Atmospheric Measurement Techniques Discussions

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Reply on RC2

Laura M. Tomkins et al.

Author comment on "Image muting of mixed precipitation to improve identification of regions of heavy snow in radar data" by Laura M. Tomkins et al., Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2022-160-AC2, 2022

We would like to thank the reviewer for their comments and feedback on this manuscript. Reviewer comments are in normal text, our responses are in bold.

Overall Recommendation:

The authors present a new reflectivity visualization technique that aims to decrease cognitive load on radar analysts by muting reflectivity in areas classified as mixed precipitation. I think there is a possible application of this technique for those who would potentially struggle with appropriately diagnosing higher reflectivity associated with melting. However, operational meteorologists are generally trained in awareness of the brightband. Moreover, the spatiotemporal evolution of winter storms (relative to severe convective hazards) allows for more time to analyze multiple products, etc. Thus, I struggle to see a significant need in the operational community for such a tool, at least given some of the concerns/shortcomings I mention below (muting of important features, simple thresholds, etc.). I think this paper could be a worthy contribution to the literature if these concerns are appropriately addressed via either a) making a stronger argument for how this would be beneficial for operational meteorologists and/or b) framing it more for non-meteorologists. Additionally, shortcomings in the algorithm logic/performance need to be addressed.

General/Major Comments:

- Winter weather scenarios, while challenging in different ways from severe convective scenarios, tend to evolve on longer timescales than severe convective scenarios. Is the time pressure in winter mixed precipitation events that high to necessitate this image muting technique for operational forecasters? Is there evidence to support this claim that even experienced meteorologists are mistaking bright banding for heavier precipitation? Not saying it isn’t occurring, but is it occurring enough to necessitate a new product? I would argue this is more of a training issue for forecasters vs the need for a separate product. That said, I could see more value in such a product being presented as a visualization tool for non-meteorologists in weather-sensitive fields (e.g., emergency management) or for the broader public, perhaps in weathercasts or in apps. I wonder if it might be beneficial to emphasize this technique as a presentation tool for non-meteorologists.

Nowhere in the original manuscript did we state that this tool was needed by operational meteorologists. Only a subset of meteorologists work for national weather services.

The authors have personally witnessed many experienced meteorologists mistake bright band regions for heavy snow dozens of times over the years. Multiple incidents occurred during field projects as real-time radar data are being viewed to make time-sensitive aircraft deployment decisions. Additionally, we have seen numerous presentations at conferences and workshops over the years that make this mistake. In academia, this misinterpretation is more likely in less experienced analysts such as graduate students. In part, this common mistake motivated this work.

To clarify, we added material to describe our intended users in the Summary and in the Abstract replaced "even experienced meteorologists" with "radar data users".

"The proliferation of weather radar web interfaces and mobile apps has made operational radar data easily accessible to a wide range of users with varying levels of radar data interpretation expertise. People who are well versed in the subtle nuances of interpreting weather radar data represent only a subset of research meteorologists and an even smaller subset of the broader set of radar data users which includes emergency managers, TV weathercasters, and airport operators." ***(lines 155-158)***

"Especially under time pressure, radar data users can mistake regions of mixed precipitation for heavy snow because of the high cognitive load associated with comparing data in two fields while simultaneously attempting to discount a portion of the high reflectivity values." (lines 4-7)

- Section 2.2: I have concerns about the thresholding process. First, by filtering out light echoes (less than 20 dBZ), you do miss areas of mixed precipitation. I've witnessed scenarios with light crystals generated at low levels (e.g., top of the boundary layer) that then melt near the surface. In those instances, correlation coefficient (CC) can remain reliable, while still suggesting the presence of mixing. In these cases, a user of this product could think that these light echoes might be pure rain or snow, when it's mixed precip in reality. Moreover, what's the advantage of using flat CC/Z thresholds to identify mixed precip when other algorithms (like the 88D Hydrometeor Classification Algorithm) take into account more data in a more nuanced fashion? Would these not perform better at identifying mixed precipitation? Could you use such an algorithm as input into a more advanced muting technique?

We are not defining a new method to detect all melting regions. Rather, we seek to de-emphasize melting regions that could be misinterpreted as heavy snow.

We found that a simple correlation coefficient threshold < 0.97 with the 20 dBZ Z threshold worked well for our intended purpose which is to de-emphasize melting that could be misinterpreted as heavy snow.

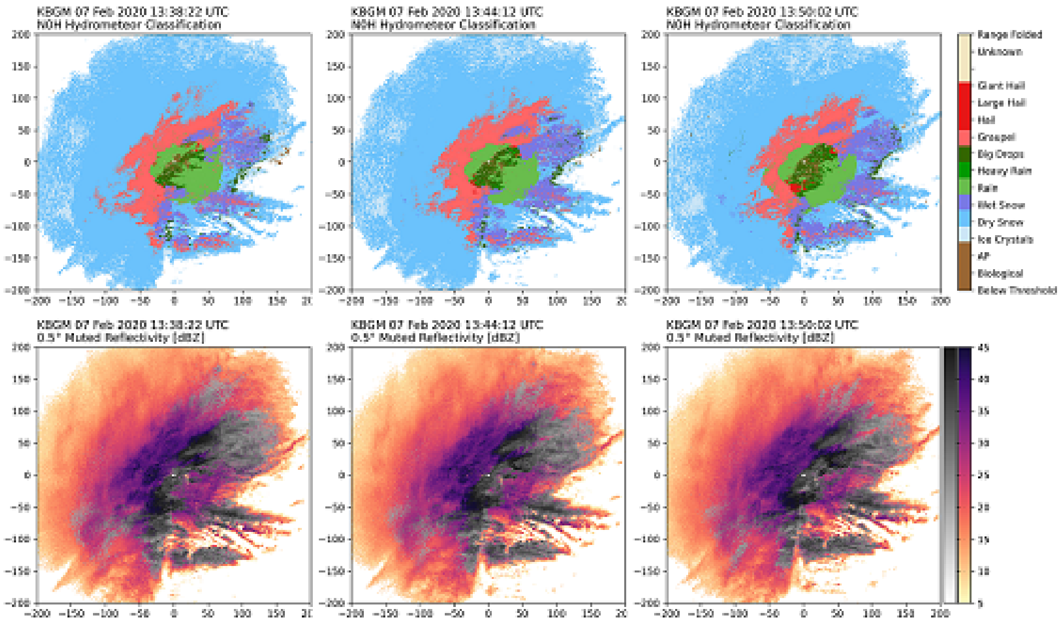
The current US NWS hydrometeor identification algorithm often struggles in winter storms. For example, Figure R1 shows a sequence of images comparing the hydrometeor classification and image muted reflectivity. While the NWS hydrometeor classification algorithm correctly identifies some of the areas with low RHOHV as wet snow, it also miscategorizes portions of the melting areas as graupel, big drops, and heavy rain. Additionally, there are "jumps" in

spatial continuity of regions with a given classification. On balance, we determined that the NWS hydrometeor classification algorithm's performance in winter weather was not well suited to our purpose.

The hydrometeor classification could be used as an input to the muting technique. We have added the following text to the summary:

"Users could apply this visualization technique using operational hydrometeor classification as an input and mute other specific regions depending on the application." ***(lines 175-176)***

Figure R1: Sequence of images from KBGM radar on 7 Feb 2020 valid 13:38 UTC (left), 13:44 UTC (center), and 13:50 UTC (right). Top panel is Hydrometeor classification, bottom panel is image muted reflectivity



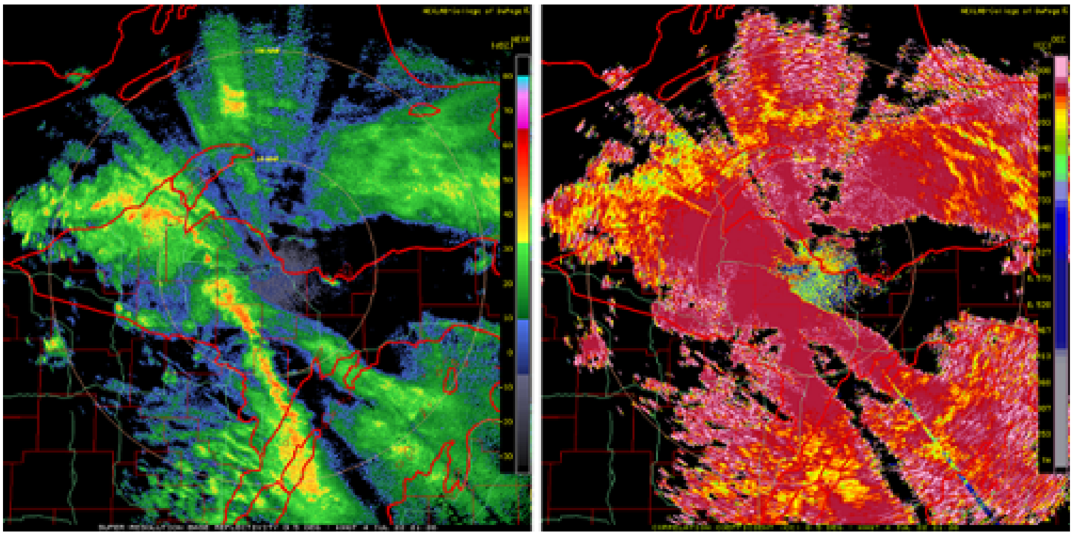
- L78-81: I'm glad the algorithm isn't muting reflectivity at farther ranges, but I think the reasoning here is incorrect. Frequently, the reason lower CC is dominating at these ranges (at least for the 88D network) is due to the radar sampling echoes at higher altitudes / colder temperatures, within the crystal generation region. The mixture of crystal habits is what's often driving CC downward. It isn't an unreliability of the signal. At a minimum, I think this is somewhat "getting it right for the wrong reasons." Most of the time, this crystal growth region should be characterized by relatively low Z, such that I don't think this would be a huge issue for the current design, but I think this needs to be corrected / clarified.

  Upon consultation with radar experts Dr. Chandrasekar (Colorado State University) and Dr. Scott Ellis (NCAR), we were made aware of a peculiar problem with the NWS NEXRAD algorithm to estimate correlation coefficient that is documented in Ivic (2019).

  NEXRAD radars use a single transmission chain that emits energy at 45 deg polarization, and two separate receivers at H and V polarization. This hardware configuration yields dual polarization data that is inherently more noisy than research radars that transmit at H and V and receive at H and V polarization.

  The current method used to compute correlation coefficient in US NEXRAD operational radars yields increased values with decreasing SNR. We have added mention of this issue and the citation to Ivic in the Introduction.

As an illustration of the problem with NEXRAD's RHOHV, please see example below, courtesy of Scott Ellis, which shows correlation coefficient values near 1 at farther ranges and low Z values where SNR is lower.



Unlike many research radars, the NEXRAD products do not include a SNR field but a minimum detectable signal (MDS) can be estimated using the following formula:

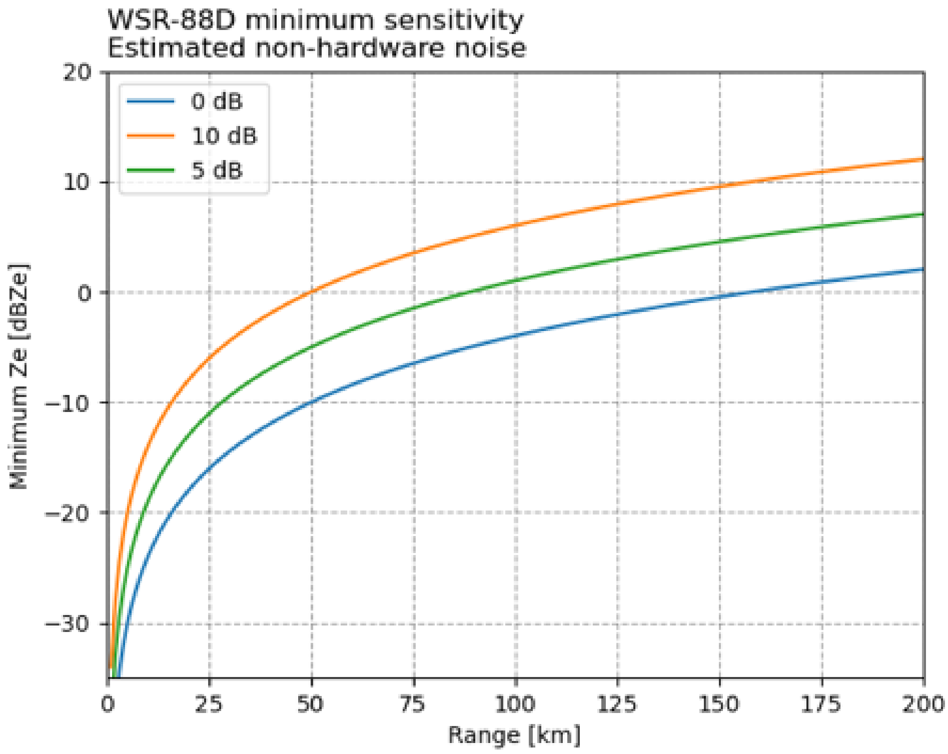
Zmin_detectable=dBZo + 20*log10(rangeinkm)

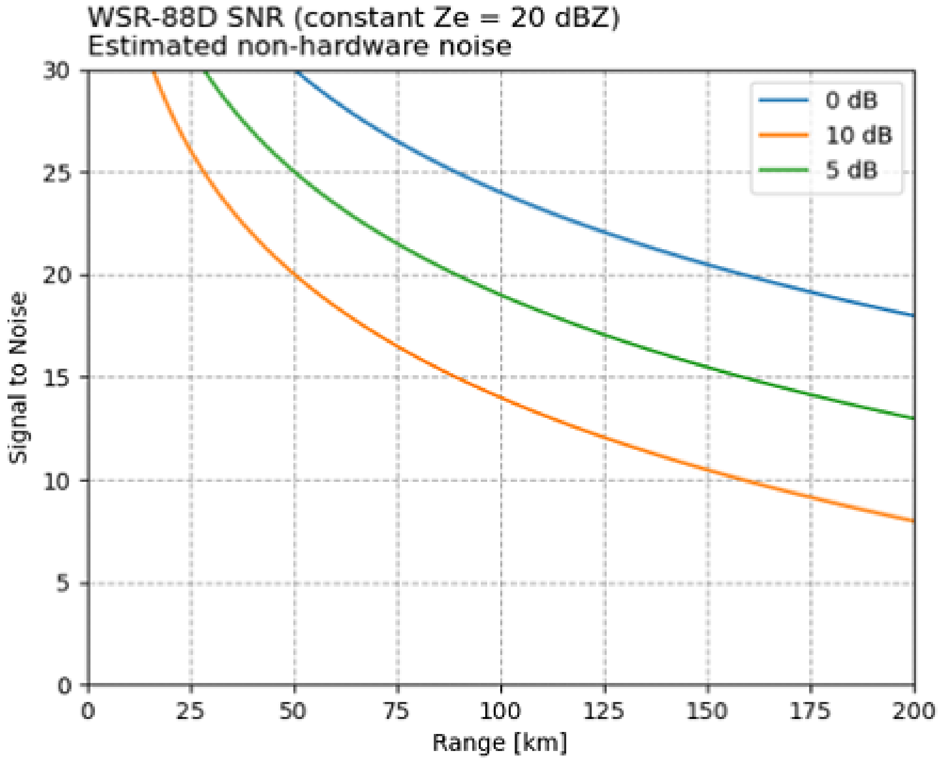
Where dBZo includes the hardware's contribution (radar system noise and receiver calibration) estimated at -44 dBm and a factor to account for non-hardware originated noise such as terrain, ground clutter, and clouds that can decrease SNR at low elevation angles.

Based on https://www.roc.noaa.gov/WSR88D/PublicDocs/NOAA_Radar_Functional_Requirements_Final_Sept%202015.pdf

We estimate the NEXRAD hardware radar constant as -44 dBm and plot values of MDS for the non-hardware noise factor from 0 to 10 dBm in the first plot and the estimated SNR for a 20 dBZ echo as a function of range in the 2nd plot. (SNR=dBZ-MDS).

Liu et al (1994, JTECH, volume 11 pages 950-963) showed that to keep rhohv with +/- 0.01 you need an SNR of > about 20 dB. So the expectation is that the NEXRAD dual polarization variable values for a 20 dB echo will start to drop off in quality starting at about ~50, ~90 km or ~150 km range depending on how much non-hardware noise one wants to include in the estimate of MDS.





If the US NEXRAD products included an SNR field we would use it. In practice, radar constants vary with radar calibration and the estimate of non-hardware noise will also vary depending on conditions and radar siting. So without an SNR field one cannot be quantitatively rigorous. Rough estimates of SNR (as in the plots above) necessitate assumptions that may well vary among individual radars.

At close ranges, RHOHV is reliable for < 20 dBZ. But, the point of our image muting technique isn't to detect all melting precipitation. The main purpose is to detect melting that is likely to be misinterpreted as heavy snow (> 20 dBZ).

- L85: A couple comments here, one minor, one major. The minor one is that I think these linear features need to be annotated/circled on the figure so it's clear which linear features you're talking about. If I am correct about the linear features to which you are referring, then here's my major comment: I'm not sure how helpful it is to mute them. The reason why is that this specific line of low CC / high Z (on individual radars, it's often a line that connects a semi-circle of low CC, which is the primary melting layer) represents the edge of the melting layer aloft, where we tend to see the melting layer descend some to the surface because temperatures are only barely above 0 C aloft, extending the melting process and allowing mixed precip to reach closer to the ground. Within this linear band, we very frequently see a zone of sleet pellets at the surface as partially melted snow falls back into a sub-freezing layer and quickly re-freezes into sleet. In fact, your Figure 4 shows this very clearly with both the radar structure and the reanalysis temp x-section. That muted line across southern Long Island is where extremely heavy sleet (i.e., inches of accumulating sleet) was occurring (Fig 6 and related discussion in Picca et al 2014). Do we want to mute such a microphysically important feature that has large implications for surface impacts? If you're just looking for pure snow, I guess it's OK, but I have large concerns about drawing attention away from this feature, at least for an operational meteorologist. Once again, for the public / non-meteorologists, I think this is fine if you wish to present a 'snow map' of sorts, but I have my doubts for forecasters. This is critical information. And if they then have to go look at CC / switch products for clarification on this muted zone, what's the point of the algorithm? I think a sizable explanation is required here to address these concerns with the current design.

  Thank you for your comment about the linear features, we have annotated them on the figure. We used this as an example since many investigators were referring to the linear features as "snowbands" when in fact they are melting precipitation. The primary purpose of this method is to *de-emphasize* regions of mixed precipitation in order to correctly identify regions of heavy snow. We agree that sleet has important winter weather impacts but its identification is outside of the scope of this paper.

- L125-132: In Figure 5 for this case, the melting layer is very evident, starting at about 100 km range (except for the collapsed portion to the north). Often at lower elevation angles and more extended ranges, the melting layer presents as a broad area of 'speckly' CC, presumably due to the decreased resolution / increased volume size. With that in mind, pockets of CC > 0.97 often occur in this zone, where perhaps the volume is encountering mainly one precipitation type (e.g., snow just beginning to melt or rain almost entirely finished with the melting process). These zones often are still characterized by higher reflectivity and we see that in Fig 5. Due to the 0.97 threshold, though, much of this melting ring is not muted, showing a shortcoming in this technique. Given this is clearly a zone of higher reflectivity associated with mixed precipitation, the lack of more widespread muting is concerning.

  Our method is not intended to replace full-featured hydrometeor identification. Rather, our goal is to do one thing, reduce mis-identification of heavy snow, robustly. In this example, the unmuted values that are part of the melting band "arc" are < 20 dBZ so would not be mis-identified as heavy snow.

Minor Comments:

- L12: Why specify coastal regions? There are plenty of mixed precipitation winter storms across the interior US.

  In our research we have applied the technique to storms in several geographic locations. The technique can be applied to anywhere mixed precipitation occurs. In the introduction we changed "mid-latitude coastal regions" to "mid-latitude regions" to reflect this.

  "Winter storms in mid-latitude regions often contain subregions with rain, mixed precipitation, and snow that move and evolve over the storm lifetime (Schultz et al., 2019)." (lines 12-13)

- L30-42: Related to my comments above, I wonder if this is truly problematic for trained analysts. Most radar software offers multi-panel views that can show Z and CC (along with other variables) side by side, reducing the need for switching, etc. Additionally, winter weather scenarios evolve on slower timescales, attenuating the cognitive load issue. Would it be better to suggest/emphasize this as a visual tool for presentation to non-meteorologists?

  We note that viewing products side by side has similar cognitive load challenges as switching back and forth between products (Sweller et al. 2011).

  We have added materials to the Conclusions to better describe the intended users who are not operational meteorologists.

  "The proliferation of weather radar web interfaces and mobile apps has made operational radar data easily accessible to a wide range of users with varying levels of radar data interpretation expertise. People who are well versed in the subtle nuances of interpreting weather radar data represent only a subset of research meteorologists and an even smaller subset of the broader set of radar data users which includes emergency managers, TV weathercasters, and airport operators." (lines 155-158)

- L53-55: Is it technically more accurate to say "...4 km above radar level" ? Radars located at higher elevations may be scanning above 4 km AGL in some areas within 200 km range, due to land sloping downward from the radar. For instance, I think High Plains radars like FTG are scanning over 4 km AGL within 200 km range to the east.

  Thank you for catching this. We have changed the text to "above radar level".

  "We include only data within 200 km range from a radar as this is sufficient for combining data from multiple radars in much of the continental US without substantial gaps and constrains the beam center to be below 4 km altitude above radar level." (lines 64-66)

- L105: Would clarify that "height of the radar beam (black X in Fig 2b)" refers to height of the 88D data used to construct the regional mapping. You do so in the figure caption but it was confusing as I read the main text because "radar" is ambiguous. At first I thought it referred to the on-board radar, which doesn't make sense of course since that's a nadir-pointing radar.

  Thank you for the comment. We have updated the text to "...height of the

NEXRAD radar beam used to create the regional map…"

"As the airplane reaches around 175 km in the transect, one can see that the height of the NEXRAD radar beam used to create the regional map (black X in Fig. 2b) begins to intersect the melting layer." (lines 122-124)

- L118-124: I suspect some, if not all, of this particular shape in the melting layer structure is because the very close range to radar allows us to resolve this structure much better (and at much lower altitude) than is usual with the 88D network. The end result of this arc-like structure is that we see re-freezing into sleet pellets within that cold air closer to the surface (as I mention above in my major comment). We almost always observe sleet pellets underneath these linear features on the edge of the 0 C isotherm aloft, which would suggest this thermal structure is pretty common and the defined arc structure is more a case of radar resolution, rather than an anomalous thermal environment. See Fig 11d in Griffin et al 2014 https://journals.ametsoc.org/view/journals/wefo/29/6/waf-d-14-00056_1.xml?rskey=9QTt6F&result=1

  Thank you for drawing our attention to this article, we have included a sentence citing the paper and the discussion of the same feature.
  "The structure of the melting layer in this example is also discussed in Griffin et al. (2014)." (lines 144-145)

Figures / Tables

- Table 1: The caption is oddly written. Suggest changing to something like "The correlation coefficient values associated with physical mechanisms that increase snow radar reflectivities when other conditions are held constant." Additionally, I think some further clarification could be necessary. In the first two columns, you are not specifying the nature of the ice particles. If it's a diverse array of crystal types, CC can be lower than 1. While not dramatically lower (let's say 0.95-1), I would say "~1" does not accurately describe such a scenario. Probably should add a condition in which we assume uniform particle habits, if you wish to maintain "~1"

  Thank you for your comment, we have changed the table caption.

  New table caption reads "Correlation coefficient values associated with physical mechanisms that increase radar reflectivities when Z > 20 dBZ and other conditions are held constant."

  Also we note Griffin et al. 2000, JAMC, (which we cite in the paper)_ https://journals.ametsoc.org/view/journals/apme/59/4/jamc-d-19-0128.1.xml?tab_body=fulltext-display paper says that detection of melting layer in weak echo (below 20 dBZ) frequently failed and provides more support for 0.97 rhoHV threshold.
  "After testing this method on several events, a threshold of ρhv ≥ 0.97 was found to exhibit the best agreement with the curvature results of FZ95. Overall, the heights of the ML top and ML bottom for the FZ95 curvature and polarimetric methods compare well within regions of higher ZH, with the FZ95 curvature method exhibiting slightly higher (i.e., approximately 200 m) ML tops and slightly higher or lower (i.e., approximately 50 m) ML bottoms. Within regions of ZH < 20 dBZ, the FZ95 method frequently failed."

- Figure 3: Since the text and the data from Fig 2 only discuss the precipitation types / radar from around 16 UTC, why do you include all of the other times from ASOS data? I think if the text / analysis comprehensively discussed the p-type changes over time at the various sites, it would be more relevant, but as it stands right now, I'm not sure why you present the other times. You do mention the transitions at KBGM in lines 111-112, but there is no synthesis with the algorithm / radar data. This would be a much better analysis if, for example, you included mosaicked algorithm output around these transition times and compared those data with the ASOS data. Without them, the additional data in Fig 3 are distracting and unnecessary.

  The figure with the ASOS time series, (now Fig. 4), complements the airborne EXRAD radar cross-sections (new Fig. 3) to serve as verification of the position (and timing) of the precipitation transitions.

  "The surface observations and timing of precipitation transitions align well with the evolution and movement of the storm (Fig. 2 and 3)." (lines 127-128)

  Other fields from the ER-2 radars to depict the spatial position of the melting layer (new Fig. 3 in manuscript)