them, is very meager. None of the concepts for the geneses of these leads have sufficient foundation in fact to fulfill justifiably the afore-mentioned requirement.

Nearly all analyzed terrestrial lead samples (except those from uranium minerals) that have been isolated from their uranium environments since Tertiary times (*12*) have isotopic compositions that fall within the range $Pb^{206}/Pb^{204} = 18.07$ and $Pb^{207}/Pb^{204} = 15.40$ to $Pb^{206}/Pb^{204} = 18.95$ and $Pb^{207}/Pb^{204} = 15.76$. When any of these leads are compared with the isotopic composition of lead from an iron meteorite, $Pb^{206}/Pb^{204} = 9.41$ and $Pb^{207}/Pb^{204} = 10.27$, a Pb^{207}/Pb^{206} age of approximately 4.5×10^9 yr is obtained. It should be recognized that an approximate age value is sufficient and should be viewed with considerable skeptictism until the basic assumptions that are involved in the method of calculation are verified.

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1. We discussed the essentials of this paper at a Conference on *Application of Nuclear Processes to Geological Problems* sponsored by the NSF and NRC, at Geneva, Wis., Sept. 1953. We gratefully acknowledge the cooperation and assistance by our colleagues, especially R. S. Cannon and G. J. Neuerburg of the U.S. Geological Survey and W. J. Blake of the California Institute of Technology. The portion of the work undertaken at the California Institute of Technology was supported by the U.S. Atomic Energy Commission, contract AT(11-1)-208.
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Effects of Atomic Explosions on Weather

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EVERY year since the explosion of the first atomic bomb, both the U.S. Weather Bureau and the Atomic Energy Commission have received many letters suggesting that atomic bombs should be used to dissipate hurricanes and tornadoes or otherwise improve undesirable weather. Since the atomic weapons testing program was enlarged in 1951, both agencies have also received complaints from many parts of the world blaming unpleasant weather on the atomic explosions.

Although a casual examination of much of the recent climatic data might appear to indicate that some of the recent anomalous weather has been associated with atomic explosions, a more careful examination of the data does not support the hypothesis that atomic explosions have changed the weather.

When the best available observational evidence and the most plausible theories are considered together, there appears to be no reason for believing that any past atomic explosion at the Nevada Proving Ground has had any significant effect on the weather more than a few miles from the test site.

Historical background. Although witnesses to atomic explosions have sought to find ways in which the awesome events may have altered the weather, few cases have been found in which even local effects occurred. The heat from the fires set by the atomic bomb at Hiroshima produced numerous showers in the moist air overlying the city, and the base surge of the underwater Bikini shot also led to the formation of showers that lasted for 20 to 30 min (*1, 2*).

Most of the clouds from explosions in Nevada have been tracked for several hours by aircraft, but none of the pilots has reported any unusual weather developments during these operations. For greater distances, the atomic cloud has been followed across the United States by means of meteorologic trajectories (*3*), and even though there has been no attempt to make a detailed study of the weather in association with the atomic clouds and areas of radioactive fallout, it is believed that any marked relationship would have been detected.

These findings suggest that if the Nevada atomic tests had any effects on the weather, they were either very slight or very obscure. This article (*4*) describes a systematic study made possible in 1954 by the accumulation of additional data beyond that available to previous investigations.

Suggested relationships. To make sure that no reasonable hypothesis concerning the effects of atomic explosions on weather would be overlooked, suggestions were solicited from most of the organizations in the United States that employ meteorologists. Of the 80 or so replies received from these inquiries, about half indicated that the writers could see no possible connection between the atomic explosions and the ensuing weather. The others suggested that the atomic debris might serve as a cloud seeding agent; that the radioactive nature of the debris might produce changes in the electric parameters of the atmosphere, and that this, in turn, might produce some changes in the more directly observable weather elements; or that the dust resulting from an atomic explosion might interfere with the amount of solar radiation reaching the earth. None of those who replied believed that the energy of the atomic bombs exploded in Nevada could have any direct effect on the weather beyond the proving ground, and several volunteered arguments against this possibility.

We cannot, with our present knowledge of meteorology, dismiss the remote possibility that the atmosphere is so unstable that some small impulse such as that given by an atomic explosion could produce a weather change that might otherwise never take place. However there does not seem to be any reason why such modification would necessarily produce worse weather than might occur naturally. A consideration of the available theoretical and observational evidence indicates that the probability of any change is small.

Cloud seeding. Condensation does not begin in completely clean air until the relative humidity is at least 500 percent. Ordinary air, however, contains myriads of tiny dust particles—condensation nuclei—around which most natural cloud droplets are formed. Some of the nuclei can become active at relative humidities as low as 80 percent, and others such as ions require humidities greatly in excess of 100 percent. However, humidities in excess of 100 percent in the free air are rare. There are usually so many of these particles present and the available moisture is divided among so many droplets that none can grow large enough by the initial condensation process to fall as rain. But if water droplets and ice crystals are present in the same cloud, the ice particles will grow at the expense of the water droplets and become large enough to fall through the air. Additional growth will be realized by accretion of smaller droplets in the path of the falling drop. According to Houghton (*5*) the ice particle mechanism is necessary to the formation of most precipitation in middle and high latitudes. However the coagulation of cloud droplets is also important and in the tropics may be the most important process.

Cloud droplets do not freeze at the same temperature as a large volume of water. Liquid water droplets have been observed in the atmosphere at temperatures as low as about −40°F and at still lower temperatures in the laboratory. However, some of the nuclei have the property of causing the cloud droplets to freeze only a few degrees below the freezing temperature of bulk water. These particles, called ice nuclei (*6*), are not always present everywhere in the atmosphere and it is conceivable that the atomic explosions may supply them in regions with a natural

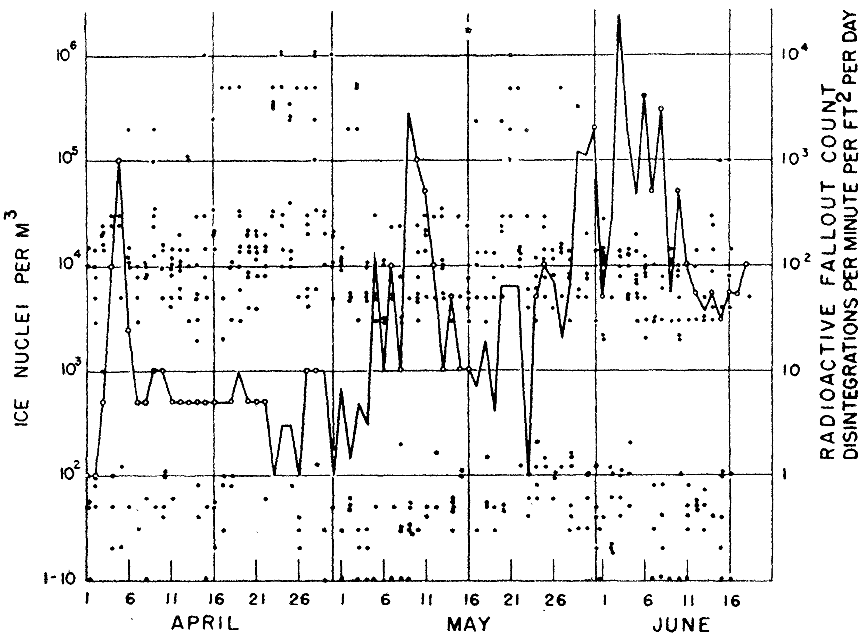

Fig. 1. Measurements of radioactive fallout (solid line) and ice nuclei count (small dots) made at Mount Washington, N.H., in 1952. Values for radioactive fallout of 10 disintegrations/ft² min are indicative of low values and not of accurate measurements.

deficiency. This possibility has been investigated by correlating the presence of ice nuclei and radioactive debris during a period of atomic explosions and by testing the nucleating properties of the material thrown into the air by the explosion.

Simultaneous measurements of the atomic debris and ice nuclei content of the air made at Mount Washington, N.H., in 1952 are shown in Fig. 1. The method of counting ice nuclei has been described by Schaefer (*7*); the method of measuring radioactive fallout has been described by Eisenbud and Harley (*8*). The continuous curve denotes the amount of radioactivity in dust deposited on the ground during a 24-hr period beginning at 12:30 P.M. EST on the date shown. The open circles are values interpolated from surrounding stations when reports from Mount Washington are missing. The smaller dots, usually eight per day, indicate the number of ice nuclei per cubic meter of air (*9*). If the debris from atomic bombs furnish good ice nuclei, the ice nuclei count should always be high when the radioactive fallout count is high. It is easy to see that this is not the case.

The only debris added to the air by an atomic explosion high above the ground is the material contained in the bomb itself, and only a small fraction, if any, of this material is thought to be effective as ice nuclei. In the case of low-altitude explosions a much greater amount of debris is thrown into the atmosphere. From the Nevada tests it has been found that more than 99 percent of the debris from a typical low-altitude atomic explosion consists of soil particles sucked up by the rising cloud without becoming radioactive or having their physical and chemical properties significantly altered by the explosion. Samples of this dust have been sent to two laboratories to be tested as ice nuclei. The Air Force Cambridge Research Center reported their findings as negative and Vincent Schaefer of the Munitalp Foundation emphasized the point by stating that the dust recovered from one rather muddy rain in Schenectady, N.Y., was 5000 times more effective than the dust from the Nevada Proving Ground.

The possibility that the radioactive nature of some of the debris might play a part in cloud seeding was also studied at the Air Force Cambridge Research Center, using laboratory sources of atomic radiations. None of the radioactive material tested was effective in promoting the formation of ice particles.

The amount of radioactivity deposited on the ground is much greater on days with precipitation than on days without precipitation when similar amounts of radioactive debris are aloft (*3*), and the precipitation is more radioactive when debris from atomic explosions is in the air than it is in the absence of such debris. However, it is well known that precipitation is effective in scavenging natural dust and smoke from the air. The available data indicate that most of the radioactive material in rainfall is collected by the scavenging process, and the presence of radioactive material in rain does not indicate that this material was instrumental in producing the rain.

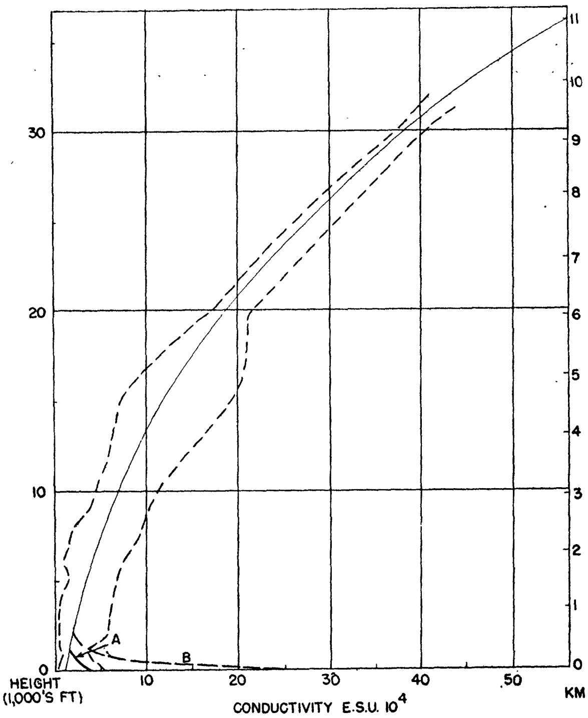

Fig. 2. Natural conductivity of the air and theoretical changes produced by fallout.

Electric effects. The radiations from the radioactive debris produced by an atomic explosion increase the ionization of the air. This should lead to an increase in the electric conductivity of the air and a decrease in the electric potential gradient of the atmosphere. A check of the records of atmospheric conductivity and potential gradient from the Tucson Geomagnetic Observatory of the Carnegie Institution of Washington for all periods of atomic tests through 1953 revealed only one case in which the electric parameters of the atmosphere were significantly altered as a result of radioactive fallout (*10*). Although very few observatories make continuous records of the electric conductivity of the atmosphere, observations of the increased radioactivity of the air, as well as theoretical considerations, indicate that the conductivity of the air near the ground may be significantly altered at many locations for four or five days after an atomic explosion.

The average natural conductivity of the free air as determined from more than 80 aircraft observations (*11*) is shown by the solid line in Fig. 2. The extreme values recorded are shown by the dashed lines. Theoretical considerations have been employed to compute the conductivity change expected in a region of moderately high fallout of radioactive material, such as may cover a few thousand square miles outside the proving ground following one of the larger bombs. This is shown by curve *A*. The conductivity to be expected near the largest observed fallout outside the test area is given by curve *B*. The radioactive decay rate of fission products is quite rapid, and curve *B* would be transformed into curve *A* within 9 days. It is seen that this layer of increased conductivity resulting from radioactive fallout is rather shallow and is not likely to have any effect on the more directly observable weather elements (*12*).

However, theoretical considerations indicate that under extreme conditions the conductivity of the free air may be increased sufficiently to interfere with the charge separation mechanism in thunderstorms in such a way that the amount of lightning produced by a given cumulonimbus cloud will be reduced. Unfortunately no evidence for checking this hypothesis (*12*) has been found.

No observational evidence or theoretical reasons have been found for believing that changes in the electric conductivity of the air will lead to any directly observable changes in the weather other than the possibility of decreasing the amount of lightning.

Effects on solar radiation. Many meteorologists believe that the amount of solar radiation reaching the ground can be greatly reduced by introducing a cloud of fine dust into the upper atmosphere, and that this will lead to a reduction in the mean temperature of the earth. The eruption of the Krakatoa volcano in 1883 threw several cubic miles of debris into the air. This was followed by a reduction in solar radiation measured at the ground (*13*).

However, according to the best available information, there appear to be many orders of magnitude separating the amount of dust required to produce any significant reduction in the world-wide incoming radiation and that produced by the Nevada explosions.

Effects of the explosion itself. None of the scientists who replied to the inquiry about A-bombs and weather felt that the energy of the explosion could have a significant effect on the weather. A few comparisons between the energy of an A-bomb and natural phenomena can help explain their position.

The energy of a nominal A-bomb (equivalent to 20,000 tons of TNT) is 2×10^{13} cal. (*2*). This is divided into thermal and kinetic energy although the latter will also ultimately be converted into thermal energy. The thermal energy from the sun falling on 1 mi^2 of Nevada ground during an average spring day supplies as much heat as two nominal bombs. The energy released by the condensation of water in a typical thunderstorm is equivalent to 13 nominal bombs. Further comparisons with natural phenomena reveal similar statistics suggesting that the energy of an A-bomb, while tremendous compared with the energy of other man-made explosions, is relatively small compared with that of many natural phenomena.

The pressure wave emitted by the explosion may cause pressure changes that can be detected at a considerable distance. Figure 3 shows the response of the Bishop, Calif., barograph (about 80 mi from ground zero) to two of the explosions. The rise at 7:20 A.M., PST, 30 October 1951 resulted from an explosion at 7:00 A.M. But following an explosion at 7:30 A.M. 1 November 1951, for example, there was no detectable pressure change. In general, only a few of the shots have been recorded on the standard weather barographs outside of the proving ground. The movement of these pressure waves depended on the temperature and wind structure of the atmosphere as well as the force of the explosion.

Observational evidence. It may be argued that the weather is being modified by the A-bomb tests in spite of our finding no theoretical reason for believing this to be the case. It is therefore necessary to inspect climatic records to detect any changes in the weather that may reasonably be connected with the Nevada bomb tests.

The climatic element most often cited as having been changed by the atomic testing program in the United States is the frequency of tornadoes. The number of tornadoes reported in 1953 (532) exceeded the previous highest annual total by more than 200 and 686 were reported in the first 10 mo of 1954. An examination of the weather patterns for the spring months of 1953 indicates that 1953 had many features in common with several previous years of unusually

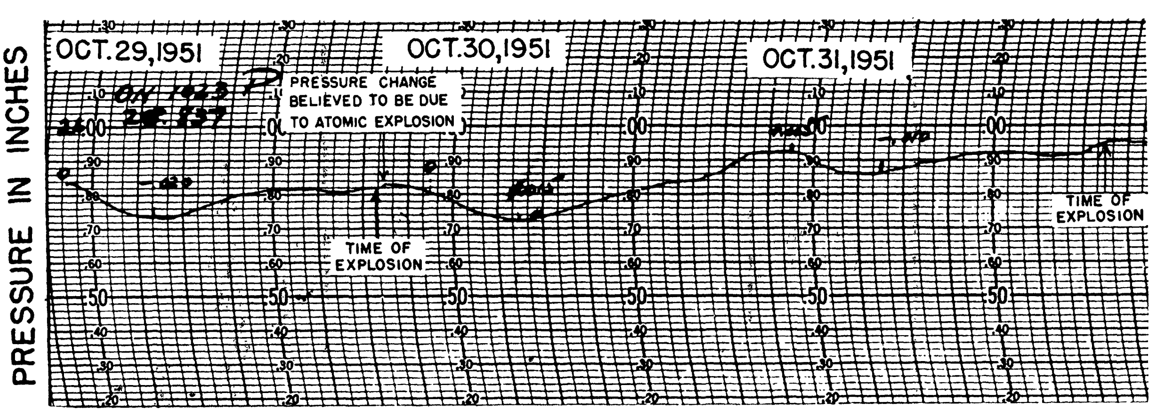

Fig. 3. Microbarograph records for Bishop, Calif., 29 Oct. to 1 Nov. 1951.

high tornadic activity, and it is likely that these favorable weather patterns contributed to making 1953 an unusual tornado year. A careful examination of the system for reporting tornadoes reveals considerable improvement since 1950, with perhaps the greatest improvement taking place in 1953 and continuing into 1954; it is believed that much of the increase in tornado reports can be traced directly to these changes (*14*).

Using the loss of life or property damage as a measure of tornado incidence, one finds that the loss of life in 1953, 516 persons, was exceeded on several occasions before 1950. The number of tornadoes doing more than $100,000 in damage, 43, was exceeded in 3 years before the beginning of atomic tests in Nevada, despite the increased property values in 1953. The total damage of 1953 did reach an all-time high of $224,345,900 because about seven tornadoes struck exceptionally valuable property. However *none* of these extremely damaging tornadoes occurred under the atomic cloud or in areas of relatively high fallout of radioactivity, and one occurred in December, more than 6 mo after the last atomic explosion in Nevada.

One significant feature of the 1953 tornado observations is the reporting of 133 tornado funnels that failed to touch the ground—more than ten times the average number of funnels aloft reported in earlier years (Fig. 4). This seems to be an indication of increased interest in tornado reporting.

A detailed study of the relationship between areas of radioactive fallout, or the presence of atomic clouds, and tornado occurrences reveals that there were relatively fewer tornadoes reported in areas of the atomic clouds or areas of large radioactive fallout than in areas of relatively small fallout. Furthermore, if one assumes that the increase in tornado reporting efficiency is approximately constant throughout any given year, the fraction of the annual number of tornadoes occurring during the Nevada test periods can be shown to be slightly less than in corresponding periods prior to 1950 (*14*). Neither of these statements is to be interpreted as proof that the presence of atomic debris inhibits tornadoes, but rather as convincing evidence that a case cannot be made for the A-bombs' increasing the likelihood of tornado occurrence.

The upper curve in Fig. 5 shows a plot of the monthly departure of the mean temperature of the entire United States from the average value for the period 1893–1950. The only record-breaking temperature in this curve since 1950 is the value of 42.9°F (8.4° above normal) in February 1954, which occurred many months after the last preceding Nevada atomic explosion. This curve shows the beginning of a trend toward warmer temperatures beginning early in 1951, and apparently continuing to the present. This is clearer in the curve for annual mean temperature shown in the lower part of Fig. 5. The heat released by an atomic bomb is certainly not enough to account for this warming; on the other hand, one of the most frequently suggested means by which the atomic bomb might affect the weather—by decreasing solar radiation—would imply lower, not higher, temperatures as the result of an atomic explosion. It may be noted that the trend toward warmer temperatures was even more pronounced during the period 1932–34.

The upper curve in Fig. 6 is a plot of the average monthly precipitation for the entire United States, plotted as a percentage of normal. The normal was computed from the data for the period 1893–1950. The only exceptional point on this graph since 1950 is the value of 26 percent of normal precipitation in October 1952. This was by far the driest month in the period of record. It occurred four months after the last atomic explosion in Nevada and at a period when there was little or no debris from atomic explosions over the United States. Although most suggested theories of the effect of atomic explosions on weather imply an increase in rainfall, this curve indicates a tendency toward drier than normal weather beginning in 1952. This trend can be seen more clearly in

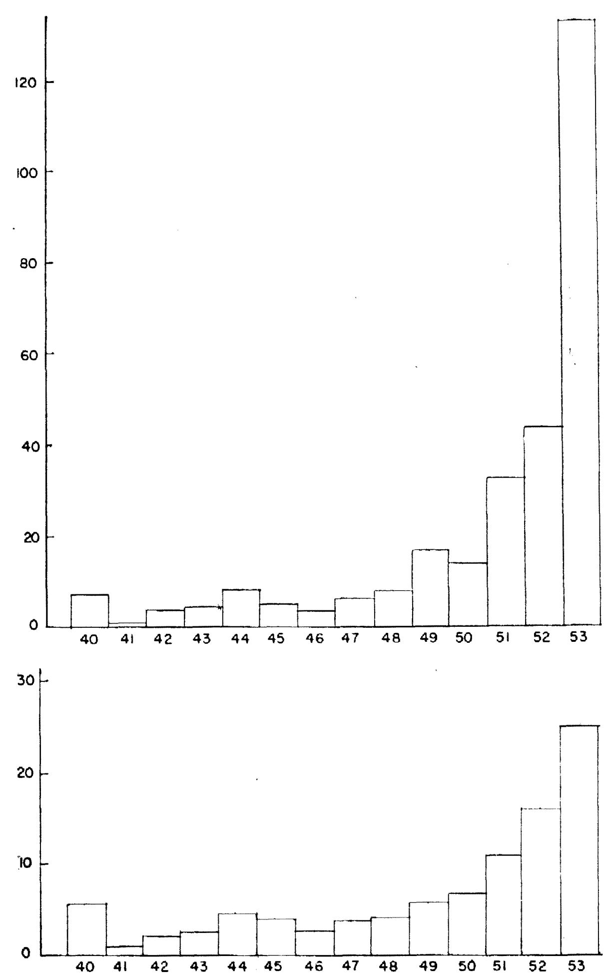

Fig. 4. Top: number (ordinate) of reported tornado funnels not touching the ground, 1940–53 (abscissa). Bottom: percentage (ordinate) of reported tornado funnels not touching the ground, 1940–53 (abscissa).

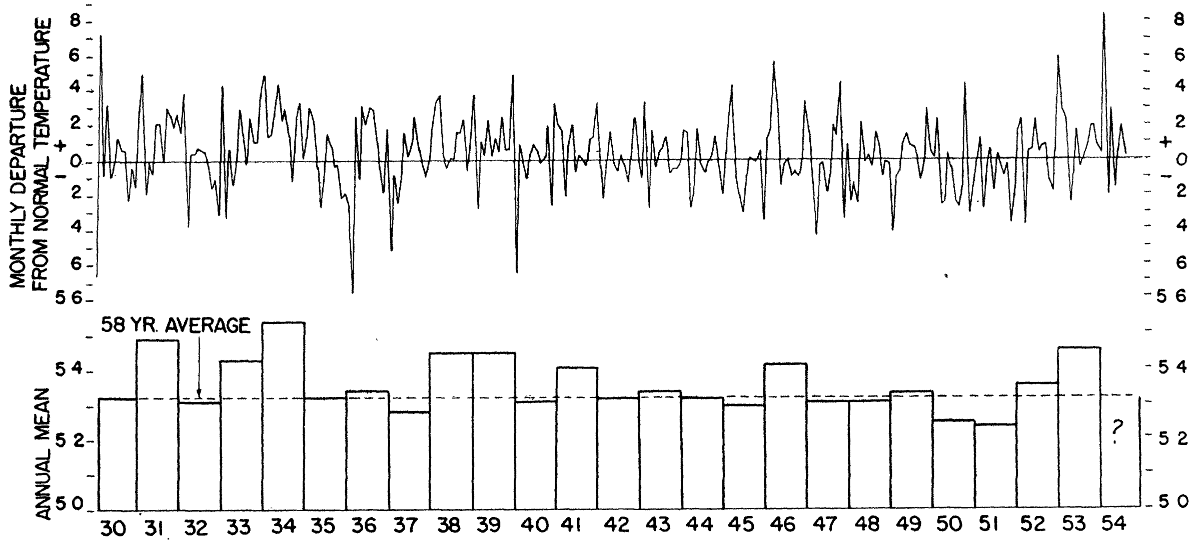

Fig. 5. Top: departure of the monthly mean temperature from the 58-year average. Bottom: average annual mean temperature, 1940–53.

the curve for annual precipitation in the lower part of Fig. 6. Rainfall in the United States has tended to be below normal since the beginning of 1952, and 1952 was the driest year since 1930. However, 1910 and 1921, as well as 1930, were drier than 1952, and there have been several periods since 1893 when the accumulated deficiency of precipitation was comparable to that recorded since 1952. The ultimate causes of these earlier periods of dry weather are also unknown. However, atomic explosions could not have caused them, and there is little reason for believing that the current dry spell has been brought on by the atomic explosions. A study of a series of individual weather stations reveals no results that differ significantly from the country-wide averages.

Pacific tests. This discussion has been limited to the effects of atomic explosions in Nevada because we have not yet examined sufficient data from the most recent Pacific tests to justify more than a tentative conclusion. However, a preliminary examination of the data does not indicate that any obvious changes in the weather have been produced by these explosions outside of the test area. The study of the data from these tests is being continued.

Conclusions. A number of suggested mechanisms by which atomic explosions might affect weather have been investigated and a study of climatologic data has been made to determine whether any weather anomalies exist that might be associated with atomic explosions. Although it is not possible to prove conclusively that atomic explosions have or have not influenced the weather, it is believed that this study has shown that such an effect is unlikely. The results of this study may be summarized as follows:

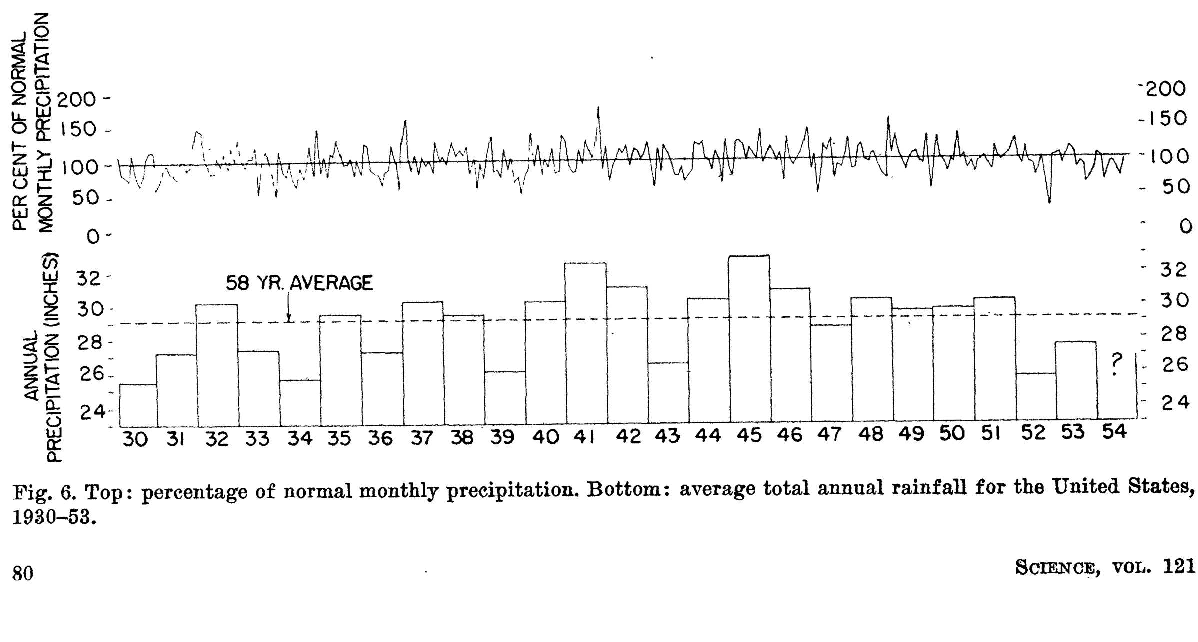

Fig. 6. Top: percentage of normal monthly precipitation. Bottom: average total annual rainfall for the United States, 1930–53.

1) No theoretical reason has been found for believing that any of the mechanisms examined could account for a significant change in the weather more than a few miles from the site of the explosion.

2) The year 1953 was an unusual tornado year. Although part of the increase in the number of tornadoes reported in 1953 may have been the result of exceptionally favorable weather patterns for tornadoes, much of the increase can be attributed to improvements in the method of collecting tornado statistics.

3) A study of the temperature and precipitation records for the United States does not seem to indicate any departures from normal that are related to the atomic explosions.

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4. We wish to express our appreciation to the Atomic Energy Commission for making available much of the data used in this study; to Vincent J. Schaefer for testing the nucleating effectiveness of the Nevada soil samples and for providing the records of ice nuclei observations at Mount Washington; to the personnel of the Cloud Physics Section of the Air Force Cambridge Research Center for testing the nucleating efficiency of soil samples and atomic radiations; and to the Carnegie Institution of Washington for permission to use the records of the Tucson Geomagnetic Observatory.
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News and Notes

Macromolecular Chemistry

The international symposium on *Macromolecular Chemistry*, under the auspices of the International Union of Pure and Applied Chemistry (I.U.P.A.C.) and the Italian National Research Council (C.N.R.), was held in Milan 26–29 Sept. and in Turin 30 Sept.–2 Oct. 1954. In Milan the meetings were held at the Museo Nazionale della Scienza e della Technica and at the Instituto di Chimica Industriale del Politechnico di Milano. In Turin they were held at the Instituto dell' Università. The total number of registrants exceeded 300, representing Austria, Belgium, Canada, Czechoslovakia, England, Finland, France, Germany, Holland, India, Israel, Italy, Japan, Norway, Sweden, Switzerland, Union of Soviet Socialist Republics, the United States, and Yugoslavia. The United States was represented by P. J. Flory, Peter H. Frank, Robert W. Kell, H. B. Klevens, Gordon M. Kline, Edmund H. Immergut, Samuel L. Madorsky, Herman Mark, Robert B. Mesrobian, Eric Proskauer, Walter H. Stockmayer, and C. A. Y. Voetelink.

The symposium was opened in Milan by addresses of welcome by V. Ferrari, lord mayor of Milan, by Luigi Morandi, president of the Lombard section of the Italian Chemical Society, and by M. G. Levi, president of the Italian Chemical Society. Herman Mark, who is chairman of the committee of macromolecular chemistry of the I.U.P.A.C., was awarded a scroll of honorary membership of the Italian Chemical Society, after which he presented an illustrated talk on "New rubbers, plastics, and fibers."

The meeting in Turin was opened with addresses of welcome by A. Peyron, lord mayor of Turin, G. Camerana, president of Salone della Technica, and A. Muzzoli, president of Congresso Materie Plastiche. H. Mark then spoke on the "Scientific basis of standardization of plastics."

There were about 80 papers presented, in five different languages: English, French, German, Italian, and Russian. These papers covered the following general subjects: (i) building reactions of macromolecules; (ii) transformation reactions of macromolecules; (iii) block polymers and graft polymers—preparation and properties; (iv) cellulose and derivatives; (v) molecular weight distribution; (vi) methods for the determination of molecular weight; (vii) branched polymers; (viii) fiber-forming polymers; (ix) general properties of polymers; (x) crystallinity and transitions; and (xi) proteins. The papers and discussions will appear shortly as a special issue of *La Ricerca Scientifica* and will be distributed through the Interscience Publishers, 250 Fifth Ave., New York.

At the meeting in Milan, Herman Mark was awarded a medal by the Instituto di Chimica Industriale del Politechnico di Milano; this is the first time the medal has been awarded to a non-Italian. Also, at the meeting in Turin, H. Staudinger was awarded a degree *honoris causa* of the University of Turin, after which he gave an address on the subject "Über die Grundlagen der macromolekularen Chemie."

The next meeting of the Macromolecular Commis-