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Radar Detection of Cloud-Seeding Effects

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Abstract. *The effects on precipitation of artificially seeding clouds with Dry Ice have been monitored from cloud to ground with a radar that has a wavelength of 8.6 millimeters.*

The evaluation of the effects of artificial ice nucleants on clouds and precipitation is a difficult task that requires, in general, careful physical measurements and statistical evaluations (*1*). We describe here a powerful physical technique that utilizes an 8.6-mm-wavelength radar (*2*) with color display for detecting the effects of artificial seeding from cloud to ground (*3*).

To test the utility of the radar, we carried out a series of cloud-seeding trials in December 1979 and February 1980. The radar was located at Grayland, Washington, on the Pacific coast. In each trial an aircraft was used to seed layers of supercooled cloud with Dry Ice along tracks oriented perpendicular to the wind direction and located at various distances upwind from the radar. The antenna of the radar was pointed vertically in order to detect the seeded tracks and unseeded portions of the cloud as they moved overhead. After seeding, the aircraft made a series of passes at different altitudes through the seeded and unseeded clouds in order to obtain detailed measurements of their microstructures (*4*).

During the course of the 2-month experiment, 108 tracks were seeded. We describe here the results obtained on 1 day.

On 20 February 1980 a broken, nonprecipitating, altocumulus cloud deck was situated over Grayland. Cloud tops

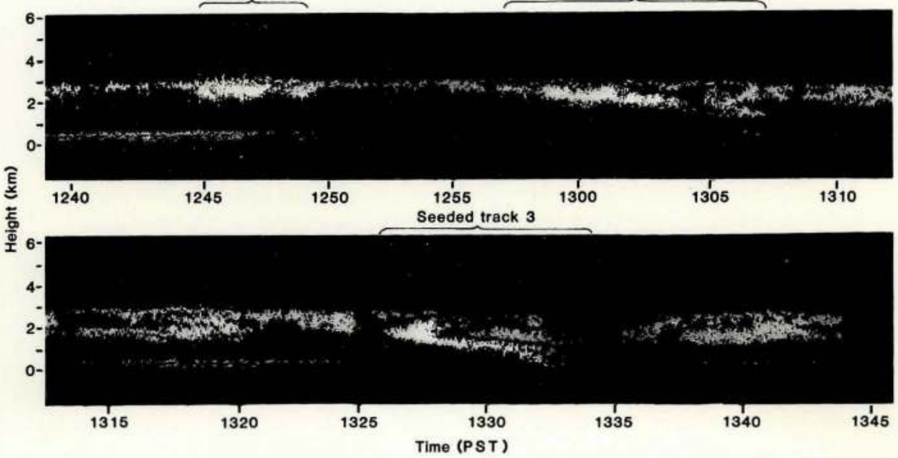

Fig. 1. Time-height display of radar echo pattern. The echo extending from ~ 0 to 0.5 km above ground is due to radar "ground clutter" and not to cloud. Clouds are located between ~ 5000 and 10,000 feet (~ 1.5 to 3 km). The gray areas represent the weakest radar echoes, black areas regions of intermediate radar echo strength, and white areas the strongest radar echoes. The third seeded track has precipitation falling from it that reached the ground at the radar site (see Fig. 3).

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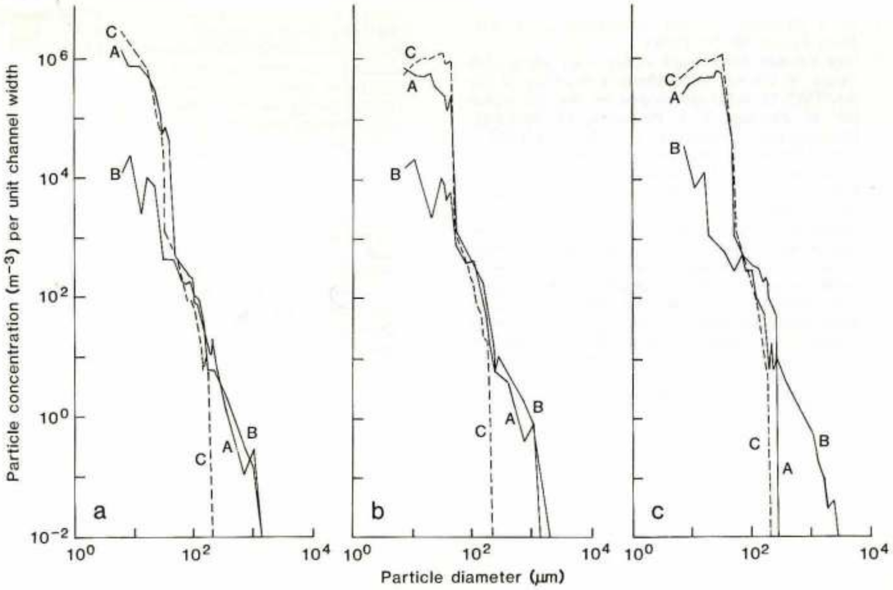

Fig. 2. Particle-size spectra measured during aircraft penetrations through the seeded (solid lines) and unseeded (dashed lines) clouds. (a) Track 1, pass A (2.3 km above MSL, −8.9°C, 33 minutes after seeding); track 1, pass B (2.0 km, −6.1°C, 39 minutes after seeding); pass C (2.4 km, −8.8°C) through an adjacent portion of nonseeded cloud. (b) Track 2, pass A (2.3 km above MSL, −9.3°C, 23 minutes after seeding); track 2, pass B (1.8 km, −5.8°C, 35.5 minutes after seeding); pass C (2.4 km, −9.9°C) through an adjacent portion of nonseeded cloud. (c) Track 3, pass A (2.4 km above MSL, −9.9°C, 7 minutes after seeding); track 3, pass B (1.6 km, −4.2°C, 41 minutes after seeding); pass C (2.5 km, −9.8°C) through an adjacent portion of nonseeded cloud.

were at an altitude of 2.5 km above mean sea level (MSL), where the temperature was −9.5°C. Winds were from 220° at 12 to 15 knots (6.2 to 7.7 m sec^{-1}). Prior to seeding, spectacular glories were observed from the aircraft flying above cloud top, revealing that the cloud contained fairly uniform water droplets (*5*). Seeding with Dry Ice was carried out at cloud top along several tracks located at various distances upwind of the radar. Measurements and observations on three of the seeded tracks will be described.

The first seeded track was situated 9 km upwind of the radar and was seeded at a rate of 0.05 kg of Dry Ice per kilometer along a line 17 km long. This track passed over the radar between 1245 and 1248 PST about 21 minutes after it was seeded. As the seeded track passed over the radar, it produced an enhanced radar echo between altitudes of ~ 2 and 2.7 km above MSL (Fig. 1).

The first aircraft penetration of the seeded portion of the cloud was at an altitude of 2.3 km above MSL (−8.9°C) 33 minutes after seeding and 12 minutes after the seeded track had passed over the radar. The size spectrum of particles measured during this penetration is shown as curve A in Fig. 2a. The seeded cloud contained particles between 200 μm and 1 mm in size in measurable concentrations, whereas the adjacent unseeded cloud (curve C) did not.

A second aircraft pass was made through the seeded cloud at an altitude of 2.0 km above MSL (−6.1°C) 39 minutes after seeding and 18 minutes after this cloud had passed over the radar (curve B in Fig. 2a). It shows concentrations of large particles similar to those of curve A, but the concentrations of smaller particles (< 50 μm) are much lower than those shown in either curve A or curve C. The progressive depletion of the smaller particles in the seeded cloud was no doubt due to their collection by the larger ice particles, since observations of the latter with instrumentation aboard the aircraft showed that they consisted of graupel-like particles and ice crystal aggregates. Precipitation particles from the seeded cloud, extending below cloud base but not reaching the ground, were observed visually from the aircraft after the cloud had passed over the radar.

The second track that was seeded was also located 9 km upwind of the radar; Dry Ice was again dispersed at a rate of 0.05 kg km^{-1} into cloud top, but the length of the seeded track was increased to 25 km. The seeded track passed over the radar 25 minutes after seeding (at 1257 to 1307 PST) and produced a more extensive radar echo than the first seeded track (Fig. 1). However, as was the case for the first track, no precipitation reached the ground at the radar site. The aircraft made four passes through the seeded cloud. The particle size spectra measured on two of these passes are shown as curves A and B in Fig. 2b. They reveal effects due to seeding very similar to those noted for the first seeded track: the appearance of large ice particles and subsequently depletion of the small particles. In this case, the measurements shown as curve A in Fig. 2b were obtained just 2 minutes before

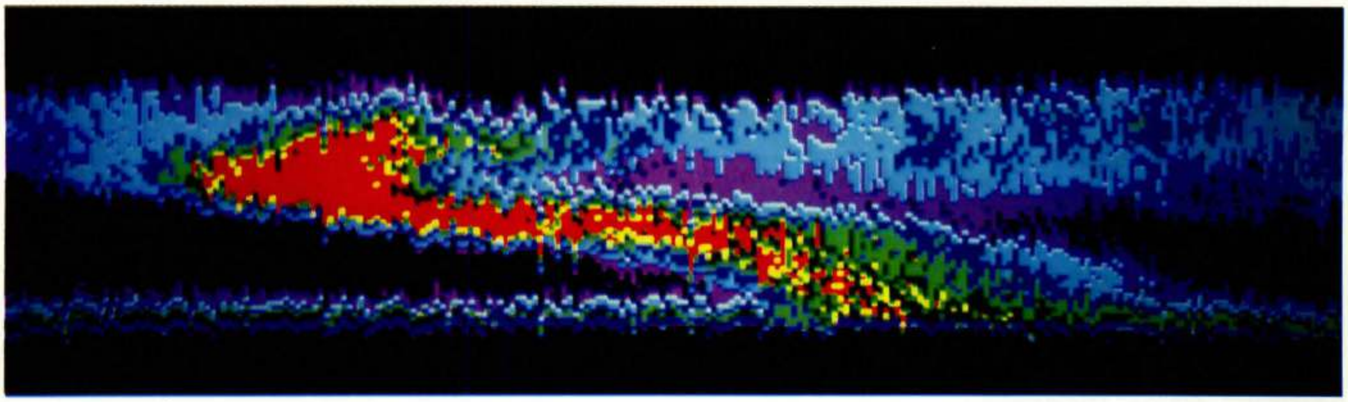

Fig. 3. A vertical cross section of the radar echo pattern of track 3 through a cloud. The natural cloud (purple and blue) is fairly uniform in structure and not precipitating. A portion of the cloud that was artificially seeded with Dry Ice produced a more intense radar echo (green, yellow, and red) and a trail of precipitation that reached the ground.

the seeded cloud passed over the radar.

The seeding of the two tracks described above produced significant changes in the structures of the clouds that enhanced their radar reflectivities. However, it appeared that the seeding was being carried out too close to the radar to allow sufficient time for the large particles produced by the seeding to reach the ground at the radar site. Consequently, the third seeded track was located 18 km upwind of the radar (twice the spacing used in the second track). In addition, the rate of Dry Ice seeding was doubled (to 0.1 kg km^{-1}).

The third seeded cloud passed over the radar between ~ 1326 and 1328 PST (~ 40 minutes after seeding). Precipitation trails from this cloud reached the ground between ~ 1331 and 1334 PST (Fig. 1). (An expanded view of the radar display of this seeded track is shown in Fig. 3, where various radar echo intensities are depicted in different colors.) The amount of precipitation that reached the ground at the radar site was quite small (observers on the ground reported a trace). The fact that the radar detected a strong signal all the way to the ground illustrates its sensitivity. The particle size spectra measured in this third seeded track are shown as curves A and B in Fig. 2c; curve C shows the measured spectrum in an adjacent cloud that was not seeded. The spectrum shown in curve B was measured at an altitude of 1.6 km above MSL (−4.2°C) just 1 minute after the seeded cloud passed over the radar. Aggregates of ice particles 2 mm in size in concentrations of ~ 30 per liter were measured on this pass.

Each one of the three seeded tracks passed over the radar within a few minutes of the times predicted by the scientist aboard the B-23 aircraft. These predictions were based on the location of the seeding with respect to the radar and the velocity of the winds.

These observations illustrate that a short-wavelength radar can provide a unique and powerful tool in evaluating the effects of cloud seeding. It permits continuous remote sensing of precipitable particles from cloud to ground, a capability that thus far has not been used in cloud-seeding research.

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References and Notes

1. R. R. Braham, Jr., and commentators, *J. Am. Stat. Assoc.* **74**, 57 (1979).
2. Our 8.6-mm-wavelength radar is an adaptation based on the use of modern technology of the AN/TPQ-11 radar developed by the Air Force [W. H. Paulsen, P. J. Petrocchi, G. McLean, *Operational Utilization of the AN/TPQ-11 Cloud-Detection Radar* (Instrumentation Papers, No. 166, Air Force Cambridge Research Laboratories, L. G. Hanscom Field, Bedford, Mass., 1970)].
3. There have been a few reports describing the use of radars with wavelengths of several centimeters for detecting precipitation produced by artificial seeding. For example, D. Atlas [*Bull. Am. Meteorol. Soc.* **46**, 696 (1965)] mentioned some demonstrations of this type in the Soviet Union. P. V. Hobbs [*J. Appl. Meteorol.* **14**, 805 (1975)] described the use of a 3.2-cm Doppler radar for detecting changes in particle fallspeeds produced by seeding. However, to our knowledge, the radar measurements reported here are unique in documenting the effects of cloud seeding from cloud to ground.
4. The University of Washington's B-23 research aircraft was used in these experiments. The extensive instrumentation aboard this aircraft for measuring the properties of clouds and precipitation has been described by P. V. Hobbs, T. J. Matejka, P. H. Herzegh, J. D. Locatelli, and R. A. Houze, Jr. [*J. Atmos. Sci.* **37**, 568 (1980)].
5. R. A. R. Tricker, *Introduction to Meteorological Optics* (American Elsevier, New York, 1970), pp. 191–209.
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