SOME RESULTS RELATED TO THE SUPPRESSION HAIL PROJECT IN ALBACETE

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ABSTRACT

A characterization of unseeded hailstorms and a comparison between seeded and unseeded hailstorms observed in the protected area of the province of Albacete (Spain) have been carried out by the use of the t-statistic distribution. For this case study several direct parameters gathered by meteorological radar and the growth factor as an indirect parameter have been selected. The results indicate that the only parameter able to distinguish the behaviour of both types of hailstorms was the growth factor which was 25% less for seeded hailstorms which is significant at the 5% level. Based on these results, a linear correlation between the growth factor and remaining radar variables has performed. The final results suggest a better correlation between most variables for the unseeded than for seeded hailstorms.

1. INTRODUCTION

Direct and indirect losses by hail on crops are dramatic around the world (Dessens, 1986; Romero and Balasch, 1985; Humphries et al.,1987). This problem is particularly important in Spain since our country mainly depends on its agricultural production.

The devastating effects of hail have focused attention on the use of weather modificaction techniques to alleviate the problem. Therefore, different countries have initiated a wide range of projects in order to study hailstorms and to design adequate technological methods for suppressing hail (Colino, 1987; Dessens, 1987; Henderson, 1975).

There is a lot of controversy over the effectiveness of hail suppression projects developed in different countries. The main part of the projects described in the literature show positive benefits for the hail suppression programes (Dessens 1987; Santolaya and Santos, 1987). However, according to the WMO, there is no scientific experimental evidence supporting the effectiveness of hail suppression (WMO, 1983, 1985, 1986). Despite this, the WMO recognizes the need for an important advance in seeded technologies and it encourages the development of experimental projects conducted to analyse the results obtained.

For the years 1978 to 1983, and from the period June through September, a hail suppression program was operated in the province of Albacete (Spain). The protected area was about 600 km^2. This area was chosen by the Ministry of Agriculture on the basis of historical data concerning hail losses encurred by insurance companies. During these operations hailstorms were seeded by aircraft flying at the -10 °C altitudes. Ejectable AgI pyrotechnics were used as the seeding material. The aircrafts were flown directly into the cloud masses based on vectors from a meteorological radar located at the control site in the protected area. The cloud with reflectivity values near 45 dbz and with vertical development greater than 6,500 meters, were considered to contain a risk of hail. When the reflectivity was higher than 35 dBZ at 6,500 meters then the clouds were seeded, subsequently the spatial and temporal evolution of the radar echoes were followed and stored in the computer. Therefore, an extensive collection of information relative to the most common radar parameters was available to study the clouds. However, neither microphysical observations of the clouds nor information on hail at the ground (i.e., size spectrum, kinetic energy...) were available.

The purpose of this paper is to present some of the results obtained concerning the main radar characteristics of the unseeded hailstorms occuring over the protected area (or in the nearby areas), to compare the characteristics and identify any statistical differences. To do this, we have used some of the most relevant radar parameters. Also, a comparison has been performed by using the "growth factor" of hailstorms proposed by Goyer (1975).

2. DATA

From all the data recorded by the radar/computer system, we have focused our attention on the clouds with hail risk. Therefore, we have selected only those clouds with reflectivities greater than 45 dBZ. In addition, we have only considered clouds with lifetimes greater than 10 minutes. The interval of time was chosen as a compromise between obtaining enough statistical data and having echo lifetime with sufficient duration in order to compare the results of seeded versus non seeded clouds. (Foote and Mhor, 1979)

For this case study, we have chosen the following direct parameters measured by the radar:

HM *maximum height of the hailstorms* (Km)
H10 height related to the 10 dBZ echo (Km)
T lifetime of hailstorms (min)
MR maximum reflectivity (dBZ)
HMR height corresponding to the maximum reflectivity (Km)
X total distance traveled by the hailstorms (Km)

As an additional part of this preliminary study, we have included an factor which takes into account the vertical growth rate of hailstorms. The factor chosen and which is referred to as GF, is defined as follow for seeded and unseeded hailstorms (see Goyer for details):

$$GF = T_1 / T_0$$

If 't_0' is the time of initiation of seeding for seeded storms, the time is perfectly known, but t_0 for unseeded storms is defined as the time when echo tops first reached 10 Km.

Then:

-'T_0' (Km.min), the initial hailstorm magnitude, is defined by the echo top integrated from 20 min before, to the time of initiation of seeding (t_0).

- 'T_1' (Km.min) is the total storm magnitude, and it is defined by its echo top integrated from 20 min before 't_0' to the time the echo drops below 7.6 Km.

3.CHARACTERISTICS OF UNSEEDED HAILSTORMS

Table 1 shows the arithmetical mean, the arithmetical standard deviations, the maximum and minimum values of each radar *variable and the* geometrical average and the standard deviations. There were 43 hailstorm cases studied.

PARAMETERS	M_a	σ_a	MAX	MIN	M_g	σ_g
HM	11.60	1.30	15.0	9.4	11.62	1.13
H10	10.70	1.43	14.3	9.5	10.71	1.13
T	71.50	62.08	282.0	10.0	57.43	2.38
MR	56.55	7.51	68.0	45.0	56.21	2.38
HMR	3.41	1.90	7.0	0.6	2.80	1.94
X	46.14	31.25	148.0	7.0	39.40	1.95
GF	5.71	3.99	22.2	2.9	4.85	1.95

Table 1 : arithmetic averaoe (M_a), arithmetic standard deviation (σ_a), *maximum* (MAX). *minimum* (MIN), geometric averaoe (M_g). and geometric standard deviation (σ_g) for unseeded hailstorms.

The examination of the frequency histograms revealed the tendency of the values of most of the variables to be *lognormally* distributed. Using Probits analysis, (Murray, and Spiegel, 1961), the figure 1 shows the cumulative frequency distribution of each variable expressed in terms of the standardized "u" variable versus the logarithms of the values *. The linear plots obtained for each variable are indicative of the lognormality of the values. The correlation coefficient related to each linear fit was never below 0.99 as *may be seen in Table 2.*

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* u is defined by u = (L x − m)/σ, where x is an individual storm value (either GF, MR, T, X, H10 or MR), m is the mean of that value over all storms, and σ is the standard deviation of that value over all storms.

PARAMETERS	r	p	V(50)	V(95)	V(5)
HM	0.990	0.1188	11.70	14.23	9.62
H10	0.998	0.1137	10.79	13.00	8.95
T	0.991	0.8077	52.65	198.80	13.94
MR	0.990	0.1105	55.50	65.56	46.30
HMR	0.998	0.4554	3.52	7.4	1.67
X	0.995	0.6451	37.23	107.6	12.89
GF	0.995	0.4861	4.61	10.25	2.07

Table 2 :correlation coefficient (r), slope (p) and values for different precentiles related to unseeded hailstorms.

In order to check the validity of the hypothesis of the lognormal frequency distribution, the Kolmogorov-Smirnov test was performed. The values obtained for the statistics confirmed the validity of this assumption at a significance level below 5%. Based on these results the geometric average and the geometric standard deviations have been determined to properly characterize the frequency distributions.

After looking at Figure 1 and the results related to different percentiles (see Table 2), the following general considerations can be drawn.

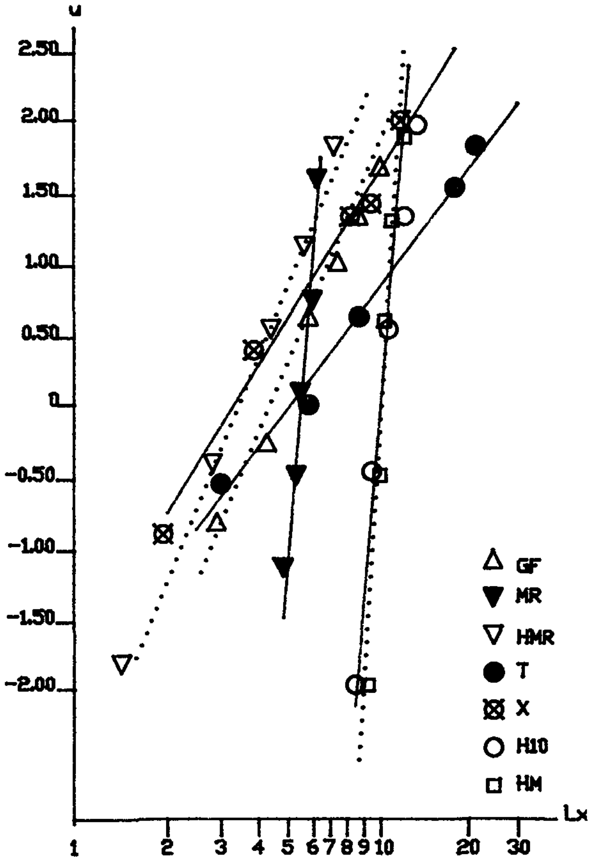

Figure 1 : cumulative frequency distribution versus logarithms of the values related to unseeded hailstorms

The lifetime of the hailstorms in the area of Albacete can be considered as moderately long because average geometric value is near 1 hour and the frequency of hailstorms whose lifetime was below 15 minutes is only 5%. This variable presents the highest geometric standard deviation, which reveals the heterogeneity of the lifetime of hailstorms. Similar results are obtained for the distance traveled.

The ratio between the average distance and lifetime is around 12 ms^{-1}, which may be considered as a realistic wind speed.

The parameters HM, H10 and MR have standard deviations quite small as can be seen in the similar slopes in the cumulative frequencies plots indicated in Figures 1 and 2. The average value obtained in the reflectivity observed indicates that the hailstorms observed in the area of Albacete are not very severe compared to other continental areas (see Foote and Mhor; 1979).

It is also interesting to note that the height of the maximum reflectivity should also be considered as average, since only 5% of the hailstorms have the maximum reflectivity located at 1.7 km above ground.

4. COMPARISON BETWEEN SEEDED & UNSEEDED HAILSTORMS

Table 3 shows the arithmetical mean, arithmetical standard deviation, maximum and minimum values, the geometric mean and geometric standard deviations of each radar parameter related to seeded hailstorms. The number of cases analyzed was 29.

PARAMETERS	M_a	σ_a	MAX	MIN	M_g	σ_g
HM	12.20	1.32	14.8	9.8	12.08	1.65
H10	11.32	1.58	14.8	9.0	11.27	1.06
T	83.50	56.40	255.0	16.0	67.50	2.25
MR	57.11	6.40	71.0	45.0	56.87	1.12
HMR	3.90	1.89	9.8	0.7	3.50	1.65
X	64.10	42.24	144.0	19.0	49.21	1.84
GF	3.99	1.72	7.6	1.5	3.65	1.50

Table 3 : arithmetic average (M_a), arithmetic standard deviation (σ_a), maximum (MAX), minimum (MIN), geometric average (M_g), and geometric standard deviation (σ_g) for seeded hailstorms.

Figure 2 shows the cumulative frequency distributions versus the logarithms of the values related to each parameter. The linear fits were again rather satisfactory as can be seen in Table 4. The Kolmogorov-Smirnov test was also performed in order to check types of storms. In fact, the examination of the geometric average values shown in Table 1 and 3 indicate a slight increase for the most of the variables. The growth factor was the only parameter which decreased for the seeded hailstorms. In order to analyze if the differences between the average values were significant from a statistical point of view, the Student t-test was applied to each variable. Table 5 shows the differences between the logarithms of each variable and the " t " statistical value. The symbol 'Y' written in the last column indicates that the differences were statistically significant at the 5% level and the symbol 'N' means that they were not.

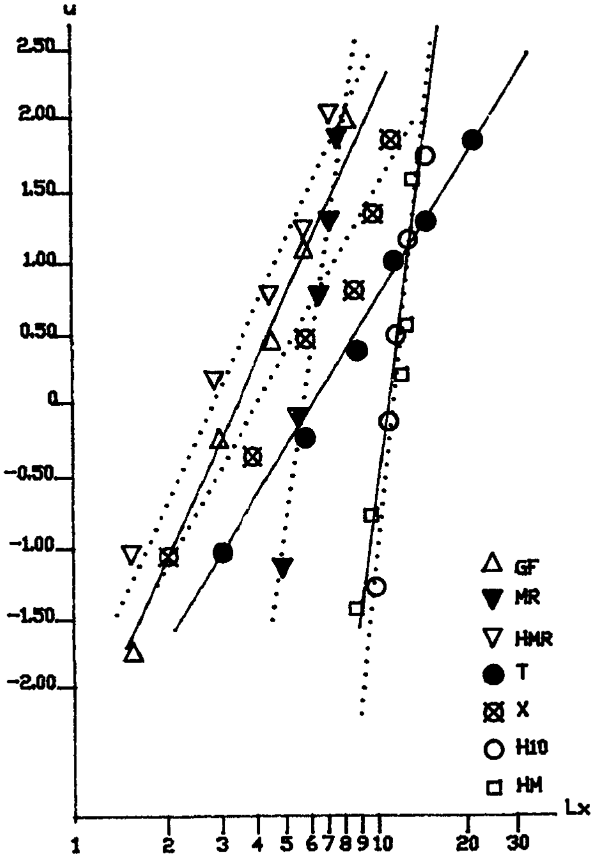

Figure 2 : cumulative frequency distribution versus logarithms of the values related to seeded hailstorms

PARAMETERS	r	p	V(50)	V(95)	V(5)
HM	0.998	0.1028	12.11	13.42	10.23
H10	0.992	0.1490	11.14	12.94	8.72
T	0.994	0.6481	67.11	194.91	23.11
MR	0.997	0.1107	56.71	68.04	47.27
HMR	0.998	0.5802	56.71	7.37	1.24
X	0.978	0.5997	45.98	17.14	123.29
GF	0.996	0.5087	3.62	8.38	1.57

Table 4 :correlation coeffient (r). slope (p) and values for different percentiles related to seeded hailstorms.

From the results shown in Table 5, we can conclude that there is not a significant difference between the radar parameters measured by the radar when unseeded and seeded storms are compared. However, for the growth factor used in this report, there is a 32.1% decrease for the seeded when compared to the unseeded hailstorms (results in table 6).

PARAMETERS	DIF	t	S(5%)
HM	0.0388	1.59	N
H10	0.0509	1.71	N
T	0.1615	0.78	N
MR	0.0117	0.43	N
HMR	0.2231	0.18	N
X	0.2222	1.41	N
GF	-0.2842	2.02	Y

Table 5 : results of the t-statistic at the 5% significance level.

GF (SEEDED) N=29				GF (UNSEEDED) N=43			
5.6	3.6	3.7	2.9	3.2	5.2	6.0	2.6
1.6	5.4	3.0	2.9	8.5	3.5	5.0	2.9
2.7	2.7	3.6	4.7	2.6	6.5	1.7	5.8
3.9	3.5	3.3	2.7	3.7	4.7	2.4	6.0
2.7	1.5	3.5	2.6	3.3	3.4	5.0	1.7
2.7	4.7	3.5	6.4	4.8	4.9	4.4	8.5
4.7	7.6	1.7	8.3	6.5	3.8	4.5	5.4
7.5				7.5	17.2	22.3	6.5
				5.9	10.4	7.2	5.3
				2.1	2.4	9.1	4.6
				2.8	5.5	10.7	

Table 6 : Values of GF for seeded and unseeded hailstorms.

5. LINEAR CORRELATION AMONG THE GROWTH FACTOR AND THE DIRECT RADAR PARAMETERS

Since the only parameter which showed a difference between the two groups of hailstorms was the growth factor we tried to establish if there was any correlation between this factor and the other radar parameters. Tables 7 and 8 show the correlation coefficient, the slopes and the intercept for the unseeded and seeded hailstorms respectively. In the last column we have included the significance level of each linear fit. The symbol 'N' means that the fit was not significant at a level below 5%.

The unseeded hailstorms correlated better with most of the parameters than did the seeded ones. A similar correlation was found with the lifetime of the hailstorms. This difference in behaviour could be indicative of a modification to the seeded hailstorms.

PARAMETERS	r	p	a	s1
HM	0.661	0.14	11.66	0.002
H10	0.637	0.22	9.62	0.002
T	0.795	0.07	2.16	0.002
MR	0.441	1.08	46.00	0.005
HMR	0.563	0.28	1.95	0.002
X	0.733	4.73	15.34	0.002

Tabla 7 : linear fits between the growth factor and the direct parameters for unseeded hailstorms.

PARAMETERS	r	p	a	s1
HM	0.180	0.140	11.66	N
H10	0.006	0.006	11.31	N
T	0.590	0.018	2.48	0.002
MR	0.322	1.204	52.47	N
HMR	0.002	0.002	4.01	N
X	0.084	1.641	50.32	N

Table 8 : linear fits between the growth factor and the direct parameters for seeded hailstorms.

6. CONCLUSIONS

A characterization of hailstorms developed in the province of Albacete has been performed with the aid of the information recorded by a meteorological radar located in the protected area. In order to describe properly the main characteristics of each of the parameters studied, two lognormal frequency distribution tests were performed : the Kolmogorov - Smirnov test and a Probits analysis. The results obtained for unseeded and seeded hailstorms have revealed that the values of all parameters were well fitted to the lognormal frequency distribution.

The unseeded storms, whose reflectivities were greater than 45 dBZ when lifetimes were greater than 10 minutes, were analyzed for the protected area. They are characterized by moderate lifetime and with long travel distances, although they were not very severe according to the reflectivity values.

The comparison between the geometric average values of each studied parameter has indicated that there is no significant difference between seeded and unseeded hailstorms. The only parameter which was demonstrated to have a significant difference was the growth factor. There was a decrease for the seeded cases.

The correlations between the growth factor and the various parameters obtained for both seeded and unseeded hailstorms revealed that there was a different behaviour for seeded and unseeded storms. The unseeded storms correlated rather satisfactorily with most of the direct radar parameters, while the linear fits were very poor for the seeded cases. This result suggests that the influence of the seeding process may have changed the radar characteristics of the hailstorms.

It should be noted that these results are based on radar observations only. In order to obtain definitive results, and according to the suggestions of the WMO, it would be important not only to complete this study with cloud microphysical information and ground truth data concerning hail size characteristics, but also to conduct these studies on the basis of a randomized seeding experiment.

7. ACKNOWLEDGMENT

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