OBSERVATIONS OF NATURAL SEEDING BENEATH ANVIL CLOUDS

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ABSTRACT. Natural seeding events were observed during aircraft and radar observations of a moderate cumulonimbus storm. The storm produced a relatively large anvil which may have resulted from natural over-seeding of the parent cloud by ice particles from the remains of an older storm which merged with the primary system. Ice particles from the anvil were incorporated into the top of a convective cloud beneath the anvil. Subsequently, rapid glaciation of the cloud top was observed followed by a substantial increase in the radar return from the cloud.

1. Introduction

Much of the ice produced by vigorous cumulus clouds remains in the upper troposphere to form the cumulonimbus anvil. Natural seeding of sub-anvil clouds by ice particles from the anvil has long been postulated (e.g. Hitschfeld, 1960). Natural seeding of a cumulus cloud by ice crystals falling from a cumulonimbus anvil is reported by Hobbs et al. (1980), who observed ice concentrations in the seeded cloud to be over one hundred times higher than in other clouds outside of the anvil.

Whether this process actually occurs with any regularity, or whether it has any significant influence on precipitation development, is not known. This process could affect regions far removed from the primary anvil-creating system; anvil clouds often exist long after the primary storm and extend far downwind (e.g. the "orphan anvils" described by Hitschfeld, 1960).

This paper presents the results of a radar and instrumented aircraft study of anvil characteristics and the effects of anvil ice on sub-anvil convective clouds. The data which were collected provide for a case study of one storm on August 22, 1979 near Miles City, MT, (46° 26 N, 105° 52 W, 802 meter MSL, see Fig 1a). Cloud systems of this size are fairly common and are possible candidates for rain augmentation cloud seeding. More details are provided in Stith (1981).

2. Facilities, Instrumentation and Data Processing

An instrumented Learjet operated by Colorado International Corp. bore instrumentation for measuring the position and meteorological state parameters and also a Particle Measuring System (PMS) 2-D-C probe for measuring cloud particle size (37-1200 μm) and concentration, a Johnson-Williams cloud liquid water detector, and an ice particle detector of modified Turner-Radke (1973) type. More details on the aircraft system are provided by Lawson, et al., (1980).

Ice particle concentrates reported here are from the 2-D instrument, as shadow images of ice particles were routinely examined to confirm presence of ice particles. Data from the 2-D probe were processed following procedures described by Cooper (1978). During the field program a gain problem was discovered with the liquid water detector; consequently, liquid water concentrations are given in relative units only. Radar data from the University of North Dakota (UND) 5.4 cm digital Skywater radar were processed by the software described by Brady et al. (1980). In addition to producing various displays of the calibrated radar data, these programs also calculate a number of properties of the radar echoes, describing size, location, height, intensity and direction of movement.

Aircraft transponder returns, also recorded in the digital radar data set, were used to position the aircraft with respect to the storm echoes; in addition, flight tracks were prepared from FAA data. Rawinsondes were launched daily at 1200 (GMT) during the field program from Baker, MT by UND personnel.

3. The August 22 Storm

On August 22, 1979 aircraft sampling began at 1920 (GMT), about 12:30 p.m. local (sun) time with two passes through a cumulus cloud system (system #1) responsible for the anvil cloud studied later in the flight. Glaciation of the upper portion of the cloud was just beginning. Another cloud system (system #2) appeared more glaciated, to the northwest.

After system #1 was sampled the aircraft climbed above the anvil to map it by flying along the top of the longest portion of the anvil and then across the anvil, permitting visual observation of anvil edges from above (Fig 1). After this mapping, the aircraft descended through the anvil and sampled another convective cloud system (system #3) beneath it.

The radar return from system #1 showed up on the UND radar at 1820. By the time of aircraft sampling, the anvil was 60 km long and oriented along the relative wind (i.e., the vector difference between the

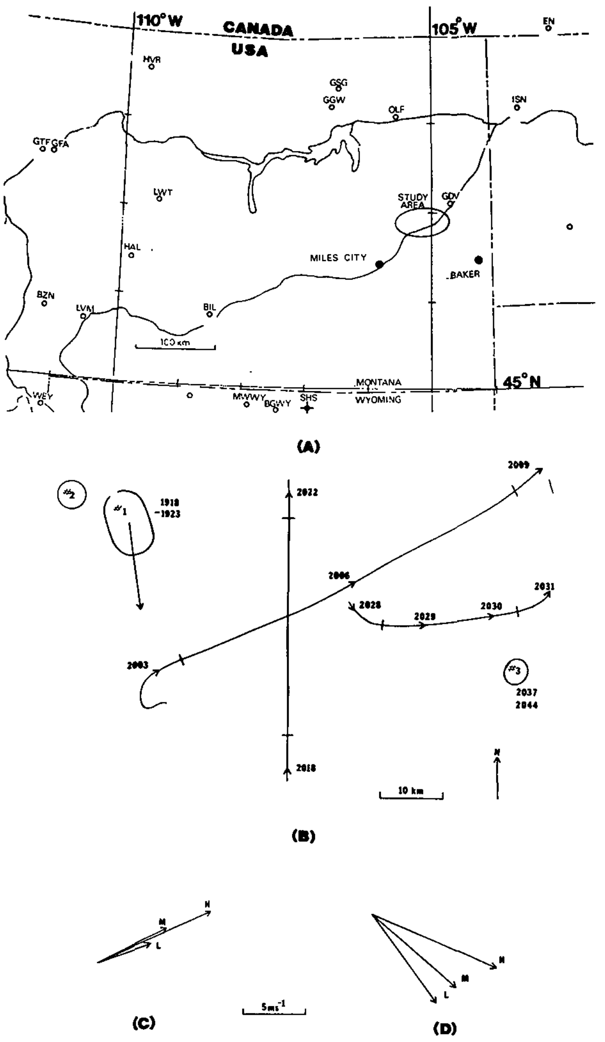

Fig. 1 A) Location of study area near Miles City, MT, on August 22, 1979. B) Locations of convective clouds (systems #1, 2 and 3). Systems #1 and #3 were sampled by the Lear aircraft at the times indicated (HHMM, GMT). The path of the aircraft as it flew over the anvil cloud from system #1 (2003-2022) at 12 km altitude (MSL), and as it descended through the anvil (2028-2031) between 12 km and 7.5 km is given. The anvil boundaries are marked (——┼——). Locations of cloud systems (and cloud boundaries) are for time of aircraft sampling; the clouds moved south-southeastward during the flight, as indicated for system #1. The location of system #2 was approximated from photographs taken at 1915. C) Winds relative to system #1, as determined from the 2000 sounding at Baker, MT, and the motion of the system (as determined by radar). H refers to the winds at anvil height (240-360 mb), M to mid-level winds (360-600 mb) and L to lower level winds (600-900 mb). D) Environmental winds from the 2000 Baker sounding.

environmental wind and the motion of the radar echo) at anvil height (Figs 1b and c). This orientation was confirmed by satellite images (Stith, 1981).

From the first echo appearance to the time of aircraft sampling (2008) of the anvil at the farthest downwind distance, 108 min. elapsed. The windspeed at anvil height, relative to the motion of the main storm was 10 m/s. For this case, the anvil length is well approximated by the product of the relative windspeed and the time since first echo. Apparently, the anvil ice did not evaporate completely during this time, but the ambient air at anvil height was not saturated with respect to ice (the dew point depression was between -10 and -25 degrees C). Evidently the anvil did not mix with ambient air enough to evaporate completely even the first ice from the storm.

At approximately 1950 system #2 merged with the larger system #1 (Fig 2), with marked increase in the echo top height of system #1, (Fig 3a). The measured liquid water and ice particle concentrations in system #1 at 1922 are given in Fig 4, and shadow images from the 2-D instrument are presented in Fig 5a. After this pass

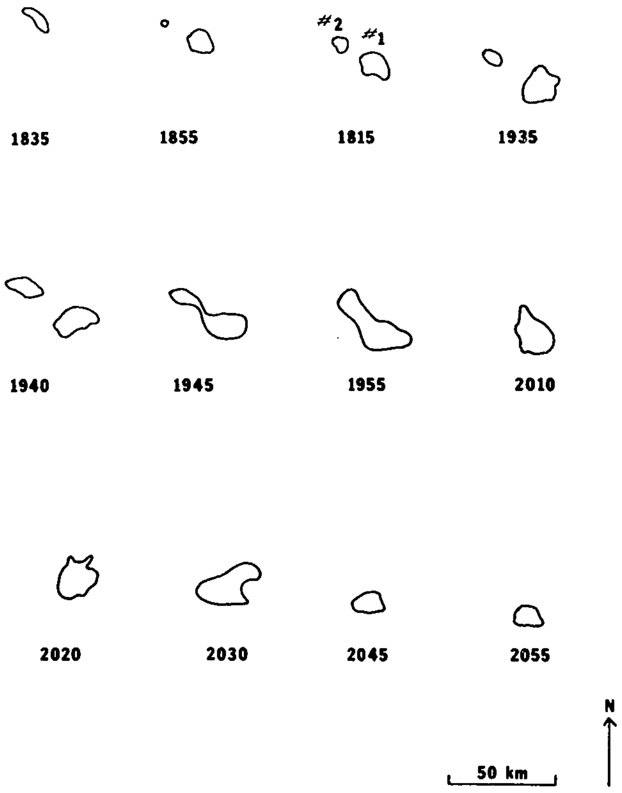

Fig. 2 Composite radar data (plan view) from Baker. Echo boundaries are drawn at the 20 dBz reflectivity level. Times are in HHMM (GMT). Radar echos from systems #1 and #2 are indicated.

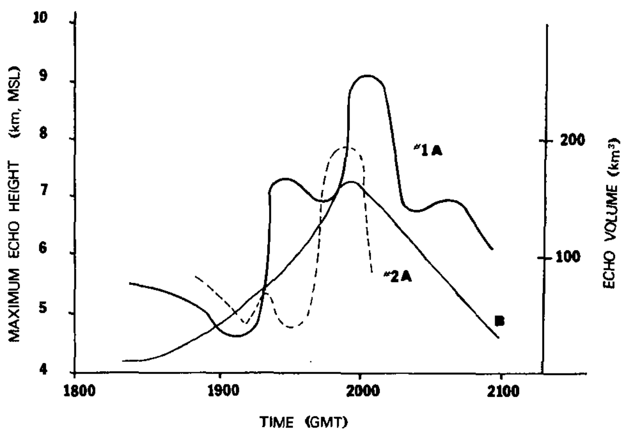

Fig. 3 Echo top heights (A) of two convective cloud systems which merged at 1950 (GMT), and echo volume (B) of system #1 for reflectivities greater than 10 dBZ.

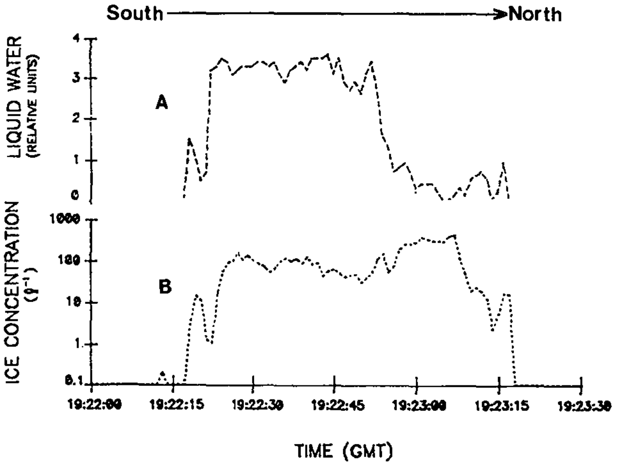

Fig. 4 Measured liquid water (A) and ice particle (B) concentrations in system #1 at 6.9 km (MSL) and a temperature of -13°C.

airframe icing was observed, confirming the presence of liquid water. The 2-D data (Fig 5a) indicate that the most common type of particle observed was graupel, also observed in the anvil, along with aggregates and fragments; however, the degree of riming is difficult to estimate solely from the 2-D data (see Fig 5b). The upper levels of the anvil contained larger particles (maximum diameters of 900 m) than did the lower levels the anvil (maximum diameters of 500 m).

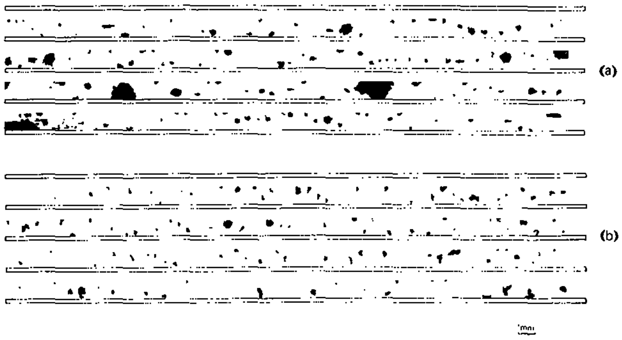

Fig. 5 Shadow images of particles sampled by the 2-D probe from system #1 between 1922:30 and 1922:34 (GMT) (a) and in the anvil cloud associated with system #1 (b), between 2028:57 and 2029:00.

Prior to its merger with the older system #2, system #1 had more than 100 ice particles per liter; liquid water was also present (Fig 4). Hence, additional ice particles from the remains of system #2 could have had an effect similar to overseeding with ice particles. Stith (1981) estimates that the water substance lost to the anvil cloud from this storm was more than twice that released as precipitation. In contrast, a larger storm studied by Newton (1966) lost only 30% of the water available for precipitation to the anvil cloud. Evidently, the August 22 storm was relatively inefficient.

From 2036 to 2043 the aircraft sampled in a cumulus cloud which had formed under the southern edge of the anvil (system #3). Streamers from the anvil were visible alongside the cloud. Several aircraft penetrations through the upper region of the cloud (Fig 6) found rapid conversion of cloud liquid water into ice (the time from the first pass to the last pass was only 5 min.). The 2-D images taken during one of these penetrations (Fig 7) show that the streamers contained ice particles somewhat larger (diameters up to about 3 mm) and more aggregated than in the main anvil region sampled earlier. Where liquid water was found (i.e., in the cumulus cloud), the ice particles appeared to be rimed (Fig 7).

Radar echo top heights, echo volumes (for returns greater that 10 dBz), and maximum reflectivity for system #3 show significant increases in echo size and intensity following development of the ice phase (Fig 8). Most increases occurred well below the top of the cloud; the echo centroid height and and the height of maximum reflectivity were between 2 and 4 km from 2040 to 2130. For this case, the most significant radar return developed after introduction of ice particles from the anvil.

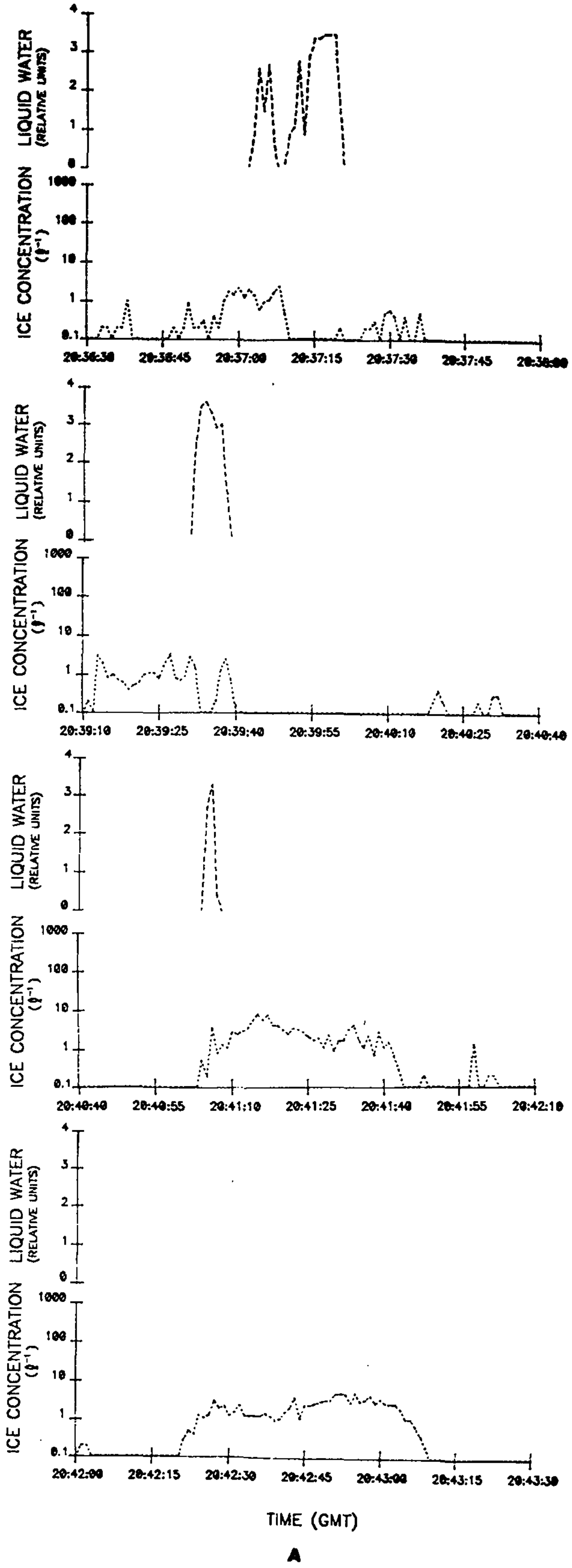

Fig. 6 A) Ice particle and liquid water concentrations measured during four aircraft penetrations at 4800 to 5100 m, MSL, through a cumulus cloud (system #3).

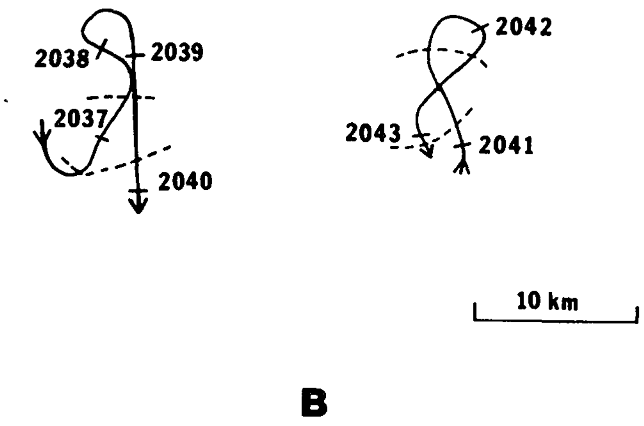

Fig. 6 contd. B) Path of the Lear aircraft during these penetrations of cloud beneath anvil. Cloud temperature was between -8 and -0.3°C. Boundaries of ice particle regions given by dotted lines.

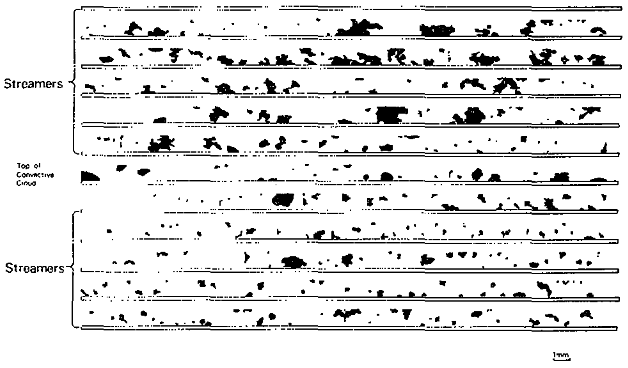

Fig. 7 Shadow images of particles sampled by the 2-D probe from system #3 from 2039 to 2041 (GMT). Ice particles associated with streamers from anvil cloud are indicated. Ice particles sampled in cloud portion with liquid water (the convective cloud of system #3) at 2039:36 are also indicated.

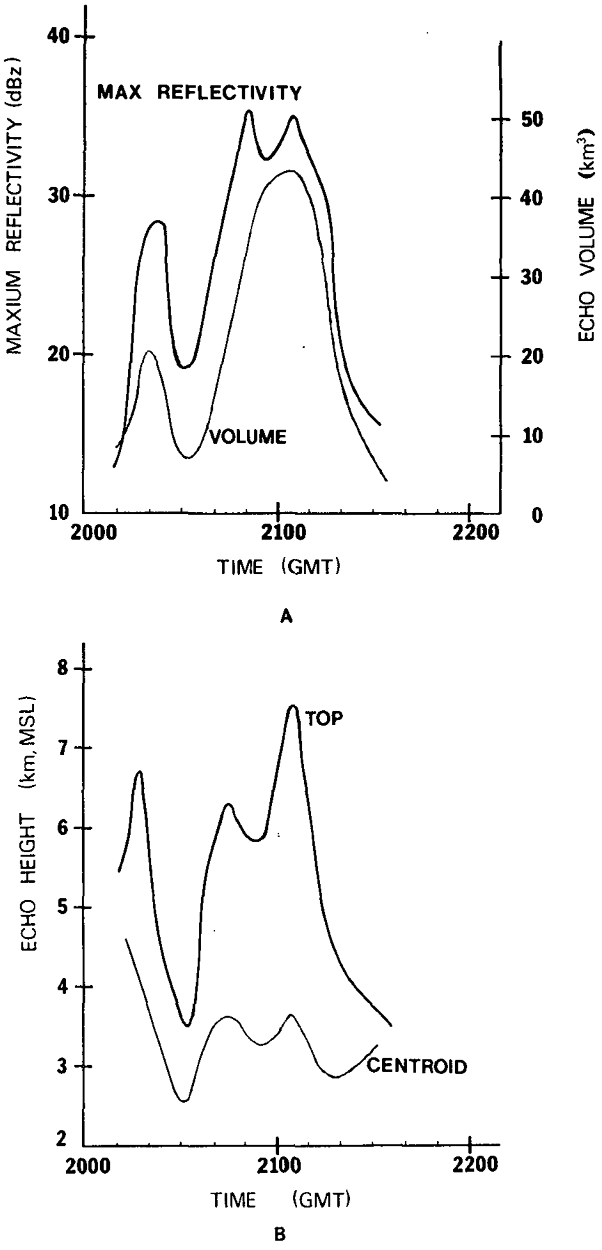

Fig. 8 A) Radar echo volume for returns greater than 10 dBz and maximum reflectivity. B) Heights of echo tops and centroid.

4. Conclusions

These measurements and observations suggest that ice particles from anvil clouds may affect the development of precipitation in sub-anvil convective clouds. A substantial increase in the radar return was observed during the glaciation of a sub-anvil cloud following incorporation of ice from the anvil. The merger of the anvil region (i.e., the remains) from system #2 could also have been an important factor in the evolution of the main system. More measurements of the natural seeding process in convective clouds will be necessary to determine the frequency of such events which have important implications for the conduct of planned seeding operations.

Acknowledgments

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