Response to Reviewer 2 (RC2)

Manuscript ID: egusphere-2026-2705

"Evaluation and Correction of Precipitation Types Measured by a PARSIVEL^2 Disdrometer in a Tropical Glacier Environment"

General assessment

Reviewer comment: *Optical disdrometers, especially commercial products are often used without examining the internal data processing. It is important to evaluate the output of optical disdrometer, that is, the main topic of this paper. The referee think that this problem is commonly recognized in cloud physics community currently and publishing this paper is expected to be timely. The title of this paper is attractive to the reviewer.*

Characteristics of measurement of PARSIVEL2 is well considered. This paper carefully presents measurement error of PARSIVEL2 and a correction method including the limitation of the method. Especially, Figure 3 is impressive to the reviewer.

The result of analysis and validation are also carefully described. Adequate description of possible errors are also shown. This paper can be recommended to the researchers and observers who use internally processed variables of commercial optical disdrometers.

Author response: We are sincerely grateful to the reviewer for the time and care devoted to our manuscript and for the encouraging assessment of its relevance for the cloud physics community and for users of commercial optical disdrometers. We particularly appreciate the large number of detailed observations, from the overall structure and the consistency between figures and text down to individual values, typos and references. Which has substantially improved the clarity and quality of our work.

Revised figures. The comments on the figures have already been implemented: the figures of the results and methods (Figs. 4–14) have been redrawn following a common standard (vector graphics, a colour-blind-safe palette, consistent units such as $\mathrm{m\,s^{-1}}$ and $N(D)$ in $\mathrm{m^{-3}\,mm^{-1}}$, and larger fonts), and those related to the reviewer's comments are shown in this response (Figs. R1–R3). Fig. 2 will be redrawn following the same standard. The revised figures will replace the original ones in the revised manuscript. While redrawing the figures and checking the text against them, as the reviewer recommended, we identified and corrected several errors, which we report here for transparency.

- In Table 2, one coefficient (lump graupel), two interchanged type names, the attribution of three relationships and the diameter ranges of the original observations (see RC2.20 and Table R2).
- In Figs. 7 and 14, the mean particle size distribution had been obtained by summing the logarithmic values reported by the instrument; it is now computed from linear concentrations.
- In Fig. 12, the widths of some diameter classes used to back-calculate the densities of the internal algorithm (see RC2.22).
- In the text, the file counts of Table 1 for November and December 2022 (RC2.18), several values quoted from the figures (e.g., RC2.39 and RC2.40).

We emphasize that none of these corrections changes the final results or the conclusions of the study. All errors found are descriptive analyses that do not enter the correction method.

Changes to the text. All other changes described below will be implemented in the revised manuscript, which will be submitted after the open discussion; for this reason, they are described in the future tense. In what follows, the reviewer's comments are reproduced in *italics*, our responses in blue, and the changes that will be made in the manuscript in black.

General comments

RC2.1 – Sentence structure and technical errors

Reviewer comment: *There are many sentences concatenating phrases using "," or ";". Some of this type of sentences were not clear to the reviewer. Dividing those sentences may improve the clarity of the manuscript. Typos were sometimes found. The reviewer checked technical errors of the manuscript at first, though skipped later, because they were too many. Checking technical errors of the whole manuscript is recommended.*

Author response: We thank the reviewer and apologize for the number of technical errors. Following this suggestion, long sentences joined by commas or semicolons will be split into shorter sentences, and the whole manuscript will undergo a thorough language and technical revision, including all the corrections listed by the reviewer.

Changes in the manuscript: Whole manuscript.

RC2.2 – Consistency between figures and main text

Reviewer comment: *There are mismatches between Figures and main text. Sometimes, referred figure number in the main text was wrong. Some values in the main text and in the corresponding figure were different. Axis labels of figure panels should be checked, for example, both "m s-1" and "m/s" are seen and "1/m^3 mm" is ambiguous.*

Author response: We thank the reviewer for this observation. All figure references and all values quoted from figures will be checked against the figures. This includes the corrections pointed out by the reviewer in the specific and technical comments (e.g., Fig. 1e instead of Fig. 1d in L. 96; Fig. 4 instead of Fig. 11 in L. 199–214; the percentage in L. 270). All axis labels will use the same unit convention (e.g., $\mathrm{m\,s^{-1}}$, $\mathrm{mm\,h^{-1}}$, $\mathrm{mm\,d^{-1}}$, $\mathrm{g\,cm^{-3}}$), and the unit of the particle size distribution will be written unambiguously as $N(D)$ ($\mathrm{m^{-3}\,mm^{-1}}$).

Changes in the manuscript: Main text and Figs. 2, 4, 7, 8, 9, 10, 12, 13 and 14.

RC2.3 – Format of citations and reference list

Reviewer comment: *Overall technical (format) check of citation in the main text and reference list is necessary.*

Author response: We agree. The format of all in-text citations (e.g., L. 107–108 and L. 132) and the reference list will be checked and corrected; residual comments, misspelled author names and incomplete entries will be corrected (see also our responses to comments RC2.24, RC2.27, RC2.28 and RC2.43–RC2.46).

Changes in the manuscript: In-text citations throughout the manuscript and reference list.

Specific comments

Abstract

RC2.4 – Meaning of the percentages

Reviewer comment: *Line 11, Line 12: What is the meaning of percentage in the parentheses.*

Author response: We thank the reviewer. The percentages are mean relative biases between the PARSIVEL^2 and Pluvio^2 event accumulations, i.e. the mean of the event-wise relative differences (positive values indicate overestimation and negative values underestimation), not correlation coefficients. Since this was not clear, the sentence will be rewritten: it will state the reference instrument explicitly and report the mean relative bias together with the slope of the regression between both instruments. Both metrics will be defined in Sect. 3.3.3.

Changes in the manuscript: Abstract, L. 7–18, and Sect. 3.3.3. The revised sentences of the abstract will read: "Relative to the Pluvio^2, the PARSIVEL^2 systematically overestimated mixed-phase and solid precipitation, with mean relative biases of +98.5 % and +84.1 % and regression slopes of 1.936 and 2.103,

respectively. For liquid precipitation, the agreement was good (slope 0.918; mean bias 0.00 mm), although light events were overestimated (mean relative bias +15.7 %)."

RC2.5 – Need for post-processing corrections

Reviewer comment: *Lines 18-19 "These results demonstrate the need for post processing corrections of disdrometer measurements": I agree this point from my own experience.*

Author response: We thank the reviewer for sharing this experience. We believe that it is important to continue evaluating the performance of disdrometers in different environments and to develop correction methods adapted to each of them.

Changes in the manuscript: No change.

1 Introduction

RC2.6 – Regional scope of the references

Reviewer comment: *Line 23: Referred papers are researches on the tropical Andes regions. "in the tropical Andes regions" would be more appropriate than "in tropical regions". Otherwise, papers on the other tropical high-altitude regions should be added.*

Author response: We agree. The statement will be restricted to the tropical Andes.

Changes in the manuscript: Introduction, L. 23: "Concerns about water availability have been linked to declining glacier cover in the tropical Andes region (Buytaert et al., 2017)."

RC2.7 – Structure of the paper

Reviewer comment: *Arrangement of chapters should be written in the last part of Introduction. It will help the readers, especially, to know that Sections 4.1 and 4.2 describe on PARSIVEL2 built-in hydrometeor classification, and that Sections 4.3 and 4.4 describe the correction method developed in this paper.*

Author response: We thank the reviewer for this suggestion. The last paragraph of the Introduction will be restructured: the objectives and the proposed method will be stated more concisely and followed by a description of the structure of the paper, which makes explicit that Sections 4.1 and 4.2 address the PARSIVEL^2 built-in classification and Sections 4.3 and 4.4 the correction method.

Changes in the manuscript: Introduction, L. 47–52. The last paragraph will read:

> "This study evaluates and adjusts precipitation estimates from a PARSIVEL^2 optical disdrometer using concurrent measurements from a weighing precipitation gauge at a high-altitude tropical glacier site in the Peruvian Andes. By comparing and combining both instruments, we assess the capabilities and limitations of the PARSIVEL^2 for quantifying liquid and solid precipitation, and we develop a correction method that reclassifies hydrometeors using empirical diameter–velocity relationships and recomputes precipitation with category-specific apparent densities. The remainder of the paper is organized as follows. Section 2 describes the study area, the instruments, and the quality control applied to the data. Section 3 presents the methods, including the PARSIVEL^2 precipitation type identification, the computation of the particle size distribution and precipitation intensity, and the proposed correction method. Section 4 presents the results: Sections 4.1 and 4.2 evaluate the PARSIVEL^2 built-in hydrometeor classification and its precipitation estimates against the Pluvio^2 weighing gauge; Section 4.3 presents the hydrometeor reclassification and the event-based precipitation re-estimation obtained with the correction method; and Section 4.4 examines its effect on the particle size distribution of the extreme events. Section 5 discusses the hydrometeor characterization and its physical implications, as well as the performance and limitations of the transfer function applied to the weighing gauge. Section 6 summarizes the main conclusions."

2 Site and data – 2.1 Area of study

RC2.8 – Type of transition

Reviewer comment: *Line 63: I could not catch whether the "transition" is "temporal transition" or "spatial transition".*

Author response: We thank the reviewer for noticing this ambiguity. The transition is spatial: the site lies between the glacier, where the most intense cold occurs, and the cold periglacial surface. The sentence will be reworded accordingly (see also the revised Sect. 2.1 in our response to comment RC2.12).

Changes in the manuscript: Sect. 2.1, L. 62–64: "Located in the spatial transition between the glacier, where the most intense cold occurs, and the cold periglacial surface, the area experiences recurring frost and seasonal snow cover (Pollard, 2018)."

RC2.9 – Maximum temperature

Reviewer comment: *Line 79: Was the same maximum value of 15 recorded in several months? Or, the measured values were truncated at 15?*

Author response: We thank the reviewer for noticing this. The values were not truncated; the paragraph contained an editing error. The statistics were recalculated from the 1-min records, and the paragraph will be corrected accordingly.

Changes in the manuscript: Sect. 2.1, L. 77–80: "The average monthly temperature ranges from 2 to 4 °C, increasing by one degree during the dry season months, with an average standard deviation of 2.31 °C (Fig. 2a). The minimum temperature, −4.4 °C, was recorded in June 2023 and the maximum, 13 °C, in December 2023. Temperature and humidity show an inverse relationship throughout the study period. The average relative humidity ranges from 54 to 95 %, with maximum values of 97 to 100 % each month."

RC2.10 – Maximum wind speed

Reviewer comment: *Line 85: Was the same maximum value of 15 recorded in several months? Or, the measured values were truncated at 15?*

Author response: As for the temperature (comment RC2.9), the values were not truncated; the text contained an editing error. The wind statistics were recalculated from the 1-min records, and the paragraph will be corrected and reorganized (see also comment RC2.26).

Changes in the manuscript: Sect. 2.1, L. 84–86: "Monthly mean wind speeds varied little, ranging from 2.26 to 2.88 $\mathrm{m\,s^{-1}}$ (Fig. 2b). The 1-min records, which are not shown in Fig. 2b, reached a maximum of 12.7 $\mathrm{m\,s^{-1}}$ in August 2023. Calm conditions (0 $\mathrm{m\,s^{-1}}$) were recorded in every month, and the lowest non-zero wind speed was 0.30 $\mathrm{m\,s^{-1}}$."

RC2.11 – Error bars in Fig. 2

Reviewer comment: *Caption of Figure 2: The meaning of error bars in (a) and (b) should be described.*

Author response: Thank you. The monthly values were computed from the 1-min records, and the error bars represent ±1 standard deviation of these records. The caption will describe the error bars and the data coverage information shown in panel (c).

Changes in the manuscript: Caption of Fig. 2: "Figure 2. Monthly atmospheric conditions during the study period. (a) Monthly mean air temperature and (b) monthly mean wind speed; error bars indicate ±1 standard deviation of the 1-min records. (c) Conditional daily mean precipitation for each month, computed from the available Pluvio^2 records; bar colours and marker shapes indicate the monthly data coverage (≥ 80 %, 40–79 % and < 40 %), and the dashed line shows the daily mean precipitation per month. (d) Monthly wind direction."

RC2.12 – Relation between Fig. 2 and the main text

Reviewer comment: *Figure 2 and corresponding part of the main text are not well related.*

Author response: We agree. The paragraphs describing the atmospheric conditions at the site will be reorganized so that they follow the order of the panels of Fig. 2 (a–d), include the corrected values (comments RC2.9 and RC2.10), and conclude by linking these conditions to the precipitation phases observed at the site and to the event-based analysis adopted in this study.

Changes in the manuscript: Sect. 2.1, L. 62–88. The revised paragraphs will read:

> "The CEMGEM site lies in the periglacial belt of a high-mountain ecosystem adjacent to a tropical glacier. Located in the spatial transition between the glacier, where the most intense cold occurs, and the cold periglacial surface, the area experiences recurring frost and seasonal snow cover (Pollard, 2018). The National Service of Meteorology and Hydrology of Peru (SENAMHI) classifies the area as very rainy, with abundant humidity throughout the year and a semi-frigid climate, with maximum temperatures of 13–15 °C, minimum temperatures of 1–5 °C and an annual precipitation of 700–1200 mm.
>
> Figure 2 summarizes the monthly near-surface conditions recorded at the station during the study period, computed from the 1-min records. The monthly mean air temperature ranged from 2 to 4 °C, about one degree higher during the dry-season months, with an average standard deviation of 2.31 °C (Fig. 2a). The 1-min temperatures ranged from −4.4 °C (June 2023) to 13 °C (December 2023). Relative humidity (not shown) varied inversely with temperature, with monthly means of 54 %–95 % and maxima of 97 %–100 % in every month. Monthly mean wind speeds varied little, from 2.26 to 2.88 $m\,s^{-1}$ (Fig. 2b). Calm conditions (0 $m\,s^{-1}$) were recorded in every month, the lowest non-zero wind speed was 0.30 $m\,s^{-1}$, and the maximum reached 12.7 $m\,s^{-1}$ in August 2023. These speeds are close to those typically found in glaciated catchments (3–5 $m\,s^{-1}$), where the complex topography accelerates or decelerates the air flow (Dadic et al., 2013), and they are relevant for snow redistribution, which also depends on the type of falling crystals (Mott et al., 2018).
>
> Because the precipitation record is incomplete, Fig. 2c shows a conditional daily mean precipitation for each month, calculated as the monthly total divided by the number of equivalent days with valid Pluvio^2 records (number of valid 1-min records/1440). Only December, February and March reached a data coverage of at least 80 %, with mean daily precipitation of 4–5 $mm\,d^{-1}$; April, May, June, August and September, with lower coverage, show values of 2–4 $mm\,d^{-1}$. Precipitation at the site is driven by the adiabatic ascent of humid air masses from the central Amazon, which the local orography channels from the northeast (Espinoza et al., 2020). However, the dominant flow measured at the station comes from the southeast and shifts toward the north, where the glacier is located, during the transition and dry seasons (Fig. 2d). At the interannual scale, the tropical central Andes are affected by ENSO: El Niño events are associated with higher temperatures and a reduced and delayed snow accumulation, whereas La Niña events bring cooler temperatures and greater snow accumulation (Maussion et al., 2015).
>
> Overall, near-surface temperatures close to 0 °C and high humidity favour the coexistence of liquid, mixed-phase and solid precipitation at the site, while the irregular temporal coverage of the precipitation record motivates the event-based analysis adopted in this study (Sect. 3.3.1)."

2.2 Instruments and data – 2.2.1 Weighing precipitation gauge

RC2.13 – Panel showing the Pluvio^2

Reviewer comment: *Line 96: Shown as "Fig. 1d" is not the Pluvio2. I guess that the facility next to PARSIVEL2 might be the Pluvio2. Figure 2 needs correction.*

Author response: We thank the reviewer. The reviewer is correct: the Pluvio^2 is shown in Fig. 1e, next to the PARSIVEL^2, and the figure reference in the text will be corrected. We understand that the correction requested refers to this figure reference; in addition, Fig. 2 will be redrawn with consistent units, larger fonts and a description of the error bars in the caption (see comments RC2.11 and RC2.12).

Changes in the manuscript: Sect. 2.2.1, L. 96: "... every minute (Fig. 1e)."

RC2.14 – Calculation of the accumulated precipitation

Reviewer comment: *Line 102 "added": "used to calculate"? I guess that the difference of weight would be converted to the increase of precipitation.*

Author response: Yes, the reviewer's understanding is correct. As described in the manufacturer's manual, the weight differences measured every 6 s are converted into precipitation increments, which are used to calculate the accumulated precipitation of each minute. The sentence will be reworded as suggested.

Changes in the manuscript: Sect. 2.2.1, L. 101–102: "It determines the precipitation intensity from the difference between the current and previous container weights, and these differences are used to calculate the accumulated precipitation."

RC2.15 – Reference to Sect. 2.2.4

Reviewer comment: *Line 109: The correction of wind-induce catch loss is described in Section 2.2.4. Adding "(Section 2.2.4)" would be kind to the readers.*

Author response: Thank you. The cross-reference will be added.

Changes in the manuscript: Sect. 2.2.1, L. 109: "In the present study, a transfer function was applied to correct the undercatch of the unshielded gauge (Sect. 2.2.4)."

RC2.16 – Evaporation losses

Reviewer comment: *On the Pluvio observation: Was the countermeasure to the evaporation loss (for example, an oil layer on the water in the collecting container) applied? If so, it should be described.*

Author response: We thank the reviewer for raising this point, which we answer together with comment RC2.17. No countermeasure against evaporation losses (e.g., an oil layer) or snow capping (e.g., antifreeze) was applied, as this was the first deployment of a weighing gauge at this high-mountain site, and no log of the maintenance operations is available for the study period. The available Pluvio^2 record consisted of the real-time intensity and the non-real-time accumulated precipitation and bucket content. Precipitation was therefore derived from the 1-min differences of the accumulated precipitation, which was the most complete variable. Drops of the accumulated value to zero identify the times when the container was emptied; according to the person in charge of the data downloads, the container was emptied during the field visits only when its content was liquid, and frozen content was left until it melted, which could last until the next visit. The resulting negative differences were removed, and only 1-min increments between 0 and 30 mm were retained, which excluded a single outlier. No further quality control was possible with the available information. We acknowledge that these limitations of the reference record add uncertainty to the comparison, particularly for snow events.

Changes in the manuscript: Sect. 2.2.1 and 2.2.4 (description of the available Pluvio^2 variables and of the quality control of the accumulated precipitation) and Sect. 5.2 (discussion of these limitations and of the need to document maintenance operations in future campaigns).

RC2.17 – Snow capping

Reviewer comment: *On the Pluvio observation: How was the countermeasure to the snow capping on the facility?*

Author response: Please see our response to comment RC2.16.

Changes in the manuscript: See RC2.16.

2.2.4 Quality control

RC2.18 – Caption of Table 1

Reviewer comment: *Caption of Table 1: The sentence below the table needs improvement and should be included in the caption. Is each line of the table indicates the result of filtering for 1-month of data?*

Author response: Yes, each row corresponds to one month of PARSIVEL^2 data. The note below the table will be moved into the caption, a column with the monthly data coverage will be added, and the meaning of each filter will be explained in Sect. 2.2.4. While re-checking the filters, we found that the counts of November and December 2022 had been misreported in the original table; they will be corrected as shown in Table R1. Filter 1 removed 12 empty files in total (between 0 and 7 per month), and Filter 2 removed 10 files with invalid characters, all in November 2022. Filter 3 did not remove any file: the sensor status remained 0 in all records, which indicates that the measurements were not affected by lens contamination or laser malfunction. The revised caption will read: "Table 1. Monthly number of 1-min PARSIVEL^2 data files before (Original) and after each sequential quality-control filter: Filter 1 removes empty files, Filter 2 removes files with invalid characters (non-standard UTF-8 encoding), and Filter 3 removes the minutes in which the sensor status variable indicates an instrument problem (status different from 0, i.e. lens contamination or laser malfunction). Coverage is the number of valid files divided by the number of minutes in the month. The last column gives the number of minutes with recorded precipitation after filtering."

Changes in the manuscript: Table 1 and Sect. 2.2.4 (L. 126–130). The revised table is shown in Table R1.

Table R1. Revised Table 1. Monthly number of 1-min PARSIVEL^2 data files before (Original) and after each sequential quality-control filter: Filter 1 removes empty files, Filter 2 removes files with invalid characters (non-standard UTF-8 encoding), and Filter 3 removes the minutes in which the sensor status variable indicates an instrument problem (status different from 0). Coverage is the number of valid files divided by the number of minutes in the month. The last column gives the number of minutes with recorded precipitation after filtering.

Month	Original	Filter 1	Filter 2	Filter 3	Coverage (%)	Precipitation (min)
2022-11	4 738	4 737	4 727	4 727	10.9	540
2022-12	25 645	25 638	25 638	25 638	57.4	5 225
2023-01	12 703	12 703	12 703	12 703	28.5	1 391
2023-02	19 880	19 880	19 880	19 880	49.3	5 671
2023-03	19 442	19 442	19 442	19 442	43.6	3 486
2023-04	25 244	25 244	25 244	25 244	58.4	1 026
2023-05	19 148	19 146	19 146	19 146	42.9	370
2023-06	4 130	4 129	4 129	4 129	9.6	179
2023-07	1 423	1 422	1 422	1 422	3.2	2
2023-08	7 867	7 867	7 867	7 867	17.6	7
2023-09	9 427	9 427	9 427	9 427	21.8	543
2023-10	1 072	1 072	1 072	1 072	2.4	115
2023-11	6 035	6 035	6 035	6 035	14.0	679

3 Methods

RC2.19 – Reference for the effective sampling area

Reviewer comment: *Line 156: Is it possible to add the reference on the description "(30 mm - Di/2)"? This definition is seen in some literature without reference.*

Author response: Thank you. The reference Tokay et al. (2014), in which this effective sampling area is described, will be added.

Changes in the manuscript: Sect. 3.2, L. 156.

RC2.20 – Hail category

Reviewer comment: *Table 2: Both "Hailstones" and "Hail" would be a single category "Hail".*

Author response: We agree. "Hailstones" and "Hail" will be merged into a single category, "Hail", in Tables 2 and 3, Eq. 3, Fig. 11 and throughout the text. Because the empirical curves of this category describe hail (Knight and Heymsfield, 1983; Allen et al., 2020; Heymsfield and Wright, 2014), the term "soft hail", used for this category in the original manuscript, will be avoided: it is commonly used as a synonym of graupel (snow pellets; American Meteorological Society, Glossary of Meteorology), which is a separate category in our scheme. While revising this table, we also re-checked every relationship against its original source and corrected one coefficient (lump graupel, $1.16\,d^{0.46}$), two interchanged type names (S5 and S6), the attribution of three relationships (rain, dendrites and hail) and the diameter ranges. A column with the curve codes used in Fig. 4 will be added. The revised table is shown in Table R2.

Changes in the manuscript: Tables 2 and 3, Sects. 3.3.2 and 3.3.3, Eq. 3, Sect. 4.3 and Fig. 11.

Table R2. Revised Table 2. Empirical fall velocity relationships (v in $\mathrm{m\,s^{-1}}$, d in mm) used to define the segmentation masks of each hydrometeor category, with the codes used in Fig. 4. Diameter ranges are those of the original observations; outside these ranges the curves are extrapolated. C is the air-density correction factor of Foote and du Toit (1969, Eqs. 7–8), equal to 1.236 for the mean pressure (582.4 hPa) and temperature (1.6 °C) of the selected events. The curves for solid hydrometeors are not corrected for altitude.

Category	Code	Type	Diameter range (mm)	Fall velocity ($\mathrm{m\,s^{-1}}$)	Reference
Rain	R	Raindrops	$d < 5$	$(9.65 - 10.3\,e^{-0.6d})\,C$	Atlas et al. (1973), based on Gunn and Kinzer (1949); C: Foote and du Toit (1969)
Wet snow	W	Wet (melting) snow	0.6–9	$4.65 - 5\,e^{-0.95d}$	Fehlmann et al. (2020)
Snow	S1	Unrimed side planes	0.4–1.2	$0.81\,d^{0.99}$	Locatelli and Hobbs (1974)
	S2	Densely rimed dendrites	1.8–4.0	$0.62\,d^{0.33}$	Locatelli and Hobbs (1974)
	S3	Aggregates of unrimed radiating assemblages of plates, side planes, bullets and columns	0.2–3.0	$0.69\,d^{0.41}$	Locatelli and Hobbs (1974)
	S4	Aggregates of unrimed side planes	0.5–4.0	$0.82\,d^{0.12}$	Locatelli and Hobbs (1974)
	S5	Aggregates of densely rimed radiating assemblages of dendrites or dendrites	2.0–12.0	$0.79\,d^{0.27}$	Locatelli and Hobbs (1974)
	S6	Aggregates of unrimed radiating assemblages of dendrites or dendrites	2.0–10.0	$0.8\,d^{0.16}$	Locatelli and Hobbs (1974)
	S7	Densely rimed aggregates	–	$1.1\,d^{0.15}$	Ishizaka (1995), in Ishizaka et al. (2013)
	S8	Rimed aggregates	–	$0.96\,d^{0.12}$	Ishizaka (1995), in Ishizaka et al. (2013)
	S9	Dendrites	–	0.3	Nakaya (1954), in Ishizaka et al. (2013)

Category	Code	Type	Diameter range (mm)	Fall velocity ($m\,s^{-1}$)	Reference
Graupel	G1	Lump graupel (ρ = 0.05–0.1 $g\,cm^{-3}$)	0.5–2.0	$1.16\,d^{0.46}$	Locatelli and Hobbs (1974)
	G2	Lump graupel (ρ = 0.2–0.45 $g\,cm^{-3}$)	0.5–1.0	$1.5\,d^{0.37}$	Locatelli and Hobbs (1974)
	G3	Lump graupel (ρ = 0.1–0.2 $g\,cm^{-3}$)	0.5–3.0	$1.3\,d^{0.66}$	Locatelli and Hobbs (1974)
	G4	Hexagonal graupel	0.8–3.2	$1.1\,d^{0.57}$	Locatelli and Hobbs (1974)
	G5	Conical graupel	0.8–3.0	$1.2\,d^{0.65}$	Locatelli and Hobbs (1974)
	G6	Graupel-like snow of lump type	0.5–2.2	$1.1\,d^{0.28}$	Locatelli and Hobbs (1974)
	G7	Graupel-like snow of hexagonal type	0.8–2.8	$0.86\,d^{0.25}$	Locatelli and Hobbs (1974)
Hail	H1	Fresh hailstones	6.3–15.4	$8.445\,(0.1d)^{0.553}$	Knight and Heymsfield (1983)
	H2	Soaked hailstones	–	$10.58\,(0.1d)^{0.267}$	Knight and Heymsfield (1983)
	H3	Hail (maximum diameter)	–	$12.43\,(0.1d)^{0.4792}$	Heymsfield et al. (2014), in Allen et al. (2020)
	H4	Graupel and hail, ρ = 0.2 $g\,cm^{-3}$	–	$5.23\,(0.1d)^{0.65}$	Heymsfield and Wright (2014)
	H5	Graupel and hail, ρ = 0.9 $g\,cm^{-3}$	–	$12.07\,(0.1d)^{0.64}$	Heymsfield and Wright (2014)
	H6	Graupel and hail, size-dependent density	–	$4.88\,(0.1d)^{0.84}$	Heymsfield and Wright (2014)

RC2.21 – Particles classified in the hail region

Reviewer comment: *Line 208 "most large frozen particles were reclassified as soft hail rather than hard hail in Fig. 11b.": Is this description corresponds to the upper three lines in Fig. 4f?*

Author response: Yes, the statement refers to the upper three curves in Fig. 4f. Because the observed fall velocities remained below 14 $m\,s^{-1}$, only a few particles fell within the hail region, and they lay close to its lower diameter and velocity bounds; this is consistent with the negligible fraction of this category in the corrected classification (0.011 % of the particles; Fig. 11). We agree that the sentence is misplaced in the list of classification boundaries: it will be moved to the end of Sect. 3.3.2, rephrased accordingly, and the figure reference corrected to Fig. 4f.

Changes in the manuscript: Sect. 3.3.2, L. 206–208: "Because the observed fall velocities remained below 14 $m\,s^{-1}$, only a few particles fell within the hail region (Fig. 4f), close to its lower diameter and velocity bounds." This sentence will be placed after the list of categories.

4 Results

RC2.22 – Caption of Fig. 12

Reviewer comment: *Caption of Figure 12: It is necessary to mention that this figure is on the values by the PARSIVEL2 internal algorithm.*

Author response: We agree. The caption will state that the densities are derived from the PARSIVEL^2 internal algorithm: since the manufacturer does not document them, they are obtained as the ratio between the precipitation intensity reported by the instrument and the intensity recalculated with Eq. 2 assuming liquid water. While redrawing this figure, we also found and corrected an error in the diameter class widths used in this calculation (0.25 instead of 0.5 mm for the classes between 2.75 and 4.75 mm), which had inflated the densities up to 1.9 g cm^{-3}. With the class widths of the manufacturer's manual, the densities range from 0.01 to 1.00 g cm^{-3}, with medians of 0.92 (liquid), 0.80 (mixed) and 0.42 g cm^{-3} (solid). This error affected only this figure, and the interpretation of Sect. 4.3.1 is unchanged. The revised figure is shown in Fig. R1.

Changes in the manuscript: Caption of Fig. 12 and Sect. 4.3.1 (L. 433–440): "Figure 12. Distribution of the apparent density values derived from the PARSIVEL^2 internal algorithm, grouped by precipitation phase. The density is the ratio between the precipitation intensity reported by the instrument and the intensity recalculated with Eq. 2 from $N(D)$ and $V(D)$ assuming liquid water ($\rho = 1\,\mathrm{g\,cm^{-3}}$), for all 1-min records with precipitation during the study period. The density values range from 0.01 to 1.00 g cm^{-3}, with mean values of 0.89 (liquid), 0.79 (mixed), and 0.44 g cm^{-3} (solid). Boxes span the 25th to 75th percentiles, the inner line is the median (0.92, 0.80, and 0.42 g cm^{-3}), whiskers extend to the most extreme values within 1.5 times the interquartile range, and dots are values beyond it."

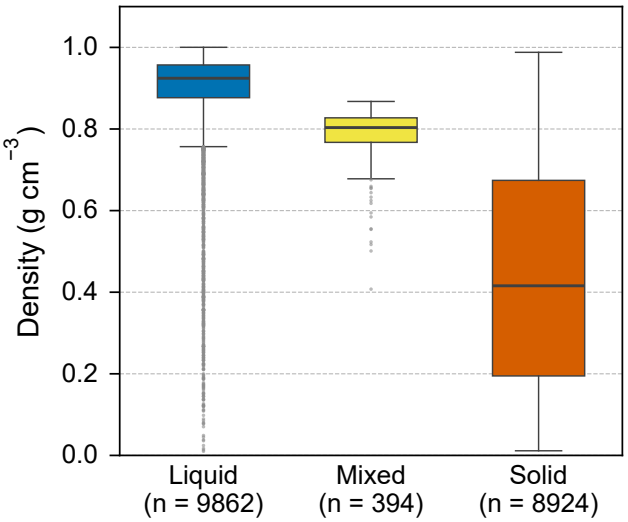

Figure R1. Revised Fig. 12.

Technical corrections

We thank the reviewer for the careful reading. All the technical corrections listed below will be implemented.

No. / Line	Reviewer comment	Author response and change
23 / Section titles	*Uppercase/lowercase of the section title words should be checked.*	The capitalization of all section titles will be made consistent, following the journal style.
24 / L. 34	*The reference should be "(Löffler-Mang and Joss, 1999)". Reference list should also be corrected.*	This will be corrected in the text and in the reference list. We note that the article was published in 2000 (J. Atmos. Oceanic Technol., 17, 130–139; manuscript accepted in 1999); it will therefore be cited as (Löffler-Mang and Joss, 2000).

No. / Line	Reviewer comment	Author response and change
25 / L. 75, 76	*"Fig. 2d": Should be "(Fig. 2d)"*	This will be corrected.
26 / L. 85	*A value of "0.30 m s-1" is not found in Figure 2b.*	The reviewer is right: $0.30\,\mathrm{m\,s^{-1}}$ is the minimum of the 1-min records and is not shown in Fig. 2b, which displays monthly means ±1 standard deviation. The paragraph will be reorganized to report first the values shown in the figure and then the 1-min extremes, stating explicitly that the latter are not shown (see RC2.10).
27 / L. 95	*"HydroMet, 2019": See comment on Line 690.*	This will be corrected to "OTT HydroMet (2019a)", with OTT HydroMet as corporate author in the reference list (see No. 45). The manuals of the Pluvio^2 and of the PARSIVEL^2 will be cited as two separate documents (OTT HydroMet, 2019a, b).
28 / L. 107	*Typically, this author is referred simply as "Goodison et al. (1998)".*	This will be corrected in the text (L. 107 and 574) and in the reference list.
29 / L. 109	*The Referring description should be checked.*	Thank you. The sentence attributed the development of transfer functions to the wrong studies. Transfer functions for the wind-induced undercatch of unshielded gauges were developed and evaluated within WMO-SPICE (Kochendorfer et al., 2017, 2018; Smith et al., 2020), whereas Jia et al. (2023) applied them. The sentence (L. 107–109) will read: "Transfer functions to correct the wind-induced undercatch of unshielded gauges have been developed and evaluated within the WMO Solid Precipitation Intercomparison Experiment (WMO-SPICE; Kochendorfer et al., 2017, 2018; Smith et al., 2020) and applied in other studies (e.g., Jia et al., 2023)."

No. / Line	Reviewer comment	Author response and change
30 / L. 124–125	*A sentence "The instruments .." need some commas.*	Thank you. The sentences will be rewritten for clarity, and the description of the diameter classes will be moved to Sect. 3.2, where the particle size distribution is defined: "The instrument stores the number of particles detected in each minute in a raw data matrix of 32 diameter classes by 32 velocity classes (1024 classes), whose values are integer counts. The diameter classes and the range covered by the data are described in Sect. 3.2. The formats and units of all variables are given in the user manual of the instrument (OTT HydroMet, 2019b)."
31 / Sect. 3.1	*Type Precipitation Identification → Precipitation type identification*	This will be corrected.
32 / L. 156	*"(raw_ data)" appear only once here. It is better to delete it.*	It will be deleted.
33 / L. 191	*"Footec and Toit (1969)": Usually, this literature is referred to as "Foote and du Toit (1969)"*	This will be corrected throughout the text, Table 2, the captions and the reference list.
34 / Table 2	*"C and J": May be "Knight and Heymsfield".*	This will be corrected to "Knight and Heymsfield (1983)".
35 / L. 199–214	*"Fig. 11" may be "Fig. 4".*	This will be corrected: rain, Fig. 4b; snow, Fig. 4d; graupel, Fig. 4e; hail, Fig. 4f.
36 / Fig. 4b	*Shading of rain area is very light and cannot be distinguished from the white background.*	Figure 4 will be redrawn: in panel (a), each segmentation region will have a distinct colour, and in panels (b)–(f) the category of the panel will be highlighted in its colour while the other regions will be shown in much lighter tints. The rain region will thus be clearly distinguishable from the background. The revised figure is shown in Fig. R2.

No. / Line	Reviewer comment	Author response and change
37 / Fig. 4b	*What is "*C" of the equation of v.*	C is the altitude correction factor of Foote and du Toit (1969), which adjusts the raindrop terminal velocity to the air density at the site (4709 m a.s.l.) and is computed with Eqs. (7)–(8) of Foote and du Toit (1969) from the ratio between the reference air density (20 °C, 1013 hPa) and the air density at the site, obtained from the measured pressure and temperature. Using the mean pressure (582.4 hPa) and temperature (1.6 °C) of the 70 selected events, this gives $C = 1.236$. It will be defined in the caption of Fig. 4 and in a footnote to Table 2, with reference to the code repository (`https://doi.org/10.5281/zenodo.19808059`), where its computation is implemented. The equations will be removed from Fig. 4, since they are listed in Table 2.
38 / L. 203	*"tha": "the"*	This will be corrected.
39 / L. 270	*In Figure 5, the amount is "30.6%".*	This will be corrected to 30.6 %, consistent with Fig. 5. The value in L. 270 had not been updated in the text after the final processing. All percentages quoted from Fig. 5 will be checked (e.g., L. 273 and the abstract).
40 / L. 275	*"2.4 m s-1": -> "3.4 m s-1"*	This will be corrected to 3.4 m s^{-1}, consistent with Fig. 6.
41 / Fig. 9 caption	*"(black asterisk)", "(black dot)": I guess "black" is not necessary, because the colors are attributed to the type of hydrometeor.*	This will be corrected to "detection of events by both instruments (asterisks) versus detection only by the PARSIVEL^2 (dots)". The caption will be fully revised, and the revised figure is shown in Fig. R3.
42 / L. 544	*" .. intensity.A finding .. ": " .. intensity; a finding .. " ?*	Thank you. The sentence will read: "... regardless of event intensity. This is a finding that may inform parameterization schemes ...".
43 / L. 614–615	*"Perez (2026b)": -> "(Perez, 2026b)."*	This will be corrected; the same format will be used for Perez (2026a).

No. / Line	Reviewer comment	Author response and change
44 / L. 650	*The author name is not correctly written.*	This will be corrected to "Goodison, B. E., Louie, P. Y. T., and Yang, D.: WMO Solid Precipitation Measurement Intercomparison: Final Report, Instruments and Observing Methods Report 67, WMO/TD-No. 872, World Meteorological Organization, Geneva, `https://library.wmo.int/idurl/4/28336`, 1998."
45 / L. 690	*"HydroMet, O.": "OTT HydroMet" is the name of a company, not surname and family name. So, "HydroMet, O." is strange.*	OTT HydroMet will be cited as corporate author: "OTT HydroMet: Operating instructions: Precipitation gauge OTT Pluvio^2 S, OTT HydroMet GmbH, Kempten, Germany, 2019a."
46 / L. 741	*Ro et al. published in 2023, however, it is included in the journal volume of "Vol. 120 (2024)". I guess that this paper should be referred to as Ro et al. (2024).*	This will be corrected to Ro et al. (2024) in the text (L. 41) and in the reference list.

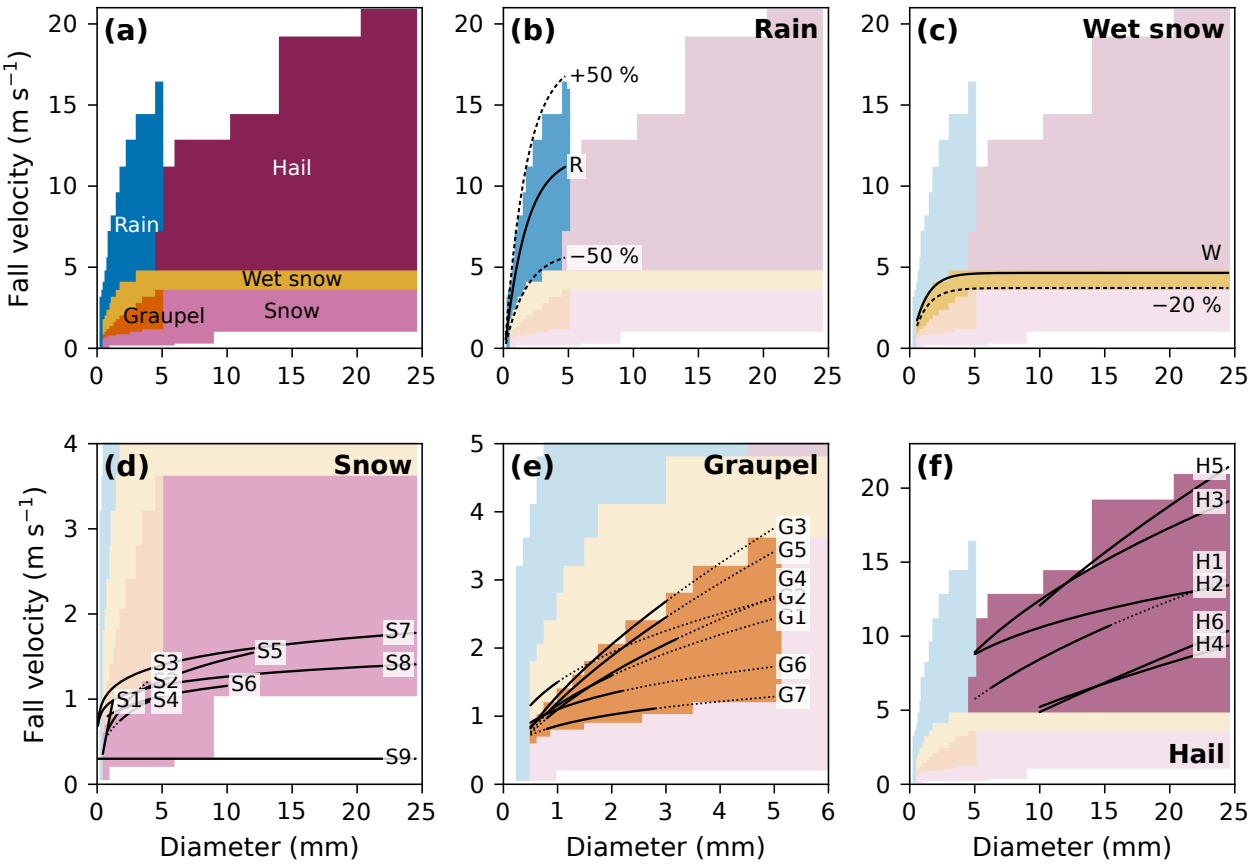

Figure R2. Revised Fig. 4 (comments RC2.35–RC2.37). Each category is highlighted in its colour, with the remaining categories in lighter tints; the empirical curves are labelled with their codes in Table 2.

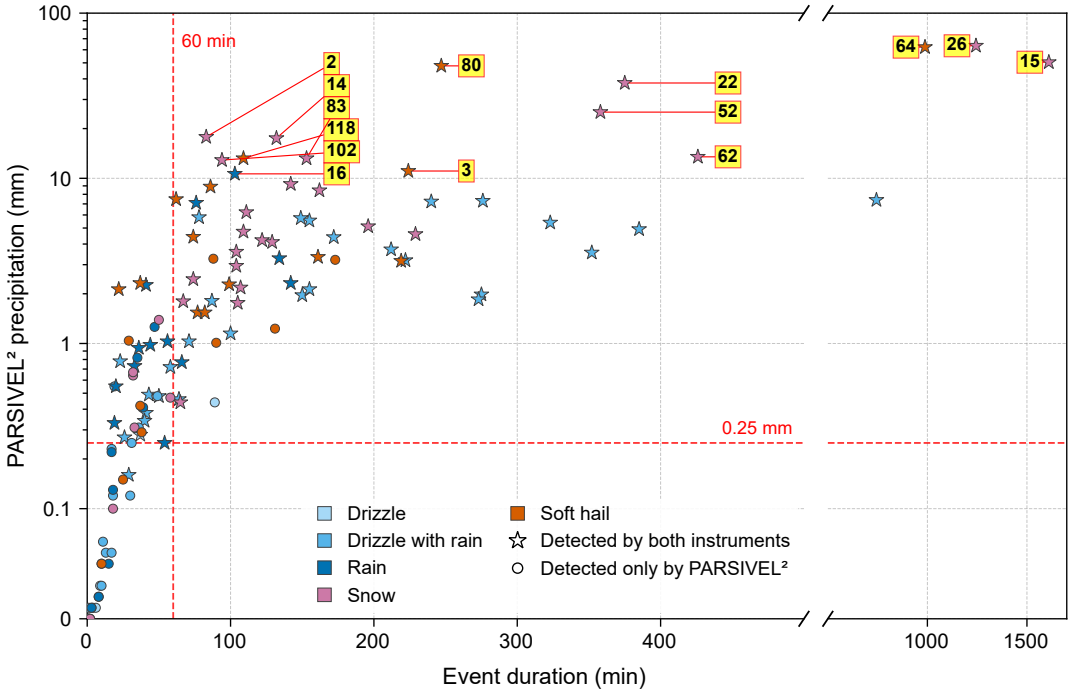

Figure R3. Revised Fig. 9 (comment No. 41).

We thank the reviewer once again for the time and effort dedicated to improving our manuscript.