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AN OVERVIEW OF WEATHER MODIFICATION ACTIVITIES IN ALBERTA

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1. INTRODUCTION

Interest and activities in hail research and weather modification have been ongoing in Alberta for almost three decades. Crop loss from hailstorm damage has always been a major problem in Alberta. The economic losses associated with hailstorms are now up to $100 million annually. Following several years of costly hail losses in the early 1950's, independent research and operational programs began. The losses prompted farmers in a district and county north and east of Calgary to seek voluntary contributions to hire I.P. Krick and Associates of Canada Ltd. to carry out a commercial hail suppression program. Later, farmers from two additional counties joined the program and formed the Alberta Weather Modification Co-operative (AWMC). The Krick program operated from 1956 to 1968 using ground-based silver iodide generators; supplemental seeding from aircraft began in 1960 (Krick and Stone, 1975).

The farmers' concern about the effects of hail and their demonstrated support for weather modification encouraged the Alberta government to investigate the hailstorm problem. Consequently, in 1956 the Alberta Research Council persuaded the Canadian Atmospheric Environment Service and the National Research Council to join it in sponsoring the Alberta Hail Studies. The Stormy Weather Group at McGill University organized the project, with the goal of systematically observing the Alberta hailstorm in order to design and test ways of suppressing hail. This phase of research operated until 1969.

The installation of a polarization diversity S-band radar, in the late 1960's, led to single-cloud seeding experiments using droppable pyrotechnics. Area seeding experiments followed in 1972, and in 1974 a full-scale operational seeding program, the Alberta Hail Project, began under the direction of the Alberta Weather Modification Board. The Board was formed by Alberta Agriculture in 1973 to administer hail suppression and hail research programs. All provincial government funds for weather modification activities were directed through the Board. When its mandate was completed in 1980, the Board was dissolved.

The Alberta Research Council, on behalf of Alberta Agriculture (the principal funding agency), now acts as the central management and research agency for weather modification activities in Alberta. Alberta Agriculture's Advisory Committee on Weather Modification (which replaced the Alberta Weather Modification Board) provides guidance to the program.

The Research Council's Atmospheric Sciences Program is organized into two major projects, Weather Modification and Applications. These projects in turn are divided into subprojects, some of which are further divided into specific experiments. Although the program now centers on developing a weather management capability, it continues to be heavily committed to hail suppression research. It has also diversified into other areas of atmospheric and weather modification research. This paper summarized the current program and recent findings.

2. WEATHER MODIFICATION PROJECTS

2.1 Hail and Rain

The major thrust of the hail and rain project is to determine if cloud seeding can have a beneficial effect on the hail and rain processes occurring inside clouds. A secondary objective is to determine the most effective seeding techniques and agents. A third objective is to determine the economic benefits from successful cloud seeding. These benefits could be enormous, especially in southern Alberta, if significant increases in total precipitation result. A final objective of the seeding experiments on hailstorms is to document the effects of seeding later in the hail-growth process. Figure 1 depicts the project's measurement capabilities of the precipitation process chain for a typical Alberta hailstorm.

The seeding hypothesis is supported by the analysis of research aircraft cloud penetrations. Figure 2 shows marked seeding signatures in ice crystal concentrations and size distributions measured after seeding a cumulus cloud (Kochtubajda, 1983). Figures 3 and 4 also show the effects of seeding but, in this case, on a hailstorm feeder cloud (Krauss, 1983).

In conjunction with some seeding experiments, in-cloud rime ice samples were collected and analyzed for silver concentration. Generally, significant silver concentrations were found in cloud turrets seeded with silver iodide (AgI) and were not found in other turrets.

2.2 Operational Cloud Seeding - Aircraft

Each year, the project conducts an operational cloud seeding program in the southern half (24,000 km^2) of its project area (Figure 5). Four aircraft, capable of seeding from either cloud top or cloud base, seed all potential hailstorms during the operational period 20 June to 31 August. The aircraft are equipped with ejector racks containing four hundred 20 gram AgI 'pencil' flares for cloud top seeding plus either two acetone burners (2 gram AgI/min output) or two wing-mounted racks each containing sixteen 150 gram AgI fusees for cloud base seeding.

The current cloud seeding program is being

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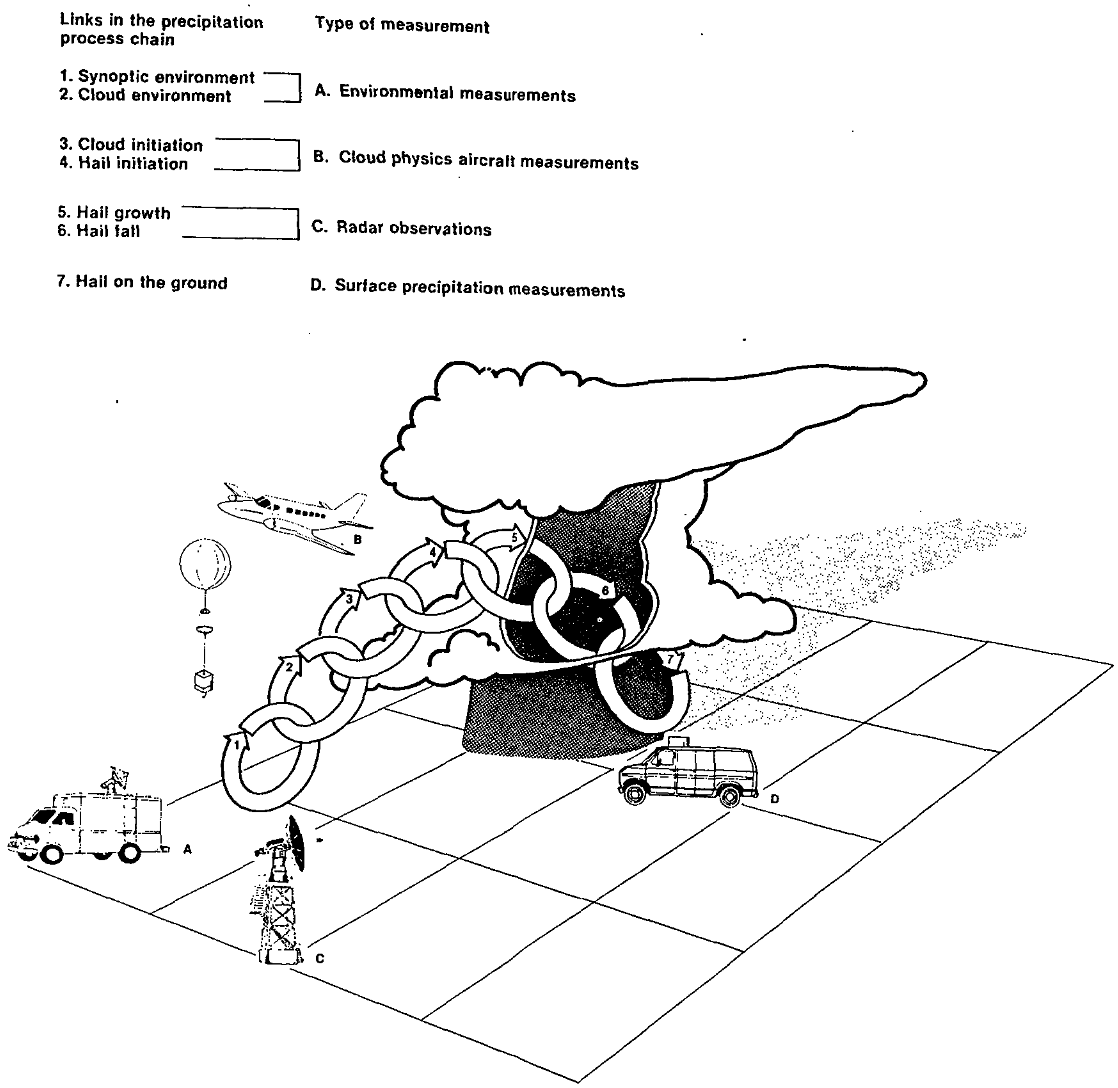

Figure 1. The precipitation process chain and its relation to the hailstorm and to various types of measurements. The macro-scale links of synoptic environment and cloud environment are investigated by means of temperature, humidity and wind measurements ahead of the storm. Droplet and ice crystal initiation processes (cloud initiation and hail initiation links) are investigated primarily through in situ research aircraft cloud physics measurements in the new growth zone. In the mature storm, the hail growth and hailfall links are studied primarily through radar observations. Finally, hail on the ground is investigated through precipitation sampling.

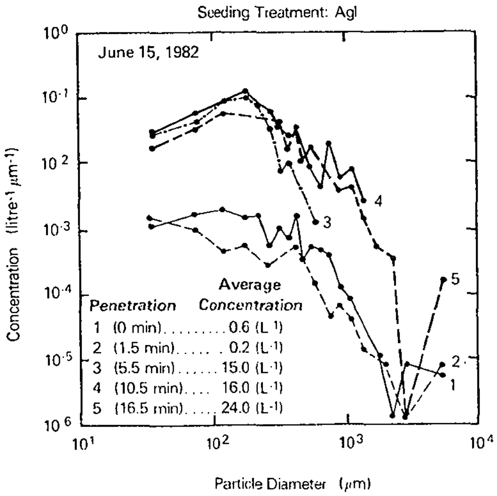

Figure 2. The ice crystal concentrations measured by the cloud physics aircraft during penetrations of a cloud seeded with AgI on June 15, 1982. Concentrations shown for the preseeding penetration are averaged over the whole cloud. For penetrations occurring after seeding, the concentrations shown are averaged over the extent of the ice crystal plume; the ice crystal plume being defined as that portion of the cloud where ice crystal concentrations are $\triangleq 10^{-1}L$ (Kochtubajda, 1983)

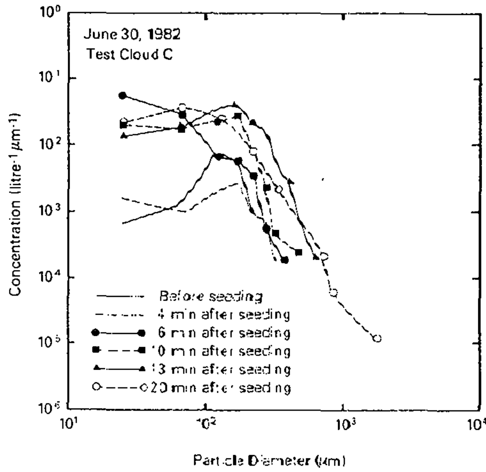

Figure 3. Evolution of the ice crystal size distribution after seeding test cloud C with AgI. The distributions are measured with a PMS 2D-C probe and are averages over the entire cloud width. The minimum detectable size is 25 µm (Krauss, 1983)

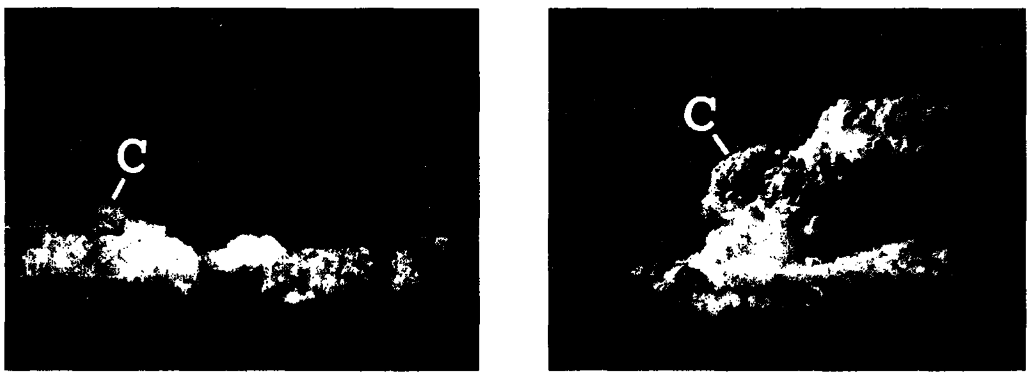

Figure 4. Two photographs of the 30 June 1982 hailstorm: (a) at 1554 looking southeast towards the southern end of the new growth zone and the seeded feeder cloud C as it appeared 5 min after seeding, and (b) at 1613 looking northwest towards feeder cloud C after it had merged with the main storm complex, 24 min after seeding.

evaluated through physical assessment of the hail and rain project described above and through a quantitative assessment that is developing statistical design and measurement criteria. Goyer and Renick (1980) discuss the results of the earlier program under the AWMB.

2.3 Operational Cloud Seeding - Ground Generators

Another operational cloud seeding project consists of a network of 92 ground-based, silver iodide generators at 69 sites in a 25,000 km^2 area south of Calgary. Irving P. Krick and Associates of Canada Ltd. operate the project with funding provided by Alberta Agriculture.

The Alberta Research Council will evaluate the ability of these coke and arc-type generators to deliver ice nuclei to the area of summertime convective cloud bases. Data from three seasons of research aircraft observations in the ground generator area are being analyzed. The final results of the evaluation will be available after

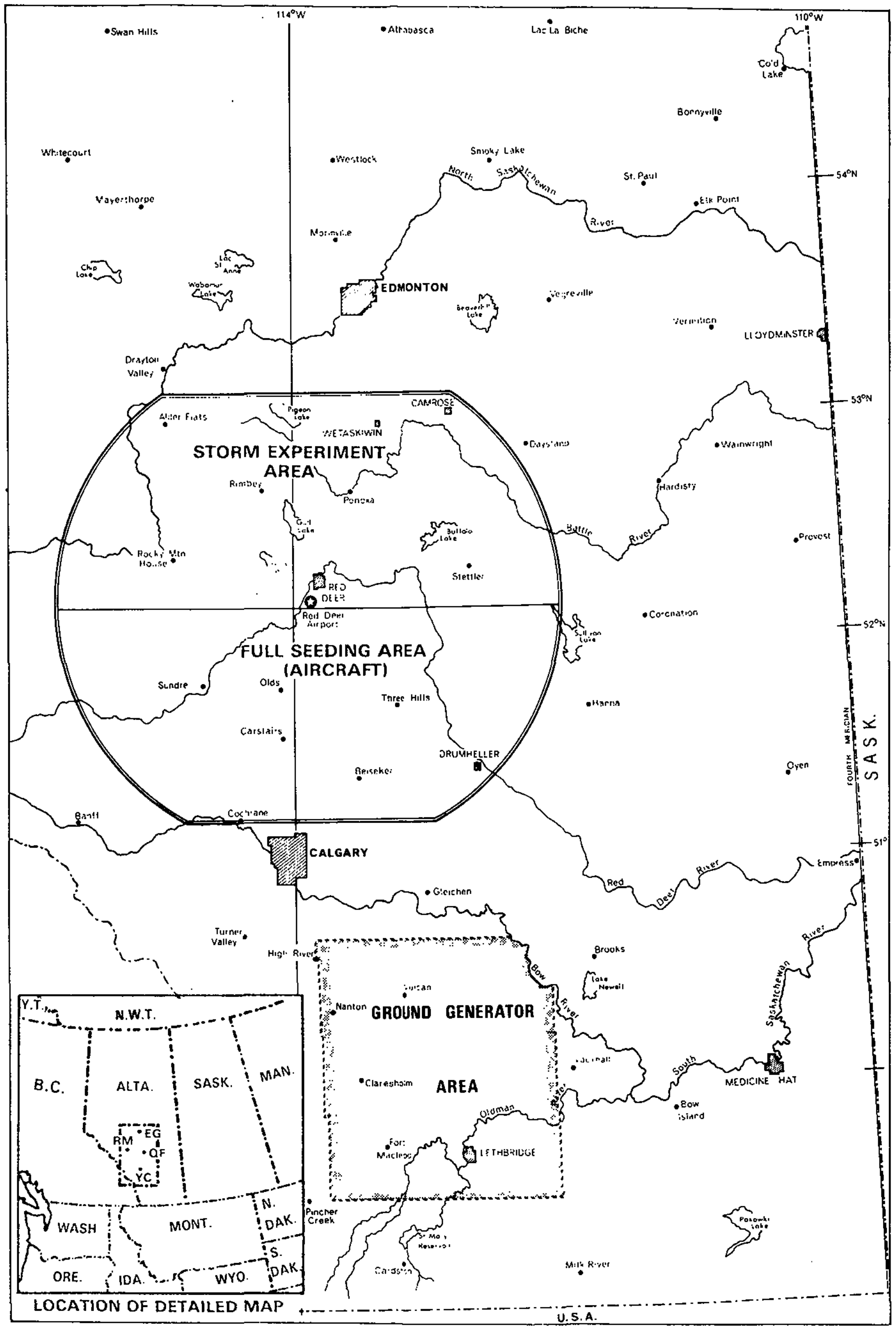

Figure 5. Atmospheric Sciences Program experiment areas. The area between Edmonton and Calgary is the principal target area of the Alberta Hail Project. The area south of Calgary is the I.P. Krick ground-based generator primary target area.

Alberta Agriculture's Advisory Committee on Weather Modification, and Alberta Agriculture, have thoroughly reviewed all data.

2.4 Sulfur and Precipitation

A project to determine if emissions from sour (natural gas) scrubbing plants affect precipitation processes was initiated. Statistical analyses of crop loss-to-risk data suggest that emissions from the gas plants help suppress hail (Wong and English, 1984).

Aerosols from gas plants and coal-fired power plants have been measured by the research aircraft on flights in both clear air and in clouds. Preliminary analyses of cloud water collections show air that is relatively clear of sulfates and nitrates.

2.5 Snow

Cloud seeding has some potential for increasing the water supply in southern Alberta by augmenting the mountain winter snowpack. Field work for the snow project has thus far been limited to four two-week periods from March 1982 to February 1984. This, unfortunately, limits data collection to only a few weather conditions that produce snow. A modest expansion will enable research aircraft, upper-air, and surface observations over a longer period. A study of the snowfall-weather system climatology will then determine the weather systems, clouds and the time periods most likely to be receptive to cloud seeding.

An analysis of measurements made in 1982 indicated that portions of one cloud system contained appreciable amounts of super-cooled liquid water that were not being effectively converted to precipitation (Krauss et al., 1983).

2.6 Weather Prediction

Statistical forecast studies center around the synoptic Index of Convection (Sc - Strong, 1979) and analyses of the boundary layer moisture field. The Sc, a statistical predictor, was originally developed as a forecast tool to predict maximum hail size for the Alberta Hail Project operations area. In recent years the Sc has been adapted as a regional predictor of maximum intensity of convective complexes. By combining the Sc with the surface Theta-E field and low-level flow fields, accurate predictions are possible of the location of storm initiation and motion, and storm intensity. Relative storm size and life history can also be inferred (Strong and Wilson, 1983). The Synoptic Index has been field-tested as far afield as Colorado and Oklahoma. Currently it is being considered for use by the Canadian Atmospheric Environment Service and agencies in the United States and abroad.

3. APPLICATIONS PROJECTS

3.1 Flow Forecasting

A spin-off project provides hydrologists at Alberta Environment with a facility for using weather radars for operational support. The River Forecast Center received a mini-computer system and color display monitor that produces real-time maps, tables and displays of radar-derived rainfall measurements (Humphries and Barge, 1979). The prototype system was successfully tested in August and September 1983. Delivery of the operational system to Alberta Environment is scheduled for the spring of 1984.

3.2 Rainsat

A research project for the Atmospheric Environment Service to improve short-term weather forecast combines the observational capabilities of the project's weather radars with GOES (Geostationary Orbiting Earth Satellite) data. The synoptic and meso-scale mechanisms that contribute to precipitation, especially from thunderstorms, are also being investigated (Bergwall et al., 1983; Strong, 1983).

Currently, both visible and infrared data sets are being examined on a particularly severe hail day, July 16, 1980. Qualitatively, the high resolution visible satellite data appears useful for determining the location of storm complexes. The infrared satellite data provide an estimate of the cloud-top temperature over a somewhat larger grid area but appear to be well correlated with the stage of storm development as determined from radar data. Quantitative comparisons between the two satellite data sets and various radar-derived quantities are presently underway.

3.3 Sulfur Removal

Alberta Environment and the Research Council are funding investigations into the dispersion of pollutants and the processes that produce acid rain downwind of energy plants in northeastern Alberta. This research is expected to provide more realistic monitoring procedures and emission control standards for such plants. Thus far, the maximum detected distance of sulfur dioxide transport (during the spring 1983 program) was 96 km. Gas to particle conversion to ammonium sulfate appears confined to distances close to the stack. The transformation rate of sulfur dioxide into sulfuric acid is relatively low at short travel times from the stack, equivalent to only a few tenths of one percent of SO_2/hr. An increase in sulfuric acid production seems to occur further downwind.

4. ATMOSPHERIC SCIENCES FIELD PROGRAM FACILITIES

Most projects in the program, which culminate during the summer months, share common data bases and support facilities. The facilities, decribed below, enable the various projects to obtain data to meet their stated objectives.

4.1 Research Aircraft

In 1981, it became imperative that if more advanced research in the field of weather modification was to continue, a full-time research aircraft must be developed. The aircraft would be equipped to penetrate clouds and instrumented for cloud physics measurements. Aircraft so equipped had been used at various times in the past, but only when funding permitted or an aircraft was available. A joint effort to purchase and equip such an aircraft was undertaken by the Research Council and INTERA, a Calgary based firm. The aircraft, a Cessna 441 "Conquest", was outfitted and tested in 1981 and used extensively during the 1982 and 1983 summer field programs. The aircraft now plays a key role in the Atmospheric Sciences Field Program by providing data for all the experiments. In addition to measurement of state parameters, the aircraft carries an array of PMS probes (FSSP, OAP-2D-C, OAP-2D-P), ice particle counter, liquid water meter, aerosol sampling manifold and cloud dynamics instrumentation. The computer-based data acquisition system permits real-time analysis and display of flight conditions and sensor data.

4.2 Radar

The project operates two radars for weather observing and one for aircraft tracking. The primary research weather radar is S-band with a beam width of 1.15 degrees. The variable polarization antenna rotates at 8 rpm and operates in a 1 degree per revolution spiral scan, programmed at either 8 or 20 degree elevation cycles. The antenna is capable of transmitting eliptically polarized radiation at any chosen axial ratio and orientation. The received radiation is then resolved into its main and orthogonal components. The radar provides information about the size, number density, shape and orientation state of hydrometeors.

The C-band, secondary radar is used for routine weather watch or if the S-band is not available. The radar has a beam width of 1.5 degrees per revolution, programmed for either 9 or 21 degree elevation cycle. During the operational field season, the C-band radar usually operates 24 hours a day, the S-band whenever research or operational usage is required.

The X-band radar is an aircraft tracking radar with a frequency adjustable receiver. The radar pulse interrogates project aircraft transponders which then reply with coded pulses at receiver frequency. This way, only the aircraft can be detected and weather echoes are not observed. Different transponder pulse codes allow identification of each aircraft. The radar has a 1.0 degree horizontal and 16.5 degree vertical beam width, eliminating the need for an elevation drive.

4.3 Field Computing

The project has three computers at the field site dedicated to a) radar data logging, display and calibration (DEC, PDP 11/34) b) research aircraft (DEC, VAX 11/750) and c) flow forecasting (DEC, PDP11/44). These computers also form part of a computer network, and support various data acquisition, display and monitor systems at Penhold and data analysis systems at the department's Edmonton office. Computer support in Edmonton includes a VAX 11/780 and a DEC PDP 11/50.

4.4 Weather Services

The project maintains and staffs its own weather office and two upper-air stations during the field season. Daily weather briefings are held before beginning operations. The briefings cover such vital details as on-set time, development area and intensity of convection, plus a maximum hail size forecast and next day outlook. The upper-air stations (Calgary and Panhold) each make a morning and afternoon sounding. Close liaison is maintained between project and Atmospheric Environment Service meteorologists to keep abreast of rapidly changing weather patterns.

4.5 Hail Surveys

Hail storms within the project area are surveyed routinely. A computer-produced map of maximum radar reflectivities for the day is used to define the storm survey area. Telephone lists of farmers in the survey area are distributed to the project's operators who then request the information as outlined on the hail or rain reporting forms. Similar reporting forms are also mailed to all Alberta farmers in order to gather additional storm information throught the province.

4.6 Precipitation Recording Network

A volunteer-operated precipitation recording network is set up each year in a 34,000 km^2 area within the project's target area. Some 600 stations record daily rainfall for June, July and August. Monthly rainfall maps are produced for the annual field program report and distribution to the farming community.

4.7 Storm Chase

Crews in three specially modified and equipped vehicles are directed underneath the high reflectivity zones of hailstorms to collect sequential, time-resolved hailstone samples and rainfall rate measurements. The collected hailstones are quenched in heptane (at dry ice temperature) to preserve the crystal structure. The hail samples provide information on the changes (with time) in the size distributions, axial-ratio, internal structure, embryo type, isotope content and chemical composition of the hailstones. From the rainfall rate measurements, radar reflectivity values can be obtained.

5. SUMMARY

The Alberta Research Council has now completed the third year of its current five-year program, following which an assessment of all five years will be made. From this, decisions will be made as to the future and direction of research in weather modification and the Council's Atmospheric Sciences Program.

6. ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance of J. Renick, Project Manager, for his guidance in preparing this paper, and to L. Shannon for her assistance in typing and editing the manuscript. The author also wishes to acknowledge the funding support of Alberta Agriculture, the Alberta Research Council, Alberta Environment and the Canadian Atmospheric Environment Service.

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