Review: Hailstorm Events in the Central Andes of Peru: Insights from Historical Data and Radar Microphysics

General comments:

1. The limitations and underlying assumptions for the data and instruments could be discussed more explicitly. It is unconventional to use a cloud radar for a convective study, partially because of attenuation. While this is part of the novelty of this study, this also warrants a discussion. Moreover, there is little to no discussion about the hail detection of Parsivel2 or the reliability of the observer hail reports.
2. There is a lack of connection between the discussion of the long-term hail reports and the microphysical assessment of 2 cases. What is the ulterior motive of diving into these 2 cases in particular? Should the detailed evaluation build the foundation for a later hail-classification algorithm the vertical profiles? This could be a clear motivation in the direction of method-development. The two cases alone are also not enough to make a general statement about the overall diversity of hail profiles.
3. Both case studies would benefit from a (brief) synoptic discussion of their cases. Is there satellite data available to e.g. estimate convective mode or storm structure? Where did the storms originate and how was their track oriented? How was the synoptic weather situation, are they related to fronts? The overall storm characteristics and atmospheric conditions impact hail development and can help understand the differing evolution of the events.
4. There is a lack of contextualization of the results. A discussion of which findings are in line with previous research and which aspects contradict other studies would be very helpful. Partially the suggestions in the outlook have been implemented in other research (Sokol et al., 2018 -> convection and hail in a Ka-band-radar; Wang et al., 2023 -> hail classification on a satellite-borne radar), this at least warrants a mention. Studies focusing on winter precipitation also go into more detail on hydrometeor classification and microphysical understanding with cloud radars and could be used as a comparison. These also often address issues mentioned here (e.g. dealiasing a spectrum).

Specific comments:

1. Line 44: Space missing before bracket
2. Line 51: Climatological trends depend a great deal on the length of observations and tend to only properly emerge after >40 years. Hence conflicting results are often an artefact of the length of the timeseries and it would be helpful to include this duration here.
   Consider including the assessment of Taszarek et al. (2021) on changes in severe convective environments.
3. Line 53: Twice Beal
4. While this is not emphasized in the introduction, convective studies in complex terrain and at high altitudes are rather rare and deserve particular emphasis. How does this compare to other complex terrain studies and hail trends in other mountain regions?
5. Section 2: To introduce the region it would be great to have a map of the area. Are the observed hail reports gathered for a larger area than just the observatory? What is considered the representative area for these reports and how does it compare to the area of the Parsivel2?
6. Line 128: What is the representative measurement area of a Parsivel2?

7. Line 142: Consider including the specification Ka-band
8. Line 162: Hail can be very spherical, especially while it is smaller. However, LDR is also influenced by the mix of phases and density in the hailstones.
9. Section 3.1: Is there any assessment of how robust the hail reports are? What were the observation criteria? How does the overall annual hail frequency compare to global hail frequency assessments (Prein, Taszarek, Raupach, …)?
10. Fig. 1 and following: please define the lines of the boxplot (mean + standard deviation / median + quartiles / …)
11. Line 185 (and throughout the manuscript): Please consider using a more precise time format that includes the time zone. Moreover, "hours" usually refers to a duration and not a time of day.
12. Line 189: twice Tokay
13. Line 193: 35 hail events in 4 years? This would mean an average of >8 hailstorms per year in the location of the observatory, which is much higher, than the long-year observed average – and much higher than global estimates for the general area.
    Overall it is not mentioned very clearly, which time period is considered for the instruments (only in the abstract).
    How confident is the hail classification of the Parsivel2?
14. Line 195: Inconsistent spelling of boxplot
15. Line 197: Eulerian duration? Here it is important to note that hail duration is determined by both hail area in the storm and the propagation speed of the storm.
16. Figure 7: Please relabel the y-axis with number of minutes. Consider using a log scale so that the frequency of the less frequent classes can still be seen.
17. Line 221: The low percentage of hail events is absolutely to be expected. Hail overall is a rare phenomenon, whereas rain is not.
18. Line 226: This is rather small for hail and most stones should be rather spherical at this size.
19. Line 227 and following: There appears to be an issue with the units, is the "s" missing for "m s^{-1}"? In later instances there are also inconsistencies on whether there is a space between "m" and "s" or not.
20. Line 227: "Less than"
21. Line 228ff: How do you unambiguously differentiate between hail and drops in Fig. 8? What is your assumed fall velocity for hail at a corresponding size? Please compare to e.g. Heymsfield et al. (2018).
22. Line 231: "Was found"
23. Line 271: significant implies a statistical test. Please avoid this word, if you do not mean statistical significance.
24. Fig 10: The pink contours are not very well visible. Please consider adding 3 more panels with the shading of the entire events to facilitate the comparison with the hail events.
25. Fig 10-14: Panel labels are missing on all figures (a, b etc)
26. Line 283: Please use a precise time format with the time zone indicator. In addition, this does not match the time shown in Fig. 11 – please convert all time labels to the same time zone. (Fig. 11 vs 12 and 13 vs 14 and correspondingly in the text).
    Please also place Figs. 11 and 12 on the same page and then 13 and 14 as well so that the timing of the Parsivel2 classification can be easily compared to the vertical profiles.

27. Line 297f: How does this altitude compare to other studies?
28. Line 308: Fig. 10 implies that between 2 and 4 km, values of 1.5-2 m/s spectral width are rather unusual for rain and more typical for hail. The discussion here seems contradictory. Especially given the statement in Line 293, that values >2.5 m/s are to be considered as outliers anyway.
29. Line 317: The discussion of this event is a bit confusing. First of all, the Parsivel2's classification is also unreliable and if it does not match well with the vertical profiles should also be questioned. Secondly (assuming Parsivel2 as truth): At LT19:25 there is high reflectivity followed by strong attenuation, very high fall velocities exceeding the Nyquist velocity, correspondingly high spectral width and an increased LDR. This does not seem that questionable for hail fall. We also know nothing about the larger spatial structure of the storm. Is the main updraft separated from the principal precipitation areas (I.e. as in supercellular convection)?
30. Line 328: What would the assumed difference be for hail?
31. Line 346: The difficulties of hail observations with a cloud radar could use a more detailed discussion. How is each variable affected by attenuation and resonance scattering?
32. Line 349f: The denominator of the LDR is dominated by ZHH, which is dominated by the largest particles (e.g. Oue et al., 2015). Hence LDR should be mostly governed by the presence of hail. Why not additionally use KDP (e.g. Trömel et al., 2017) and possibly RhoHV as well for hail identification? KDP could help with attenuation issues. (e.g. Kennedy et al., 2001)
    For polarimetric hail identification on scanning radars, there is a whole host of additional literature, but of course it does not apply directly to vertical-pointing radars.
33. Line 371: Looking up weather code "SYNOP wawa4860" only leads to this publication. Please include a reference that defines what this is.
34. Lines 372ff: It is unclear which statements refer to the observational record and which refer to the Parsivel2. I.e. Parsivel's annual hail occurrence is approximately 8 per year – this notable difference with the observed frequency should be discussed somewhere.
35. Line 377: Given that this study does not focus on hail stone size and the size is not discussed with respect to the radar signatures, this statement is a far reach. Both events come with different sizes and their different vertical profile might be tied to the hail size. Moreover, two events are not enough to establish relationships with hail size.
36. Line 402: Twice Williams
37. Line 409ff: The outlook is very vague and seems a bit over the top. What kind of applications and insights are you aiming for in future? How can the research benefit the affected communities?

Suggested References

- Taszarek, M., Allen, J.T., Marchio, M. *et al.* Global climatology and trends in convective environments from ERA5 and rawinsonde data. *npj Clim Atmos Sci* **4**, 35 (2021). https://doi.org/10.1038/s41612-021-00190-x
- Oue, M., M. R. Kumjian, Y. Lu, J. Verlinde, K. Aydin, and E. E. Clothiaux, 2015: Linear Depolarization Ratios of Columnar Ice Crystals in a Deep Precipitating System over the Arctic Observed by Zenith-Pointing Ka-Band Doppler Radar. *J. Appl. Meteor. Climatol.*, **54**, 1060–1068, https://doi.org/10.1175/JAMC-D-15-0012.1.

- Kennedy, P. C., S. A. Rutledge, W. A. Petersen, and V. N. Bringi, 2001: Polarimetric Radar Observations of Hail Formation. *J. Appl. Meteor. Climatol.*, **40**, 1347–1366, https://doi.org/10.1175/1520-0450(2001)040<1347:PROOHF>2.0.CO;2.
- Andreas F. Prein, Greg J. Holland, Global estimates of damaging hail hazard, Weather and Climate Extremes, Volume 22, 2018, Pages 10-23, ISSN 2212-0947, https://doi.org/10.1016/j.wace.2018.10.004.
- Raupach, T. H., Martius, O., Allen, J. T., Kunz, M., Lasher-Trapp, S., Mohr, S., Rasmussen, K. L., Trapp, R. J., and Zhang, Q.: The effects of climate change on hailstorms, Nature Reviews Earth and Environment, 2, 213–226, https://doi.org/10.1038/s43017-020-00133-9, 2021.
- Sokol, Zbyněk, Jana Minářová, and Petr Novák. 2018. "Classification of Hydrometeors Using Measurements of the Ka-Band Cloud Radar Installed at the Milešovka Mountain (Central Europe)" *Remote Sensing* 10, no. 11: 1674. https://doi.org/10.3390/rs10111674
- Wang F, Liu Y, Zhou Y, Sun R, Duan J, Li Y, Ding Q and Wang H 2023 Retrieving Vertical Cloud Radar Reflectivity from MODIS Cloud Products with CGAN: An Evaluation for Different Cloud Types and Latitudes *Remote Sensing* **15** 816 Online: http://dx.doi.org/10.3390/rs15030816
- Heymsfield, A., M. Szakáll, A. Jost, I. Giammanco, and R. Wright, 2018: A Comprehensive Observational Study of Graupel and Hail Terminal Velocity, Mass Flux, and Kinetic Energy. *J. Atmos. Sci.*, **75**, 3861–3885, https://doi.org/10.1175/JAS-D-18-0035.1.
- Trömel, S., A. V. Ryzhkov, M. Diederich, K. Mühlbauer, S. Kneifel, J. Snyder, and C. Simmer, 2017: Multisensor Characterization of Mammatus. *Mon. Wea. Rev.*, **145**, 235–251, https://doi.org/10.1175/MWR-D-16-0187.1.