Discussion link: https://egusphere.copernicus.org/preprints/2025/egusphere-2025-5568/

Valero et al. present in this manuscript a newly developed balloon-sounding system for atmospheric-state, aerosol, cloud-droplet, and trace-gas observations from the ground to 30 km altitude. A custom payload structure containing instruments, power supply, data acquisition, and telemetry is carried by single-use weather balloons with the potential to recover the payload after balloon collapse. The system was launched 28 times during two campaigns in Germany. A case study provides a single profile of observed parameters, focusing on observations through a low-level cloud below the first two kilometers. In summary, the presented work provides insights into possibilities for vertical atmospheric observations using a low-cost approach.

Although the approach is valuable, the presented work is not suitable for publication with AMT as it is. The manuscript is not in a mature state, as would have been appropriate for the journal. Most importantly, some sections are written in poor English, with incomplete or doubled sentences that make it difficult for the reader to grasp the essence of entire paragraphs. The analysis lacks coherence and appears inconsistent, with generally weak treatment of the data and several critical elements seemingly omitted. In general, the scientific scope of the presented study remains unclear, and many open questions remain for the reader. What are the targeted atmospheric conditions and the scientific question intended to tackle? How is the payload actually recovered? When it is modular, why only show one setup? Why focus only on 2 km coverage for one profile when 28 flights potentially reached up to 30 km in altitude? Was the development successful and feasibility proven or not?

The methods and conclusions drawn indicate that the authors may need to further develop their understanding of certain fundamental principles of aerosol science. Freely available literature and information on the use of the optical particle size spectrometer were likely not considered or evaluated in sufficient detail. For instance, arbitrary aerosol refractive indices were assumed (no explanation for their use was given), without accounting for corrections for the calibration materials used. No attempt was made to correctly quantify the measured variables or to evaluate their plausibility. The authors state that the presented data only serve as a qualitative description of atmospheric processes. Some sensors did not perform well because they were not suitable for the application, which is probably true of other sensors as well, but the authors did not consider this. Inlet sampling issues for the aerosol sensors were not sufficiently considered.

The authorship statement suggests that the corresponding author was primarily responsible for manuscript preparation, with limited apparent involvement in other aspects of the work. This may partially explain the current state of the manuscript, yet the presence of senior co-authors implies a shared responsibility to ensure that the paper meets an appropriate scientific and editorial standard. The challenges encountered in reviewing this submission, including the substantial time required to provide detailed and constructive comments, highlight how burdensome such poorly prepared manuscripts can be for reviewers. In its present form, the manuscript gives the impression that essential elements of PhD supervision and internal quality control were deferred to the external review process, which is not an appropriate use of peer review.

>We thank the reviewer for the thorough and constructive feedback. The manuscript has been extensively revised to improve clarity, correct grammatical errors, and eliminate incomplete or duplicated sentences, ensuring it meets the scientific and editorial standards of AMT.

The introduction has been modified to clarify that the primary purpose of this publication is a proof of concept. At this stage, the study does not target specific atmospheric conditions, with the exception of convective conditions and vertical uplift. While the overall development of the platform was successful and its feasibility proven, this work represents an ongoing learning process. We have changed the wording across the entire paper to better reflect the system configuration without misleading the reader regarding the presented setups, and we have explicitly added details on the payload recovery process, which consists of tracking the radio signal and physical recovery by a team.

To address the data coverage, the main text focuses on the low-altitude data where the relevant atmospheric features observed during the case study are located. However, to provide a more comprehensive view of the flight data, we have added plots extending up to 7.5 km in the supplement. Testing different sensors under high-risk sounding conditions was part of this learning process; we discovered that the platform does not work under all environmental conditions for certain instruments. Specifically, the results demonstrate that the sounding conditions were overall not suitable for the CO sensor, and that other sensors (such as the TFS) have a limited operational range. These limitations are now openly discussed as a valuable outcome of the study, providing a clear path for future platform improvements.

Regarding the aerosol measurements, we have accounted for different refractive indices in our analysis, and the corresponding sections have been rewritten to provide the necessary explanation and justification. Quantifying and calibrating these variables in an airborne, low-cost setup presents inherent difficulties, as it is technically impossible to operate a reference instrument alongside the payload during these flights. To evaluate the plausibility of our data, we attempted comparisons using satellite data and established literature references (Moormann et al., 2025), and we now rely on laboratory calibrations, which have been included in the manuscript. Additionally, we have expanded the text to include specific considerations regarding inlet sampling issues related to the UCASS, POPS, and impactors, supported by references to relevant literature.

Formatting:

Introduce all instruments consistently: general instrument name (model, manufacturer, country) e.g. radiosonde (RS41-SGP, Vaisala, Finland)

>To help the reader, all the instruments are centralized with the same format in the main instrument table.

Introduce all abbreviations: nitrogen (N), optical particle spectrometer (OPS), etc.

>The chemical elements and the abbreviations have consistent format along the text.

Introduction

The motivation should focus more on scientific needs and questions that the system can target than on available instrumentation. The logical flow seems interrupted by introducing instrument selection and the instrument's working principle, then returning to science, and then back to the instrument description.

>The section has been thoroughly restructured to prioritize the scientific motivation. The detailed descriptions of the instrument's working principles and selection criteria have been consolidated and moved to the Methodology section. The introduction now solely introduces the deployed system as the specific methodological solution to the identified scientific needs, ensuring an uninterrupted logical flow. The introduction is now:

“Atmospheric aerosols and cloud droplets play a critical role in the Earth’s climate system, influencing the radiation budget and hydrological cycle (Szopa et al., 2021). Accurate characterization of the particles’ properties, such as particle size distribution (PSD) (O’Sullivan et al., 2020) and their physico-chemical properties (Pöschl et al., 2010), is a fundamental approach to reducing uncertainties in climate models (Seinfeld et al., 2016). It also improves our understanding of atmospheric processes such as aerosol-radiation interactions (Feingold et al., 2016) and cloud formation (Costa-Surós et al., 2020). Measuring a broad spectrum of aerosol sizes, from the nucleation to the coarse mode, is essential for understanding their impacts on climate and atmospheric dynamics (Carslaw et al., 2010). Consequently, high-resolution vertical profiles of thermodynamic conditions are necessary to investigate aerosol behavior and its effects.

Despite their scientific importance, obtaining in-situ measurements within and above the planetary boundary layer has historically presented significant logistical and financial challenges. While aircraft-based research campaigns provide detailed microphysical characterization and excel at providing horizontal transects or spiral profiles across vast regions (Pikridas et al., 2019), they are inherently expensive to deploy and operate (Rossi et al., 2022). The substantial cost per flight hour restricts the feasibility of extensive studies (Li et al., 2025b) and limits the temporal coverage of atmospheric soundings (Dubey et al., 2022). Furthermore, vertical profiling with aircraft is often constrained by minimum safe altitudes and flight restrictions within deep convective clouds.

Balloon-borne sounding systems offer a flexible and operationally cost-effective alternative for acquiring vertically resolved atmospheric data (Joly et al., 2016). Weather balloons, capable of reaching the Upper Troposphere/Lower Stratosphere (UTLS) (Golden et al., 1986), provide a platform for in-situ measurements with significantly reduced operational costs compared to aircraft (Rossi et al., 2022) or satellite deployment missions (Li et al., 2025b). In contrast to the rapid horizontal passage of an aircraft, the slow ascent of a balloon provides a detailed vertical profile, enabling the resolution of fine-scale features within dynamic systems that can extend throughout the troposphere, such as desert dust intrusions (Papayannis et al., 2008), developing clouds (Evan et al., 2020), volcanic dust plumes, and wildfire-derived aerosol injections (Kloss et al., 2022; Dumelié et al., 2024). Additionally, the limited lifespan of atmospheric events means the window of opportunity is short, ranging from hours (Piper et al., 2019) to a few days (Varga, 2020). Unlike the fixed instrumentation of satellites or the extensive planning required for an aircraft campaign (Li et al., 2025b), balloon platforms offer significant flexibility and can be prepared for immediate deployment to capture these transient phenomena.

Because balloon payloads are subject to strict physical and legal weight constraints, instrumentation must be strategically selected to address specific scientific objectives. To investigate vertical aerosol-cloud interactions, we prioritized measuring both aerosol size distributions and chemical composition. For acquiring high-resolution size distributions, optical particle spectrometers (OPSs) are the most suitable instruments. OPSs offer high temporal resolution, providing essential data on particle number concentrations from the accumulation to the coarse mode (Mamali et al., 2018). Different aerosol size modes exhibit distinct properties that govern their interactions within tropospheric air masses (Li et al., 2025a), particularly their ability to act as cloud condensation nuclei (CCN) (Kasparoglu et al., 2024).

In this study, we focus on the accumulation (0.1–1 μm) and coarse (> 2.5 μm) modes, as particles in these ranges are more likely to activate into cloud droplets under typical atmospheric supersaturation conditions (Seinfeld and Pandis, 2016; Pöhlker et al., 2023). However, obtaining accurate size measurements with optical instruments requires careful consideration of environmental factors. For instance, hygroscopic growth can significantly increase the apparent particle size in humid air, a phenomenon observed in most atmospheric aerosols, including mineral dust (Swietlicki et al., 2008; Koehler et al., 2009). OPSs have been widely employed on both stationary (Dupont et al., 2025) and mobile platforms (Moormann et al., 2025); moreover, the continued development of lightweight, cost-effective sensors has made them particularly advantageous for small unmanned aircraft systems (UASs) (Bates et al., 2013; Altstädter et al., 2015) and balloon deployments (Kezoudi et al., 2021).

Nevertheless, while OPSs effectively characterize the physical size distribution, a comprehensive understanding of aerosol origins and processing requires physical particle collection for subsequent chemical analysis. Given that aerosol concentrations are typically low at the targeted altitudes, nozzle impactors are necessary to efficiently capture particles based on their inertia (Kandler et al., 2009). This physical collection enables detailed offline characterization using scanning electron microscopy coupled with energy-dispersive X-ray spectrometry (SEM-EDX).

This paper presents the technical proof-of-concept deployment of the Light-weight Observatory for sOuNdIng clouds and aeroSol (LOONIS) platform. To demonstrate the platform's observational capabilities, this study utilizes data collected during the BrIdging Surface emissions, Transport and UTLS Matter (BISTUM) field campaign, which aimed to investigate the transport of aerosols and precursors from the planetary boundary layer into the UTLS.

Specifically, we aim to answer the following technical and scientific questions using a combination of OPSs and ex-situ analysis techniques:

- Can the integration of multiple OPSs with distinct detection ranges reliably characterize the continuous vertical distribution of aerosols from the planetary boundary layer into the free troposphere?
- How effectively does the coupling of high-resolution in-situ optical sizing with ex-situ physico-chemical analysis (SEM-EDX) differentiate aerosol types (interstitial versus

activated) and link their microphysical properties to specific environmental sampling conditions?"

Balloon:

Describe operation and ground preparation. How is the balloon recovered? Description of parachute etc.

>A new section (Section 2.4) describes the operation, ground preparation, and parachute specifications:

"A custom Lagrangian trajectory model is employed to simulate spatial movements using wind velocities from the ICOsahedral Non-hydrostatic (ICON-D2) weather model. The ICON-D2 analysis data provides a temporal resolution of 3 hours, a horizontal spatial resolution of approximately 2 km, and a vertical resolution of 30–100 m in the lower troposphere. The model algorithm performs linear interpolation in space and time to determine the wind vectors driving the trajectories.

This model serves a dual operational and scientific purpose:

- **Payload Recovery (Forward Trajectories):** It calculates forward trajectories to predict the balloon's landing location and time. This estimation, combined with live GPS telemetry from the Vaisala RS41-SGP radiosonde, enables the team to execute immediate payload retrieval.
- **Source Attribution (Backward Trajectories):** It computes backward trajectories to trace the history of the sampled air masses. These are initiated every minute during the flight at the corresponding spatial and temporal coordinates, running backward for 24 hours or until the air parcels exit the ICON-D2 operational domain.

To achieve the target vertical ascent rate of 6 m s^{-1}, ground preparation requires precise helium inflation to achieve a total lifting mass equal to approximately 2.5 times the overall payload mass. This specific lifting ratio was empirically determined to ensure a stable vertical ascent while preventing the payload from stalling or entering a prolonged horizontal drift in the lower troposphere.

The flight train connects the balloon to the payload via a mechanical unwinder, which deploys a tether during the initial ascent to physically separate the instruments from the balloon's turbulent wake. A 2.4 m diameter parachute is integrated into the platform to provide a controlled descent speed below 4 m s^{-1}. The parachute dimensions were optimized through empirical drop tests from a height of 42 m, which confirmed that the selected diameter limits landing impact forces to protect the sensitive optical instruments."

Instruments:

The balloon reached an altitude of up to 30 km, which requires proof of instrument performance at these pressure levels.

>The 30 km altitude refers to the burst altitude of the meteorological balloon, and we have shown the limitations of the sensors which varies from sensor to sensor. The manuscript has been revised to explicitly state that instruments like UCASS and POPS (cite section) are validated for and operated within this specific atmospheric region (e.g., up to 7.5 km for the free troposphere profile), and no claims of instrument performance are made up to the 30 km burst altitude. The conclusions now include a summary table of the instruments performance. POPS:

Why were these refractive indices chosen and not the PSL equivalent diameter taken? Add the inlet specification and estimate sampling efficiency

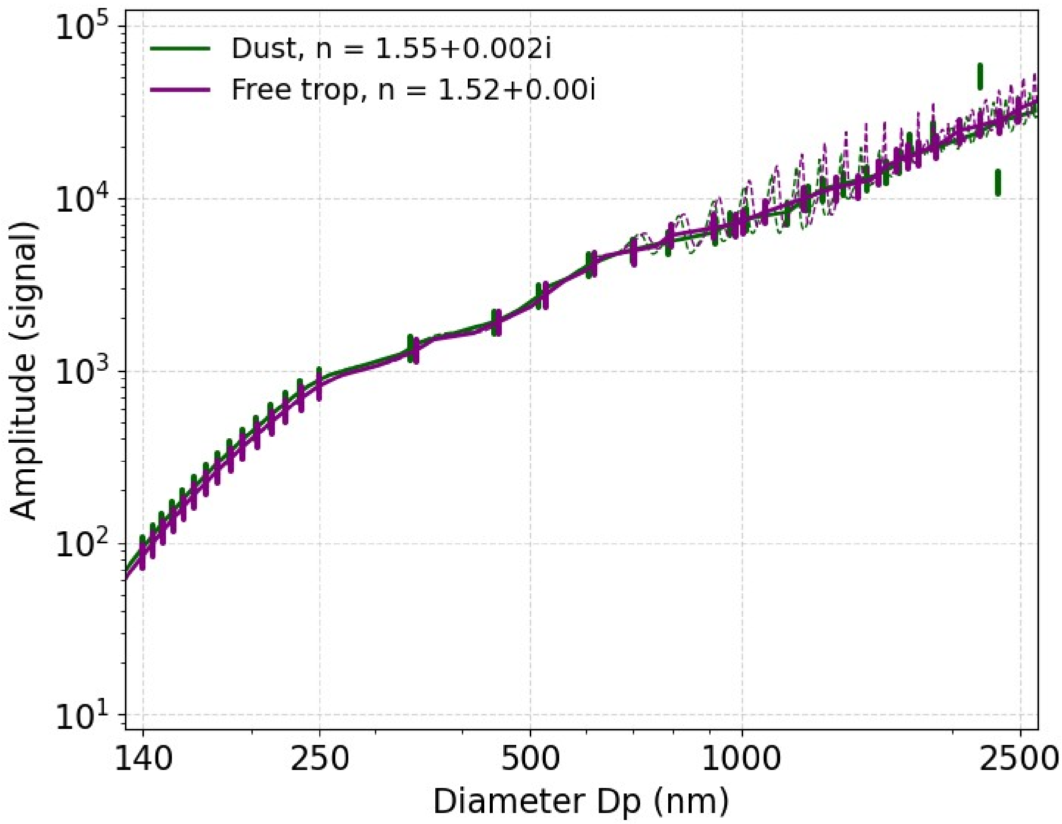
>The paragraph in Section 2.2.2 detailing the POPS instrument and the data processing has been thoroughly revised to explain the choice of index of refraction assumption, binning scheme and the reprocessing capability offered by the non-commercial version of the software used in the present investigation.

POPS measures the peak amplitude and width of the pulses of scattered light observed as a particles in the sample flow pass through the laser beam in the instrument optical chamber. The POPS used during these flights were running a software version from the NOAA Chemical Sciences Lab that differs from the Handix version commercially available. One of the main differences is that the raw data (amplitude and width) of scattering event interpreted as a particle is recorded on the µSD by default. Although this data is more cumbersome to use, it is more complete than a pre-binned data. Upon retrieval of the instrument the data can then be re-processed potentially using assumptions that can differ from the pre-set configuration. Note that for this platform including an impactor for offline analysis, recovery is of paramount importance for completeness of the atmospheric aerosol picture.

The atm-py package, available online from Hagen Telg's GitHub (https://github.com/hagne/atm-py), offers ample python-based code to process the POPS data in various ways. While only a single point calibration is performed in the lab using PSL spheres (usually 508 nm), the POPS response is well known and scales with the PMT gain set during that calibration.
In other word, one only need to know the expected POPS signal from their calibration material (size, IOR) and set the gain where it should be. Hence, when the instrument is operating in condition where one can assume a bulk index of refraction, it is possible to re-process the data for that particle IOR. POPS being initially developed for stratospheric aerosol measurements, the default has been 1.45+0.00i for sulfates as presented in Todt et al.

A PSL-like sizing is not satisfactory for several reasons. It is certainly not a helpful metric to compare measurements together. Also, the POPS-derived products such as surface area, volume, extinction, and effective radius are all PSL independent although entitled to the assumption used for sizing. Hence, they can provide meaningful constraints for models, and apple to apple comparison with satellite retrievals.

For this study, 1.55+0.002i was used when air masses were impacted by dust transport. For the rest of the profiles, instead of 1.45, the new version of the data will use an IOR of 1.52+0.00i for better representation of the European continental background aerosol (Aldhaif et al., 2018). The Mie curves and binning scheme for each IOR are plotted below.



The paper now reads "The Portable Optical Particle Spectrometer (POPS) is a lightweight (800 g), low-power (5 W) instrument that measures aerosol number concentration and size distributions for particle diameters between approximately 140 and 2500 nm (Gao et al., 2016). Individual particles are detected by light scattered as they traverse a 405 nm laser beam. The amplitude of the scattered-light signal is used to assign the particles to pre-determined bins that correspond to particle diameter based on Mie scattering calculations with an assumed particle refractive index. The instruments deployed in this study used a NOAA Chemical Sciences Laboratory firmware version that additionally records the raw scattering-event information (signal amplitude and width) for each particle to onboard storage. This capability allowed post-flight reprocessing of the data using alternative sizing assumptions, rather than relying solely on pre-binned size distributions generated during acquisition.

Prior to deployment, each instrument was calibrated following the protocol described in Todt et al. (2023) using nebulized 508 nm polystyrene latex (PSL) spheres to ensure consistent measurement across all units. Data processing was performed using the atm-py software package (Hagen Telg and Gao, 2017), which applies Mie-theory-based sizing curves derived from the calibration response and an assumed particle refractive index. For aerosol layers influenced by mineral dust transport, a refractive index of 1.55 + 0.02i was assumed (Ukhov et al., 2021; Spyrou et al., 2025), whereas a refractive index of 1.52 + 0.00i, representative of continental background aerosol (Aldhaif et al., 2018), was used for all other profiles. Particle size distributions were reported using 36 size bins derived from the corresponding refractive-index-specific Mie response curves. By using these segment-specific RI assumptions, particle sizing and all derived quantities (e.g., surface area, volume, extinction, and effective radius) are consistent and directly comparable with model and remote-sensing products.

The suitability of POPS instruments for airborne measurements has been demonstrated in UAV (Hagen Telg and Gao, 2017), aircraft (Liu et al., 2021), and high-altitude balloon-borne applications (Asher et al., 2024; Todt et al., 2023). The complete size range and the corresponding Mie response curves are detailed in the supplement (Table S4, Figure S5, and Figure S6).”

UCASS:

Show the calibration results for the UCASS (e.g. as histogram plot)

>The manuscript was updated to clarify the distinction between the formal instrument calibration and the pre-flight screening. The text now explains that the pre-flight procedure was strictly a binary functional check using different-sized materials to verify sensor response, not a calibration process. The comprehensive calibration procedure and the resulting data for the deployed UCASS units are already published in Girdwood et al. (2025). Calibration results are now available on the supplement, detailing the bins for each unit.

CO monitor:

>Why use the same instrument for the entire campaign when it is not suitable for balloon applications? Simply delete everything about this failure from the document, as it is of no benefit to the reader

We acknowledge the reviewer's observation regarding the sensor's unsuitability for balloon applications. However, documenting instrumental limitations and negative results is essential for methodological transparency and informs future payload designs within the community. To address the concern, regarding manuscript length and focus, we have removed the detailed sensor analysis and reduced the CO sensor discussion. This aims for full transparency and why other groups should be careful adding this kind of sensors.

Detailed comments:

Line 79: cancel “that”

>Removed "that" from "The platform that can be divided..." in section 2.1 Overview of LOONIS.

Line 80: “,” before b), exchange “.” with “,”

>The punctuation was in section 2.1 Overview of LOONIS modified to: 'a) technical parts comprising the core electronics and power systems, b) data acquisition, transmission and structural elements (see table 1), c) instruments for environmental measurements (see table 2).

Line 86: radiosonde (RS41-SGP, Vaisala, Finland)

>Vaisala RS41 radiosonde model SGP and the electrochemical concentration cell (ECC) for ozone (from Environmental Science Corporation)" to "radiosonde (RS41-SGP, Vaisala, Finland) and the electrochemical concentration cell (ECC) for ozone measurements (Model 6A, ENSCI, USA)" in section 2.1 Overview of LOONIS. This change is also noted in Table 2.

Line 87: add “measurements” after ozone, instrument naming see above

>We added the word "measurements" and applied the requested standardized instrument naming format. Please take note of previous comment.

Line 89: attaches the rope to what? Or is the rope attached to the upper end of the rod?

>“This rope attaches to" changed to "This rope is attached to" in section 2.1 Overview of LOONIS.

Line 90: centered in relation to what and why? An imbalance in what and how is it mitigated with a simple rod? Is there a flexible weight on the rod?

>A change was made in section 2.1 Overview of LOONIS: “Due to the optional integration of different instruments, the payload's overall center of mass cannot remain perfectly aligned with the central vertical axis. Although the basic setup structure is balanced around the central suspension rod, the addition of other instruments inevitably creates a lateral mass offset. To mitigate the impact on the vertical alignment a long pole was chosen"

Figure 1: Add a photograph of the system; the figure description is redundant to the text.

>We added a photograph to of the fully assembled LOONIS platform to the schematic drawing in Figure 1. Removed parts of the figure description and added a new description detailing the components shown in the photograph in Figure 1. Caption was adapted as well.

Table 2: “sampling time” is not useful for continuous measurements, consistent instrument naming (see above), add pump model and manufacturer

>Replaced "Sampling time" with "Temporal resolution" in Table 2. Corrected "RS41-SGP Vaisala Radiosonde" to "radiosonde (RS41-SGP, Vaisala, Finland)" in Table 2. Corrected "ECC ozonesonde" to "electrochemical concentration cell (ECC) for ozone measurements (Model 6A, ENSCI, USA)" in Table 2. Added "(CTS Series, Parker Hannifin, USA)" to the Pumps entry in Table 2.

Line 92: The maximum weight of what?

>Corrected "The maximum weight" to "The maximum weight of the payload" in section 2.2 Balloon Instrumentation Payload.

Line 94: introduce all variables and units properly, e.g. aerosol particle number concentration (N in cm-3), carbon monoxide (CO in ppb) …What about particle number size distribution?

>Replaced text with “The chosen variables to collect are: particle number concentration (N in cm^{-3}), particle number size distribution (PSD), carbon monoxide (CO in ppb), O_3 partial pressure (O_3 partial pressure, hPa), temperature (∘C), relative humidity (%) and GPS position”. Please, refer to table 2.

Line 95: Are cloud particles also collected?

>Yes, cloud particles are collected; however, physical limitations regarding the size of the sampled cloud droplets and the efficiency of the inlet have been considered. The manuscript

was updated to define this physical limitation clearly. Section 2.2 states the impactor "actively collects cloud elements".

Section 4.4 details the limitation: "Because of particle inertia, larger cloud droplets cannot follow the air streamlines into the downward-facing inlet... the transmission efficiency for this inlet configuration drops to less than 5% for particles larger than approximately 6 µm... Consequently, the impactors do not collect mature cloud droplets. The in-cloud sample therefore consists almost exclusively of interstitial aerosols…".

Line 97: cancel “platforms”

>Corrected "balloon-borne OPCs platforms" to "balloon-borne instruments" in section 2.2 Balloon Instrumentation Payload.

Line 101: an optical particle spectrometer is abbreviated OPS not OPC, the UCASS is used on UAS but it was designed for balloons

>We removed the reference to UAS design in section 2.2.1. The text now states: 'The Universal Cloud and Aerosol Sounding System (UCASS) is an optical particle counter (OPC) designed for the in-situ characterization of atmospheric aerosols and cloud particles from balloon soundings'.

Line 103: “laser diode beam”

>The phrase 'diode laser beam' was replaced with 'The beam emitted by the laser diode ' in section 2.2.1 UCASS.

Line 104: the scattered light intensity is also correlated to the particle's chemical composition (refractive index) and shape

>Corrected the description in section 2.2.1 UCASS. We modified the sentence to explicitly include composition and shape: 'When particles pass through this area, they cause the light to scatter, and a detector measures the intensity of this scattered light, which is correlated to the particle's size, shape, and composition.

Please, refer to the discussion on the POPS.

Line 105: What is calibrated with the pitot tube?

>Added clarification in section 2.2.1 UCASS: "To ensure measurement accuracy, UCASS units are calibrated".

Line 108 to 116 should be at the beginning of the section or even in the introduction

>The paragraph detailing previous field deployments and validations was moved to the beginning of Section 2.2.1. It now directly follows the instrument's introduction: "The Universal Cloud and Aerosol Sounding System (UCASS) is an optical particle counter (OPC) designed for the in-situ characterization of atmospheric aerosols and cloud particles from balloon soundings... Its utility for providing high-resolution vertical profiles has been well-demonstrated in previous field deployments. For instance, (Kezoudi et al., 2021)...”

Line 132: remain consistent with UCASS subscripts

>Standardized instrument nomenclature throughout the manuscript, updating references from 'UCASSa' and 'UCASSb' to 'UCASS_A' and 'UCASS_D'. A and D refer to the two types of UCASS, Aerosol and Droplet, which are commonly used by the manufacturer.

Line 133: add the calibration results. What were the usual sizing deviations, and on what basis was it defined that it is a faulty unit or not?

>The clarification regarding the pre-flight testing and calibration procedure has been added to section 2.2.1 UCASS:

- The calibration procedure applied to the UCASS units acquired for this campaign is detailed in Girdwood et al. (2025), which outlines the methodology used to characterize the optical response and derive linear calibration coefficients for each unit.

- A unit was classified as faulty and excluded from deployment if it failed to register any scattering response, indicating an optical or hardware failure. This simple, binary check served only to verify that the unit was operational. Given that the UCASS units were not uniform in terms of bin sizing, we utilized different sized materials to test for a detection response.

To show all the calibrations derived from Girdwood et al. (2025) a table showing all the result is included in the supplement.

Line 139: the POPS is an optical particle spectrometer, as it provides aerosol size information, and not only number

>Corrected "optical particle counter" to "optical particle spectrometer" in section 2.2.2 POPS to accurately reflect that it provides both particle number and size distribution information.

Line 142: Why was 1.45 +0.00i chosen? It does not seem representative of ambient atmospheric aerosol

>1.45+0.00i is the default for operative reasons (relevant for stratospheric sulfuric acid aerosol). We re-processed the data for the region of interest in this analysis using 1.52+0.00i to be more representative of the continental background aerosol over Europe. All the plots related to this refractive index have been updated.

Line 143: As PSL has a different refractive index from that chosen above, the diameter size bins provided by the manufacturer are not applicable.

>The binning scheme used here differs from the manufacturer’s standard scheme. Bin edges are specifically calculated with a method similar to that described in Todt et al (2023) and the data reprocessed for each of the assumed IORs. Using the atm-py python package, we encompass the flat area of the POPS response (looking at the “Mie curve” relating signal to particle size) into larger bins to account for the decreased dsignal/dDp, the rest being evenly log-spaced.

The sizing accuracy of the POPS is insufficient to support the use of 36 size bins, as shown by other studies, e.g. Pilz et al. (2022; https://doi.org/10.5194/amt-15-6889-2022).

It is unclear from Pilz et al. what were the quality thresholds applied to the data. As mentioned in that work, unit-to-unit differences exist. Here we use only data that passes somewhat strict noise level (baseline STD <12). Gao et al. (2016) shows a signal distribution for ~500 nm PSLs with a 1σ full width of 12%, while the present instrument bin widths range from 12 – 15% across the range and 30 – 60% in low dsignal/dDp regions.

Line 146: This size range refers to the refractive index of PSL and not to your chosen refractive indices. It has to be recalculated with Mie theory for your indices.

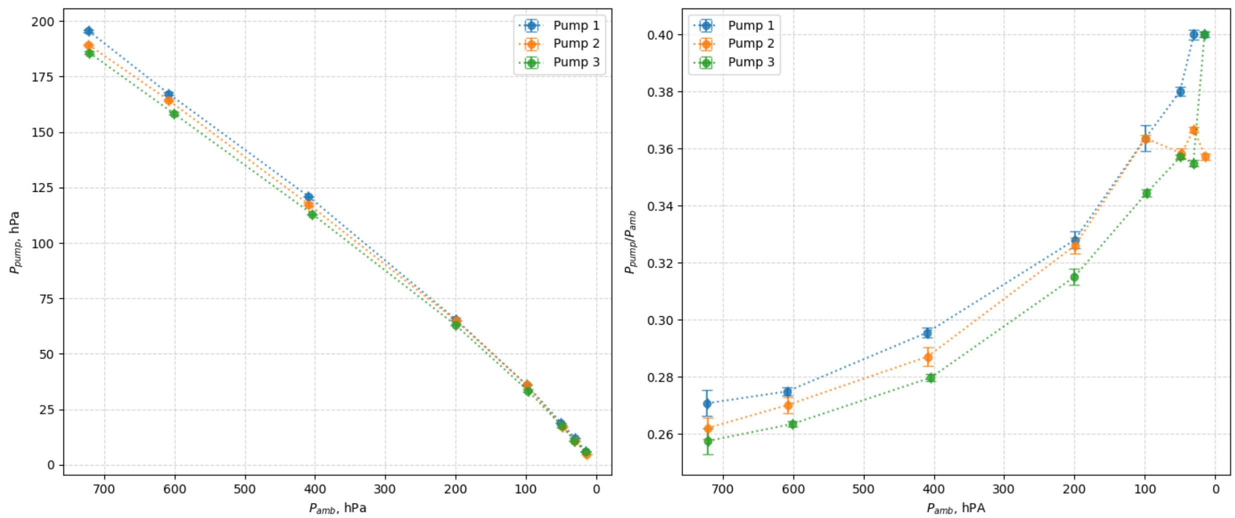
>It was poorly explained in the original text, only referencing Todt et al., but the reprocessing using Mie theory at the assumed RI is exactly what is done. This has been clarified in the text.

Line 152: Are the pumps capable of providing the critical pressure drop over the orifice and the volumetric flow at higher atmospheric levels? Please provide the pump specifications

>To ensure the performance of the aerosol impactors, the miniature pumps were verified to provide the critical pressure drop required for size-segregated particle collection across the targeted altitude range. Pre-flight laboratory simulations, conducted under low-pressure conditions, confirmed that the pumps maintain the necessary volumetric flow rate and critical pressure drop down to approximately 150 hPa, ensuring consistent particle deposition on the impactor substrates throughout the flight. The complementary plot reflects the performance of the pumps. The plot and a brief explanation is now included in the supplement.

Line 156 to 158: Please provide the equations or references for the impactor design. Provide a plot for the efficiency curves and specify what less steep curve means. The upper limit is probably more constrained by the sampling efficiency of the downward-facing inlets. Please discuss or provide calculations.

We have updated the manuscript to explicitly cite Raabe et al. (1988) and Kandler et al. (2007) for the foundational equations and geometric scaling used in the impactor design. Operating at a volumetrically constrained flow rate of 8.3 cm^3/s, the first stage (0.75 mm orifice) reaches a jet velocity of approximately 19 m/s, while the second stage (0.25 mm orifice) accelerates the flow to approximately the speed of sound.



We clarified that a "less steep curve" refers to a broad aerodynamic transition zone (30 to 150 nm) rather than a sharp step-function cut-off. This limitation does not affect our findings, as our microscopy analysis determines relative size contributions rather than absolute concentrations. The text is now:

"The impactors are constructed to sample two size fractions divided at an approximate particle diameter of 1 µm. The theoretical efficiency cut-offs for these stages are calculated using the dimensionless Stokes number framework detailed in (Raabe et al., 1988). The lower limit is defined by a less steep efficiency curve—meaning the transition from 0 % to 100 % collection efficiency occurs over a broader particle size range rather than a sharp step—and ranges from approximately 30 nm to 150 nm. Conversely, the upper limit is constrained mainly by the transmission efficiency of the downward-facing inlet. Because of particle inertia and gravity, inlet performance deteriorates rapidly for larger micrometer-sized particles, reducing transmission efficiency to less than 5 % for particles with diameters larger than, approximately, 3 to 4 µm (Ebert et al., 2016)."

Line 195: Battery weight seems to be a constraint regarding scientific payload, so why not use fewer batteries when the entire battery capacity is not used?

>To clarify the rationale for the battery configuration in Section 2.3.1, the text now reads as follows:

"The payload batteries were conservatively oversized to exceed the typical duration of a balloon sounding. This configuration provides a safety margin and introduces critical degrees of freedom for mission planning. The surplus capacity permits flexible adjustments to ascent rates and flight durations, while also accommodating the integration or swapping of supplementary instruments."

Line 239: Introduce all chemical elements as in line 242

>Corrected the notation for chemical elements in Section 2.4.2: 'Some of the elements are S (sulfur), Na (sodium), Al (aluminum), Si (silicon), K (potassium), Ca (calcium), Fe (iron), and Pb (lead).

All chemical elements previously found and mentioned hereafter follow the same format consistently.

Line 268: Please specify what aerosol nucleation refers to, cloud droplet activation or secondary particle formation?

>Replaced "aerosol nucleation" with "cloud elements activation" in section 3.2.1 to clarify the atmospheric processes being investigated and remove ambiguity. The original phrasing was written with aerosol nucleation as a synonym of cloud droplet activation, which is not correct and not specific enough.

Line 275: The warm front appears to approach from the southwest and move to the northeast

>Corrected the description of the warm front movement in Section 4.1 to specify that it was "The warm front was approaching from the southwest across Frankfurt towards the launch site".

Line 277: What is the meaning of the value (0.15 Jkg-1)?

Figure 3: Please reduce the figure size. The caption states a different CAPE of 1.6 Jkg-1 compared to the text. Please check

>Corrected the text and the caption to consistently state the convective available potential energy (CAPE) as 1.6 J kg−1 in section 4.1 and Figure 3. The value of 0.15 J kg−1 in parentheses, previously used to clarify 'near-zero', has been removed. Reduced the size of Figure 3 as requested.

Lines 284 to 294 are redundant, as the same information is given above in Sec. 2.2.1. Please shorten.

>Restructured the paragraphs in Section 4.2 to eliminate redundant information already covered in Section 2.2.1 and condensed the text to improve flow and conciseness.

Line 294: There seems to be an inconsistency between the flow rate comparison and the particle concentration deviations of the two methods. In Figure 4, the GPS ascent rates appear mainly higher than the TFS flow rate, with only a few outliers. Hence, the particle concentration based on the TFS should be mainly higher than that of the GPS. This seems true for UCASS A (red dots) in Fig. 6. Where are the – 30% deviation by the UCASS d from? The deviations seem to correlate well with the cloud layer between 900 and 800 hPa? Please elaborate!

>We have elaborated on this to clarify the deviation Section 4.2: Data Analysis and Instrument Comparison. We attribute this deviation to the interaction between instantaneous internal flow fluctuations and the saturated environment, rather than a true discrepancy in the macroscopic ascent rate. Regarding the contradiction the plots have been reviewed and updated, misaligned data from the descent was included, increasing the number of points with a positive deviation.

Lines 295 to 309: It is obvious that UCASSa, with a detection size range of 0.3-32.5 µm, must provide higher particle number concentration outside of clouds than UCASSd, with a detection range of 9-51.5 µm. The effect of particle sampling losses due to impaction (which is textbook knowledge, e.g., Barron & Willeke) is negligible for comparing the two UCASS units with entirely different size ranges for measurements of the ambient aerosol size distribution. The number concentration of aerosol particles < 1µm is often orders of magnitude higher than above 9 µm.

Section 4.2 has been updated. The difference in total particle number concentration is driven by the distinct detection size ranges of the two units (0.3 µm vs. 9 µm), as submicron particles naturally dominate ambient aerosol concentrations. We have removed phrasing that incorrectly framed this expected difference as an 'instrument-specific overestimation' or 'discrepancy'. Additionally, we restructured the paragraph to ensure the discussion of sampling losses due to non-isokinetic flow and inertial impaction is contextually presented as a general limitation for measuring coarse mode particles, rather than as an explanation for the difference between the two UCASS units. Compare overlapping bins in the UCASS.

Lines 320 to 325: Why does the overestimation of LWC from overrepresenting larger cloud particles align with the overcounting of smaller particles? Please elaborate

To address the reviewer's concern regarding the logical inconsistency, the following clarification has been added to Section 4.3:

"This overcounting of small particles alone cannot mathematically account for the overestimation of LWC observed. Instead, the inflated LWC is likely the result of coincidence errors. In dense cloud environments, or when droplet shattering creates a sudden, localized burst of smaller droplets (Spanu et al., 2020; Huang, 2021), multiple particles pass through the instrument's measurement volume simultaneously. The OPS registers their combined 390 scattered light as a single, artificially large droplet. Because volume scales cubically, erroneously shifting these counts into larger size bins leads to an inflation of the calculated LWC."

Line 344 to 345: To which particle size range do these concentrations refer?

>To improve clarity, the paragraph now reads: During the initial 600 m of ascent, significant particle concentrations were detected in both water-saturated and unsaturated air parcels. This high particle loading was visually corroborated by video footage showing decreased visibility, indicative of water condensation on aerosols. Within the saturated air parcel between 1000 and 2000 m ASL, total particle concentrations measured by both UCASS instruments peaked at 1000 particles per cm^3, before decreasing with altitude to approximately 50 particles per cm^3.

Line 346: Which two instruments?

>The ambiguity was removed for this comment and the previous comment by specifying that the text refers to the two UCASS units.

Line 353 to 356: In Figure 10, there is no comparison between the UCASS and the POPS possible for the overlap size range from 0.3 to 2.6 µm. Please add the entire size range of down to 0.3 µm for the UCASS a to Fig. 10 and discuss potential differences between the two instruments.

>Figure 10 has been updated. We clarify that the plot is not intended as a direct comparison between UCASS and POPs, but rather reports the size ranges and measured concentrations for both instruments. A direct comparison of the boundary bins under edge conditions is avoided, as it targets different modes and does not accurately reflect either instrument's performance. Furthermore, Schön et al. (2024) note that the first UCASS bins must be interpreted with caution.

Figure 10: There is an inconsistency between the covered height range and the averaging time. With the balloon's average ascent rate of about 6 m/s, a 1-minute average should cover an altitude range of about 360 m, not 56 m, as the difference between 1761 and 1817 m. Please correct

>We agree, the plot is a 10 second average. Therefore the figure caption was corrected from 'one-minute average' to '10 seconds average' to accurately correspond to the 56 m altitude range (1761 m to 1817 m).

Line 360: rephrase “aerosol-water activation” into “cloud droplet activation”. The POPS cannot differentiate between hygroscopic and hydrophilic particles.

>The phrase was replaced. The text now reads: 'This pattern is a direct in-situ observation of cloud droplet activation.

Line 368: What is Jacobson’s modeled mode? It seems to be non-activated particles in a water-saturated environment. Provide more information

>The mode we were referring to represents the non-activated (interstitial) particles residing within the water-saturated cloud environment. The paragraph now clearly states: “Jacobson (2003) showed through modeling that within a water-saturated cloud environment, aerosol populations partition into two distinct modes based on their chemical composition and size: activated cloud droplets and unactivated interstitial aerosols.”

Figure 9 Caption: What means: “UCASSa, UCASSd (middle) have an optical particle diameter of 1.51µm and POPS (right) of 1.41µm.”?

>The caption for figure 9 has been updated to describe precisely the assumed refractive index for each instrument. The revised caption of Figure 10 reads: "UCASSA, UCASSD (middle) were derived assuming a refractive index of 1.51+0.00i, while POPS data (right) were processed assuming a refractive index of 1.52+0.00i"

Line 380: At a constant pump power consumption across declining ambient pressure during ascent, results probably in a continuously decreasing sample flow due to decreasing air density. Without monitoring the sample flow or at least the necessary critical pressure drop across the orifice, a constant sampling cannot be assumed. Hence, the aerosol population at lower altitude levels is potentially overrepresented in your impactor samples.

>The reviewer confuses mass flow with volumetric flow. Aerosol sampling depends on volumetric flow, not mass flow. Laboratory tests (Fig. S8) show the system maintains a stable

volumetric flow despite pressure drops. Therefore, samples from lower altitudes are not overrepresented. We added this clarification to the text and retained the operational limitations in Section 4.4.

Line 385: It seems unlikely that the downward-facing inlets of the impactors collect cloud particles of 25 µm size when the balloon is ascending at 6 m/s, because of particle inertia. Please provide a calculation of the impactor inlet sampling efficiency.

>We agree with the reviewer’s assessment. At an ascent rate of 6 m/s, the sampling conditions are highly sub isokinetic. Due to their high inertia, large mature cloud droplets (such as 25 µm) cannot follow the streamlines into the impactor inlet and are effectively excluded from the sample.

We realize that our phrasing in the original manuscript loosely implied that we were collecting these large cloud droplets to analyze their residuals, which caused understandable confusion. Rather than providing a theoretical calculation of sampling efficiency, we rely on the established empirical limits for this specific inlet and impactor configuration. We clarify in Section 2.2.3 of our manuscript that the transmission efficiency of this inlet sharply deteriorates for larger particles.

We have revised Section 4.4 to explicitly clarify this physical limitation and correct our description of the sampled air.

Line 389 - 393: This is inaccurate, and the authors may improve foundational knowledge of aerosol science. A well-mixed atmospheric layer is usually defined by atmospheric stability and turbulence. The aerosol population in the boundary layer, on the other hand, is almost always a mixture of different aerosol sources (primary or secondary). Thus, heterogeneity in the aerosol population within a well-mixed atmospheric layer is expected. Aerosol particles of different origins coexist within an air mass and are not confined to single air parcels that coexist beside each other. The case does not point towards a complex atmospheric structure; in fact, the observed structure is rather common.

>We agree with the correction. The previous text misinterpreted the relationship between atmospheric mixing and aerosol heterogeneity. The paragraph has been rewritten to accurately state that a heterogeneous mixture of particles is the expected result of multiple regional sources integrating within a well-mixed boundary layer, rather than an indicator of unmixed, isolated air parcels.

Line 396: The sentence is too strong as written. Ammonium sulfate is common in aged continental aerosol, but it is not universally present nor uniquely defining in every sampled air layer or region.

>We agree that ammonium sulfate does not exclusively define atmospheric aging. We have revised the text to remove the absolute claim and clarify the common connection.

Figure 11: Decrease the size of the figure in height by plotting in two columns.

>The figure size has been reduced and reformatted into two columns to save space.

Line 403: Which Lagrangian back trajectory tool was used? Please provide references

>The description of the tool has been added to Section 2.4, as it is better suited for the methodology section.

Lines 409 to 417: The whole paragraph needs rephrasing as multiple sentences appear twice.

>We have removed the redundant sentence and slightly rephrased the paragraph.

Line 419: introduce all abbreviations!

>The abbreviations were introduced accordingly.

Line 418 to 426: Cancel the whole paragraph as it does not concern the presented platform but some sample treatment issues. Also, only a certain specific type of particles entering the impactor through diffusional processes (which are they???) is not in line with the fundamentals of aerosol physics.

>We agree with this assessment. The referenced paragraph has been removed from the revised manuscript.

Figure 12: Decrease the figure size.

>Figure caption: “The presence of ammonium sulfate, a secondary aerosol species, indicates that the sampled air mass has undergone significant atmospheric aging.” is inaccurate. Ammonium sulfate can also exist in relatively fresh air masses. More indicators are necessary to derive atmospheric aging.

The figure size has been reduced and the caption has been revised to remove the absolute claim regarding atmospheric aging.

Figure 13: Combine with Figure 13.

>The figures 11, 12, 13 have been combined in one single plot, with the caption reading as:

“All separate particle figures were combined into a single multi-panel figure (Figure 12), utilizing panels (a) through (f) of the sampled aerosol particles. The new caption reads:

Examples of individual aerosol particles collected by the dual-stage impactors during the BISTUM24 flight on 14th June 2024, analyzed via SEM and EDX. The panels display the chemical heterogeneity of the sampled aerosol particles. Particles collected as cloud residuals by the first impactor (500-4500 m) include (a) an iron-rich agglomerate likely from industrial or traffic sources, (b) an aged secondary sulfate particle, and (c) an alumino-silicate mineral dust grain. Particles from the free troposphere (4500-7600 m) are shown in (d) illustrating complex, internally mixed aerosols characteristic of aged continental air masses. The corresponding EDX spectra (e) reveal elemental signatures of Nitrogen (N), Sulfur (S), and Oxygen (O), consistent with a composition of nearly pure ammonium sulfate (NH4)2SO4. The EDX spectra for (f) reveal elemental signatures of Potassium (K) and Calcium (Ca).”

Figure 14: Move to supplement. The trajectories do not add information. From the wind direction alone, it can be inferred that the boundary-layer aerosol at the sample location is influenced by different anthropogenic sources in the Rhine-Main region.

>Moved to the supplement as requested.

Line 436: Figure 15 is introduced but not discussed. Can be deleted

>Figure 15 and its corresponding references in the text were removed entirely from the manuscript.

Line 451: Sentence appears twice

>Sentence corrected in Section 4.5. The duplicate phrase "These limitations are particularly pronounced in humid conditions" has been removed.

Line 476: No modularity was shown; only a single configuration was shown.

>The manuscript has been corrected to eliminate the inaccurate claim of modularity in Section 5. Our intention was to highlight the platform's *flexibility*, its structural and electronic ability to accommodate different lightweight instruments depending on a campaign's scientific goals.

Line 479: How do you know that the cloud droplets were newly formed?

>Removed the word "newly formed" from the text in Section 5 and replaced it with: “While POPS measured the depletion of accumulation mode particles, the UCASS simultaneously captured an increased number of cloud droplets."

Line 481 - 483: This conclusion is not supported by the study. Only single samples of the aerosol population were shown, which are not representative of the population as a whole.

>The particle origin was connected to a broad region, and the back trajectories did not add further information. Finally, it was shown that aerosol particles were activated into cloud particles, but no quantification was provided. In summary, there is not much added value.

The conclusion has been revised to clarify that these measurements are qualitative snapshots demonstrating the platform's capabilities, rather than a statistically representative quantification of the aerosol population which would need a stronger statistical base.

Line 484: The process level view is not supported without a proper quantification of aerosol and cloud particle number concentration.

>The case study does not give exact particle number concentrations for different sized particles and thus the process level is not captured accordingly. The text has been rephrased.

Line 487: Compared to tethered balloons, the ascent rate is quite high

>Tethered balloons offer an advantage over free-floating balloons, as ground control mechanisms allow them to elevate or descend on command at varying speeds. However, compared to typical aircraft, free-floating balloons provide higher vertical resolution and a significantly wider vertical range than tethered balloons.

Line 493: It was not mentioned before that the impactors remain open during descent.

>This was not mentioned previously, now it is mentioned in the impactor section 2.2.3 that the geometry is open.

Line 505: It does not seem cost-effective to single-use an instrument like the POPS, which costs about 20 k€, if the balloon gets lost.

>Payload loss significantly reduces cost-effectiveness. Our initial assessment was based on the recovery rate achieved during two proof-of-concept campaigns. The manuscript has been revised to explicitly acknowledge this limitation with the phrase: “Operationally, although the payload is designed for recovery and repeated use to ensure cost-effectiveness, the inherent risk of instrument loss remains a financial limitation.”