Timing of the Apparent Effects of Cloud Seeding

Abstract. *The average hourly precipitation amounts, on 96 experimental days without cloud seeding in the Whitetop experiment, show a marked maximum between 4 and 7 o'clock in the afternoon, presumably reflecting the convection activity caused by heating of the ground occurring during an earlier period. No such maximum is observed on the 102 days with seeding. The hypothetical explanation presupposes that seeding with silver iodide creates early general cloudiness, which prevents ground temperatures from rising to levels usually attained on days without seeding. This hypothesis may explain not only the mechanism of the loss in rain in the Whitetop experiment, apparently induced by seeding, but also may explain certain phenomena noticed in the Grossversuch III experiment.*

Earlier studies indicated that, through mechanisms that still remain obscure, cloud seeding increases the rainfall in some conditions (*1*) and decreases it (*2*) in others. The understanding of the complex phenomena involved, particularly the apparent widespread decrease in summer rainfall (*2*) on days with seeding, may be advanced through timing of the indicated effects. The availability of recording rain gages in the area of the Whitetop experiment (*3*) (conducted over five summers, 1960 to 1964) offers an unusual opportunity for timing the effect of seeding.

The data used in the calculations reported below are taken from Braham (*4*). Only 24 rain gages were included, namely, those that during the period of experiment were not moved far from their original locations and only those with a reasonably continuous record. The locations of these 24 gages and their distances from the center of the target are given in Table 1. The first 13 of the gages are those installed by Braham. The remaining 11 are gages of the U.S. Weather Bureau. All the calculations reported refer to amounts of precipitation averaged from the 24 stations listed in Table 1.

The results obtained are summarized in Fig. 1. Of the two curves, one refers to the 102 days with seeding and the other to the 96 experimental Whitetop days without seeding. The quantity measured on the horizontal axis is the hour from 8 a.m. of the experimental day to 10 a.m. of the next. The quantity measured on the vertical axis is the average precipitation during the hour preceding that against which each given point is plotted. Thus, for example, the points on the two curves plotted against 8 a.m. represent average amounts of precipitation, seeded and not seeded, fallen between 7 and 8 a.m.

The intended period of seeding in the Whitetop experiment was 6 hours. In 1960 and 1961 the seeding commenced at 11 a.m. In the other 3 years it commenced at 10 a.m. Thus, the points of the two curves in Fig. 1 corresponding to 8, 9, and 10 a.m. are not affected by seeding on the given day and refer to two random samples from the same population of days. The differences between the two curves over these 3 hours are due to the variability of rainfall, probably affected by the circumstances of the preceding day, which could have been either nonexperimental, experimental without seeding, or experimental with seeding. The period of these 3 hours, ending at 10 a.m., will be denoted by T_0 and described as the pretreatment period.

Inspection of Fig. 1 indicates the desirability of distinguishing the periods of time: T_1 from 11 a.m. to 2 p.m. of the given day, period T_2 from 3 p.m. to perhaps 8 p.m., period T_3 from 9 p.m. to 1 a.m. of the next day, period T_4 from 2 to 6 a.m. of the next day, and period T_5 from 7 a.m. of the next day to 10 a.m.

Period T_1, composed of 4 hours during which some effect of seeding might be expected, shows no sign of any such effect. On the other hand, a strong effect of seeding is apparent during T_2 (from 3 to 8 p.m.). The curve corresponding to days without seeding rises to a strong maximum at 5 to 6 p.m. and then declines. Apart from a dip at 3 p.m., the curve corresponding to days with seeding is generally parallel but substantially below the "nonseeded" curve. The 5 to 6 p.m. maximum of the natural precipitation is commonly attributed to the convection cumuli, initiated by the heating of the ground during the preceding several hours. The absence of such pronounced maximum of precipitation on seeded days deserves notice.

During period T_3, the two curves are rather close together, but the "seeded" curve is steadily below that "not seeded." In period T_4 (from 2 to 6 a.m. of the next day), the two curves crisscross and we have the impression of no effect of seeding. On the other hand, the final period T_5 appears suggestive of a mild aftereffect of seeding: the two curves are more or less parallel, that corresponding to seeded days being below that for days without seeding.

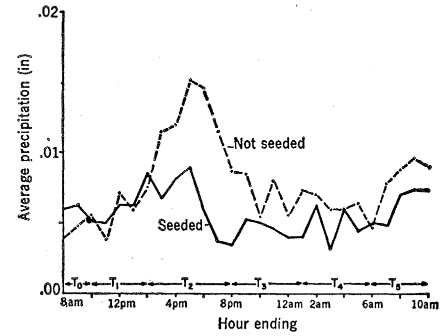

Fig. 1. Average hourly precipitation amounts on days with (102 days) and without (96 days) seeding. Horizontal axis, hour from 8 a.m. of the experimental day to 10 a.m. of the next day. Vertical axis, average precipitation during the hour preceding that against which each given point is plotted.

With the data from Fig. 1, the evaluation of the average 24-hour precipitation amounts, seeded and not seeded, was performed, covering the period from 10 a.m. of one day to 10 a.m. of the next. The results show a decrease in the rainfall of 28 percent ascribable to seeding. That the effect may be real is suggested by the results of the two-tail test, $P = .155$.

The only mechanism of a decrease

Table 1. List of recording gages used.

Location	Distance from target center (miles)
Alicia, Ark.	67
Alton, Mo.	14
Batesville Livestock, Ark.	65
Bull Shoals Dam, Ark.	57
Marshfield, Mo.	80
Maumee, Ark.	74
Mt. Home C of E, Ark.	50
Norfork Dam, Ark.	48
Tyrone 2 NNW, Mo.	36
Wappapello Dam, Mo.	76
Wasola, Mo.	51
West Plains, Mo.	11
Wheeling, Ark.	32
Birch Tree, Mo.	18
Cabool, Mo.	36
Fremont, Mo.	30
Houston, Mo.	44
Koshkonong, Mo.	10
Mt. View, Mo.	17
Round Spring, Mo.	41
Siloam Springs, Mo.	23
Summersville, Mo.	30
Van Buren, Mo.	39
Vanzant, Mo.	34

in the rainfall, which is occasionally mentioned in the meteorological literature, is that of "overseeding." Ordinarily, it is discounted as a practical impossibility. An alternative hypothesis, informally suggested to us by J. Hughes (*5*), depends upon the presumption that the dispersal of silver iodide smoke causes widespread cloudiness. If this is so, then the ground temperatures at midday and early afternoon on days with seeding are likely to be lower than on days without seeding, with the consequent difference in the cumuli formation in the late afternoon. Primarily, the above explanation applies to period T_2, and the tapering off of the effect in T_3 to zero in T_4 appears as an intuitive possibility. The differences between the seeded and the natural precipitation observed in T_5, amounting to some 20 percent of the latter, are not very large, but the shapes of the two curves in Fig. 1 are suggestive, and the question arises whether the general cloudiness generated by seeding on the preceding day could continue to affect cumuli formation, for example, between 8 and 9 a.m. of the next day.

The hypothesis of early effects of seeding requires confirmation, possibly through cloud-chamber experiments and certainly through the analysis of observations in the free atmosphere. At this time we wish to point out that the hypothesis tends to explain certain of our findings relating to the Swiss experiment Grossversuch III.

Motivated by certain considerations not related to the present problems, we subdivided (*6*) the experimental days of Grossversuch III into three roughly defined categories: days of "incipient" storm periods, days of "middle" storm periods, and days of "dissipating" storms. Because of the tendencies of some experimenters to seed summer clouds ahead of the anticipated period of convection, we expected that the precipitation on incipient storm days with seeding will be much larger than that on days without seeding. To our surprise we found the contrary to be true; for the incipient category the precipitation on seeded days was significantly less than that without seeding. In the middle of the target (zone 3) the indicated loss in the rainfall due to seeding was 62 percent of what might have fallen without seeding ($P = .021$). It is just possible that this phenomenon is a simple consequence of the mechanism hypothesized by Hughes: The seeding from 7:30 a.m. on, in the absence of well-developed clouds, could have created widespread cloud cover that prevented the heating of the ground at midday and thus attenuated the development of cumuli.

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References and Notes

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Mars: Water Vapor in Its Atmosphere

Abstract. *With the use of newly obtained spectrograms of Mars in the region of the water vapor band at 8200 angstroms, we have derived a value of 35 ± 15 microns for the amount of precipitable water in a vertical column in the Martian atmosphere.*

We have made a new determination of the abundance of water in the atmosphere of Mars, based on observations of the planet during February and March 1969. Since the discovery of water vapor lines in the spectrum of Mars (*1*) and their subsequent evaluation (*2*), only one other study of this problem has been reported (*3*). Both sets of observations were obtained at reciprocal dispersions in excess of 4 Å/mm, and in each case the quality of the data was considered to be the limiting factor in the abundance determination. The amount of precipitable water in the Martian atmosphere was found to be about 15 μ in both investigations.

The importance of a reliable determination of the abundance of water vapor cannot be overemphasized. If the Martian atmosphere is the result of crustal outgassing like the atmosphere of Earth, 18 times more water than carbon dioxide by mass may have been evolved, and there are several possible fates for the water (*4*). The suggestion that the polar caps and some of the ground deposits are actually solid carbon dioxide has raised the possibility that earlier estimates of the abundance of atmospheric water vapor might be too large (*5*). Moreover, the amount and distribution of Martian water is important for biological considerations.

To redetermine the amount of atmospheric water, we used the coudé spectrograph of the 82-inch (208-cm) telescope at the McDonald Observatory to record the spectrum of Mars at 2 Å/mm in the region of the 8200-Å water vapor band. The projected slit width varied from 0.020 to 0.030 mm. A preliminary spectrogram obtained

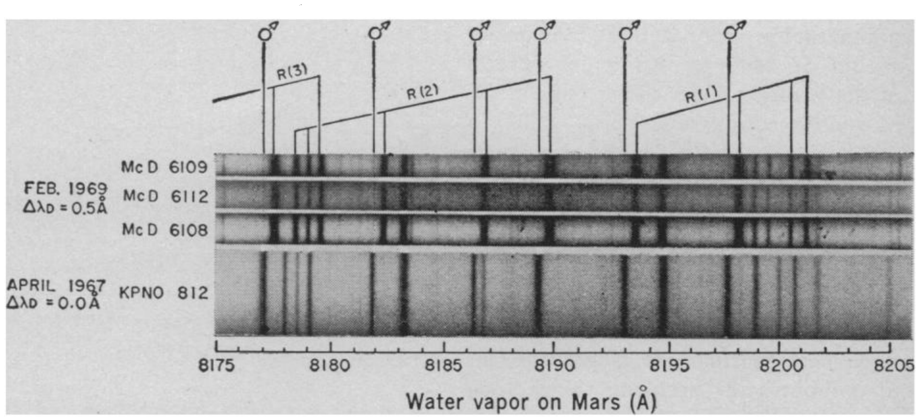

Fig. 1. Spectrum of Mars near 8200 Å. The McDonald (*McD*) and Kitt Peak (*KPNO*) plate numbers of the spectrograms are given, as well as the approximate Doppler shift ($\Delta\lambda_D$) at the time of observation. Martian water vapor lines are indicated by the symbol ♂; the strong lines for terrestrial water are identified by their rotational quantum numbers *R*.