Mapping Precipitation Intensity to Radar Observations and Derivatives

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ABSTRACT

This is a feasibility study to investigate whether a 2-D analysis of precipitation intensity (i.e., light, moderate, heavy) can be derived from existing products within the Multi-Radar/Multi-Sensor (MRMS) system in order to better detect events with rapidly-accumulating snow or ice. This is done by comparing Automated Surface Observing System (ASOS) observations of intensity to various MRMS fields, including base reflectivity, composite reflectivity, and instantaneous precipitation rate for the 2016/17 winter season. Since there is a rather limited number of mixed phase and refreezing habits, only pure classifications of rain and snow (RA and SN) are considered. Even when the data were filtered to include only SN events with low wind speeds and only sites that are within about 50 km of the nearest radar, no meaningful correlation between SN intensity and the MRMS fields was found. There was a clearer correlation between RA intensity and the MRMS fields. However, the different intensity categories still had significant overlap indicating that any threshold based on a single MRMS field will result in a significant number of misclassifications. An attempt to define intensity based on linear and nonlinear combinations of multiple MRMS fields was also made, but again, a clear set of discriminants could not be found. While these results are largely unpromising, it is possible the low correlations could be due to the way in which the ASOS observations were partnered with the MRMS data. It is also possible that other fields, such as echo depth, may provide improved correlation. Efforts to investigate these things are underway.

1. INTRODUCTION AND BACKGROUND

Winter storms are high-impact weather systems partially due to the range of precipitation types they can produce, including rain, snow, ice pellets, and freezing rain. Precipitation type is a public safety concern because transportation and public services can be shut down by icing and heavy snowfall. Reeves et al. (2016) developed a surface precipitation-type classification algorithm, which they referred to as the spectral bin classifier. This algorithm was developed to improve precipitation type diagnosis, and the algorithm is capable of diagnosing six categories of precipitation (Reeves et al. 2016). While this algorithm predicts type, it does not predict intensity. With winter precipitation, the type of precipitation can be as important as the amount of that precipitation that falls (Ralph et al. 2005). Therefore, decision making for these events can be improved with more precise identification of intensity alongside precipitation type. The aim of this study is to provide a feasibility assessment of the potential for including intensity as a part of this emerging surface hydrometeor classification algorithm.

In this study, Automated Surface Observing System (ASOS) observations of intensity for different categories of precipitation were compared to fields from the Multi-Radar/Multi-Sensor (MRMS) system. This study seeks to compare commonly available measurements of intensity to determine their

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usefulness in producing a categorical precipitation intensity for the spectral bin classifier. The ASOS makes continuous automated observations, including sky conditions, visibility, pressure, ambient temperature, precipitation accumulation, and wind measurements (NOAA, 1998). Of the measurements taken by the ASOS, the most relevant observations to this study are precipitation accumulation, intensity, and type such as rain, snow, and freezing rain (NOAA 1998). The MRMS system includes about 180 operational radars to create a radar mosaic with a temporal resolution of 2 minutes and spatial resolution of 1km (Zhang et al. 2016). Radar data in MRMS is supplemented with rain gauge observations to improve the estimated rain rate (Zhang et al. 2016). For this study, three products from MRMS were used. The first, base reflectivity, is the echo intensity from the lowest available radar beam, which is commonly at the lowest tilt angle (0.5 degrees). The second, composite reflectivity, is the highest reflectivity value from any radar elevation within the column above a point. The third, two-minute precipitation rate, is the liquid equivalent precipitation that fell in the previous two minutes. Precipitation rate estimates are subject to a number of known limitations, including issues related to attenuation, vertical variations in reflectivity, and limited radar coverage, especially low-level (altitudes below 2 km) coverage. (Zhang et al., 2016).

For identifying precipitation type, the ASOS uses the Light Emitting Diode Weather Identifier (LEDWI) (NOAA, 1998). The LEDWI measures the scintillation pattern of the precipitation to determine the precipitation type and intensity (NOAA 1998). The LEDWI does well at discriminating between rain and snow; however, it is not as good at detecting freezing rain and cannot detect ice pellets and mixed precipitation types. For this reason, this study examines only observations of rain and snow. The LEDWI produces both a precipitation type and intensity, though higher intensities will not always indicate a higher precipitation rate, particularly in snow (Rasmussen et al. 1999). As snow intensity depends on the measured visibility at the ASOS site, ASOS-reported snow intensity is susceptible to other effects that reduce visibility, such as wind-blown snow. Due to the error in estimating snowfall intensity based on visibility, Rasmussen et al. (1999) recommended that estimating snowfall intensity using visibility should only be used as a guideline, not a reliable source.

2. METHODS AND DATA

ASOS data from 385 stations was compiled for this study. These stations were specifically chosen because they have a LEDWI sensor. From each station, five-minute METAR observations were collected, and the precipitation type and intensity were extracted from the METAR. In addition, the corresponding MRMS liquid precipitation rate, base reflectivity, and composite reflectivity were determined. These values were chosen by finding the nearest MRMS grid point to the ASOS station. A 10 km by 10 km box was created around that point and the maximum value of the parameter within that box was chosen. This was done to mitigate any issues due to the cone of silence if a radar and an ASOS station are close together.

Since precipitation type identification is most important during the cold season, data from October 2016 through March 2017 were used. The MRMS data are quality controlled, so some ASOS reports of precipitation did not have associated MRMS information, particularly with very light precipitation. If the MRMS data were missing for any reason, the station was filtered out. Two additional datasets were used in this analysis. First, annual enplanement data from the FAA (FAA, 2018) were used to select ASOS sites in the medium and large hub categories, as these sites typically have a human observer to augment the automated ASOS observation. Second, the distance from each ASOS site to the nearest radar site was calculated to examine the sensitivity of the results to distance from the nearest radar site. The outcome of tests including these data did not substantially affect the data presented in this study, so the results presented here are from using the full ASOS dataset.

3. RESULTS

a. Scatterplots of Rain and Snow

This section presents an overview of the data. Here, the data have been separated into individual scatterplots based on the ASOS-derived intensity, with each point plotted based upon the corresponding MRMS base reflectivity and precipitation rate. The vertical lines at 100 mm hr^{-1} on each of the plots represent a cap that MRMS uses for thunderstorms. As this study focuses on the cold season, when thunderstorms are rarer, the impact of this cap on the results is minimal.

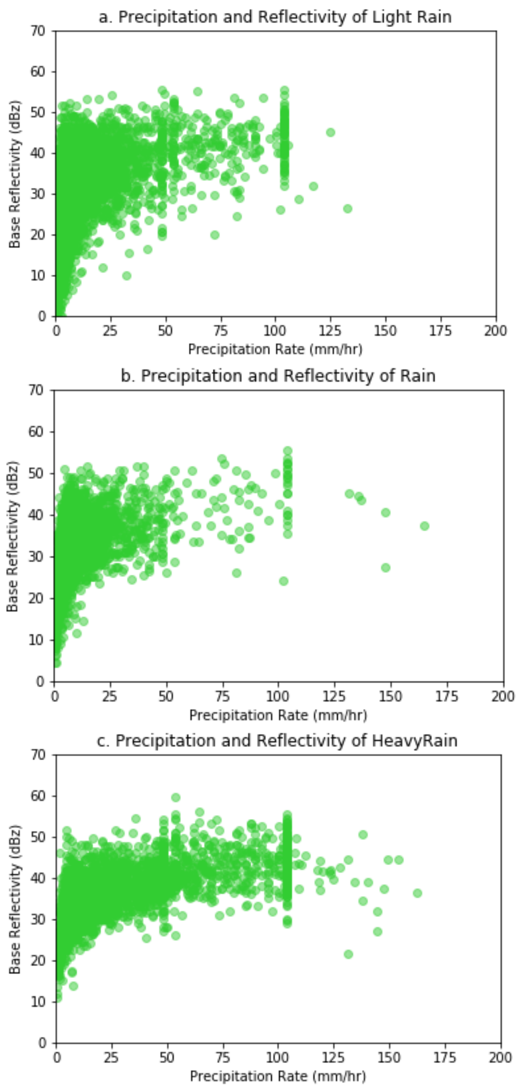

Figure 1: Scatterplots of MRMS precipitation rate (mm hr^{-1}) and base reflectivity (dBZ) associated with ASOS reports of rain. The three panels are for ASOS reported intensities of light rain (a), moderate rain (b), and heavy rain (c).

Figure 1 contains three scatterplots of the MRMS precipitation rate and base reflectivity for observations in the dataset where the ASOS reported rain, with the panels corresponding to the three ASOS-reported intensities. Base reflectivity was chosen because it is more representative of the precipitation falling at the surface. In the case of light (Fig. 1a) and moderate (Fig. 1b) rain, the results span a much larger range overall of base reflectivity with the majority of precipitation rates less than 50 mm hr^{-1}. They both also tend to have the majority of events with base reflectivity below 50 dBZ. Heavy rain (Fig. 1c) contains fewer observations with low reflectivity (<20 dBZ), and a few more observations above 50 mm hr^{-1}. In general, the difference between heavy rain and light and then moderate rain is much greater than the difference between light and moderate rain. However, in all three categories of rain, the majority of the data lies within the lower left quadrant of the scatter plot. The degree of overlap between the different categories of intensity will be looked at statistically in the next section of the paper.

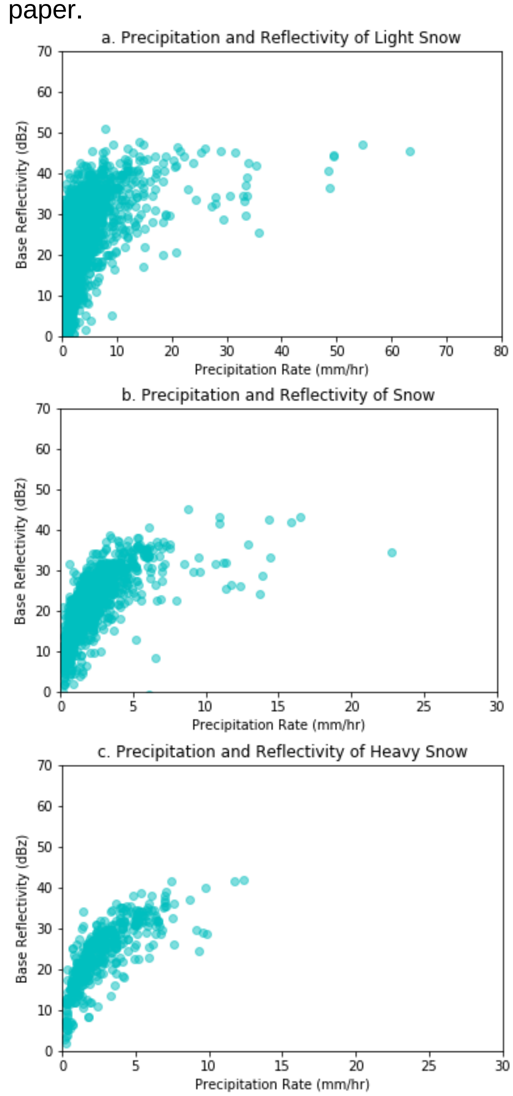

Figure 2: Scatterplots of MRMS precipitation rate (mm hr^{-1}) and base reflectivity (dBZ) associated with ASOS reports of snow. The three panels are for ASOS reported intensities of light snow (a), moderate snow (b), and heavy snow (c).

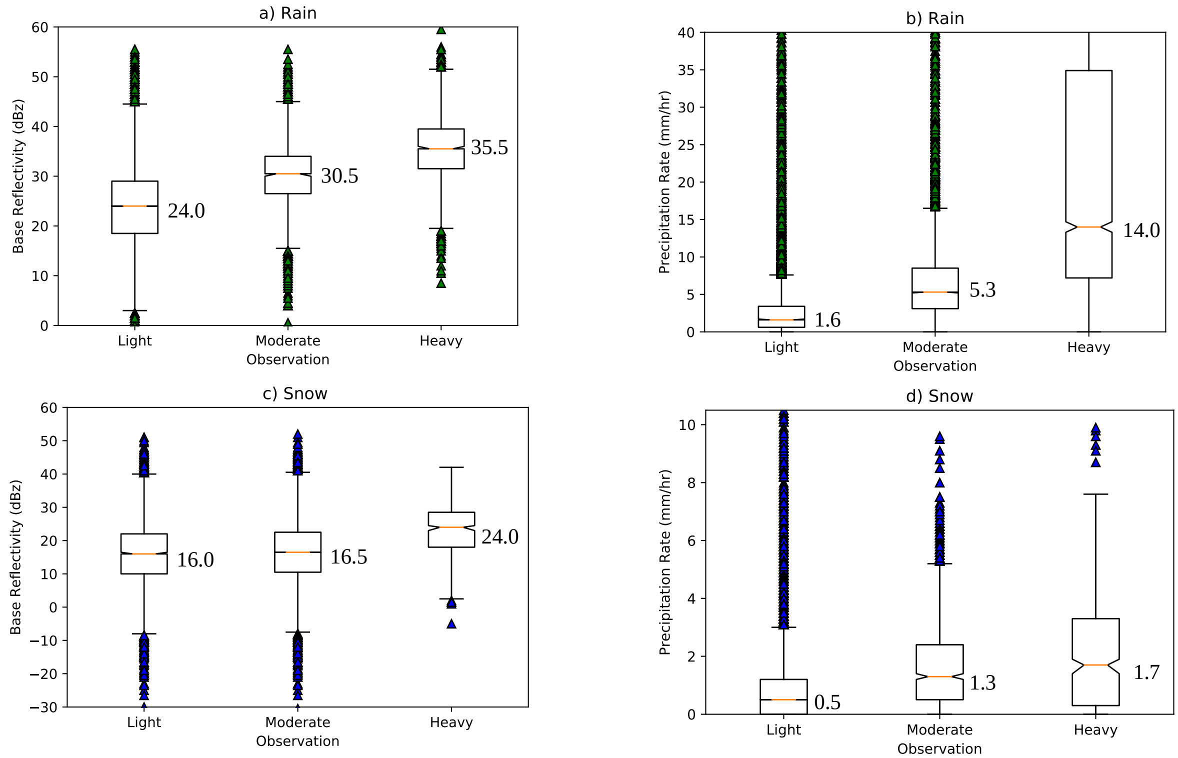

Figure 3: Box and whisker plots of ASOS reports of rain (a, b), and snow (c, d), with observations of intensity versus MRMS base reflectivity (a, c) and precipitation rate (b, d). Each observation is labeled 1 through 3, which corresponds to an intensity of light (1), moderate (2), and heavy (3).

The scatterplots in Figure 2 present the same analysis as Figure 1, except for times where the ASOS reported snow. As is expected with snowfall, the precipitation rates for all three intensities are lower than the corresponding plots in Figure 1. While the shape of the graphs are similar to the shape of the rain scatterplots, the majority of data points in all three plots fall below 40 dBZ reflectivity, whereas it was mentioned before that the average reflectivity of rain lies below 50 dBZ. The most noticeable difference between the categories is that the larger MRMS intensity outliers (both reflectivity and precipitation rate) are found with ASOS reports of light snow (< 30 mm hr^{-1}), and the number of these outliers decrease as ASOS intensity increases. The change in MRMS variables between categories is likewise small, with much overlap between the categories where snow has most events happen within the lower left quadrant of the scatter plot below 40 dBZ and 10 mm hr^{-1}.

b. Statistical analysis of observation versus base reflectivity

While using scatter plots gives an overview of the data, a more statistical framework is necessary to ascertain whether the reported ASOS intensity provides a useful discriminator for precipitation intensity. Notched box and whisker plots were generated to determine if binning the MRMS observations by ASOS precipitation intensity produces statistically distinct categories. These plots are used to show whether the difference between medians are statistically significant, how much variance is in the data, and whether or not the middle quartiles overlap. The triangles within the plots represent the outliers, however, as outliers, they will not be used in this analysis.

Figure 3 contains box and whisker plots of MRMS base reflectivity (a) and precipitation rate (b) for observations where the ASOS has reported rain. The uncertainty was determined by using 1000 bootstrapped samples from each category. In Fig. 3a, the median for each observation of light, moderate, and heavy rain increases with respect to base reflectivity as expected. This is very similar in Fig. 3b as the median precipitation rate increases as ASOS-indicated intensity increases. Additionally, the medians' uncertainty ranges do not overlap therefore, the increase in the medians between categories is statistically significant.

While the medians are statistically distinct, the distributions must also be reasonably distinct for the ASOS intensity categories to be meaningful. Comparing each intensity category in Fig. 3a, light rain has the greatest interquartile range (IQR), which stretches between 20-30 dBZ. This large IQR shows a greater variance in the data, especially compared to heavy rain and moderate rain, which have similarly sized IQRs. In Fig. 3b, heavy rain has the greatest IQR stretching from just below 10 mm hr^{-1} to just below 35 mm hr^{-1}. This variance is large enough, that the scatter plot for precipitation rate shows too much unreliability. In Fig. 3a the 3rd quartile and upper half of the IQR of light rain (~30 dBZ) overlaps the 2nd quartile and lower half of the IQR of moderate rain (<30 dBZ). This is similar for moderate rain and heavy rain. In Fig. 3 (b) the same pattern is observed, where the 3rd quartile of each category overlaps the 2nd quartile of the following category. This consistent overlap indicates that the distributions of MRMS intensity variables overlaps significantly between the ASOS intensity categories.

The same plots for the cases of snow are shown in Figures 3 (c) and (d). While rain categories had median values of MRMS variables increasing as ASOS intensity increased, the snow box plots show a less clear dependence on ASOS-measured intensity. In Fig. 3c, the box plot of light snow lies within the uncertainty interval of moderate snow, meaning that the categories' medians are not statistically different. However, the notches for light snow and moderate snow, do not overlap with heavy snow. In Fig. 3c all three intensity categories are nearly identical in IQR (~10 dBZ), however, these ranges have significant overlap, far more than the rain categories in Fig. 3 (a, b). This means that ASOS intensity has little usefulness in distinguishing between MRMS base reflectivity measurements. When comparing the snow categories' precipitation rates (Fig. 3d), there is even less distinction between categories of snow than there is for reflectivity. It is seen that the notches in the median for light snow do not overlap with the notches of either moderate or heavy snow. Therefore, there is a statistically significant difference between the medians. However, the notches for moderate and heavy snow do overlap, showing no statistically significant difference between the medians. In contrast to what was seen in Fig. 3c, the IQRs of each of the categories shows an increase of variance as the intensity increases. Light snow has the smallest variance (0-1 mm hr^{-1}) while heavy snow has the greatest variance (0 to 3 mm hr^{-1}). As with reflectivity, the 3rd quartile of each category of precipitation rate overlaps the 2nd quartile of the following category. This is especially seen in Fig. 3c, where light and moderate snow overlap almost completely, while also overlapping the bottom quartile of heavy snow. As was shown with base reflectivity, this analysis shows that the ASOS intensity for snow does not produce useful categories for precipitation intensity.

c. Maps of MRMS Base Reflectivity

Figure 4. shows examples of MRMS base reflectivity for the Denver International Airport. The red box represents the 10 km by 10 km bounding box used to select MRMS data.

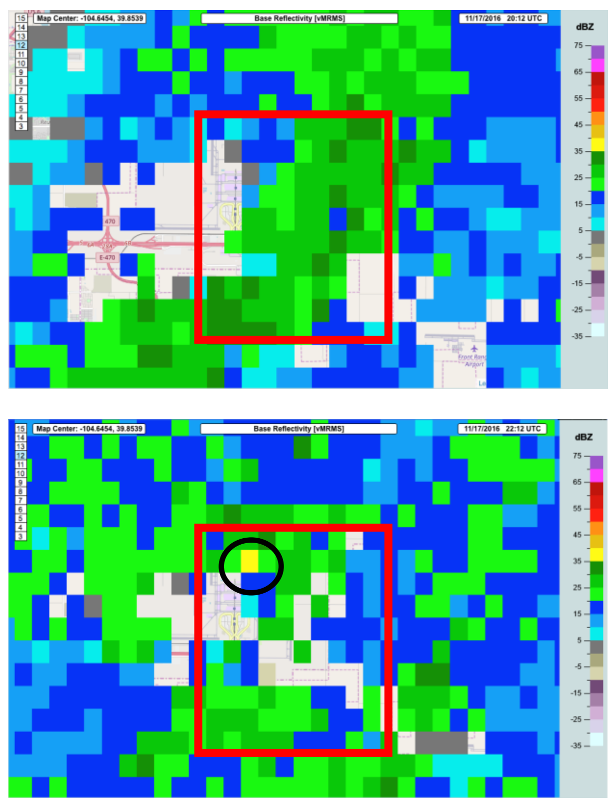

Figure 4: Map of MRMS base reflectivity for two different events of snow at the Denver International Airport in Denver, Colorado. Both events happened on 17 November 2016 at 20:12 UTC and 22:12 UTC.

In the previous section, large variances and overlapping regions were seen within the data. The radar images in Fig. 4 (a, b) show one potential cause of this. Overall, the reflectivity within the bounding box is very similar for both maps. The pixel containing the location of the ASOS for Fig. 4a shows a base reflectivity of 32.5 dBZ, a composite reflectivity of 34.5 dBZ, and a precipitation rate of 5.1 mm hr^{-1}. In Fig. 4b, a base reflectivity of 35.0 dBZ, composite reflectivity of 33.5 dBZ, and precipitation rate of 4.1 mm hr^{-1} are recorded. The base reflectivity, composite reflectivity, and precipitation rate for each instance is relatively close to each other, however, Fig. 4a is for a heavy snow event and Fig. 4b is for a light snow event. In Fig. 4b, there is one high reflectivity outlier (circled) (35-40 dBZ) for the light snow observation. This value is unrepresentative of the other observations within the bounding box. Since maximum values were chosen, this high reflectivity would be used within the data set. This methodology likely produced similar high, unrepresentative MRMS values for other observations.

4. CONCLUSION

The possibility of including precipitation intensity in the MRMS hydrometeor classification algorithm was explored. ASOS precipitation type and intensity, and MRMS base reflectivity, composite reflectivity, and two-minute precipitation rates were compared to see how well ASOS intensity can be used to produce distinct categories of these MRMS products for data from the cold season. The MRMS data were selected by using the maximum value within a 10 km by 10 km box surrounding the ASOS site. These data were used to create plots of categories of intensity as a function of base reflectivity, composite reflectivity, and precipitation rate.

The analysis was performed for all categories of intensity for both rain and snow. For rain, median MRMS measures of intensity increased as ASOS intensity increased, however, there was some overlap between the distributions of MRMS values, meaning that there is no clear way to use ASOS intensity for rain with the methodology presented here. For snow, the medians for MRMS measures of intensity were similar for each category, despite the increase in ASOS intensity between categories. There was also much more overlap between the distributions of MRMS values than there was in rain, meaning using ASOS intensity for snow is unlikely, consistent with the findings of Rasmussen et al. (1999).

While these results suggest that the mapping of ASOS to MRMS variables for snow is unlikely, the chance for rain remains inconclusive. Future work will look at ways to decrease the likelihood of unrepresentative data, including the possibility of using a smaller value such as the mean or median rather than the maximum. Other possibilities would be to look at the size of the “bounding” box created around the ASOS, and possibly other variables associated with ASOS and MRMS. Should these changes produce similar results, it would confirm the findings of this study that ASOS-based measures of intensity do not do an adequate job of representing the actual precipitation intensity.

6. ACKNOWLEDGMENTS

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