CHARACTERISTICS OF HAILSTORMS IN THE HIGH PLAINS AS DEDUCED FROM 3-CM RADAR OBSERVATIONS

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ABSTRACT

Measurements were made of thunderstorm reflectivity structure in eastern Colorado from 15 May - 31 July 1962.

Using a CPS-9 3-CM radar at Lowry AFB which was equipped with a stepped-gain system, measurements were made of RHI tops, maximum reflectivity, elevation of maximum reflectivity, and reflectivity at 20, 30, and 40 thousand feet MSL. An analysis of variance was performed to determine whether significant (usually at the 5% level) differences occurred in these parameters between months or between categories of hail intensity. From the data presently available it appears possible to differentiate between hail and non-hail cases for June and July. It does not appear to be possible at this time to make this distinction in May, nor does it appear possible to differentiate between classifications of hail intensity, using either maximum hailstone diameter or "impact energy" values.

Using another 3-CM radar at New Raymer, Colorado, the angles of "tilt" of radar echoes were determined from PPI positions of the tops of echoes and the positions of the points of maximum reflectivity at the base of the echoes. The azimuth of "tilt" of hail-producing cells was clockwise from the wind shear vector, and that of non-hail producing cells was counterclockwise from the wind shear vector. While these differences were not significantly different from zero, there was a significant difference in this angle for hail vs. non-hail cases.

Higher mean reflectivities were found in the front than in the rear of precipitation echoes, and higher reflectivity values were found in the right-hand segment of precipitation echoes than in the left-hand segment.

1. INTRODUCTION

A variety of measurements of properties of thunderstorms and hailstorms were made with radar in eastern Colorado from 15 May - 31 July 1962. Verification of hail events for the CPS-9 data was accomplished from data collected in the Colorado State University hail network (1), permitting a time variation of ± 30 minutes between the radar observation and the corresponding report of hail occurrence. The "non-hail" classification was reserved for precipitation cells definitely known not to have produced hail. Cells for which verification of hail occurrence was uncertain were classified as "unknown." For as many hail cells as possible, the hail events were classified according to the maximum diameter of stone, and the "impact energy" value (2) of hail from the storm. For studies of "tilt" and internal reflectivity, a "hailer" was defined as a cell known to have produced hail at some time during its life cycle.

2. IDENTIFICATION AND CHARACTERIZATION OF HAILSTORMS FROM CPS-9 DATA

2.1 Collection and analysis of data

The CPS-9 radar at Lowry AFB, Colorado, was equipped with a stepped-gain system, and calibrated to the same receiver gain values as described by Coleman (3). Using this equipment, measurements were made of the six parameters indicated in Figure 1. The numbers of cases, means, and standard deviations of the various parameters are shown in Figure 1. The results of an analysis of variance between means are shown by dividing lines between categories significantly different.

Figure 1 shows that fewer significant differences between hailers and non-hailers were noted for May than for June or July. Also, it may be seen that the amount of data obtained from the one season of observations are inadequate to identify differences in intensity of hail, based either on stone diameter or "impact energy" values.

2.2 Use of radar data to categorize cells as hailers or non-hailers

Classes of radar data shown to be significantly different in Figure 1 were used to categorize individual echoes as "hailers or "non-hailers," using a value of the radar parameter half-way between the mean values for hailers and non-hailers. Classification was made by a "majority rule" of the significant parameters. The results are shown in Figure 2.

From Figure 2 it can be seen that no skill in separating hailers from non-hailers was demonstrated in May, but that significant skill was demonstrated in June and July. The data of Figure 2 suggest that radar measurements can be used for differentiating between hail and non-hail cases in June and July, but that such separation is not possible in May. The reasons for this seasonal difference are not obvious. It is possible that precipitation cells may be more isolated in late summer than in spring, hence attenuation would be less likely and individual cells could be more easily identified.

3. TILT OF RADAR ECHOES

Using a 3-CM tracking radar located at New Raymer, Colorado, the "tilt" of precipitation echoes was examined. Determination of "tilt" was made from PPI observations of tops of the echoes and the strongest return at the bases, as shown in Figure 3. The azimuth angle of the plane of "tilt" was compared with the azimuth of the wind shear vector between 14,000 and 35,000 ft MSL. As shown in Table 1, the mean differences (β-γ) were not significantly different from zero, but were significantly different for hail cases vs. non-hail cases. The mean azimuth angle of tilt was found to be clockwise from the wind shear vector, which is consistent with results from previous studies in Colorado (1) which showed that hail paths averaged 23 degrees clockwise from the wind at 18,000 ft.

Table 1. Results of "t" test for significance of differences between mean ($\overline{\beta-\gamma}$) values vs. zero (columns 1 - 4) and between mean ($\overline{\beta-\gamma}$) values for Hailers vs. Non-Hailers (column 5). See Figure 3 for definitions of β and γ.

	All Cases (1)	Hailers (2)	Non-Hailers (3)	Unknowns (4)	H vs. NH (5)
$\overline{\beta-\gamma}$	- 9.6	- 20.9	+ 5.8	- 7.0	
std dev, s	95	85	107	100	
"t"	1.24	1.65	0.39	0.31	2.21
d.f.	144	74	51	19	125
P	≈ 25%	≈ 9%	> 50%	> 50%	≈ 3%

Simple correlations were made between the horizontal distance between the base and top of the echoes, and the magnitude of the wind shear vector between 14,000 and 35,000 feet. The results were not significant.

4. INTERNAL REFLECTIVITY STRUCTURE OF THUNDERSTORMS

Previous studies (5) based on surface observations of hail and rain at the ground indicated a higher probability of hail in the right-hand segment of the precipitation cell than in the left-hand segment (observer looking in the direction of motion of the cell). The same studies indicated little difference in the probability of hail between the front vs. the rear of the cell.

To examine this question in greater detail, a 3-CM vertical scanning radar (modified Navy SO-12 unit) was equipped with a stepped-gain unit and calibrated to yield approximate Z values, using the technique described by Atlas and Mossop (6). This unit was also located at New Raymer, Colorado. The criteria of position and movement used to determine differences in reflectivity between front vs. rear and right vs. left are shown in Figure 4. Vertical scans were made at successively reduced gain steps at a particular azimuth, after which the azimuth angle was changed and vertical scans were again made. Data were reduced from photographs made of the scope presentation. An analysis was made of all echoes (including merged cells and squall lines). This analysis was repeated for single cells only (7). The results of this study are shown in Table 2 which shows that significantly higher reflectivities occurred on the front and right hand segments than on the back and left-hand segments of the echoes. These results are consistent with the findings noted previously, as well as with the findings of other investigations (8, 9).

Table 2. Mean reflectivities, standard deviations, and numbers of cases for which there were significant differences (5% level) between Front vs. Back and Left vs. Right portions of precipitation echoes. Significance of differences were determined by a "t" test.

Category	Month	Type	$\overline{10 \log_{10} Z}$	s	N	$\overline{10 \log_{10} Z}$	s	N
			Front			Back		
All	June	H	35.2	9.2	67	32.1	7.6	62
Single	June	H	37.0	10.1	47	31.7	7.5	42
Single	June	H+NH	35.6	10.0	65	31.3	7.2	59
			Left			Right		
All	June	H	31.8	7.3	46	35.8	7.8	49
All	July	H+NH	30.6	5.3	36	34.0	8.0	35

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6. REFERENCES

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		All Echoes				Hailers only									
		Season	May	June	July	Diam.	Season	May	June	July	Impact Energy ft lb/ft²	Season	May	June	July
RHI Tops KFT MSL at power received -95 d.b.m	Hailers	N = 71	14	57		≤ 1/2"	N = 12	10		2	≤ 10	N = 5	3		2
		$\bar{x}$ = 32.3	26.8	33.7			$\bar{x}$ = 29.9	29.5		32.0		$\bar{x}$ = 33.8	35.0		32.0
		s = 7.7	5.7	7.5			s = 6.8	6.7		9.9		s = 5.2	0.0		9.9
	Non-Hail.	N = 24	7	17		1/2" - 1"	N = 6	2		4	10-100	N = 11	7		4
		$\bar{x}$ = 25.9	24.3	26.5			$\bar{x}$ = 39.3	32.0		43.5		$\bar{x}$ = 32.4	26.0		43.5
		s = 6.4	9.8	4.7			s = 7.2	4.8		3.1		s = 10.1	5.9		3.1
	All Cases	N = 247	43	112	92	≥ 1"	N = 33	22		11	≥ 100	N = 24	15		9
		$\bar{x}$ = 31.7	29.4	32.6	31.6		$\bar{x}$ = 33.0	31.0		36.9		$\bar{x}$ = 31.8	28.5		37.3
		s = 7.1	7.8	7.3	6.4		s = 6.9	7.4		3.4		s = 7.0	6.8		2.8
Elev. of Max. Z, KFT MSL	Hailers	N = 71	71			≤ 1/2"	N = 12	12			≤ 10	N = 5	5		
		$\bar{x}$ = 17.7	17.7				$\bar{x}$ = 17.3	17.3				$\bar{x}$ = 18.4	18.4		
		s = 5.4	5.4				s = 4.3	4.3				s = 3.2	3.2		
	Non-Hail.	N = 24	24			1/2" - 1"	N = 6	6			10-100	N = 11	11		
		$\bar{x}$ = 12.8	12.8				$\bar{x}$ = 21.3	21.3				$\bar{x}$ = 18.6	18.6		
		s = 4.2	4.2				s = 6.6	6.6				s = 6.7	6.7		
	All Cases	N = 244	43	110	91	≥ 1"	N = 33	33			≥ 100	N = 24	24		
		$\bar{x}$ = 16.8	16.1	17.2	16.8		$\bar{x}$ = 17.7	17.7				$\bar{x}$ = 17.2	17.2		
		s = 5.7	4.6	6.2	5.5		s = 5.7	5.7				s = 5.7	5.7		
Log_{10} Max Z	Hailers	N = 71	14	36	21	≤ 1/2"	N = 12	10		2	≤ 10	N = 5	3		2
		$\bar{x}$ = 4.33	3.94	3.97	5.21		$\bar{x}$ = 3.70	3.45		4.95		$\bar{x}$ = 4.09	3.52		4.95
		s = 0.38	0.79	0	0.81		s = 0.84	0.42		1.55		s = 1.14	0.32		1.55
	Non-Hail.	N = 23	7	8	8	1/2" - 1"	N = 6	2		4	10-100	N = 11	7		4
		$\bar{x}$ = 4.25	4.09	3.45	4.70		$\bar{x}$ = 5.06	3.81		5.68		$\bar{x}$ = 4.25	3.43		5.68
		s = 0.00	0.67	0.40	0.83		s = 1.04	0.0		0.52		s = 1.24	0.50		0.52
	All Cases	N = 243	43	109	91	≥ 1"	N = 33	22		11	≥ 100	N = 24	15		9
		$\bar{x}$ = 4.27	4.07	3.80	4.94		$\bar{x}$ = 4.53	4.16		5.26		$\bar{x}$ = 4.68	4.17		5.52
		s = 0.85	0.71	0.40	0.88		s = 0.69	0.24		0.71		s = 0.72	0.08		0.46
Log_{10} Z at 20 KFT	Hailers	N = 64	12	31	21	≤ 1/2"	N = 6	4		2	≤ 10	N = 2	0		2
		$\bar{x}$ = 4.29	3.88	3.92	5.06		$\bar{x}$ = 3.72	3.16		4.95		$\bar{x}$ = 4.95			4.95
		s = 0.77	0.57	0.33	0.76		s = 1.24	0.45		1.55		s = 1.55			1.55
	Non-Hail.	N = 21	6	7	8	1/2" - 1"	N = 6	2		4	10-100	N = 10	6		4
		$\bar{x}$ = 3.99	3.98	3.87	4.11		$\bar{x}$ = 4.95	3.81		5.51		$\bar{x}$ = 4.21	3.34		5.51
		s = 0.00	0.80	1.75	0.97		s = 0.91	2.00		0.36		s = 1.20	0.49		0.36
	All Cases	N = 223	39	96	88	≥ 1"	N = 32	21		11	≥ 100	N = 23	14		9
		$\bar{x}$ = 4.08	4.01	3.66	4.58		$\bar{x}$ = 4.48	4.11		5.18		$\bar{x}$ = 4.61	4.09		5.42
		s = 1.12	0.40	0.55	1.53		s = 0.62	0.00		0.70		s = 0.66	0.00		0.49
Log_{10} Z at 30 KFT	Hailers	N = 54	33		21	≤ 1/2"	N = 4	2		2	≤ 10	N = 2	0		2
		$\bar{x}$ = 3.94	3.50		4.64		$\bar{x}$ = 3.31	2.78		3.84		$\bar{x}$ = 3.84			3.84
		s = 0.98	0.83		0.81		s = 0.96	0.00		1.31		s = 1.30			1.31
	Non-Hail.	N = 11	6		5	1/2" - 1"	N = 4	0		4	10-100	N = 6	2		4
		$\bar{x}$ = 3.62	3.81		3.40		$\bar{x}$ = 5.34			5.34		$\bar{x}$ = 4.48	2.78		5.34
		s = 0.00	1.72		1.00		s = 0.33			0.18		s = 1.33	0.00		0.18
	All Cases	N = 167	26	78	63	≥ 1"	N = 29	18		11	≥ 100	N = 21	12		9
		$\bar{x}$ = 3.78	3.46	3.28	4.10		$\bar{x}$ = 3.97	3.46		4.82		$\bar{x}$ = 4.18	3.55		5.02
		s = 0.00	0.79	0.76	0.94		s = 0.91	0.62		0.63		s = 0.93	0.66		0.44
Log_{10} Z at 40 KFT	Hailers	N = 19	19			≤ 1/2"	N = 0	0		0	≤ 10	N = 0	0		0
		$\bar{x}$ = 3.97	3.97				$\bar{x}$ = 0					$\bar{x}$ = 0			
		s = 0.70	0.69				s = 0					s = 0			
	Non-Hail.	N = 2	0			1/2" - 1"	N = 4	0		4	10-100	N = 4	0		4
		x = 3.87					$\bar{x}$ = 4.53			4.53		$\bar{x}$ = 4.53			4.53
		s = 0.00					s = 0.41			0.41		s = 0.41			0.52
	All Cases	N = 43	5	19	19	≥ 1"	N = 12	6		6	≥ 100	N = 11	5		6
		$\bar{x}$ = 3.65	3.45	3.42	3.93		$\bar{x}$ = 3.87	3.44		4.29		$\bar{x}$ = 3.95	3.55		4.29
		s = 0.73	0.47	0.58	0.84		s = 7.72	1.41		0.81		s = 0.74	0.50		0.81

Figure 1. Summary of seasonal differences and differences between categories of hail events as determined from measurements made with CPS-9 at Lowry AFB, Colorado in 1962. Months were combined if non-homogeneity could not be shown at less than 5% confidence level. Significant seasonal differences are shown by heavy vertical dividing lines. Differences between categories are shown by heavy horizontal dividing lines if significant at the 1% level.

May

Obs \ Fcst	H	NH
H	7	7
NH	4	3

June

Obs \ Fcst	H	NH
H	31	2
NH	4	3

July

Obs \ Fcst	H	NH
H	19	1
NH	3	4

Skill Scores (See reference 2)

	May	June	July
Heidke	= +0.07	= +0.38	= +0.58
Appleman	= -0.57	= +0.14	= +0.43

Figure 2. Results of determining whether echoes were Hailers or Non-Hailers from examination of significant parameters of hailers vs. non-hailers in Figure 1.

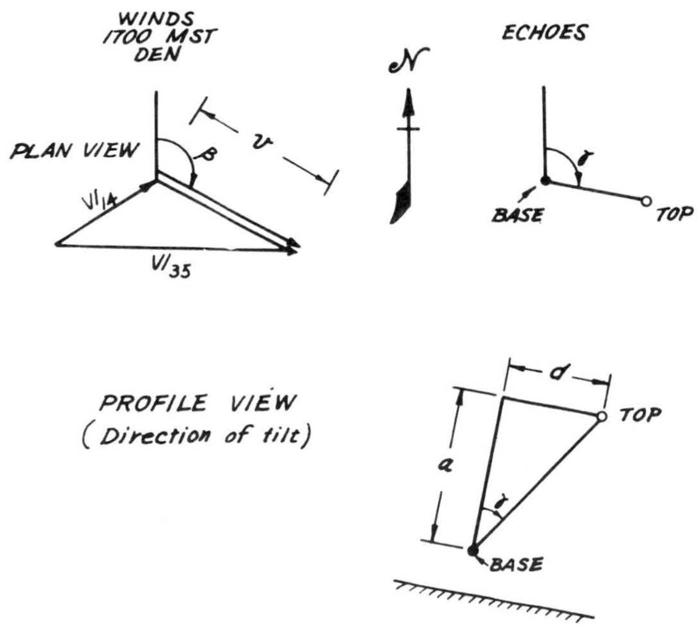

Figure 3. Definitions of symbols used in calculations of angles of "tilt".

F-M-B

quadrant	$d \geq 30$	$10 \leq d < 30$	$d < 10$
NE	$A - 90^0 = B \pm 30^0$	$A - 90^0 = B \pm 20^0$	Not Used
SE	$A + 90^0 = B \mp 30^0$	$A + 90^0 = B \mp 20^0$	Not Used
SW	$A + 90^0 = B \mp 30^0$	$A + 90^0 = B \mp 20^0$	Not Used
NW	$A - 90^0 = B \pm 30^0$	$A - 90^0 = B \pm 20^0$	Not Used

L-C-R

quadrant	$d \geq 30$	$10 \leq d < 30$	$d < 10$
NE	$A = B \pm 30^0$	$A = B \pm 20^0$	Not Used
SE	$A = B \mp 30^0$	$A = B \mp 20^0$	Not Used
SW	$A - 180^0 = B \pm 30^0$	$A - 180^0 = B \pm 20^0$	Not Used
NW	$A - 180^0 = B \mp 30^0$	$A - 180^0 = B \mp 20^0$	Not Used

d = Distance of precipitation echoes from radar in nautical miles.
A = Position of precipitation echoes from radar, degrees azimuth.
B = Direction of motion of precipitation echoes, degrees azimuth.

Figure 4. Position and movement criteria of precipitation echoes analyzed for reflectivity in Front-Middle-Back or Left-Center-Right categories. (Middle and Center categories were discarded in analysis of data).