P6.1

WINTER PRECIPITATION TYPE CLASSIFICATION WITH A POLARIMETRC WSR-88D RADAR

Terry J. Schuur, Alexander V. Ryzhkov, and S. E. Giangrande

Cooperative Institute for Mesoscale Meteorological Studies, The University of Oklahoma
and NOAA/OAR National Severe Storms Laboratory, Norman, Oklahoma

1. Introduction

While S-band polarimetric radars have been used to study a variety of precipitation systems over the past decade, relatively little work has focused on polarimetric signatures in winter precipitation. Using data from the NSSL Cimarron radar, Ryzhkov and Zrnic (1998) identified polarimetric signatures that might be used to distinguish between rain and snow. Trapp et al. (2001) also used data from Cimarron to study the precipitation structure of a winter precipitation event that occurred over northern Oklahoma in 1994. More recently, Ryzhkov et al. (2005) presented some of initial results of winter storm observations made by the National Severe Storms Laboratory KOUN WSR-88D radar, which was upgraded to include dual-polarization capabilities in the spring of 2002. Their study presented results that showed how polarimetric radar, when combined with surface observations, can be used to remotely identify regions of freezing rain.

As we move towards a national network of polarimetric WSR-88D radars, the opportunities to study winter precipitation events is sure to increase. Since the upgrade of the KOUN radar, polarimetric radar data have been collected in 15 winter weather events and several others where, though rain was observed at the surface, a low freezing level provided information on the transition from ice to water phase. Combined, these data provide statistical information that allows us to quantify the polarimetric characteristics of cold season precipitation in Oklahoma. In this study, we present results of preliminary analyses of recent winter weather events observed by the polarimetric KOUN radar. Particular attention is given to the discrimination between precipitation types. Radar reflectivity (Z), differential reflectivity (Z_{DR}), specific differential phase (K_{DP}), and correlation coefficient (ρ_{HV}) are used to characterize the polarimetric differences between regions of dry and wet snow, sleet, ice pellets, and freezing rain. Rain/snow transition lines and the polarimetric signatures of melting snow and low bright band regions are also investigated.

Corresponding author address: Terry J. Schuur, National Severe Storms Laboratory
1313 Halley Circle, Norman, OK, 73069
email: Terry.Schuur@noaa.gov

While the dataset is now being examined in bulk, we present here examples of four events that occurred during the winter of 2004-2005.

2. 22 December 2004 event

KOUN data collected on 22 December 2004 demonstrate polarimetric signatures for an event that exhibited widespread light snow. The 0000 UTC sounding on 22 December 2004 exhibited moist layers at about 1550 and 6750 m MSL, but was overall quite dry. A nearly-isothermal layer at about 0ºC was observed from 1250 to 2450 m MSL, and wet bulb temperatures were below 0ºC at all levels except at the surface. A north-south oriented band of virga moved into western Oklahoma around 0300 UTC, and reached central Oklahoma between 0600 and 0700 UTC. The virga caused evaporative cooling of the atmosphere, and the lower part of the 1200 UTC OUN sounding was considerably colder and more moist. Only the lowest ~1.5 km was unsaturated, and the temperature was below 0ºC throughout the profile. Precipitation first reached the ground in the form of light snow in a west-east oriented band north of the KOUN at approximately 0900 UTC, and light snow was falling over most of the area by 1200 UTC.

Fig. 1 shows a 0.43º elevation 4 panel display of KOUN Z, Z_{DR}, ρ_{HV}, and K_{DP} at 1300 UTC on 22 December 2004. Observations of many winter precipitation events have shown that a distinguishing feature of regions of light, dry snow is a somewhat smooth and banded reflectivity structure. This type of structure, which is quite evident in the reflectivity panel presented in Fig. 1, can be contrasted with a more granular reflectivity structure that is typically produced by regions of rain, freezing rain, and wet, aggregated snow (compare with figures presented for other winter precipitation events). An examination of the Z_{DR} reveals that much of the precipitation echo has a differential reflectivity of approximately 0.2 to 0.3 dB, which is typical of dry, aggregated snow. An extensive region of much higher Z_{DR}, however, is evident to the north of the radar. We believe that this feature, which we have seen in numerous other winter precipitation systems, is indicative of a region of higher density ice crystals. While additional analysis is needed to understand the origins of these regions of high Z_{DR}, in this case it is possible that it was associated with depositional growth in the -12 to -20°C layer (enhanced ascent near 600 mb, which falls within this layer, was supported by an analysis of upper air data). In the future, it is possible that ice density measurements might be used improve forecasts of winter precipitation accumulation.

3. 5 January 2005 event

The winter precipitation event of 5 January 2005 provides a good example of how polarimetric radar data can be combined with sounding and surface measurements to identify region of freezing rain. Over approximately a 24 hour period starting on 4 January 2005, a slow-moving trough of low pressure moving from southwest to northeast combined with a cold, moist air mass over the central eastern Oklahoma to produce an ice storm that blanketed the area with up to 3 cm of ice. As the cold air surged southward, freezing rain and sleet moved into northern and central Oklahoma. In total, some areas north of Interstate 40 in northwest Oklahoma received up to 5 cm of ice accumulation while other areas received from 3 to 5 cm of sleet.

Fig. 2 shows a 0.43º elevation 4 panel display of KOUN Z, Z_{DR}, ρ_{HV}, and K_{DP} at 0804 UTC on 5 January 2005. Atmospheric soundings taken at 0000 and 1200 UTC show the evolution of the atmosphere over central Oklahoma as the cold air moved southward. At 0000 UTC, the 0°C level at OUN was located at a height of 3800 m MSL, a sharp inversion with a maximum temperature 14°C was located at a height of 930 m, and the surface temperature was approximately 3°C. At 1200 UTC, the 0°C level height had dropped about 400 m, but was still situated well above ground. The inversion, however, was higher and had weakened considerably, having a peak temperature of 7°C at a height of 1590 m MSL. More importantly, unlike the 0000 UTC profile, which had above freezing temperatures all of the way up to the inversion, the 1200 UTC profile exhibited an approximately 700 m deep layer immediately above the surface wherein the temperature was as much as -3.5°C below freezing.

The location of the radar bright band can be clearly seen in the Z, Z_{DR}, and ρ_{HV} fields. As indicated by both soundings, the 0°C level height appears to be well above ground level. This is particularly apparent in the ρ_{HV} field, which shows the first indication of bright band contamination at a range of 100 km (despite being collected at a 0.5 elevation and, at that distance, having a radar resolution volume width of 1.5 km). At closer distances, the ρ_{HV} field has a signature that is clearly indicative of rain, especially near the leading edge of the precipitation where a couple of pockets of high Z_{DR} indicates possible regions of enhanced rainfall. When combined with surface temperature data from the Oklahoma Mesonet (not shown), which has 107 sites located across the state of Oklahoma, the dual-polarization data presented here can be used to diagnose rainfall at locations where surface temperatures are sub-freezing. Additional analyses will focus on the identification of polarimetric signatures that might indicate re-freezing of liquid precipitation in regions where the sounding profile indicates a deep column of sub-freezing temperatures.

4. 28 January 2005 event

The ability of the KOUN radar to discriminate between winter precipitation types is further demonstrated by data collected for a winter precipitation event that occurred on 28 January 2005. Fig. 3 shows a 0.43º elevation 4 panel display of KOUN Z, Z_{DR}, ρ_{HV}, and K_{DP} at 1603 UTC on 28 January 2005. The region of precipitation depicted in Fig. 3 formed in advance of an approaching 500 mb short-wave trough. At the time of the 1200 UTC OUN sounding, which showed surface temperatures of approximately 3°C and a 0°C level that was a mere 300 m above the surface, central Oklahoma was experiencing light rainfall. Shortly after 0100 UTC, however, surface temperatures quickly cooled and the precipitation switched over to a heavy wet snow. We believe the sudden cooling and change in precipitation type on the southern edge of this system might have been due to microphysical processes such as the melting of snow under a region of enhanced mesoscale ascent.

Fig. 3 shows this system at 1603 UTC, approximately 3 hours after precipitation changed to a heavy wet snow in central Oklahoma. At that time, a band of heavy wet snow, as indicated by a 150 km long north-south oriented band of high Z_{DR} and low ρ_{HV}, is centered 110 due east of the KOUN radar. In contrast, precipitation to the northwest of the band has dramatically lower Z_{DR} and higher ρ_{HV}, indicative of a region of widespread light, dry snow. As demonstrated for an earlier case (22 December 2004), the light dry snow is characterized by a somewhat uniform field of Z_{DR} with a magnitude of approximately 0.2 to 0.3 dB.

5. 30 January 2005 event

Finally we present an example from a winter precipitation event that occurred on 30 January 2005 event, wherein polarimetric signatures can be used to help discriminate between regions of a rain/snow mixture and regions of possible drizzle/sleet. By 1500 UTC on 30 January 2005, light rain was being reported in far southwestern Oklahoma with light freezing drizzle in parts of central Oklahoma. At 1800 UTC, more widespread light precipitation extended from northwestern into southwestern Oklahoma, with light freezing drizzle continuing in central Oklahoma. The band of heavier precipitation moved into central Oklahoma by 21 UTC. Light snow was noted in the Clinton-Enid areas and northwestward, light rain was reported generally southeast of an Altus-Lawton-Oklahoma City line, and a mix of rain and snow was reported between.

Fig. 4 shows a 0.0º elevation 4 panel display of KOUN Z, Z_{DR}, ρ_{HV}, and K_{DP} at 2114 UTC on 30 January 2005. A somewhat uniform reflectivity field throughout the domain provides no evidence of distinguishable differences between the rain to the SE of KOUN and mixed-phase precipitation over central Oklahoma. When combined with the polarimetric variables, however, the differences in precipitation types are quite apparent. The rain to the SE of the radar is characterized by a somewhat uniform field of ρ_{HV} with a magnitude that is close to 1.0; the Z_{DR} in this region reaches values of up to 1.5 dB. Over central Oklahoma, however, the ρ_{HV} field is characterized by interspersed regions of both high (close to 1.0) and low (0.85-0.95) correlation coefficient. It can be further seen that the low ρ_{HV} is associated with high Z_{DR}, indicating a region of rain/snow mixture, and the high ρ_{HV} is associated with low Z_{DR}, indicating regions of drizzle/sleet. While surface observations were not detailed enough to confirm the location of each precipitation cell that was producing drizzle/sleet, these measurements are in agreement with observations that indicated that both rain/snow and drizzle/sleet were occurring over central Oklahoma at this time. A more detailed analysis will be undertaken to see if any signatures in ρ_{HV} and Z_{DR} that might be associated with the refreezing of small drops to forms sleet might be seen in the observations.

6. Summary

Over the past 3 years, polarimetric KOUN WSR-88D radar data have been collected in 15 winter precipitation events, as well as several other events that can be used to study ice phase microphysics. The 4 examples presented here provide evidence that polarimetric radar can be used to classify precipitation types for a variety of winter precipitation systems. In one system, polarimetric signatures indicated widespread dry snow over central Oklahoma. High differential reflectivities in one quadrant of the storm, however, suggested the presence of a region of more pristine, higher density ice crystals. In the future, such information may be used to improve snowfall accumulation estimates. Another case demonstrated that, when combined with automated surface information, polarimetric radars can be used to remotely identify regions of freezing rain. In a third case, the polarimetric data proved useful in identifying the location of bands of heavy snowfall. Finally, we showed data from a system that had a mixture of winter precipitation types over central Oklahoma. Preliminary analyses suggest that differential reflectivity and correlation coefficient might be used to discriminate between regions of rain/snow and drizzle/sleet. Additional work will be needed to discern whether distinct polarimetric signatures associated with the refreezing of drops are present, thereby possibly providing information that might be used to discriminate between drizzle and sleet.

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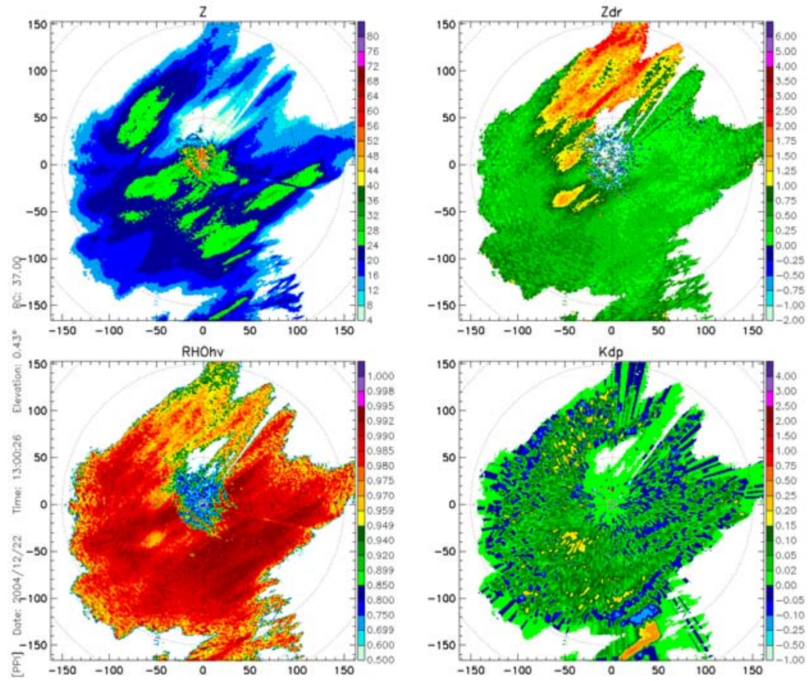

Fig. 1. Polarimetric KOUN WSR-88D at 0.43° elevation of radar reflectivity (Z), differential reflectivity (Z_{DR}), correlation coefficient (ρ_{HV}), and specific differential phase (K_{DP}) of the 22 December 2004 winter precipitation event at 1300 UTC.

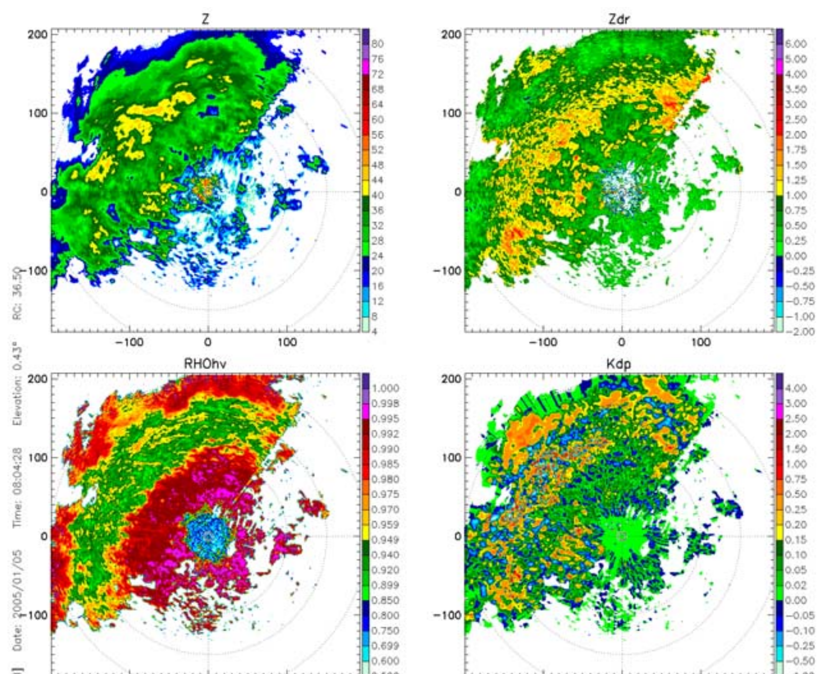

Fig. 2. Polarimetric KOUN WSR-88D at 0.43° elevation of radar reflectivity (Z), differential reflectivity (Z_{DR}), correlation coefficient (ρ_{HV}), and specific differential phase (K_{DP}) of the 5 January 2005 winter precipitation event at 0804 UTC.

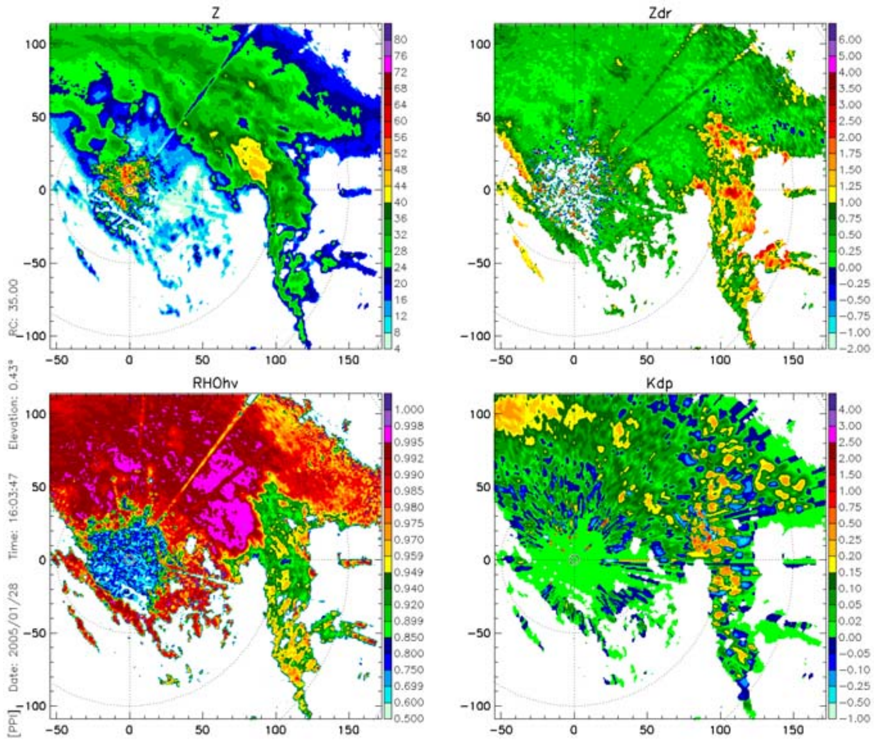

Fig. 3. Polarimetric KOUN WSR-88D at 0.43° elevation of radar reflectivity (Z), differential reflectivity (Z_{DR}), correlation coefficient (ρ_{HV}), and specific differential phase (K_{DP}) of the 28 January 2005 winter precipitation event at 1603 UTC.

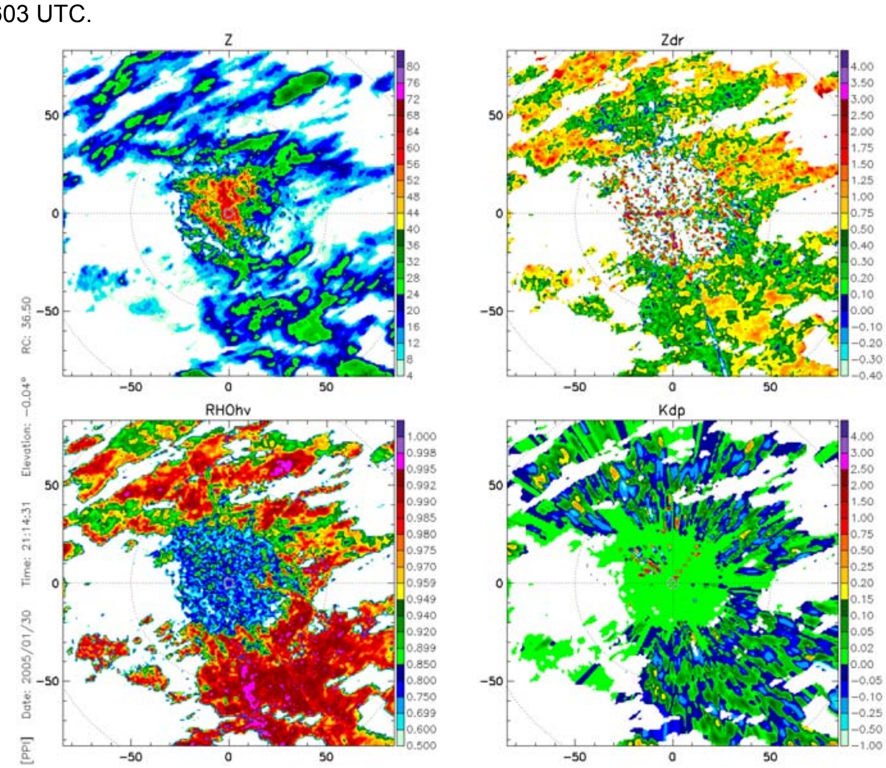

Fig. 4. Polarimetric KOUN WSR-88D at 0.0° elevation of radar reflectivity (Z), differential reflectivity (Z_{DR}), correlation coefficient (ρ_{HV}), and specific differential phase (K_{DP}) of the 30 January 2005 winter precipitation event at 2114 UTC.