Reviewer #2

General Comments

General comment #1: The standard abbreviation of the 5th generation ECMWF reanalysis is "ERA5". Thus, all instances of "ERA-5" throughout the manuscript should be revised.
Thank you for pointing this out, this correction has been made in the manuscript.

General comment #2: Relatedly, the only major concern I have about the construction of the effort relates to the reliance on monthly mean ERA5 fields for the broad correlation analysis used. The precipitation events comprising the multimodal cases occur sporadically throughout the year and are seldom evenly distributed throughout the month. Reducing the information content of the reanalysis to a monthly mean would seem to be counterproductive to identifying prevailing relationships with environmental characteristics and the cases evaluated. Namely, I would imagine that in some months a multimodal case could occur within an environmental extreme compared to the monthly mean and thus the correlations assessed would be mostly meaningless. I recommend utilizing the higher-rate (i.e., hourly) and higher-resolution ERA5 output sampled representatively from each event as the basis for this work.

Thanks for this comment. We originally used the monthly values to assess if any potential patterns did exist on a broader, climatological scale as well as with consideration to the file size/computational burden when requesting and using hourly pressure level data. Ultimately, we agree that using these averaged quantities is not the best approach and we have decided to remove this analysis. To better investigate how atmospheric liquid and cloudiness correlates with events, we are replacing this analysis with the aforementioned analysis using observational datasets including precipitable water vapor from the MWR, liquid water path, cloud base/top heights, and cloud thickness.

Because of extended periods of missing KAZR data in 2022 and missing MWR data in 2023, we currently use only 2020 for this analysis. 2020 has only one date of missing KAZR data and 12 dates of missing MWR data.

The new analysis for this section contrasts the flagged events vs. non-flagged cloudy periods, as Reviewer 1 suggested. Cloudy periods are determined using the micropulse lidar (MPL) and radar derived cloud fraction, from the nsaarmbecldradC1 product. We tested several thresholds of cloud fraction to determine if the hour is cloudy or not, and presently are using cloud fraction exceeding 75% to define a cloudy hour.

First, we analyzed the flagged hours and cloudy hours across 2020 (Fig. R. 1). This analysis found that when using a cloudiness threshold of cloud fraction exceeding 75%, a total of 6321 of 8784 hours in the year were cloudy. 16.6% of those cloudy hours (1057 hours) were also flagged as exceeding 100 flags per hour (11.9% of all hours in the year). Interestingly, five hours were flagged that do not meet the cloudiness threshold. Note that this analysis examines all hours with flag count of 100 or greater, not just events that see persistent signals of 2 or more hours.

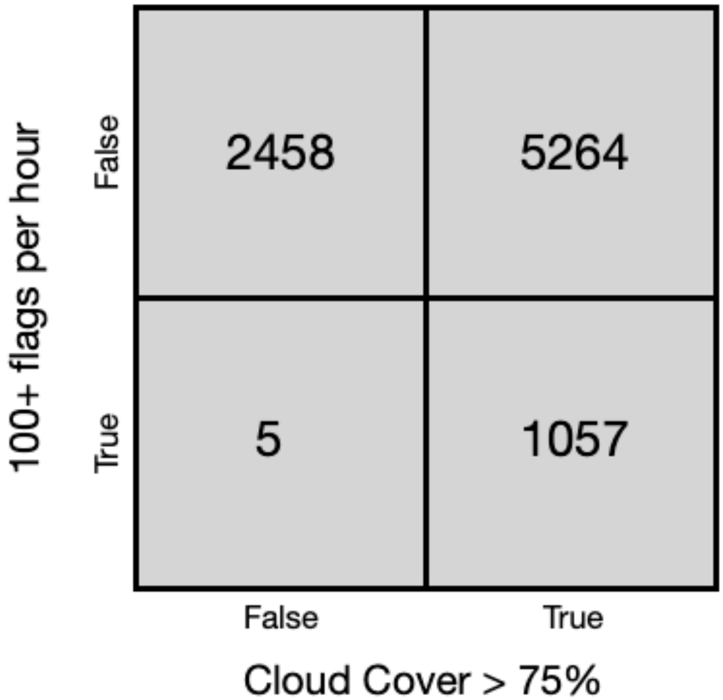

Fig R. 1: Matrix visualization of the hours of 2020 that are cloudy and that meet the 100+ flag criteria for an event hour.

Second, we examined observations of precipitable water vapor (PWV), liquid water path (LWP), cloud base, cloud top, cloud thickness, and hourly precipitation for hours with (1) greater than 100 criteria flags per hour and cloudy conditions and (2) under 100 criteria flags per hour and cloudy conditions. Because these observations do not conform to normal distributions, t-tests and Pearson correlations were not very conclusive, and we instead visualize the distributions of these two datasets with violin plots. This is shown in Fig. R. 2. As a general trend across this analysis, the flagged events had more moisture and deeper clouds. The cloud tops and thicknesses from this dataset were very broadly spread for both the flagged and unflagged cloudy periods. For cloud thickness both interquartile ranges were approximately 4000 m wide, which is largely related to the variability in cloud tops. This may be affected by high level cirrus clouds, rather than the tops of the specific cloud layers producing a multi-modal signal. We did retest this for varied definitions of cloudiness by total cloud cover with little impact on the results.

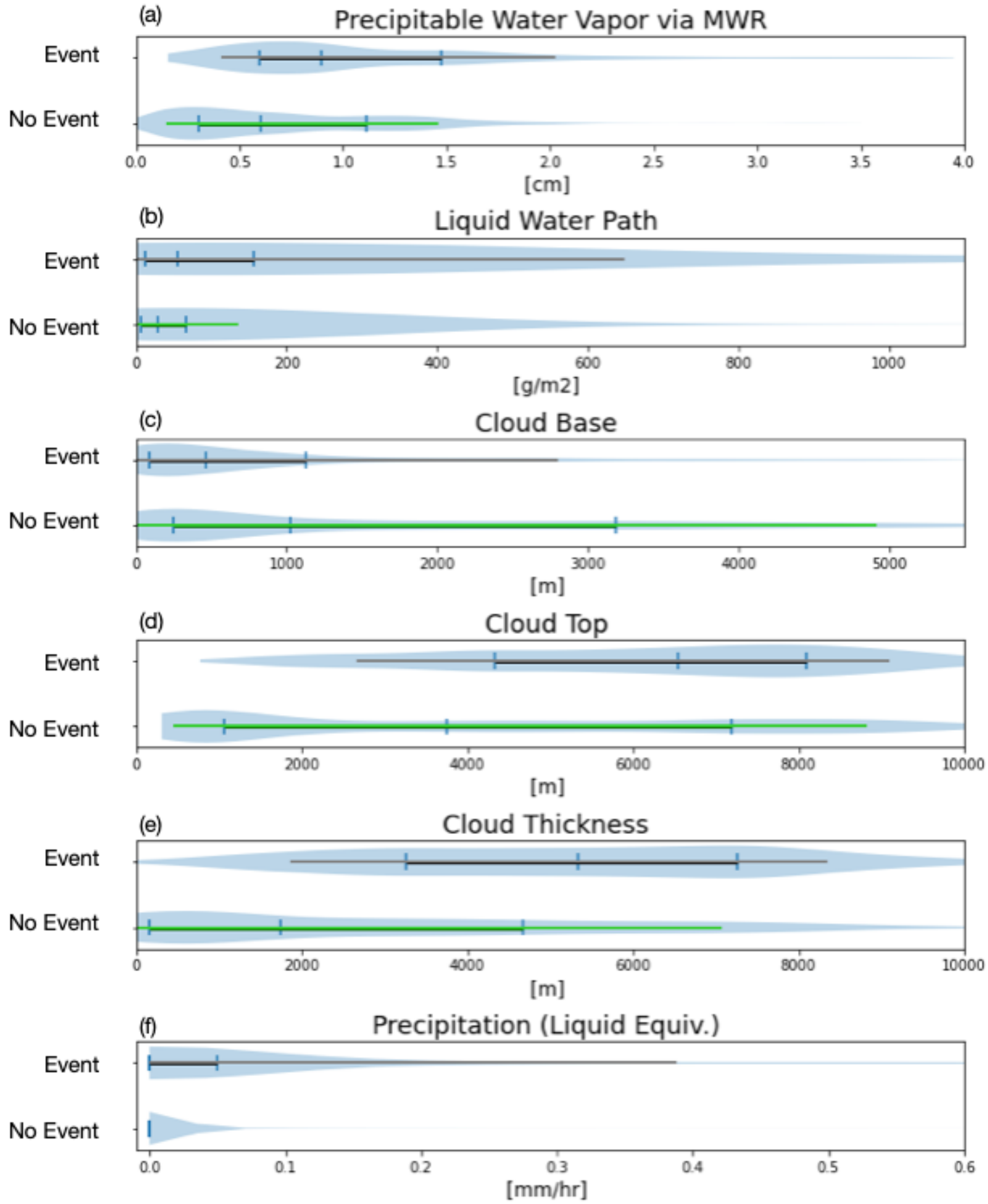

Fig R. 2: Violin plots of observed quantities shown for hours in 2020 that contain 100 or more criteria flags per hour and hours in 2020 that do not meet this criteria, but do exceed 75% cloud cover. For events: the thick black line spans in the interquartile range and the thin grey line spans from the 10^{th} to 90^{th} percentiles. For no event: the thick green line spans in the interquartile range and the thin light green line spans from the 10^{th} to 90^{th} percentiles. (a) Precipitable water vapor as observed by MWR (b) liquid water path (c) cloud base (d) cloud top (e) cloud thickness (f) hourly liquid equivalent precipitation.

In panels (a) and (b) you can see the tendency for flagged periods to be moister than unflagged cloudy periods, though there is significant overlap between them. In panel (c), there is a clear difference in the cloud bases of flagged events and non-flagged cloudy periods. The interquartile range (IQR) of event hour cloud base is 84-1124 m and of non-event cloudy hours is

245-3189 m. If we instead consider average cloud base, the height for event hours is 942 m and non-event hours is 1886 m. This is potentially indicating that colder, higher clouds are not producing multi-modal signals and are not a significant portion of the detected events. Note this also lines up with the results shown in Figure 3, which for events of 2 or more hours showed a mean detected layer height near 1750 m and mean detected layer depth of approximately 1250 m.

In the last panel when examining hourly precipitation, there is a clear indication that flagged hours have greater hourly precipitation rate. This makes sense because the coexistence of multiple hydrometeor types (e.g. snow aggregates and cloud ice or graupel and liquid cloud droplets) would be expected to produce a multi-modal spectrum as the precipitation should typically has a faster downward vertical velocity (fall speed) than cloud liquid or cloud ice.

Thanks to both reviewers for comments on this analysis; we feel that the new iteration using hourly observations is a much stronger representation of the conditions associated with these signals.

With the additional datasets used to replace the original analysis as well as to supplement the cases examined in more detail, citations for additional ARM observational datasets and value added products (VAP) are attached:

Cadeddu, Maria, et al. "Microwave Radiometer Profiler (MWRP), 2004-02-19 to 2023-09-28, North Slope Alaska (NSA), Central Facility, Barrow AK (C1)." Atmospheric Radiation Measurement (ARM) User Facility, doi:10.5439/1025254. Accessed 25 May 2025.

Cromwell, Erol, et al. "Precipitation Imaging Package (PRECIPIPMP), 2018-10-23 to 2025-04-21, North Slope Alaska (NSA), Central Facility, Barrow AK (C1)." Atmospheric Radiation Measurement (ARM) User Facility, doi:10.5439/1489525. Accessed 25 May 2025.

Chen, Xiao, and Shaocheng Xie. "ARM Best Estimate Data Products (ARMBECLDRAD), 1998-01-01 to 2023-12-31, North Slope Alaska (NSA), Central Facility, Barrow AK (C1)." Atmospheric Radiation Measurement (ARM) User Facility, doi:10.5439/1333228.

Zhang, Damao, et al. "Cloud Type Classification (CLDTYPE), 1998-03-25 to 2023-08-30, North Slope Alaska (NSA), Central Facility, Barrow AK (C1)." Atmospheric Radiation Measurement (ARM) User Facility, doi:10.5439/1349884.

General comment #3: Though it could be argued to be beyond the scope of the study, an example with collocated aircraft data would be a tremendously meaningful addition to the manuscript, primarily as a more robust validation exercise for the algorithm. I recognize that such data may not exist for the site used, but it would be helpful for that to be acknowledged as justification for not executing such work, should that be the case.

Thanks for this comment, if aircraft data for these years did exist at the NSA site it would be immensely useful. Within our conclusions, we will now note that the repetition of this with aircraft data from a field campaign directly over a Ka-band radar would be advantageous for better understanding the observations and associated signals and attributing processes.

Specific Comments
Line 13: "access" should be "assess"
Thank you for pointing this out, this correction has been made.

Lines 36-39: this is a complicated and confusing sentence. Please clarify and split into 2 sentences.
Apologies for this, the sentence is now split into two and clarified.

Line 150: simplify "the vast majority of" to "most"
Thank you for pointing this out, this correction has been made.

Lines 233-234: this was already said. Add citations to previous mention or delete.
Thank you for pointing this out, this has been consolidated with the previous mention.

Figure 13: this image is very blurry. Please improve resolution.
Apologies for this, we regenerated the figure and this is now corrected.

Line 439: Unnecessary comma after "cases"
Thank you for pointing this out, this correction has been made in the revision.