P11R.7 **OBSERVATIONS OF A NORTHERN PLAINS SNOWFALL**

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1. INTRODUCTION

On 15-16 March 2005, the UND C-band polarimetric Doppler radar, a video disdrometer, a digital still camera, and visual snowflake observations captured a snowfall event over Eastern North Dakota and Northwestern Minnesota. The snowfall event was minor with the system only lasting several hours. However, there was a unique signature in the polarimetric differential reflectivity (Z_{DR}) field that indicated that the snowflake orientation between the northern half and southern half had different characteristics. Based on the Z_{DR} field, the snowflakes on the northern part of the storm were horizontally orientated indicated by positive Z_{DR} values and in the southern region the snowflakes were vertically oriented based on the negative Z_{DR} signature. This orientation shift was confirmed by visual inspection and from particle retrievals using a video disdrometer.

On 14 March, an Alberta Clipper began to propagate away from the Canadian Rockies into extreme northwestern North Dakota. By 21 UTC on 15 March a shield of snow supported by differential positive vorticity and warm air advection began to progress over the University of North Dakota and the Department of Atmospheric Science's field site located at the Glacial Ridge Nature Conservancy, near Mentor, MN. This site is approximately 65 km to the southeast of the UND radar.

2. INSTRUMENTATION

The original components of the UND radar were built by Enterprise Electronics Corporation (model: Weather Surveillance Radar - 1974 C-band: WSR-74C). In January 2003, the radar was upgraded with a SIGMET, Inc. digital receiver and signal processor (RVP8), radar antenna controller (RCP8), and radar control, analysis and display software (IRIS). In January 2004, the radar was upgraded to a dual-polarized system with the installation of an antenna mounted receiver (AMR) and has been operated in support of the research and academic programs of the Department of Atmospheric Sciences. Besides collecting the traditional fields of radar reflectivity, mean Doppler velocity, and Doppler spectrum width, the upgrade provides the opportunity to collect a subset of the full matrix of polarimetric parameters which include: differential reflectivity, depolarization ratio, the phase, and correlation between the horizontal and vertical channels. The radar is currently co-located with the Atmospheric Sciences Department on top of Clifford Hall at the west end of the UND campus.

The Snowflake Video Disdrometer (SVD) is an experimental instrument that was initially developed at NASA/Wallops Flight Facility to observe raindrop size distributions. It uses a 640x240 pixel grayscale CCD camera to capture approximately 60 frames per second in a sample volume 2 meters from the camera housing. The focal plane has a cross-section of 32x24 mm, hence the pixel size is 0.05 by 0.1 mm. About 1.5 m behind the sample volume is a 300 W flood lamp that provides adequate lighting for the camera to operate with a shutter speed of approximately 1/100,000th of a second. This extremely short exposure time is needed to remove blurring due to particle motion.

The SVD images are transmitted to a PC through coaxial cable and are compressed and stored on the PC by acquisition software written with National Instrument's LabView software package. Each minute of SVD images corresponds to a sample volume of roughly 1 m^3. A separate processing program is run to produce tab delimited ASCII text files that contain time and particle information. This processing algorithm uses edge detection to determine the outer edges of a particle and then built-in LabView image processing routines are used to output information describing all identified hydrometeors. Yet another program has the ability to re-construct user selected images from the compressed files. Because the SVD captures images at a rather high resolution, ice crystal habit can be determined when sampling snowfall.

3. OBSERVATIONS AND DISCUSSION

At approximately 21 UTC 15 March, a southeast to northwest orientated line of snow began to move over Grand Forks, North Dakota (radar site) and the Glacial Ridge field site. Figure 1a displays horizontal reflectivity (Z_H) from the UND radar at 2210 UTC 15 March. The UND radar is located at the center of the figures while the SVD, located at the Glacial Ridge site, is approximately 65 km ESE of the radar. When looking at any of the radar displays, an "X" on the radar display indicates the location of the SVD. The horizontal reflectivity information gave the inclination that this event was typical clipper system producing around 2-3 cm of snowfall for the region.

An examination of the Z_{DR} field led to the discovery of a distinct transition zone in the latter half of the overarching snow band. Figure 1b displays Z_{DR} from the UND radar at 2210 UTC 15 March. The leading half of the snow shield contained banded areas of positive

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Z_{DR} (> 1 dB) while the majority of the stratiform area is within roughly a half dB of zero (+/- 0.5 dB). Interestingly, these banded positive Z_{DR} anomalies do not seem to be associated with the bands of higher Z_H. The positive Z_{DR} areas seem associated with the weaker echo region between the two stronger bands.

A review of the literature (Heymsfield 1972, Kajikawa 1972, Heymsfield and Kajikawa 1987) shows that dendrites typically have terminal velocities between 0.2 and 0.5 m/s, while Locatelli and Hobbs (1974) report that dendritic aggregates have terminal velocities between 1.0-1.5 m/s when larger than about 2 mm. The heavier snow bands were characterized with mainly dendritic aggregates. Because of their generally prolate spheroid shape one would expect slightly positive Z_{DR}. Their larger size will be weighted more in the calculation of Z_{DR}, due to the D^6 dependence on reflectivity, and give the bulk Z_{DR} values seen in the more intense snow bands. Schuur et al. (2003) showed that snowfall comprised of individual crystals has Z_{DR} values ranging from 0.5 – 3 dB. This corresponds almost exactly to the range of Z_{DR} seen in the areas between the heavier snow bands in this case. Because of the lower terminal velocities of dendritic crystals, the weaker returns between the two snow bands may have been comprised of mainly individual crystals, giving rise to the higher Z_{DR} values.

Behind the second intense snow band, a transition to primarily negative (< -0.5 dB) Z_{DR} takes place. When examining the Z_H field, there is no noticeable difference between the negative Z_{DR} area and the rest of the snow shield. From the definition of Z_{DR}, this means that the predominant hydrometeor orientation switched from horizontal to vertical in the bulk sense. This could come from a change in crystal habit or a change in the shape of the snowflakes. Observations from the SVD and by the authors qualitatively show the Z_{DR} shift was caused by a shift in the orientation of the dendritic aggregates.

Figure 2a shows a digital photograph taken at 2225 UTC March 15, during the positive Z_{DR} portion of the snow event. A tape measure is present with the numbered markings on tape indicate centimeters with each tick being one millimeter. We believe this image gives a representative sample of the ice crystals comprising the snowflakes around the time of the image from visual inspection of the falling snow. An examination of the image show stellar and spatial dendrites along with sectored plates. These crystals seem to range from 1-2 mm in their maximum diameter.

Observations made by the authors during this time period indicated that the snowflakes were similar to the aggregate form noted by Magono and Nakamura (1965). These aggregates are characterized by having an elliptic shape in when looking at a horizontal or vertical cross section. A respectable analog to this type of aggregate is that of scaled down chicken egg on its side. The vertical extent of the flake is almost as large as the horizontal. The actual size of these flakes is unknown due to their breakup on contact with the photographic surface, however images taken from the SVD at the Glacial Ridge site indicate sizes of around 3-6 mm for their maximum horizontal dimension.

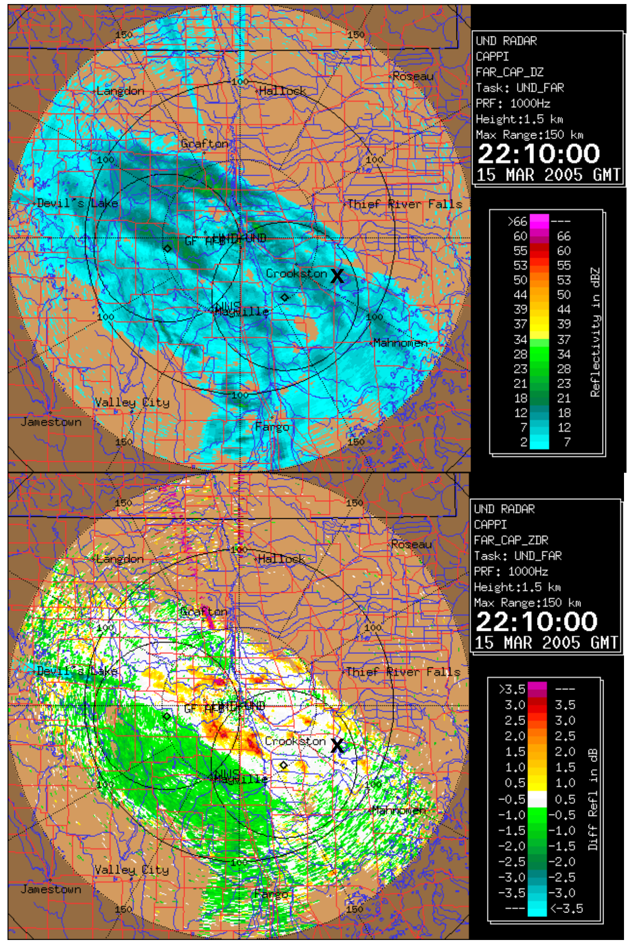

FIG. 1. CAPPIs at 1.5 km of Z_H (a) and Z_{DR} (b) taken from the UND radar at 2210 UTC 15 March, before the shift to negative Z_{DR} took place over UND and the SVD. This SVD is located at the Department's Glacial Ridge field observation site, marked with an "X" in the displays.

Shortly after the transition to negative Z_{DR} another series of digital photographs were taken and visual observations of the falling snowflakes were made. A very interesting discovery was made during this observation period. Figure 2b displays one of the photographs taken around 0040 UTC. When examining this figure, a couple interesting features emerge. The first feature is the crystal type has switched to mainly ordinary and fernlike dendrites. Therefore these crystals are more complex than those in Figures 2a-b and this may be due to a change in the supersaturation in cloud. Two perfect examples of this crystal habit change are the crystal directly above the left center of the tape measure in Figure 2b along with the crystal along the top of the image near the centerline. According to Magono and Lee (1966) as the supersaturation increases in clouds producing sectored plates and stellar dendrites the crystal type will shift to the more complex ordinary and fernlike dendrites.

The second interesting difference is the much larger crystal size in the second pair of images. The increase in supersaturation causing the habit change should also lead to faster diffusional growth due to the increased water vapor gradient around the ice crystals. If we assume a comparable cloud residence time to earlier in the storm, one would expect larger crystals due to the increased growth rates. The validity of this assumption is unknown, but reasonable thought suggests it is valid due to the relative lack of variation in updraft strength in stratiform clouds. Although larger crystals would tend to fall faster, this effect is offset partially by the change in habit to a more complex shape (Heymsfield and Kajikawa 1987) suggesting fall speed variations would be minimal as well. The increased crystal size is clearly seen when comparing Figures 2a and 2b. In the first image the crystal size ranges from roughly 1 – 2 mm, while in the latter image few crystals are 1 – 2 mm. The majority of the individual crystals in these images are 2 – 3 mm with one crystal as large as 5 mm.

While the minor change in crystal habit and size is interesting, it should not cause a distinct shift in Z_{DR}. The single crystals during this time frame would still produce positive Z_{DR} values and aggregates similar to earlier ones would produce similar Z_{DR} values. After the photographs were taken, the authors visually examined the snowflakes as they fell. The snowflakes observed after the Z_{DR} shift had a distinctly different shape than those earlier in the event. It appeared to the authors that many of the snowflakes had a central mass with a smaller area connected to the upper edge of the central mass some distance from its central radius. Because of this interesting shape, the snowflakes had a unique fall motion. The shape of these snowflakes caused them to precess as they fell. This means the snowflakes rotated around a central axis through the main snowflake mass. This would create a conical shape if one took the area swept out by the snowflake. The bottom of the central mass at the axis of rotation would be the apex of the cone and it would increase in radius as one moved up the axis of rotation due to the smaller attached portion of the snowflake.

Figure 3a-d show images taken from the SVD during this event. Figure 3a-b are example images during the positive Z_{DR} portion of the event and Figure 3c-d are taken from the negative Z_{DR} portion. Notice the difference in the maximum dimensions between Figure 3a-b and Figure 3-d. In Figure 3a-b the snowflakes have a slightly larger horizontal dimension while in Figure 3c-d the vertical dimension is slightly larger. Also, the precessing motion of the vertically oriented aggregate flakes can be seen somewhat in Figure 3c-d. In Figure 3c, it appears as though the snowflake is rotated so the attached crystals are pointing towards or away from the camera. Figure 3d is a cross section through one of these snowflakes, which shows the attached flakes 90^o rotated from that in Figure 3c.

This change in snowflake shape is the most probable explanation to why the later half of the event had negative Z_{DR} returns. This area would have crystal formation in the new temperature/moisture regime and would have experienced the more complex dendritic crystals and the new snowflake shapes because of the change in the regime characteristics.

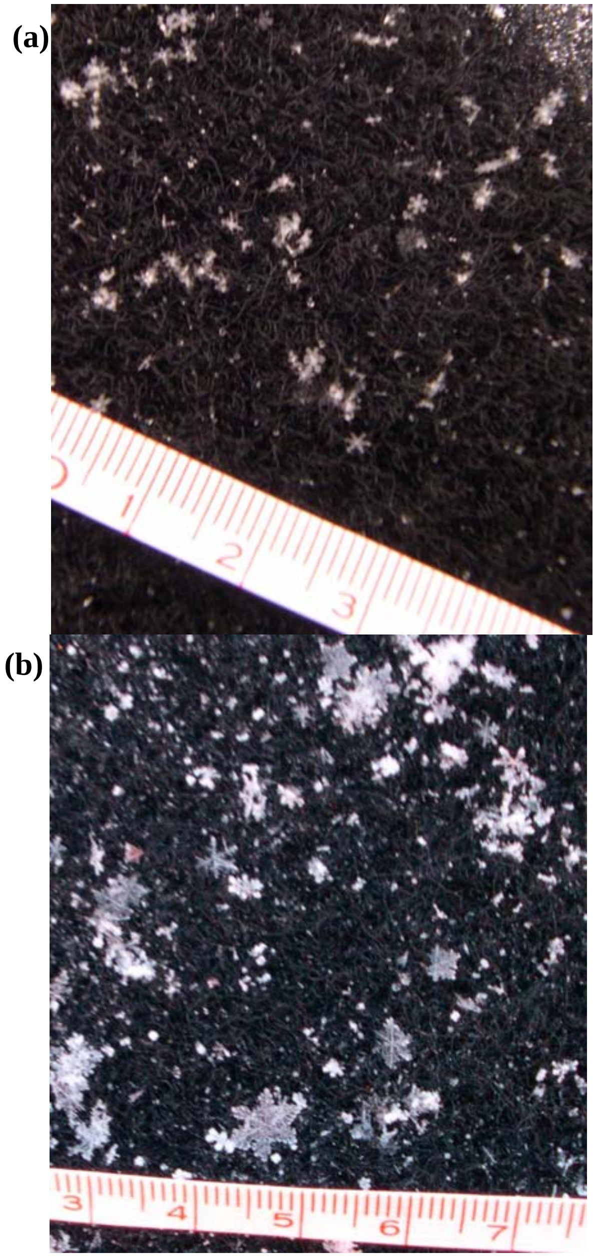

FIG. 2. Manual photographs taken at UND using a digital camera with a zoom lens. (a) Taken at approximately 2230 UTC 15 March, while the positive Z_{DR} echoes were over UND and the SVD. (b) Taken at approximately 0040 UTC 16 March, shortly after the negative Z_{DR} echoes began to move over UND and the SVD.

4. CONCLUSIONS

The UND C-band polarimetric Doppler radar and the SVD captured a brief snow event on 15-16 March 2005. In conjunction with these measurements, digital photographs of crystals and visual observations of the falling snowflakes were made at near the radar. The event was characterized as a typical Alberta clipper type snowfall event when examining Z_H. However an interesting shift in Z_{DR} was noted without any distinction in the Z_H field. Through the examination of the digital photographs, SVD images, and visual observation of the falling snowflakes, it was determined that a change in snowflake shape was the cause of the Z_{DR} shift, not a distinct change in crystal habit. Although the crystals changed from stellar and spatial dendrites and sector like plates, to mainly ordinary and fernlike dendrites this would not cause a distinct Z_{DR} shift because these crystals are all of very similar shape. However the shift of the snowflakes major axis from primarily horizontal to vertical would cause a distinct shift in Z_{DR}. It was also noted that the snowflakes after the Z_{DR} shift had a very interesting fall motion due to their shape.

5. REFERENCES

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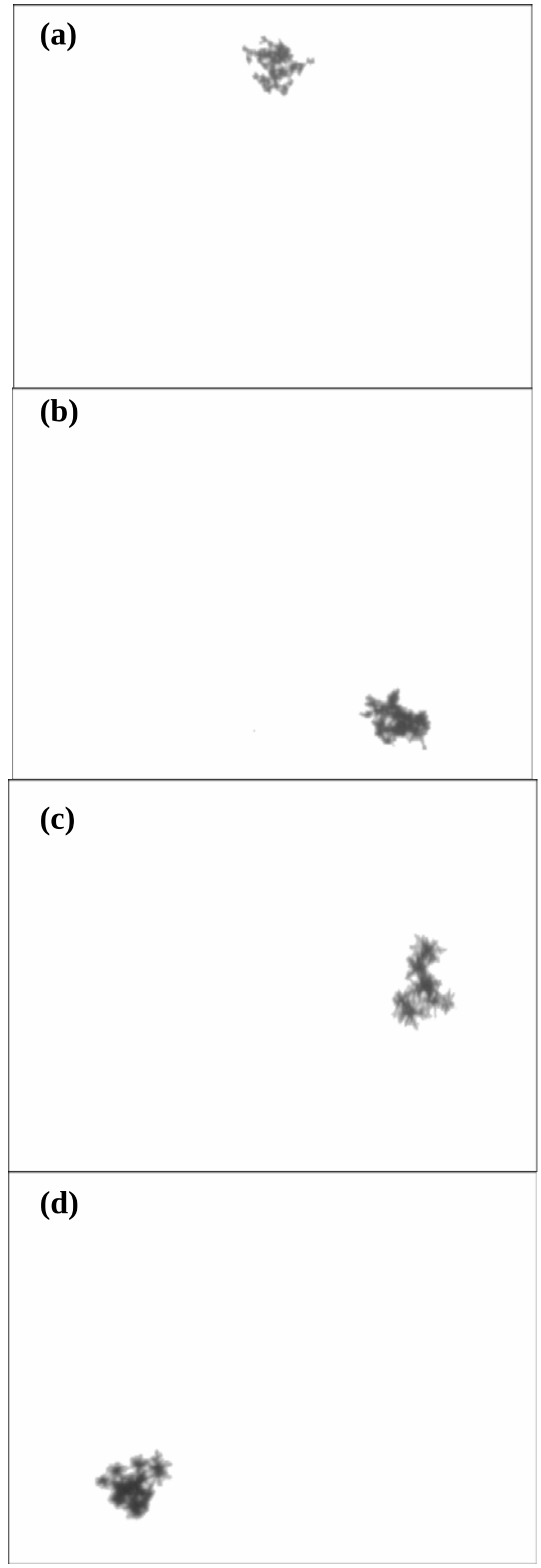

FIG. 3. Images taken from the SVD. (a)-(b) Taken between 22-2200 UTC 15 March. (c)-(d) Taken between 0030-0300 UTC 16 March.