COMPARISON OF RAINWATER SILVER CONCENTRATIONS FROM SEEDED AND NON-SEEDED DAYS IN LEON (SPAIN)

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ABSTRACT: The long-term hail suppression projects arouse the public opinion's interest in the levels of pollution that may be reached in the precipitation. Even though the seeding material that is usually employed is AgI, and in spite of numerous references denying the toxicity of these emissions, it is easy to estimate the amount of AgI in rainwater, and the results obtained reassure the public opinion.
Within the hail suppression project corresponding to the acronym PALA (Plan for Hail Suppression Aims), which has been carried out in León (Spain) since 1986, there is a network of generators giving a total of nearly 200 grams of AgI per hour. 34 rain gages were employed to collect rainwater samples that have then been analyzed to determine the silver concentration. The average concentration on seeding days is 4.6 ppb, which is well below toxic concentration levels.

1. INTRODUCTION

Hail suppression activities are usually designed to be carried out over a period of many years, and the amount of AgI employed for seeding purposes may be significant. In areas where AgI has been released by ground generators for several years, it is advisable to measure the silver concentration present in the rainwater falling in that area.

Standler and Vonnegut (1972) and Howell (1977) raised a discussion about the possible effects of cloud seeding on human health in their articles, which are still prevailing. Several measurements carried out by other authors in various Weather Modification Projects were mentioned in these articles, and they all pointed out that the concentrations found were extremely low in comparison with toxic concentrations. More recent documents, like the one published by the WMO (1996) insist on the non-existent toxic impact of the Ag seeding procedures for Weather Modification purposes. There is a general consensus considering that silver concentrations in precipitation from storms seeded with silver iodide do not represent a risk factor for the environment, even in long-term projects (Klein, 1978; Potapov et al., 1996). On top of that it is necessary to consider that if a generator network has been "properly" installed, the concentrations of Ag in the rainwater fallen in the area surrounding the generators should be considerably higher on seeding days than on non-seeding days.

Therefore, the measurement of the Ag concentration in the rainwater helps in detecting whether the AgI emissions have reached the clouds chosen to be seeded. This does not mean, however, that Ag concentrations higher than the background concentration indicate that the AgI has "fulfilled" its function properly. Nevertheless, it can be considered as an additional factor contributing to evaluate whether the ground generator network for seeding aims was properly planned and carried out or not. So, there are references about measurements of Ag concentration in rainwater in the High Plans that indicate that the seeding agents had not been released in the proper locations in and around many "seeded" thunderstorms (Linkletter and Warburton, 1977, Warburton et al., 1982).

A network of automatic generators is being employed since 1986 for PALA (Plan for Hail Suppression Aims), a project that has been developed in León (Spain). The design of the network, especially the location and number of generators, was decided on the basis of the conclusions extracted from a previous climatological analysis (Sánchez et al., 1994).

In the years 1993 and 1994, the concentration of Ag in the rainwater was measured in 34 different places scattered over the target area, some on seeding days, some on non-seeding days. The aim was to establish whether the Ag concentration was significantly higher than the background concentration. This paper contains some results found.

2. EXPERIMENTAL DESIGN

The 10 generators are located as shown in figure 1. They have been installed covering an area of approximately 600 km2. Most of these generators are located outside the zone intended to be protected, because the network design was based on the goal of increasing the number of ice nuclei in the areas of storm formation. Therefore, the aim of the design was to install the generators mostly in those areas, even though in this case they are thus located outside the study zone. Once the storms have started, the winds (the prevailing winds are those with components of the third quadrant) often transport the AgI towards the target area. (Sánchez et al., 1994) The project design has the disadvantage that the winds do not always transport the seeding material into the storms that affect the target area.

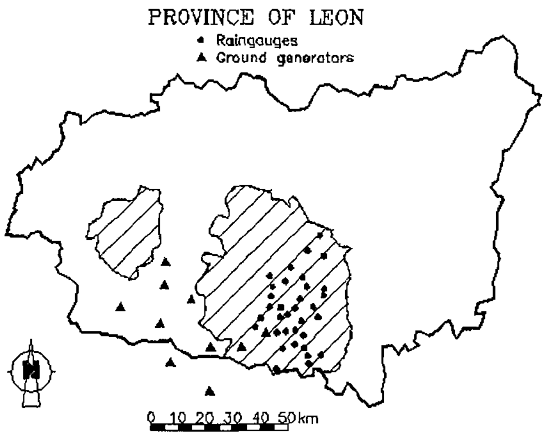

FIGURE 1: The triangles represent the location of each generator employed by PALA. The striped zone represents the protected area. The circles represent the location of the rain gage stations used to collect the samples.

It is important to take into account that this layout was not designed as an operative project. Its main objective is the improvement of our knowledge about the precipitation processes of thunderstorms, and about the changes that hail suppression activities may cause within these thunderstorms. It is thus necessary to gather data about seeding situations and non-seeding situations, to allow the comparison of databases. The layout helps establishing these two data series without too much social pressure on the part of the farmers for not being able to seed all the risk situations.

The use of the 10 generators forming a network installed in León leads to a total network emission of approximately 200 grams of AgI per hour, which means that 1,5 kg of AgI are given out on every seeding day.

Ag concentrations in rainwater superior to 50 ppm may have negative effects (U.S. Public Health Service). Thus, rainwater samples were taken in different parts of the target area. 34 rain gages were distributed to a number of volunteers, who situated them in different places within the target area to collect precipitation samples. Figure 1 shows the location of the 34 rain gages employed for taking rain samples. The different rain gauges are situated at a distance of between 5 and several tens of kilometers from the generators.

Every gage was inspected daily, and it was carefully cleaned and dried, to prevent pollution coming from the dry aerosol deposition that Ag compounds may contain. Once the precipitation had taken place (solid or liquid) it was poured into sterilized jars, and later put into a freezer. The volunteers stored the samples, and the PALA staff collected them regularly.

The samples were measured in a specialized laboratory of the Environmental Department of the Regional Authorities (Junta de Castilla y León). An atomic-absorption spectrometer was used, equipped with a graphite furnace. The samples were analyzed very carefully following the routines of the atomic absorption methods: drying for solvent evaporation, charring for matrix elimination, atomization for free atom formation and cleaning to remove the last traces of sample (Lacaux, 1972).

3. RESULTS AND DISCUSSION

Due to the fact that the land on which the generators were situated was rather mountainous, the plumes followed complex trajectories. Thus, it is important to be very cautious with any statement in this field. Nevertheless, if the precipitation caused by the most common storms in this territory is approximately of 10^4 or 10^5 m^3, with the network design established it would be unlikely that a storm could be seeded with more than 50 or 100 g of Ag. This means that the maximum Ag concentration that may be found in the rainwater should not exceed 0.5 or 1 ppm.

The analyzed samples correspond to those places where a precipitation of over 10ml was registered (corresponding to 2 mm precipitation). 10ml was the minimum established by the Laboratory of the Environmental Department for the sample to be analyzed with a guarantee of high accuracy.

Due to the fact that PALA employs a randomized seeding system, 147 valid samples were collected for analysis. 88 were obtained during seeding days and 59 during non-seeding days. These samples were taken on 34 different days.

The authors would like to point out that the stratification of the data has not taken into account other factors such as whether the plumes of the different generators approached the storms that precipitated over the target area or not. The main objective was to measure the Ag concentration found in the rainwater collected during those 34 days.

Finally, it is necessary to point out that in all cases the samples of rainwater collected were registered during the months of June, July and August, which are months during which the precipitation comes mainly from thunderstorms or hailstorms.

Table 1 shows the results found for seeding situations and non-seeding situations.

The Kruskall-Wallis test was applied to establish whether the samples belonged to the same distribution or to two different ones. The results show that for the significance level $\alpha=0.01$ they belong to two different distributions.

Besides the results shown in table 1, the following points should be highlighted:

1. The average Ag concentration in rainwater on seeding days, taking into account all the rain gauges, is 3.2 times the concentration found on non-seeding days. The seeding material obviously leaves a trace in the rainwater. The layout of the generator network is thus consistent with the hypothesis that the seeding material appears in the precipitation collected in the protected area. There were 15 cases in which the Ag concentration found was below the minimum that can be detected (established in 0.1 ppb). The fact that 9 of these cases took place in seeding situations is not unexpected, for the layout of the generators does not guarantee that all the storms are actually seeded.
2. The maximum value found on seeding days - 157.7 ppb - is almost 9 times the maximum value found on non-seeding days. This finding might be expected. But what draws out attention is the fact that in both cases the samples were collected by rain gages located at a great distance from the western border of the area.
3. The Ag concentrations found in rainwater collected on non-seeding days are relatively high on average. This may be due to the fact that the atmosphere is not able to purify itself quickly from the AgI given out on seeding days. There is another possible explanation for this fact, namely the daily testing of the generators. All generators were working daily for approximately 15 - 20 minutes, even on non-seeding days, to test their correct performance. This small emission given out by the whole network (hardly 60 or 70 g of AgI) may leave a detectable trace in the rainwater.
4. Taking into account the fact that the Ag concentration required to be considered polluting should be around 50 ppm, we may conclude that not even in the worst of all cases have the concentrations reached these limits.

Variable	Seeded (ppb)	Unseeded (ppb)
Mean	14.8	4.6
Std	26.22	5.1
Max	157.7	18.4
Median	4.2	3.4
No. of times undetectable	9	6
No. of valid samples	88	59

Table 1: Statistical values for thunderstorms seeded and unseeded (see text)

CONCLUSIONS

With concentrations so far below the established limits any toxicity problem that could be attributed to the Ag emissions can be ruled out. Even if a person should drink the rainwater of the seeded storms without mixing it with any other water not containing this element, he or she would be completely safe. This result is similar to those found by Teller et al, (1976) in the San Juan Mountains (Colorado), Warburton (1973) in Alberta, Canada, and Super and Huggins (1992) in Utah.

And it reinforces the view that cloud seeding activities do not lead to toxic Ag concentrations in rainwater.

The Ag concentrations in the rainwater samples collected on seeding days strengthen the main idea of other research projects that have already been published. The Ag concentrations in the rainwater samples collected on seeding days follow a different distribution than the concentrations found on non-seeding days. This fact reinforces the idea that the AgI emissions are reaching the storms according to the hypothesis established in the project design. (Sanchez et al, 1994; Dessens et al, 1998).

ACKNOWLEDGEMENTS

This work is based on a project supported by the Junta de Castilla y León (Spain). The authors want to thank José Miguel González for his helpful comments, the laboratory of the Environmental Department of the Regional Authorities (Junta de Castilla y León) for the facilities supplied, and Noelia Ramón for her help in translating the final version of this paper.

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