Tomkins et al. (2022) review response #2

RC2:

Overall Comments

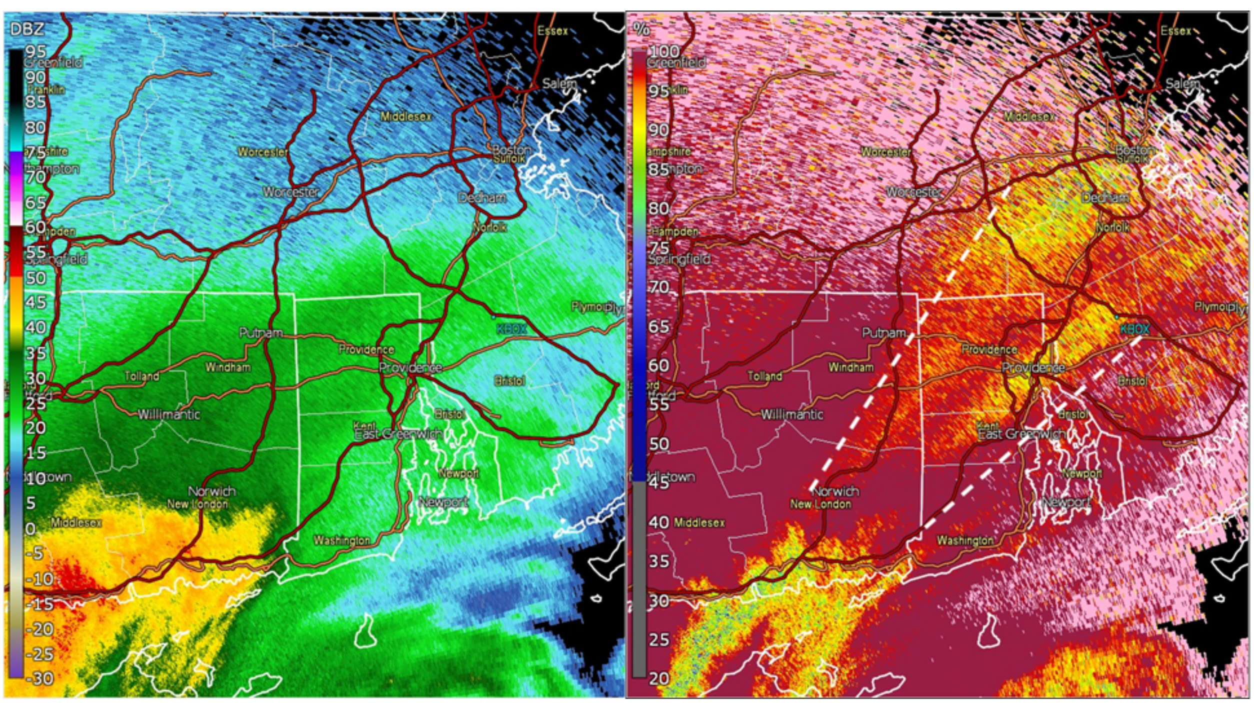
I appreciate the authors' efforts in revising the paper, and the added research on SNR by consulting with experts in the field is admirable. The paper has improved from the prior version. However, the authors failed to address my significant concern about the algorithm performance, chiefly that there are weaknesses in this algorithm that diminish its efforts in trying to reduce cognitive load. Due to the thresholding, the algorithm will at times mute gates that are characterized by moderate/heavy snow (see the NBF discussion below), and it will also fail to mute gates that are characterized by high Z from melting snow and thus could be mistaken for heavy snow (see the KDIX case discussion below). Nowhere in the text can I find discussion of these weaknesses, potential solutions, or further development.

I'm not trying to badger the point, and as somebody who has developed polarimetric-based algorithms with a similar goal in mind (reducing load on the analyst while still incorporating the wealth of data from polarimetric variables), I understand very much the challenges. I appreciate your efforts in trying to make this information more usable and accessible for radar analysts in winter weather, and application of image muting seems very promising. I applaud that, and you've opened my eyes to the potential capability there. However, you have to acknowledge the drawbacks and weaknesses in your technique to make this paper publishable in my opinion. This is a major concern for me until you do so.

I'll note that I don't think you need to overhaul the paper or that it would necessarily take that long to address these major concerns. However, I think you need to reasonably address the shortcomings by stating what they are, when they may be more common, and how users should approach these situations.

Major Comments

L32-39: I very much appreciate your efforts in digging into radar data quality with range, resultant impacts on SNR, and how that could then feed into your technique. That said, I can state with confidence that reductions in hv due to NBF frequently occur at more distant ranges and is often not masked by the SNR effect with range. And not just with convective / warm- season scenarios, but in winter weather as well. I've even seen it caused by pure heavy snow at S band, presumably from a large concentration of crystals within part of the beam. Granted, pure- snow NBF is pretty rare. However, significant NBF from melting snow, which impacts legitimate heavy-snow gates down-radial, isn't all that uncommon. I've included an example from the 8-9 February 2013 storm over southern New England (0.5deg KOKX 02/09/2013 0025 UTC). Annotated is an NBF corridor of hv < 0.97 in many snow gates associated with Z > 20 dBZ (I went through GR myself and sampled 20-30 dBZ in these gates). These gates would be incorrectly muted in your technique.



With this in mind, I don't think it would be all that uncommon for this technique to incorrectly mute moderate/heavy snow gates due to the influence of NBF, especially in more intense winter storms with more pronounced melting layers / NBF. This needs to be addressed, at a minimum acknowledging the weakness and perhaps suggesting possible improvements going forward.

Even if at least stating that users will need to be aware of such radial artifacts in the algorithm.

To make users aware of the potential artifacts we have revised the following text:

(lines 32-33) While correlation coefficient is insensitive to radar power calibration, it does suffer from other data quality problems. Artificially lower rhoHV values can occur along radials downrange of sharp gradients in differential phase (Ryzhkov, 2007).

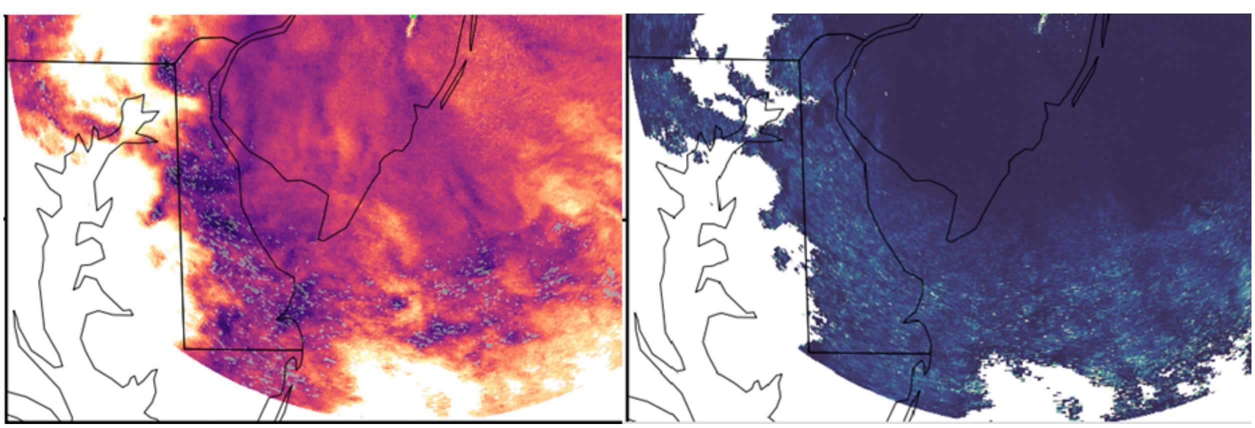
(lines 38-44) Unlike radars that transmit at horizontal and vertical polarizations, the NEXRAD radar transmits at a single polarization oriented at 45 degrees which reduces the overall sensitivity of the radar and in conditions with canted, oriented ice can reduce the correlation coefficient (Rauber and Nesbitt, 2018). In practice, the impact of SNR tends to be much more prevalent than non-uniform beam filling. This suggests that the SNR effect masks most of the effects of non-uniform beam filling in NEXRAD correlation coefficient data quality. Dual polarization radar variable data quality problems are more pronounced when there are mismatched antenna patterns in the horizontal and vertical polarizations (Bringi and Chandrasekar, 2001) which are more common in operational radars than research radars.

(lines 95-100) Any method relying on a particular variable as input will not work well when there are data quality problems with that variable. Data quality problems with correlation coefficient along radials downrange of sharp gradients in differential phase will yield sporadic image muted areas radial to the radar that will not move consistently with the advection of locally enhanced reflectivity bands within the storm. Regions of speckled image muting based on the method described here could either be a result of small spatial scale variations in the melting of snow or noise in the

correlation coefficient field related to low signal to noise ratios which are more common at farther ranges from the radar (Ivić, 2019).

(lines 193-195) Enhanced reflectivity bands that are snow or contain mixed precipitation will generally move consistently with the advection of other reflectivity features rather than being fixed either concentrically or radially to the radar position. Hence, our image muting method is best used as part of movie loop sequences rather than as individual images.

Secondly, and apologies that I wasn't clear enough in my original comments, your response to my comment on what was then L125-32, referring to then Fig 5 (now Fig 6), is incorrect. There are absolutely unmuted pockets of > 20 dBZ within the melting arc for the KDIX case (see the darker, unmuted values over Delaware, for instance, in screengrabs from your figure – added below). It appears they are unmuted as a result of being above the rhv threshold, which I understand. But as I mentioned in my original comment, you often can see this occur in the melting layer where either large snow aggregates are just beginning to melt (dielectric constant is up so Z increases but the diversity isn't quite enough to drop rhv below 0.97) or you have mainly large drops where the melting process has almost finished.

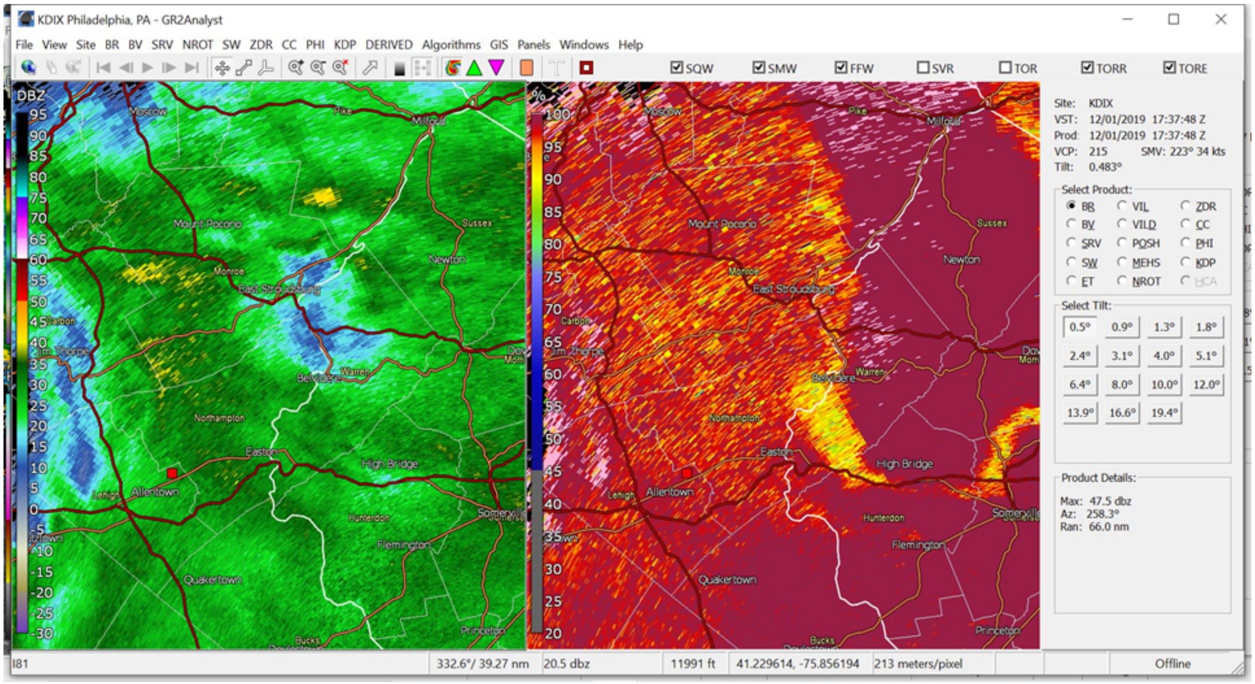


If the argument is that these gates are so far south in this particular case that a radar analyst would know they can't be heavy snow, then why are we muting other gates nearby (the speckled grays)? Either we should be muting much more of this region or we shouldn't. This is a drawback as currently designed.

Moreover, if we look farther north at the same radar scan time, we find more examples of unmuted high Z gates in the melting arc. I pulled the data from KDIX at 1737 UTC, 01 Dec 2019 and took a quick look in eastern Pennsylvania (attached GR image below). At 0.5 deg overhead the corridor from Allentown to Easton, there are many gates of > 20 dBZ (in fact some 30-35 dBZ) with rhv > 0.97, resulting in them being unmuted. For example, overhead the KABE station (red marker in the attached GR image), Z is ~25 dBZ while rhv > 0.97. In turn, these are unmuted gates. The KABE observations at this time, understandably, are all freezing rain, as we have melting occurring overhead:

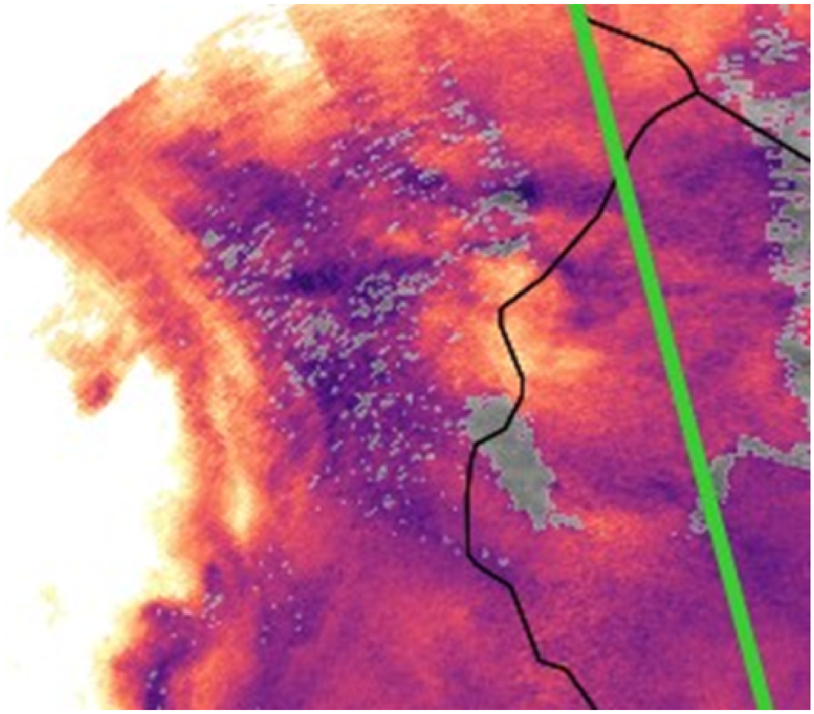
```
ABE,2019-12-01 17:11,KABE 011711Z 08009KT 3SM FZRA OVC011
M01/M04 A2982 RMK AO2 SFC VIS 4 RAE05FZRAB05 PRESFR P0003 I1001
T10111039
ABE,2019-12-01 17:43,KABE 011743Z 08014KT 3SM FZRA OVC008
M01/M04 A2974 RMK AO2 SFC VIS 4 RAE05FZRAB05 PRESFR P0006 I1002
T10111039
ABE,2019-12-01 17:51,KABE 011751Z 07015G20KT 3SM -FZRA BKN006
OVC012 M01/M03 A2971 RMK AO2 SFC VIS 5 RAE05FZRAB05 PRESFR
SLP066 P0007 60007 I1002 I6002 T10061033 10000 21011 58067
```

From your comments to the reviewers, I now understand that your algorithm is not supposed to be an all-encompassing melting detection. However, this example is classic bright-banding that, based on your stated intentions, should be muted. This deficiency needs to be acknowledged in the manuscript. If we expect and hope for non-expert users to use and trust your technique, then potential pitfalls need to be clearly stated.



Note how many high-Z gates of this melting-layer bright-banding are not muted in your figure (including in the vicinity of KABE, where Z of ~25 dBZ is present with FZRA being reported at the surface). Are users expected to mentally apply speckled muting to other gates? This seems counter-productive to reducing cognitive load. If we don't expect most users to be expert radar analysts, which I agree is a reasonable expectation, then it needs to be pretty clear that all of the inflated Z in this area is from melting; otherwise, I can easily envision non-expert users interpreting these high-Z gates as heavy snow, due to the gates being unmuted. Thus, this must be addressed in the text. I am not saying you need to solve this problem for this manuscript.

Rather, you need to acknowledge the problem and suggest possible remedies, improvements, training considerations, and/or avenues for future development to attenuate the issues.



We have added the following text to the manuscript:

(lines 165-169) Users should use caution interpreting features at longer ranges from the radar where RHOHV suffers from quality issues related to low signal to noise ratio. For example, in Figure 6, the speckled muting beyond 100 km range of the radar is likely the result of the superposition of an increase in correlation coefficient associated with low signal to noise ratio and a decrease associated with melting. The animation of this figure in the Supplement illustrates that the concentric speckled region remains approximately stationary to the radar and hence can be visually distinguished from advecting reflectivity bands.

(lines 200-205) The method to detect melting regions is not perfect in large part since such algorithms are limited by the input data quality. For U.S. NEXRAD data, without improvements in the data quality of RHOHV, detection of melting regions particularly at farther ranges will be more speckled than at closer ranges. If the signal to noise ratio field is made available it can be used to filter out questionable RHOHV values and improve the detection of melting regions. Users are advised to utilize movie loops to assess the time and spatial continuity when distinguishing

band-like enhanced reflectivity features corresponding to heavy snow bands from those that include melting.

Minor Comments:

L28-29: should be 'e.g.' instead of 'i.e.' These are examples of the situations, not other ways of saying them. For instance, mixed precipitation isn't the only situation causing diversity. A mixture of ice crystal habits aloft can reduce rhv, for example.

Thank you for catching this. We have updated the text in the manuscript.

(lines 27-30) Correlation coefficient is approximately one in regions with single hydrometeor types (e.g. only rain or only snow) and decreases in regions where there is an increasing diversity of hydrometeor orientations and shapes (e.g. mixed precipitation such as rain with snow and/or partially melted ice) (Giangrande et al. 2008, Rauber and Nesbitt, 2018).

Figure 1: Thank you for adding the oval annotations, but the color choice makes them pretty difficult to see (at least for somebody like me with a slight color deficiency). I had to really stare at them. Would suggest a lighter color for the annotations.

Thank you for your comment. We have updated the annotations to be white.

L100: Would change to "…could be misinterpreted as *purely* snowbands…" Some parts of these bands are absolutely heavy snow (as indicated by rhv and your muting technique).

We have added the suggestion to the text.

(lines 110-111) This example shows two linear features in central New York that could be misinterpreted as purely snowbands when analyzing the reflectivity alone (white ovals in 1a)

L113: “through” is misspelled

Thank you for catching this. We have updated the text in the manuscript.

(line 123-126) The gray region in the image muted regional map indicates a quasi-linear region of mixed precipitation extending through eastern New York up to Vermont and New Hampshire (Fig. 2a) between areas of primarily snow (to the northwest in upstate New York) and primarily rain (to the southeast over southern New England).

L119: Since these values would be *more* negative, it should either be < -4 ms-1 or that the magnitude is > 4 ms-1

Thank you for catching this. We have updated the text in the manuscript.

(line 130) Under the melting layer, the values of downward pointing Doppler velocity < -4 ms^{-1} indicate the rain layer.