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Improving the Quantitative Precipitation Estimate for Hydrometeors Classified as Dry Snow by Polarimetric Radars

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ABSTRACT

Between 2011 and 2013, National Weather Service (NWS) Weather Surveillance Radar 1988 Doppler systems (WSR-88D) were upgraded with a dual polarization capability. The polarimetric upgrade is a significant enhancement that provides new and improved information about precipitation type, intensity, and size. Much work has gone into improving quantitative precipitation estimates (QPE), but the dual polarization QPE system only uses a modified version of the legacy reflectivity - rain relation for returns classified as dry snow that applies a multiplication factor of 2.8 to take into account the lower reflectivity returns associated with dry snow. NWS Forecast Office Buffalo, NY was upgraded with dual polarization during April 2012 and together with surrounding offices noticed an overestimation in the dual polarization QPE for several cold season events when the radar beam was above the melting layer. This study used gauge-to-radar comparisons for 722 hourly cases to test whether the coefficient was causing the overestimation. The results showed that the default coefficient of 2.8 was too high and led to a high bias in QPE. The mean dual polarization QPE was nearly double the gauge measured precipitation. When the coefficient was lowered to 1.4, the mean dual polarization QPE was still 19% higher than measured precipitation, but much improved over the initial values.

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1. Introduction

From 2011 to 2013 the National Weather Service (NWS) network of Weather Surveillance Radars (WSR-88D) across the United States were upgraded with the addition of a dual polarization (DP) capability. This enhancement made it possible to gain new and improved information about precipitation type, intensity, and size (National Oceanic and Atmospheric Administration 2013). Following the installation of DP radar, forecasters at Weather Forecast Office (WFO) Buffalo, NY (BUF) and Cleveland, OH (CLE) noticed a high bias in Quantitative Precipitation Estimates (QPE) for several cool season events (Jamison and LaPlante, personal communication 2012). Although, much work has gone into improving QPE, the initial implementation of the DP QPE system still utilizes a basic reflectivity to rainfall (liquid equivalent) relationship for returns classified as dry snow rather than employing any of the polarimetric variables. An initial assessment of QPE found that the polarimetric radar precipitation estimation system may overestimate QPE when the lowest radar slice samples above the melting layer (Cocks et al. 2012).

The DP QPE algorithm uses the pre-DP legacy precipitation processing system equation (PPSE) for returns classified as dry snow (e.g., the convective Marshall-Palmer relationship). When the DP Hybrid Hydrometeor Classification (HHC) algorithm classifies an echo as dry snow, the DP QPE system multiplies the legacy PPSE by 2.8 to derive the QPE (Giangrande and Ryzhokov 2008). The QPE for dry snow is determined using the following relationship (Ulbrich and Lee 1999):

$$QPE = 2.8R(Z),$$

where $R(Z) = (0.017)Z^{0.714}$

The 2.8 coefficient is applied to echoes classified as dry snow to account for lower reflectivity returns usually associated with these hydrometeors. As previously mentioned, initial assessments have shown this to be excessive regardless of the surface precipitation type. The Buffalo area receives a variety of snowfall types with synoptic, lake effect, and hybrid events. Dry snow QPE is critical to estimating snowfall rates and for river forecasts when precipitation melts and reaches the ground as rain. However, until a more robust algorithm can be developed for dry snow, QPE will depend on using a legacy PPSE correction factor.

Working with the Radar Operations Center (ROC), WFO Buffalo undertook a study to quantitatively evaluate the DP dry snow QPE. The goals of this study were to determine if DP QPE could be improved by adjusting the 2.8 coefficient, and to develop a methodology for determining a more appropriate value.

2. Data Collection

First, the WFO BUF gauge network was carefully assessed in order to find reliable precipitation data. Gauges had to provide reliable hourly data for all precipitation types and record precision to a hundredth of an inch. Selection of sites utilized local knowledge of gauge type, exposure, and track record for availability and data quality. Only gauges between 10 km and 100 km of the Buffalo WSR-88D radar were used (see Fig. 1). This was done to avoid close sites which fall in the cone of silence and distant sites prone to overshooting and sampling issues associated with broader beam widths at longer ranges. Close proximity to Canada, Lake Erie, and Ontario further limited candidate locations.

These criteria yielded a total of 13 gauges to be used for this study.

Events were selected from cold season months between October and April and the data was collected for two cold seasons, between October 2012 and April 2014. Potential events were considered if at least 5 of 13 gauges received greater than 0.10 inch of precipitation. From this subset of events precipitation at each gauge location was checked to see if the radar classified the return as "dry snow" using the DP HHC for one continuous hour. Archived Level II radar data and other products such as the HHC, DP QPE, and gauge precipitation data were collected from the Multi-Radar Multi-Sensor (MRMS) System website at http://nmq.ou.edu/ (Zhang et al. 2011 and 2015). Brief periods of missing, undetermined, or anomalous data were quite common. Therefore, at least 90% of the hour had to be classified as dry snow to qualify as a preliminary hourly case.

Preliminary cases were further screened for accuracy, keeping in mind gauge limitations in certain environments. A co-located or nearby site was used to determine wind speed and ground precipitation type. Windy surface conditions can cause unshielded precipitation gauges to significantly underestimate precipitation (Theriault et al. 2012). In order to mitigate this impact, events with winds in excess of 4 m/s were eliminated at the 9 gauges without wind shields.

Other factors were also considered based on the data collected. Blowing snow can cause a gauge to incorrectly report precipitation from snow blown into the gauge. Heated tipping bucket gauges can sometimes get clogged or not melt heavy snow fast enough to measure (Rasmussen et al. 2012). Data exhibiting these issues were eliminated. As a final check, questionable gauge data was compared to measurements from nearby cooperative observer or CoCoRaHS measurement. These criteria yielded 722 hourly cases which occurred on 33 different days.

Preliminary results from this research provided strong evidence for lowering the coefficient for dry snow. On 6 February 2014, the coefficient was changed to 1.4 for real-time DP QPE product generation. 102 of the 722 cases occurred after the switch of the coefficient.

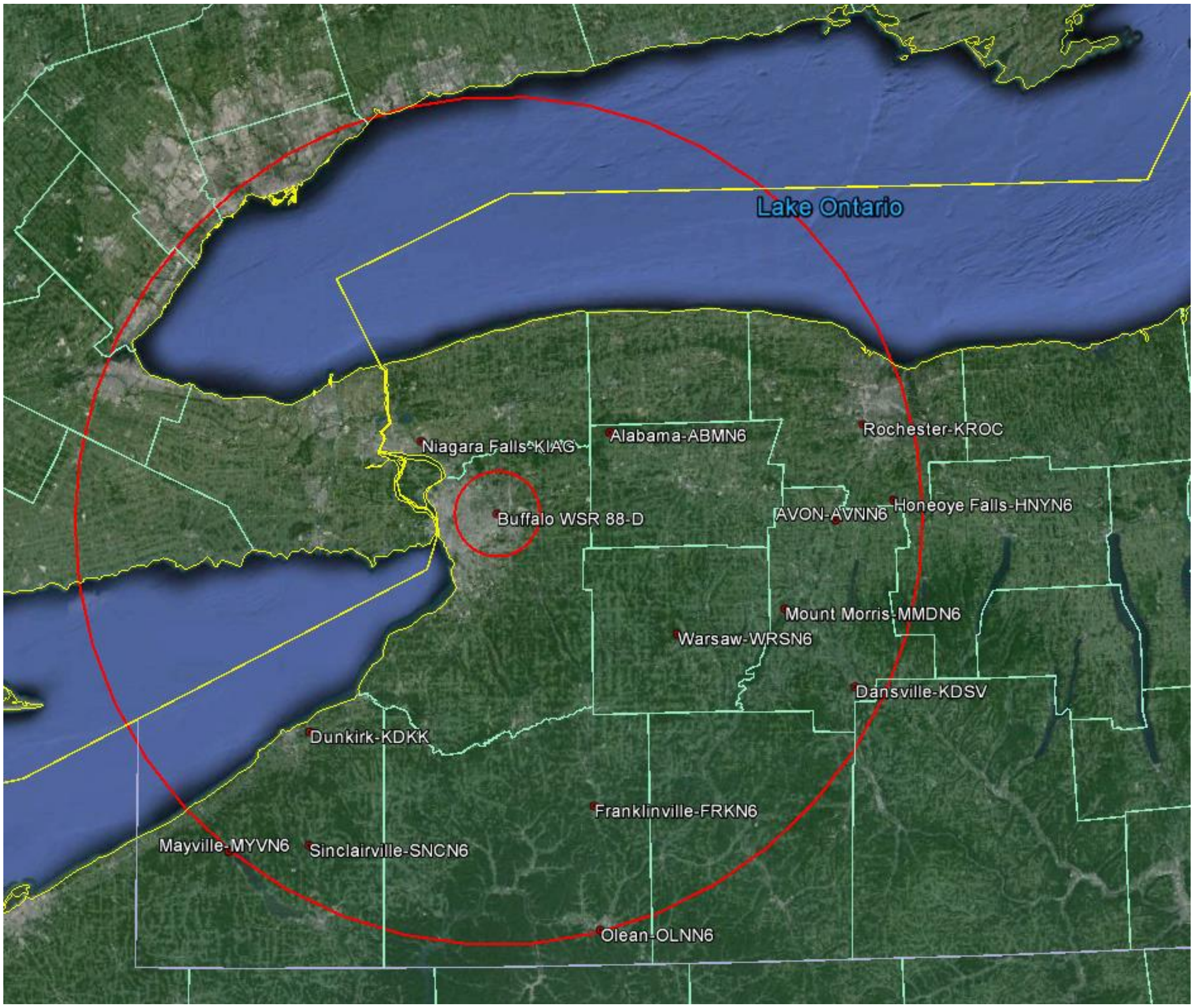

Figure 1. A map showing the location of the 13 precipitation gauges used for this study and range rings at a distance of 10 km and 100 km from the Buffalo WSR-88D.

3. Results

DP QPE and gauge precipitation can be used to calculate a coefficient for each hourly case. This was done by multiplying the gauge measured precipitation by 2.8 and then dividing the result by the DP QPE. Of the 722 cases, 620 cases with a coefficient of 2.8 resulted in a positive bias of 101%, that is, the radar based QPE was nearly double that of gauge data (Fig. 2 and Table 1). For cases after 6 February 2014, the new coefficient of 1.4 was used for this calculation. For these 102 cases, radar based QPE still showed a positive bias (19% above gauge data), but this was a notable improvement when compared to the cases using the original default coefficient of 2.8 (Fig. 3 and Table 1).

The calculated coefficient varied for each event depending on the type of precipitation sampled at surface gauges. Since the radar is sampling the precipitation above the surface, many of the HHC identified cases of dry snow resulted in other precipitation types at the surface as the hydrometeors fell through a melting layer below the radar beam. Table 2 shows the calculated coefficient for all rain, all snow, and mixed precipitation events. The coefficient for all snow events was higher than other events, with an average coefficient of 1.78. For events which precipitation was classified as snow at radar level, but melted before it reached the ground the coefficient was 1.33 and the coefficient for mixed precipitation cases was 1.30. It is uncertain why the coefficient is lower for rain and mixed precipitation cases, but one factor may be that these type of events have a melting layer in close proximity. This could result in an overestimation if bright band returns are incorrectly classified as dry snow. All rain and mixed precipitation cases were more common than all snow, with all snow events only making up 13% of the cases.

Sites closer to the radar had a slightly lower coefficient than stations further from the radar (Table 3). In some cases the radar may be overshooting heavier precipitation at lower levels, which is common in lake effect snow. However, it is important to note that despite the close proximity to Lake Erie and Lake Ontario, the majority of cases used for this study were synoptic scale events. Based on archived forecast discussions, only about 30% of the cases were impacted by lake effect, with the remaining cases synoptic scale events.

As an example, the ROC post-processed radar data for an event on 28 October 2012 is used to compare QPE calculated using different coefficients. Figure 4 shows the DP storm total QPE using the default 2.8 coefficient for this event. There is a noticeable ring of higher QPE about 120 km from the radar which is about where melting layer is. Figure 5 shows the same event using 1.5 as the coefficient. Notice that there is less discontinuity at and above the melting level in the QPE.

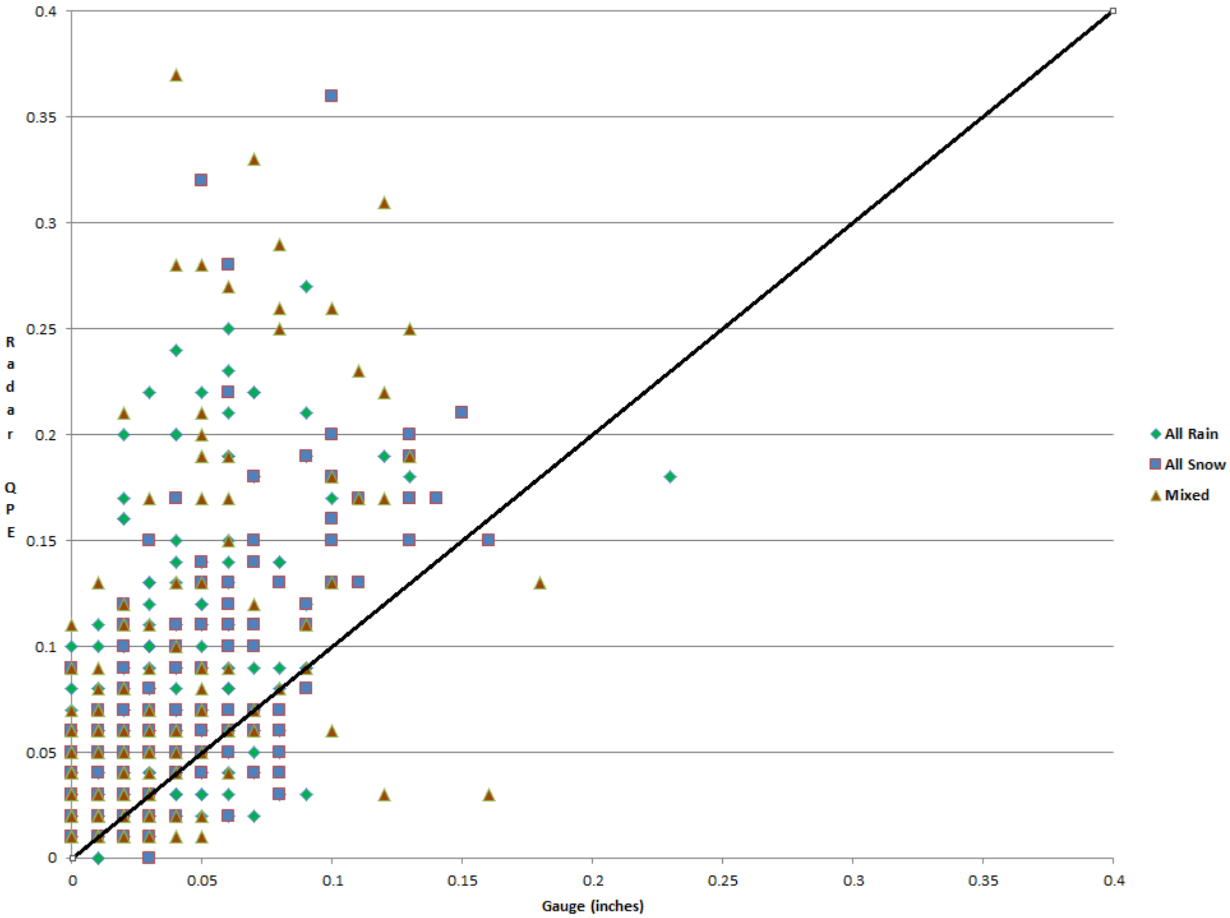

Figure 2. A scatterplot graph which compares DP QPE to gauge measured precipitation for 620 hourly cases with a 2.8 coefficient categorized by precipitation type at ground level.

Table 1. A comparison of coefficients used for hydrometeors classified as dry snow for DP QPE and the calculated error for each one.

Dual-pol Coefficient for Dry Snow	Number of Hourly Cases	Dual-pol QPE (inches)	Gauge Measured Precipitation (inches)	% Error
2.8	620	43.37	21.52	101%
1.4	102	5.16	4.35	19%

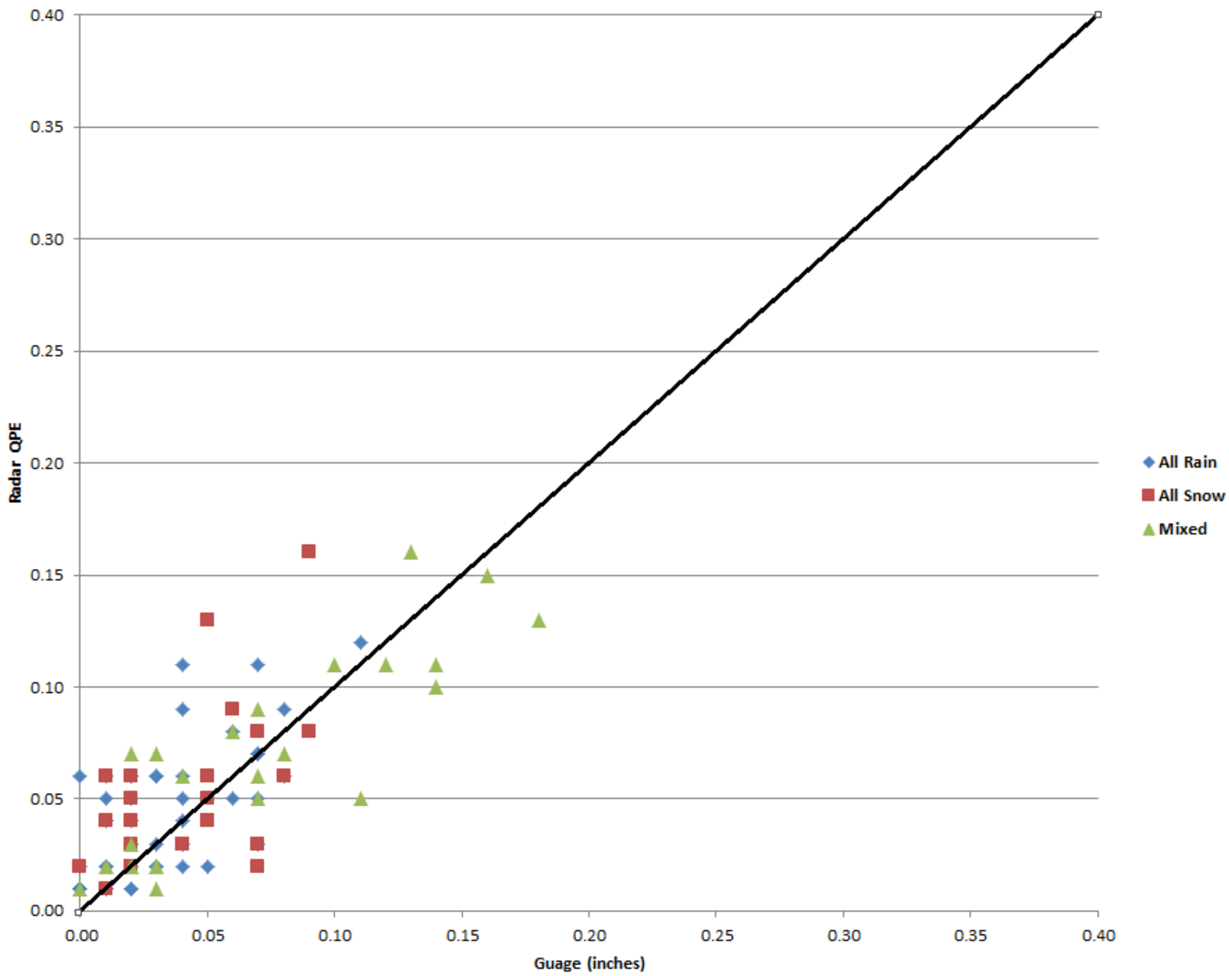

Figure 3. A scatterplot graph which compares DP QPE to gauge measured precipitation for 102 hourly cases with a 1.4 coefficient categorized by precipitation type at ground level.

Table 2. The mean calculated coefficient for hydrometeors classified as dry snow separated by different type of precipitation at ground level.

Event Type	**Hourly Cases**	**Calculated Coefficient**
All Rain	232	1.33
All Snow	94	1.78
Mixed	389	1.30
Total	715	1.35

Table 3. The mean calculated coefficient for hydrometeors classified as dry snow separated by distance from the Buffalo WSR-88D radar.

Event Type	**Hourly Cases**	**Calculated Coefficient**
Close to Radar (<75 km)	284	1.23
Far from Radar (75-100 km)	489	1.42
Total	715	1.35

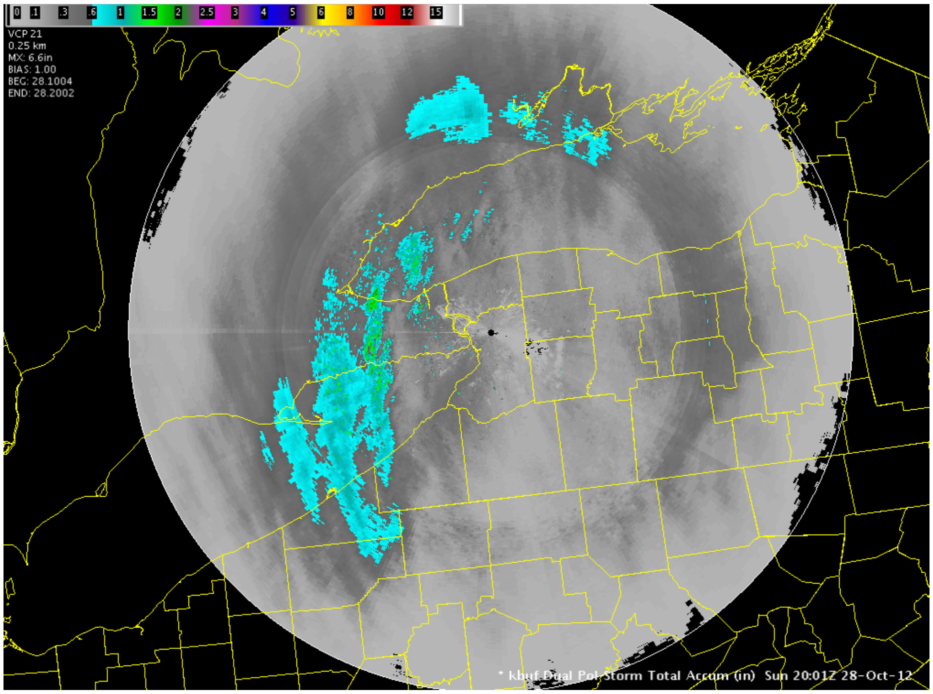

Figure 4. DP Storm Total Precipitation QPE from the Buffalo radar on October 28th, 2012 between 1004Z and 2002Z. The default 2.8 multiplier is used for dry snow and ice crystals. Note the melting layer discontinuity ring.

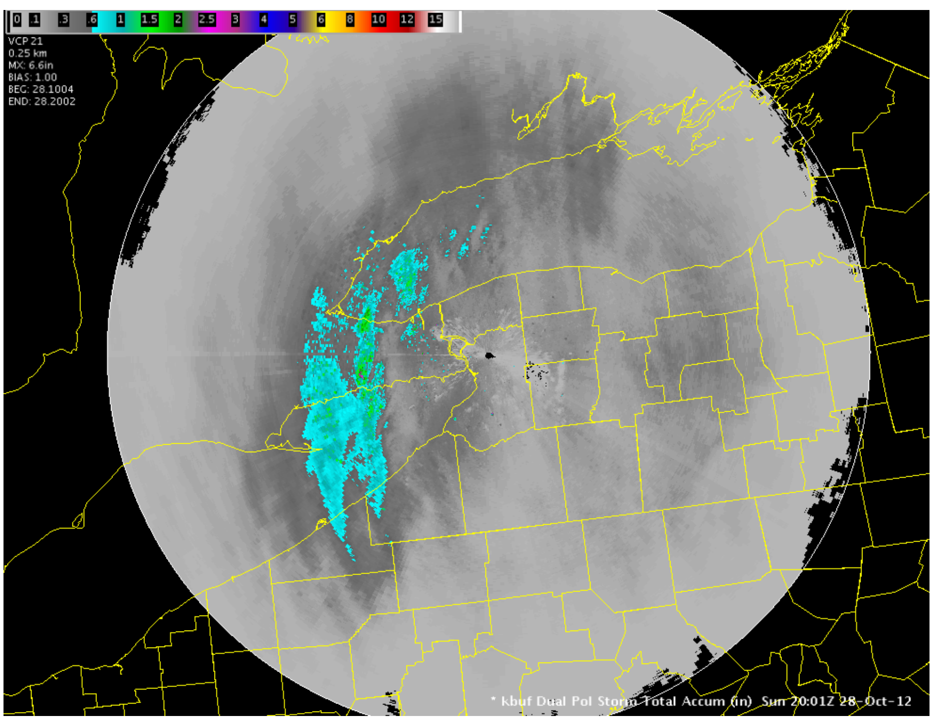

Figure 5. DP Storm Total Precipitation QPE from the Buffalo radar on October 28th, 2012 between 1004Z and 2002Z. This is the same event but using a multiplier of 1.5 for snow and ice crystals. Note the reduction of the melting layer discontinuity ring.

4. Conclusions and Future Work

Results of this research suggest that the default coefficient of 2.8 used in NWS radar algorithms for hydrometeors sampled as dry snow is too high, resulting in DP QPE overestimates. While there is considerable event by event variation in the coefficient, the data suggests the vast majority of events would have benefited from a lower coefficient for dry snow. This study showed that a better coefficient for the Buffalo WSR-88D might be closer to 1.35. When this coefficient was lowered to 1.4, the mean error was reduced significantly. However, this may not be representative for other locations since snow formation is complex and the climatology will vary by location. Concurrent with this research, similar data was collected for five other NWS offices. Supported by preliminary results from this research, NWS Radar Product Generator (RPG) build 14.0 was upgraded in mid-2014 to make this coefficient adjustable for each office, dependent on a similar study conducted to determine an optimal new coefficient (Warning Decision Training Branch 2014). Similar research conducted for other regions of the U.S. to provide an improved dry snow coefficient for each radar location could significantly reduce DP QPE error for hydrometeors classified was dry snow.

This research did not attempt to classify specific snow types, and based on ground temperatures and soundings, it would be difficult to infer snow structure. Further research could also be done on snow structure, to see if it is possible for dual polarization radar data to differentiate between different types of snow reflectors. It is possible a more robust HHC algorithm that accounts for transition zones between radar detection and the surface could also improve QPE.

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