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RADAR OBSERVATIONS OF A FREEZING DRIZZLE CASE IN COLORADO

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1. Introduction

Freezing drizzle represents a significant in-flight icing hazard, as documented by Bernstein (2000) for instance. Due to the small sizes of drizzle drops, radar reflectivity is typically less than 0 dBZ during these events. However, the sensitivity of the WSR-88D radars is sufficient to detect reflectivities down to −12 dBZ and therefore allows the possibility for automatic detection of drizzle. This paper discusses a case study of freezing drizzle in Colorado, and shows that such detection is indeed possible.

Freezing drizzle in Colorado most often results from upslope winds that are from directions between north and northeast. A statistic study of freezing precipitation from Bernstein (2000) reports that freezing drizzle is common after passage of an arctic cold front from Canada, along with an influence from the Denver Cyclone on occasion. A similar synoptic set up occurred on 4 March 2003. A strong surface low pressure center formed over eastern Colorado while an arctic front advanced southward, eventually resulting in a favorable condition for the formation of freezing drizzle in eastern Colorado. The precipitation on this day changed from freezing fog, to freezing drizzle, to light snow, to heavier snow in relation to the movements of the arctic front and the low pressure center. However, freezing drizzle was observed prior to the arctic cold frontal passage rather than after the frontal passage.

2. Synoptic settings

The weather conditions on 4 March 2003 were dominated by a southward-advancing Canadian arctic cold front and a low pressure center moving through eastern Colorado. The surface map from 0000 UTC on 4 March shows the low pressure center associated with the arctic airmass over the Great Lakes and its cold front extending across the northern U.S. indicated by a strong thermal gradient (Fig. 1a). By this time, another low pressure center had formed in eastern Colorado. It was accompanied by a well-defined thermal ridge over the eastern Colorado state border that initiated an advection of warm, moist air into the Great Plains. This low pressure center reached the southeastern corner of Colorado by 0600 UTC (Fig. 1b). In the next six hours, the low pressure center moved out of Colorado as the arctic cold front advanced into northern Colorado (Fig. 1c). Consequently, a steady surface pressure increase from 810.5 mb at 0700 UTC to 812 mb at 1200 UTC was observed at Marshall field site (Marshall, hereafter). [Marshall is located ~50 km west-northwest of the WSR-88D radar near the Denver International Airport, or just south of Boulder, Colorado.] Also, as the surface wind speed increased, the wind direction changed from southwesterly prior to 0700 UTC, to northerly between 0700 and 1000 UTC, and to northeasterly by 1200 UTC (Fig. 2a). An evolution of the low-level moisture tongue around the low pressure center is clear in the 0600 and 1200 UTC surface analyses (Figs. 1b and c).

Eventually, the arctic cold front penetrated to southeastern Colorado before propagating eastward (Fig. 1d). Surface pressure at Marshall fell slightly between 1800 and 2000 UTC. Winds slowly turned with time, changing from northerly or north-northeasterly to easterly during this time period, suggesting passage of the surface cold front.

Figs. 3a and b are soundings from Denver, Colorado for 1200 UTC 4 March and 0000 UTC 5 March, respectively (note that sounding release times are typically one hour before the nominal time). The atmosphere was dry prior to 1200 UTC. By 1200 UTC (0500 LST), the 725-745 mb layer moistened. The 700 mb analysis from this time shows a thermal ridge to the east of Colorado—the area corresponding to the low-level moisture tongue in Fig. 1c. Southeasterly to southerly winds between 700 and 725 mb promoted an advection of warm air into Colorado developing a temperature inversion in the 725-745 mb layer. Above this layer, winds were mostly from the west keeping the upper atmosphere dry and the cloud top height at ~725 mb. The cloud top temperature was -5^{o}C. Below the inversion layer, weak northeasterly winds prevailed.

In the next 12 hours surface temperature decreased by ~3^{o}C. The sounding shows that the saturated layer deepened to 625 mb and the temperature inversion between 710 and 750 mb strengthened (Fig. 3b). The saturated layer (between 625 and 750 mb) was much cooler than that of the previous sounding. During this time period, temperature in the atmosphere remained <0^{o}C. The soundings show a typical vertical structure for the formation of freezing precipitation through collision-coalescence process as discussed in Cober et al. (1996).

3. Precipitation

Precipitation associated with the low pressure system in Colorado ranged from freezing fog, freezing drizzle, light snow, to snow showers over the 21 hour period between ~1200 UTC 4 March to ~0900 UTC 5 March in north central Colorado. Fig. 4 displays precipitation regimes between 1000 and 2200 UTC on 4

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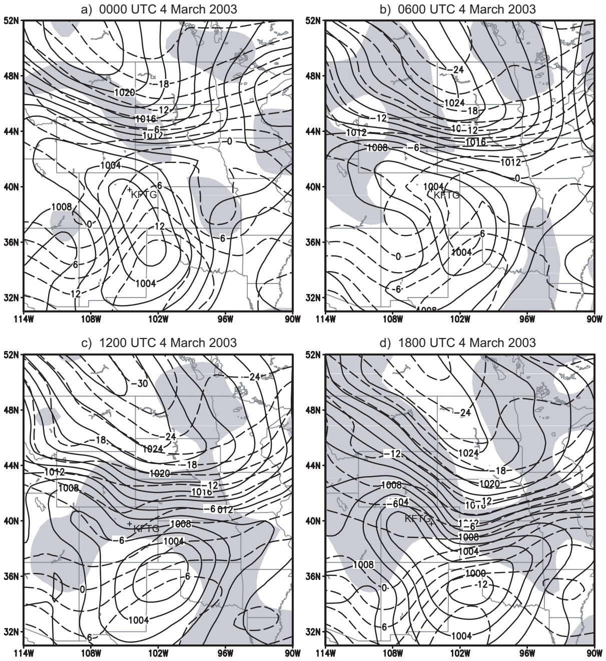

Figure 1: Surface analysis for the times indicated. Solid lines are pressure (mb) contours with 2-mb interval. Dashed lines are isotherms (^oC) with 3^oC interval. Shading indicates relative humidity greater than 90 percent. The cross indicates the location of the Denver WSR-88D radar (KFTG).

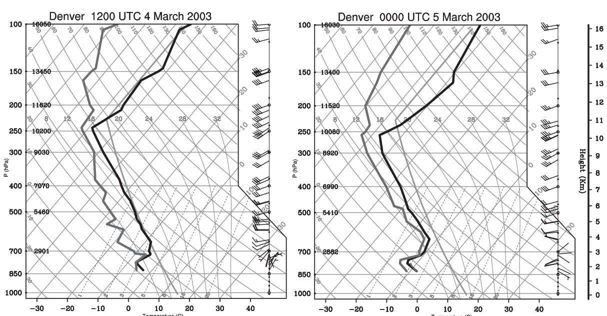

Figure 3: Skew-T soundings from Denver, Colorado valid at a) 0000 UTC 4 March and b) 1200 UTC 5 March. Full flags on wind barbs are 10 m s^{-1} and half flags are 5 m s^{-1}.

March reported from surface observation sites in Arapahoe county (KAPA), at Buckley Air Force Base (KBKF), and Denver (KDEN). [On this day, human observers were at surface observation sites in Arapahoe county (KAPA) and Denver (KDEN).] At Marshall, the 2D-Video disdrometer (Kruger and Krajewski 2002) began detecting hydrometeors just before 1200 UTC.

Freezing drizzle was reported only from KAPA during three time periods: 1252-1430 UTC, 1512-1538 UTC, and 1611-1629 UTC. These reports were generally consistent with hydrometeor images from the disdrometer. Although they are of similar elevation, Marshal is far from KAPA; some differences in observed hydrometeor habits are to be expected. Most of the hydrometeors observed by the disdrometer in the above time periods were spherical, small (equivalent diameter

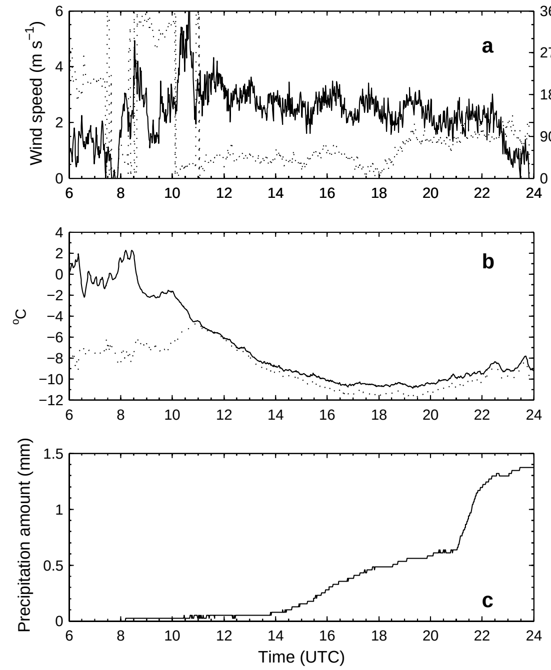

Figure 2: Surface measurements of a) wind speed (solid) and direction (dashed), b) temperature (solid) and dewpoint temperature (dashed), and c) precipitation amount collected at Marshall, Colorado on 4 March 2003.

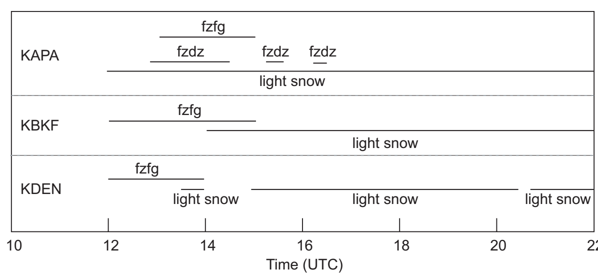

Figure 4: Time series showing durations of precipitation from Arapahoe county (KAPA), Buckley Air Force Base (KBKF), and Denver (KDEN) between 1000 UTC and 2200 UTC 4 March. fzdz and fzfg represent freezing drizzle and freezing fog, respectively.

of <1.5 mm), and had fall velocities in the order of 0.5-1.7 m s^{-1}. The presence of freezing drizzle was also detected by the freezing rain sensor installed at Marshall, indicated by a sudden fall in the rain sensor frequencies. A small drop in frequency between 1124 and 1250 UTC was followed by a significant decrease between 1318 and 1545 UTC.

Precipitation was light for most of the time (Fig. 2c). Between 1400 and 2100 UTC, the precipitation rate was essentially constant, averaging at ~0.1 mm per hour. The precipitation was most intense (0.7 mm hr^{-1}) between 2100 and 2200 UTC, well after passage of the cold front. Snow ended over much of north central Colorado by 0900 UTC on 5 March.

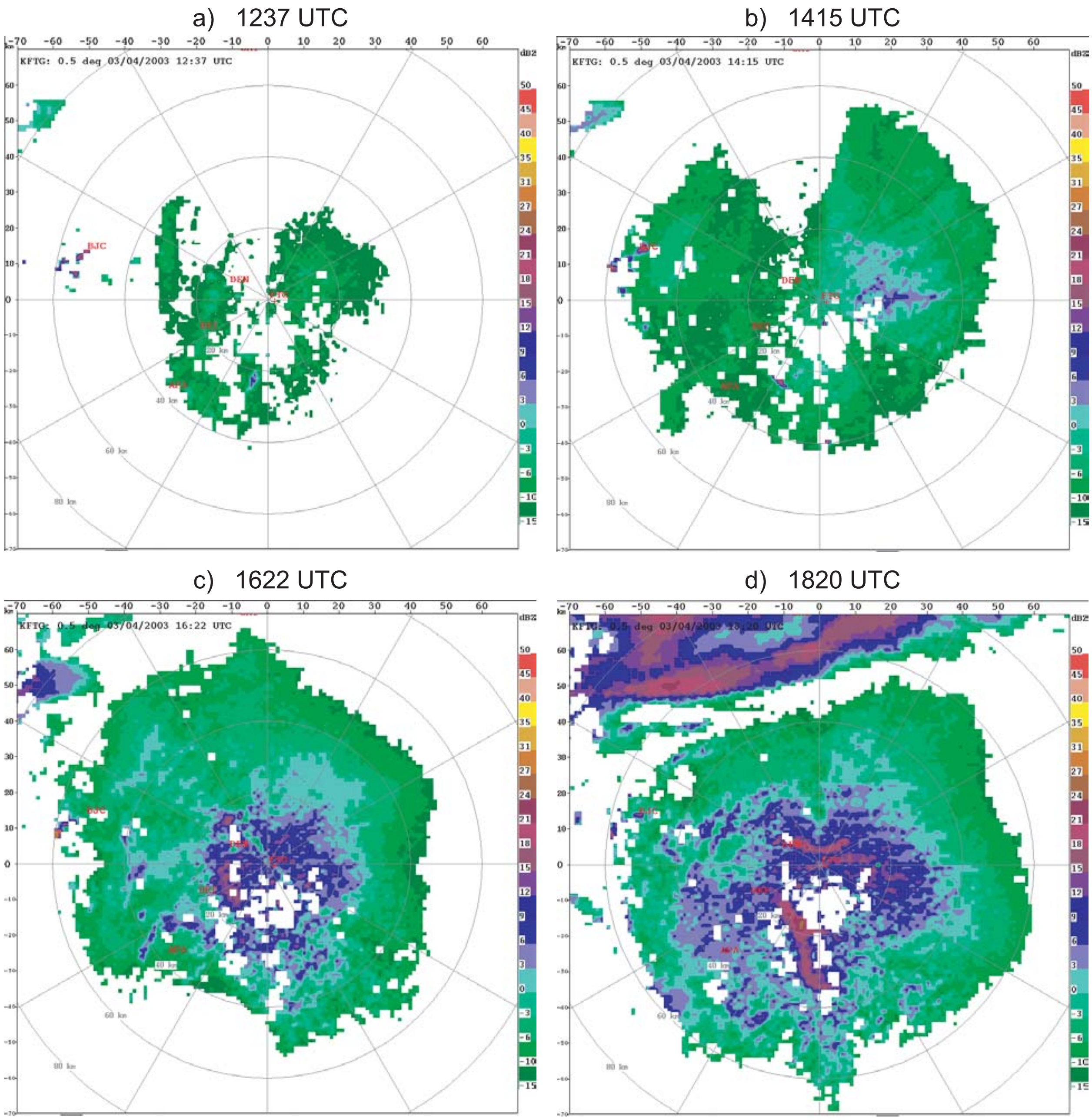

Figure 5: Radar reflectivity (dBZ) at 0.5 deg. elevation angle from the Denver WSR-88D radar. Color schemes for reflectivity are shown on the right. Range rings are in increments of 20 km.

4. Evolution of freezing drizzle observed by radar

In this section we examine the WSR-88D radar data collected near the Denver International Airport to describe evolution of freezing level signatures during this precipitation event and compare to those of light snow. Sample images of contoured radar reflectivity images from the freezing level period (Figs. 5a-b; according to reports from KAPA and analyses of the 2D-Video disdrometer data) and the light snow period (Figs. 5c-d) are shown in Fig. 5. The radar was in clear-air mode throughout this time period.

Weak reflectivities of <–6 dBZ began to fill an area close to the radar by 1237 UTC (Fig. 5a). The maximum reflectivity in this area was 8 dBZ, located at ~25 km to the south of the radar. A few pixels of higher reflectivity (~25 dBZ) near Boulder (BJC) suggest snow at higher elevation. By 1415 UTC (Fig. 5b), a much larger area is filled with weak reflectivities. However, stronger precipitation, indicated by reflectivity of 4-12 dBZ, can be seen to the east of radar. During the time between Figs. 6a and b, reflectivity over KAPA was persistently weak, on the order of –12-0 dBZ. At this time, cloud top temperature derived from infrared satellite images was –10°C.

The radar echoes did not extend beyond the 50-km range after 1424 UTC. The area of higher reflectivity to the east of the radar moved southwestward with time, positioning over the radar site (and KDEN) by 1552 UTC (not shown). As clouds with the cloud top temperatures of -15°C or colder moved over the radar site, surface observations began reporting light snow. Fig. 5c shows a radar image from this time. Much of the area within the 30 km range is dominated by reflectivity of 0-21 dBZ. Reflectivity at KAPA appears to be –3 dBZ or less.

As the cold front approached Colorado from the north, a snow band having reflectivity of >15 dBZ propagated southward while reflectivity enhanced steadily within the 50-km rang. By 1820 UTC (Fig. 5d) the snow band reached the 60-km range, directly north of the radar site. Near the radar, relatively strong echoes dominate, and weak reflectivity is measured only along the perimeter of the 40-km range ring.

Although subtle, there are some differences between the echo patterns in freezing drizzle and snow. While freezing drizzle was reported at KAPA, the radar echoes were weak. The average reflectivity in a 15 km radius of KAPA was ~–7 dBZ. Also, the echo pattern close to KAPA was nearly uniform having relatively little spatial variation (~0.4 dBZ km^{-1}). In the 15-km range from KBFK, a similar pattern was observed. On the other hand, the average reflectivity increased to >0 dBZ during the light snow period. The spatial variation was similar to that of the freezing drizzle period or only greater by <0.07 dBZ km^{-1}. The maximum spatial variation was found in the transition period from freezing drizzle to light snow, and it was greater by 0.14 dBZ km^{-1}.

Signatures of freezing drizzle and medium-heavy snow are undoubtedly distinguishable. However, differences between those of freezing drizzle and light snow is more difficult. We plan to further examine the radar data using the Radar Echo Classifier (Kessinger et al. 2003) to seek additional signatures that might be unique to freezing drizzle.

5. Summary and concluding remarks

A freezing drizzle case in Colorado was documented using radar and other observational data. The surface analysis showed a surface low pressure center over the southeastern corner of Colorado at the time of freezing drizzle observations. Upslope flow promoted by the flow around the surface low carried warm, moist air from the Gulf region—a favorable set up for freezing precipitation in eastern Colorado (Bernstein 2000). The warm, moist air was evident in the two soundings from Denver. The temperature profile contained an inversion layer, as in the typical freezing precipitation soundings.

Freezing drizzle was observed at KAPA during the beginning of the precipitation event associated with this low pressure system. At Marshall, the freezing rain sensor reacted to freezing drizzle, and the 2D-Video disdrometer showed images that appeared to be supercooled drizzle drops.

With the onset of freezing drizzle, the WSR-88D radar images began showing an area of weak reflectivity. This area enlarged with time. The freezing drizzle period was characterized by this weak reflectivity (generally <0 dBZ) that spread across the area with little spatial variation. As reports of light snow from surface observation sites became more frequent, reflectivity increased slightly. The onset of light snow was also associated with a colder cloud top. The southward propagating cold front brought a heavier snow indicated by a band of much larger reflectivity measurements.

These results indicate the potential for automatic detection of freezing drizzle, based on the presence of radar reflectivity less than 0 dBZ that is horizontally uniform. Further work is necessary to prevent false detections from light snow displaying similar structures.

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