CRITERIA FOR A REMOTE GROUND GENERATOR NETWORK IN LEON (SPAIN)

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1. INTRODUCTION

In 1985, the Agriculture Department of the Province of León (Diputación de León), worried about the frequent occurrence of hailfalls, asked the Laboratorio de Física de la Atmósfera de la Universidad de León to perform research on hail climatology and the economic repercussions of hail on agriculture. In order to do that, a target area was defined (Fig. 1) in which the agrarian production is high, and a network of meteorological observers was established in a density of one for each 17 km². This network has provided a useful data base for the summer hail period since 1986 when the project started. The target area comprises a good part of the provinces of León and Zamora and has an extent of 12,500 km².

After three years, the results allowed us to develop an action project of hail suppression, named PALA, for the problem caused by the hailfalls and the possible losses to agriculture they cause, to be carried out from 1989 to 1992. The main aim has been to obtain climatological information on the hailfalls and establish risk maps of high or low hail incidence. There are many references about the results found (Sánchez *et al.*, 1987, 1991, 1992; Fraile and Sánchez, 1989; Fraile *et al.*, 1991, 1992; Castro *et al.*, 1992; de la Madrid and Sánchez, 1989).

In 1993, following the initial project, the first stage of a planned four-year operating project was initiated, and the first experimental actions of cloud seeding with glaciogenic nuclei started. The PALA sponsors, that is to say, the provincial and regional Departments of Agriculture, have taken special care in trying to follow the suggestions emanated from the WMO. They are looking for a balance between the practice of an operational programme to reduce hail damage without forgetting the need for seeding control and research associated with this kind of activity.

In this paper, we describe the characteristics of the seeding systems and the criteria used for their implementation.

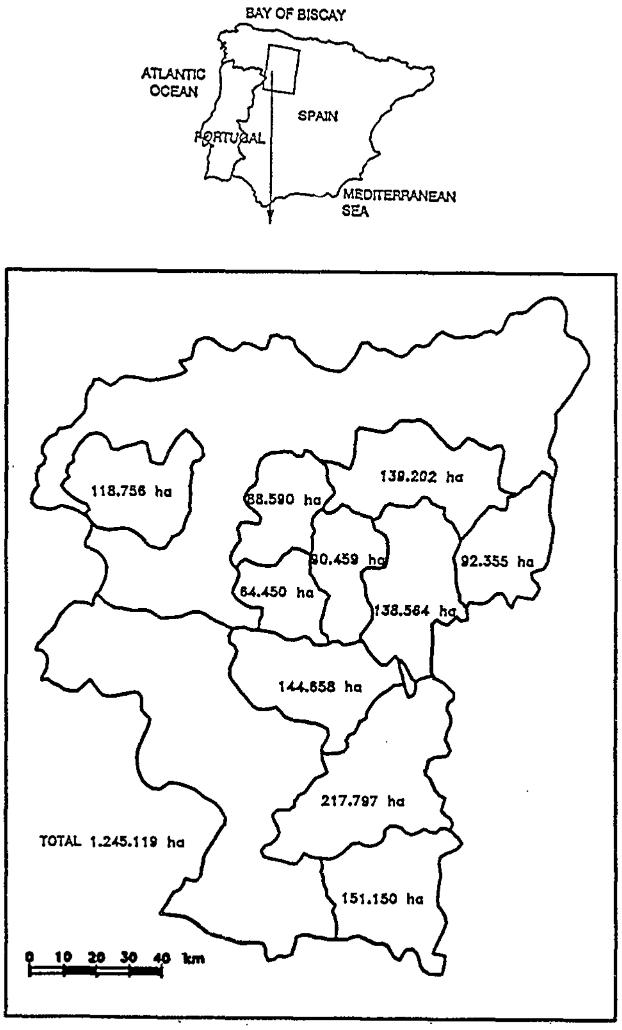

Fig. 1: The target area is divided into areas which size is shown.

2. SOME CLIMATOLOGIC CHARACTERISTICS OF THE FORMATION OF STORMS

2.1 Introduction

In the southeast of the Iberian Peninsula, the first studies carried out in 1976 showed that the occurrence of hailstorms is usually highly connected to the geographical area on which they take form (Dávila *et al.*, 1978). Since then, in other places on the Peninsula, analogous results have been ıound (Sánchez and Castro, 1990; Sánchez *et al.*, 1986, 1988; Castro and Sánchez, 1990; Castro *et al.*, 1989, 1990, 1991). For these reasons, one of the first aims of the current programme was the determination of geographical areas more inclined to the formation of storms.

The determination of these areas can be carried out with the help of a radar. In our case from 1989 to 1992, we used a digitized C band radar, which has allowed us to achieve this aim as well as to determine some characteristics of the summer storms.

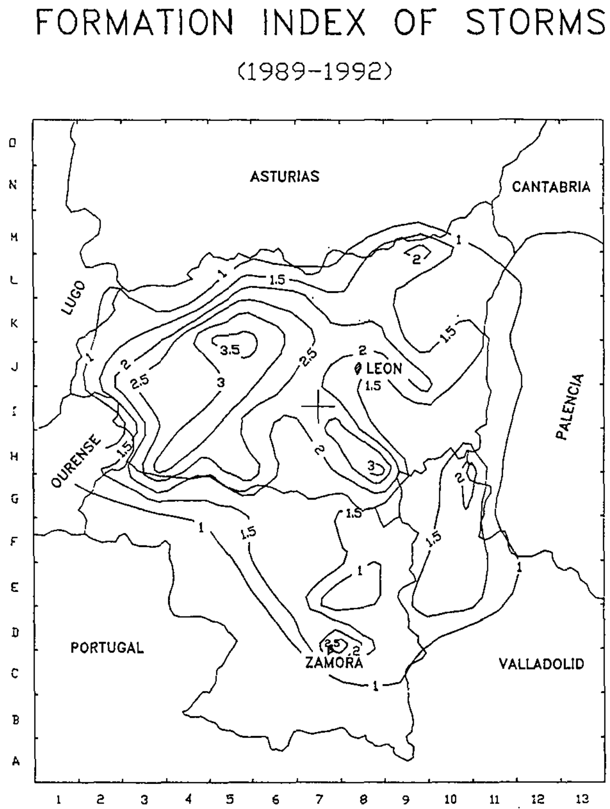

Fig. 2: Spatial distribution of the storms' formation indexes.

2.2 Storm Formation Climatology

2.2.1 Formation index. In a previous paper (Sánchez *et al.*, 1985), a dimensionless index was defined. The index shows the areas with a higher probability of storm formation. The value of the index is expressed in such a way that the higher the index, the higher the risk of the formation of storms in that area. In order to do that, we have established over the provinces of Léon and Zamora, as well as the bordering areas, a grid of 169 squares of 20 km on a side. Figure 2 shows isolines of the spatial distribution of this index in the period between 1989 and 1992, with a sample of 769 storms. The results show that there are basically:

1) An area of about 20 squares which goes from map index H3 to K6 in which, in comparative terms, the formation of storms is very frequent. This area corresponds with a mountainous area formed by various ranges with heights that, in some cases, go beyond 2000 m.

2) Two small areas associated with squares H8 and D7 which also have high index values without, in this case, any relevant reason from the geographical point of view.

2.2.2 Storm trajectories. With the help of the information supplied by the radar, we have calculated the trajectories of the storms which caused severe precipitation over the target area shown in Fig. 1. The trajectories were classified into 16 different directions and the results are shown in Fig. 3. The most frequent trajectories are the ones that

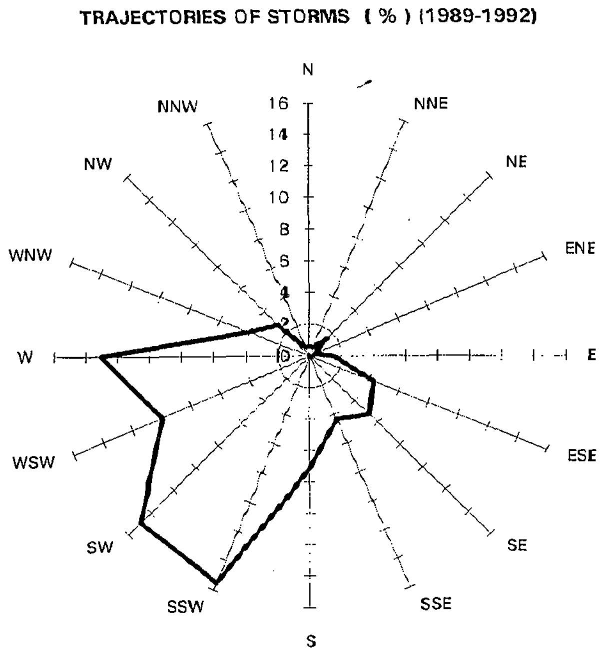

Fig. 3: Trajectories followed by the storms and calculated with the help of the meteorological radar.

have components of the third quadrant (W, WSW, SW, SSW, S). It is proper to bring out that 13% of the storms were stationary.

Taking into account the number of hail days recorded in the summers of 1986-1992 (Fig. 4), we can interpret that

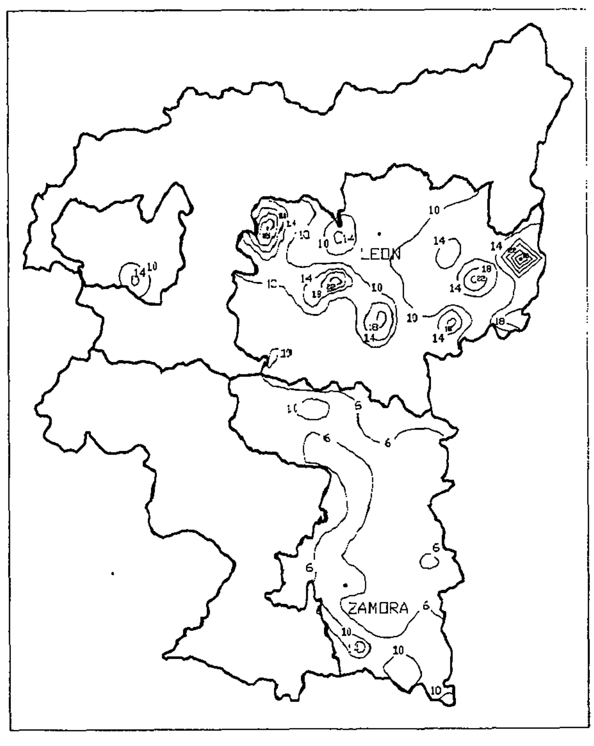

Fig. 4: Spatial distribution of the total number of days in which have been recorded hail on the ground in summer (1986-1992).

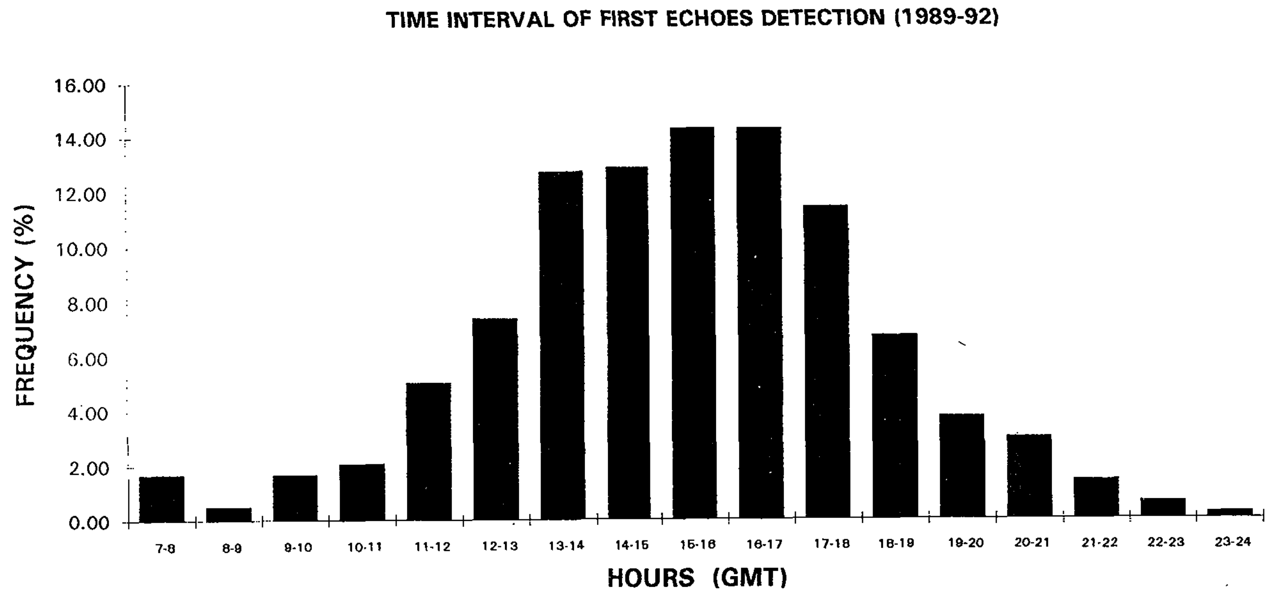

Fig. 5: Time interval of storms' formation.

many storms generated in the high index areas referred to in section 2.2.1 follow trajectories that give rise to the occurrence of hail in the regions with higher agrarian production and cause important economic losses.

2.2.3 *Time interval of storms' formation.* In Fig. 5, we have represented the fraction of storms formed in each time interval. Almost 80 percent of the storms form between 10 and 18 hours, with a sharp decrease after 18 hours; few storms form at night.

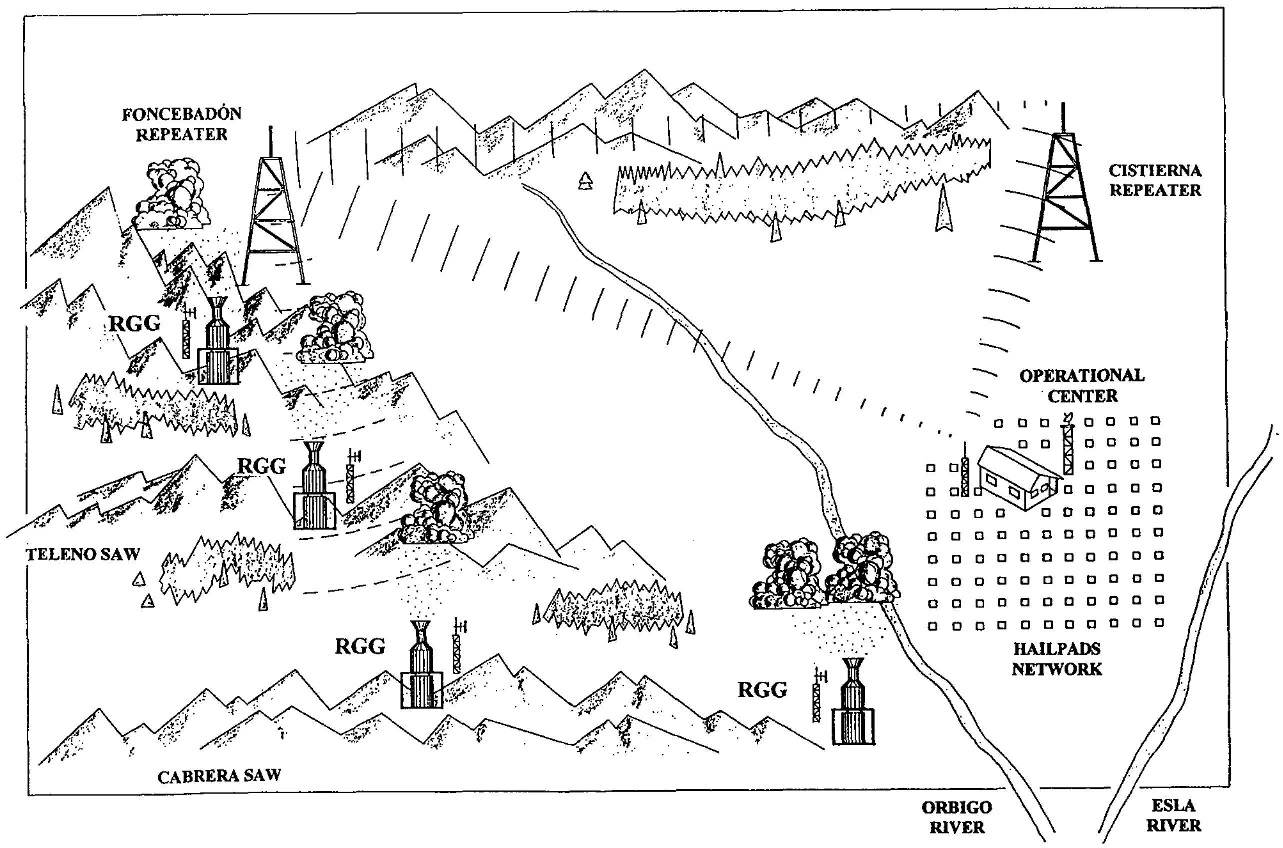

Fig. 6: Schematic operation of the generator network: the central station, two signal repeaters, and the RGG which are the nuclei generators.

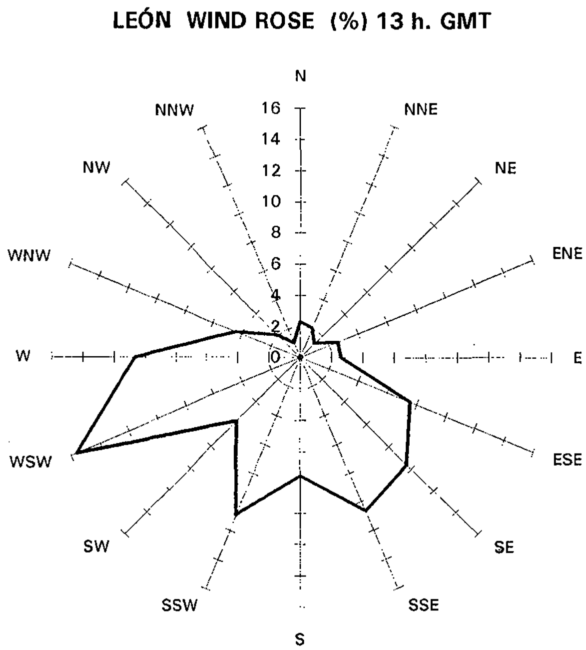

Fig. 7: Wind rose of the low levels corresponding to a historic series of 25 years and calculated starting from the data obtained in the days in which storms were recorded.

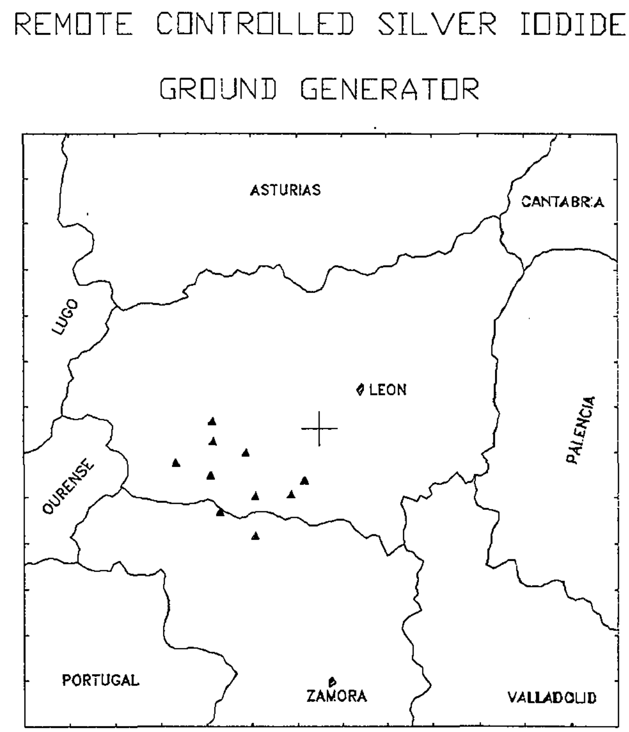

Fig. 8: Location of the 10 automatic generators.

3. DESCRIPTION OF THE SEEDING SYSTEM

3.1 General Criteria for the Selection of the Seeding System

The target area to which we have referred in Fig. 1 is a geographically flat area but very close to the mountainous ranges, where navigation aids are not enough to be able to guide seeding from airplanes with security guarantees. Taking into account that cloud seeding projects elsewhere in Spain (Dessens, 1986; ANELFA, 1993), and in a good part of eastern Europe, use ground generators, and that especially in France they have much experience in the effectiveness of ground generators, the PALA sponsors selected this system. According to the climatologic study, from the radar data, the storms form mainly in the mountainous areas close to the target area. Since these sites are remote and not close to populated areas, it was necessary to set up a network of automatic ground generators controlled by radio signals.

3.2 Characteristics of Remote Ground Generator Network

After various tests, we decided to select the model RG288-A/P made by Atmospherics, Inc., using a system of communications based on Motorola Intrac 2000 System equipment. In this way and by means of a system of signal boosters, the operation is controlled from the central station. In Fig. 6, we show schematically the operation of the network.

The maker showed us some nucleation yields that *a priori* seemed satisfactory for our aims. Nevertheless, with the help of a cloud chamber, we checked that they were accurate and obtained the values that are shown in Table 1.

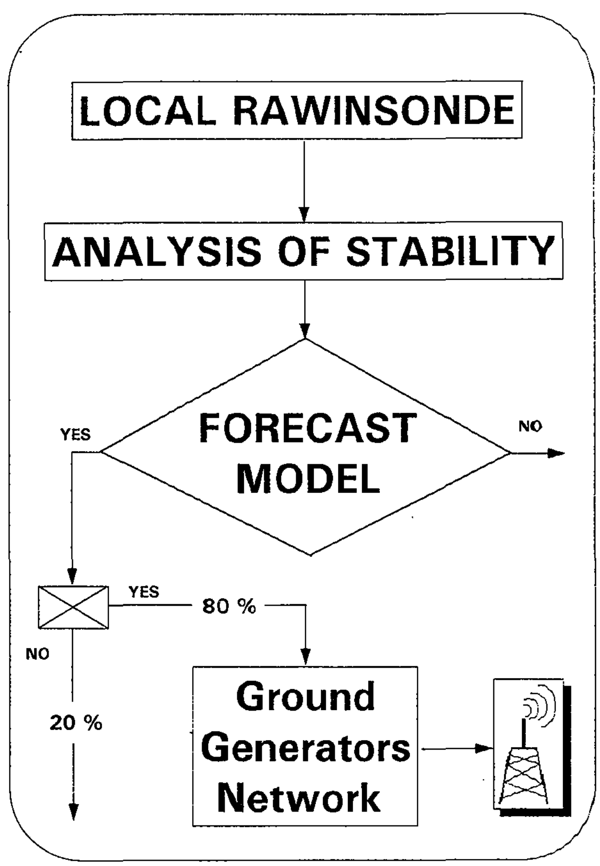

Fig. 9: Scheme of the methodology followed in order to declare seeding or non-seeding days.

TABLE 1

Formation of Ice Crystals Per Gram of Nucleant for AgI Aerosols Produced by Combustion of 1.2 AgI, Acetone

Cloud Temperature (°C)	-8	-13	-17
Yield (Crystal/g AgI)	10^{12}	$2*10^{14}$	$9*10^{14}$

3.3 Selection of the Priority Area

The chosen seeding system has two basic determinants:

a) The seeding system must work provided that there is enough warming of the lower level cumulus clouds to transport nucleant material towards higher atmospheric levels. It implies, in practice, an operation time of 6 or 7 hours more or less, that is to say from 10 (Z) to 17 (Z).

b) The trajectory of the plume of the nucleant material formed at the end of the stack of the generator is determined by the horizontal component of the wind. Taking into account that the directions of the winds in the low levels in the target area (Fig. 7) fall in the third quadrant in a majority of cases, the PALA managers decided to give priority protection to the area on which the agrarian production is higher, with irrigated crops more sensitive to the falling of hail. The said area, shown in Fig. 8, has an extent of more or less 5000 km^2. This priority area is smaller than the target area, and an objective for the future is the progressive increasing of the area until both coincide.

3.4 Location of the Generators

From the beginning, one of the PALA aims has been to be able to establish an evaluation of the seeding. In section 2 and especially in the analysis of Fig. 3, we showed that the hailstorms are generated mainly in a mountainous area. That is why we decided to seed exclusively from that area, trying to increase significantly the number of ice nuclei in these areas where a high number of storms are formed. That is to say, the aim is to introduce into the environment of the surface layer of air a high concentration of ice nuclei in order to ensure that the storms that will be formed ingest significant amounts of nuclei. Thus it will be possible to say that they have been seeded with the aim of increasing the beneficial competition.

We established a network of 10 automatic generators taking into account:

a) The characteristics of the plumes of the nucleant material in various conditions of atmospheric stability, which affect the dispersion of the nucleant material and the characteristics of the emission.

b) The number of active AgI nuclei that the generator is able to produce with the solution in use.

c) The geographic situation of the priority area to be protected and the area of formation of storms (Figs. 2 and 8).

d) The need for the significant increase of the concentration of ice nuclei mainly in the area of formation of storms.

In Fig. 8, we have the location of the generators that are placed at elevations which range from a high of 2050 m to a low of 900 m.

4. METHODOLOGY FOR THE SEEDING ACTIONS

The seeding system chosen needs a short-term prediction system that will be reliable. Early in the morning, we launch a radio sounding. Based on the data received, we evaluate with a prediction model (de la Fuente, 1993) the probability of hailfall in the priority area. The model uses discriminant analysis as a statistical procedure, which allows us to obtain a criterion for classification of risk situations of having or not hailfalls.

Following the scheme in Fig. 9, we can see that once a hail producing condition is predicted, in 80% of the cases we proceed to activate the system of generation of freezing nuclei. The remaining 20% is used to obtain a natural storm evolution pattern, that is to say, a control series, and in this way to be able to establish the effectiveness of the system.

The knowledge of the activity at the ground is acquired by means of:

1) A network of more than 500 meteorological observers that send a card daily with observations.

2) A network of 250 hailpads, each representing 4 km^2 of area.

3) A network of 50 pluviometers.

The trajectories and the characteristics of the storms are determined through the information given by the radar and by means of the analysis of the Meteosat PDUS images.

5. DISCUSSION ABOUT THE SEEDING ACTIONS FOR THE PRIORITY AREA OF PROTECTION

With the seeding system chosen, that is to say ground generators, we are inserting "on many occasions" the ice nuclei in the low levels somewhat like seeding of clouds in the base. In contrast with the placing of the ANELFA generators in France, where the goal is to keep a concentration of ice nuclei constant in the entire area of protection, we have carried out a previous study to locate the AgI generators in the places that have been considered more advantageous from the point of view of the formation of storms. Depending on the results that we are measuring, we will carry on with this location or it will be complemented by the installation of additional generators.

The determination of the "defended area" is not easy since after setting up the existing generator network, we can find some storms that follow trajectories in such a way that they do not pass over the priority area. When this happens, the defended area is not the priority area of protection. On the other hand, we can have storms which form in areas located south of the operational area, where there are no generators for the seeding nuclei, and then more over the area to be protected. We can also find that during the time of operation of the generators there have been been storms that have given rise to hailfalls, but still storms with hail will be registered in the agrarian areas.

In order to establish if the storms that cause precipitation in the priority area of proection were seeded by means of our system of hail suppression, we need a day-by-day, hour-by-hour analysis, both of the activity registered on the gound and of the characteristics of the formed storms. The creation of this data base will allow us to establish an adequate evaluation of the effectiveness of the designed hail suppression system.

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