now indicated in the text. Potential effects of the Balloon (Advanced Max Planck CloudKite platform) and different mounting options will be discussed in a future publication, currently in preparation, about the Advanced Max Planck CloudKite system (Helikites and instrument box). Importantly, the maiden flight configuration was still valuable because the instrument was freely suspended and therefore experienced motion and stability conditions similar to those expected in the final tether-mounted configuration. Thermal effects from the balloon will also be negligible in tether-mount configuration.

(C7): Line 298: Typographical correction: replace “near 0°” with the correct form “near 0°”

(A7): We thank the reviewer for pointing this out. The typographical error has been corrected to “near 0°”.

(C8): Line 316: 1D Pitot Tube Filtering: The text notes that an "8-point-filtering was still set" on the 1D pitot tube, which smoothed the data. To aid reader understanding, please clarify why this filtering was active during the test flight—was it due to a default configuration, an oversight, or intentional for noise reduction?

(A8): We thank the reviewer for this comment. The filtering was part of the instruments default configuration. We now refer to it throughout the manuscript as “default 8-point filtering” to make this clear.

We want to thank the reviewer again for their helpful comments and positive assesment. We have made additional minor revisions to streamline the manuscript and enhance clarity. Furthermore, the CloudTarget analysis for z = 12.2 has been improved with a more accurate tilt and “ghost-layer” (see Thiede 24, EGUsphere, 2025, 1–39, 2025b) correction. The velocity results in Figure 13 (previous Figure 12) are now shown for the final sub-volume, for consistency, which is also indicated in the revised manuscript. All other revisions are clearly indicated in the marked-up version of the manuscript.