Note on Cloud Seeding Evaluation with Hourly Precipitation Data

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1. Introduction

The basic precipitation data of the Santa Barbara Weather Modification Project consists of numerous recording rain gage records which were collected by the California State Water Resources Department from an extensive network maintained by them during the months of January through April in the years of 1957 through 1960. These data were reduced by them to tabulations of hourly amounts, although in the statistical evaluation itself, appearing in the official report,[1] and in an article by Neyman *et al.* (1960), only 12-hr (10 a.m. to 10 p.m. and 10 p.m. to 10 a.m.) units of observation were employed in the years 1957 through 1959. In 1960 (not reported upon), storm length units of observation were used. Twelve-hour units of seeding and of no seeding (of seedable storms) was an essential part of the 1957–1959 design; whereas, in 1960, whole seedable storms were seeded or not seeded. In all four years the seeding was randomized separately in Santa Barbara and Ventura counties, except that Ventura was not seeded at all in 1957 and was seeded on every opportunity in 1958.

The question arises: will an analysis of the hourly

[1] State of California, Department of Water Resources, 1960: Santa Barbara weather modification interim report of the board of directors. Sacramento, Calif., 143 pp.

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data reveal more information than did that of the 12-hourly data? Although, in the case of the 12-hourly data, there was approximately 45 per cent more precipitation in the target when there was any seeding than when there was no seeding whatsoever, the difference was not significant at the 5 per cent level. It was estimated that it would take 9 years of testing with the existing design before significance would be achieved, assuming a 50 per cent increase. It is felt that the hourly data can be employed to isolate the time of maximum possible effect of the seeding and thus to increase the sensitivity of the test.

Aerial sampling[2] of winter storms in the Santa Barbara area has shown that the concentration of supercooled cloud water is greatest in those parts of the storm where vertical upward motion is concentrated, and where precipitation rates are highest. Another feature is that convective overturning is also frequently found there. One should therefore expect cloud seeding to be most effective in these regions largely because of the presence of the greater abundance of supercooled water at temperatures where silver iodide smoke particles can serve as effective nuclei; but also because of the strong upward motion, particularly if it is associated with convection, which leads to the rapid entrainment and the necessary dilution of silver iodide smoke from low level sources.

2. Data treatment

The hourly gage records were analyzed by comparing the hourly precipitation amounts for seeded and non-seeded hours at the time of the peak hourly rate, and separately for each of the 3 hours preceding and the 3 hours following the peak. In some cases, the outlying hours fell outside of the seeded or the non-seeded period and were not used. In the case of double peaks, the first was used. The 1960 data were included, but due to drought conditions in that year, there were very few cases.

The four categories of seeding opportunities were:

(i) No seeding in either county;
(ii) Seeding in Santa Barbara, but no seeding in Ventura;
(iii) No seeding in Santa Barbara, but seeding in Ventura;
(iv) Seeding in both counties.

The four target stations employed in this analysis were those with the most complete project records which could represent each of the following four physically significant divisions of the target area (see Fig. 1):

(i) Back Range (Station: Cachuma Saddle)—a range with highest elevations of 4000 to 6000, oriented E–W and parallel to the coast, located approximately 20 mi north of the coast line.
(ii) Santa Ynez Valley (Station: Gibraltar Dam)—a narrow low level valley between the Back Range and the Coastal Range.
(iii) Santa Ynez Range (Station: TV Peak)—a coastal ridge with elevations of 3500–4000 ft, oriented E–W and parallel to the coast, located approximately 5 mi north of the coast.
(iv) Coastal Plain (Station: Carpinteria) a narrow flat plain between the coast and the Santa Ynez Range.

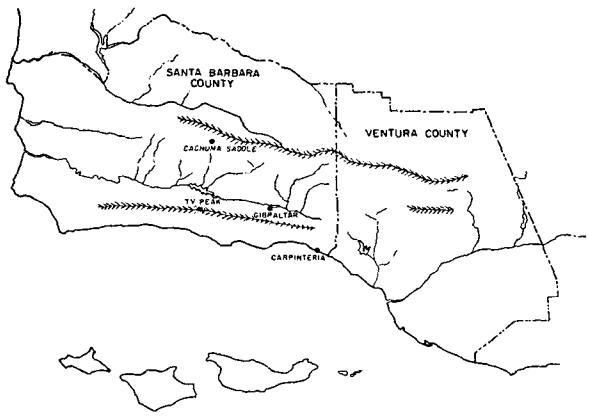

FIG. 1. Santa Barbara—Ventura County area and station locations.

In the process of computing averages of the hourly precipitation rates over all cases for each station and each seeding category, it was found that: first, there was almost no difference between the rates for the three mountain stations; and second, there was almost no difference between the rates for categories ii, iii, and iv. This indicated that if seeding was effective, then there was no difference between the effects of the Ventura County and Santa Barbara County generators at these stations. For this reason, the mountain stations and these categories were combined in computing the average rates that are shown in Table 1. Because of the fact that not all stations recorded during all storms, there were slightly different numbers of cases involved at different stations. At peak hour there were 10 to 11 cases per station for category i, and from 29 to 54 cases per station in the combined ii, iii, and iv categories.

From the table it is seen that for the peak hour, the seeded rate is 87 per cent higher than that of the non-seeded rate in the mountains, and is only 43 per cent higher in the coastal plain. The net difference in the rates between the seeded and non-seeded cases, which is the important item from the physical viewpoint, is by far the greatest at the peak hour in both areas.

[2] Elliott, R. D., and E. L. Hovind, 1961: Investigation of cloud-water budget of Pacific storms, second interim report to National Science Foundation. Aerometric Research Inc., Santa Barbara, Calif., 94 pp.

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TABLE 1. Average hourly precipitation rates (inches per hour) for various categories.

Category	Hour: −3h	−2h	−1h	Peak	+1h	+2h	+3h
Mountain i	.026	.052	.070	.163	.068	.045	.021
Mountain ii, iii, iv	.096	.107	.175	.304	.161	.101	.094
Mountain ii, iii, iv, excluding 1958	.105	.118	.166	.335	.195	.090	.088
Coast i	.051	.014	.041	.126	.034	.007	.010
Coast ii, iii, iv	.047	.066	.089	.180	.087	.056	.045
Coast ii, iii, iv excluding 1958	.057	.080	.110	.200	.092	.043	.040

During 1958 the Ventura generators were used on every opportunity, and because these generators appear to affect the stations studied, strict randomization did not prevail in that year. For this reason, the same computations were performed deleting 1958. These figures are also shown in Table 1. It is seen that the peak seeded rate was more than double the nonseeded rate in the mountains. However, there is little overall change in rates from those obtained when 1958 data are included.

The non-parametric Mann-Whitney U test (Siegel, 1956) was applied to the samples of seeded and non-seeded values (excluding 1958) at individual mountain stations for −1h, peak hour, and +1h. The probability that the seeded and non-seeded values were drawn randomly from the same population was less than 5 per cent in 5 out of the 9 cases. These figures are not offered as confirmation of the seeding effect because the intensity analysis was not part of the original design. However, the data suggest that the intensity type of analysis is more sensitive than that employed.

The critical role of air-mass stability in orographic precipitation has been discussed by Elliott and Shaffer (1962) and its role in cloud seeding by Smith (1962). For this reason, the data were divided into stable and unstable cases, employing the catalogue developed by Smith. Striking differences appeared, with the stable cases exhibiting no apparent difference between the seeded and the non-seeded rates while the unstable cases showed a much greater excess of seeded over non-seeded rates than those which appear in Table 1. However, the ratio of mountain to coastal plain precipitation enters into the determination of stability regime and it is therefore difficult to interpret these results.

3. Discussion

The ex-post facto nature of this study must be granted; however, it suggests that in the design of a cloud seeding experiment it may be worthwhile incorporating an intensity type analysis. The indicated increases are considerably higher than the 10 to 15 per cent values arrived at by the Advisory Committee on Weather Control.[3] It is believed that the difference is ascribable, at least partially, to a lower efficiency of the natural precipitation mechanism in Santa Barbara County than in those mountain seeding projects evaluated by the Advisory Committee, which had loftier orographic barriers.

The question may be asked at this point: would a finer-detailed analysis than hourly yield still more information concerning seeding effects? The author believes that precipitation analyses down to the quarter-hour resolution are feasible and that finer scale resolution is possible through the use of an expanded scale on the recorder chart. Furthermore, there appears to be a wealth of meso-scale detail in precipitation records which is glossed over in the hourly-type analysis. Storms exhibit a number of shorter duration precipitation peaks which are associated with moving convection lines embedded in the storm and which are distinct from the main frontal precipitation peak. One would expect seeding to be effective within such bands. On the other hand, between the bands a degree of stability may exist (although the air mass is potentially unstable), such that silver iodide smoke released during these intervals would spread out under the gradient level until entrained by a new band. For example, such a drift in the low level southeasterly flow characterizing most storms in the Santa Barbara area would carry the smoke released in the western part of Ventura County out along the south slope of the coastal range into Santa Barbara County, before entrainment. This could fully account for the effects of the Ventura County generators on the Santa Barbara stations studied.

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[3] Advisory Committee on Weather Control 1957: *Final Report of the Advisory Committee on Weather Control.* Washington, D. C., Vol. 1, 31 pp., Vol. 2., 422 pp. [L. C. Card 58–600.06.]

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