One point that could be discussed, albeit briefly, is the uncertainty of the estimates obtained from the network of rain gauges, whether from the operational network or from the ski resorts. Like radar data, rain gauge data can be subject to measurement error, particularly in strong winds and/or snowy conditions. So, the different scores presented for the various radar products and rainfall ensembles take as their reference values from ground-based rain gauges, which can sometimes be accompanied by significant uncertainty. Another remark that is a little outside the scope of this article is that in general the kriging with external drift used to merge rainfall and radar data provides both an estimate of the rainfall values and also an estimate of the associated uncertainty that could be used. Perhaps this information could have been considered for this study.

--> What do the authors think?

The authors fully agree with the limitations of in-situ precipitation measurements as outlined in this remark. These limitations have already been discussed in the introduction and in the section “Evaluation data” (now section 2.5), and a mention of them has been added in the section “Gauge kriging) (now section 2.3) :

“As already mentioned, gauges measurements are known to be affected by significant undercatch in case of solid precipitation and in windy conditions (Rasmussen et al., 2012; Kochendorfer et al., 2020)”

However, in-situ observations from ski resorts are the only available independent data available for the evaluation of the various precipitation products. This precision has been added in Section 2.5 (“Evaluation data”, line 197).

The under-catch issue in snowy conditions is also briefly discussed in section 4.1 (“Evaluation of existing precipitation products”, line 407-410) :

“Similar results are obtained when only snowfall events are considered (Figure B1). Other results (frequency of relative errors less than 20%, not shown) also support the choice of ANTILOPE as the best precipitation product available for an ensemble analysis system, especially since ANTILOPE performs equally well when only solid precipitation is considered (see Figure B1 in Appendix C).”

The potential use of the uncertainty coming from the kriging with external drift algorithm has been added in the perspectives (Section 5.2, lines 521-522): “The uncertainty information generated by the kriging with external drift algorithm used in the ANTILOPE raw product could be used to improve the estimation of the associated observation error.”
However, this uncertainty does not explicitly take into account the precipitation patterns associated with the relief, as does the AROME model, which is used in this study instead.

Specific comments and questions

Page 5: Figure 2 is a very good illustration of the problem encountered in mountainous areas. However, I'm not sure that the coloured band at 3500m is easy to understand and I wonder whether it could be misleading or misinterpreted. Is it an estimate of rainfall at a constant altitude of 3500 m or is it the cumulative total on the ground along the transect between the Moucherotte radar and the Pic Blanc? The chosen radar (Moucherotte in this case) is perhaps not the best one for this illustration, as there is a strong under-estimate near the Pic Blanc "upstream" / before the highest summits, whereas these strong under-estimates should rather be the result of masking by the relief "downstream", i.e. after the relief. In all likelihood, this area of underestimation is more likely to be the result of the Colombis radar being masked by the Ecrins massif (between La Meije and Colombis radar)? In fact, what's hard to highlight from this coloured band is that it's a combination of data from several radars (or rather, at each point it's data from a single elevation selected from a single radar). Morover, the indication "radar information not used" and "use if corrected radar information" only apply here if only the Moucherotte radar was used.

-> Perhaps it would be better to remove this coloured band to avoid misinterpretations or misunderstandings?

The coloured band at 3500m is the yearly ANTILOPE precipitation accumulation along the transect between the Moucherotte radar and the Pic Blanc (the colorbar is common to both panels, it has been moved in between the two panels and the legend has been modified to improve the clarity of the figure). We think that it is important to show this coloured band because it reveals a major shortcoming of the ANTILOPE product that is not visible in observations. The main objective of this figure is to highlight the spatial artefacts affecting the ANTILOPE product and the need to mitigate them from a user's point of view.

Concerning the origin of the problem, a secondary objective of this figure is indeed to point out that areas with major precipitation under-estimation seem associated to ground clutter problems ("upstream" and above mountain ridges) rather than beam masking "downstream". This is supported by the fact that unrealistically low precipitation accumulations are observed "upstream" (because the bottom of the radar beam can reach the ground before the top) and above mountain ridges (within the area circle in red) and precipitation accumulations "downstream" (within the area circle in blue) are more consistent with precipitation in front of the relief.

We acknowledge the challenge of disentangling the sources of error when working with a composite product, but the use of such product is necessary for large scale applications. We have based our reasoning on the assumption that the contribution of the Moucherotte radar is dominant for the estimation of precipitation over the Pic Blanc since the Colombis radar is about twice as far away from the Pic Blanc (70km) as the Moucherotte radar (37km). Figure 1 below also shows that the quality index, which is used to weight the contribution of each radar to the final product for a given situation, is higher for the Moucherotte radar than for the Colombis radar in the vicinity of Pic Blanc.

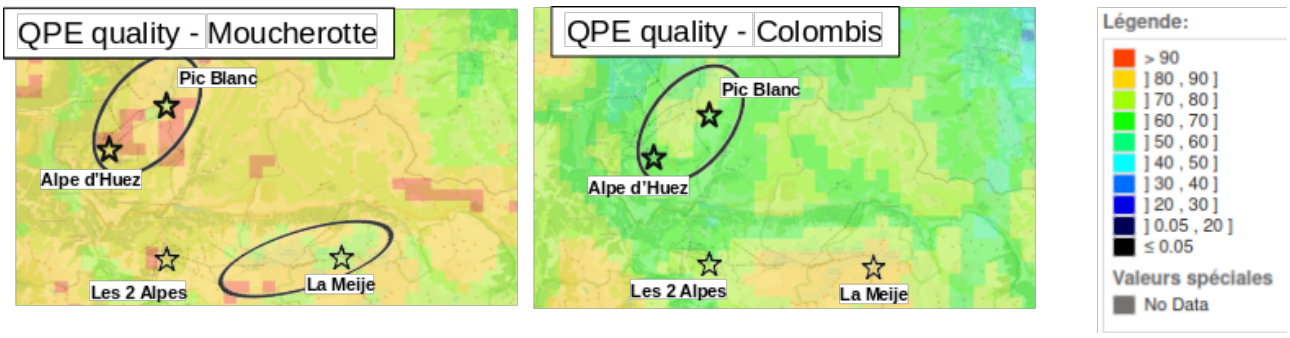

Figure 1: Quality index of the Moucherotte radar QPE (left) and Colombis radar QPE (right) over the Grandes Rousses domain. This quality index is used to weight the contribution of each single radar QPE in the final composite QPE product.

Moreover, the Colombis radar beam towards the Pic Blanc only crosses the western part of the Ecrins massif with no peaks well above 3000m as shown in Figure 2 bellow. This figure also confirms that the underestimation of precipitation over the Pic blanc is not due to the masking of the Colombis radar beams, since the precipitation accumulation in the valley between the Ecrins massif and the Pic Blanc (between 50km and 60km from the Colombis radar and affected by the same masks) is much higher than that over the pic Blanc (the colour scale is the same as the one in Figure 2).

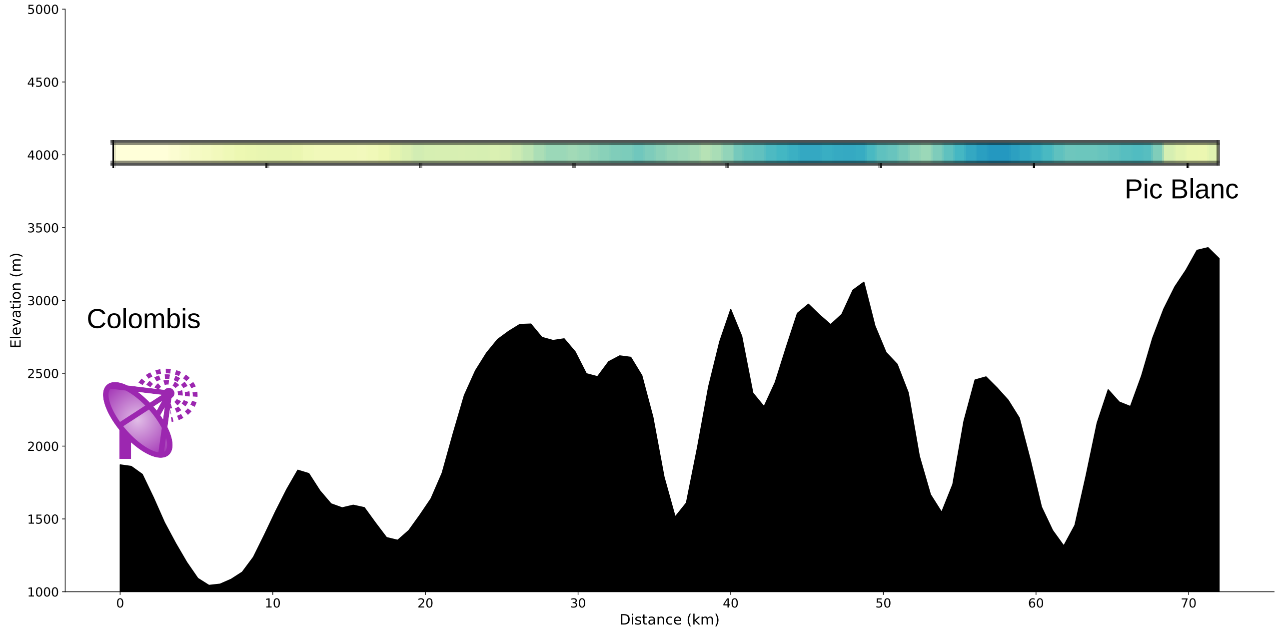

Figure 2: Relief cross section between the Colombis radar and the Pic Blanc and corresponding yearly ANTILOPE precipitation accumulation.

Page 5, Line 109: I propose to replace "measured" by "estimated"

The proposed modification has been applied.

Page 10, section 3.1.2: the ratios are estimated on an annual basis. ANTILOPE uses PANTHERE products, which combine data from different radars with elevation angles that can change over time depending on weather conditions and the availability of radars in real time.

-> Is this a problem and/or is this effect compensated/corrected in the dynamic stage of section 3.1.4?

The error estimation method is based on the assumption that the magnitude and spatial patterns of the ANTILOPE error remain relatively constant on average from year to year. This is a questionable assumption for the reasons that you have highlighted. The WMA step is only designed to remove spatial artefacts. It is not a reliable solution for cases where the ANTILOPE error deviates significantly from its climatology.

~~However, t~~The following perspective has been added to address these issues (lines 523-524):

"The error estimation method described in Section 3.1.1 could be applied to daily precipitation fields in order to improve the handling of instances where the ANTILOPE error is significantly different from its climatological value."

Page 11, equation 8: Is it possible to give physical meanings to the two different terms in this equation?

The two terms in equation 8 can be seen as metrics of the two main sources of uncertainty associated with the method itself. The following information has been added in the explanation of equation 8 :

- [The first term] increases as the estimated ratio deviates from 1, thereby indicating a likely systematic bias.

- [The second term] increases with S_i, increasing the estimated uncertainty in case diverging ratio estimates are obtained when applying the method to different reference gauges.

Please note that a numerical illustration of the ANTILOPE error estimation method has been added ("Appendix A : ANTILOPE climatological error estimation method illustration", page 29), which provides a practical interpretation of these two terms in different situations.

Page 12, line 273: About the weight cik: Can it tend towards infinity if Uk tends towards 0?

U_k is indeed always greater than 2 : there was an error in the definition of A_i and B_i, which are designed to be higher than 1. Equation 9 has been fixed (line 262), thank you for pointing out this mistake.

Eq 10, Pk would be to be defined in the text

Equation 10 was a mistake, P_k has been replaced by the proper value R_{ik}^d, thank you again for noticing this inconsistency.

Page 13: What exactly does Cii correspond to? I'm having trouble convincing myself that this could be a special case of Cik defined on the previous page.

C_{ii} is the weight of pixel in in the window centred on pixel "i" as defined on the previous page. In this case d_{ii}=0 and C_{ii}=1/U_i is inversely proportional to the estimated uncertainty of pixel "i".

Line 379: I propose to put kg/m2 instead of g/m2

The unit correction has been made, thanks for pointing it out

Line 399, title of 4.2: add the word "ensemble" in the title?

This section also deals with the evaluation of the deterministic ANTILOPE post-processing method, not only the ensemble analyses.

Line 255. Given the equation for U and the elements in Appendix 1, do you confirm that U have the unit kg/m²? If confirmed, I propose to mention it in the text and in the colorbar of fig. 5D

U is indeed in kg/m², this unit has been added in the text (line 259) as well as in the colorbar of fig. 5d and 4b.

Page 9: Figure 3a: what do the shapes used (triangles, circles) correspond to?

The following explanation has been added to the legend of Figure 3 and Figure 7 :

“The marker associated with each evaluation station is a circle if the ratio between ANTILOPE and the reference gauge precipitation estimates is not considered significant (between 0.8 and 1.2) and a triangle facing up (resp. down) if this ratio is significantly higher (resp. lower) than 1.”

Page 12: Figure 4a: How can the large differences between the background colour and the local rainfall ratio value be explained? Is this just an effect of the weighting carried out in 3.1.2?

These differences can indeed be partly explained by the weighting carried out in 3.1.2, but also by the conservatism of the method, which tends to estimate a ratio closer to 1 when no significant signal can be detected.

Page 14: Figure 5 suggests that there is little difference between a) and c) and that, consequently, the correction provided by knowledge of b) is weak, whereas the structure of the image b) seems to show very high variability and a strong capacity to correct the raw image a).

-> Isn't this surprising? As a result, figure 5e) gives the impression that it is the WMA that contributes most to the correction of a)

-> Is this what we should understand?

Please note that the correction method was illustrated in Figure 5 over the Mont Blanc massif, where the ANTILOPE error is most significant. This can be seen in Figure 3 and Figure 7 (a black rectangle has been added to highlight the area covered by the precipitation fields of Figure 5), for a date with a pronounced artefact (no precipitation over the Mont Blanc summit and more than 20mm in nearby Chamonix). The precipitation fields used as an illustration in Figure 5 have been modified to avoid suggesting that the first correction step is ineffective.

The objective of the initial correction step aims at removing systematic biases estimated in the raw ANTILOPE product. As you point out, Figure 5c showed that this correction alone is not sufficient in extreme cases (in particular, if ANTILOPE fails to detect any precipitation, this multiplicative correction is indeed ineffective). Nevertheless, the impact of this correction on the estimated precipitation climatology is clearer in the new Figure 5. This is corroborated in Figure 7, which shows the yearly precipitation accumulation before and after the implementation of this first correction step alone (a black rectangle has been added to highlight the area covered by the precipitation fields of Figure 5). The mitigation of spatial artefacts over the Mont Blanc is notable, and systematic biases observed at reference stations are often reduced as expected.

You are right to point out that overall the WMA correction has a predominant impact on the structure final daily precipitation fields. However, it does not affect the climatology of the final product. This step is essential for the complete removal of spatial artefacts, but it produces daily precipitation fields that appear too smooth to be realistic on their own. These fields must therefore be interpreted in conjunction with the associated error fields that account for the removed spatial variability.

Page 14, this figure 5 could be enlarged to make it easier to read the axes and colorbars of the individual figures.

Figure 5 has been enlarged as suggested.

Line 460: The symbol “?” might be replaced by a reference or deleted

The reference to Germann et al., 2022 in line 460 (now 465) has been fixed.