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ANALYSIS OF THE CHARACTERISTICS OF STORMS LOCATED IN THE MIDDLE EBRO VALLEY (SPAIN): PREPARATION FOR A NEW STAGE OF HAIL SUPPRESSION

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Abstract In this work we present an analysis of the characteristics of storms in the Middle Ebro Valley that have not been seeded. The object is to have this for comparison with future seeded data from a hail suppression project. For this we have used radar images, adhering to a criteria of observation, to classify the storm types. Our sampled data was sub-mitted to rigid statistical guidelines, permitting us obtain the measured values of the variables such as: area traversed, average life time, maximum reflecti-vity and heights at the moment of reaching peak values.

1. INTRODUCTION

The history of hail suppression in the Middle Ebro Valley dates back to 1969. Farmers that were tired of the occasional but continuing crop damage due to hail began to use burners. These burners were the activated charcoal type and were placced at varius points in the Middle Ebro Valley.

In 1974 a combined effort was made to coordinate a hail suppression proyect. The Ministry of Agriculture, farmers, local and provincial administration installed a network of ground generators. These were modeled after the French L` ANELFA system, (Dessens, 1985). At the same time an "X" band radar was incorporated in the hail suppression progam to observe storms formation and movement, (Dávila et al., 1975-86 and Aparicio et al., 1987). The area that was selected consists of portions of the provinces of Logroño, Navarra, and a small zone of Alava. This "historic area" is show in figure 1.

Before the confidence of the farmers could be gained in this type of weather modification, the project defence area was extended to other areas of the Middle Ebro Valley.

In 1984 the Ministry of Agriculture, in colaboration with the Autonomy of Aragon, installed a "C" band - 250 Kw power output meteorologic radar near the city of Zaragoza. The object, among others was to analyze the behavior of the storms and general cloud mass in the Middle Ebro Valley. Figure 1 illustrates the study area, circular with a radius of 140 km and the center positioned at the Zaragoza Aiport.

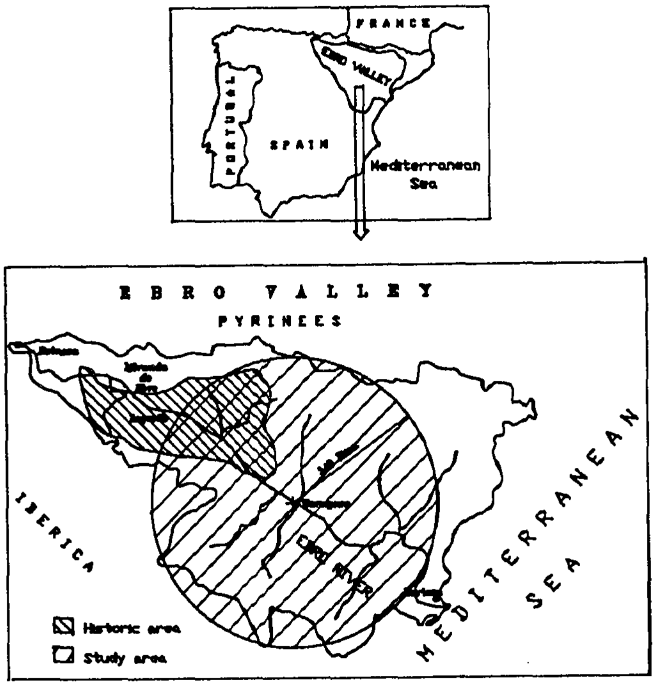

FIGURE 1: Study area: Middle Ebro Valley

During 1984 and 1985 a hail suppression project was operational in the area of 1,000,000 Ha. Aircraff in cloud top penetrations using AgI pyrotechnics was the method incorporated. Extremely dry conditions prompted the decision to discontinue this system of cloud seeding. For this reason an in-depth study of the characteristics of the storms in this area was not accomplished. The pressure of the Farmers Association, who had been trying to suppress hail damage for 15 years, forced their wishes to be respected that only AgI ground generators be incorporated in the "historical" area.

In this work we will refer to some of the results found when the meteorological radar data was analyzed, as mentioned before. During the specifified period between 1984 and 1987. The meteorological radar observations were intended to be made within the zone (or in the immediate vicinity) where storms were known to develop. The hail suppression seeding operations limited our study to the days when the cloud masses were not treated with by AgI nuclei resulting from seeding.

The data for this study was collected between the summers of 1984 and 1987. A total of 1297 cloud masses formed during a total of 101 days however, only 645 thunderstorms developed as a result. These storms were within a total of 94 days and were a designated as "active days".

To give a better characterization of the storms in the study area, we have classified them with respect to the structure presented by the radar images.

The result of seeding for hail suppression "should give" as a result: a sudden increase in maximum reflectivity and/or an increase in the overall cell structure, covering a larger area therefore producing a larger quantity of precipitation. In reality the theory of competing embryo is not necessarily a consideration in dynamic seeding (as some authors, such as Dennis (1980) call dynamic seeding) when AgI nuclei are introduced into a storm center. However, considerable literature exists to support the probability that where seeding takes place there will be a small augmentation in precipitation. At least there is sufficient reason to hope for this possibility. There is a increase in the cell heigth resulting from seeding and for this reason we have introduced this as a variable in our measurementes. In this work we are going to refer to the following characteristics found in each type of storm: area traversed, average life time, maximum reflectivity factor, height of the 10 dBZ contour vertically cut at the maximum reflectivity point and maximum height of storm. Hopefully in the near future there will be the opportunity to collect additional data for comparison.

2. CLASSIFICATION OF STORMS: CRITERIA

When one observes the structure of a storm with a meterological radar, a mass of active cloud is detected. This means that the area of the cloud that forms precipitation can be one or several cells. Normally in the form of towers.

Although there are many existing methods of classifing storms, by viewing the structure with radar, we can basically distinguish between ordinary cells and supercells (Browning, 1962).

In whichever case, normally and to a first approximation, unicellular storms (which we will call group I) are closed systems that tend to drift with the mean tropospheric winds (Browning, 1977). These are short-lived, by dissipating soon after forming, and are considered relatively simple structures. If two or more ordinary cells are associated, they are known as multicell storms (group II).

On occasions a storm will develop into a longer lasting structure with a duration of at least 50 minutes and producing reflectivities of 45 dBZ or greater. In these cases strong updrafts are formed (possibly reaching 30 to 40 m/s in velocity). Storms of this nature are known as supercells. These storms can produce different intensities and forms during their lifetime. If a supercell produces only one cell, we can say that it has unicellurlar characteristics (group III). However, if we can distinguish ordinary cells that can be deferenciated within the supercell, the storm is a supercell with multicell characteristics (group IV). This is similar to the classification proposed by Fankhauser and Mohr (1977). Therefore, we can consider group II and IV as one which can distinquish between a multicell complex of moderate or strong intensity.

In an analysis of storm characteristics in the Middle Ebro Valley, we used this criteria, apart from the meteorological radar data, to segregate the cloud masses. A zone of intense precipitation was taken into consideration, whereas the reflectivity factor was least 45 dBZ and maintained for at least 5 minutes (Foote and Mohr, 1979). In the application of this criteria we were able to reduce the 1297 samples of first echos to a total of 645 storms. The results of using this criteria has represented a significant restriction by reducing our initial samples by 50%. However, we prefer to follow this criteria as it guarantees a better comparison with analysis carried out in other zones.

Of the 305 days that the data acquisition system was completely operational, 94 days (33.81%) showed the presence of at least one active storm. The quotient between the 645 storms and the 94 active days was found to average 6.86 storms/active day.

Our results for the classification of storms in the Middle Ebro Valley using the criteria previously explained are shown in Table 1.

TYPE OF STORM	GROUP	CASES	%
UNICELL	I	350	54.3
MULTICELL	II	250	38.8
SUPERCELL (unicell.)	III	26	4.0
SUPERCELL (multicell.)	IV	19	2.9
TOTAL		645	100

TABLE 1 : Types of storms.

This table shows that the most frequent storms are those with uni-cellular characteristics. Within these, the supercell (as expected), is less evident. The unicells standout as being more frequent than the storms that are more complex and are considered multicells.

3. AREA TRAVERSED

To calculate the area traversed by a storm, we must consider the movement of the most active part, (Browning, 1977). This is recorded from when the radar first detects the storm until the echo representing the storm is lost.

Of the total of 645 detected storms, 89 or 13.8% of them proved to be stationary in nature. This means that from their formation through their growth and dissipation they remained virtually in the same location. This phenomenon was also observed by Knight et al..1982 during their studies in the Central High Plains of Colorado, (6% in the 52 active storm days). Concluding that storms with unicellular characteristics have a greater possibility of being stationary than any of the other groups, (see table 2).

TYPE OF STORM	GROUP	CASES	%
UNICELLULAR	I	68	76.40
MULTICELL	II	20	22.47
SUPERCELL (unicell.)	III	0	00.00
SUPERCELL (multicel.)	IV	1	1.12

TABLA 2: Frequency distribution of stationary storms, depending on the type, in a total of 89 cases.

A total of 556 storm samples were used in our calculations in the distance traversed by storms. Table 3 shows the results found for the different types of storms. We can clearly see that the supercell storms of the multicell characteristics represent the greatest area covered. A distance of 97.50 Km. Whereas the unicellular storms of less displacement measured 30.81 Km.

To determine if there exists a significant difference between the different pairs of groups, formed by the four groups of storms, we applied the Mann-Whitney Test, (Calvo, 1987). We then could observe the existing differences between all the pairs of groups except between II and III, (table 4). In those the traverse for this type of storm does not depend on it being multicellular or a supercell with unicell characteristics. The statistical and significant level being $|Zu|=0.72$ resulted in 46.65%.

4. AVERAGE LIFE TIME

We have taken as the average life time; the interval of time during which a storm maintains a minimum reflectivity factor of 45 dBZ. (Foote and Mohr. 1979 and Federer et al. 1978/79). This life time falls within the time from the moment the storm is detected on the radar screen until the moment of disappearance on the monitor, which is the final phase of dissipation.

Table 5 illustrates that the unicell storm type has a shorter average life. The 31.59 min., is a clear contrast to any other, such as, the supercell group (nearly 2 hours in duration is reached), and the multicell group (nearly 1 hour). Battan (1953) and Knight et al. (1982)., encountered values somewhat inferior for the unicells. However, in respect to the average life of the supercells observed in the Middle Ebro Valley, were generally inferior. Although one case was found to last 3 hours. Something similar was encountered by Rinehart et al. (1984), also Carte et al. (1978) amongst others.

After applying the Mann-Whitney Test to the different groups, we obtained the results shown in the Table 6. As we can see, all the groups except the supercells, show differences between them.

TYPE OF STORM	GROUP	CASES	%	$\bar{x}$	σ
UNICELL	I	282	50.72	30.81	25.50
MULTICELL	II	230	41.37	68.11	48.60
SUPERCELL (UNICELLULAR)	III	26	4.68	61.92	48.44
SUPERCELL (MULTICELL)	IV	18	3.23	97.50	66.83
TOTAL		556	100	49.85	44.15

TABLE 3: Study of the variable distances with respect to different types of storms.

TYPES OF STORMS TO COMPARE	GROUP	$\lvert Zu \rvert$	α(%)
Unicell and Multicell	I&II	10.03	0.00
Unicell and Supercell (unicell)	I&III	3.76	0.02
Unicell and Supercell (multicell)	I&IV	5.41	0.00
Multicell and Supercell (unicell)	II&III	0.72	46.65
Multicell and Supercell (multicell)	II&IV	2.15	3.13
Suprcell (unicell) & Supercell (multicell)	III&IV	2.19	2.86

TABLE 4: Application of the Mann-Whitnev Test "U" to the distance traversed by different pairs of storm types.

TYPE OF STORM	GROUP	CASES	%	$\bar{x}$	σ
UNICELL	I	309	52.02	31.59	27.02
MULTICELL	II	241	40.57	58.02	49.87
SUPERCELL (UNICELL)	III	26	4.38	113.92	70.09
SUPERCELL (MULTICELL)	IV	18	3.03	127.28	66.72
TOTAL		594	100	48.81	47.77

TABLE 5: A study of the variable average life in respect to different storms types.

TYPES OF STORMS TO COMPARE	GROUPS	$\lvert Zu \rvert$	α (%)
Unicell & Multicell	I & II	6.66	0.00
Unicell & Supercell (unicell)	I & III	7.11	0.00
Unicell & Supercell (multicell)	I & IV	6.25	0.00
Multicell & Supercell (unicell)	II & III	4.48	0.00
Multicell & Supercell (multicell)	II & IV	4.49	0.00
Superc.(unicell) & Superc.(multic.)	III & IV	0.90	36.82

TABLE 6: Application of the Mann-Whitney Test "U" to the variable average life (t45) of different pairs of storm groups.

5. MAXIMUM REFLECTIVITY FACTOR

In Table 7 we can see a clear difference in the variable that agrees with that type of storm. The obvious results showed that the unicells were less intense. The Test of Mann-Whitney showed no significant difference between the supercell with unicell characteristics and multicell ($|Zu|=0.97$. with one of 33.2%, enabling to consider them equal for the variable time of average life inside the same group). It is obvious that the rest of the types of storms are different between themselves to a level of significance of 0.00%, with its maximum reflectivity factor necessary for its evolution. (see table 8).

The general form in which the values of this variable were observed, relating to the different types of storms in the Middle Ebro Valley, coincides with values observed by other authors. The unicells reveal this concordance (Knight et al. 1982 & Dye et al. 1983). The supercells with multicell or unicell characteristics (Knight et al.,1982; Jameson et al..1980: Nelson. 1983; Krauss et al.. 1984 and Foote. 1984 amongst others). The value of the reflectivity factors of the multicells (Group II), did not reach the higher values of 60 dBZ (Heymsfield. 1983; Knight et al. 1982).

TYPES OF STORMS	GROUP	CASES	%	$\bar{x}$	σ
UNICELL	I	295	52.96	51.19	4.58
MULTICELL	II	222	39.86	54.35	6.00
SUPERCELL (unicell)	III	23	4.13	62.35	4.13
SUPERCELL (multicell)	IV	17	3.05	63.18	5.28
TOTAL		557	100	53.27	6.01

TABLE 7: A study of the variable factor of maximum reflivity according to the type of storm.

TYPES OF STORMS TO COMPARE	GROUPS	$\|Zu\|$	α(%)
Unicell & Multicell	I & II	6.01	0.00
Unicell & Supercell (unicell)	I & III	7.15	0.00
Unicell & Supercell (multicell)	I & IV	6.08	0.00
Multicell & Supercell (unicell)	II & III	5.64	0.00
Multicell & Supercell (multicell)	II & IV	4.97	0.00
Superc.(unicell) & Superc.(multic)	III & IV	0.97	32.92

TABLE 8 : Application of the Mann-Whitney "U" Test to the variable maximum reflectivity factor (Zmax) with respect to different pairs of storm types.

6. 10 dBZ CONTOUR HEIGHTS VERTICAL CUTS TAKEN AT MAXIMUM REFLECTIVITY POINT.

The 10 dBZ contour indicates the limit of the active portion of the cloud mass. However the maximum height (which we denominate as Htopzmax) that this contour reaches does not exactly correspond to the height of the cloud when observed visually. According to Saunders et al. (1962). 10 cm radars can differenciate those heights. The actual and what is "seen" by the radar does not exceed one km. This height reflects the highest and lowest intensities of the updrafts found inside the cloud mass.

As we can see in Table 9 that the supercells (groups III & IV) are the storms that reach the greatest vertical development, at the same moment showing the highest reflectivity. Heights of nearly two kilometers are reached, significantly higher than the heights displayed by the unicells and multicells. In the Mann-Whitney Test application of this variable, the supercell did not present significant differences. On the contrary, the rest of the groups remained well differenciated. (table 10).

TYPE OF STORM	GROUP	CASES	%	$\bar{x}$	σ
UNICELL	I	295	52.96	10.05	1.86
MULTICELL	II	222	39.86	10.48	1.96
SUPERCELL (unicell)	III	23	4.13	12.29	1.67
SUPERCELL (multicell)	IV	17	3.05	12.27	1.41
TOTAL		557	100	10.38	1.96

TABLE 9 : Study of the variable Tops of the of vertical cuts (RHI) at the maximum refectivity point in respect to different storm types.

TYPES OF STORMS TO COMPARE	GROUPS	|Zu|	α(%)
Unicell & Multicell	I & II	2.18	2.90
Unicell & Supercell (unicell)	I & III	4.99	0.00
Unicell & Supercell (multicell)	I & IV	4.56	0.00
Multicell & Supercell (unicell)	II & III	4.05	0.00
Multicell & Supercell (multicell)	II & IV	3.65	0.03
Superc.(unicell) & Superc.(multic)	III & IV	0.20	81.59

TABLE 10: Application of the Mann-Whitney "U" Test of the variable Tops, a vertical cut at the point of maximum reflectivity (Htopzmax) with respect to different pairs of storm types.

7. MAXIMUM HEIGHTS

The maximum height of a cell is expresed as "Hmax", and is the height, in kilometers, that the 10 dBZ contour reaches during its life cycle.

On many occasiones the maximum height coincides with the height of the top of the vertical cut at maximum reflectivity point (Htopzmax). This is to say, that when the storm reached maximum intensity, it also reaches its maximum vertical growth. This in general lines, represents values very similar as we will note further on. The results of our study revealed this coincidence in 63.25% of the 557 available cases. The regression line between both heights is:

$$Hmax = 0.90\ Htopzmax + 1.52$$

with a coefficient of correlation "r" of 0.89 . and a confidence level of 99.9%.

During our case study, occasions were found when storms reached a maximum of 15 km in altitude, taking note of the important updrafts that occur in their interior. In 68.4% of our cases, heights that exceeded 10 km were observed. Although a percentage of the storms that had less development, but not because their intensities were less, as their observed maximum reflectivities averaged 50 dBZ. A total of 557 cases were used to create a new regression line between the maximum reflectivity factor, indicating the level of intensity in the cloud, and the maximum height reached during its development:

$$Hmax = 0.17\ Zmax + 1.84$$

with a correlation index of 0.5 and level of significance 0.1% , a clear linear relation can be made between the variables.

In general the storms in the Middle Ebro Valley maintain an average height superior to the storms observed by Held (1978) in the South African Highveld, and the ones detected by Lipovscak (1982) in Istra (Yugoslavia). They heights are less than the storms observed by Miller et al. (1975) in South Dakota and similar to the ones found by Waldvogel et al. (1979) in Switzerland.

In Table 11, we observe the maximum height that was reached by the storms. It is less for the unicells (I) than for the rest of the groups, however the supercells don't show a difference between themselves, if we distinguish between the unicell (group III) and multicell (group IV) characteristics, α = 45.12%, (table 12).

8. CONCLUSIONS

In application of the classification of then storms, adhering to the radar criteria, we found those with unicell and multicell character demonstrate a very different behavior between themselves for the variables; average life time, maximum reflectivity factor, height of the 10 dBZ contour at maximum reflectivty and maximum altitude. If these types of storms are considered together with supercells the values would be wide spread. However, no substantial difference is demostrated between supercells with unicell characteristics and supercells with multicell characteristics if the variables mentioned are considered. If one thinks of the structure of one or the other as being quite different.

TYPES OF STORMS	GROUPS	CASES	%	$\bar{x}$	σ
UNICELL	I	295	52.96	10.41	1.87
MULTICELL	II	222	39.86	11.00	2.02
SUPERCELL (unicell)	III	23	4.13	13.19	1.32
SUPERCELL (multicell)	IV	17	3.05	12.87	1.29
TOTAL		557	100	10.84	2.01

TABLE 11: Study of the variable maximun height for different storms types.

TYPES OF STORMS TO COMPARE	GROUPS	|Zu|	α(%)
Unicell & Multicell	I & II	3.60	0.03
Unicell & Supercell (unicell)	I & III	6.23	0.00
Unicell & Supercell (multicell)	I & IV	5.13	0.00
Multicell & Supercell (unicell)	II & III	5.04	0.00
Multicell & Supercell (multicell)	II & IV	3.81	0.01
Superc.(unicell) & Superc.(multic)	III & IV	0.75	45.12

TABLE 12 : Application of the Mann-Whitney "U" Test to the variable Top heights of vertical cuts at the maximum reflectivity factor (Htopzmax) in respect to different pairs of storm groups.

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