Formation of a Rain Shower by Salt Seeding

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ABSTRACT

Salt seeding took place below one end of a line of stratocumulus clouds with 350 lb of NaCl released. Cloud base was 9000 ft and cloud tops were at 15 to 18,000 ft above sea level. Cloud top temperature was near −2C and updraft speeds below the base were near 3 m sec^{-1}. The resulting shower was monitored by radar with the total rainfall being estimated at 280 acre feet. No rain fell from the unseeded portion of the cloud line or from any other clouds within 50 mi.

1. Introduction

Although hygroscopic cloud seeding agents have been used in tropical regions to stimulate rain formation by coalescence (e.g., Biswas *et al.*, 1967), they have not been used much elsewhere except for fog dissipation. This may be because they do not produce the dramatic visual effects sometimes associated with the artificial nucleation of supercooled clouds by dry ice or silver iodide. However, experiments using common salt as a seeding agent to initiate precipitation in convective clouds have been underway for several years in South Dakota. This paper describes the experiment of 23 July 1970, in which a moderate rain shower was produced from part of a line of stratocumulus cloud in a polar airmass by releasing finely milled salt particles in the updrafts below the cloud base.

2. Background of the experiment

Some preliminary experiments using common salt as a seeding agent were carried out in the Rapid City area in 1966 (Dennis *et al.*, 1967) and a randomized series of 22 single-cloud experiments was conducted in 1967 (Schock, 1968). A salt powder with median particle diameter just under 10 μ was released in amounts up to 50 kg in updrafts below cumulus congestus clouds. The results of the randomized experiments were monitored from the seeding aircraft and by an instrumented aircraft making repeated cloud penetrations at the −5C level. Unfortunately, the 9 clouds selected as seed cases were (by chance) wetter than the 13 no-seed cases at the time of their selection. Therefore, no firm conclusions could be drawn, despite the fact that the seeded clouds produced heavier showers than the unseeded ones.

In 1969 the Institute began a three-way (no-seed, salt seed, or silver iodide seed) randomized project which is evaluated principally on the basis of radar data processed by an on-line computer and recorded on magnetic tape. Test cases are defined in terms of a grid of squares 10 n mi on a side. Examination of radar data collected during the 42 cases of the 1969 season suggested that the salt-seed cases produced new radar echoes at lower elevations than did the unseeded or AgI-seed cases, but the evidence was not considered conclusive (Dennis *et al.*, 1970).

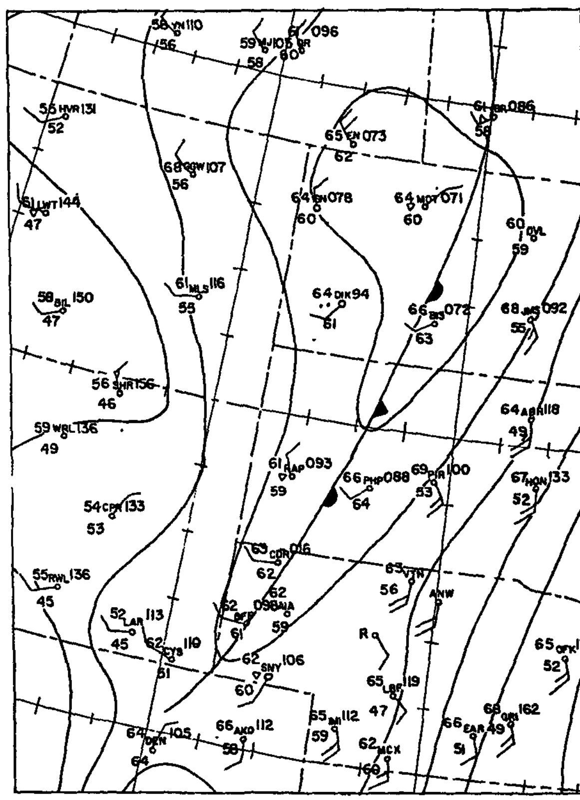

FIG. 1. Synoptic chart for 0800 MDT 23 July 1970. The cold occluded front had passed Rapid City during the night.

During the winter of 1969–70, a numerical study of the effects of salt seeding in convective clouds was carried out using a model of droplet growth developed by Musil (1970). This model, originally developed to study the growth of hailstone embryos in a one-dimensional but time-dependent cloud, yielded trajectories and growth rates of salt particles of various sizes introduced into the updraft of a convective cloud of the Northern Great Plains region. The initial droplet size at cloud base was estimated on the basis of work on condensation on large hygroscopic particles by Keith and Arron (1954).

The calculations showed that salt seeding would not be very efficient unless the updrafts were strong enough to support raindrops big enough to undergo breakup and set off a Langmuir (1948) chain reaction. It was found that the salt used in 1967 and 1969 could not produce optimum effects, as it contained a few particles with diameters $>100\,\mu$. Therefore, the number of raindrops initially produced in the cloud per unit mass of salt released could not be very large, and many of them would fall out before rising into the regions of strong updrafts where the chain reaction could take place.

A finer grind of salt with median diameter near $5\,\mu$ was obtained for use in the 1970 Cloud Catcher program. Unfortunately, this salt tended to cake in the hopper even though it contained a chemical agent to counteract this, and had to be mixed with the coarser salt to insure that it would flow. A 50–50 mixture by weight of fine and coarse salt was used on the 23 July experiment.

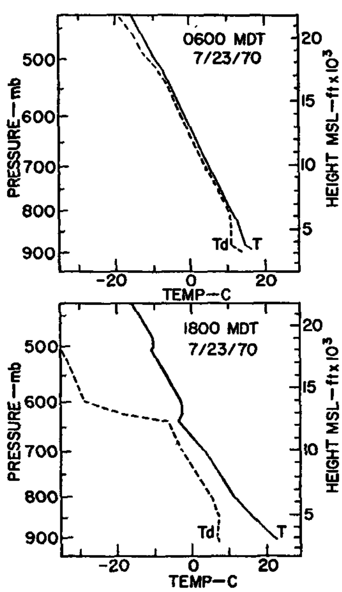

FIG. 2. Pseudo-adiabatic diagrams for morning and evening soundings at Rapid City showing temperature (T) and dewpoint (T_d). Evening sounding indicates cool dry air following the front, with inversions at 12,500 and 18,000 ft MSL.

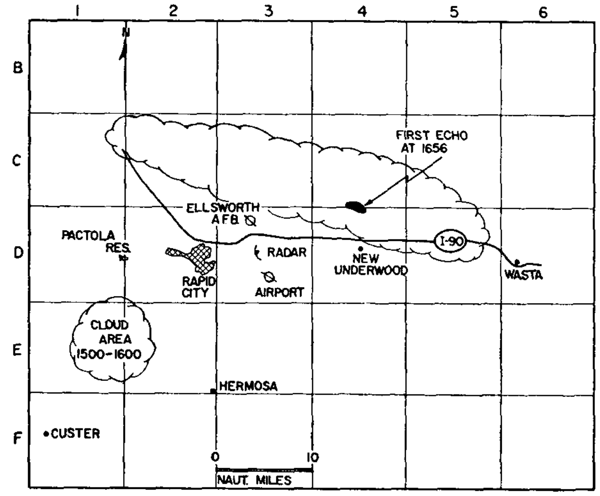

FIG. 3. Positions of cloud area of the first, unsuccessful case of seeding between 1603 and 1607, and the first radar echo observed with a high-power radar. The cloud line moved further east during the experiment. Each square is identified by number and letter.

3. Weather situation

A cold occluded front (Fig. 1) passed Rapid City at 0030 (all times MDT) on 23 July followed closely by a 700-mb trough. This weather system yielded 0.33 inch of rain at the Rapid City Regional Airport,[1] with clearing during the forenoon. The cooling and drying following the front can be noted by comparing the 0600 and 1800 radiosondes for Rapid City (Fig. 2). The precipitable water fell from 1.26 to 0.67 inch and cooling was noted at levels from 850 through 450 mb.

At about 1500 cumulus clouds formed southwest of the radar site (Fig. 3). Most of them failed to penetrate the strong inversion at the 12,500-ft level (Fig. 2). Some seeding was carried out below them between 1603 and 1607 but without any apparent effect.

About an hour later an east-west line of cumulus and stratocumulus clouds became identifiable almost directly over the radar site. The Airport observations show a wind shift between 1600 and 1700 from 350° at 5 kt to 190° at 10 kt. A definite convergence line was being formed; a period of calm was noted at the radar site as the clouds were overhead. As the line shifted northward, the cloud base became darker, the tops firmer, and the surface wind at the radar site also shifted to the south.

4. The experiment

The project meteorologist called a special seeding case (outside of the three-way randomization scheme) at 1643 on the cloud line just north of the radar site (Fig. 3). No radar echoes were observed at the time. The updrafts experienced below the cloud by the seeding

[1] Hereafter referred to as Airport.

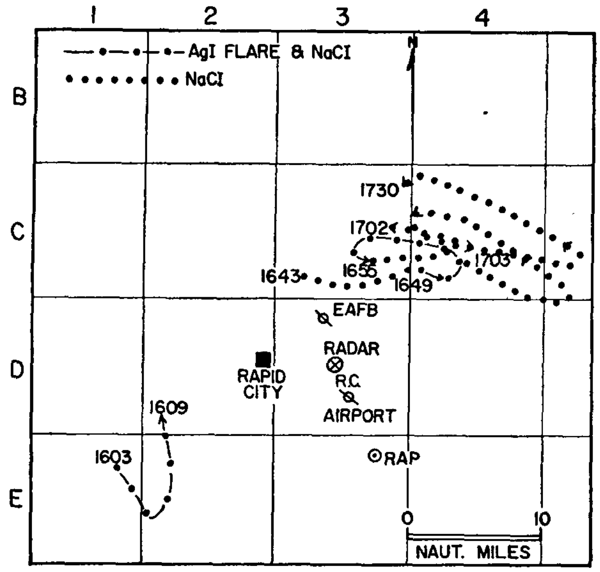

FIG. 4. Track of the aircraft during seeding. The seeding was done only on the eastern part of cloud line. Grid squares are designated as in Fig. 3.

aircraft were not strong, having a maximum of 3 m sec^{-1} and an average of $\sim$1.5 m sec^{-1}.

Seeding was carried out by releasing 150 kg of salt powder under the eastern end of the line between 1643 and 1730 (Fig. 4). A flare containing 120 gm AgI was burned for 6 min below the darker base area, but AgI seeding was discontinued when it was realized that the clouds were failing to rise above the 0C level, apparently stopping at the inversion near 18,000 ft. No seeding was done on the western part of the cloud line at any time as can be seen by comparing the seeding track on Fig. 4 with the cloud position given in Fig. 3. The seeding was limited to the eastern part due to flight restrictions over Ellsworth Air Force Base approaches.

The first radar echo was detected at 1656 at 17,000 ft by a high-power, height-finding S-band radar. Shortly afterward more echoes appeared at lower elevations. At 1705 a few drops of rain were detected over the windshield of the seeding aircraft, and within a few minutes a visible rain shaft extended to the ground.

The low echo tops in the growing stage suggested that the updraft was not strong enough to carry the embryos to cloud top before they had grown to precipitable size. The highest echo top recorded by the height-finding radar on this day was 18,000 ft at 1719 MDT. By 1727 moderate showers were reaching the ground with echo tops at about 17,000 ft; the maximum reflectivity factor was at 9000 ft.

At 1734 showers covered the whole of the eastern part of the cloud line without any development of showers or radar echo in the western portion (Fig. 5). Fig. 5 also shows that there was no vertical cloud development and no formation of ice associated with the shower.

The computer-generated displays of 3-cm radar data indicated shallow echoes. Precipitation was first detected by this radar at 1714. The echo strength and coverage increased subsequently and reached their maxima about 1727 (Fig. 6). At that time the shower area was about 12 *n mi* across, but there were only isolated echoes at 15,000 ft and none at 20,000 ft. (Resolution of this system is 5000 ft in the vertical.) A more detailed examination of 1730 (Fig. 7) shows essentially the same situation.

The shower continued for more than 40 min. The rain produced can not be estimated from standard raingages as their readings included the morning rain. A computer analysis of taped radar reflectivity data

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Salt seeding took place below a line of shallow clouds north of the radar site between 1643 and 1730 MDT, with 350 lb of NaCl released below the southeastern half (right end) of the cloud line. Cloud base was 9000 ft and cloud tops were 15- to 18,000 ft above sea level. Maximum updraft at the time of seeding was about 3m sec^{-1}. First radar echo was observed at 1656 and about 20 minutes later a shower was reaching the ground from the southeastern end of the line. It lasted about an hour with no rain or radar echo at any time from the northwestern (unseeded) part of the line. There were no other showers in the vicinity. Total rain output estimated from radar was about 280 acre feet and maximum rain intensity was 0.72 inches per hour.

FIG. 5. The cloud line as seen at 1734 from the radar site showing western part with no rain and eastern part with shower reaching ground (photo by P. L. Smith).

indicates the water produced was approximately 280 acre feet (340,000 m^3) and the maximum point rainfall rate was about 18 mm hr^{-1}.

5. Conclusions

The experiment clearly demonstrated that the introduction of proper size rain embryos at cloud base can sometimes initiate the Langmuir chain reaction of precipitation growth.

The time sequence in which the first radar echo appeared 13 min after seeding started and rain below cloud base in 22 min is compatible with the times required to grow raindrops around 50 μ embryos in shallow cumulus clouds. With decreasing low-level moisture, dry air above, and increasing stability, there was little chance of much cloud growth and only a remote possibility of natural precipitation. This was also obvious from the fair-weather cumulus of the day, which had no precipitation, virga or radar echo anywhere but in the seeded region. The cloud line on which the experiment was conducted, with an average depth of 7000 ft, maximum depth of 9000 ft, average updraft of 1.5 m sec^{-1}, and maximum updraft of 3 m sec^{-1} itself showed little chance of natural precipitation. This is confirmed by the fact there was no rain from the unseeded end of the cloud line.

It is true that we rarely get such clear-cut cases to differentiate artificial from natural rain. Furthermore, we cannot draw conclusions for large shower clouds or widespread convective rains, involving more complex processes, on the basis of this experiment. However, the results of the 23 July experiment clearly justify increased attention to the use of hygroscopic agents in initiating precipitation formation in convective clouds.

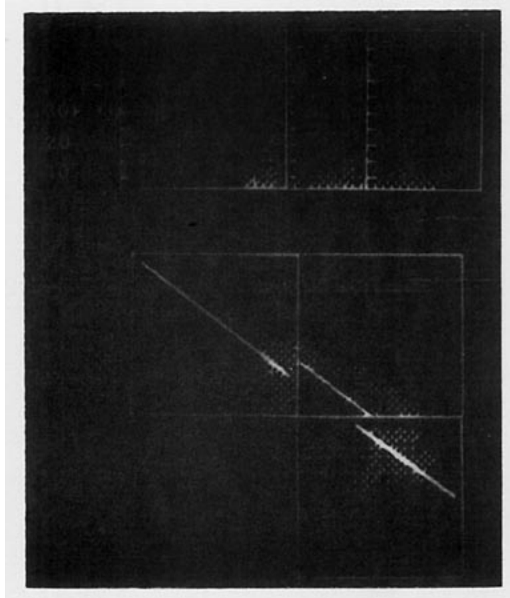

FIG. 7. Horizontal section of radar echo at 10,000 ft at 1730 (bottom), and vertical sections (top) along the lines shown in the bottom picture. Display interpolates between 5000-ft intervals; echoes were recorded for 10,000 and 15,000 ft only.

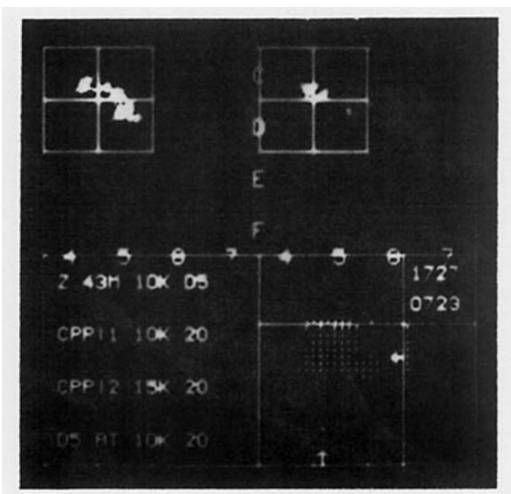

Fig. 6. Computer-generated radar displays at 1727, the time of maximum shower coverage. Top left shows horizontal section at 10,000 ft and top right the horizontal section at 15,000 ft. Echoes spread over three squares of Fig. 3 (C4, C5, D5). Lower picture shows expanded view of square D5, where reflectivity factor peaked at 43 dBz as indicated by arrows, and north-south and east-west vertical sections through this point.

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