THE NEW ALBERTA HAIL SUPPRESSION PROJECT

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Abstract. A new hail suppression project was started in Alberta in 1996. Weather Modification Inc. (WMI) of Fargo, North Dakota was awarded a five year contract by the Alberta Severe Weather Management Society of Calgary, Alberta to conduct cloud seeding to reduce urban property damage from hail, particularly for the Calgary and Red Deer areas. The operational program runs from June 15th to September 15th. This project is rather unique because it is funded entirely by private insurance companies with the sole intent to mitigate the damage to property by hail storms.

The seeding program is based upon the hailstorm conceptual model, seeding methods, and storm forecasting techniques of the previous long-term hail research project conducted by the Alberta Research Council from the late 1960's through 1985. In 1996, a C-band weather radar with computer recording and communications systems and three cloud seeding aircraft were dedicated to the project. The aircraft and radar crews provided 24 hr coverage, seven days a week throughout the period. The program has been welcomed by the local communities and has rekindled much interest in cloud seeding.

1. INTRODUCTION

Hailstorms pose a serious threat to the province of Alberta. Historically, claims for agricultural hail damage in Alberta are received on an average of 50 days each year between 1 June and 10 September (Summers and Wojtiw, 1971). Estimates of the average annual crop loss to hail have continued to increase with time, from $50 million annually in 1975 (Renick, 1975) to more than $150 million annually during the period 1980 - 1985 (Alberta Research Council, 1986). In more recent times, the high insurance costs of urban hailstorms have escalated due to the replacement cost clauses in homeowner policies. When Denver Colorado was pounded by golf ball to tennis ball sized hail on July 11, 1990, damages reached a record (for the U.S.A.) $625 million. The insurance costs associated with the severe hailstorm which struck Calgary on 7 September 1991 have been estimated at $400 million (Charlton et al., 1995). The direct costs due to hail damage to property have exceeded agricultural losses. As a result, the new Alberta Hail Suppression Project was created and funded by private insurance companies, with the sole objective of reducing the damages to property by hail.

Weather Modification Inc. (WMI) was awarded a five year contract to conduct the Alberta Hail Suppression Project by the Alberta Severe Weather Management Society (ASWMS). The ASWMS is a private, non-profit society established by the insurance companies and brokers to administer the cloud seeding program. Operations were conducted from June 15th to September 15th 1996.

The project is based upon the techniques, methods, and results of the long-term hail research project conducted by the Alberta Research Council from the late 1960's through 1985 (Alberta Research Council, 1986). The new program incorporates several notable advances:

- an improved, fast-acting formulation for the silver-iodide flares of Weather Modification Group which provides approximately 100 times more ice nuclei per gram of seeding material (4×10^{13} ice nuclei per gm at -10°C) with the ability to nucleate ice as warm as -4°C,
- the use of high performance, twin engine aircraft for quick response and timely seeding,
- the injection of the seeding material directly into the developing cloud turrets as the most frequent seeding method, and

- the use of a very experienced meteorological and aviation staff to direct the seeding aircraft as well as to accurately identify the proper regions of storms for seeding,
- the use of GPS tracking and computer technology to display the aircraft locations on the radar displays to improve the controlling of aircraft and facilitate the direction of seeding operations to the most critical regions of the storms.

The project area is shown in Fig. 1 and focuses on the area from Lacombe to High River, with priority given to the cities of Calgary and Red Deer. The dedicated project radar was located at the Olds-Didsbury airport, midway between Calgary and Red Deer. The location of the airport in the Fig. 1 corresponds to the "2A" highway marker. The project area dimension is approximately 220 km (N-S) by 120 km (E-W).

Three aircraft specially equipped to dispense silver iodide (AgI) were used. One Cheyenne II prop-jet and one Cessna 340 were stationed at Calgary and one Cessna 340 was at Red Deer.

2. HAIL SUPPRESSION HYPOTHESIS

The seeding is based on a conceptual model of Alberta hailstorms which evolved from the experiments and studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss (1981), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986). Evidence indicates that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote, 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

The cloud seeding hypothesis is based on the cloud microphysical concept of "beneficial competition". Beneficial competition assumes a deficiency of natural ice nuclei in the storm updraft and that the injection of silver iodide (AgI) will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled

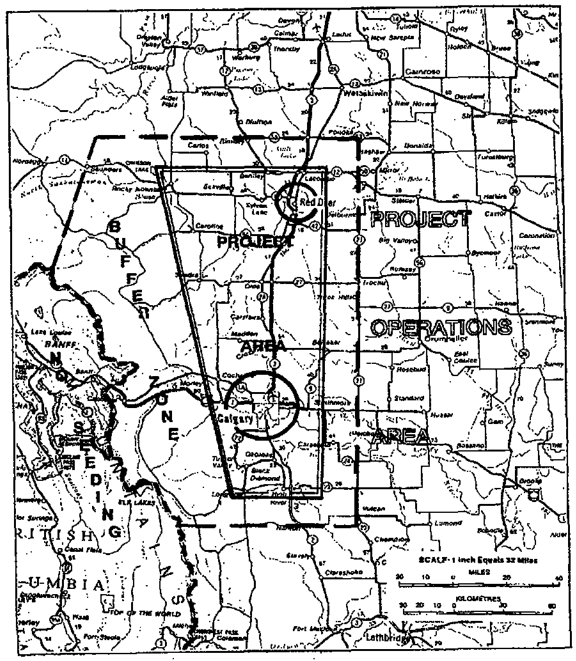

Figure 1: *A map of southern Alberta showing the project area and buffer zone. The radar is located at the Olds-Didsbury airport, midway between Calgary and Red Deer.*

liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If sufficient nuclei are introduced into the new growth region of the storm, then the hailstones will be small enough to melt completely before reaching the ground. Cloud seeding operations alter the microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a deficiency of natural ice nuclei.

Seeding is conducted by aircraft to deliver ice nuclei to regions of new storm updraft with high concentrations of super-cooled liquid water; the primary condition responsible for the growth of hail.

2.1 Cloud Seeding Methodology

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail. All storm cells (identified by radar) with maximum reflectivity >35 dBZ within the cloud layer above the -5 °C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project areas, are seeding candidates. Priority is given to storms which threaten towns or cities, with special priority given to storms which threaten the cities of Calgary and Red Deer. Radar observers and aircraft controllers are responsible for making the "seed" decision and directing the cloud seeding missions. Patrol flights are generally launched before clouds within the target areas or buffer zones meet the radar reflectivity seeding criteria. When thunderstorms with hail potential are forecast, patrol flights are launched when towering cumulus clouds are observed or when radar cells exceed 5.5 km height over the higher terrain along the western border. These patrol flights provide an immediate response to developing cells.

Launches of more than one aircraft are determined by the number of storms, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is used to provide uninterrupted seeding coverage at either cloud-base or cloud-top and/or to seed three storms simultaneously if required.

Storms are seeded from cloud top or cloud base depending upon storm structure, visibility, cloud base height, or time available for aircraft to reach seeding altitude.

Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between the -8 °C and -15 °C levels with 20 g ejectable flares. These flares fall approximately 1.5 km (approximately 10 °C) during their 50 s burn time. The seeding aircraft penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the -10 °C altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5 °C and -

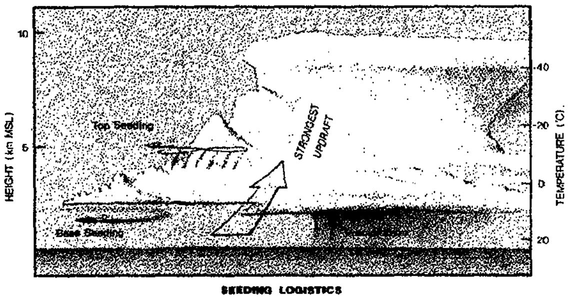

Figure 2: A schematic figure showing the cloud seeding methodology at cloud-base and cloud-top for a mature hail storm (adapted from ARC, 1986).

10 °C, a seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and seed using an end-burner flare and inject droppable pencil flares when updrafts are encountered.

A schematic figure showing the cloud seeding methodology is shown in Fig. 2.

2.2 Seeding Rate

Silver-iodide (AgI) is dispensed by three sources using either droppable flares, end-burning flares, or AgI acetone burners.

A seeding rate of one 20 g flare every 5 s is used during cloud penetration. A slightly higher rate is used (e.g. 1 flare every 2 s) if updrafts exceed 10 m/s and the storm is particularly intense. A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). If not, a 5 to 10 min waiting period may be used, to allow for the seeding material to disperse and the storm to dissipate, glaciate, or for radar reflectivity values to decrease and gradients weaken. This waiting period precludes the waste of seeding material and assures its optimum usage. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is sufficient to deplete the liquid water content produced by updrafts of 10 m/s or less, thereby preventing the growth of hailstones within the seeded cloud volumes (Cooper and Marwitz, 1980).

For cloud base seeding, 1 or 2 end-burner flares (150 g each) are used, dependent on the updraft velocity at the cloud base. For an updraft >5 m/s, 2 flares per seeding run are typically used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners with 2% AgI solution are also used to provide continuous silver iodide seeding at low concentrations (2.85 to 5.7 gm AgI per min.) if extensive regions of weak updraft are found at cloud base and in the shelf cloud region. Base seeding is not conducted if no updrafts are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics (new WMG-2 formulation) with an ice nuclei effectiveness of approximately $4x10^{13}$ nuclei per g of nucleating agent at -10 °C, as determined by independent cloud chamber tests at Colorado State University.

3. METEOROLOGY

Near real-time weather information from Environment Canada is now readily available on the WWW/Internet. In addition, special arrangements were made with Environment Canada to automatically access the necessary upper-air sounding data, weather charts of objective analyses, forecasts, and bulletins to properly prepare a daily weather and operations briefing for the hail project.

3.1 Convective Day Category (CDC)

For simplicity, the weather forecast was synthesized into a single number referred to as the convective day category (CDC). This technique was developed for Alberta by Strong (1979) and gives the cloud conditions and threat of hail for the day. A description of the weather conditions for each CDC is given in the following table.

Table 1: Description of Convective Day Category (CDC) values.

-3	No deep convection
-2	Towering cumulus, alto cumulus and some showers
-1	Scattered showers
0	Thundershower but no hail
1	Pea or Shot size hail (.1 - 1.2 cm Diameter)
2	Grape maximum size hail (1.3 - 2.0 cm)
3	Walnut maximum size hail (2.1 - 3.2 cm)
4	Golfball maximum size hail (3.3 - 5.2 cm)
5	Larger than golfball size hail (> 5.2 cm)

The hail days were distributed relatively evenly during 1996 with the month of July being the most active. Hail was reported on 22 of 93 days (24%), therefore, there were 71 days without hail (76%). Walnut or larger size hail was reported on 5 days (5%). The forecast was correct in forecasting "no-hail" on 59 of 71 days (83%) and correctly forecast "hail" days on 14 of 22 days (64%). The forecast failed to correctly forecast hail on 8 of the 22 hail days (36%) and incorrectly forecast hail (false alarm) on 12 of the 71 days without hail (17%). The exact forecast CDC type of weather was observed on 50 of 93 days or 54% of the time. The forecast weather was correct to within one CDC on 70 days or 75% of the time. Regardless of the forecast, the project meteorologists generally maintained a radar watch throughout the day and no threatening storms were missed or not-seeded.

3.2 Cloud Base Temperature

The temperature at cloud base is an important meteorological parameter. Cloud base temperature determines the initial conditions for many of the microphysical processes within the cloud and often determines the extent to which cloud water drops, as opposed to ice crystals, will affect the development of precipitation. The distribution of cloud base temperature is shown in Fig. 3.

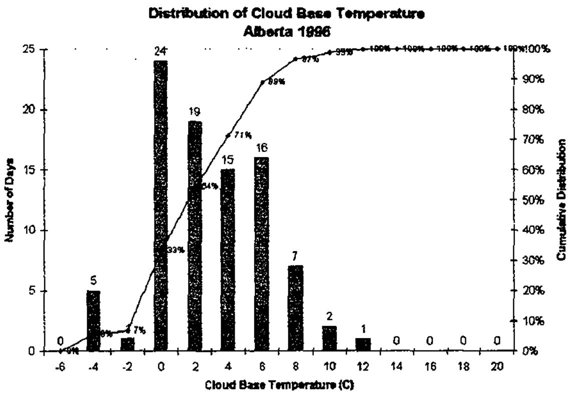

Figure 3: Frequency of occurrence and cumulative distribution of cloud base temperature, summer 1996.

The average cloud base temperature was +4 °C. The cloud base temperatures given here correspond to the lifted condensation level in the atmosphere allowing for some mixing in the lowest

50 to 100 mb. On the most severe hail days, pilot observations indicated that the lowest cloud base (i.e.; warmest cloud base temperature) was occasionally several degrees warmer than the mixed, lifted condensation level indicating that the main storm inflow was feeding from the surface layer. The warmest cloud base temperature observed by the pilots was 15 °C. There is a tendency for "deep" convection and more severe hail storms on the days with warmer cloud base temperatures. Hail was observed on only one day when the temperature at cloud base was colder than 0 °C.

4. FLIGHT OPERATIONS

The total number of operational flight hours (air time) was 159.1 hrs. The median time for take-off was approximately 4 p.m. The median landing time was approximately 6:30 p.m. The preferred time for thunderstorms to form was in the late afternoon during the time of maximum temperature. The average flight duration was approximately 2 hrs.

The WMI weather radar control and communications centre was equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the radar display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The colour coded aircraft position on the PPI displays enabled radar controllers to discriminate between all project aircraft.

5. WEATHER RADARS

The dedicated project radar is the WMI owned C-band (5 cm wavelength) radar manufactured by Enterprise Electronics Corp. (EEC) located at the Olds-Didsbury Airport. The WMI radar station housed the project operations, communications, and control centre. The central siting of the WMI radar enabled storm tracking and aircraft direction for the entire project area. Radar products from two Environment Canada radars located near Calgary and Edmonton, were accessed via the internet to support operations and act as a backup to the project radar if required.

The WMI C-band (5 cm wavelength) radar is tower mounted and enclosed in a radome to provide safe, all weather operation. The nominal specifications of the C-band radar are: peak power = 250 kw, minimum detectable signal = -105 dBm, circular beam width = 1.65 deg. The minimum detectable signal is 10 dBZ at 100 km range.

The WMI radar was usually operated in a PPI (Plan Position Indicator) mode at constant elevation between 1 and 2.5 degrees. PPI displays were sent to a WWW site at 30 min intervals. The recording interval was typically set to 5 or 6 min when aircraft operations were being conducted or whenever severe storms were near the project area.

A daily maximum reflectivity composite map was constructed from the recorded PPIs. These maps are the most useful in displaying the track of maximum storm intensity and potential damage. Two useful maps from the Calgary radar are the 24 hr radar derived accumulated rainfall and the composite maximum reflectivity map. In addition, the LIVERAD product from the Edmonton radar displays an animated sequence of radar PPIs at 10 min intervals for the most recent 2 hrs whenever it was downloaded from the Internet. These radar products provided excellent guidance and monitoring for real time operations and also provide excellent documentation for analysis and assessment purposes. All of the WMI and Environment Canada radar products for the summer were recorded on CD-ROM for easy access by personal computers for future reference purposes.

6. SUMMARY

The 1996 Alberta hail suppression program received considerable positive public and media attention, including numerous newspaper stories, local television coverage, National CTV news coverage, as well as a special Discovery Channel TV program. Many tours of the operations were conducted and an open house and special information seminar were held. The program has been welcomed by the local communities and has rekindled much interest in cloud seeding.

Sixty-five cloud seeding flights took place on thirty storm days. The total number of silver-iodide flares dispensed was 3817 ejectables (76.3 kg AgI) and 542 end-burners (81.3 kg AgI). A total of 80.42 gallons of AgI-acetone solution was dispensed (5.5 kg AgI). Operations were conducted at least once a week until the third week in August when there was no activity between August 20th and 30th. The 10 most active days were July 3rd, 4th, 9th, 15th, 16th , 24th, 26th and August 6th, 15th and 17th. Hail was reported within the project area on

22 days. Walnut or larger sized hail was observed on 5 days. Severe storms struck the city of Calgary on July 16th and 24th. The ASWMS will asses the benefits of the project using insurance information. Future physical assessments will be conducted primarily using radar data.

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