

Specific comments

Line 2: What does “their” in “to capture their complexity” refer to?

→ “Their” refers to “precipitation fields”, the phrase has been modified to make it more explicit.

Lines 6-9: The combination of the two sentences seems to suggest that the radar product is unbiased, in contrast to the precipitation fields from the biased NWP products. Is this correct?

Radar products can be locally biased (among other shortcomings) while NWP products suffer from widespread systematic biases. This precision has been added in lines 6-9.

Lines 13-14: Please rephrase “radar and gauges precipitation estimation products” to “precipitation estimates by radar and gauges” or similar.

The suggested rephrasing has been applied.

Line 19: Does “ski resort” provide any relevant information here?

Ski resorts sample typical high-stakes areas for all snow related activities. Therefore, specifying that the reference data come from ski resorts implies that the system is evaluated over areas where it is designed to be the most relevant.

Line 24: Maybe change “human activities” to “practical applications”?

The proposed modification has been applied

Lines 45-48: Please also mention that the precipitation measurements are affected by systematic undercatch in case of solid precipitation.

The issue of gauge undercatch in cause of solid precipitation has been added, thank you for pointing out this omission

Lines 58-78: These two paragraphs lack a clear statement about the research gap of current studies, and what research is needed for filling this gap.

These paragraphs have been adapted to more clearly identify the research gap of current studies and propose a way forward to address this gap. In particular, the following information have been added :

“The spatial structure of the error associated with [radar-based] products in mountainous areas and its overall magnitude have not been investigated in depth.”

and

“[Existing ensemble precipitation analyses] were not designed to meet the requirements of snow data assimilation in a high-resolution snowpack modelling system.”

Lines 80-83: Perhaps move these lines to the end of the paragraph.

Theses lines have been moved to the end of the paragraph as suggested.

Lines 90-91: Consider moving the sentence “Evaluation data is only available for the period from 1 December 2021 to 30 April 2022” to section 2.4 describing the evaluation data.

The proposed modification has been applied.

Line 90-94: Consider adding information here stating that 24 h sums of all precipitation products up to 08:00 CET were analyzed in this study (if this is the case).

This information has been added.

Section 2.4 and 2.5: The authors have chosen to first present grid-based products based on observations (section 2.1 to 2.3), followed by the point evaluation measurements (section 2.4), and finally the gridded data from the NWP (section 2.5). To me, it seems more logical to first present all gridded products (currently sections 2.1-2.3 and 2.5), followed by the evaluation data (currently section 2.4). Thus, consider swapping order of section 2.4 and 2.5.

Section 2.4 and 2.5 have been swapped as suggested, thank you for this very relevant change.

Figure 2: What is the blueish horizontal bar in the left panel?

This is the ANTILOPE precipitation accumulation along the cross section. The colorbar has been shifted in between the two sub-figures and an explanation added to the legend to make it more explicit.

Figure 2: The text in the figure is very small. Please try to enlarge where possible.

Font size has been enlarge.

Figure 2, caption: Consider changing the color of the line in Figure 1 showing the radar beam from Pic Blanc to Grandes Rousses massif from gray to a more prominent color.

The colour of the line in Figure 1 indicating the cross section of Figure 2 has been modified to purple.

Heading 2.2: Consider changing to “radar-rain gauge combination” which seems to be a more common terminology (Ochoa-Rodriguez et al., 2019).

The proposed modification has been applied

Line 130: I wonder whether the usage of “1x1 km²” is correct. Maybe “1 by 1 km” is better. Or even “...is available at a 1 km resolution...”. If adapting another convention, please change throughout the paper.

The convention “... X km resolution...” has been adopted throughout the paper

Line 139: Rephrase from “the errors’ magnitude” to “the magnitude of the errors”.

The phrase has been modified, thank you for this correction

Section 2.4: Please provide the number of stations including their minimum, mean and maximum altitude.

These informations have been added in section 2.4, as well as the number of stations above 2000m a.s.l in section 5.1 (line 482)

Lines 159-162: Add a reference to a study about undercatch issues with precipitation gauges such as Rasmussen et al. (2012).

References to Rasmussen et al. (2012) and Kochendorfer et al. (2020) have been added

Line 160: Change from “under-catchment” to “undercatch”.

The change has been applied

Lines 167-170: Why were precipitation sums calculated as a 24 h sum up to 06:00 UTC and not up to 08:00 CET as with the other products? What influence does this have on the analysis presented in the study?

Precipitation were indeed summed up to 07:UTC (8:00 CET winter time) as with the other products. This mistake has been fixed, thank you for pointing it out. However, few sentences have been added in section 2.5 to discuss the (limited) impact of time change on the analysis in this study (lines 181 to 185). This gap is expected to have very limited impact on the results, as fewer reference observations are available in April (due to the closure of ski resorts) and only two significant precipitation events occur during this period

Line 177: What region does “metropolitan France” refer to?

Metropolitan France refers to mainland France, the world has been modified

Line 188: Change from “half those” to “half of those”.

The correction has been made, thanks for noticing

Line 188: Change from “in between” to “between the two peaks”.

The rewording has been applied.

Lines 188-190: Please rephrase this sentence since it currently does not read well. Maybe even spilt into two sentences.

The sentence has been split in 2 as proposed.

Lines 205-206: Please use either “true” or “real” precipitation, and align this with the notation used for the variables. Likely, “true” is a better terminology than “real” precipitation.

The word “true” has been applied everywhere, thank you for noticing this inconsistency.

Equation 1: Consider renaming the variable representing accumulated precipitation (RR) to an acronym that cannot be confused with the variable representing the ratios (R). The current usage of variable names is confusing.

The variable representing precipitation has been changed from “RR” to “P”

Line 215: Change from “gauges locations” to “location of gauges”.

The proposed modification has been applied

Line 222: Change from “far from pixel i of a distance d_{ik} ” to “with a distance d_{ik} separating point i and k ”.

The rewording has been applied

Line 225: What does this ratio express? Please provide a meaning to the reader for easier understanding of the methods.

The following explanation has been added (line 270):

“This estimated ratio conveys the hypothesis that the expected precipitation accumulation over an unobserved pixel can be retrieved from the precipitation accumulation observed at a nearby gauge

by applying the AROME precipitation accumulation ratio between these two locations. The underlying hypothesis is that AROME simulates realistic vertical gradients of precipitation even if it may be biased”

Section 3.1.1 to 3.1.4: The explanation of these methods needs to be improved. Potentially a hypothetical numerical example will help the reader to understand the methods better illustrating the core concept of the method using (a) one location including a gauge observation, (b) one location where the ANTILOPE is free of artifacts, and (c) a final location where ANTILOPE is affected by ground cluttering.

A supplementary appendix has been included to provide illustrative numerical examples of the core concept of the method as suggested (“Appendix A : ANTILOPE climatological error estimation method illustration”, page 29) and some clarifications have been made in sections 3.1.1 to 3.1.4. Additionally, Figure 5 has also been revised to better illustrate the impact of the different steps of the method.

Lines 291-306: What do the authors mean with a spatial observation error and a dynamic error? Is the first constant in space while the second varies in space?

The spatial observation error refers to the spatial structure of the error associated with measurement issues (variable in space) and the dynamic error refers to the uncertainties associated with each individual precipitation event (variable in time). These precisions have been added in the text (lines 318-320):

”The spatial observation error E_i accounts for the intrinsic spatial structure of the error associated with measurement

issues in the ANTILOPE product described in section 3.1 and comes from the preprocessing step (Section 3.1.4). The dynamic

error is associated to the uncertainty of each individual event and is expressed as a fraction of the precipitation intensity.”

Lines 321-322: Reformulate. Likely the reference does suggest to reduce the number of assimilated observations in general, but not to reduce the number of particles to 16 and the number of observations to 1 in particular, as I understand the current text.

The explanation has been modified as suggested (line 340) :

“To deal with the known problems of the PF algorithm for large numbers of observations, Snyder et al. (2008) suggests to reduce the dimension of the problem by splitting a large set of observation into smaller subsets. Here we chose to apply the particle filter algorithm for each pixel independently, reducing the problem dimension to 1 observation for a 16-member ensemble.”

Line 353: What does “improved predictive added value” mean?

This part has been reworded to avoid the use of this unclear formulation, without using bullet points as suggested in another remark (lines 375-377) :

“This ensemble analysis should reduce the systematic biases of the ensemble mean and improve precipitation estimation as compared to other existing products. Finally, spatial artefacts affecting

the radar-based precipitation fields must not be propagated to the analysis, meaning that each individual ensemble member should feature realistic spatial structures”

Line 355: Consider removing “local” from the sentence.

“Local scale” has been replaced by “point scale”

Line 361: What is the difference between systematic errors and biases?

The wording of the phrase has been modified to remove the confusion (lines 384-385):

In the case of deterministic products, this evaluation focuses on the magnitude of systematic biases and their spatial distribution as well as on the consistency of the spatial structure of the precipitation fields.

Lines 367-368: Change from “the estimated and observed 24 h precipitation values time series” to “the estimated and observed time series of 24 h precipitation records” or similar.

The proposed rewording has been applied

Line 386: Repetition of “when only solid precipitation is considered”.

Thank you for noticing, the duplicate has been removed

Line 387-390: Consider swapping order of these two sentences.

The two sentences have been swapped as suggested

Lines 396-398: Where are these results?

The reference to figure 9 showing those results has been added

Line 402: The first sentence on this line should probably be combined with the previous sentence.

The two sentences have been combined (lines 424-425):

“The ensemble precipitation analyses in this study are based on the ANTILOPE preprocessing step described in Section 3.1.4, which relies on the error estimation method described in Section 3.1.1.”

Section 4: For the reader, it is likely easier if single sections presents results with a focus on individual figures. As an example, results from Figure 8 and 9 are presented in section 4.2.1 on lines 407-409, and again in section 4.2.2 on lines 411-417. In this example, the heading of the first section could be changed to “Impact of pre-processing procedure on spatial precipitation patterns” and the second section to “Skill of the precipitation estimates” (or similar) to allow for a focus of individual figures in single sections. Of course, cross references are allowed, but the current presentation of the results is confusing to me.

The position of the figures were fixed to respect your recommendation as best as possible. Only Figures 7 and 8 remain associated to the same section.

Figure 8: Please find a more descriptive label for the vertical axis.

The vertical axis label has been changed to “Precipitation estimation / reference ratio”

Figure 9, caption: Rephrase to “Ratio between estimated and observed accumulated precipitation for the different methods assessed in this study” or similar.

The caption of Figure 8 has been changed to:

“Ratio between estimated and observed accumulated precipitation over all ski-resorts reference stations for the different methods assessed in this study”

Lines 420-421: Change from “(along the black line Hopson, 2014)” to “(along the one-to-one line) as described by Hopson et al. (2014)” or similar.

The proposed modification has been applied

Line 424: What does “quite comparable” mean? Please avoid fuzzy terms.

A more precise rewording has been applied (lines 450-451) :

The spread skill of the RS analysis (Figure 10b) shows that the magnitude of the ensemble spread match the magnitude of the ensemble mean error, with the spread on average slightly higher than the error (red dashed lines).

Line 426: “To a lesser extent” than what?

A rephrasing has been applied to clarify the meaning.

Figure 10, caption: Please split the last sentence into two sentences to improve readability.

The last sentence has been split in two as requested

Line 448: Remove “estimation” in the part “precipitation estimation products”.

The word “estimation” has been removed

Line 449: Consider changing from “more competitive” to “provide better results”.

The proposed modification has been applied

Line 465-467: Please provide the number of stations above 2000 m.a.s.l.

The number of stations above 2000m (31) has been added line 465-467 (now 473-474) , as well as the total number of stations (512)

Line 473: Consider changing from “suffers from some” to “has”.

The proposed change has been applied

Line 483: Consider changing from “It will compare” to “In such a study, we will”.

The rewording has been applied

Lines 475-493: In my opinion, the authors overuse bullet list making the text difficult to read. Please consider reducing the use of bullet points throughout the paper.

The author tried to reduce then use of bullet list as suggested.

Line 504: “More spatially homogeneous errors” than what and why?

Thank you for pointing out this inaccuracy, the sentence has been completed.

Line 519-520: Note that a precipitation product with shortcomings was assimilated and not direct observations. Please discuss the implications of this approach for the final results.

The following precisions have been added (lines 544-546) :

“This is typically the case with the ANTILOPE product, at least where reference data is available. However, in instances where the ANTILOPE uncertainty is significantly higher than the PEAROME error, the impact of these algorithms on the background ensemble is minimal.”

Line 531: What does “despite major shortcomings” refer to?

It refers to spatial artefacts in the radar based precipitation product. However, the point of the last sentence is to specify that we do not know if these spatial artefacts have been mitigated in a satisfactory manner so this precision has been removed.

Line 535: What does “the advanced” mean in this context?

The term implies that the best available products are considered. It has been replaced by “state of the art” for clarification.

Line 537: Consider changing from “local 24 h precipitation” to “24 h precipitation sums” or similar.

“local 24 h precipitation” has been replaced by “24 h precipitation accumulation”

Line 540: Is the ARMOE system “the most advanced high-resolution numerical weather prediction model” of all NWP’s in the world?

PEAROME is the only high resolution ensemble model available over the study area of the French Alps, this precision has been added.

Line 543: Consider changing from “The authors” to “In this study, we”.

The proposed modification has been applied

Line 546: Reformulate. Change from “They also applied a correction algorithm” to “A correction algorithm was applied” or similar.

The proposed rewording has been applied

Line 549: “Local” seems to refer to station observations. Please clarify.

The phrase has been modified to clarify that the proven improvement only concerns the set of reference stations.

Line 550: Please give one or two examples of possible refinements in the conclusion.

Two examples of possible refinements presented in section 5.2 have been added

Technical comments

Line 37: A misplaced comma.

The comma has been moved to the right place

Line 44: Rephrase to “precipitation inputs provided”.

The rephrasing has been applied

Line 59-61: There seems to be an error with the usage of parenthesis here.

The parenthesis usage has been fixed

Line 80: Remove “preliminary”.

The modification has been done

Line 148: Change from “Fig. 1” to “Figure 1”.

The change has been made

Line 379: Wrong units: “g m⁻²”.

The unit has been fixed, thank you for pointing out this mistake

Line 380: “This Figure”. Misplace capital letter.

The capital letter has been removed

Line 383: Inconsistent usage of units: “kg/m²/24h”. Please also correct many of the figure titles.

Figures 3, 6, 7, 9, 10, 11, A1, B1, C1, D1, E1, F1, G1 have been updated

Line 387: Likely refers to appendix B and not A.

The reference has been fixed

Line 393: A white space is missing.

White space added

Line 395: Error in figure reference.

Reference fixed

Line 401: Likely wrong reference to section 5.

Reference to section 3.1.4 fixed

Line 416: Change from “Figure 9” to “Figure 9b”.

Change done

Line 440: Consider changing from “Figure 11” to “Figure 11e and f”.

Sub-figures references added

Line 460: Wrong reference.

Reference fixed

Line 510: Wrong reference format.

Format fixed

Line 583: Remove “has” from the sentence.

Sentence fixed