"REVIEWED"

CLOUD SEEDING SOUTHEAST OF MEXICO CITY, 1974-76

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Silver iodide was emitted from ten burners from 09 to 13 CST on about half the days, randomly selected before the start of the five-month rainy season, June-October, south and southeast of Mexico City in 1974, 1975 and 1976. Five burners were of voltiac arc type, operating at approximately 2500 C; the other five used butane gas, burning at about 1,000 C. Neither type was calibrated, so no information is available on their output of freezing nuclei. On each seeded day, an average of seven burners operated, consuming 0.24 kg of AgI per day.

The Comision de Aguas del Valle de Mexico referred to its project as in the Sierra de Chichinautizin, a major mountain range southeast of Mexico City, culminating in Popocateptel and Ixrlzihautl two snowcovered volcanoes reaching more than 5 km above sea level and 3 km above the Valley of Mexico. The present evaluation of the project, based on rank sums of precipitation totals, reaches conclusions different from those of the Comision (1979).

The 35,000 km^2 target area was divided into six zones (Fig. 1). Zone I included the mountains south of Mexico City and contained six of the ten burners. Two each were close by in Zones II, just to the east, and III, to the south. Zones IV, including Mexico City, was to the north, V to the west, and VI to the east, beyond Zone II. The six zones contained 9, 3, 18, 10, 6, and 10 raingages, respectively. The present analysis is based on the daily means of the 9 gages in Zone I, and of all 56 gages, on seeded and unseeded days.

The design and operation of the project involved many hoptheses:

a. All clouds over the target are supercooled and hence will respond to silver iodide seeding;

b. Despite the presence of the two snowcovered volcanoes, natural freezing nuclei are very scare in the target area, so that almost all precipitation comes from a Wegener-Bergeron three-phase process;

c. Silver iodide ice nuclei, produced at the ground, are dispersed by winds throughout the six target zones in adequate concentrations;

d. Photolytic decay of the silver iodide nuclei, even in strong sunlight, is unimportant;

e. Silver iodide nuclei do not persist from a seeded day to the next one, possibly unseeded;

f. The silver iodide nuclei reach the clouds in adequate concentrations to affect their colloidal structure;

g. Meteorological conditions are the same on seeded and unseeded days;

h. Each of several rainy periods during a seeded day is equally affected by the silver iodide;

i. Tropical cyclones and hurricanes do not affect the target area, even though it is only 328 km from the Gulf of Mexico and 411 from the Pacific Ocean;

j. All target area clouds need the same numbers of artificial ice nuclei;

k. Silver iodide nuclei reach clouds and are effective within the target area, and are not carried outside by winds.

Most of these hypotheses cannot be tested, for lack of data. Only the most available information, the 24-hour catch of each raingage, is used in this report. Effects of ten tropical cyclones did reach the target area, but are not considered specifically here.

Average 24-hour precipitation for all 9 gages in Zone I (Table 1.) and of all 56 gages in all six zones, was obtained for each of the 153 days during each of the three rain seasons. These daily means were then ranked and subjected to the Mann-Whitney U-test (Siegel, 1956) for each year, for pairs of years, and for all three years combined (Table 2). The hypothesis that the distributions of rainfall amounts on seeded days did not differ from that on unseeded days was rejected at the 5% significance level, for 1974 and 1975. In those years the seeded day ranks exceeded those of unseeded days. For further investigation the simple ratio of mean precipitation on seeded and unseeded days in each year was computed. Only in 1976 was the ratio less than unity (Table 1.) but this was not found to be significant at the 5% level for that year.

The ratios were evaluated by permutation ("rerandomization") procedures. All days of a given rainy season were combined into a single sample which was then randomly divided into two parts, arbitrarily called "seeded" and "unseeded", and the ratio taken. After this had been done 100 or more times, the distribution of the resulting ratios were tabulated (Table 3.), and used to evaluate the actual observed ratio. In 1974 and 1975 the positive departures from unity are significant at the 5% level, and in 1976 the ratio difference from unity was so small it could have been accidental.

According to Neyman's criterion (Neyman and Scott, 1967), the power of the ratio test based on all three years combined is only 0.40, and a total of nineteen years would be needed to obtain significant results. Although the results are somewhat conflicting, the significance of the Mann-Whitney test in 1974 and 1975 does suggest positive results

with a ratio of 1.21 for the seeded/unseeded means of all years combined.

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TABLE 1.

RAINFALL AMOUNTS ON SEEDED AND UNSEEDED DAYS IN ZONE I

		1974	1975	1976
Days without rain, JUN-OCT		21	29	19
Days with mean rain > (mm.)	10	26	19	30
	20	5	1	9
	30	1	0	2
Tropical cyclones affecting Zone I		5	4	1
Number of days	seeded	70	76	78
	unseeded	83	77	75
Mean rain at 9 gages (mm.)	seeded	6.72	5.24	5.98
	unseeded	3.82	3.85	7.22
	total	5.14	4.54	6.59
Ratio, seeded mean/unseeded mean		1.76	1.36	0.83
Standard deviation	seeded	5.40	4.12	5.52
	unseeded	4.60	4.27	9.43
	total	6.06	4.51	8.37

TABLE 2.

RESULTS OF RANK SUM TESTS. (* indicates significance at 5% level)

	ZONE I				ALL ZONES			
	Rank Sums		Results		Rank Sums		Results	
YEARS	Seed	Not	U	Z	Seed	Not	U	Z
1974	6 235.0	5 546.0	2 060.0	-3.09*	5 812.0	5 969.0	2 364.0	-1.95*
1975	6 124.5	5 556.5	2 653.5	-1.00	5 898.5	5 882.5	2 879.5	-0.171
1976	5 904.0	5 877.0	2 785.0	-0.51	5 990.5	5 790.5	2 871.5	-0.197
1974+1975	24 632.5	22 338.5	9 458.5	-2.88*	23 383.5	23 587.5	10 473.5	-1.55
1974+1976	24 230.0	22 741.0	10 180.0	-1.96*	23 632.0	23 339.0	10 545.0	-1.47
1975+1976	24 044.5	22 926.5	11 293.5	-0.52	23 666.5	23 304.5	11 676.5	-0.36
All Years	54 643.5	50 926.5	23 196.5	-2.20*	52 981.0	52 589.0	24 511.0	-1.27

THE PRECIPITATION ENHANCEMENT PROJECT OF THE WORLD METEOROLOGICAL ORGANIZATION, PROGRAM AND PROGRESS

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ABSTRACT. In the first half of 1981 the Precipitation Enhancement Project, PEP of WMO will be in the third year of its Site Selection Phase in the Duero River basin centered about Valladolid, Spain. The purpose of this field investigation is to establish if the clouds and cloud systems are suitable for seeding to enhance precipitation, and if they occur frequently enough. The basic goals of PEP are discussed and an up-to-date view is presented on the status of the operation.

1. INTRODUCTION

The Seventh World Meteorological Congress in 1975 agreed that the time had come to embark upon an internationally planned, executed and evaluated experiment in artificial precipitation augmentation, and approved the WMO Precipitation Enhancement Project (PEP). The Eighth Congress in 1979 endorsed the more detailed plans for PEP dealing with the continuation of the field measurement program of the Site Selection Phase 3 (SSP-3) and the preparation for the seeding experiment, should the site in Spain be found suitable. It allocated substantial funds for management, scientific planning and international coordination. Thereby, it has to be remembered, that WMO carries out large projects with the help of resources committed and scientists seconded by its Members, i.e. the different national weather services.

The objectives of PEP are listed in Appendix A. They were discussed by List (1976), who also gave background and progress in planning in the early stages of this international venture.

PEP consists of three phases. They are:

Site selection;
The seeding experiment;
Evaluation.

The selection of the site for conducting the main (seeding) experiment, the second part of PEP, has always been regarded as crucial to the whole project. It must take account of the major aim of PEP, which is to demonstrate at a statistically significant level whether precipitation at the ground can be increased or not over an area where it would also provide economic benefits.

After an initial selection of the more promising six sites (in Algeria, Australia, India, Spain, Tunisia and Turkey) from among 16 originally proposed, numerical simulation experiments were carried out on the basis of rainfall data. Their purpose was to establish if a hypothetical increase in rainfall of 10 to 20% would be detectable above the natural local precipitation variability, as evident from the records over the previous ten or more years. The Commonwealth Scientific and Industrial Research Organization of Australia performed these experiments.

In the light of the results, together with visits to proposed sites and climatological studies, WMO Executive Committee Panel of Experts on Weather Modification reached the conclusion that the sites in Australia and Spain best met the conditions required for the PEP experiment. Because no substantial resources could be made available for a study of the Australian site, SSP-3 was limited to Spain by the PEP Board. This led to the third stage in Spain of the site-selection phase which is aimed at establishing if the clouds over the proposed site are suitable for seeding and whether they occur frequently enough to warrant expectations of a detectable and significant precipitation increase. To do this requires an intensive on-site cloud and cloud microphysics investigation extending over two or three years. Such a study is now under way.

The Plan for PEP appeared as WMO PEP Report No. 3 in 1976, whereas the Operations Plan for SSP 3 appeared as No. 11 in 1978. The PEP Design Document is Report No. 9 (1978). These are the key planning documents which were laid out by the Panel, the Scientific Planning Group at the WMO Secretariat, together with seconded scientists from all over the world. Important detailed aspects of PEP were studied (and are continued to be studied) by groups of experts and led to other documents (see Appendix B) related to precipitation enhancement. (WMO's documentation of its programs and their progress is also important to its Members, because of the value of expert and technical advise).

2. THE SITE-SELECTION PHASE, STAGE 3.

The Spanish site is located in the northwestern part of the country in the Duero River basin. The city of Valladolid (population about 240,000) is near the center of the area; the field headquarters is installed at the local airport (Figure 1). The precipitation climatology can be summarized as follows for the period January to May (when precipitation enhancement is considered): Monthly average of precipitation 44mm, number of days with precipitation in Valladolid 10, in Salamanca 9; days per month with low or middle clouds 25, days with clouds of vertical development 6. For further details see PEP Report 10.