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First Partial Report
on the
Artificial Production of Precipitation

Stratiform Clouds -- Ohio, 1948

By

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Participation of Cooperating Agencies

The Cloud Physics Project was established as a result of recommendations made by the Meteorological Subcommittee of the Air Coordinating Committee on August 19, 1947. The Project is a cooperative effort of the U. S. Air Force, the National Advisory Committee for Aeronautics and the U. S. Weather Bureau.

The Air Force provided, operated and maintained at Wilmington, Ohio, a number of airplanes for the evaluation of cloud modification techniques. High powered ground radar equipment was also provided together with office space and necessary ground facilities.

The National Advisory Committee for Aeronautics cooperated by assigning from time to time, a highly experienced cloud analysis team and their especially equipped airplane.

The U. S. Weather Bureau set up, operated and maintained a surface and upper-air network of stations to observe the micro-meteorology of the operating area. The technical planning and scientific leadership of the Project were provided by the Physical Research Division of the Weather Bureau.

The U. S. Navy provided on loan much of the equipment installed in the meteorological network.

Various individuals from Universities and other interested agencies acted in an advisory capacity.

Basic Objective

The basic objective of the Project was to determine in definite quantitative terms the practical limits and general utility of cloud modification processes in producing or suppressing precipitation and increasing the visibility from flying aircraft. In order that the effects of the induced modifications may be clearly separated from those occurring naturally, a closely coordinated attack using all available measuring facilities was adopted.

History

The possibility that weather might be controlled by artificial means has long excited the interest of man but as yet little active progress has been made. As early as 1898 Congress appropriated money to conduct rainmaking experiments, and some work was done using explosives and other alleged stimulating agents. None of the earlier experiments were based on a substantial understanding of weather processes and were, therefore, foredoomed to failure. The first* rational experiments directed to the production of precipitation by artificial means were carried on by a Dutchman, August Veraart [See 1 through 9, Bibliography], who conducted experiments in Holland in 1930 with limited success. Veraart was impressed by the limitations imposed by the weather upon air operations and the special requirements of man. He remarked in his publications that the artificial modification of clouds would find important application to: (a) the reduction of hail storms, (b) the relief of drought, (c) the improvement of health in highly populous cities, by increasing the sunshine, (d) the control of flood conditions, (e) the control of forest fires, (f) the dispersion of fog from airports, (g) the dissipation of clouds for extensive and highly specialized astronomical observations, (h) the production of snow for ski resorts and winter sports areas, and finally, (i) the production of clouds to reduce the chance of frost at night. He further noted the convenience that would result from having rain fall always at night rather than in the daytime. Although Veraart's knowledge of classical meteorology was not too thorough, he had had practical observational experience in the air. He was convinced that precipitation could be produced from clouds at will, by various types of "trigger action". He emphasized the existence and importance of supercooling of the cloud elements in the liquid phase and thought that the supercooling of water droplets could extend down to -10 or -20 degrees centigrade. In this concept he was far ahead of the practicing meteorologists of that time. He recognized the possibility of supersaturation in the lower five kilometers of the air, and the occurrence of super-adiabatic lapse rates which can exist for a considerable time but which may become violently unstable when subject to certain types of impulses. He further mentioned the release of heat when a supercooled cloud is converted to the ice phase and thought that this might produce progressive cloud changes and convective activity.

It is clear from Veraart's writings and reviews that the effect of sublimation nuclei and their importance in modifying supercooled clouds were beyond his experience. Working mainly with the idea that weather processes could be stimulated by adequate refrigeration of the air, he distributed into clouds by airplanes solid carbon dioxide, or water ice cooled to temperatures of solid carbon dioxide and expected that these would induce a continuing convective activity. It may be noted that the temperatures of the dispersed mixtures were so low that large numbers of sublimation nuclei must have been produced and scattered throughout the supercooled clouds he treated. Many attempts were made by Veraart to dispel fog or to make rain by dropping the various mixtures from aircraft. Most of his attempts were failures. However, in the summer of 1930, he made several public demonstrations and was credited with producing slight amounts of rain (a few hundredths of an inch) on several occasions.

Even Veraart's worthwhile work and new ideas were largely discredited because of his highly publicized and sweeping claims that large amounts of precipitation could be produced by artificial means. These claims [3] were not justified in view of the very few uncontrolled experiments he performed.

The foundations of present day understanding of cloud modification were laid by W. Findeisen in a series of important papers [13 through 18]. Findeisen examined with some care an earlier suggestion by A. Wegener [10, 11] that the coexistence of ice and water in a supercooled cloud leads to colloidal instability. Bergeron [12] already had postulated that large amounts of rain were released by the presence of ice crystals formed or somehow transported through water clouds. Findeisen [16] summarized the contrasting characteristics and functions of condensation nuclei and sublimation nuclei in the atmosphere and gave estimates of their abundance. Findeisen also emphasized the importance of the conversion of supercooled water clouds into ice clouds by sublimation. He pointed out clearly enough that this conversion required the presence of a moderate number of sublimation nuclei and that usually these were relatively scarce in the normal atmosphere. The conversion of a supercooled water cloud into an ice cloud by a relatively insignificant mass of such sublimation nuclei was recognized as a "trigger process", and Findeisen [16] was led to write, "It must accordingly be concluded that with a relatively small expenditure, it is possible occasionally to produce rain artificially, to remove icing danger and to prevent the formation of hail."

The investigations of Wegener, Bergeron and Findeisen formed the background for the important discovery by V. Schaefer [19] in 1946 that sublimation nuclei could be produced artificially in prodigious numbers by the introduction into a cloud of any object cooled below about -40 degrees centigrade. These sublimation nuclei are spontaneously produced ice crystals formed from the water vapor existing in the air. Carbon dioxide snow, because of its relatively large latent heat, its low temperature (-78.5 degrees centi-

Note

*It has been reported that Wegener and Schneider sprayed liquid air into clouds from aircraft in 1923 but we have been unable to find a reference to the work.

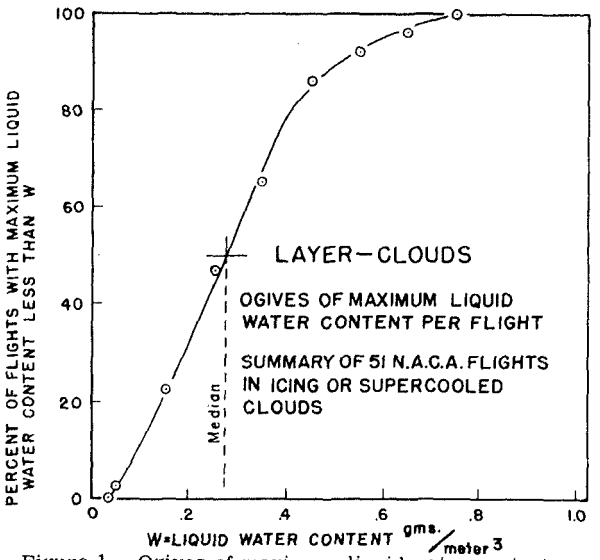

Figure 1.--Ogives of maximum liquid water content per flight in layer clouds. Summary of 51 N.A.C.A. flights in or supercooled clouds.

grade) and its ready availability, has been found to be an ideal source for such sublimation nuclei. Other more stable chemical types are also suitable for the production of sublimation nuclei, and Schaefer and Langmuir [19] have mentioned some of these, including silver iodide.

By dropping large numbers of small pellets of carbon dioxide snow into a supercooled cloud, Schaefer and Langmuir [19] have demonstrated that a cloud may be largely converted into an ice-crystal or snow cloud. The photographs of such treated clouds at temperatures below about -5 degrees centigrade usually show remarkable changes in the optical characteristics of the cloud elements. While the artificial conversion of the cloud, at sufficiently low temperatures, is real, there is little indication as yet that it has an important bearing upon economic aspects of weather processes.

Precipitation from a Supercooled Water Droplet Cloud

Since this report summarizes an investigation to assess the economic importance and limitations of artificial precipitation processes in stratiform clouds, it seems worthwhile to review briefly some basic concepts involved in the production of precipitation. A point that seems to have been lost in recent discussions of rain production is that it is impossible to extract more water from clouds or air than is contained therein. It is well known that large amounts of precipitation are only produced when continuous large scale lifting of moist air masses, or appreciable vertical convection arising from thermal sources, takes place. Each of these processes implies the transport into a given area of new air and moisture constantly to replace that appearing in the form of precipitation. In a stable cloud without these processes the only precipitation that can be extracted is to be found in the cloud itself, and this is small in the economic sense.

Consider as an example, a typical stratus cloud composed of large numbers of supercooled water droplets at a favorable temperature such as -10 degrees centigrade. In the absence of sublimation nuclei or ice crystals, each cloud droplet is in dynamic equilibrium with its neighbors, and in a given interval of time each droplet evaporates and condenses the same amount of moisture. Figure 1 summarizes the experience of the N. A. C. A.'s Icing Research Team [20] as determined in 51 flights where liquid water content and cloud size distribution measurements could be made. This summary of observational data shows that the liquid water content in a typical layer cloud is approximately 0.3 gram per cubic meter. In addition to the liquid water content, at the temperature mentioned above, there are 2.36 grams per cubic meter that exist in the vapor phase and which will become available only if the temperature of the cloud is greatly reduced. Thus, in typical supercooled stratus clouds, one kilometer thick (3,280 feet), the total water content in all forms is less than .27 gram per square centimeter, since a one square centimeter prism extending up through the cloud has a volume of 1/10 cubic meter. Most of this moisture is unavailable without the expenditure of energy for further refrigeration. With the stratus cloud in this condition, suppose that sublimation nuclei either naturally or artificially produced are suddenly mixed with the cloud. The instability described in detail by Findeisen immediately sets in. Because the vapor pressure over ice is appreciably less than that over water, water vapor migrates at a moderate rate from the surface of the water droplets and condenses upon the associated ice particles or sublimation nuclei. When there are adequate numbers of ice crystals present, the entire supercooled water droplet cloud is converted to ice or snow in a few minutes. This conversion may proceed in such a manner that large snow flakes are produced. These flakes will fall out of the cloud, evaporating in part on their way to the ground. Even under the most favorable conditions it is clear that the precipitation reaching the ground will be less than 0.27 centimeter or 0.10 inch of water.

The conversion of a water droplet cloud to ice crystals modifies the air within it in two ways: (a) by the release of the latent heat, and (b) by the shift of the equilibrium vapor density from that of water to that of ice. At -10 degrees centigrade this latter effect amounts to 0.219 gram per cubic meter or a desiccation equivalent to a reduction in temperature of 1.3 degrees centigrade. Since the latent heat of fusion of ice is 80 calories per gram and since the data of Figure 1 show that the maximum free water content encountered in stratus clouds does not exceed one gram per cubic meter, it is clear that the heat released by the converted water in a cloud one kilometer thick will seldom exceed 8 calories per square centimeter. Now, if it is assumed further that the center of the cloud is at the 800 millibar pressure level (about 6,400 feet), then the release of 8 calories per square centimeter within the cloud will raise its temperature by 0.31 degree centigrade. Because of the reduction of vapor density, some 13.1 calories per square centimeter are also available, and this will raise the temperature by a further 0.52 degree centigrade. The release of 21 calories per square centimeter in the modified cloud due to the above processes will reduce appreciably the density therein, and one might conclude that convective activity on a large scale would be produced. The quantitative aspects of convective activity in such a heated cloud layer are obscure, but our experiments show that any such vertical development resulting from the conversion is transitory and of small magnitude. Perhaps one would not expect appreciable convection when it is recalled that the sun transfers into the earth's atmosphere about 40 calories per square centimeter per daylight hour in temperate latitudes. Although this approximates the rate of release in the seeded stratus cloud, the convective activity in the normal atmosphere is not very great.

With the object of obtaining sufficient basic data on cloud modification techniques to assess the reality of artificial methods for the production of precipitation and to determine objectively the factual and economic aspects of the problem, this investigation was initiated October 16, 1947.

Facilities

The facilities in the vicinity of Wilmington, Ohio, used by the Cloud Physics Project, have been described in other papers [21, 22]; they are virtually the same as those utilized by the Thunderstorm Project. However, to reacquaint the

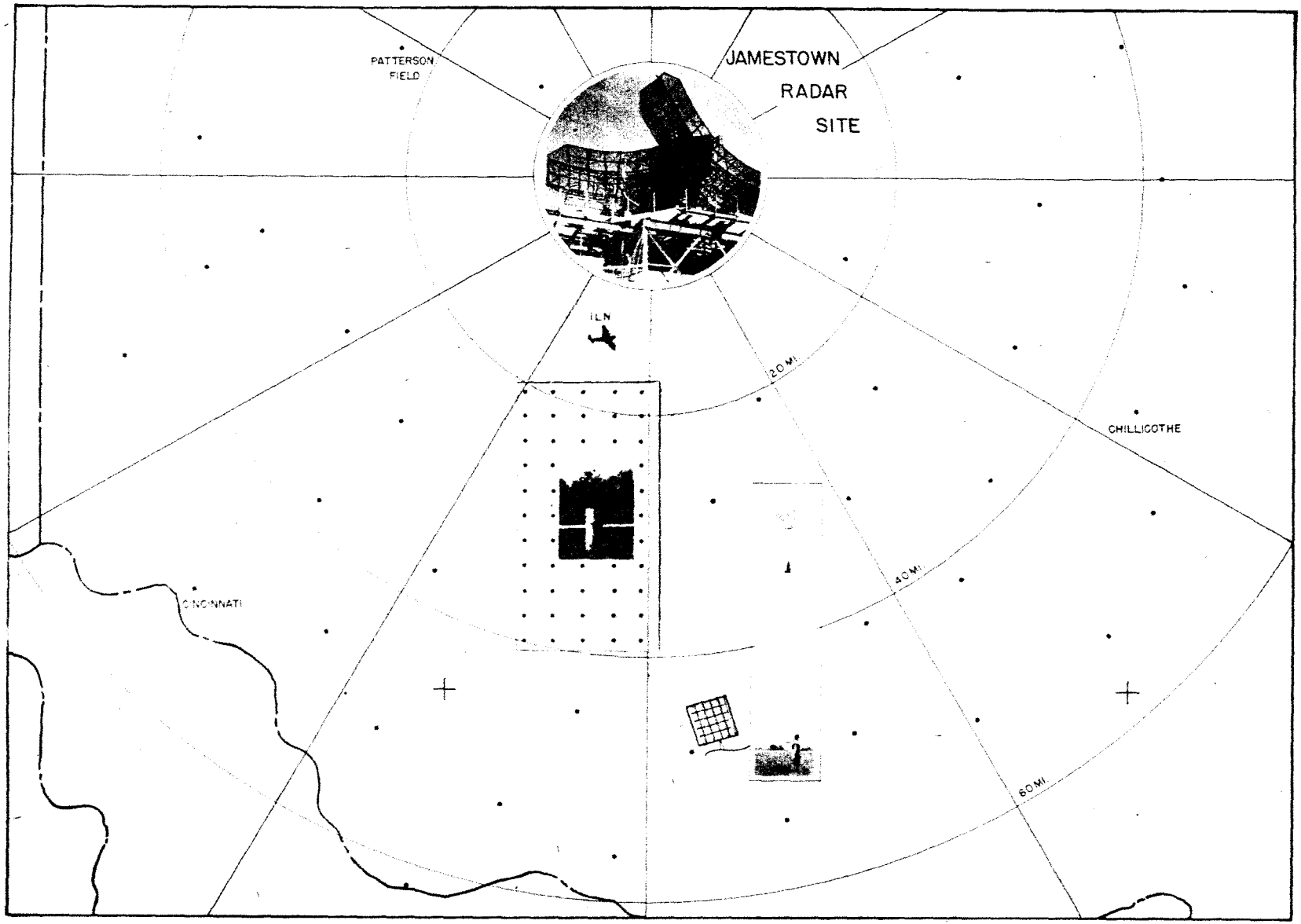

Figure 2.--Locations of installations in southwestern Ohio. ('ILN' designates Clinton County Air Force Base, Wilmington, Ohio.)

reader with the facilities, and especially with their utilization on this project, a short discussion of them is given.

Figure 2 shows the locations of the various installations in southwestern Ohio. Near Jamestown, Ohio, is situated the AN/CPS-6 (V-Beam) Radar which is the focal point of all cloud seeding operations. Not only is this radar desirable for controlling and indicating the path of each of the aircraft involved in the investigation, but also it indicates the presence of precipitation areas whether they be formed naturally or as a result of seeding. The scope presentations of this radar are photographed automatically at 10 second intervals. On each frame of film there is recorded a data card and a clock properly to identify the picture. There is located at the same site an AN/TPS-10 height-finding radar whose scopes are also photographed.

To the south of the radar site, as indicated in Figure 2, is a rectangularly shaped area 8 by 20 miles within which are spaced 55 recording weather stations. Each of these records rainfall, wind velocity, temperature, pressure and relative humidity on charts which are removed each day. The Ferguson weighing type rain gage is used at each of these locations. These gages are modified to increase the accuracy and sensitivity of rainfall rate measurements. They utilize throats which give catches 2 1/2 times larger than the normal ones, and they are geared for one revolution of the clock drum every six hours. In addition to the rectangular network, there is located within the immediate vicinity a number of other recording rain gages as indicated by the small dots in Figure 2. Within the rectangular network, there are located also two rawinsonde stations which provide, as required, necessary information regarding the temperature, pressure, moisture and winds of the upper atmosphere.

Clinton County Air Force Base, as shown in Figure 2 by its designator, "ILN", is conveniently located with respect to the other facilities. Based there are a number of specially instrumented Air Force planes which participate in seeding missions. A short description of the responsibilities of each of the aircraft participating in stratus cloud seeding missions is given in order to outline the plan of operation.

A B-17 with a calibrated seeding conveyor drops dry ice into the cloud at such locations and on such headings as directed through radio contact by the radar controller located at the Jamestown site. The controller attempts to plan the seeding in such an area that its maximum effects will be noted and measured over the surface network. The dry ice used is crushed and separated so that it consists of particles no larger than 3/8 inch in effective diameter. Whenever possible, the rates of seeding are varied on successive runs in order to determine the effects of over or under seeding. In general, however, a minimum amount of dry ice is dropped so that over-seeding will not result. The seeding conveyor is carefully calibrated and indicators of its periods and rates of operation are photographed from remote reading instruments installed in a photo panel along with indicators of other important parameters, such as temperature, pressure altitude and absolute altitude. Also installed in the B-17 is an AN/APS-10 light weight radar, which is used to indicate the presence of light precipitation areas. In addition, photographs of the seeding operation are taken with still and motion-picture cameras from various points within this plane. Upon completing a seeding run, this plane circles the area of seeding, photographing and observing any results.

Two high altitude photo planes, an F-15 and a modified P-61, are positioned by the controller directly above the B-17 at the start of the seeding run. The F-15 maps the seeded area by flying directly over it, while the P-61 secures oblique pictures by flying in a circle of about 10 mile radius. Clocks and data cards are included in the field of view of the cameras in these planes, so that the pictures secured can be easily identified and coordinated. Paths of these planes along with all others participating in the mission are recorded on the photographs of the ground radar scopes. It is possible from these photos to determine the exact location of any plane at any instant since the planes are easily identified by special radar-operated beacon codes.

Several other aircraft participate in these flights in order to determine the structure of the cloud before and after seeding and to investigate the seeded areas and any precipitation falling from them. These planes, also controlled from the ground radar, fly above, within and beneath the cloud, making observations and taking pictures of all interesting phenomena. All such reports are transmitted by radio and recorded on wire and disc recorders located both in the B-17 and on the ground.

To conduct inner cloud studies, a specially instrumented hot wing B-25 provided by the Flight Propulsion Research Laboratory of the N.A.C.A. in Cleveland, is provided on occasion.

Design of the Experiment

Each cloud seeding mission is so designed that the information gained from the sources mentioned above is utilized to best advantage. Usually, seeding operations are performed in a cloud area which, moving with the upper winds, will pass over the network of recording stations within 15 to 30 minutes. The path of the seeded area can be traced from aircraft reports and the radar tracks of the various aircraft which follow it. Results of the seeding can be noted from observations taken from several points of vantage: namely, from the radar which indicates any resulting precipitation, by observers flying in airplanes above the cloud who note changes in cloud structure, by other observers flying in planes beneath the cloud who detect and note precipitation of very light intensity which is not detected by the radar, and by visual observers located on the ground who observe the presence of precipitation reaching the ground and any changes in the base of the cloud deck.

On most of the operations the following quantities are determined in flight: height of base and top of seeded cloud decks, relative humidity above and below, temperatures inside and outside the clouds, lapse rates, optical characteristics and extent and character of the precipitation. Also, an attempt is made to determine if precipitation reached the ground.

Mission of January 21, 1948. An Example

Considering all the sources of data available and from the close coordination maintained on each mission, it is possible to evaluate the results of any seeding operation in definite and quantitative terms. In order to show exactly the importance and use of the information gathered, a particular seeding operation is discussed in some detail. The mission of January 21, 1948, was chosen for this purpose since it required utilization of all sources of data for the proper evaluation of the results of the seeding.

Over one inch of snow fell in the vicinity of Wilmington within 18 hours of the completion of the cloud seeding mission. The important question to be answered from the analysis of the data is whether or not this snow resulted from the seeding. An analysis of the synoptic situation at the approximate seeding time is shown in Figures 3 and 4. A layer of altostratus clouds based at 4,000 feet and extending to 8,700 feet existed in the area at the time of seeding. The temperature at the top of the clouds was measured as -13 degrees centigrade. Figure 5, a rainfall map for the 24 hour period ending 0800 EST, January 22, 1948, indicates the amounts of precipitation in hundredths of an inch of melted snow and the time of first occurrence

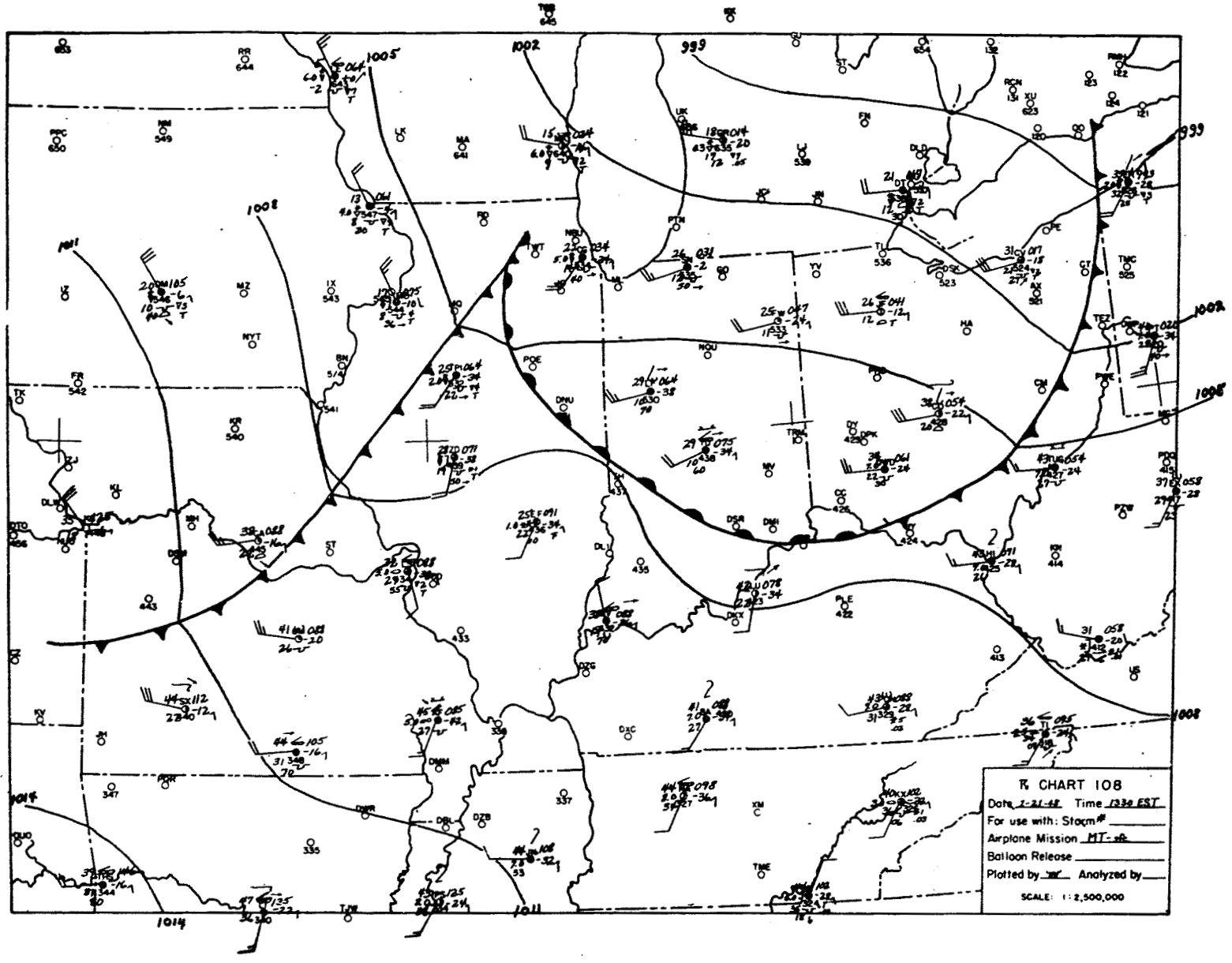

Figure 3.--Surface map, 1330 EST, January 21, 1948

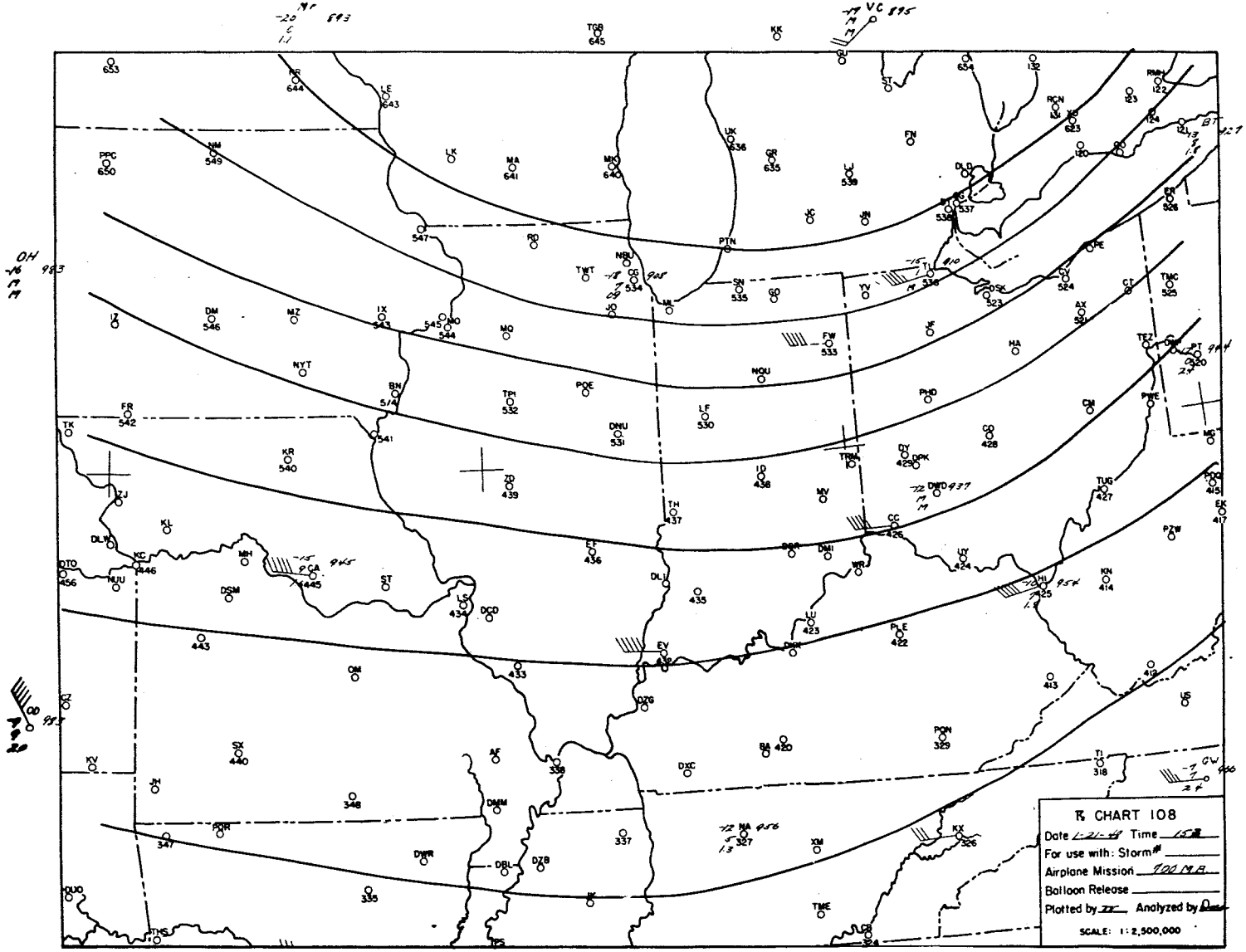

Figure 4.--700 mb. chart, 1100 EST, January 21, 1948.

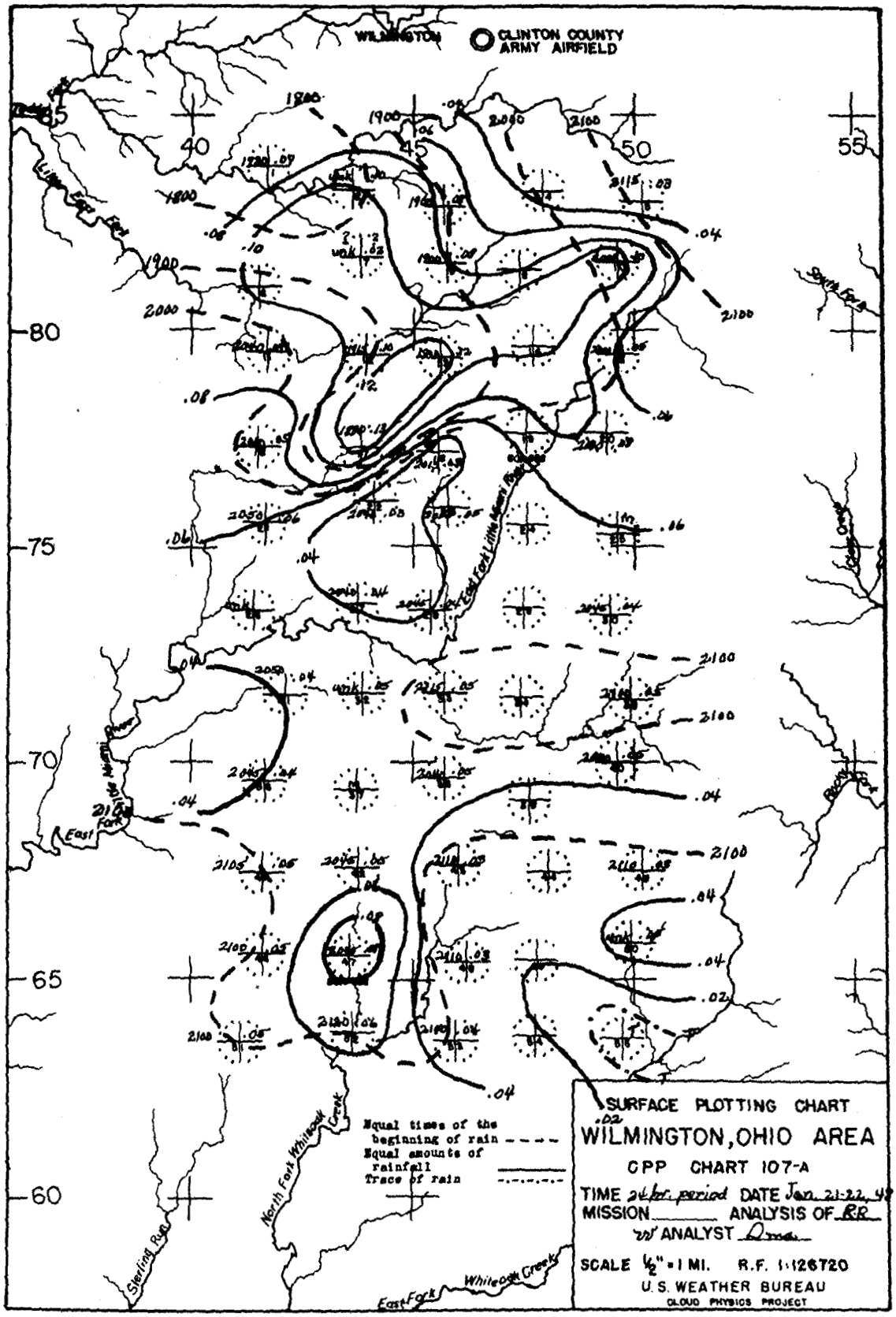

Figure 5.--Times of beginning of precipitation and precipitation amounts for 24 hour period ending 0800 EST, January 22, 1948. (Precipitation amounts in hundredths of an inch.)

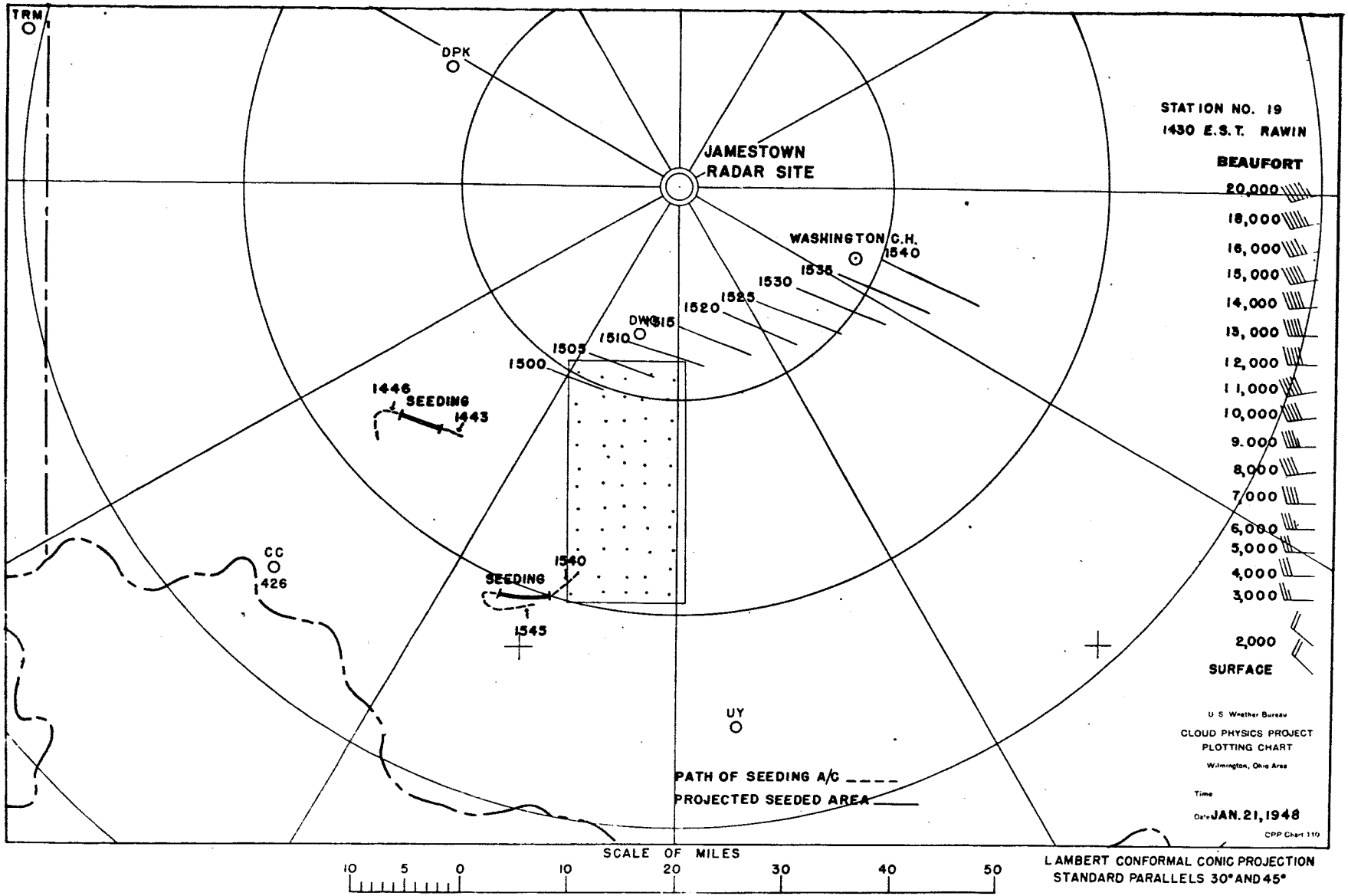

Figure 6.--Paths of seeding aircraft and projected positions of seeded cloud, January 21, 1948.

of sufficient snow to actuate the rain gages. It should be noted that the Ferguson type weighing rain gages used are not too satisfactory for indicating the time of beginning of snow, for it takes at least .01 inch of melted precipitation to cause a motion of the recording arm. It is possible for light snow to fall for several hours before enough is accumulated to show on the rain gage. Precipitation reports are also available from other recording rain gages in the area whose locations have already been indicated in Figure 2.

The first task in analyzing the data is to ascertain the place of seeding and the path followed by the seeded clouds. This is absolutely necessary in order to determine if the precipitation that fell, as indicated in Figure 5, came from the seeded clouds. By a direct operation, it is possible to trace onto a single map consecutive positions of each of the aircraft from the projected enlargements of the radar pictures. Figure 6 indicates the paths of the seeding plane at the time of the two seedings. The first seeding run was made from 1443:45 EST to 1445:15 EST when dry ice was dropped into the cloud at the rate of 4 lbs. per mile. Examples of radar pictures used are shown in Figures 7 through 14. The range circles are at 10 mile intervals. The vertical line runs north-south while the others are spaced at intervals of 10 degrees. From these, the position of each aircraft can be found from its coded beacon signal.

Before seeding, the cloud deck was composed of supercooled water droplets but ice crystals formed immediately along the seeded line as the dry ice was dropped. Figure 15, which was taken from 12,000 feet directly above the seeded line and about one minute after the conclusion of the seeding, indicates the immediate effect. Although the picture is somewhat blurred, the seeded line can be seen running from the top center of the picture toward the lower left corner. Observers in the high photo plane reported that the seeding aircraft looked like a snow plow moving across the cloud deck. A trough about 300 feet deep soon developed in the overcast along the seeded line, and clouds along its edges boiled up an estimated 100 feet (see Figure 21). These changes in the cloud structure made it possible for planes to follow the seeded area for about 45 minutes before mixing dissipated the lines of demarcation between the clouds affected by the seeding and others unaffected. From the reported positions of the airplanes with respect to the seeded area, it was possible to get several approximate positions of the seeded cloud. Particularly accurate fixes can be obtained from the path of the high photo plane which was known to be directly over the seeded area when its vertical camera photographed the seeded line. Small irregularities in the path were smoothed to obtain the one used in the analysis. Positions at several consecutive five minute intervals were calculated and they are indicated on Figure 6 and Figures 7 through 14. These positions were then used as reference marks in studying the source of precipitation measured on the ground.

The first snow echo to be detected by the radar and resulting from the seeding is shown on Figure 9 taken approximately 30 minutes after the seeding operation. The position of the echo corresponds very well with that of the seeded line, as determined above. It should be noted that Figure 7, a picture of the radar screen taken 15 minutes earlier, indicates the presence of snow echoes in the immediate vicinity which could not have been caused by the seeding. Thus, the first conclusion to be made is that the seeding resulted in the production of a precipitation area which was indicated on the radar scope and was also verified by visual observation from an aircraft flying beneath the cloud, but that similar snow echoes existed in the immediate undisturbed area.

The movement of the precipitation associated with the seeded area can be seen from the radar photographs. Also shown on several of these are the calculated positions of the top of the seeded cloud. In general, it appears that the snow echo lagged behind the seeded area from which it originated. This can be accounted for by considering the vertical wind shear that existed on this particular day. The seeded clouds moved from a direction of 250° at 51 miles per hour. This movement was slightly different from the winds measured to be from 260° between 45 and 50 miles per hour at the seeded altitude. The vertical distribution of winds, shown in Figure 6, was computed from data secured simultaneously with the seeded run. These data show that the wind speed at 4,000 feet was only 26 miles per hour, about half that at the seeded level. Therefore it seems quite logical that snow from the seeded area would fall from the cloud somewhat to the windward of the cloud top position marked on the radar scope pictures. Since wind directions were nearly constant from the surface to the seeded level, the falling snow should have reached the ground near the path followed by the seeded cloud. The seeded area passed over rain gages in the northern part of the Cloud Physics Project network (see Figure 6) and also over or near the rain gage at Washington, C. H., Ohio. Crews in the planes did not follow the seeded cloud as far as Washington, C. H., but extrapolation of the path of the seeded cloud and its precipitation echo shows that the area passed very close to the town. However, examination of Figure 12 shows that the echo that resulted from the seeding had almost disappeared by the time it had reached this particular rain gage station. Snowfall from the seeded clouds, while crossing the surface network, was too small to affect the rain gages; therefore, we do not have an actual record which would verify that snow reached the ground at that time. However, an observer at one of the northern stations in the rectangular network reported light snow flurries at 1510 EST. These quite probably fell from the seeded clouds. The recording rain gage at Washington, C. H., recorded .07 inch of melted snow from 1500 to 2000 EST; but by 1600, only .01 inch of the precipitation had fallen into the recording gage. Even if snow from the seeded cloud did persist until it had passed over this gage, it would have stopped falling by about 1600. Since so many unseeded clouds in the neighborhood were precipitating, it is logical to assume that most of the .07 inch of melted snow came from unseeded clouds.

An examination of the radar pictures shows that a snow echo began to develop somewhat to the south of the original seeded area by 1535 EST. Since it is apparent that naturally caused snowfall was prevalent in the general area previous to the seeding, it is not definite that this snow resulted from the seeding. If it had resulted from seeding, it would have developed much farther to the east in a position very close to the seeded line. Snow continued to fall from the unseeded clouds for several hours after completion of the mission. However, the snow did not become heavy enough to affect the rain gages of the Cloud Physics Project until 1800, long after the seeded cloud had passed to the east. By this time snow which probably resulted from warm front action was reported at such distant stations as Dayton, Indianapolis, Toledo, Fort Wayne, and Cincinnati, several of which are to the windward of the area of seeding operations.

Prints of photographs taken from 12,000 feet above the seeded deck are shown in Figures 15 through 20. Although aged film and poor processing detract from the clarity of these pictures*, it is still possible to determine the outlines of the ice crystal area. These photographs, on which the seeded area can be recognized, cover the seeding run and a subsequent period of approximately 30 minutes. Analysis of the pictures makes it possible to study the rate of growth of the seeded line. Various portions of the seeded area appeared to grow at different rates. First, one part of the

*It may be worthwhile to mention that vertical photography of such flat stratus decks is indeed difficult because of the lack of contrast in such decks.

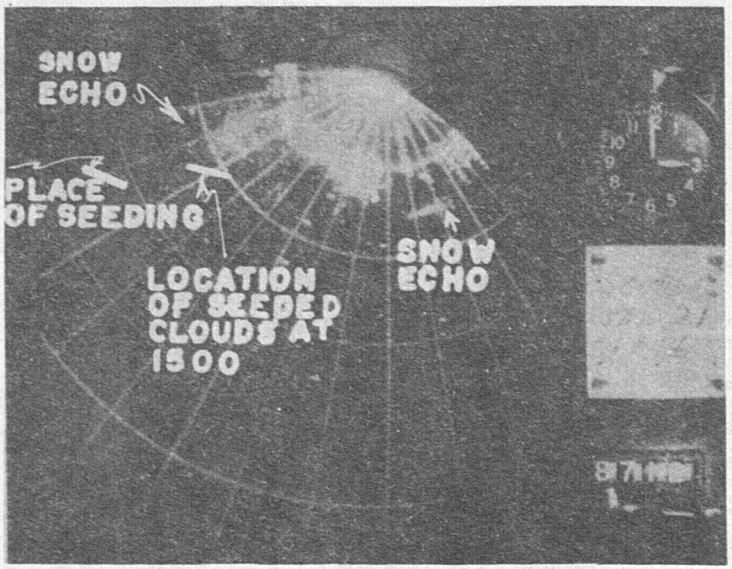

Figure 7

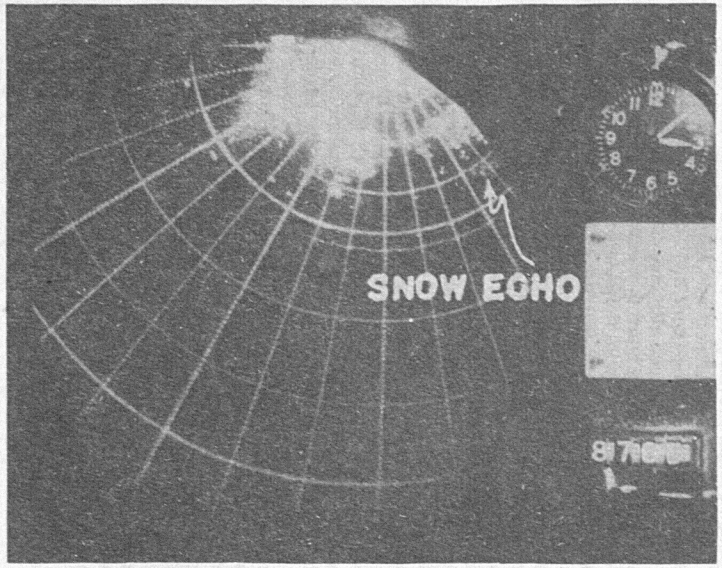

Figure 8

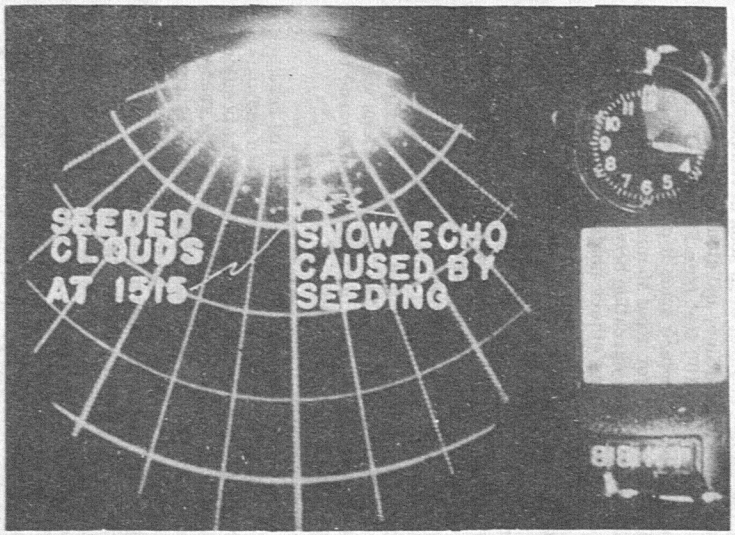

Figure 9

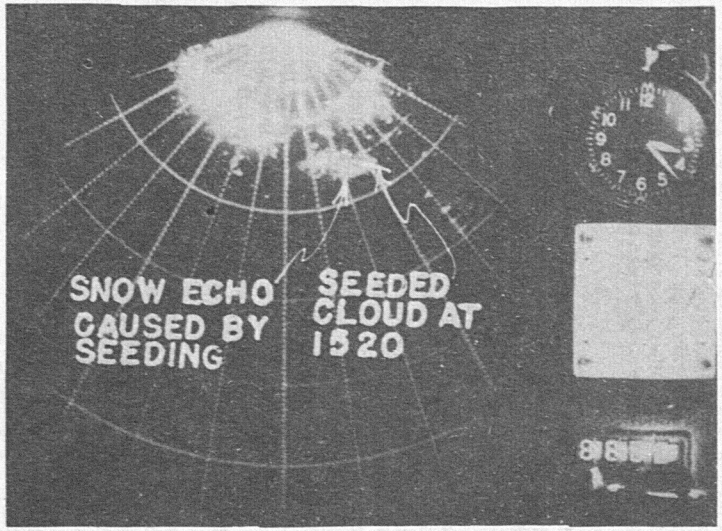

Figure 10

Figures 7-10.--Radar scope pictures for first seeding run, January 21, 1948

Figure 11

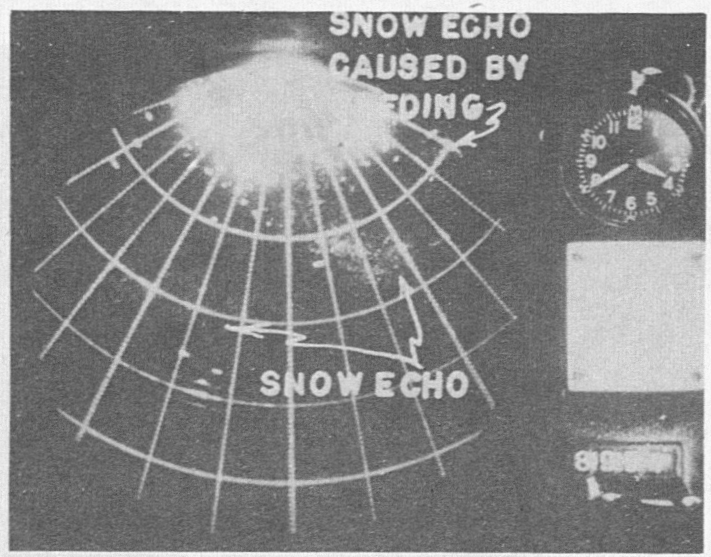

Figure 12

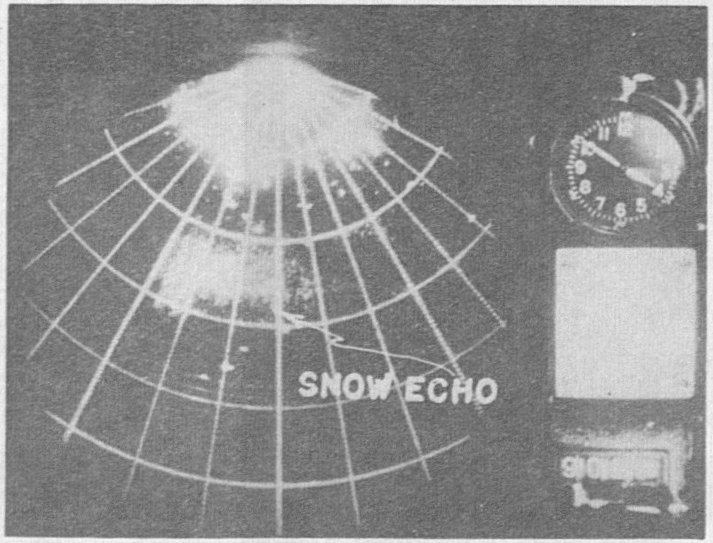

Figure 13

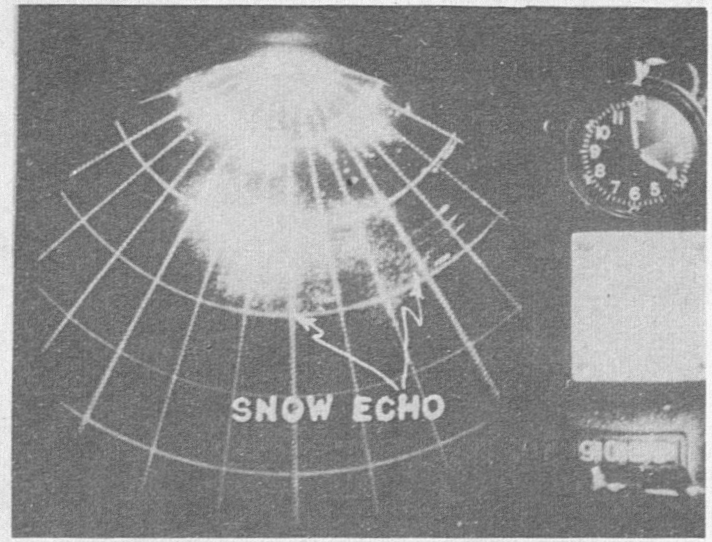

Figure 14

Figures 11-14.--Radar scope pictures for first seeding run, January 21, 1948

Figure 15.--Vertical view of portion of seeded line taken at 1445 EST, January 21, 1948, immediately after dry ice drop.

Figure 16.--Vertical view at 1452 EST, January 21, 1948. Seeded area is at top left. This picture should be compared with Figure 21, an oblique taken at the same time. The overlap of the two views is apparent.

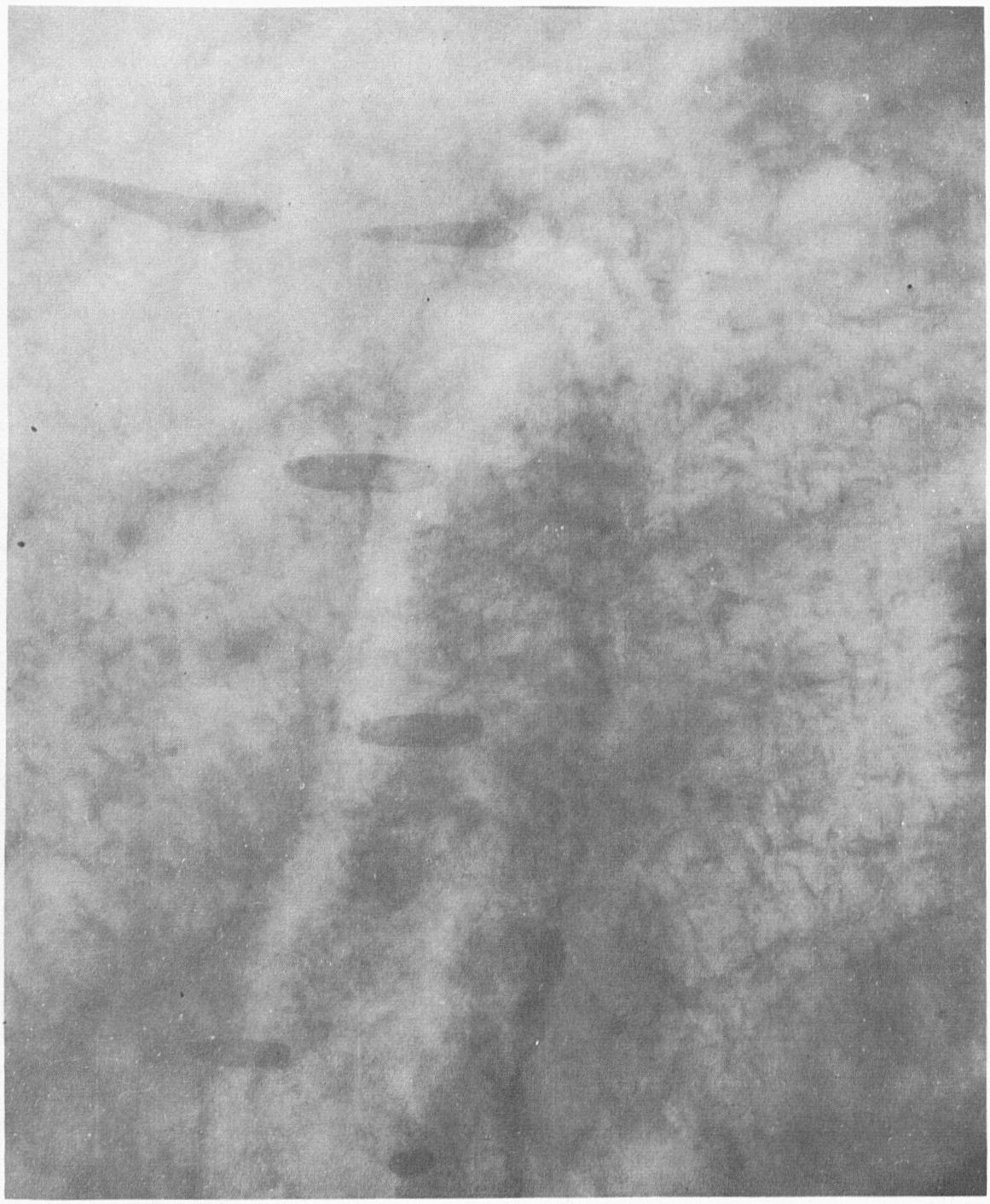

Figure 17.--Vertical view at 1457 EST, January 21, 1948. The lateral diffusion of the ice crystal area can be seen when comparing this picture with Figure 16.

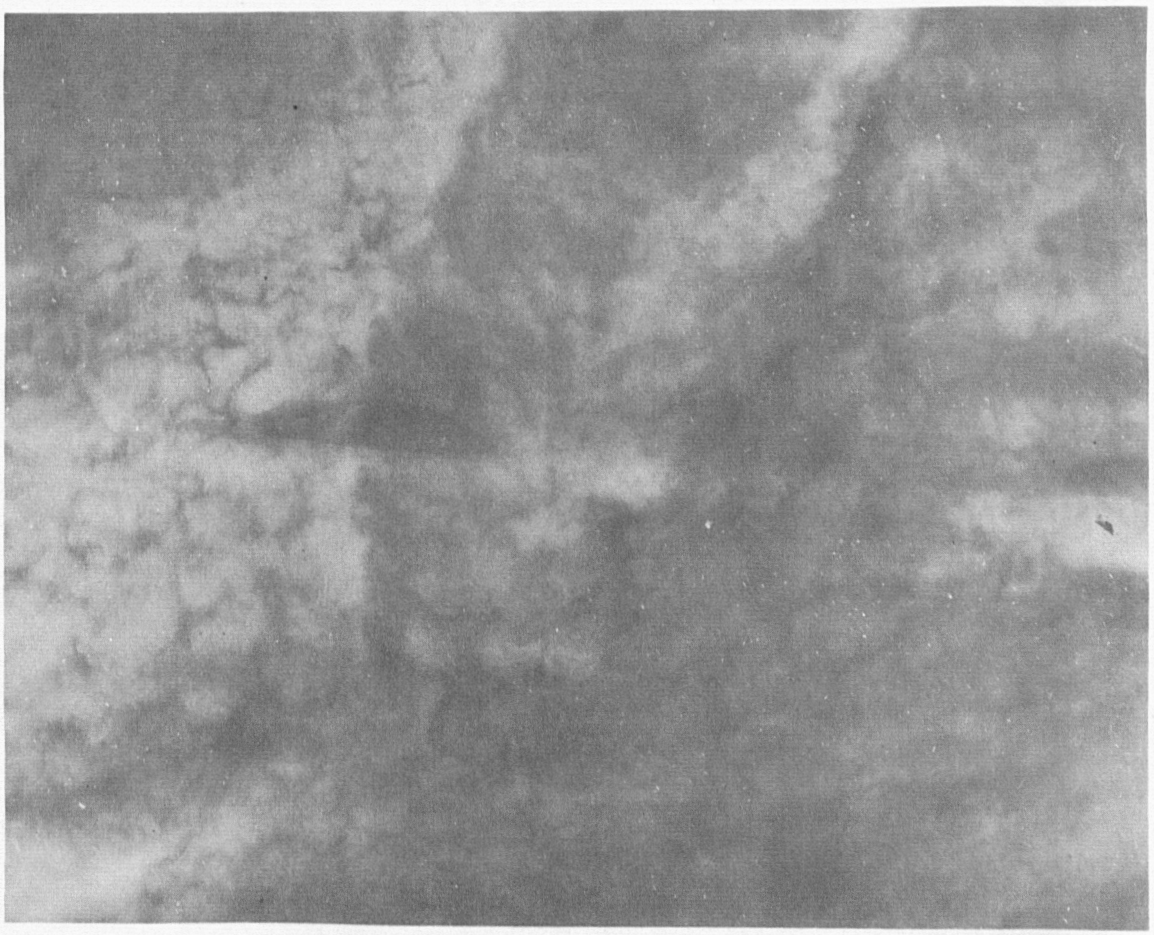

Figure 18.--Vertical view at 1501 EST, January 21, 1948. The northwest extremity of the seeded line is shown.

Figure 19.--Vertical view at 1506 EST, January 21, 1948. The seeded area covers the left side of the picture. Water cloud can be seen reforming in the seeded trough.

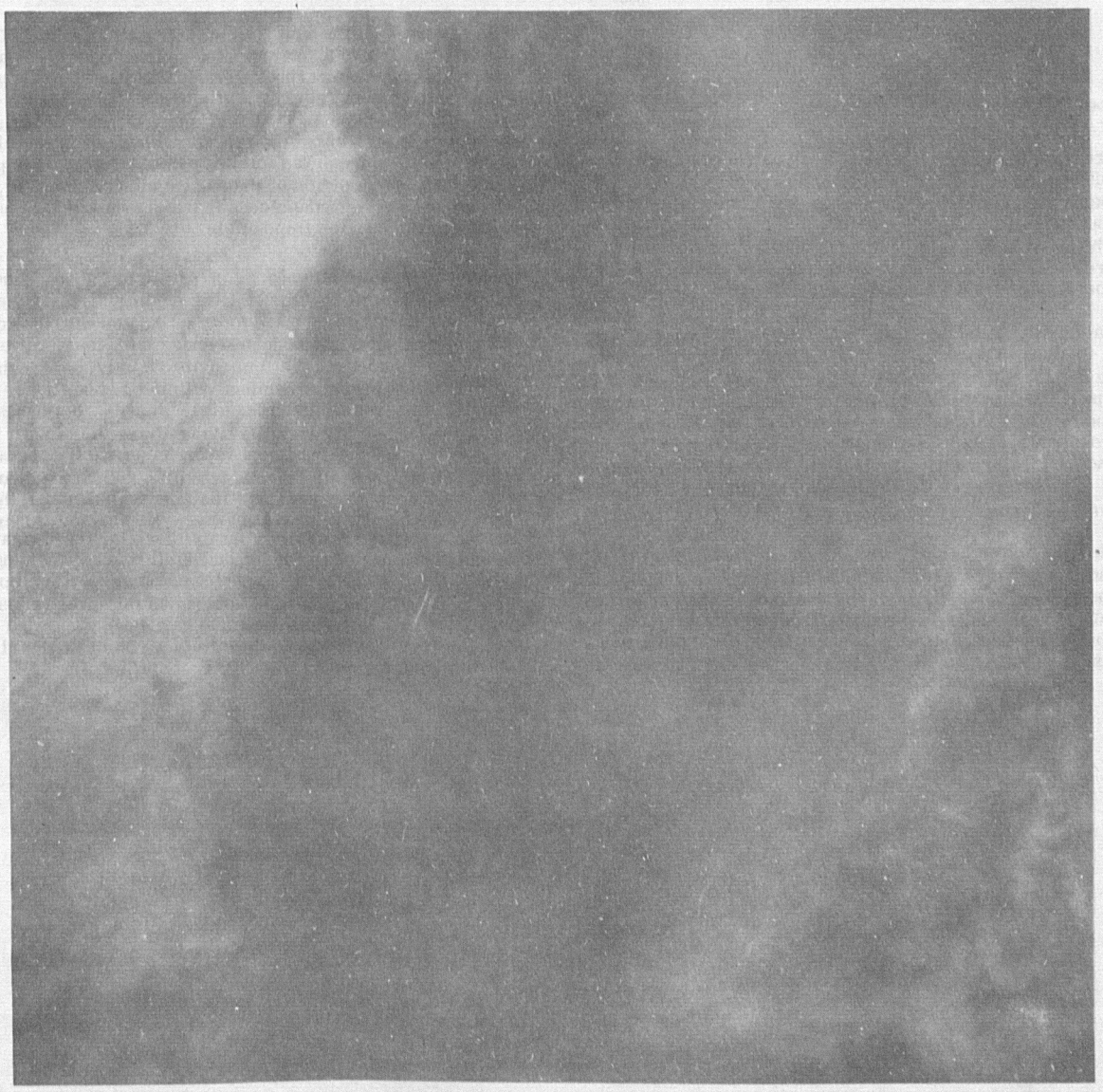

Figure 20.--Vertical view at 1515 EST, January 21, 1948. The seeded area runs from bottom to top center of picture. Figure 23, an oblique view taken at the same time, indicates the broken condition of the unseeded cloud deck.

Table 1.--Rate of Lateral Diffusion of Effects of Seeding

Photographic Run	Time Lapse in Min. from Previous Fix	Increase in Width in Feet Since Previous Fix	Rate of Growth Since Previous Fix. Feet/Min.
1	1.0	385	385
2	4.5	1,615	360
3	4.0	2,000	500
4	4.5	1,000	250
5	6.5	3,500	540
6	9.0	3,500	390
Total	29.5	12,000	
		Average	404

area would expand rapidly, then its rate of growth would subside to some extent while another section would start to expand. In computing the average rate of growth, one spot was picked which had easily-recognizable contours and whose rate of growth seemed about average for the whole area. The width of the seeded area was calculated at this spot for the first 6 photographic runs.

Calculation of the width is fairly simple. The focal length of the lens is 6 inches and the width of the film is 9 inches, so that the width of the area covered by each picture is 1 1/2 times the distance from the top of the cloud to the photo plane. The altitudes at these points are easily determined from photographs of radio altimeters installed in the photo and seeding aircraft. Table 1 gives the rate of expansion of the seeded area at a point which appeared to have an average rate of growth.

Oblique photographs from the same photo aircraft are shown in Figures 21 through 23. These photos indicate the condition of the clouds nearby and show several naturally caused openings. The lower parts of these also show sections of the seeded area. Examination of these pictures and visual reports indicate that the seeding did not cause any hole of appreciable size to be formed in the cloud deck. However, the visibility within the seeded portion was increased slightly, and from beneath the clouds, visual observers reported that the base of the seeded area appeared brighter than that of the surrounding cloud.

The second seeding run was started at 1540:30 EST as indicated in Figure 6 and was only 9 miles south of the area where snow was occurring naturally. Dry ice was dropped at the rate of 4 lbs. per mile. Before the seeding run was completed, the plane passed over an area that was entirely free of clouds. No precipitation or changes in the cloud structure were observed following this seeding. It is possible that some portion of the seeded cloud dissipated, but the broken nature of the clouds in the area made any observation of dissipation impossible.

In summary, a definite change in texture of the supercooled cloud deck was caused by the first seeding. Shortly thereafter a radar echo was noted to be associated with the seeded area and snow was observed underneath it. However at the same time and in the immediate vicinity, snow echoes were existing or were forming. Within one hour after the seeding, the area could no longer be visually distinguished by observers in the aircraft flying above the cloud. The snow echo, as indicated on the radar scope, had disappeared also. At no time was there a definite hole broken through the cloud deck as a result of the seeding, although there were large breaks indicated nearby. There was no concrete evidence that the seeding caused either a self-propagating storm or the one inch of snow which fell south of Wilmington within 18 hours after the completion of the seeding operation. Without the facilities utilized on this project, especially the radar, it probably would have been concluded that the one inch of snow was definitely a result of the cloud seeding operation.

Figure 21.--Oblique view of seeded area at 1452 EST, January 21, 1948, shows vertical development on edges with sinking in middle.

Figure 22.--Oblique view at 1513 EST, January 21, 1948, shows natural openings in the seeded cloud deck. Also note the edge of the deck at the top of the picture.

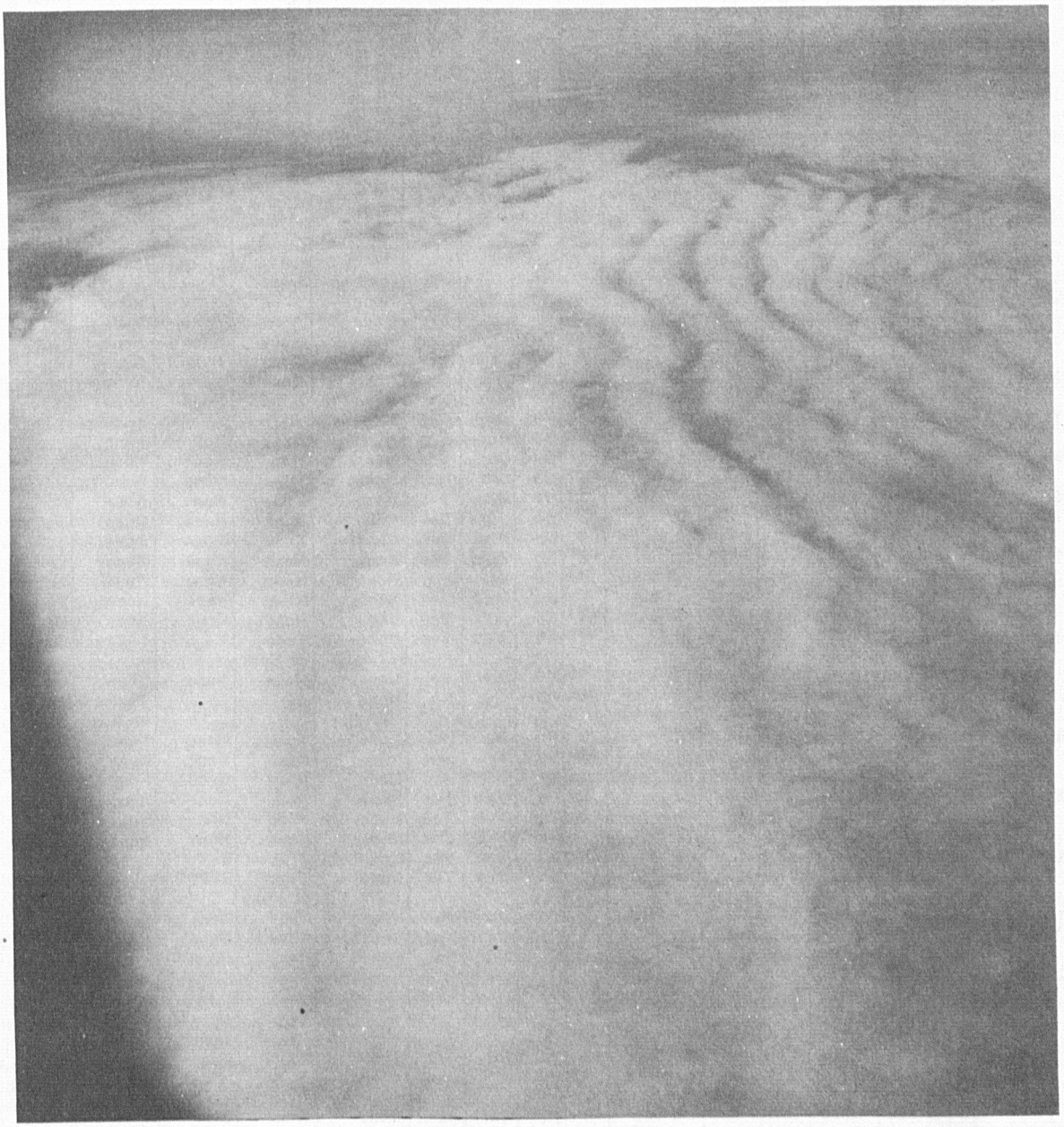

Figure 23.--Oblique view at 1515 EST, January 21, 1948, shows natural openings in cloud deck. This picture should be compared with Figure 20, a vertical view of the seeded area at the same time.

Table 2. -- Summary of results of 38 operations for seeding stratiform clouds, Ohio, 1948

Date	Seeding Run	Height of Top of Seeded Clouds (feet m.s.l.)	Height of Base of Clouds (feet m.s.l.)	Temperature at Top of Seeded Clouds (degrees centigrade)	Temperature at Base of Clouds (degrees centigrade)	Type of Clouds Seeded	Rate of Seeding (lbs. per mile)	Was Hole Formed?	Was Depression Formed?	Were Ice Crystals Observed in Cloud Deck after Seeding?	Intensity of Echo from Seeded Clouds on Radar Scope	Largest Precipitation Amount Falling in Any Rain Gage from Seeded Clouds	Type of Precipitation Falling from Seeded Clouds	Type and Estimated Amount of Precipitation Falling from Seeded Clouds to Ground	Was Precipitation Falling from Other Clouds in Same Air Mass and within 30 Miles of Seeded Cloud?
1/5/48	a	4,200	3,000	-6.0	-6.0	Sc	1	No	No	No	None	None	None?	None?	No
1/7/48	a	8,800	8,400	-7.0	-6.0	Sc	?	No	No	No	None	None	None?	None	No
	b	8,800	8,400	-7.0	-6.0	Sc	?	?	?	No?	None	None	None	None	No
1/9/48	a	5,000	2,500	-3.0	-1.2	St	2?	No	Yes	Yes	None	None	None	None	No
	b	5,000	2,500	-3.0	-1.2	St	4?	No	Yes	Yes	None	None	None?	None?	No
1/16/48	a	5,540	3,700	-9.0	-11.0	Sc	1	No	No	No	None	None	None	None	No
	b	5,540	3,700	-9.0	-11.0	Sc	4	No	No	No	None	None	None	None	No
1/21/48	a	8,700	4,000	-13.0	-8.0	Ac	4	No	Yes	Yes	Moderate	.01 in.	S-	S-.01 in.	Yes
	b	8,700	4,000	-13.0	-8.0	Ac	4	No	No	Yes	None	None	None	None	Yes
1/30/48	a	11,400	9,000	-7.0	-4.0	As	4	No	Yes	Yes	None	None	None	None	No
	b	11,400	9,000	-7.0	-4.0	As	4	No	No	No	None	None	None	None	No
2/5/48	a	6,300	5,500	-5.0	-6.0	Sc	3	No	No	Yes	None	None	None	None	No
2/11/48(AM)	a	4,000	3,000	-2.0	0.0	Sc	2	No	No	No	None	None	None	None	No
	b	4,000	3,200	-2.0	0.0	St & Sc	2	No	Yes	Yes	None	None	None	None	Yes
2/11/48(PM)	a	4,900	3,000	+1.0	0.0	Sc	4	No	Yes	Yes	None	None	None	None	Yes
2/25/48	a	12,500	10,500	-4.0	-1.0	As & Ac	2	No	No	No	None	None	None	None	Yes
	b	12,000	10,500	-3.0	-1.0	As & Ac	2	No	Yes	Yes	None	None	None	None	Yes
	c	14,000	10,500	-6.0	-1.0	As & Ac	11	No	Yes	Yes	None	None	None	None	Yes
3/3/48	a	4,500	2,200	-3.0	0.0	St	1	No	Yes	Yes	None	Trace or None	L-	L-Trace	Yes
	b	4,500	2,200	-3.0	0.0	St	3	No	No	Yes	None	None	None	None	Yes
	c	5,000	2,200	-3.0	0.0	St	24	No	No	No	None	**	L- .	Trace or None	Yes
3/4/48	a	4,400	3,400	-8.0	-7.0	Sc	2	No	No	No	None	None	None	None	No
	b	4,550	3,400	-8.0	-7.0	Sc(Dsptg)	15	No	No	No	None	None	None	None	No
	c	5,200	3,400	-9.0	-7.0	Sc(Dsptg)	1	No	No	No	None	None	None	None	No
3/8/48	a	4,500	3,200	-3.0	-5.0	Sc	3	No	Yes	Yes	None	None	None	None	No
	b	4,500	3,200	-3.0	-5.0	Sc	8	Yes	Yes	Yes	None	None	None	None	No
	c	4,500	3,200	-3.0	-5.0	Sc	5	Yes	Yes	Yes	None	None	None	None	No
3/11/48	a	6,400	2,800	-8.0	-11.0	St	5	No	Yes	Yes	None	Trace	S-	S-Trace	Yes
	b	6,400	2,800	-8.0	-11.0	St	2	No	Yes	Yes	None	Trace or None	S-?	S-Trace	Yes
4/1/48	a	10,100	9,500	-5.0	-3.5	Ac	8	No	No	No	None	None	None	None	Yes
	b	12,000	9,500?	-8.0	-3.5	Ac	7	No	No	No	None	None	None	None	No
	c	12,700	9,500?	-9.0	-3.5	Ac	4	No	No	No	None	None	None	None	No
4/2/48	a	12,400	7,500	-19.0	-7.2	Cu Top Abv. Ac Deck	15	No	No	?	None	None	S-(before and after seeding)	None	Yes
	b	13,500	7,500	-17.5	-7.2	Cu Top Abv. Ac Deck	15	No	No	?	None	None	None	None	Yes
	c	11,600	7,500	-15.1	-7.2	Cu Top Abv. Ac Deck	5	No	No	?	None	None	S-	None	Yes
4/29/48	a	10,000	7,500	-8.0	-4.0	As - Ac	8	No	Yes	Yes	None	None	None	None	No
	b	10,000	7,500	-8.0	-4.0	As - Ac	8	No	Yes	Yes	None	None	None	None	No
	c	10,000	7,500	-8.0	-4.0	As - Ac	8	No	Yes	Yes	None	**	R-?	None?	Yes

** No Rain Gage in Proper Location

Other Seeding Experiments

Summaries of each of the seeding operations conducted between January 5 and May 1, 1948, conclude this report. The results in each case are based upon an analysis procedure such as described above.

The overall results of the investigation to date are briefly stated in Tables 2 and 3.

Table 3.--Cloud dissipation results of seeding stratiform clouds (based on Table 2.)

Observed	No. of Cases
Hole Opened	2
Depression Formed Only	15
Change in Cloud Structure Only	3
No Effects Observed	18

Cloud Seeding of January 5, 1948

Synoptic Situation--The seeding area was located in a weak north-south circulation between two cold frontal systems - one cold front off the Atlantic Coast and another through Iowa approaching the seeded area at a moderate rate.

Atmospheric Sounding--The cloud seeded was a stratocumulus deck approximately 1,200 ft. thick. The cloud base, 3,000 ft. m.s.l., was just below an isothermal region; the cloud top, 4,200 ft. m.s.l., extended into the constant temperature portion of the ascent curve. Distribution of temperature and moisture indicated that the cloud was the result of turbulent mixing in the lower levels of the air mass. The lapse rate was dry adiabatic from the ground to the base of the cloud. The average lapse rate from the base of the cloud for two thousand feet above the top of the cloud was stable. Figure 24 shows the complete temperature - moisture relationships plotted on a pseudo-adiabatic chart.

Conditions of Seeding--The cloud deck was supercooled with temperatures of approximately -6.0 degrees centigrade throughout. One seeding run was made.

Rate of Seeding--Three pounds of dry ice were dropped at the rate of one pound per mile.

Time and Duration of Seeding--The drop was made in the afternoon; actual time of seeding is not available.

Results--The observed dissipation and structural results were negative. Since no results were observed after ten minutes, the area was abandoned because of difficulty in tracking the seeded cloud. Negative precipitation results were questionable; but if any precipitation did fall from the seeded cloud, neither the precipitation from it nor from any other clouds was observed on the radar scope.

Method of Verification--

1. Structural
   a. First Seeding: Aerial observations (Visual).
2. Precipitation
   a. First Seeding: Visual observations of radar scope; no pictures taken.

Comments--Planes, personnel and equipment were not available for a full scale mission. The main purpose of the flight was to calibrate the ice dispensing mechanism; therefore the observation of seeding results was incidental to the objective of the mission. Furthermore, the Cloud Physics Project was not fully organized so that complete and thorough observations of the results of seeding could be made.

Cloud Seeding of January 7, 1948

Synoptic Situation--The seeding area was on the northern edge of a moderate anti-cyclone. At 0130 EST a frontal system was located through North Dakota and moderate pressure falls were indicated to the northwest of seeding operations.

Atmospheric Sounding--The sounding indicated relatively dry and stable air. The cloud seeded was a stratocumulus cloud deck between 8,400 ft. and 8,800 ft. m.s.l. There was an isothermal layer and an inversion present below the cloud deck with the air relatively dry between these two layers. An almost isothermal layer approximately 95 mbs. thick hindered any future vertical development of the cloud. (See Figure 25.)

Conditions of Seeding--The observed temperatures of the cloud were -7.0 degrees centigrade at the top and -6.0 degrees centigrade at the base. Two seeding runs were made on the cloud deck.

Rate of Seeding--Six pounds of granular dry ice were dropped on the first run and 20 pounds of powdered dry ice were released on the second drop. The actual rate of seeding is unknown, but the rate did not exceed four pounds per mile.

Time of Seeding--The drop was made in the afternoon. Actual time of seeding is not available.

Results--Negative structural and dissipation results were observed on the first run. Reports of observed results after the second seeding run were conflicting. One pilot reported a trough after the seeding, and another pilot observed no change in the cloud. The pilot had the following to report after the second seeding run: "Next run was on 360 degrees in a different locality. I followed the seeding ship this time. Made a wide procedure turn around to observe and noticed a large clearing in the overcast. Jamestown Master Control stated that I was close to the line of seeding and the depression in the overcast was undoubtedly due to the seeding operation. The depression was very large and had misty segments scattered throughout."

No precipitation echoes were observed on the radar scope but since the cloud deck was only 400 ft. thick precipitation should not have been expected from it.

Method of Verification--

1. Structural
   a. First Seeding: Aerial observations (Visual).
   b. Second Seeding: Aerial observations (Visual).
2. Precipitation
   a. First Seeding: Visual observations of radar scope.
   b. Second Seeding: Visual observations of radar scope.

Comments--The flight was controlled by radar from Jamestown. Although the pilot who reported the trough in the overcast was advised that he was in the seeded area, the dissipation results were not conclusive. The cloud deck was so thin that the trough reported may have been a natural one and not the result of the seeding.

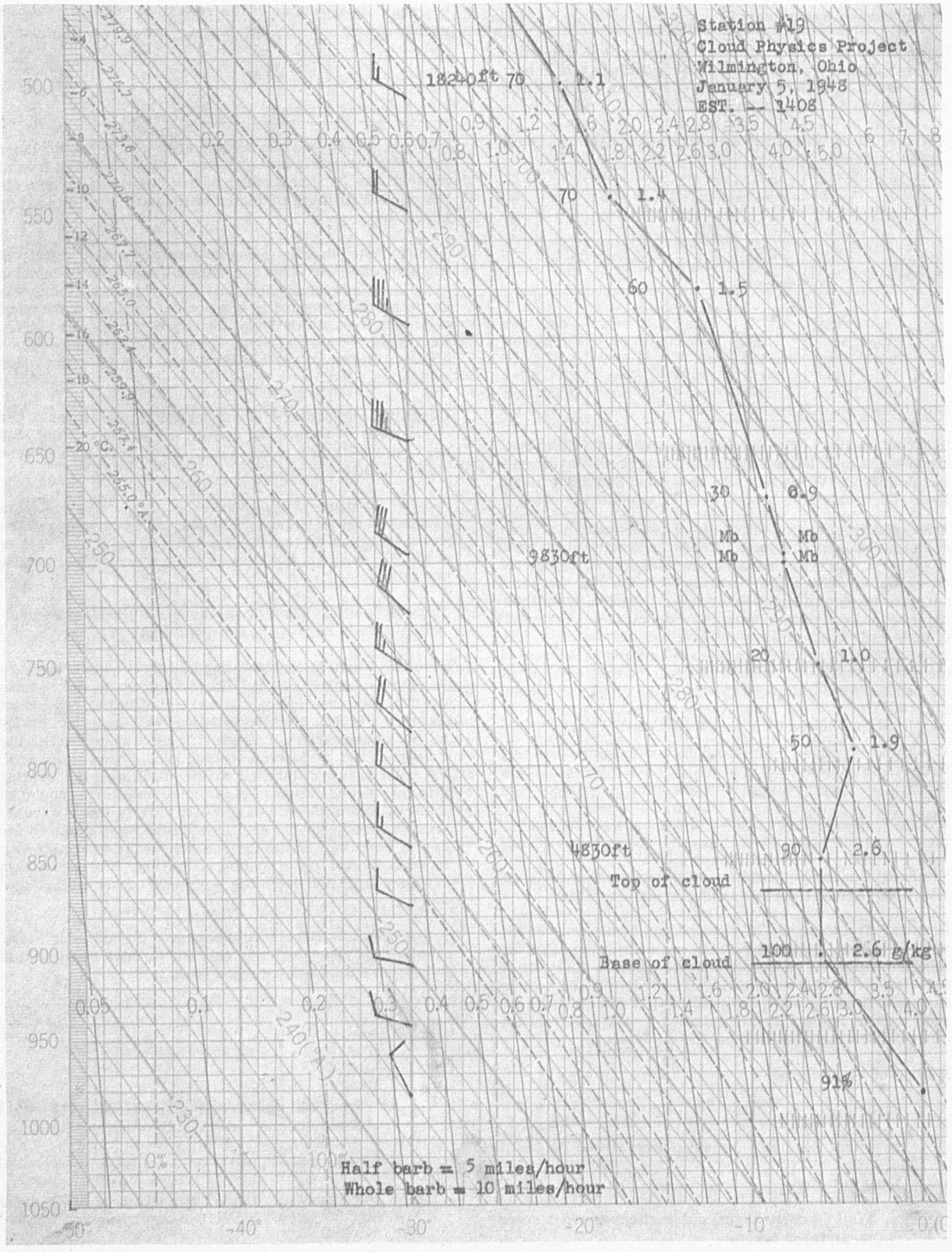

Figure 24.--Atmospheric sounding, 1408 EST, January 5, 1948.

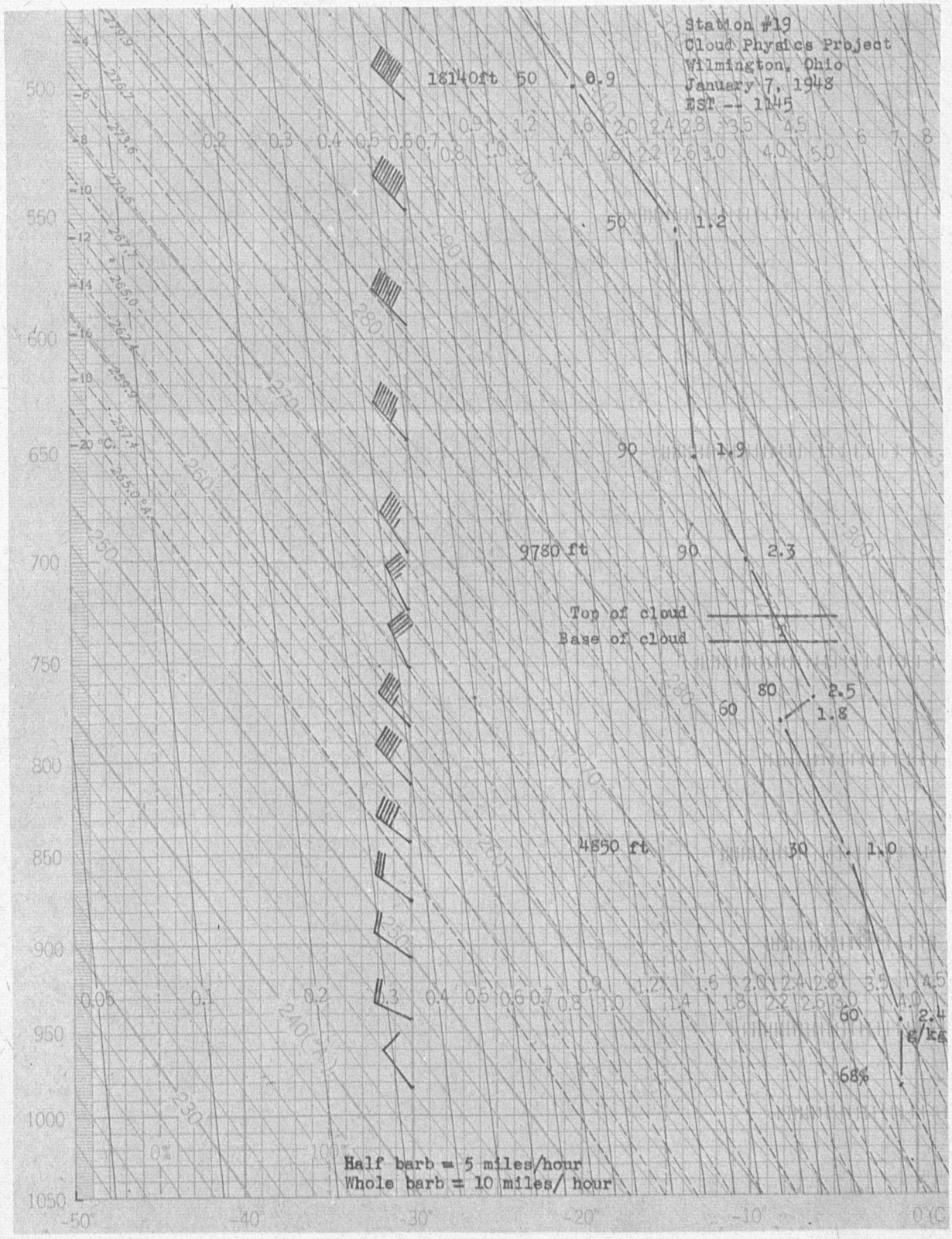

Figure 25.--Atmospheric sounding, 1145 EST, January 7, 1948.

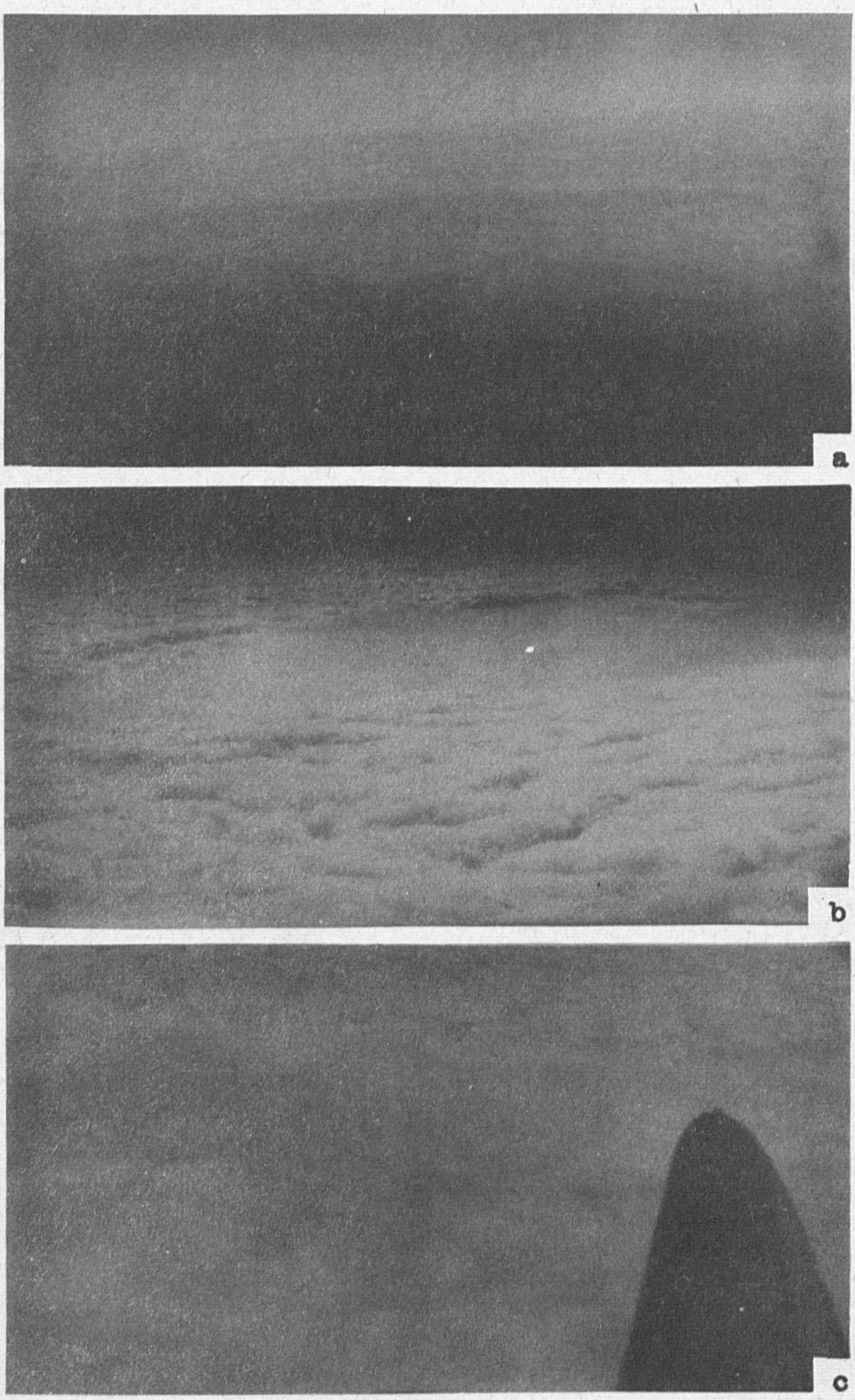

Figure 26.--(a), (b), (c)-Three views of second seeded area taken at different ranges. January 9, 1948.

Cloud Seeding of January 9, 1948

Synoptic Situation--At 0130 EST the seeding area was immediately ahead of a cold front but by the time of seeding operations the area was in a north-south circulation west of the frontal system. A cold front through Iowa at 0130 EST was in the process of dissipation. Large pressure rises were indicated in the cold air mass northwest of the frontal system.

Atmospheric Sounding--No local sounding was made on this date. Because of the synoptic situation, other soundings available in the area present some question as to their representativeness for the locality; therefore no sounding has been included on this date. A stratus deck extending from 2,500 feet m.s.l. to 5,000 feet m.s.l. was seeded.

Conditions of Seeding--Two seeding runs were made. The temperature at the top of the cloud was approximately -3.0 degrees centigrade, but within the cloud it was somewhat colder. The temperature at the base of the cloud was -1.2 degrees centigrade. The clouds, at 4,000 feet m.s.l., were reported by the observers to be heavy when the plane ascended through them.

Rate of Seeding--Three pounds and six pounds of dry ice at the rate of two pounds per mile and four pounds per mile, respectively, were dropped in 30 seconds on the two seeding runs.

Time and Duration of Seeding--

First Seeding: 1523:30 EST; zero plus 30 seconds.
Second Seeding: 1532:40 EST; zero plus 30 seconds.

Results--A change in texture and the formation of a trough approximately 1/2 mile long, 1/8 mile wide and 500 feet deep were observed after both seedings. Both troughs were active for about 30 minutes.

The pilot of the seeding aircraft made the following report: "On the second run, six pounds of dry ice were released over an area of approximately two miles. During the climb up to observe the results, the first seeded area was undergoing a change in texture of the cloud. It became very light in color in comparison with the surrounding clouds; and as the sun was very bright, it would appear that the water in the cloud had turned to ice crystals and was reflecting the light. As the aircraft circled the area, a definite trough formed up gradually with definite walls and slight bulges on the rims. Both seeded areas, within a very short time, were very large; and in flying over the troughs, each was approximately the size of the field here at CCAFB. They appeared to be circular in shape rather than oblong as they were expected to be. Both troughs were active for approximately thirty minutes."

No precipitation was observed to have fallen from the seeded clouds.

Method of Verification--

1. Structural
   a. First Seeding: Aerial observations (Visual).
   b. Second Seeding: Aerial observations (Visual and photographic. See Figure 26, (a), (b), and (c). Note seeded area running from left to right through center of photographs).
2. Precipitation
   a. First Seeding: Surface and aerial observations. Radar inoperative.
   b. Second Seeding: Surface and aerial observations. Radar inoperative.

Comments--The V-Beam radar was not operating and no plane flew beneath the cloud base at the time of seeding to watch for results. Therefore, one cannot be certain that precipitation did not fall from the seeded clouds. However, none was noticed by the planes after they descended through the clouds, and none was reported by the regular surface stations.

Cloud Seeding of January 16, 1948

Synoptic Situation--The 1330 EST surface map indicated that the seeding area was in a relatively dry and cold continental air mass. A cold front oriented northeast to southwest lay along the West Virginia-Ohio state boundaries moving very slowly to the southeast. The only precipitation occurring at 1330 EST was in the immediate vicinity of the cold front.

Atmospheric Sounding--A dry adiabatic lapse rate extended from the surface to approximately 910 mbs. with a temperature inversion from 910 mbs. to 750 mbs. The inversion was more pronounced between 910 mbs. and 830 mbs. The seeded cloud was a stratocumulus deck with its base at 3,700 ft. m.s.l. and its top at 5,540 ft. m.s.l. The cloud was situated in the more stable portion of the temperature inversion. The stability of the air surrounding the cloud would indicate that no vertical development should be expected after the seeding operations. (See Figure 27.)

Conditions of Seeding--The temperatures of the cloud ranged from -11.0 degrees at the base to -9.0 degrees centigrade at the top. Two seeding runs were made. The first seeding was into an overcast, and the second seeding was into a broken cloud layer.

Rate of Seeding--The first seeding was at the rate of one pound per mile and the second seeding was at the rate of four pounds per mile.

Time and Duration of Seeding--

First Seeding: 1408:00 EST; 4 minutes plus zero seconds.
Second Seeding: 1445:55 EST; 1 minute and 20 seconds.

Results--No precipitation or structural changes were reported by any observers in the planes.

Method of Verification--

1. Structural
   a. First Seeding: Aerial observations (Visual).
   b. Second Seeding: Aerial observations (Visual).
2. Precipitation
   a. First Seeding: Radar pictures showed no precipitation in or around the seeded area.
   b. Second Seeding: Radar pictures showed no precipitation in or around the seeded area.

Comments--This was the first flight organized in which as many as four planes cooperated. The main purpose of the flight was to give all personnel practice to test various pieces of equipment as well as coordination techniques. The temperature in the clouds was low enough to meet the theoretical criterion for dissipation of the clouds; therefore the negative results are significant. Since the humidity data from the radiosonde soundings were low, the liquid water content of the clouds was probably near zero; consequently no precipitation should have been expected.

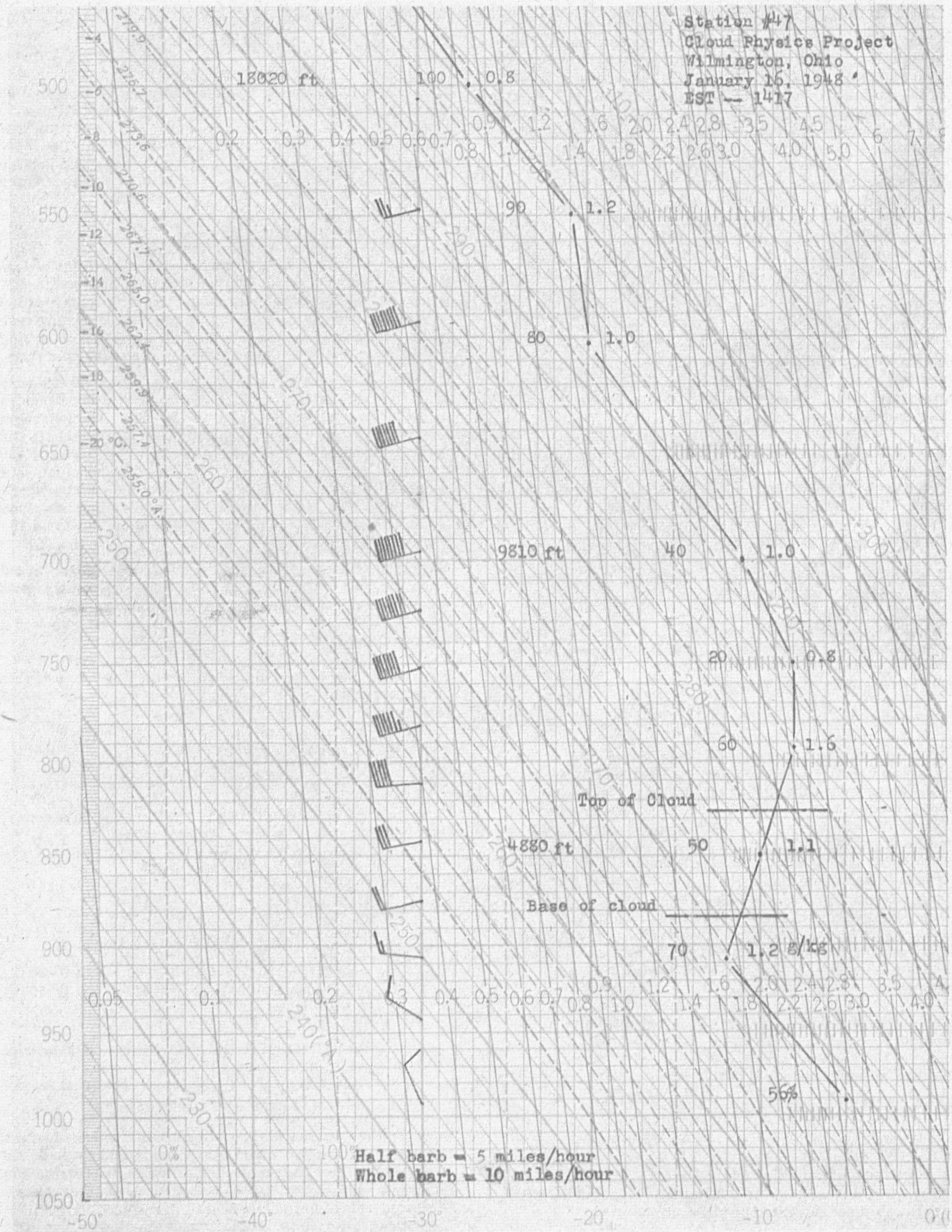

Figure 27.--Atmospheric sounding, 1417 EST, January 16, 1948.

Cloud Seeding of January 21, 1948*

Synoptic Situation--The seeding area at 1330 EST was located just north of a frontal system oriented northeast to southwest from northeastern Ohio to northern Kentucky; thence as a warm front from that point to northern Illinois. The 1330 EST surface map did not indicate any precipitation north of the frontal system, but scattered snow showers developed in the seeding area prior to the seeding operations. Pressures were falling rapidly on both sides of the front.

Atmospheric Sounding--The sounding was conditionally unstable from the surface to 850 mbs. and stable throughout the remainder of the ascent curve. The altocumulus cloud deck which was seeded extended from 4,000 ft. m.s.l. to 8,700 ft. m.s.l., with conditionally unstable air below the bases and stable air above the top of the cloud. (See Figure 28.)

Conditions of Seeding--Two seeding runs were made. The temperatures of the cloud ranged from -8.0 degrees at the base to -13.0 degrees centigrade at the top of the cloud. Snow was falling about 20 miles north of the first seeded area and about 9 miles north of the second seeded area at the time of the respective seedings.

Rate of Seeding--Dry ice pellets were dropped at the rate of four pounds per mile on both seeding runs.

Time and Duration of Seeding--

First Seeding: 1443:45 EST; one minute plus 30 seconds.
Second Seeding: 1540:30 EST; one minute plus 30 seconds.

Method of Verification--

1. Structural
   a. First Seeding: Aerial observations (Visual and Photographic).
   b. Second Seeding: Aerial observations (Visual).
2. Precipitation
   a. First Seeding: Visual observations (surface and aerial). Radar pictures showed precipitation echoes in seeded area and within 30 miles of seeded area.
   b. Second Seeding: Radar pictures showed precipitation within 30 miles of seeded area.

Cloud Seeding of January 30, 1948

Synoptic Situation--The seeded area was located in a post cold frontal position. On the 1330 EST surface map, the cold front was lying across central West Virginia, northern Kentucky and southern Indiana. Pressure changes of about the same magnitude on both sides of the front indicated that it was a slow-moving cold front. No precipitation was indicated on the surface map to the north of the frontal system at 1330 EST.

Atmospheric Sounding--The sounding taken at 1430 EST indicated, on the average, marked stability above 950 mbs., but it was interspersed with occasional thin layers of conditionally unstable air. The altostratus deck that was seeded had its base at 9,000 ft. m.s.l. which was in an almost isothermal portion of the temperature curve, and top of the cloud deck was at 11,400 ft. m.s.l. - a region of an almost dry adiabatic lapse rate. An inversion, with its base at 620 mbs., indicated that if any vertical currents should develop after the seeding, they would be capped at that level. (See Figure 29.)

Conditions of Seeding--Two seeding drops were made. The temperature at the top of the cloud was -7.0 degrees and at the base it was -4.0 degrees centigrade.

Rate of Seeding--The seeding, on both runs, was at the rate of four pounds per mile.

Time and Duration of Seeding--

First Seeding: 1426:09 FST; three minutes plus 56 seconds.
Second Seeding: 1507:25 EST; four minutes plus 26 seconds.

Results--After the first seeding, a trough about 10 miles long and about 600 ft. wide was observed. The trough was rather shallow. At spots along the seeding line, the ground could be seen through breaks in the clouds but in general the seeded clouds did not dissipate. The clouds along one edge of the seeding line appeared to boil and build above the neighboring clouds. No changes in the texture of contours of the clouds were observed after the second seeding run.

No precipitation was observed after the seeding runs.

Method of Verification--

1. Structural
   a. First Seeding: Aerial observations (Visual).
   b. Second Seeding: Aerial observations (Visual).
2. Precipitation
   a. First Seeding: Visual observations of radar scope at Clinton County Air Force Base indicated no precipitation in or around the seeded area. Rain gages did not record any precipitation.
   b. Second Seeding: Visual observations of radar scope at Clinton County Air Force Base indicated no precipitation in or around the seeded area. Rain gages did not record any precipitation.

Comments--The V-Beam radar at Jamestown, Ohio was inoperative; therefore no full scale mission was organized. We cannot be sure that precipitation did not fall from the seeded clouds; however, the precipitation, if any, was too light to affect recording rain gages or to show on the radar scope at Clinton County Air Force Base. Conditions were favorable for dissipation, so lack of more positive results is significant.

* For complete data concerning this mission, see discussion included elsewhere in this report.

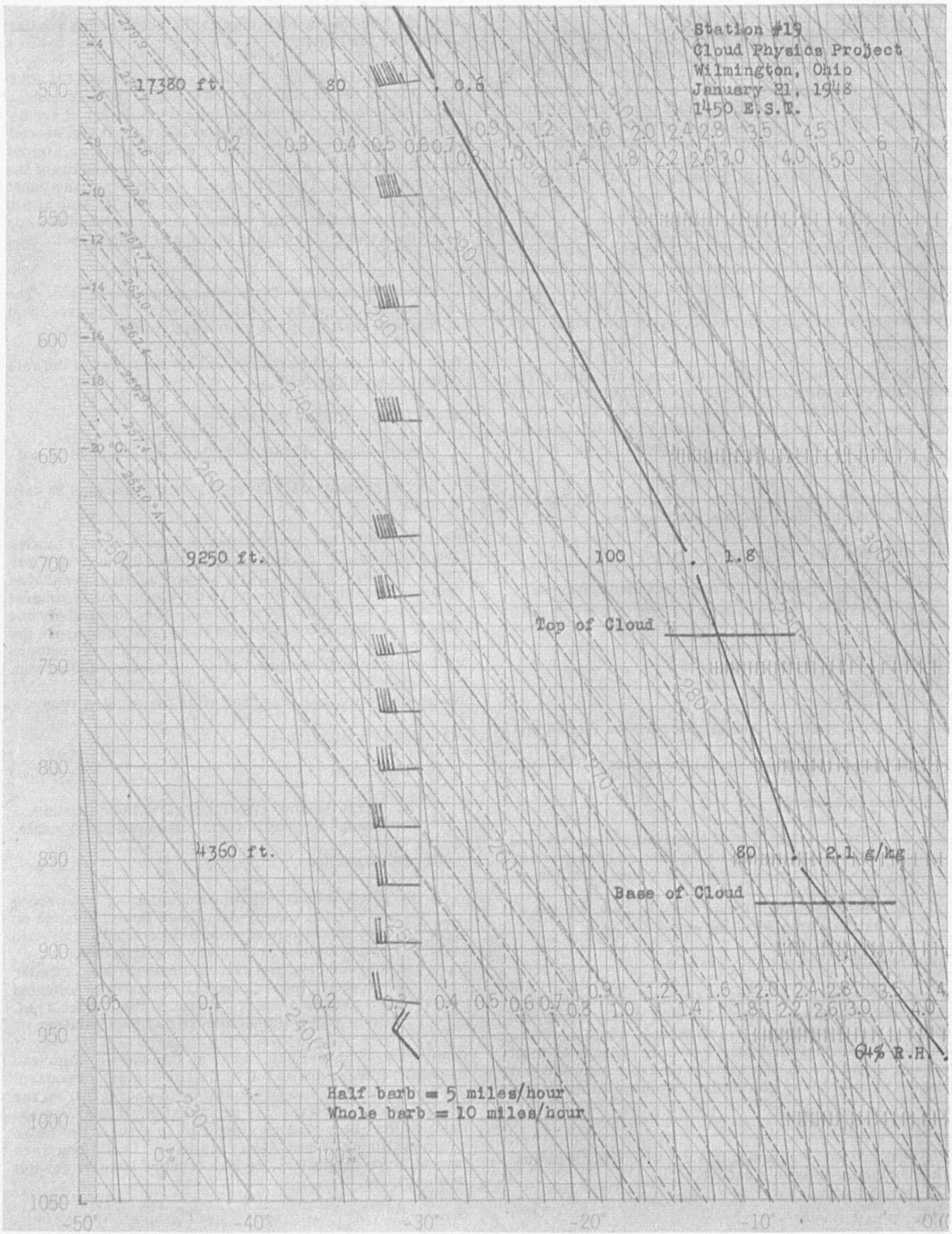

Figure 28.--Atmospheric sounding, 1450 EST, January 21, 1948.

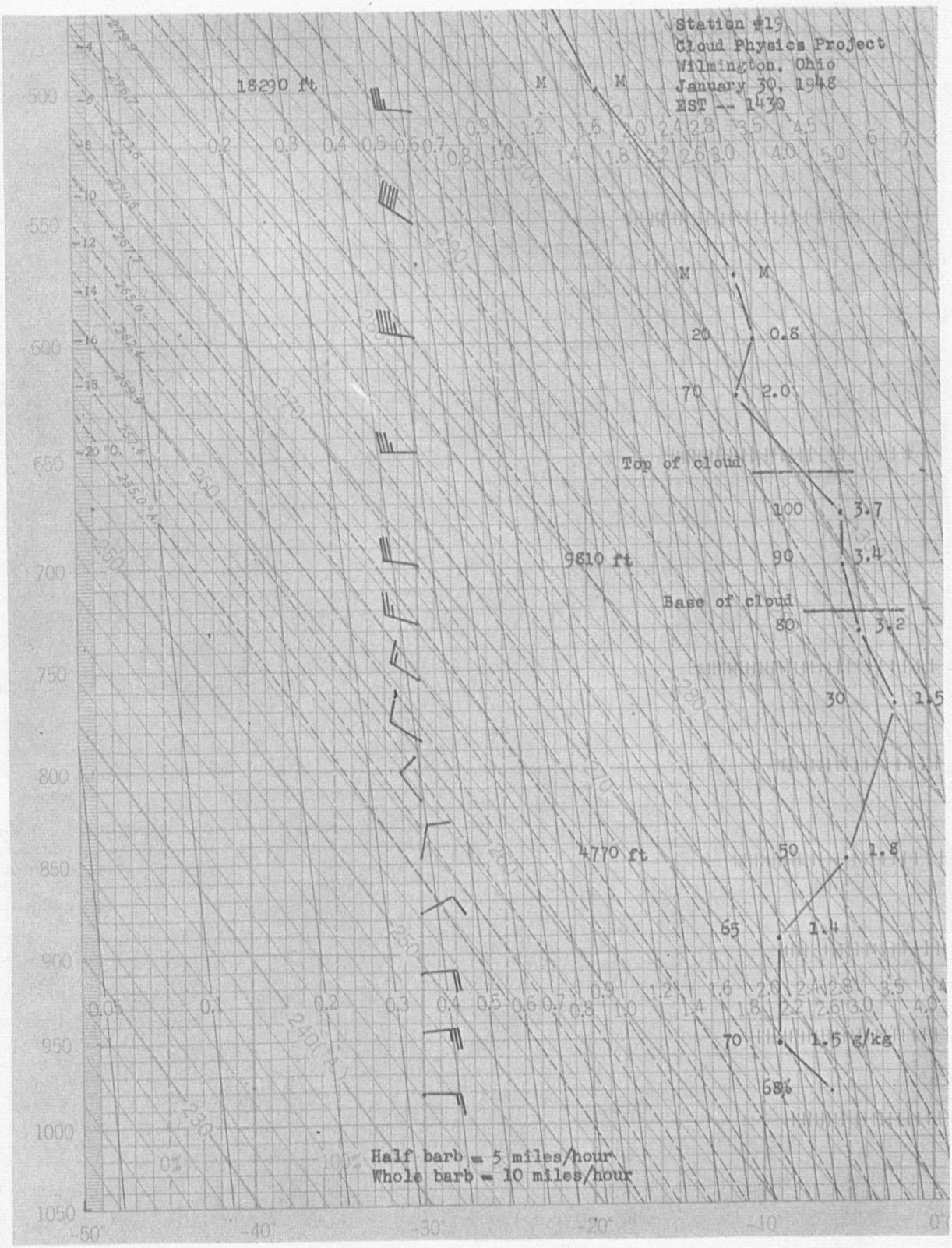

Figure 29.--Atmospheric sounding, 1430 EST, January 30, 1948.

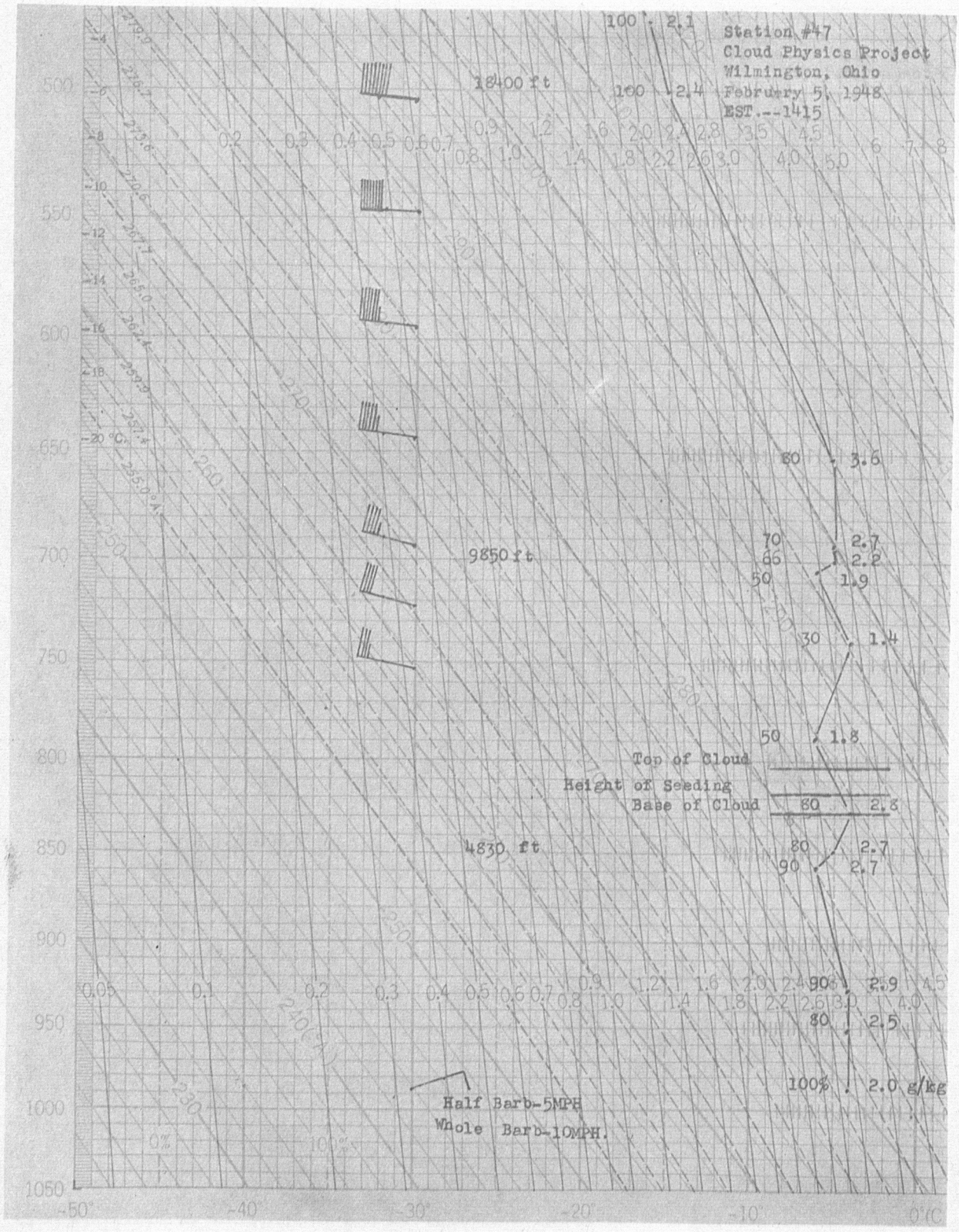

Figure 30.--Atmospheric sounding, 1415 EST, February 5, 1948.

Cloud Seeding of February 5, 1948

Synoptic Situation--The area of seeding operations was located in an air mass situation on the southern edge of a moderate anticyclone. At 1330 EST, the surface map indicated a generally overcast sky condition throughout Ohio, Kentucky, and Indiana. A light intermittent snow shower at Indianapolis, Indiana, was the only precipitation indicated in the vicinity of the seeding area, although, Wilmington, Ohio, recorded a trace of precipitation during the six hour period from 0730 EST to 1330 EST.

Atmospheric Sounding--The sounding at 1415 EST indicated marked stability with numerous inversions and isothermal layers from the surface to 655 mbs. An inversion above the cloud deck indicated that marked vertical currents would be hindered if they should develop after the seedings. The seeded cloud was a stratocumulus deck between 5,500 ft. m.s.l. and 6,300 ft. m.s.l. (See Figure 30.)

Conditions of Seeding--From the ground there appeared to be a solid overcast, but aerial reconnaissance revealed that the solid overcast was actually composed of several layers of broken clouds. The lower cloud deck was seeded twice. The water content of the clouds averaged 0.02 gram per cubic meter, and the average droplet size was 6 microns.

The first drop was made into a hazy portion of one of the breaks in the cloud. The drop was made at 5,880 ft. m.s.l. The second drop was made from above the cloud deck but because of difficulty in observation and location of the seeded area the results of this run were omitted from Table 2. The temperatures of the seeded cloud ranged from -6.0 degrees at the base to -5.0 degrees centigrade at the top.

Rate of Seeding--The dry ice was dispensed at the rate of three pounds per mile.

Time and Duration of Seeding--

First Seeding: 1521:48 EST; two minutes plus 46 seconds.
Second Seeding: 1553:50 EST; omitted from report.

Results--After the dry ice was dropped into the haze layer, a thin ice crystal cloud which resembled a vapor trail formed. This cloud persisted for a few minutes and then began to dissipate but it was lost before complete results could be observed.

Difficulty of observation made the results of the second seeding doubtful.

Method of Verification--

1. Structural
   a. First Seeding: Aerial observations (Visual).
2. Precipitation
   a. First Seeding: Radar pictures indicated no precipitation in or around seeded area. No precipitation was recorded by any of the rain gages.

Comments--Theoretically the conditions were favorable for dissipation; therefore the formation of ice crystals after the first seeding drop was significant. Results of the second seeding were questionable due to difficulty of observation, and no definite conclusions could be drawn; therefore the results were omitted from Table 2.

Cloud Seeding of February 11, 1948 (a.m.)

Synoptic Situation--On the 1330 EST surface map, a trough of low pressure lay northeast to southwest from Lake Michigan to northwestern Arkansas. A cold front in the trough was located in Central Illinois. The seeding drops were made in the warm air mass preceding the cold front. The skies were overcast stratus and strato-cumulus east of the cold front with patchy areas of light drizzle or snow.

Atmospheric Sounding--The sounding at 1200 EST indicated a moist adiabatic lapse rate from the surface to 875 mbs. Between 838 mbs. and 875 mbs. there was a marked temperature inversion. The seeded strato-cumulus cloud deck was below the inversion with the base at 3,000 ft. m.s.l. on the first run and 3,200 ft. m.s.l. on the second run. The tops of the clouds were at 4,000 ft. m.s.l. on both seeding runs. (See Figure 31.)

Conditions of Seeding--The temperature at the top of the overcast was -2.0 degrees centigrade, and at the base it was 0.0 degrees centigrade. The overcast at the time of seeding was very thin. Two seeding runs were made.

Rate of Seeding--Dry ice pellets were dropped at the rate of two pounds per mile.

Time and Duration of Seeding--

First Seeding: 1020:00 EST; two minutes plus zero seconds.
Second Seeding: 1041:00 EST; one minute plus 25 seconds.

Results--Results were negative on the first run. Immediately after the second seeding run, a pilot flying about 9,000 ft. above the seeded clouds observed a slight impression and change in texture in the cloud deck, but it disappeared in a few minutes.

No precipitation was observed to have fallen from the seeded areas.

Method of Verification

1. Structural
   a. First Seeding: Aerial observations (Visual).
   b. Second Seeding: Aerial observations (Visual).
2. Precipitation
   a. First Seeding: Aerial and ground observations (Visual).
   b. Second Seeding: Aerial and ground observations (Visual).

Comments--The air and cloud elements were too warm to have expected any widespread results. According to theoretical standards, borderline conditions prevailed in the cloud; therefore the lack of more positive results is not conclusive.

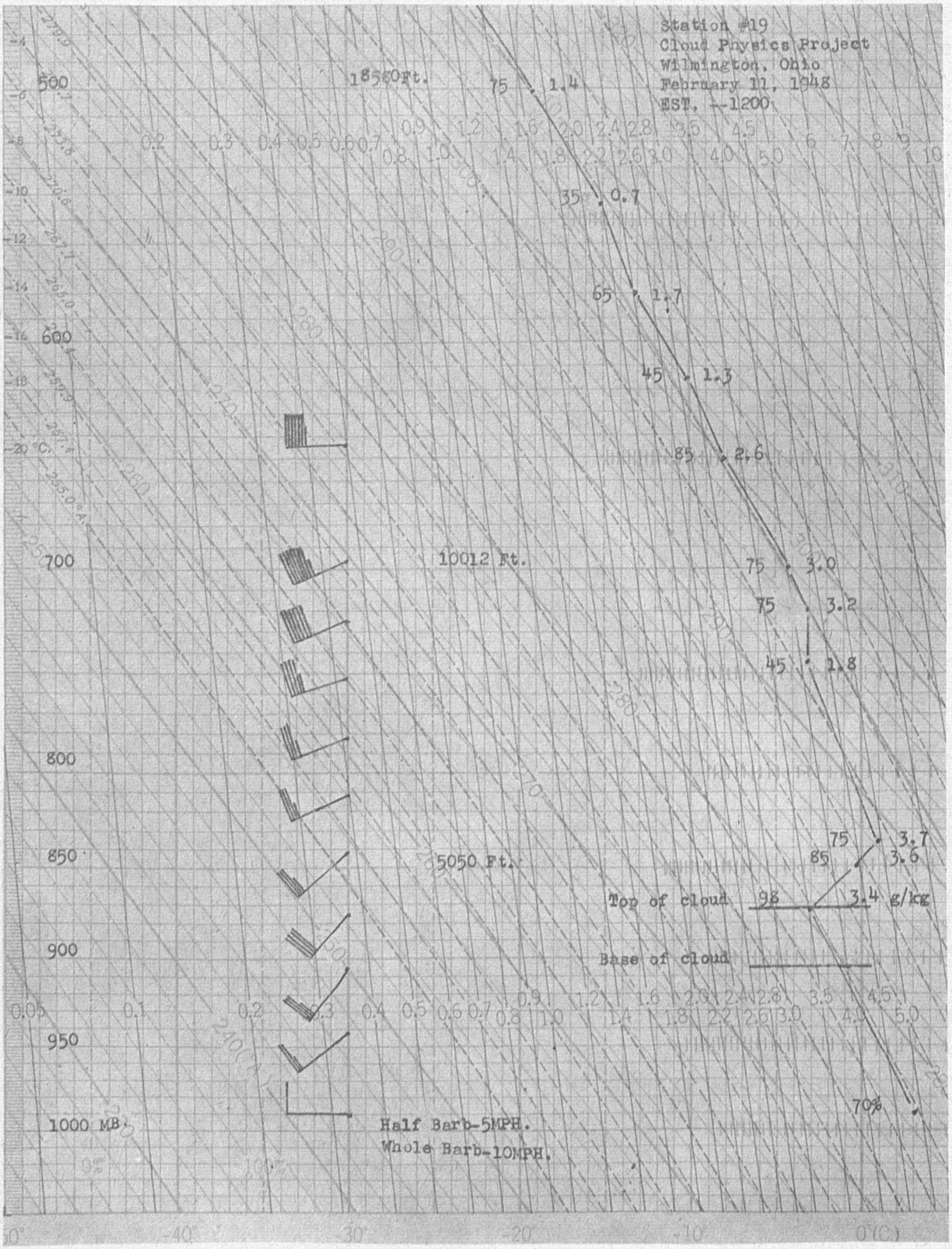

Figure 31.--Atmospheric sounding, 1200 EST, February 11, 1948.

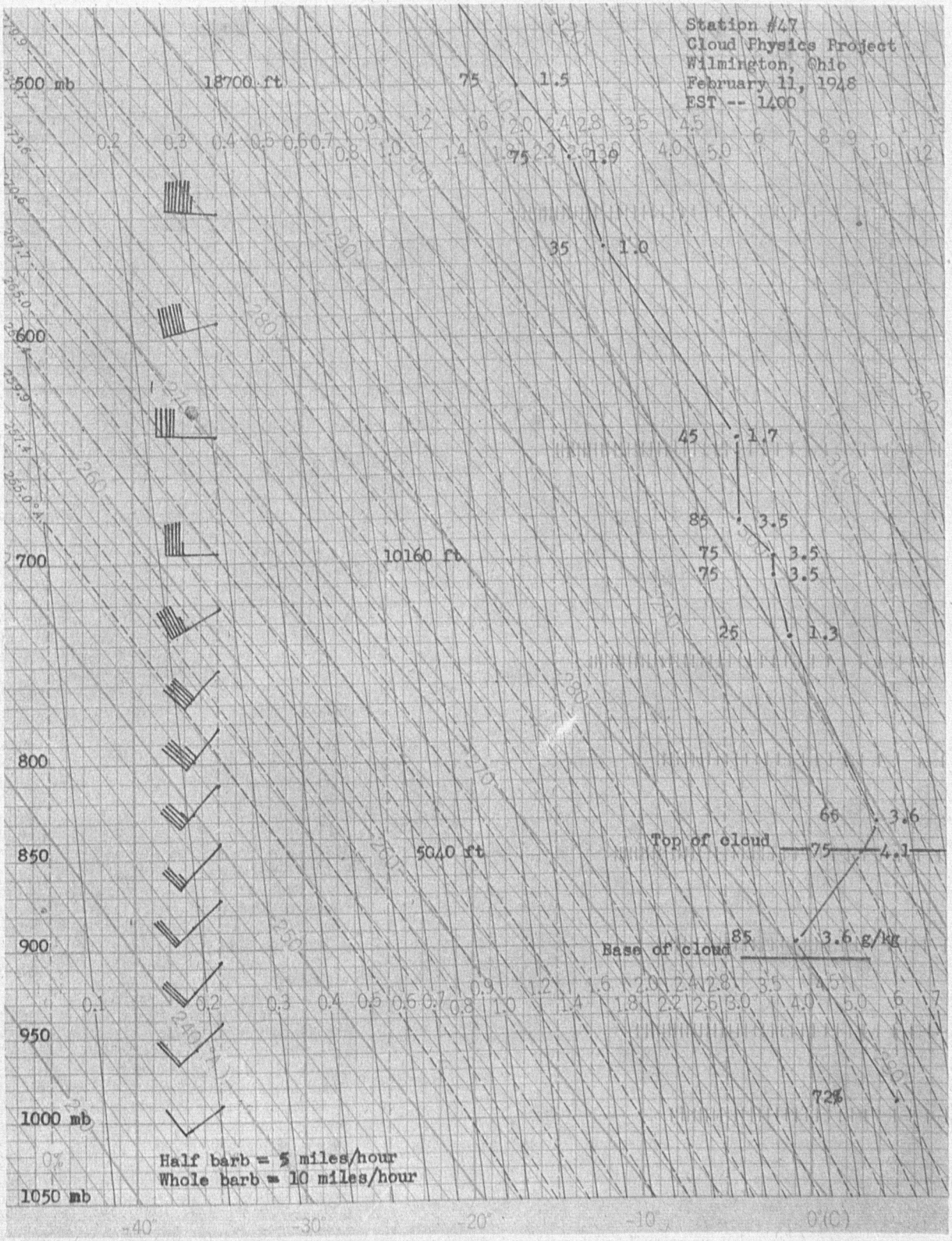

Figure 32.--Atmospheric sounding, 1400 EST, February 11, 1948.

Cloud Seeding of February 11, 1948 (p.m.)

Synoptic Situation--On the 1330 EST surface map, a trough of low pressure lay northeast to southwest from Lake Michigan to northwestern Arkansas. A cold front in the trough was located in central Illinois. The seeding drops were made in the warm air mass preceding the cold front. The skies were overcast stratus and strato-cumulus east of the cold front with patchy areas of light drizzle or snow.

Atmospheric Sounding--The sounding at 1400 EST indicated a conditionally unstable air from the surface to 900 mbs. Between 900 mbs. and 830 mbs., there was a marked temperature inversion. On the second run, the seeded strato-cumulus cloud deck was based at 3,000 ft. m.s.l., a point below the inversion, and the top was at 4,900 ft. m.s.l., a point near the top of the temperature inversion. (See Figure 32.)

Conditions of Seeding--The cloud was seeded three times. Dry ice was dropped on the second run in the shape of an "L". That is the only drop considered in this report, because crushed water ice was used on the first and third drops. Temperature at the base of the cloud was 0.0 degrees centigrade and +1.0 degrees centigrade at the top. The temperature within the cloud was -1.0 degrees centigrade.

Rate of Seeding--Dry ice pellets were dropped at the rate of four pounds per mile.

Time and Duration of Seeding--

First Seeding: Not included in this report.
Second Seeding: 1421:00 EST; one minute plus 15 seconds.
Third Seeding: Not included in this report.

Results--After the second seeding, a shallow trough, about one-half mile wide and in the same "L" pattern as the seeding run, developed in the clouds. The texture of the cloud changed with ice crystals forming in the seeded area.

No precipitation was reported to have fallen from the seeded clouds.

Method of Verification--

1. Structural
   a. Second Seeding: Aerial observations (Visual and photographic. See Figure 33.)
2. Precipitation
   a. Second Seeding: Aerial and surface observations (Visual).

Comments--The temperatures were too high for conditions to be considered ideal for either complete dissipation of the clouds or appreciable amounts of precipitation to have been expected. After the seeding, the plane underneath the clouds flew through a light snow shower a few miles from the seeded clouds. This snow was upwind from the seeded area and could not have been caused by the seeding. The lack of precipitation from the seeded cloud is significant since a natural shower was observed nearby.

Cloud Seeding of February 25, 1948

Synoptic Situation--The seeding area was located south of a quasi-stationary front which lay east-west across central Ohio and Indiana. Overcast skies and areas of light precipitation were occurring on both sides of the frontal system at 1330 EST. The pressure gradient was weak and the pressure was falling on both sides of the front.

Atmospheric Sounding--There was an inversion in temperature from 928 mbs. to 880 mbs. and a stable layer from 880 mbs. to 781 mbs. The air was conditionally unstable from 781 mbs. to 594 mbs. The cloud layer was in this region of conditional instability. The seeded cloud was an altostratus-altocumulus deck with its base at 10,500 ft. m.s.l. on all seeding runs. The tops were variable between 12,000 ft. and 14,000 ft. m.s.l. (See Figure 34.)

Conditions of Seeding--Three seeding runs were made. Several cloud layers were present. The temperature at the base of the seeded cloud was -1.0 degree centigrade on all three runs. Temperatures at the top of the cloud on the three runs were -4.0, -3.0, and -6.0 degrees centigrade respectively. On the third run, an isolated cumulus top protruding 1,300 ft. above the remainder of the cloud deck was seeded. Rain and/or drizzle was falling within twenty miles of the seeded area before, during, and after seeding.

Rate of Seeding--Two pounds of dry ice per mile were dropped during the first and second seedings, and eleven pounds per mile were dropped during the third seeding.

Time and Duration of Seeding--

First Seeding: 1359:10 EST; two minutes plus 3 seconds.
Second Seeding: 1419:30 EST; two minutes plus zero seconds.
Third Seeding: 1459:12 EST; one minute plus 3 seconds.

Results--No change in cloud structure or precipitation was noted after the first seeding. A very shallow, narrow trough opened in the top of the cloud deck after the second seeding. A change in texture of the cloud was also observed. The top of the seeded cumulus cloud dissipated within five minutes after the third run, and a shallow trough developed in the cloud deck where the cumulus top had protruded. No precipitation fell from any of the seeded clouds.

Method of Verification--

1. Structural
   a. First Seeding: Aerial and ground observations (Visual).
   b. Second Seeding: Aerial and ground observations (Visual). Photographs were taken but pictures were not satisfactory for verification because of lack of definition of cloud tops.
   c. Third Seeding: Aerial and ground observations (Visual). Photographs were taken but pictures were not satisfactory for verification because of lack of definition of cloud tops.
2. Precipitation
   a. First Seeding: Radar pictures showed precipitation in vicinity of seeded area but not in seeded area. See picture of radar scope at 1359 EST, Figure 36. Note cloud echoes from unseeded clouds between 180 degrees and 200 degrees and 30-50 miles from the Jamestown radar site. The seeding drop was made at 220 degrees and 30 miles. (Note plane echo.)
   b. Second Seeding: Radar pictures showed precipitation echoes in vicinity of seeded clouds but not in seeded area. See pictures of radar scope at 1419:55 EST, Figure 37. Note cloud echoes between 140 degrees and 190 degrees and 30-50 miles from the Jamestown radar site. Another large echo was present between 320 degrees and 360 degrees and 30-40 miles from Jamestown radar site. The seeding drop was made at 215 degrees and 30 miles. (Note plane echo just to the right of the seeded position.)

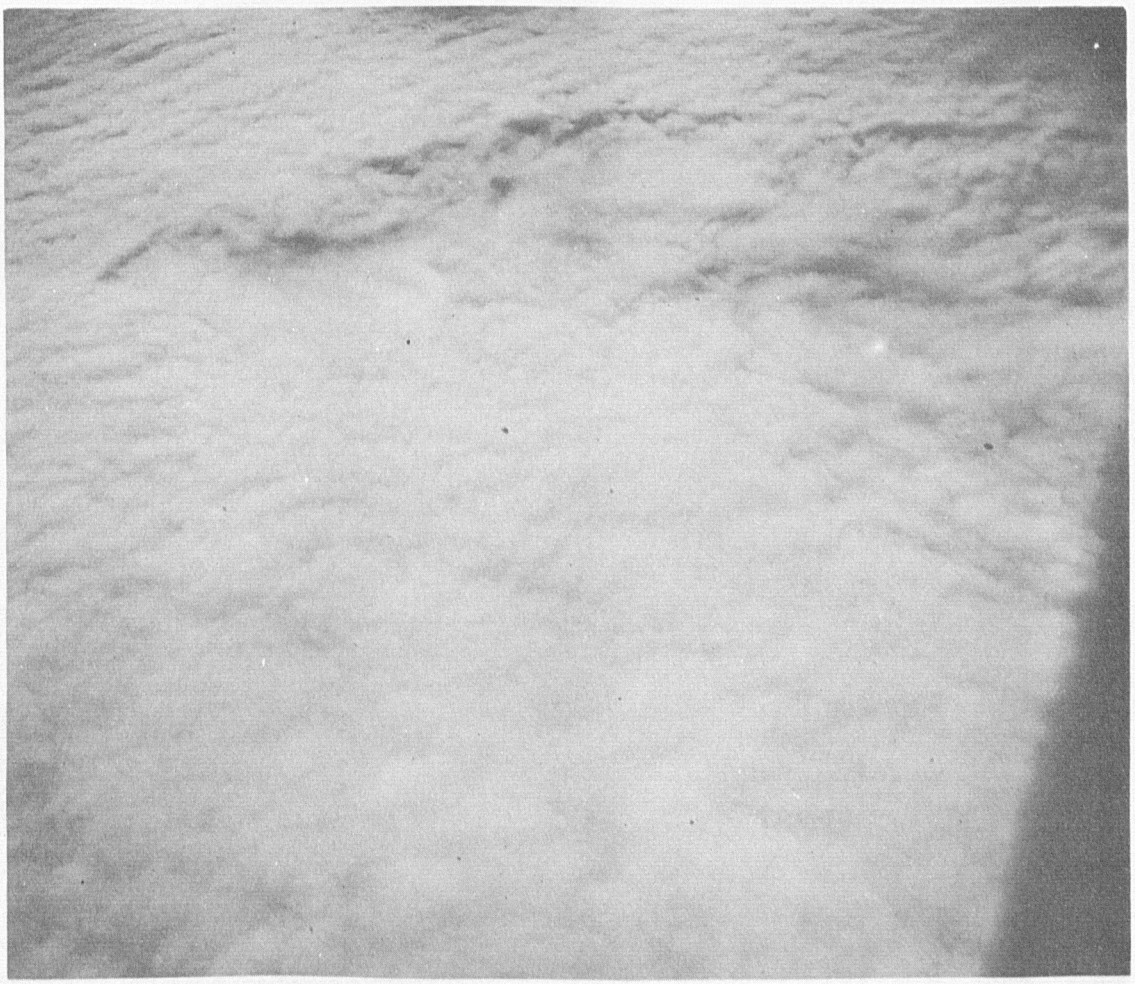

Figure 33.--View of part of shallow trough resulting from dry ice drop. February 11, 1948. The picture, taken forty minutes after seeding, still shows slight convective activity on the far edge of the trough while the center is beginning to refill with supercooled water.

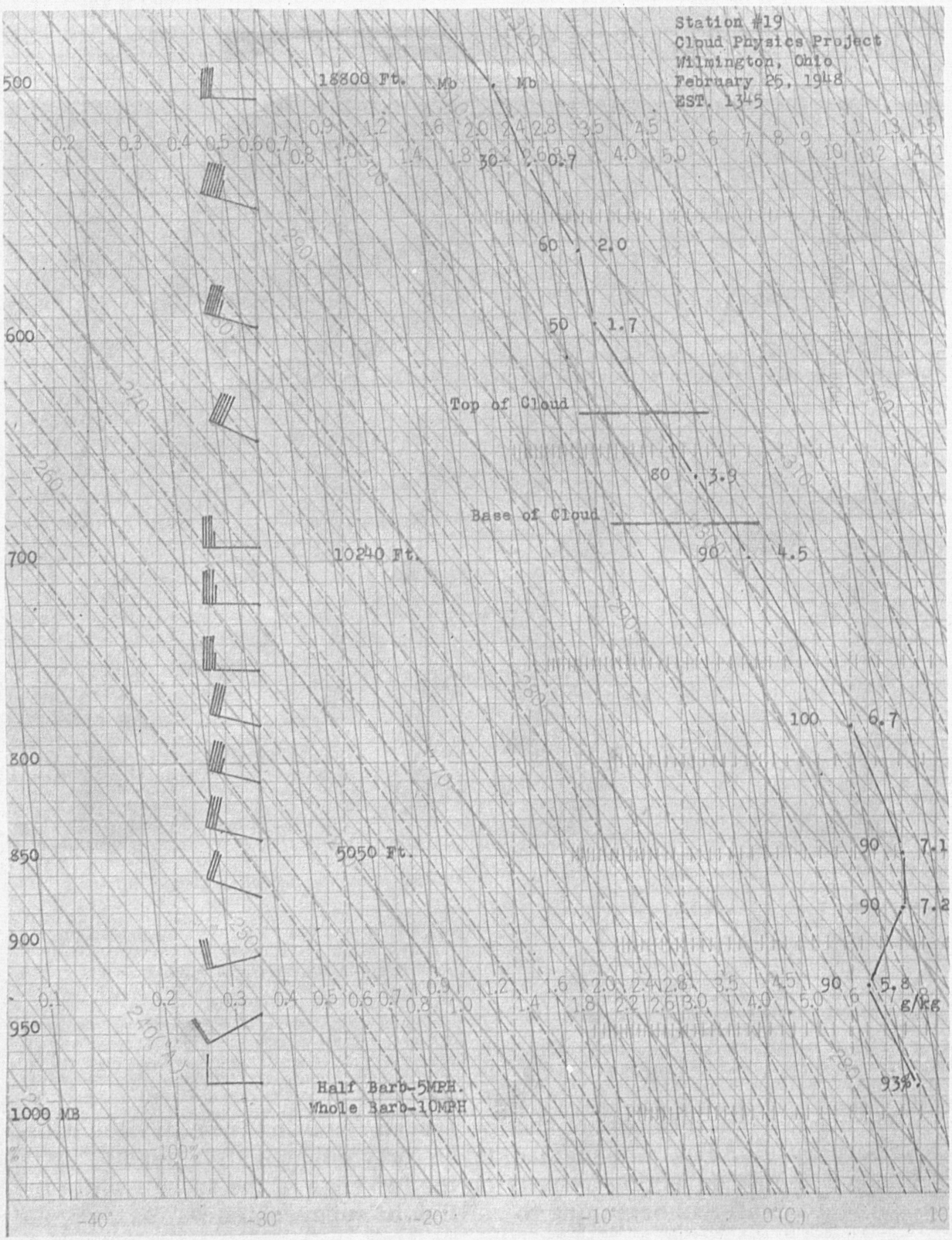

Figure 34.--Atmospheric sounding, 1345 EST, February 25, 1948.

c. Third Seeding: Radar pictures showed precipitation echoes in the vicinity of seeded clouds but not in the seeded area. (Note change in size of cloud echoes between 1350 EST and 1420 EST as they progressed across the radar scope, Figures 35, 36 and 37. Cloud echoes on the radar scope at 1350:15 EST (Figure 35) are present between 180 degrees and 200 degrees and 30-50 miles from the Jamestown radar site. A small echo is just appearing at 305 degrees and 50 miles from Jamestown.

Comments--Cloud temperatures were at least 4 degrees below zero; the clouds were thick enough to produce small amounts of precipitation, furthermore rain was occurring nearby in the same air mass. Therefore, conditions were favorable for making precipitation by artificial nucleation; hence, the negative results for rain making are significant.

Cloud Seeding of March 3, 1948

Synoptic Situation--The seeding operations took place in a cold air mass on the southeastern edge of a moderate anticyclone. The nearest frontal system at 1330 EST was oriented northeast-southwest through central South Carolina, Georgia, and southern Alabama. A widespread area of stratocumulus clouds covered Illinois, Indiana and Ohio. Drizzle and sleet were general over western Ohio and over Indiana at 1330 EST.

Atmospheric Sounding--There was a dry adiabatic lapse rate from the surface to the base of the seeded clouds at 930 mbs. The air was stable from the top of the cloud deck to 700 mbs. The seeded cloud, a stratus deck, was capped with an inversion from 850 mbs. to 826 mbs. The cloud base was at 2,200 ft. m.s.l. on all three seeding runs. The tops of the clouds were at 4,500 ft. m.s.l. on the first and second run and 5,000 ft. m.s.l. on the third run. (See Figure 38.)

Conditions of Seeding--Three seeding runs were made. The temperature at the top of the clouds was -3.0 degrees centigrade and 0.0 degrees centigrade at the base on all three seedings. Ice accumulated on the wings of the planes when they were flown at 2,300 ft. m.s.l. and at 4,000 ft. m.s.l., but it melted when the planes were flown through the clouds at 3,200 ft. m.s.l. On the third run dry ice was dropped into a small cumulus top extending 500 ft. above the stratus deck.

Rate of Seeding--One pound per mile and three pounds per mile were dropped on the first and second runs, respectively. On the third run, twenty-four pounds per mile were dropped.

Time and Duration of Seeding--

First Seeding: 1430:10 EST; two minutes plus ten seconds.
Second Seeding: 1502:48 EST; one minute plus ten seconds.
Third Seeding: 1520:00 EST; zero minutes plus ten seconds.

Results--A shallow trough about eight miles long and about 500 ft. wide was formed in the top of the clouds after the first seeding. A change in texture was also observed. A slight change in texture was observed after the second seeding run. No change in structure or texture of the clouds was observed after the third seeding attempt.

Observers in a plane flying beneath the seeded clouds reported light drizzle about 45 minutes after the first seeding and about two minutes after the third seeding. Sufficient evidence is available to say that the drizzle was coming from the seeded cloud; but it is not known whether the seeding was the cause since drizzle was observed at another place nearby at about the same time. The first seeded area moved across the surface network operated by the Cloud Physics Project, and the rain gages recorded no precipitation beneath the path of the clouds. (Note: It sometimes takes .01 or .02 inch of water to effect the weighing type rain gages used.)

Method of Verification--

1. Structural

   a. First Seeding: Aerial observations (Visual and photographic. Note seeded line near center of picture but slightly toward the upper right in Figure 39.)

   b. Second Seeding: Aerial observations (Visual).
   c. Third Seeding: Aerial observations (Visual).

2. Precipitation

   a. First Seeding: Surface observations (Visual). Track of aircraft and seeded area from radar scope pictures.
   b. Second Seeding: Surface observations (Visual). Track of aircraft and seeded area from radar scope pictures.
   c. Third Seeding: Surface observations (Visual). Track of aircraft and seeded area from radar scope pictures.

Comments--Temperatures of the clouds were too warm for the conditions to have been considered ideal for seeding. The clouds were so thin that the water content must have been necessarily small. Therefore, even without the evidence from the recording rain gages, one would assume that not more than a trace of precipitation reached the ground.

Cloud Seeding of March 4, 1948

Synoptic Situation--The 1330 EST surface map indicated that the seeding area was located on the southeastern side of a strong anticyclone centered in Canada. Pressures were rising slowly in the area of seeding operations. Very flat and patchy cumuli that had formed as the result of dissipating stratocumuli were predominant over Ohio and Indiana. No showers were falling at map time in the seeding area although light showers had occurred north of Wilmington, Ohio, at the beginning of the six hour period from 0730 to 1330 EST.

Atmospheric Sounding--The sounding taken at 1030 EST indicated a dry adiabatic lapse rate extended from the surface to 900 mbs. The air was stable between 900 mbs. and 686 mbs. through which several temperature inversions prevailed. The seeded cloud, a stratocumulus deck, was located in the stable portion of the ascent curve. The base of the cloud deck, 3,400 ft. m.s.l. on all seeding runs, was at the top of the dry adiabatic lapse rate that prevailed from the surface to 900 mbs. The top of the clouds was at 4,400 ft. m.s.l., 4,550 ft. m.s.l., and 5,000 ft. m.s.l. respectively on the seeding runs. (See Figure 40.)

Conditions of Seeding--A broken stratocumulus deck was seeded on the first seeding run; but active, natural dissipation of the clouds necessitated the seeding of fair weather cumulus on the second and third runs. Temperatures at the base of the clouds were -7.0 degrees centigrade on all seeding runs, but temperatures at the top of the clouds changed from -8.0 degrees on the first and second runs to -9.0 degrees centigrade on the third run.

Rate of Seeding--Two pounds of dry ice pellets per mile and one pound per mile were dropped on the first and third seedings, respectively; fifteen pounds per mile were released on the second drop.

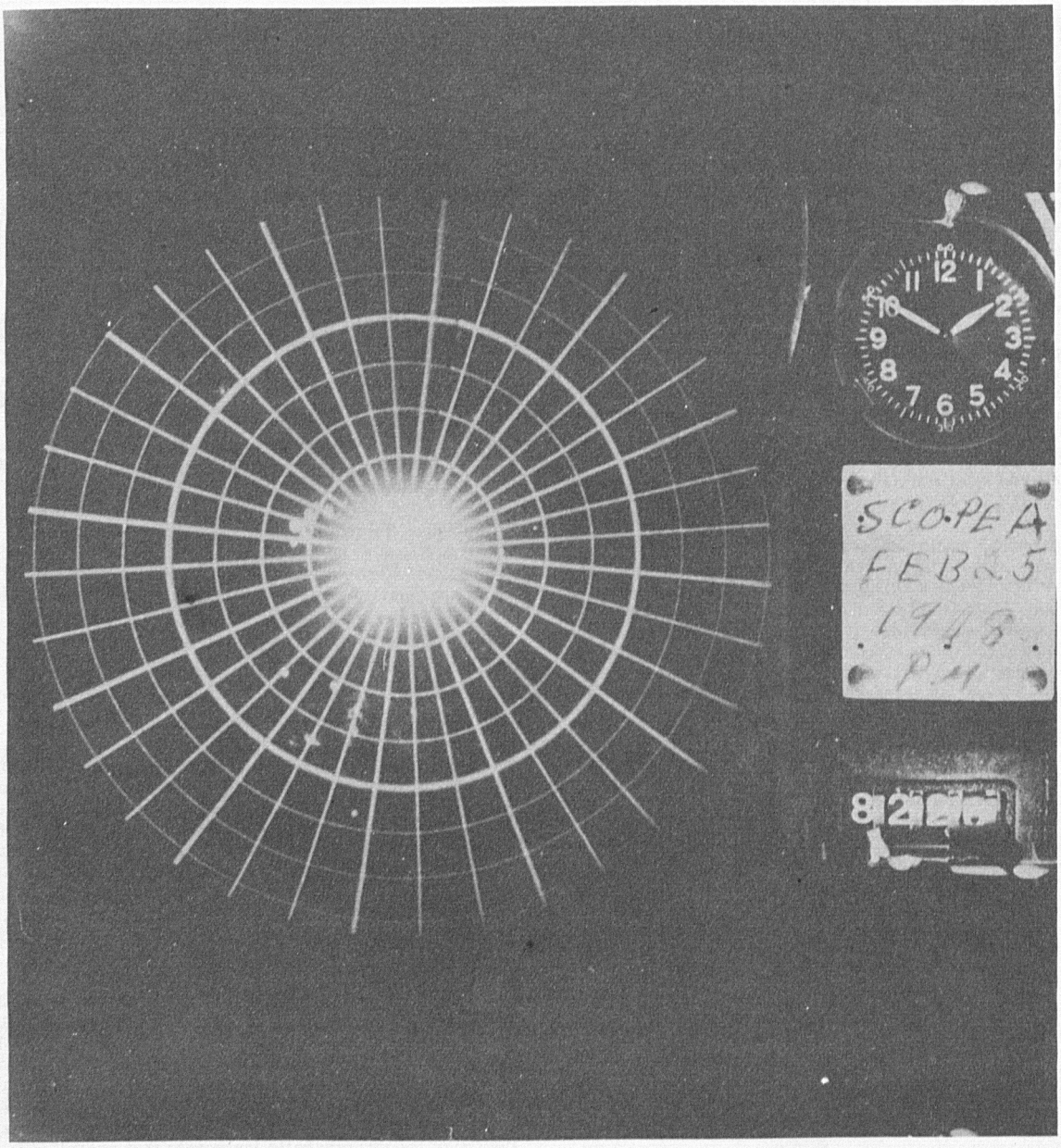

Figure 35.--Radar scope picture, 1350:15 EST, February 25, 1948.

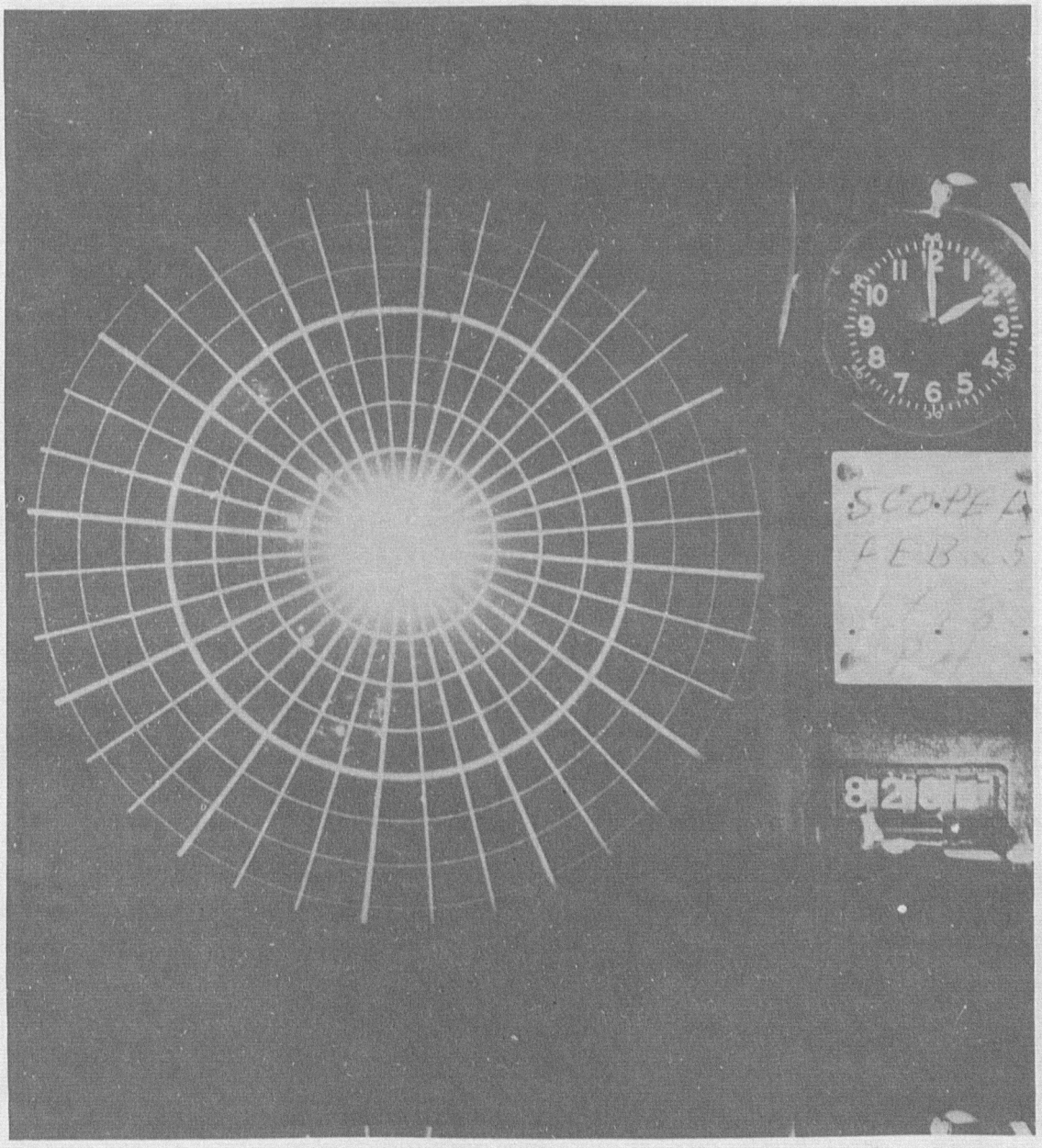

Figure 36.--Radar scope picture, 1359:45 EST, February 25, 1948.

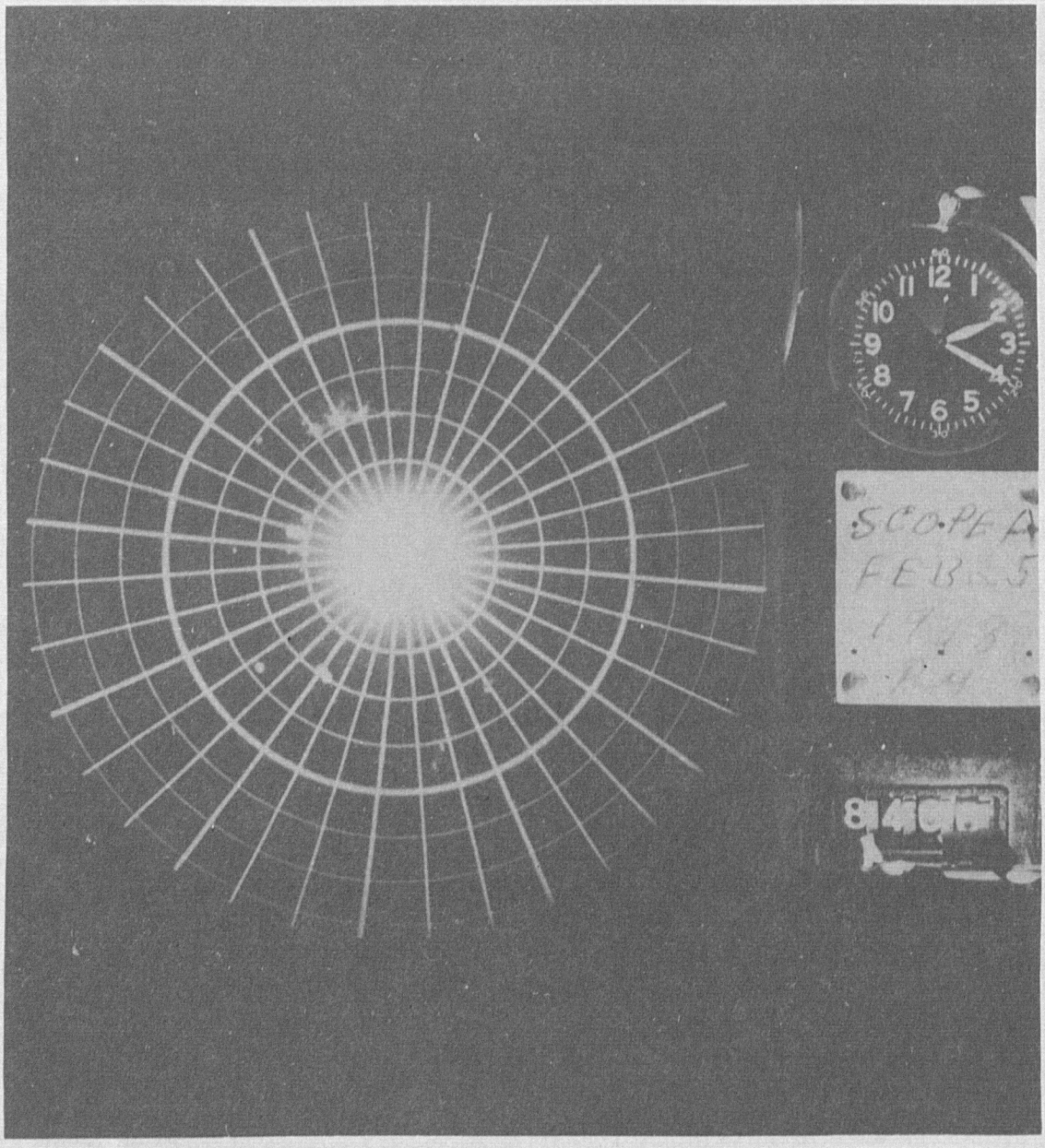

Figure 37.--Radar scope picture, February 25, 1948.

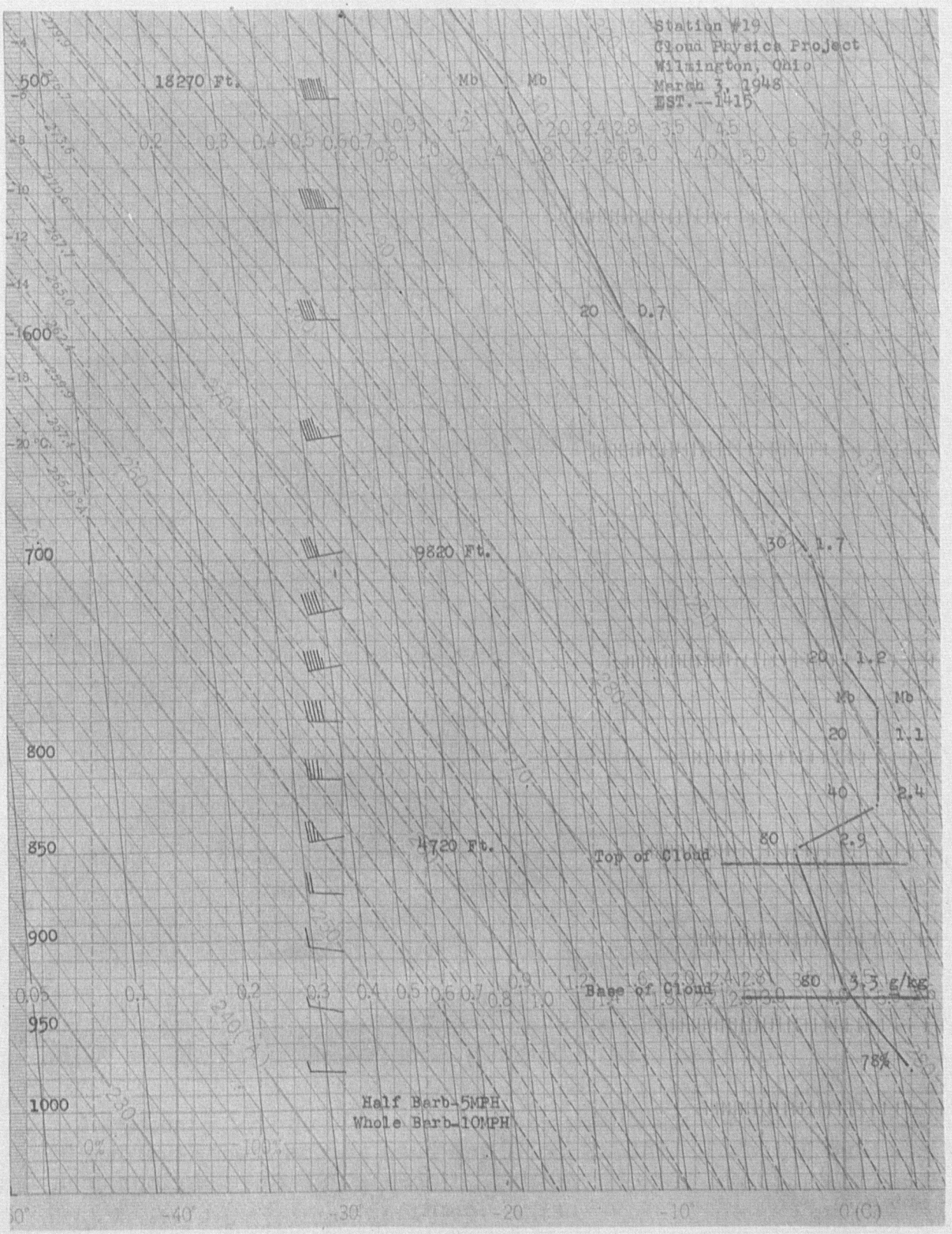

Figure 38.--Atmospheric sounding, 1415 EST, March 3, 1948.

Figure 39.--View showing some vertical build up five minutes after seeding, March 3, 1948. Seeded line runs across cloudy furrows in center of picture. Note interesting difference in texture of cloud deck in the vicinity.

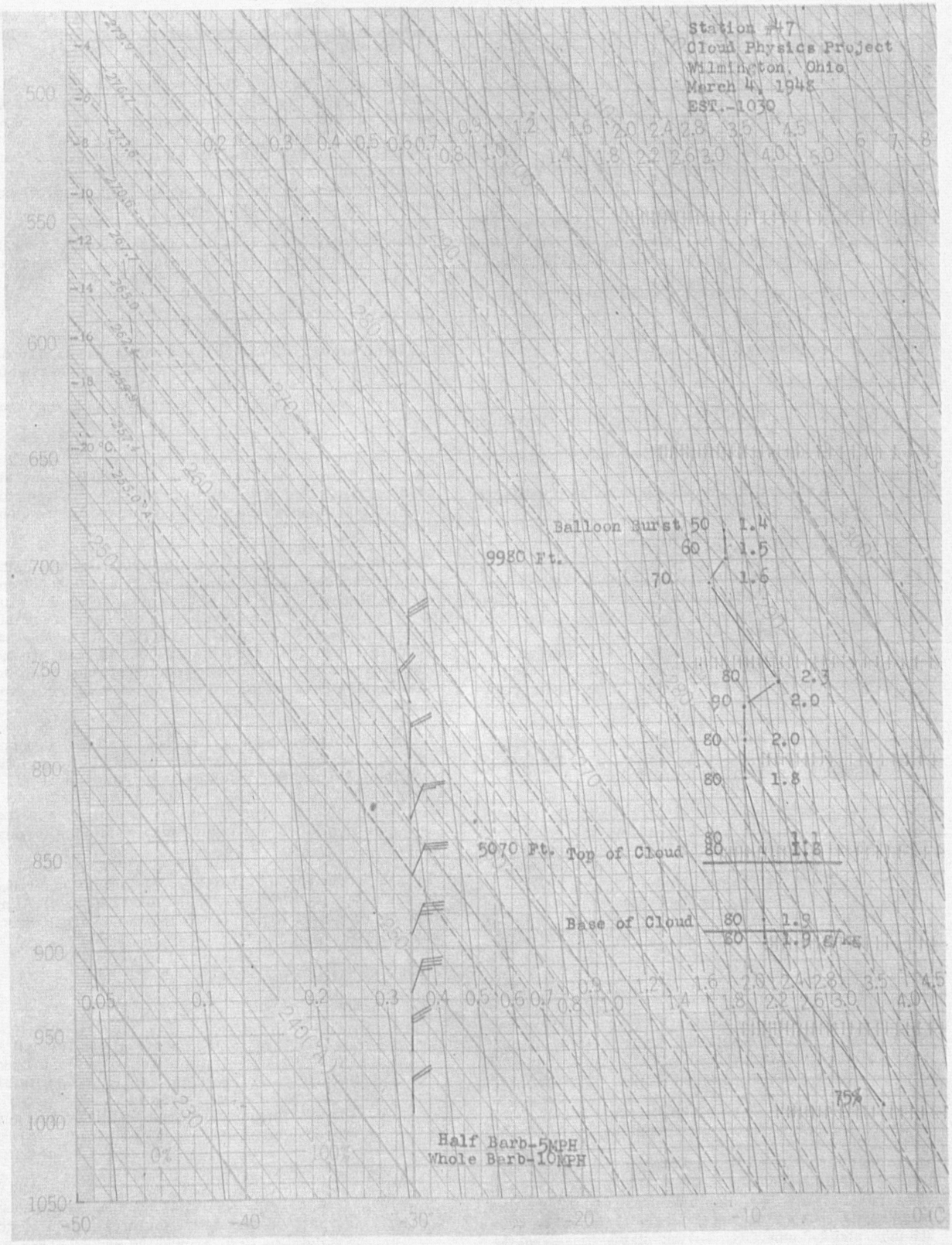

Figure 40.--Atmospheric sounding, 1030 EST, March 4, 1948.

Time and Duration of Seeding--

First Seeding: 1106:34 EST; two minutes plus eleven seconds.
Second Seeding: 1135:28 EST; zero minutes plus three seconds.
Third Seeding: 1140:00 EST; two minutes plus 45 seconds.

Results--Evidence regarding dissipation of the clouds was inconclusive and contradictory. The original run was made over a broken cloud deck which was already dissipating. Although dry ice may have caused the cloud to dissipate more rapidly, observers could not be sure. No effect of the seeding was observed after the second and third seedings.

No precipitation fell from any of the clouds that were seeded.

Method of Verification--

1. Structural

   a. First Seeding: Aerial observations (Visual and photographic).
   b. Second Seeding: Aerial observations (Visual and photographic).
   c. Third Seeding: Aerial observations (Visual and photographic).

2. Precipitation

   a. First Seeding: Aerial and surface observations (Visual). Radar pictures indicated no precipitation in or around the seeded area. Rain gages did not record any precipitation.
   b. Second Seeding: Aerial and surface observations (Visual). Radar pictures indicated no precipitation in or around the seeded area. Rain gages did not record any precipitation.
   c. Third Seeding: Aerial and surface observations (Visual). Radar pictures indicated no precipitation in or around the seeded area. Rain gages did not record any precipitation.

Comments--Negative results are significant for the temperatures and the cloud structure were favorable, according to theoretical standards, for dissipation of clouds. Any positive results would lack significance, insofar as dissipation of the clouds was concerned, for the cloud deck was breaking up before any dry ice was dropped. Even if all the moisture in the clouds had been precipitated, the liquid water content of the clouds was too low for much rain to have fallen.

Cloud Seeding of March 8, 1948

Synoptic Situation--On the 1330 EST surface map, the seeding area was on the northeastern side of a weak high pressure cell centered in southern Missouri. Variable amounts of stratocumulus clouds prevailed in the vicinity of the seeding area. The only precipitation occurring was falling in the extreme northeastern section of Indiana. The pressure gradient was very weak over the entire area.

Atmospheric Sounding--The sounding taken at 1330 EST indicated a super-adiabatic lapse rate from the surface to 958 mbs. Between 958 mbs. and 880 mbs., the air was conditionally unstable. A temperature inversion lay between 880 mbs. and 850 mbs. The air was stable also above the top of the seeded cloud deck except for a thin layer of unstable air from 838 mbs. to 820 mbs. There was an isothermal region from 820 mbs. to 768 mbs. The seeded cloud, a strato-cumulus deck, had its base at 3,200 ft. m.s.l. which was just below the base of the temperature inversion. The top of the cloud extended to 4,500 ft. m.s.l. and into the region of the temperature inversion. Very dry air, with unmeasureable amounts of moisture, prevailed in the region immediately above the cloud tops. (See Figure 41.)

Conditions of Seeding--Three seeding runs were made. Temperatures at the base of the clouds were -3.0 degrees centigrade and at the top -5.0 degrees centigrade on all three runs. The deck was beginning to dissolve when the seeding mission took to the air, but areas where the overcast was still solid for several miles in all directions were picked for seeding. The pilots reported minor turbulence while flying above the cloud tops.

Rate of Seeding--Dry ice pellets were dropped at the rate of 3, 8, and 5 pounds per mile, respectively, on the three seeding runs.

Time and Duration of Seeding--

First Seeding: 1336:58 EST; one minute plus 32 seconds.
Second Seeding: 1348:00 EST; zero minutes plus 50 seconds.
Third Seeding: 1408:45 EST; one minute plus zero seconds.

Results--Immediately after the first seeding a white line appeared in the cloud following along about 100 ft. behind the seeding plane. This line, however, soon disappeared, and the seeded area again resembled the remainder of the cloud deck.

After the second seeding a white line also developed in the cloud deck and within five minutes it had spread and deepened until the whole section of the clouds seemed to drop out of the overcast. The ground could be seen through this opening, but some ice crystals or haze remained in the area. About fifteen minutes after the hole was formed, stratocumulus clouds began to build into the opening from the surrounding bank of clouds, but the opening was never filled.

After the third seeding a hole opened as after the second seeding, but this time no stratocumulus built into the opening. The seeding run was in the shape of an "L". About thirty minutes after this seeding, the entire cloud deck dissipated. This was accomplished by the expansion in size of the seeded holes and other holes which had formed naturally.

No ice accumulated on the planes which were flown through the holes opened by the second and third seedings. At no time did observers flying beneath the seeded areas detect any precipitation.

Method of Verification--

1. Structural

   a. First Seeding: Aerial observations (Visual).
   b. Second Seeding: Aerial observations (Visual and photographic. See Figure 42 and note natural breaks in the cloud nearby.)
   c. Third Seeding: Aerial observations (Visual and photographic).

2. Precipitation

   a. First Seeding: Aerial and surface observations (Visual). Radar scope pictures indicated no precipitation in or around the seeded area.
   b. Second Seeding: Aerial and surface observations (Visual). Radar scope pictures indicated no precipitation in or around the seeded area.
   c. Third Seeding: Aerial and surface observations (Visual). Radar scope pictures indicated no precipitation in or around the seeded area.

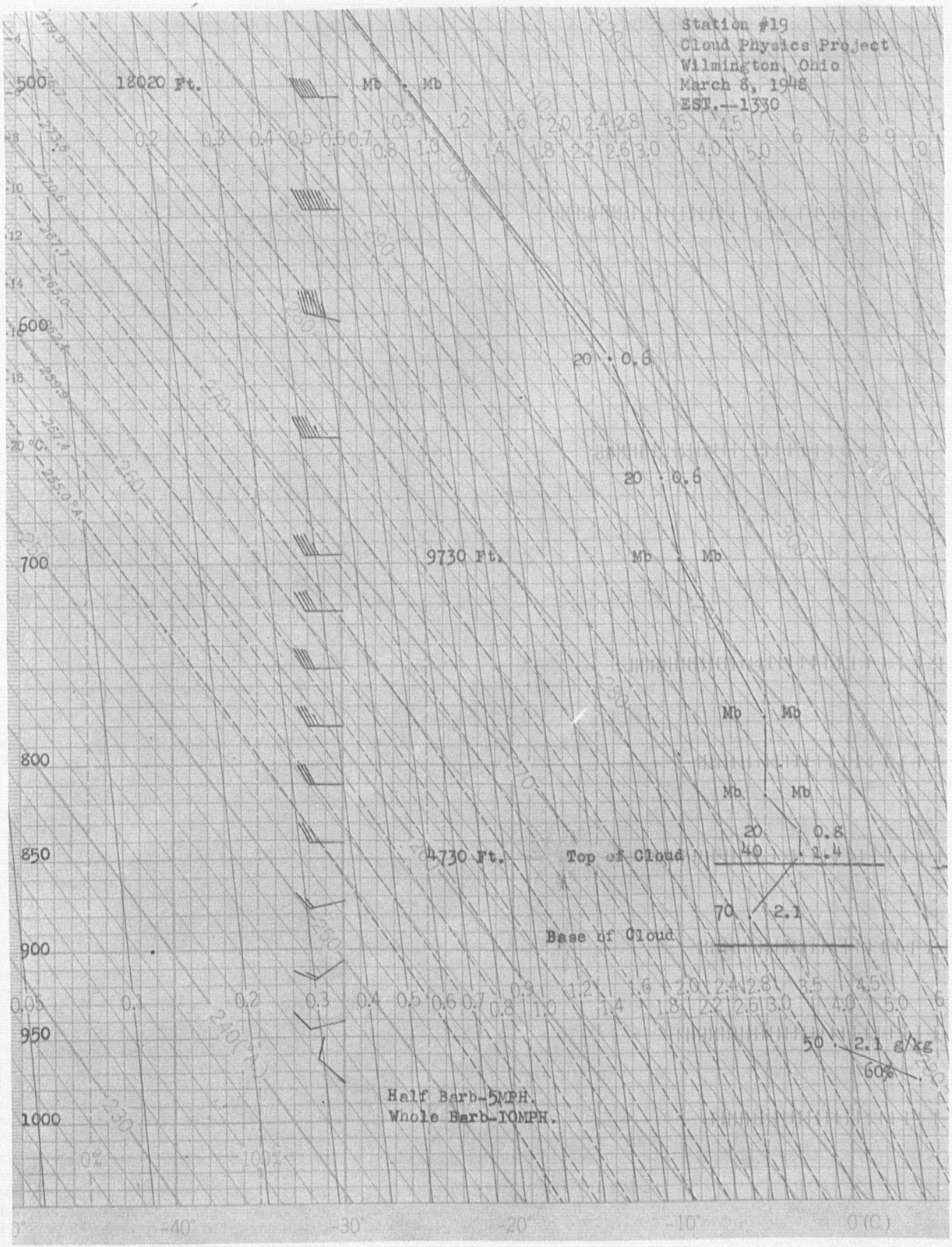

Figure 41.--Atmospheric sounding, 1330 EST, March 8, 1948.

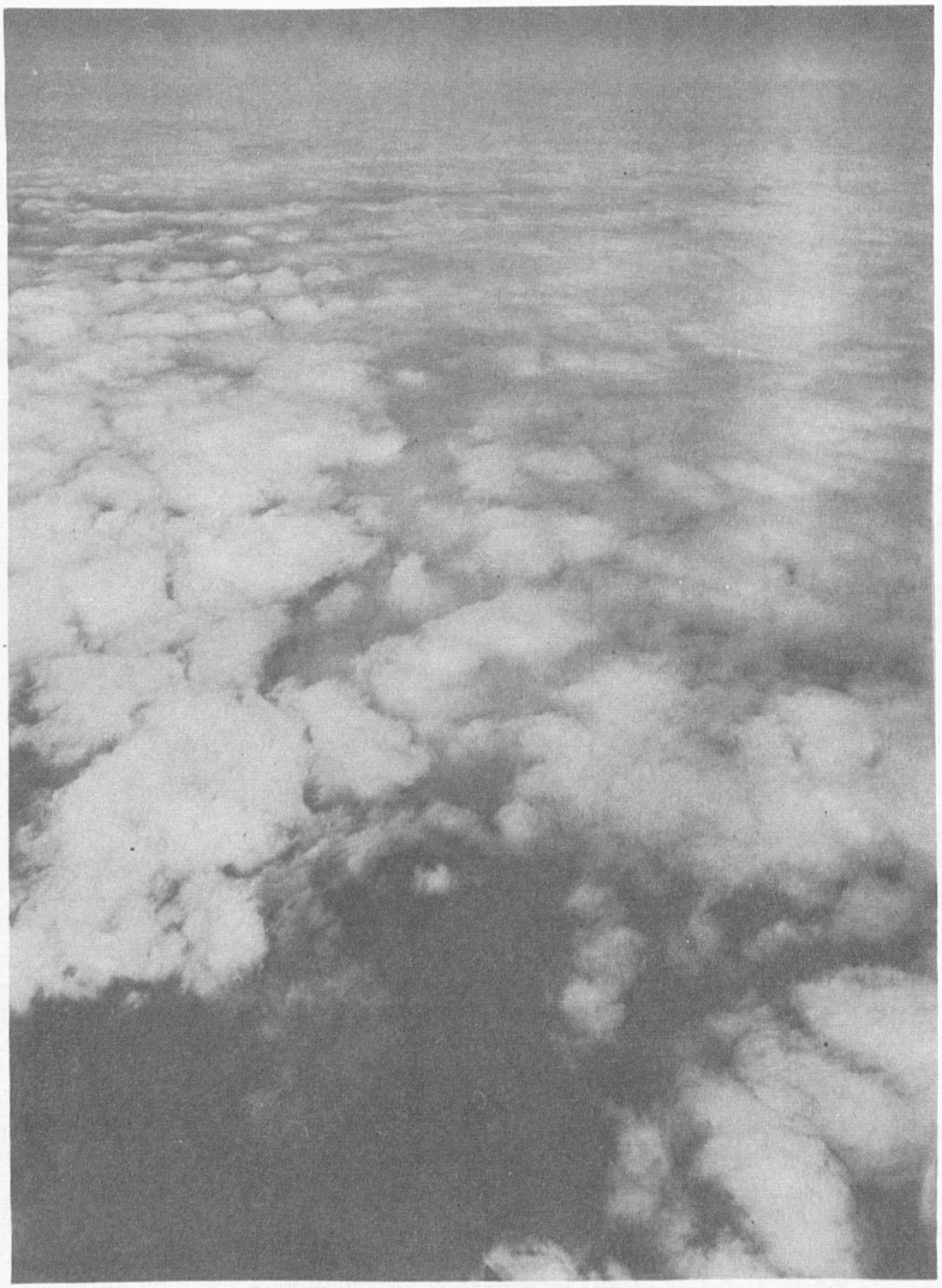

Figure 42.--View of ice crystal area in cloud deck four minutes after seeding, March 8, 1948. The ground soon could be seen through the seeded area. Note natural openings in cloud deck.

Comments--This mission gave best results for cloud dissipation of any mission to date. Impressive as the results were, however, they lack significance. The first time dry ice was dropped, the clouds did not completely dissipate. Twelve minutes later dry ice was again dropped into the cloud deck, and a sector of the clouds either completely dissipated or turned to ice crystals. This also happened after the third seeding which was twenty minutes later. However, within an hour after the second seeding the whole cloud deck had almost completely disappeared, and there was no evidence to indicate that this disappearance would not have occurred without the seedings.

Cloud Seeding of March 11, 1948

Synoptic Situation--The seeding area, according to the 1330 EST surface map, was located on the eastern edge of a high pressure cell. The pressure gradient was moderate with rising pressure indicated over the entire area. Stratocumulus overcast covered Ohio and Kentucky, but only scattered clouds were present west of the seeded area in Indiana. Snow showers and patches of fog were prevalent in and around the seeding area.

Atmospheric Sounding--The lapse rate was dry adiabatic from the surface to 900 mbs. There was a stable layer between 900 mbs. and 750 mbs. containing two inversions in temperature. The seeded cloud, a stratus deck, had its base just below the first inversion with its top extending to a point where the second inversion became more pronounced. The cloud layer was 3,600 ft. thick extending from 2,800 ft. m.s.l. to 6,400 ft. m.s.l. (See Figure 43.)

Conditions of Seeding--Two seeding runs were made. The temperature at the base of the cloud was -8.0 degrees and -9.0 degrees centigrade at the top. Planes that passed through the clouds before and after the seeding accumulated glaze ice. Snow had fallen on the preceding night and over one inch was on the ground at Wilmington, Ohio. Although no snow was falling at the airfield when the seeding mission was organized, snow showers were reported by observers in the planes and on the ground in the vicinity of the seeding area immediately before and after seeding.

Rate of Seeding--Dry ice pellets were dropped at the rate of five pounds per mile on the first seeding and two pounds per mile on the second seeding.

Time and Duration of Seeding--

First Seeding: 1137:06 EST; one minute plus 14 Seconds.
Second Seeding: 1243:05 EST; four minutes plus 20 seconds.

Results--Noticeable changes in the composition and structure of the clouds took place along the first seeded line, and probably along the second seeded line. Poor visibility restricted observation following the second seeding, but those observations available indicated that the second seeded area developed similarly to the first. The first area was followed by observers in airplanes for about fifty-five minutes, and changes in the cloud structure were definite enough that no trouble was experienced in differentiating between the seeded and adjacent unseeded clouds. The depression was estimated to be about six miles long and two miles wide. Although planes accumulated ice while flying through adjacent unseeded clouds, they accumulated none while making repeated passes through the seeded clouds. The contrast between the seeded and unseeded clouds was noticeable for just beyond the area affected by the seeding the clouds were so opaque that no trace of the sun could be seen. Observers flying through the seeded clouds reported that the visibility was restricted by haze. (It is possible that the "haze" was ice crystals.) Observers called the seeded area a window, i.e., one could see the sun through it, but considerable substance remained to restrict the visibility. Light snow fell from the seeded clouds to the ground, but the amount was not more than .01 inch and was probably only a trace. Both seeded areas passed over the surface network operated by the Cloud Physics Project, but none of the weighing type rain gages recorded any snowfall beneath the path of the seeded clouds. (Note: At least .01 inch of melted snow is needed to affect the rain gages.) Observers flying 500 ft. above the ground reported snow falling to the ground from the first seeded clouds. Poor visibility restricted observations of the second seeded area, but observers reported another light snow shower which was believed to have come from the second seeded clouds.

Method of Verification

1. Structural
   a. First Seeding: Aerial observations (Visual and photographic. See Figures 44 and 45. A small portion of dry ice was dropped along side the seeded area. Note bright spot ("sun dog" produced by reflection of sun from the ice crystals) in the area just to the left of the main seeded portion.)
   b. Second Seeding: Aerial observations (Visual).
2. Precipitation
   a. First Seeding: Track of aircraft and seeded area from radar pictures. Aerial and ground observations (Visual).
   b. Second Seeding: Track of aircraft and seeded area from radar pictures. Aerial and ground observations (Visual).

Comments--Sufficient data were available to ascertain that snow fell from the seeded clouds to the ground, but it was very light for at no time was it heavy enough to cause an echo on the radar scope or to affect the weighing type rain gages. Since snow fell from nearby unseeded portions of the same cloud deck before and after the seeding, one cannot be sure that the dry ice was instrumental in starting precipitation.

Any dissipation that occurred in the seeded area is significant for there was no evidence that the cloud deck was dissolving. Since the seeding did not open a complete hole in the clouds through which a plane could be flown under visible flight rules, we conclude that the seeding did not produce positive, tangible, practical results. However, from the point of view of the Cloud Physicist studying composition and structure of clouds, the mission furnished some very interesting results.

Cloud Seeding of April 1, 1948

Synoptic Situation--At 1330 EST the seeding area was located on the eastern edge of a very weak anticyclone. A stationary frontal system was located northeast to southwest along the West Virginia-Ohio boundaries. The pressure gradient was weak and the pressure changes indicated that the situation was stagnant. Overcast stratocumulus with scattered showers and light rain prevailed over western Ohio and northern Kentucky.

Atmospheric Sounding--The sounding taken at 1345 EST indicated instability from the surface to 889 mbs. with stable or neutral stability from 889 mbs. to 715 mbs. The lapse rate between 715 mbs. and 600 mbs. was slightly less than the moist adiabatic rate with a slightly more stable layer approximately 28 mbs. thick immediately above the 600 mbs. level. The seeded cloud, an altocumulus deck, was based at 9,500 ft. m.s.l. on all seeding runs, but the tops varied between 10,100 ft. and 12,700 ft. m.s.l. (See Figure 46.)

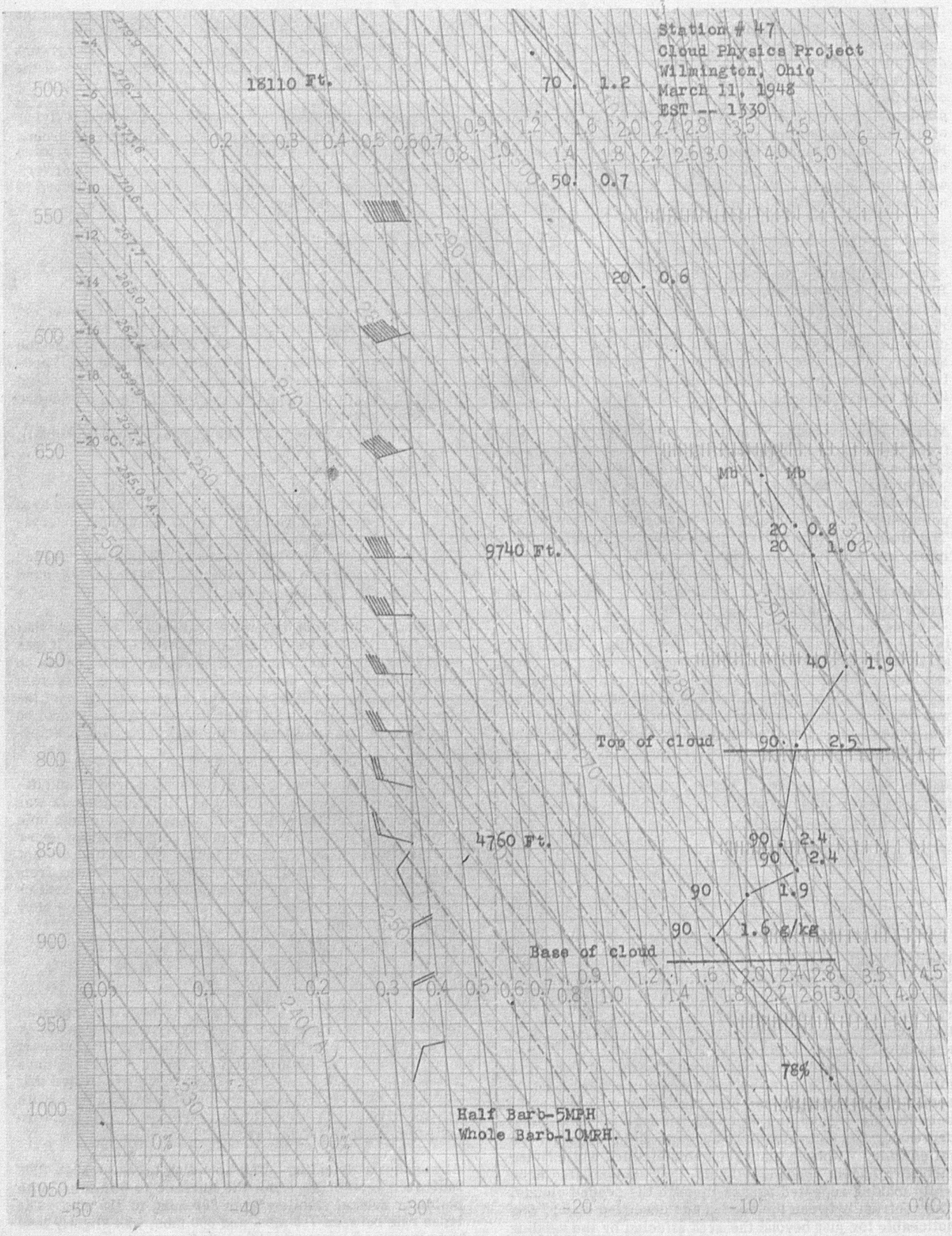

Figure 43.--Atmospheric sounding, 1330 EST, March 11, 1948.

Figure 44.--View of trough 15 minutes after seeding, March 11, 1948. Sun dog indicates where handful of dry ice was dropped.

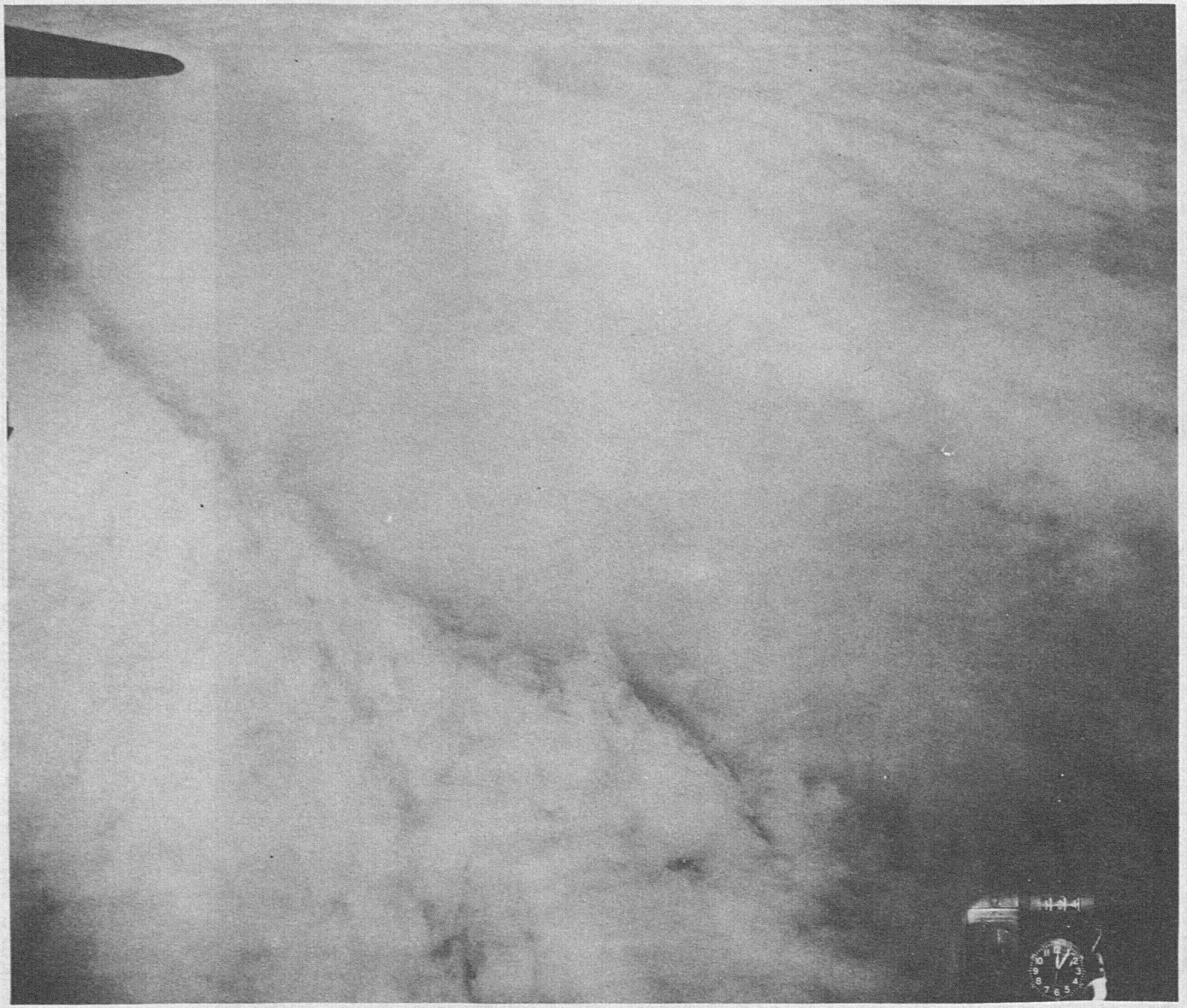

Figure 45.--Close-up view of seeded area one half hour after dry ice drop, March 11, 1948.

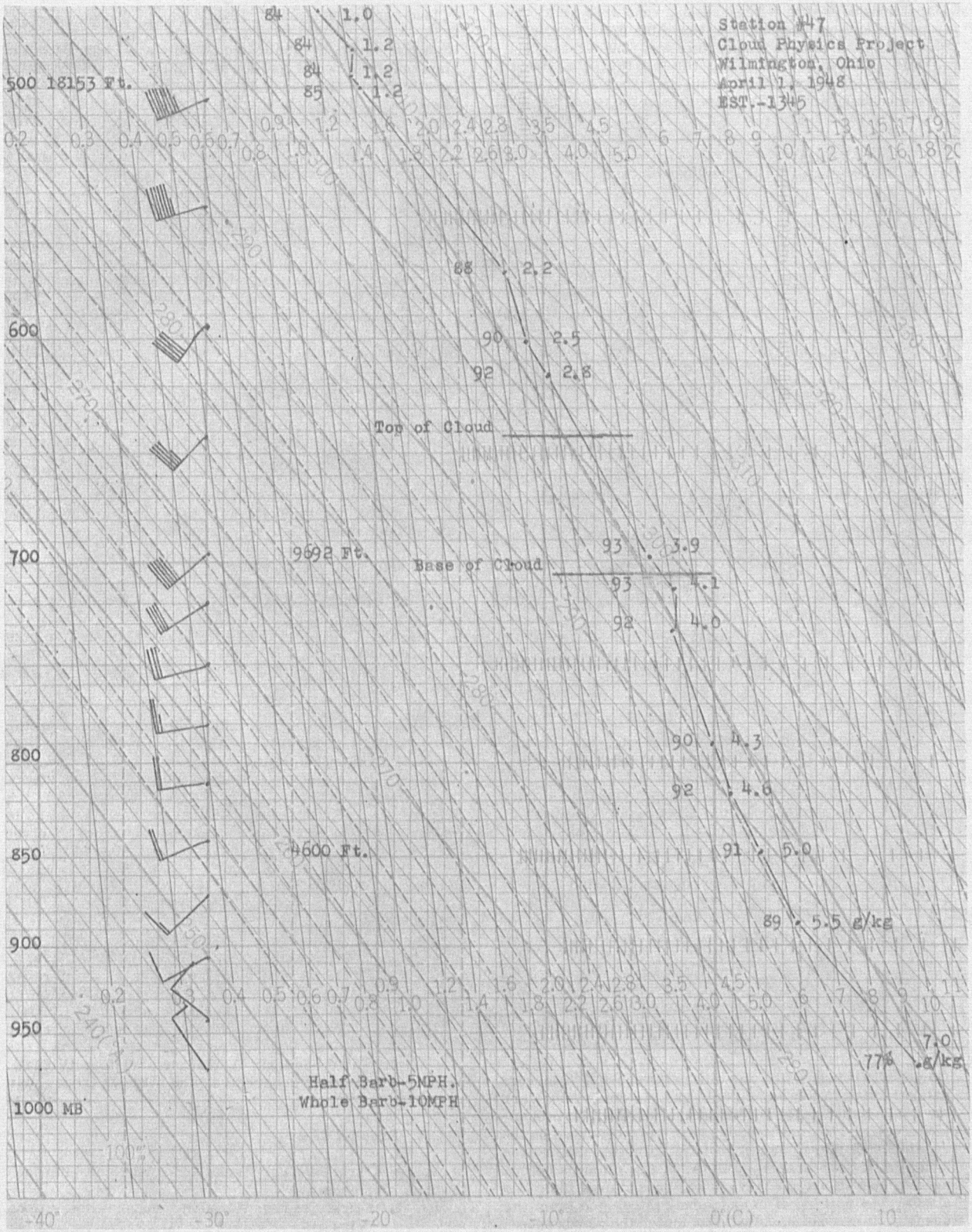

Figure 46.--Atmospheric sounding, 1345 EST, April 1, 1948.

Conditions of Seeding--Three seeding runs were made. Two cloud decks were present. The top of the lower deck was at 5,750 ft. m.s.l. and the temperature was +2.0 degrees centigrade. The upper deck was the one that was seeded. Cumulus tops protruding above the deck were seeded on the second and third runs. Temperatures at the top of the cloud varied from -5.0 degrees on the first run to -8.0 degrees centigrade on the second run and -9.0 degrees centigrade on the third run. Temperature at the base of the clouds was -3.5 degrees on all three seeding runs.

Rate of Seeding--Dry ice pellets were dropped at the rate of 8, 7 and 4 pounds per mile, respectively, on the three seeding runs.

Time and Duration of Seeding--

First Seeding: 1520:30 EST; zero minutes plus 10 seconds.
Second Seeding: 1530:10 EST; zero minutes plus 10 seconds.
Third Seeding: 1545:10 EST; zero minutes plus 36 seconds.

Results--Negative structural and precipitation results were observed on all three seedings.

Method of Verification--

1. Structural
   a. First Seeding: Aerial observations (Visual).
   b. Second Seeding: Aerial observations (Visual and photographic). Track of photographic plane and seeded area from radar pictures.
   c. Third Seeding: Aerial observations (Visual and photographic). Track of photographic plane and seeded area from radar pictures.
2. Precipitation
   a. First Seeding: Radar pictures indicated precipitation from clouds other than the one seeded. Surface observations (Visual).
   b. Second Seeding: Radar pictures indicated no precipitation from seeded clouds or within 30 miles of seeded clouds. Surface observations (Visual).
   c. Third Seeding: Radar pictures indicated no precipitation from seeded clouds or within 30 miles of seeded clouds. Surface observations (Visual). See pictures of radar scope, Figures 47, 48, and 49. Note progress and slight dissipation of cloud echoes on eastern half of scope between 1520 EST and 1550 EST. Position of seeding aircraft is indicated by its beacon code on the scope at 1520 EST at 190 degrees and 33 miles from the Jamestown radar site. The aircraft may be located also on the radar pictures at 1530 EST and 1550 EST.

Comments--Observation was difficult because of numerous natural holes in the cloud deck, and the observers were never able to locate the seeded area accurately. No precipitation echoes from the seeded areas were observed on the radar scope; therefore any precipitation that might have fallen must have been very light. A few minutes before seeding operations, a heavy shower passed over the radar station; yet nothing of consequence developed from the seeding. It may be noted that even though the clouds seeded had temperatures below freezing, the planes did not pick up ice while flying through them - a possible indication that the clouds were already composed of ice crystals and not favorable for seeding.

Cloud Seeding of April 2, 1948

Synoptic Situation--The Clinton County Air Force Base was in a pre-cold frontal position at 1330 EST. A cold front lay northeast to southwest from Dayton, Ohio to western Kentucky. The only precipitation reported at 1330 EST in the vicinity of the seeding operations was at Dayton, Ohio. Pressures were rising rapidly behind the cold front with slight falls ahead of it indicating that it was moving at a moderate speed toward the seeding area.

Atmospheric Sounding--The lapse rate was dry adiabatic from the surface to 730 mbs. with an average lapse rate slightly less than the moist adiabatic from 730 mbs. to 650 mbs. A temperature inversion existed between 650 mbs. and 634 mbs. The seeded cloud was an altocumulus deck with its base at 7,500 ft. m.s.l. and the tops varying between 11,600 ft. m.s.l. and 13,500 ft. m.s.l. (See Figure 50.)

Conditions of Seeding--Three seeding runs were made. The temperature at the base of the clouds was -7.2 degrees centigrade on all three runs. The temperatures at the tops of the clouds were -19.0 degrees, -17.5 degrees, and -15.1 degrees centigrade, respectively, on the three runs. All three drops were made into the cumulus tops protruding above the altocumulus deck.

Rate of Seeding--Dry ice pellets were dropped at the rate of fifteen pounds per mile on the first and second runs and five pounds per mile on the third seeding.

Time and Duration of Seeding--

First Seeding: 1435:00 EST; zero minutes plus 30 seconds.
Second Seeding: 1459:10 EST; zero minutes plus 20 seconds.
Third Seeding: 1512:00 EST; zero minutes plus 11 seconds.

Results--On the first and third runs, snow fell from the cloud to be seeded before and after seeding, but the precipitation evaporated before it could reach the ground. According to the radar scope, no change in intensity of precipitation was observed after seeding. Partial dissipation of the clouds was also observed. There is some doubt as to whether the seeded clouds were the ones actually observed in every case. Nothing was observed after the second run.

Method of Verification--

1. Structural
   a. First Seeding: Aerial observations (Visual). Track of seeded area and aircraft from radar pictures.
   b. Second Seeding: Aerial observations (Visual). Track of seeded area and aircraft from radar pictures.
   c. Third Seeding: Aerial observations (Visual). Track of seeded area and aircraft from radar pictures.
2. Precipitation
   a. First Seeding: Aerial and surface observations (Visual).
   b. Second Seeding: Aerial and surface observations (Visual).
   c. Third Seeding: Aerial and surface observations (Visual).

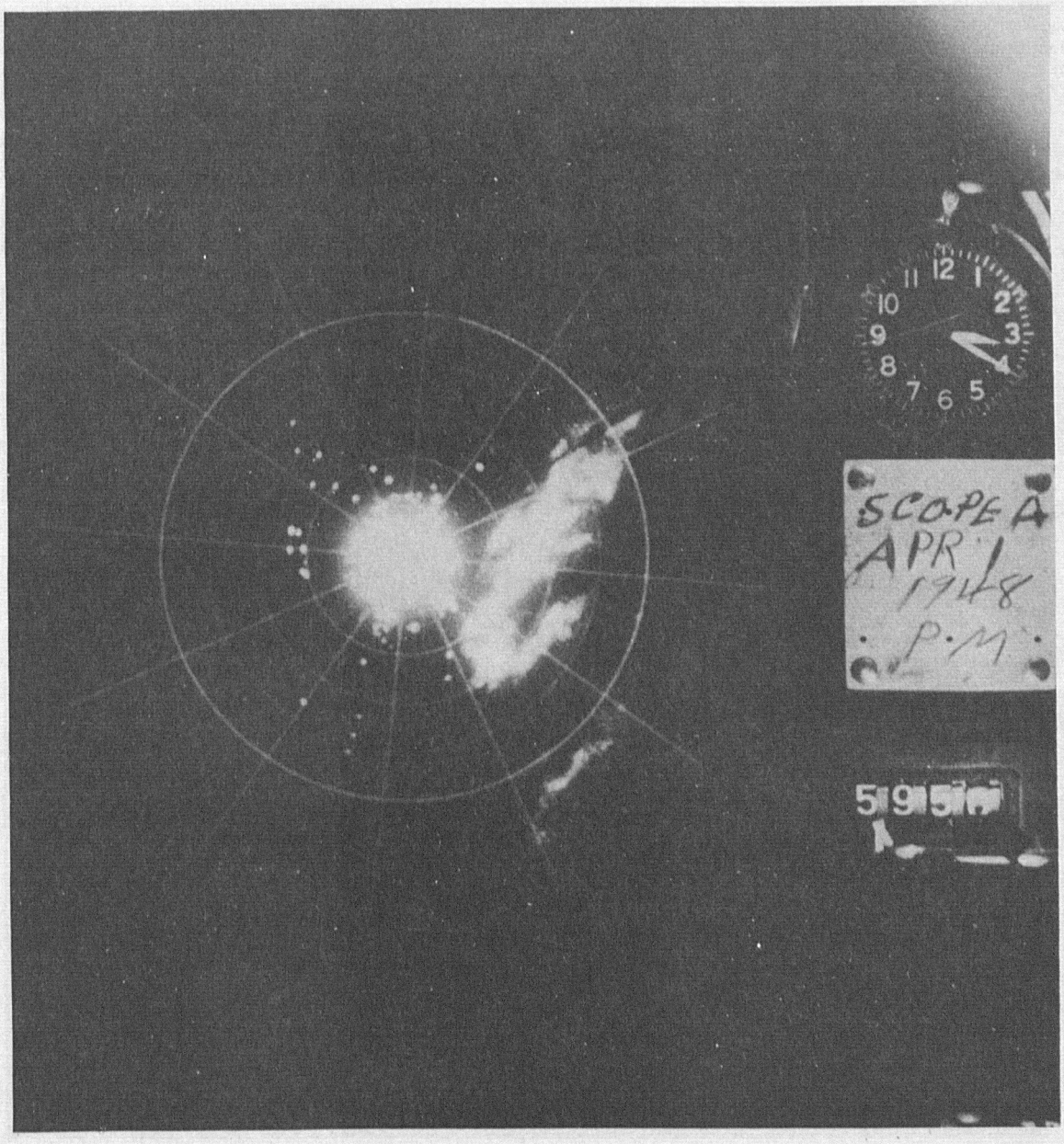

Figure 47.--Radar scope picture, 1520 EST, April 1, 1948.

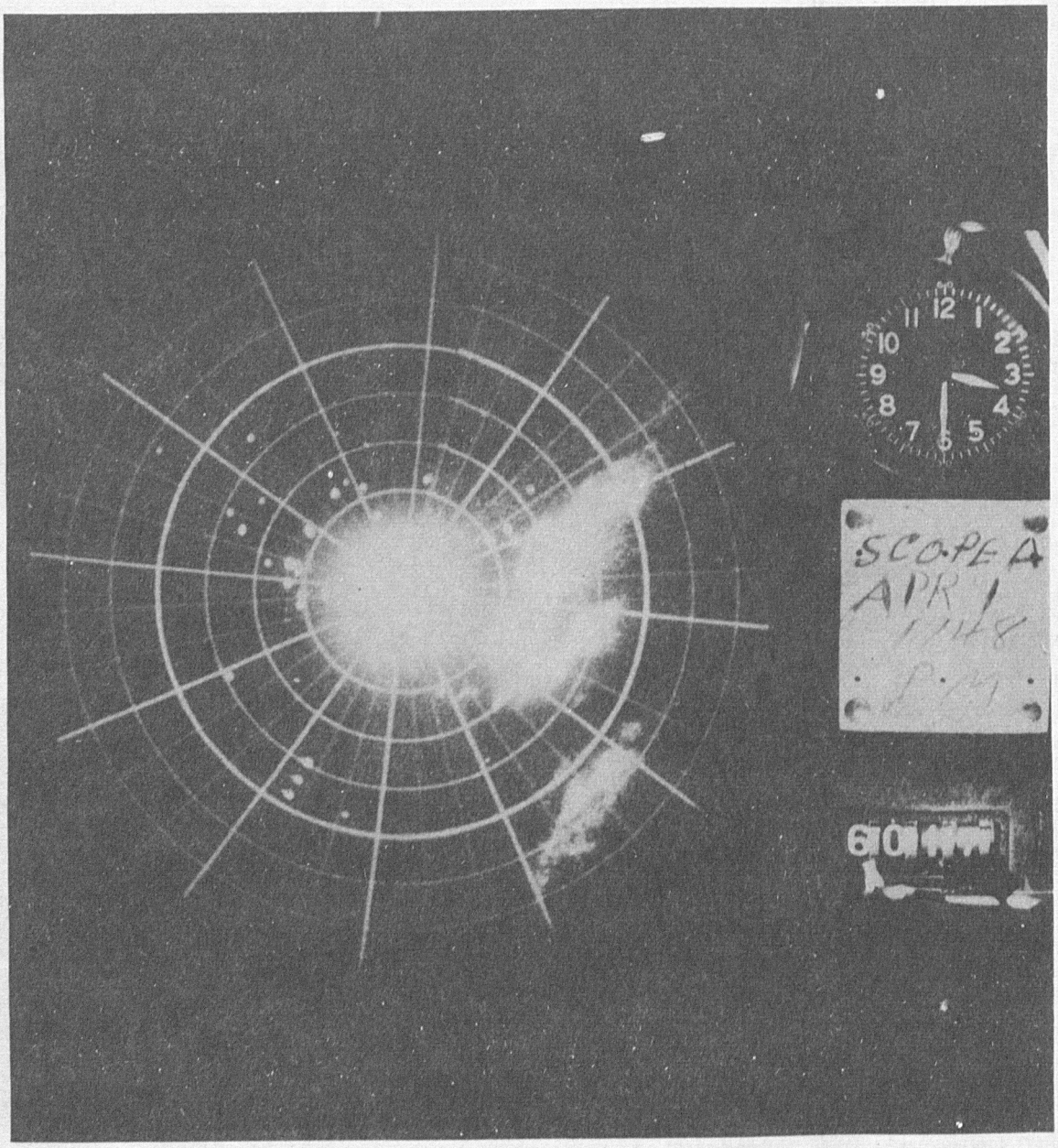

Figure 48.--Radar scope picture, 1530 EST, April 1, 1948.

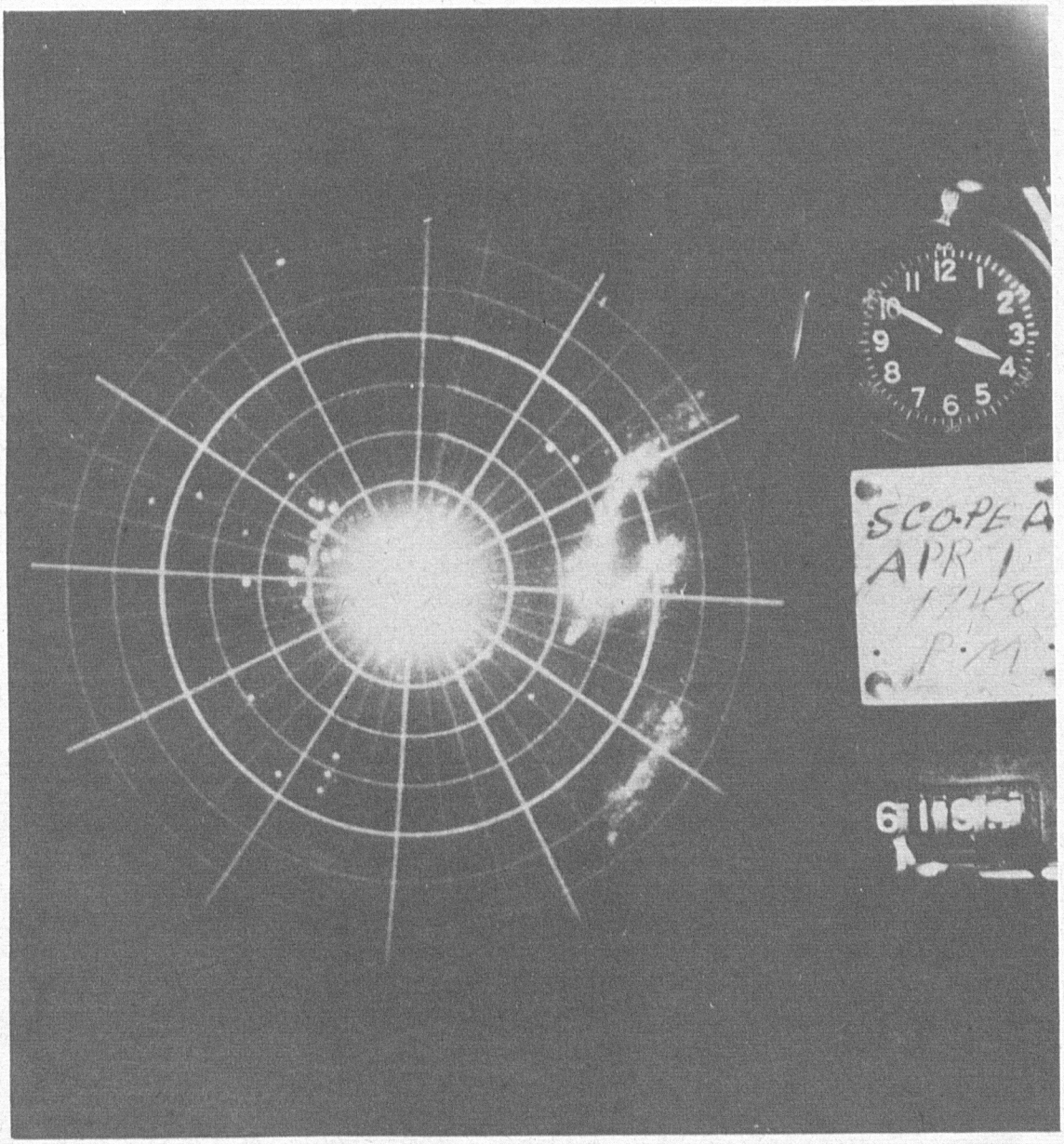

Figure 49.--Radar scope picture, 1550 EST, April 1, 1948.

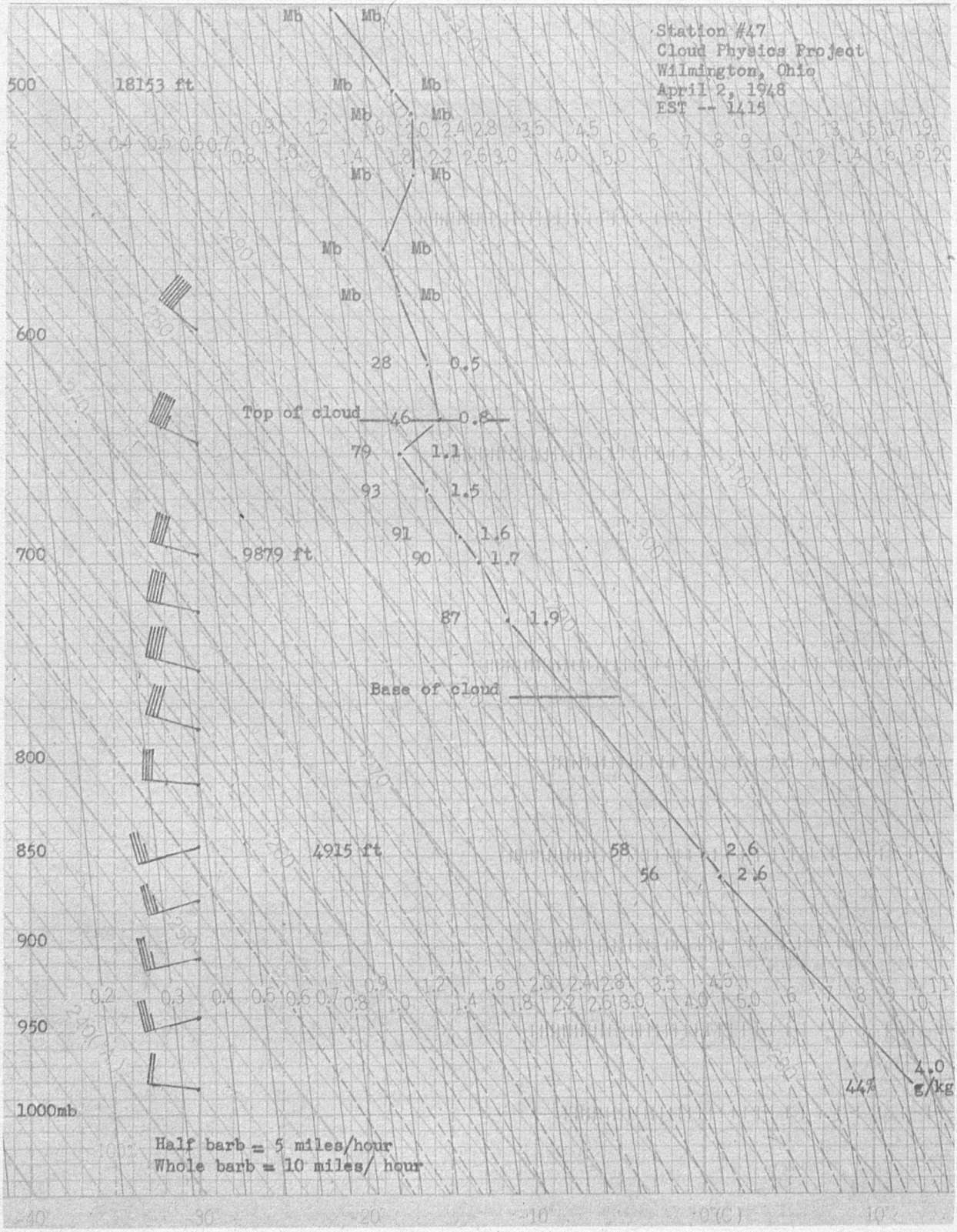

Figure 50.--Atmospheric sounding, 1415 EST, April 2, 1948.

Comments--A preliminary run was made on the cloud to be seeded and icing conditions were observed. The positive precipitation results lack significance since natural precipitation was already occurring in and around the seeded area. Positive dissipation results could have significance since the cloud was thoroughly ideal for seeding, but the low observation plane reported several natural openings already existed in the cloud deck.

Cloud Seeding of April 29, 1948

Synoptic Situation--The area of seeding operations was on the eastern edge of a weak anticyclone. A low pressure system was located along the eastern coast of Virginia. There were no fronts in the immediate vicinity of Clinton County Air Force Base. A fragmentary portion of a stationary front was situated through northeastern South Carolina extending eastward into the Atlantic Ocean.

Atmospheric Sounding--There was a dry adiabatic lapse rate from the surface to 930 mbs. and moist adiabatic from 930 mbs. to 724 mbs. except for a thin layer that had a lapse rate less than the moist adiabatic rate between 841 mbs. and 815 mbs. Another layer with a lapse rate less than the moist adiabatic rate was existent between 724 mbs. and 695 mbs. Several cloud layers were present but the altostratus-altocumulus deck between 7,500 ft. m.s.l. and 10,000 ft. m.s.l. was the deck that was seeded. (See Figure 51.)

Conditions of Seeding--Three seeding runs were made. Two cloud decks were present below the seeded deck. The lowest deck extended from 2,000 ft. to 4,500 ft. m.s.l. The next cloud layer was between 5,300-6,500 ft. m.s.l. The temperature of the seeded cloud ranged from -4.0 degrees centigrade at the base to -8.0 degrees at the top on all seeding runs.

Rate of Seeding--Dry ice pellets were dropped at the rate of eight pounds per mile on all seeding runs.

Time and Duration of Seeding--

First Seeding: 1122:00 EST; zero minutes plus 25 seconds.
Second Seeding: 1139:55 EST; one minute plus 20 seconds.
Third Seeding: 1158:30 EST; zero minutes plus 52 seconds.

Results--A trough was formed in the clouds on each seeding. The first trough was estimated to be about 150 ft. deep and the third one was estimated to be about 500 ft. deep. The second trough was in the shape of an "L" and the depth was not estimated. Light rain was reported after the third seeding, but there is some doubt as to whether it was the result of seeding. A noticeable change in texture was observed also on all three seedings.

Method of Verification--

1. Structural

   a. First Seeding: Aerial observations (Visual and photographic).
   b. Second Seeding: Aerial observations (Visual).
   c. Third Seeding: Aerial observations (Visual and photographic). See Figure 52. Time of photograph is doubtful because of insufficient data, but all available data indicate the seeded path running diagonally across the photograph is the result of the third seeding. The area noted in the upper portion of the photograph is the result of the first seeding.

2. Precipitation

   a. First Seeding: Aerial and surface observations (Visual).
   b. Second Seeding: Aerial and surface observations (Visual).
   c. Third Seeding: Aerial and surface observations (Visual).

Comments--The thermal structure of the clouds was theoretically ideal for positive dissipation results. The aircraft also reported icing conditions in the second and third cloud layers from about 5,300 ft. to 10,000 ft. m.s.l. indicating supercooled water droplets were present; therefore the positive dissipation results are significant. One of the aircraft flew into all three troughs. Although icing was picked up in the clouds, no icing was encountered in the seeded areas. In the second area some moisture was observed.

Light rain was observed for about five seconds below the base of the lower cloud deck after the third seeding, but it is not believed to have been the result of seeding. There was no aircraft flying between the cloud decks immediately below the seeded clouds; consequently it could not be definitely determined whether the precipitation came from the seeded cloud deck or one of the lower cloud layers. Prior to the seeding operations, one aircraft reported light rain while climbing through the lower cloud deck from 2,500-4,000 ft. m.s.l. Therefore, it seems logical to assume that the rain originated in the lower deck rather than in the seeded cloud deck. Furthermore, the pilot did not report the rain until after he had landed; consequently a coordination of the location of the rain area and the seeded area could not be made.

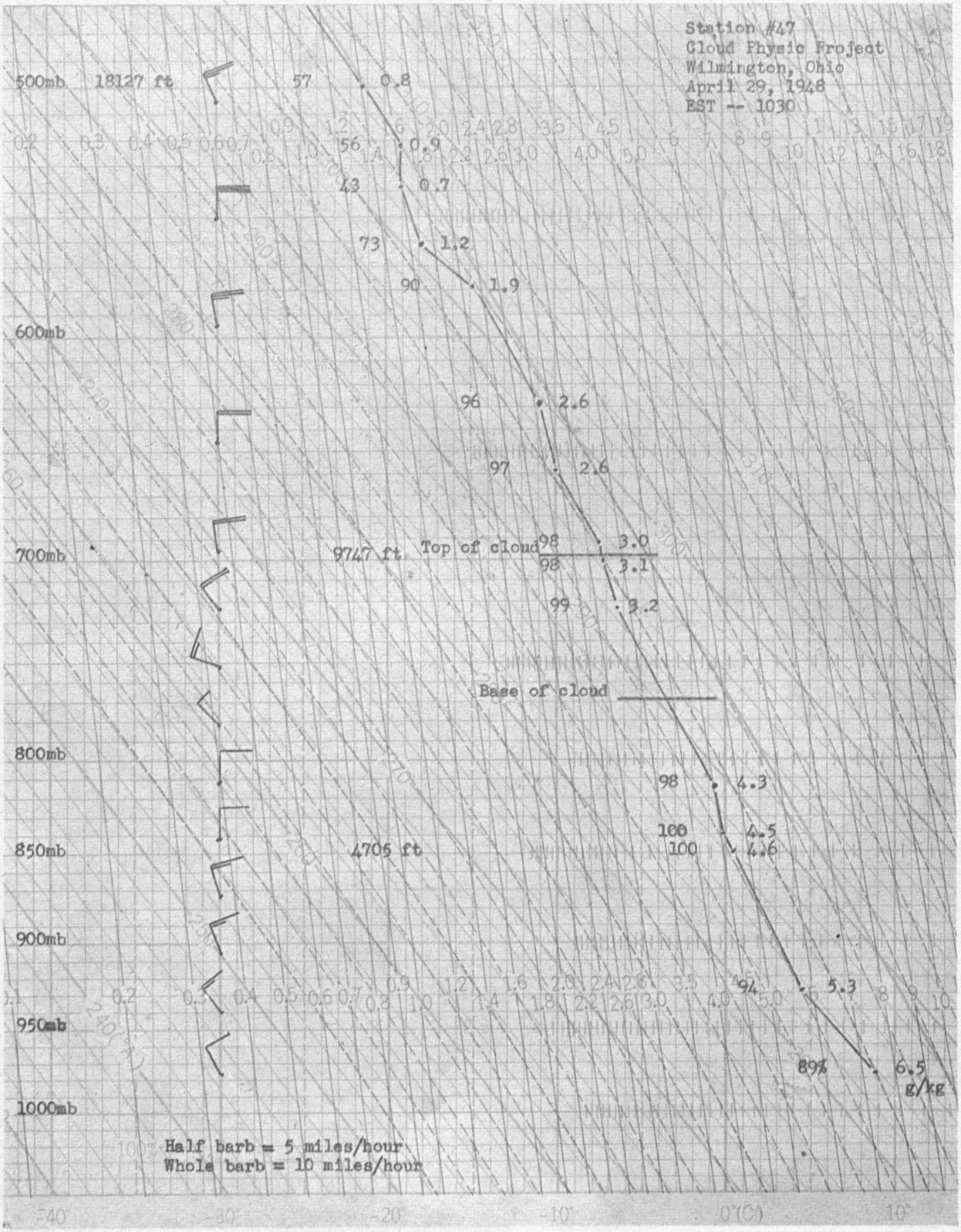

Figure 51.--Atmospheric sounding, 1030 EST, April 29, 1948.

Figure 52.--View showing seeded trough running through middle of picture, and showing a second area, toward top of picture, seeded forty minutes earlier, April 29, 1948.

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