Comments and Communications

Dr. Langmuir's Article on Precipitation Control

In his article entitled "Control of Precipitation from Cumulus Clouds by Various Seeding Techniques" (*Science,* **112**, 35 [1950]), Dr. Langmuir states that the results of silver iodide seeding in New Mexico on October 14, 1948, and July 21, 1949, seem to him to "prove conclusively that silver iodide seeding produced practically all of the rain in the State of New Mexico on these two days." Because of the widespread public interest in the possibility of artificially controlling precipitation, and the economic implications which would follow from successful experiments of the scale noted in the article, Dr. Langmuir's statement should be subjected to a careful examination. It will therefore be interesting to examine closely the methods by which he arrives at his conclusion.

Three main arguments appear to be used in the analysis: (1) the similarity or correlation between the patterns of rainfall over the state of New Mexico on October 14 and July 21; (2) the closeness of fit of each of these patterns to the hypothesis that the rainfall should be a maximum in the vicinity of the seeding point and thence decrease outward; and (3) that the time of beginning of rainfall on July 21 became progressively later in the day as the distance from the seeding point increased and fitted closely the travel time of the silver iodide based on observed winds.

Using these three approaches, and making computations from the rainfall data of the region on the two days in question, Dr. Langmuir obtains extraordinarily high probability figures, suggesting that the patterns observed could not have occurred as a consequence of natural causes. These probabilities are computed on the assumption that the rainfall values for the subareas into which he divides the state can be treated as so many independent random numbers.

The main difficulty with this type of analysis is that in actual weather situations the distribution of rainfall is not purely random, and that adjacent areas are not independent of one another. The occurrence of rainfall depends upon many factors, such as the moisture content of the air, the convergence of the air flow at various heights, the presence of air-mass discontinuities, and the topography of the ground, to mention several. Since these quantities are neither separately nor jointly distributed at random over a region on a particular day, it is equally true that the areal distribution of rainfall is not random.

It therefore appears that it would be necessary to find out what the true distribution of correlations between rainfall patterns actually is before stating that the correlation on the two days in question was much higher than would occur naturally, and therefore indicated significant results. Rainfall records have been taken at many stations in New Mexico for many years, and it is thus possible to examine these records and determine the natural frequency of occurrence of patterns similar to Dr. Langmuir's or to any other particular pattern. Then, having established what is normally to be expected in the way of rainfall patterns, those patterns occurring on the two seeding days can be studied to see whether they departed significantly from the normal.

As an example of the type of analysis in such cases, William Lewis, of the Weather Bureau, who was attached to General Electric's Project Cirrus with which Dr. Langmuir is associated, divided the state of New Mexico into 30 areas of approximately equal size by using even degrees of latitude and longitude. Eight two-day rainfall periods were selected at random from a list of cases in which rainfall occurred at at least 125 stations within the state. Rainfall quantities similar to those used by Dr. Langmuir were obtained for each of the 30 areas for each of the eight days, and all possible (28) correlations between the patterns on the different days were obtained. The correlation between the patterns on Langmuir's two seeding periods was also calculated—using the rainfall on October 14–15 versus that on July 21–22—and it came out to be 0.45. Of the 28 values obtained from the random sample, three were numerically greater than on the seeding days, with two others almost as high. With little effort it was also possible to pick out two other periods (July 4–5, 1945, vs. August 24–25, 1946) where the patterns were much more similar than on the seeding days, the correlation coefficient being 0.77.

This analysis would seem to indicate that it is not particularly unusual to encounter rainfall periods in New Mexico in which the patterns bear considerable similarity. Thus it would appear that the similarity noticed between the patterns on the two seeding occasions has little, if any, significance. The differences which might be expected from using a somewhat different choice of areas, and of using two-day instead of one-day rainfall, are not considered to be critical. The correlations, both for the seeding days and for the past data, would presumably be larger when fewer areas were used, and vice versa. For instance, the correlation between October 14 and July 21, using data from individual stations, is .02, or essentially zero.

It would be equally simple to determine the frequency of occurrence of particular patterns following Dr. Langmuir's hypothesis that they should be related to the position of the seeding generator, or of the occurrence of rainfall patterns which move in particular directions. Since Dr. Langmuir has not made such analyses, however, it is not clear how he can determine the probability that the behavior of the rain on the seeding days was so abnormal.

It will be recalled that as a result of his analysis

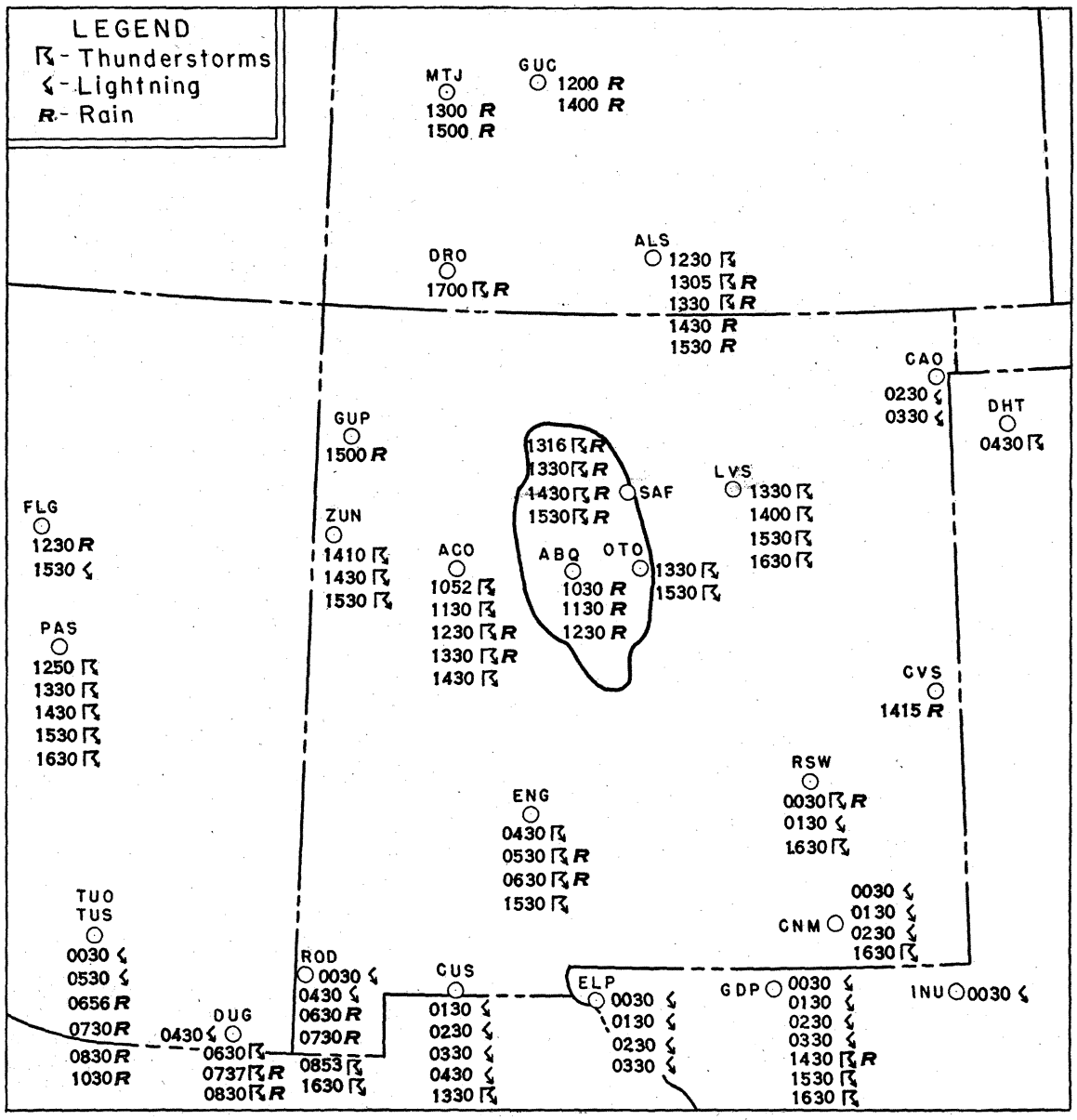

FIG. 1. Map of New Mexico area with contour showing maximum possible drift of silver iodide by 1530 hours on July 21, 1949, and showing times of occurrences of thunderstorms, lightning, and rain at various stations on the same day.

along the aforementioned lines, Dr. Langmuir stated that there was no appreciable background of nuclei in the atmosphere on October 14 and July 21, and therefore that substantially no rain could have fallen on the state on those two days without the presence of silver iodide. There is another method available to check the correctness of this statement. On July 21 it is stated that the silver iodide generator was turned on at 0530 and operated continuously thereafter for 13 hours. Upper wind observations were taken by the Weather Bureau at Albuquerque (about 10 miles from the generator) at 0800, 1100, and 1400 hours on that day. Using the most favorable combinations of winds reported from the surface up to 20,000 ft, the maximum extent of drift of the silver iodide particles was determined as of 1530 hours. The envelope of these values is shown superimposed on a map of the New Mexico area in Fig. 1. On this map are also shown the times of occurrences of thunderstorms, rain, and observed lightning for a number of stations outside this envelope. As is evident from the map, thunderstorms and rain showers were occurring throughout the state and in surrounding areas far beyond the limit of drift of the silver iodide. It is obvious, therefore, that it was quite possible for rainfall to have occurred naturally on the day in question.

It would be possible to examine the weather situation on these two days even more closely, and to point

out natural factors that would lead to the similarity in rainfall that Langmuir detects on the two days. If days from the past records on which the weather situations were equally similar had been chosen for establishing the frequency of pattern correlations, the expected correlation would have undoubtedly been much higher than in the example presented above.

It is generally accepted that the seeding of clouds with dry ice or other agents has the effect of converting supercooled water droplets into ice crystals. Photographs of the trenches and holes cut in stratus clouds present very striking spectacles. The value of this discovery and its usefulness in studying the physics of clouds are not to be underestimated. Many observers have also noted that small amounts of precipitation begin to fall from the cloud bases below the paths of the seeding airplanes soon after the planes have completed their seeding runs. In most cases, however, it appears that this precipitation evaporates before reaching the ground. In many other cases observers have noted that seeding causes the clouds to dissipate and thus seems to inhibit the possibility of rain.

Although there are a few cases where visual observations suggest that the precipitation may have been affected as the result of seeding clouds with dry ice or silver iodide, there is as yet no conclusive proof that this actually occurred. And the further question as to how much of the rainfall would have fallen naturally is even more in doubt. Regarding those claims of success in increasing the rainfall, the majority appear to be based upon cases where the rain has occurred primarily, if not entirely, as a result of natural causes. Carefully controlled experiments under various meteorological conditions, and over considerable periods of time, will be required to permit sound conclusions as to the quantity of usable rainfall that may be expected to result from cloud seeding.

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AT VARIOUS times during the past year certain periodicals, both technical and popular, have devoted considerable attention to the subject of rain making. Special mention has been made of two particular rain-making experiments carried out near Albuquerque, New Mexico, on October 14, 1948, and on July 21, 1949, by Irving Langmuir and a group of his associates from the General Electric Research Laboratory. Dr. Langmuir has claimed (*Science,* **112**, 35 [1950]) that these experiments produced copious rainfalls over very large areas. More recently the daily press (New York *Times,* Oct. 13, 1950, e.g.) has reported a statement made by Dr. Langmuir at the Schenectady meeting of the National Academy of Sciences to the effect that the abnormally large amounts of rainfall that occurred in the Mississippi Valley last winter appear to have been caused by the systematic release of silver iodide "smoke" at Socorro, New Mexico, during that period.

Several months ago the undersigned were afforded the opportunity of discussing at some length with Dr. Langmuir the various circumstances and details surrounding these particular experimental operations, and of examining the evidence put forward by him as proof of success in making rain on a large scale. Subsequent to this meeting we were asked by the president of the American Meteorological Society to prepare an informal report based on the results of the conference. Our conclusions are summarized in the following paragraphs.

In the first place, it should be emphasized that the formation and coalescence of atmospheric ice and water particles are as yet only imperfectly understood, despite recent great advances, which are due in large measure to the investigations of Langmuir, Schaefer, and their co-workers. At present it is still impossible to deduce conclusively from purely physical reasoning the complete future sequence of events if a given quantity of silver iodide "smoke" is introduced into a cloud whose meteorological parameters are known. Furthermore, there may be a limit to the length of time in which silver iodide remains efficient as a cloud-seeding agent when it is exposed to solar radiation. Since the limit does not yet appear to be definitely known, it seems impossible to state with certainty the distances to which this material will retain its effectiveness when carried along in the atmosphere. For these reasons, and because of the impossibility of controlling the atmosphere so as to permit a precise prediction of the weather that would occur if no attempt at cloud modification were made, it is extremely difficult to evaluate claims of success in rain making.

There are two possible approaches to the problem of determining the effect of cloud seeding on rainfall, both of which involve thorough study if any satisfactory objective judgment is to be achieved. One approach is to estimate the amount of rain that might be expected to fall naturally under the meteorological conditions prevailing at the time of a particular experiment. In this respect it can be said that at the time of the two experiments near Albuquerque the broad-scale weather pattern was quite favorable to the natural development of the thunderstorms and moderately heavy rainfall that occurred in both instances. However, a satisfactory quantitative estimate of the naturally occurring rainfall would have to be based on the results of a number of carefully controlled experiments, conducted under a variety of weather conditions. Since sufficient data of this kind have not yet been accumulated, it cannot be determined to what extent the future weather development may have been altered by artificial initiation of precipitation, nor is it possible to decide how much, if any, of the rainfall that occurred at individual points surrounding the site of the experiments in question should be attributed to cloud seeding.

In the case of the heavy rainfall over the Mississippi Valley in the winter of 1949, it is even more difficult to judge the effect of cloud seeding on the over-all weather pattern. Even if silver iodide does remain an efficient seeding agent for long intervals and over large distances, it is virtually impossible to evaluate the horizontal and vertical transport, and, hence, the contingent distribution and concentration of the silver iodide through the atmosphere when the distances involved are as great as those between New Mexico and the Mississippi Valley. On the other hand, it can be said with certainty that the patterns of weather and rainfall over the United States during this period were quite similar to a number of corresponding periods in the past, and that they fit very naturally and normally into the rather unusual Northern Hemisphere weather pattern of that period. To anyone who is fully aware of the world-wide character of the mechanics of the large-scale wind systems and of the apparently secondary and incidental role of rainfall distribution in the world-wide meteorological pattern, the implication that the purported artificial production of precipitation in the Mississippi Valley significantly modified this pattern seems fantastic. It is impossible, however, either to verify or to disprove Langmuir's contention in this respect from his analysis of the data as presented to us.

The other approach to the problem of determining the effect of cloud seeding on rainfall is primarily statistical. In the case of the Albuquerque experiments such an approach involves a careful consideration of the striking similarity of the rainfall patterns during the two days on which the allegedly successful experiments were conducted, particularly an investigation of the odds against the occurrence of such a degree of similarity by chance alone. In order to accomplish a reliable determination of these odds, a complete analysis of the entire situation should be made, starting with an objective analysis of original data pertaining to moisture distribution, winds, and rainfall in relation to topography. (Topography alone could be expected to produce a certain similarity in precipitation patterns on different days.) In addition, it would be necessary, because of the amount of serial correlation that occurs in weather patterns, and also the similarity that oftentimes exists between patterns, to determine from a study of climatological records what are the probabilities of such an occurrence of agreement between patterns. As far as we have been able to discover, however, these necessary statistical precautions were not taken in the original analysis of the two Albuquerque experiments. Therefore, we cannot accept as proved the odds against chance occurrence that have been cited by Langmuir. It is our considered opinion that the artificial production of substantial amounts of rainfall over an area of the order of 100,000 square miles definitely has not been demonstrated in these two cases.

A similar statistical approach must be made in order to achieve an effective evaluation of the high correlation between the days on which silver iodide "smoke" was released at Socorro, New Mexico, and the subsequent occurrence of rainfall in the Mississippi Valley. On the basis of a purely random situation this high correlation between the release of silver iodide and the rainfall probably is significant, but because of the general statistical behavior of rainfall patterns the situation in question should be carefully compared with the behavior of previous cases of abnormally heavy winter rainfall in that vicinity to see whether the periodicity exhibited in the present case is a likely occurrence by pure chance. Since, to the best of our knowledge, such a comparison has not yet been undertaken by Dr. Langmuir, we cannot accord credence to the sweeping inference that the abnormal character of the basic weather pattern was the result of the silver iodide operations at Socorro.

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