SEVERE HAIL SIZE DISCRIMINATION USING DUAL-POLARIZED WEATHER RADAR DATA. A DUAL-WAVELENGTH COMPARISON BETWEEN C AND S BAND.

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I. INTRODUCTION

FIG. 1: Hail damage on an airplane (airlieners.net)

Severe, large hail inflicts the most damage to property on ground and is a serious risk for aviation aloft (Fig. 1). The detection and forecasting of very large hail (Fig. 2) is still one of the main topics in nowcasting, where weather radar data are used extensively to monitor the three-dimensional storm structure (e.g. Witt et al., 1998).

One of the advantages of dual-polarization weather radars is their capability to discriminate between different precipitation types and nonmeteorological echo (e.g. Ryzhkov et al., 2005; Park et al. 2009 at S band and Alberoni et al., 2002; Gourley et al., 2006 among others at C band).

Therefore, many European countries are implementing polarimetry into their operational networks (Sugier and Tabary, 2006; Mammen et al., 2010; Saltikoff and Nevvonen, 2011) which offers new possibilities to improve existing algorithms for hail detection and determination of its size (e.g. Depue et al., 2007). Existing polarimetric methods for hail detection at S band are based on the assumption that differential reflectivity Z_{DR} of hail is low due the almost random orientation of hailstones having high reflectivity Z (Bringi and Chandrasekar 2001).

FIG. 2: Oklahoma hail cases: giant opaque hail in May 2010 and small hail in June 2011

Polarimetric characteristics of hailstones depend on their size, shape, falling behavior, and are strongly affected by the degree of melting and the probing radar wavelength. Strong attenuation and differential attenuation in hail at C band further complicates the issue of hail detection / sizing (Ryzhkov et al., 2009; Kumjian et al., 2010a).

According to the definition of the US National Weather Service, hail is considered large and capable to inflict substantial damage if its diameter is larger than 1’’ (2.54 cm). Exceptionally large hail with sizes exceeding 5 cm is treated as “giant” in our study.

II. DATA AND METHODOLOGY

In this study, severe hail cases in Oklahoma / USA are investigated by analyzing the data simultaneously collected by two closely located polarimetric weather radars operating at S and C bands. One of them is the OU-PRIME C band radar operated and maintained by ARRC / University of Oklahoma and another one is a polarimetric prototype of the WSR-88D S band radar (KOUN) belonging to NOAA / NSSL.

Polarimetric radar variables measured in the presence of hail at C band are quite different from the ones at S band due to more pronounced effects of resonance scattering and much stronger impact of attenuation (Ryzhkov et al. 2009).

The differences are particularly strong in melting hail below the freezing level, but they can be substantial even at higher altitudes where hail is dry or grows in wet regime. As a consequence, the algorithms for hail detection and determination of its size developed at S band can not be directly applied to C band.

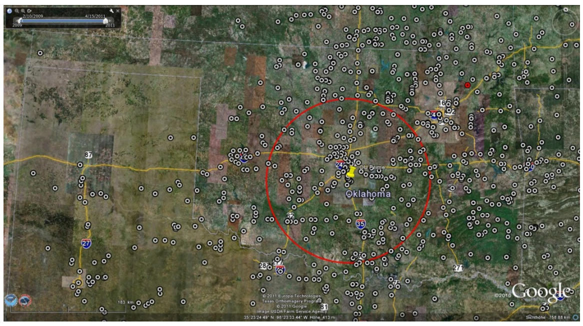

FIG. 3: Map of Oklahoma showing Storm Prediction Center hail reports for Oklahoma betweenFebruary 2009 and April 2011 indicated as white dots. Location of the OU Prime radar is marked by yellow pin and red circle is drawn at 125 km from the radar.

In our analysis , we utilize surface hail reports (Fig. 3) and S band polarimetric measurements as a “ground truth” for defining the rules for hail detection and rough estimation

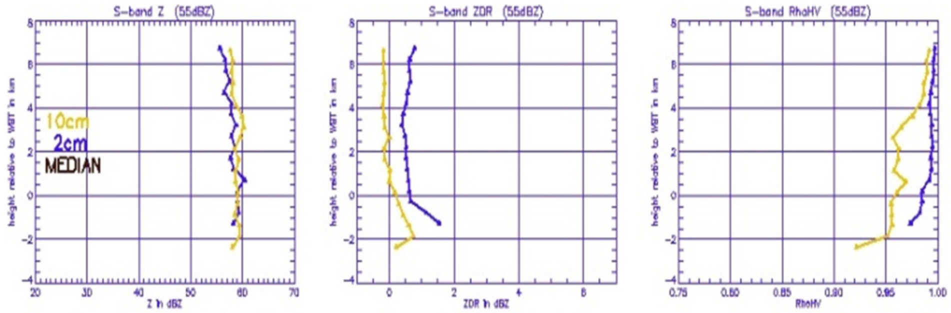

FIG. 4a: Average vertical profiles of the polarimetric variables for S band within regions of $Z \geq 55$ dBZ for cases with 2 cm and 10 cm hail size reports. From left to right Z, Z_{DR} and ρ_{hv}. The heights are shown with respect to the level of zero wet bulb temperature where melting is supposed.

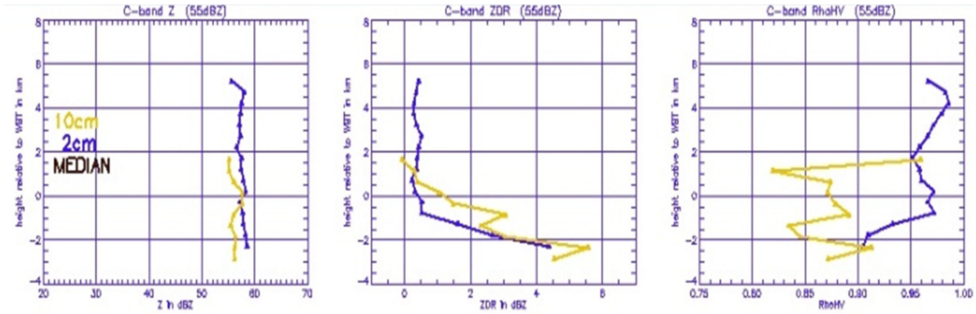

FIG. 4b: as Fig. 4a except for simultaneously measured C band polarimetric variables

of its maximal size at C band assuming that hail detection is done reliably at S band. The differences between vertical profiles of radar reflectivity Z, differential reflectivity Z_{DR}, and cross-correlation coefficient ρ_{hv} in hail-bearing parts of the storms are in the focus of our analysis (Fig. 4).

III. RESULTS AND DISCUSSION

The difference between polarimetric radar characteristics of hailstorms with different maximal hail sizes at S and C bands is illustrated in Fig. 4. Average vertical profiles of Z, Z_{DR}, and ρ_{hv} within the regions of Z exceeding 55 dBZ are presented for the storms with maximal hail sizes 2 cm and 10 cm reported on the ground.

It is interesting that there is no dramatic difference between average Z for the small (2 cm) and giant (10 cm) hail cases. However, it should be noted that due to more pronounced resonance effects at C band, the C band reflectivity is somewhat smaller than S band Z although it might be partially attributed to stronger attenuation at shorter wavelength.

Much bigger differences are observed in terms of Z_{DR} and ρ_{hv}. It is shown that in the presence of hail (Fig. 4a,b), $Z_{DR}(C)$ is usually higher than $Z_{DR}(S)$ and $\rho_{hv}(C) < \rho_{hv}(S)$. The height of radar resolution volume with respect to the freezing level has to be taken into account in polarimetric hail detection / sizing. Subsequent heights with respect to the level of zero wet bulb temperature are used. Fig. 4 demonstrates that giant hail is commonly associated with pronounced depression of ρ_{hv} in the areas of hail generation above the freezing level (about 1.1 km above 0° wet bulb freezing level) and the corresponding drop in ρ_{hv} at C band is much stronger than at S band. Vertical profiles of polarimetric variables show different behaviors and developments in hail-bearing cells with respect to different observed hail sizes at ground and to the height of hailstones relative to the melting layer. These offer the possibility to distinguish between areas of high reflectivity with and without hail and to discriminate between smaller-size and giant hail.

Tables 1 and 2 summarize the comparisons between C- and S band data within regions of Z≥55 dBZ for different hail cases. The C band polarimetric measurements may provide better capability to discriminate between different hail sizes compared to S band because it turns out that median Z_{DR} associated with melting giant hail is much higher than for hail of smaller size and the corresponding reduction of ρ_{hv} is more dramatic at C band (bold marked numbers) The C band median values of Z_{DR} and ρ_{hv} are consistent with results of C band hail studies in France (Tabary et al., 2010). The variability of Z_{DR} and ρ_{hv} within the 50-dBZ contours was also quantified and presented as standard deviations of mean values in Tables 1 and 2.

		MEDIAN		Standard-Deviation	
		Large hail	Giant hail	Large hail	Giant hail
Z_{DR}	C band	+4dBZ	**+7dBZ**	1.4dBZ	2.2dBZ
Z_{DR}	S band	+1dBZ	+1.5dBZ	1.1 dBZ	0.8dBZ
ρ_{hv}	C band	0.91	**0.84**	0.04	0.09
ρ_{hv}	S band	0.94	0.92	0.02	0.06

Table 1: Comparison of Z_{DR}/ ρ_{hv} changes below wet bulb freezing level height for two hail classes

ρ_{hv}	MEDIAN		Standard-Deviation	
	Large hail	Giant hail	Large hail	Giant hail
C band	0.95	**0.82**	0.04	0.09
S band	0.94	0.92	0.02	0.06

Table 2: Comparison of ρ_{hv} at -10°C wet bulb temperature height for two hail classes

IV. HAIL BACKSCATTERING EFFECTS WHICH AFFECT DUAL POL MOMENTS AND CORRESPONDING VERTICAL STRUCTURE:

Secondary polarimetric radar signatures caused the three-body scattering, side-lobe contamination, Z_{DR} column, and depolarization are commonly observed in association with severe hail (Fig. 5). These signatures can be used for visual hail discrimination but are hard to be implemented in automatic algorithms for further automatic hail size determination which use polarimetric weather radar data (see Kumjian et al, 2010b).

Therefore initial algorithms may be applied only in the high reflectivity areas to isolate secondary polarimetric radar signatures or effects of partial beam filling.

Fig. 5a/b shows the three-body scatter dualpol signatures for C and S band (e.g. explanation is given in Picca and Ryzhkov, 2011).

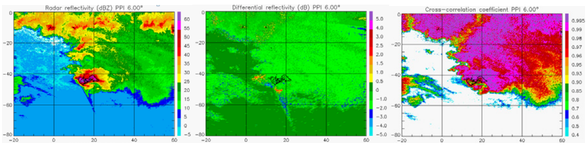

Fig. 5a: Hail Spike seen at ppi elevation 6° from 27 March 2009 16:47 UTC in C band for 2,5cm hail report. Left Z, middle Z_{DR} and right ρ_{hv}. Radar position is at 0 in meridional and zonal axis (in km).

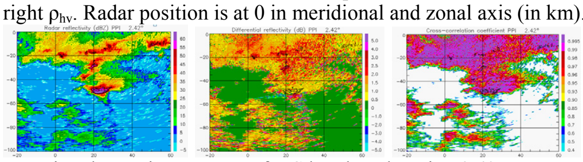

Fig. 5b: as Fig. 5a expect for S band at elevation 2,4°.

C band analyses of the lowest elevation for hail events are strongly affected by attenuation and resonant effects. Nonmonotonic radial dependencies of differential phase are often seen which may be caused by backscatter differential phase (same noted by Tabary et al., 2010).

V. CONCLUSION

Vertical profiles of Z, Z_{DR} and ρ_{hv} can be efficiently utilized at C band for hail detection and determination of its size

Strong increase of median and standard-deviation of Z_{DR} values within hail-bearing cell below wet bulb freezing level at C band (median +4dBZ for large hail, +7dBZ for giant hail) is observed with increasing hail size. . Strong decrease of ρ_{hv} occurs below the freezing level due to melting hail mixed with rain and resonance effects. A secondary minimum at -10 °C temperature level is also regularly observed in the hail generation area where wet growth of hail occurs

At C band, the dramatic reduction in ρ_{hv} can be seen at all levels for giant hail class. The variability of polarimetric variables within the areas of high Z well correlates with their median values and can be utilized if , for example, Z_{DR} is not calibrated properly or strongly biased by differential attenuation.

VI. ACKNOWLEDGMENTS

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