Forecasting and characterization of mixed precipitation events using the MicroRainRadar

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Figure 1. Locations in the United States where MRR data were obtained for this study.

1. Introduction

Mixed precipitation events that include transitions among snow, sleet, freezing rain, and rain are examined using vertically-pointing 24.1 GHz METEK MicroRainRadar (MRR) data (Löffler-Mang et al. 1999; Peters et al. 2002) from several sites in the United States. Transitions among precipitation types are difficult to observe with scanning weather radar since shallow, near surface, cold and warm air layers often occur below the lowest level scanned. Accurately forecasting the timing of the onset of snow and changes in precipitation type is critical for transportation and other public agency decision makers.

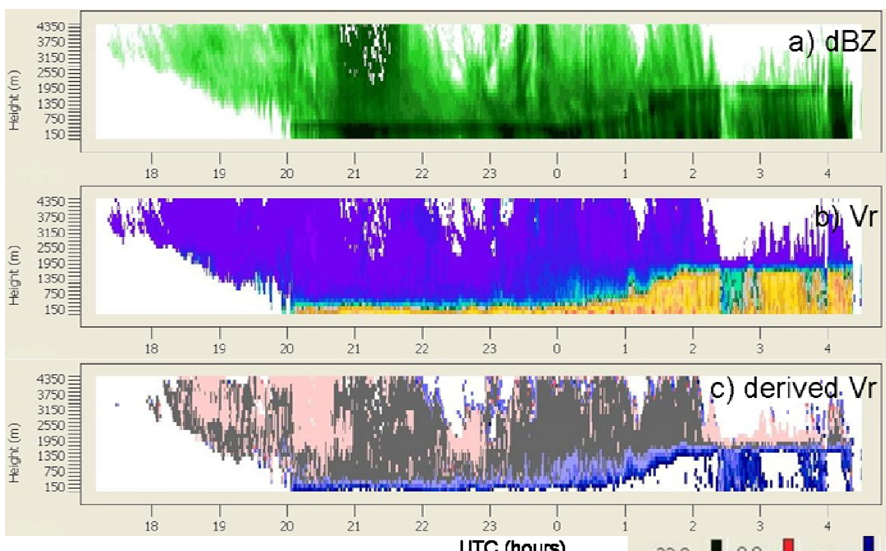
Vertically-pointing profilers and radars can detect the melting layer height at intervals of ≤ 1 min within precipitation by using a combination of information on the radar bright band and fall speed gradients (White et al. 2002). The gradient in Doppler velocity associated with the change in particle fall speed as the particle melts from snow into rain provides a clear indication of the melting layer height even in conditions where reflectivity is attenuated. We use MRR data to examine the value added by vertically-pointing radar data sets in different types of mixed precipitation events.

2. Data

MRR time-height profiles of radar reflectivity and Doppler velocity were obtained at four locations during the winter season (Fig. 1). Portland, Oregon (OR) is in the Willamette Valley between the Coastal and Cascade Mountain Ranges. Poga Mountain, North Carolina (NC) is at 1018 m altitude above sea level and is west of the crest of the Appalachian Mountains. Raleigh, NC is in the Piedmont between the Appalachian Mountains and the coastal plain. Stony Brook, New York (NY) is on Long Island in the Atlantic Ocean. The MRR deployment was the first time that vertically-pointing precipitation radar data had been collected in these locations.

3. Frontal systems

There is often broad ascent associated with a warm front as the warm air aloft is lifted over a low-level cold region. This ascent deepens as the front approaches, resulting in a lowering of the cloud base (virga) and associated moistening of low-level air. Within the warm air aloft there can be instability and narrow convective towers (seeder cells).



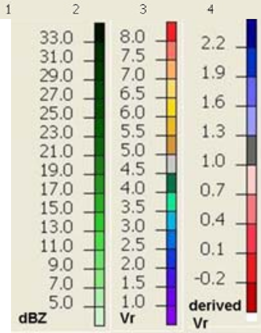


Figure 2. Time-height plots from Portland, OR for 31 Jan to 1 Feb 2006 warm front passage. a) reflectivity, b) Doppler velocity, c) derived Doppler velocity using Nyquist interval centered on 0 m/s. Color scales for this and subsequent time-height plots to the right.

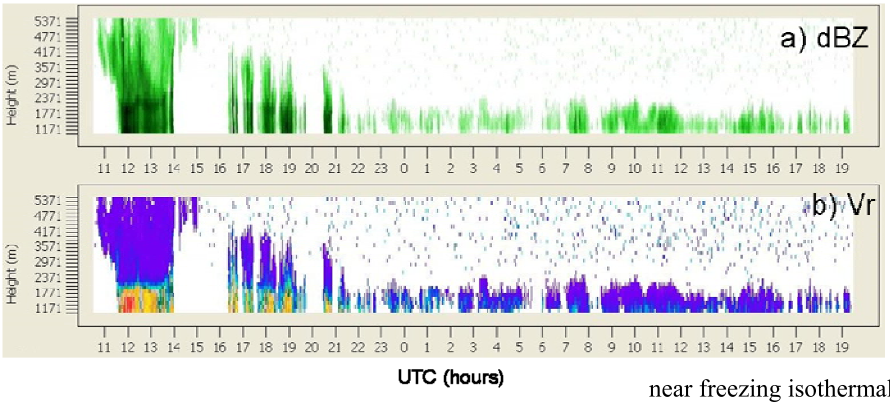


Figure 3. Time-height plots from Poga Mountain, NC for 26-27Feb 2008 storm. a) reflectivity, b) Doppler velocity.

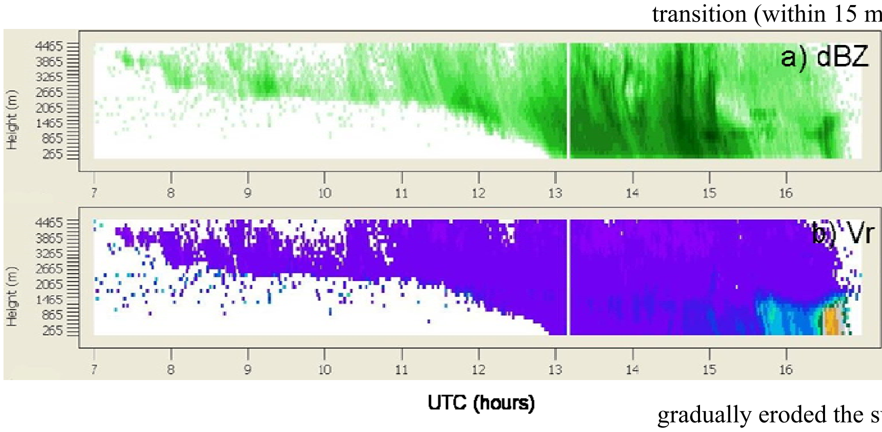


Figure 4. Time-height plots from Raleigh, NC for 1Feb 2007 storm. a) reflectivity, b) Doppler velocity.

In contrast, a cold front has a stronger vertical circulation along its leading edge given the sharp gradient in temperature across the front. The low-level air is frequently more unstable along the front, which can result in narrow bands of convection. In time-height plots, a warm front is usually associated with more continuous precipitation while a cold front is associated with more discontinuous precipitation.

Contrasting examples of a warm front passage in Portland and a cold front passage at Poga Mountain are shown in Figures 2 and 3. In the warm front case, the surface precipitation was preceded by the descending base of virga from 1755 to 2000 UTC. Surface snow mixed with rain occurred from 2005 to 0000 UTC. As the melting layer gradually increased in height, surface precipitation transitioned to rain. The Portland, OR National Weather Service (NWS) used the trend in melting layer height to forecast the transition from snow to all rain. In the case from Poga Mountain (Fig. 3), the increasing melting layer height characteristic of a warm front is followed by more intermittent post cold frontal rainbands. The discontinuous nature of the precipitation made estimation of the trend of decreasing melting layer height with time more difficult to determine in the post frontal rainbands. The lower echo tops during periods of surface snow compared to rain are a typical feature of winter storms at Poga Mountain.

4. Complex mechanisms including diabatic and dynamic processes

During winter storms in Raleigh, NC, the depth of the cold air varies but it is typically shallow. Warm, moist air, often originating from the Gulf of Mexico or the Atlantic Ocean, surges over the cold air resulting in a highly varied temperature profile. In some cases, a deep, near freezing isothermal layer can develop in the temperature profile.

An example of complex mechanisms yielding an abrupt transition (within 15 min) from snow to rain occurred in Raleigh on 1 Feb 2007 (Figure 4). The Raleigh, NC NWS characterized this storm as an in-situ cold air damming event. In early morning, a cold and dry air mass was present over central NC. Low level southwesterly wind flow brought warm moist air from the Gulf of Mexico. Initially the warm air was lifted over the cold, near surface air. As the morning progressed, the warm, moist air gradually eroded the surface cold air mass. The MRR allowed forecasters to see the first signs of melting at around 1400 UTC and an abrupt change from snow to rain at the surface in Raleigh at 1540 UTC as the warm air overwhelmed the cold air.

5. Storm with sleet

The 13 Dec 2007 storm at Stony Brook yielded 4.5 cm of sleet on the ground and 0.5 cm of ice on tree branches (Fig. 5). Surface observations of precipitation and ice crystal type provide detailed documentation of the precipitation types during the storm (Table 1). The MRR observed a sharp decrease in the vertical profile of reflectivity during periods when moderate to heavy sleet either occurred by itself or in combination with snow (e.g. 1815-1925 UTC, 2008-2030 UTC, black boxes in Figure 5). Rain and sleet have similar fall speeds. For the same size and number of scatterers, the change in reflectivity associated with the change in dielectric constant is 6.7 dB. The observed reflectivity decrease varied between 2 to 7 dB over a 300 m height interval. The sharp decrease in reflectivity with height did not occur when the sleet was mixed with freezing rain (e.g. 2040-2137 UTC).

It is likely that the gradient in reflectivity during the periods with sleet represents the top of the near surface cold layer responsible for the transition of melted particles to sleet. If this interpretation is correct, then in conditions of sleet a vertically-pointing precipitation radar can provide temperature profile information on both the highest altitude 0 °C isotherm via a sharp gradient in Doppler velocity as snow melts and also on the altitude of the lower level 0 °C isotherm via a sharp gradient in reflectivity as rain freezes into sleet.

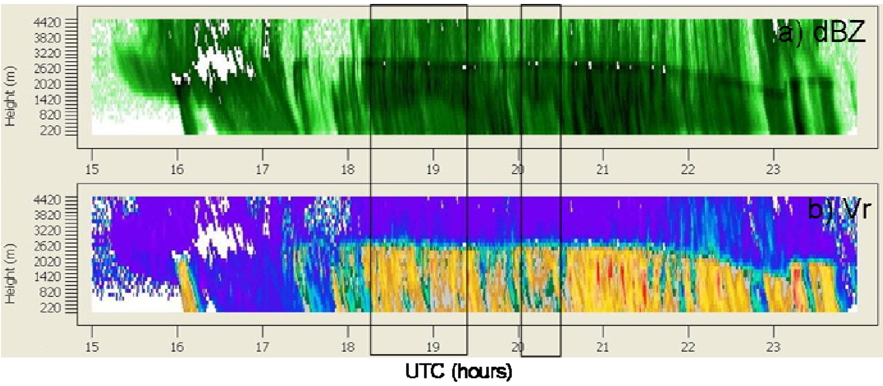


Figure 5. Time-height plots from Stony Brook, NY for 13 Dec 2007 storm with sleet. a) reflectivity, b) Doppler velocity.

Table 1. Precipitation type observations during 13 Dec 2007 Stony Brook, NY storm.

Time (UTC)	Description
1610	Very heavy sleet
1630	Large lightly rimmed aggregates (1-3 cm diameter)
1705	Small aggregates, needles, and dendrites
1730	Light sleet and some needles
1758	Moderate sleet, few rimed aggregates
1820	Heavy sleet
1921	Moderate sleet and needles
2014	Moderate sleet, ~2.5 cm sleet accumulation
2049	Heavy sleet with some freezing rain
2140	Moderate sleet and some freezing rain (ice accumulation on trees)
2208	Moderate sleet and needles
2250	Light sleet, no snow
2339	Light sleet and freezing drizzle (accumulation of 4.5 cm sleet on ground and 0.5 cm of ice on tree branches)

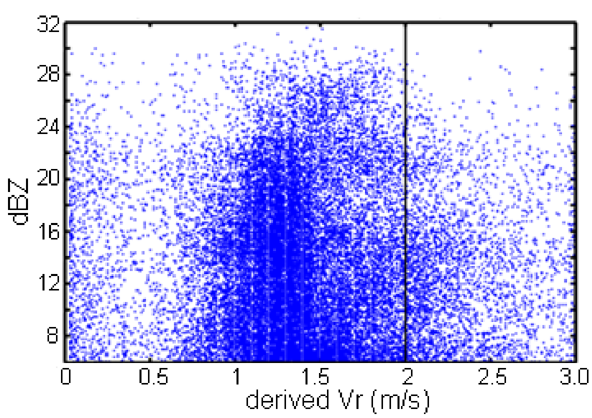


Figure 6. Scatterplot of derived Doppler velocity versus reflectivity for all heights during all snow periods at Stony Brook, NY over 2007-2008 winter season. Vertical line at 2 m/s.

6. Areas of upward motion

Nominally, MRR Doppler velocities are in the range from 0.95 m/s to 12.195 m/s, with positive values downward. Post-processing MRR raw data files to center the Doppler velocity Nyquist interval on 0 m/s can yield derived Doppler velocity information on regions of upward motions within snow layers. The measured Doppler velocity is the sum of particle fall speed and vertical air motion. Assuming a fall speed of snow of 2 m/s, regions with Doppler velocity near 2 m/s have near 0 m/s air motion and regions with Doppler velocity < 2 m/s have upward motion (Yuter and Houze, 2003). Since the Ku-band reflectivity is often attenuated, a reflectivity to fall speed relation cannot be applied with confidence to retrieve the vertical air motions in the rain layer. An example of this post-processing is shown in Figure 2c for the Portland warm front storm. The color scale in Figure 2c was chosen to emphasize the weak and upward velocities in the snow layer. The lack of correlation in the pattern of areas of stronger upward motion and higher reflectivities in snow is typical of many snow layers examined from the four sites. Scatter plots indicate poor correlation between derived Doppler velocity and reflectivity during snow periods (e.g. Fig. 6 for Stony Brook).

7. Conclusions

The high temporal and spatial resolution of the vertically-pointing MRR makes it well suited to monitor both the height of the melting layer in mixed-phase precipitating clouds and the altitude of virga. The changes in the vertical profiles of reflectivity and Doppler velocity that indicate transitions among different surface precipitation types within mixed precipitation events usually occur within 2 km of the surface. Information on current conditions from the MRR complements information from operational scanning radars by providing data on layers below where the scanning radar can observe and in areas within mountainous terrain where the scanning radar is blocked.

Data from the MRR can aid short-term forecasting of the onset of surface precipitation and transitions among precipitation types. Trends in melting layer height are most easily observed in conditions associated with a classic warm front, i.e. nearly continuous precipitation and a gradual transition in melting layer height. In cold fronts, the transition between conditions favorable for rain versus snow can occur between individual precipitation bands making prediction of the trend in melting layer height more difficult. Near the US east coast, complex interactions among dynamical and diabatic processes can yield abrupt transitions among precipitation types with no obvious precursors.

During periods of moderate to heavy sleet during the 13 December 2007 storm at Stony Brook, reflectivity abruptly decreased with height consistent with a change in phase and the associated dielectric constant as rain became sleet. The altitude at which this transition occurred varied with time, indicating a varying depth of the near-surface layer of cold air.

Reprocessing the raw MRR Doppler velocity data to center the Nyquist velocity interval on 0 m/s can yield information on the regions of upward air motions within snow. In the snow events examined, the correlation between derived upward vertical motion and reflectivities is weak.

The MRR's ≤1-min time series of the height of the melting layer within precipitation can also be used to evaluate forecast models. Preliminary analysis of model forecast and observed melting layer heights will be shown in the conference presentation.

Acknowledgments

Special thanks to Daniel Horn and David Spencer for software and hardware development and support. This material is based upon work supported by the National Science Foundation under Grant No. 0544766 and a University of North Carolina General Administration grant. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation (NSF). Mention of a commercial company or product does not constitute an endorsement by the National Weather Service.

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