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SNOWFALL AND SNOWFALL ACCUMULATION NEAR CLIMAX, COLORADO

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ABSTRACT

An investigation of snowfall over the higher elevations of the Rocky Mountains in Colorado is being carried out by Colorado State University. This investigation is described and preliminary findings are discussed. The current field program includes daily snow observations of new snow at 65 sites spaced at about one mile intervals over Fremont, Hoosier, and Vail Passes. In addition, certain atmospheric observations are being made and seeding is being carried out with silver iodide generators from upwind sites on randomly selected days.

Specific investigations being carried out consider: (1) the efficiency of snowfall observing devices; (2) the characteristics of representative snowfall observing sites; (3) snowfall variations with elevation and exposure for various weather situations; (4) concentrations of atmospheric ice nuclei and their relationship to snowfall; and (5) differences in snowfall and in atmospheric conditions between seeded and unseeded days. This is a continuing investigation in which the atmospheric observations are being expanded.

INTRODUCTION

Water demands in many areas of the West already exceed minimum, average, and in some cases maximum supplies. Increasing demands can be expected. Improved water utilization, including converstion of salt water, can be expected to help alleviate growing shortages to only a limited extent. Actual increase in water supplies are needed. These can be obtained from only one source - the atmosphere.

Investigations have been initiated at Colorado State University to evaluate the potential for additional water supplies that might be obtained from improving the precipitating efficiency of orographic clouds being lifted over the mountain ranges of the West, particularly those in Colorado. The purpose of this paper will be to describe the program in progress and discuss some of the preliminary findings.

THE COLORADO STATE UNIVERSITY ARTIFICIAL SNOW RESEARCH PROGRAM

The specific objective of the research program is to study orographic clouds which form over the high elevations of the Rockies, and the snowfall which they produce, in order to obtain an improved understanding of the cloud and precipitation characteristics and processes under different weather situations during the winter season. Additional objectives are to investigate changes in these clouds and precipitation when artificial ice nuclei are supplied, and to engineer techniques based on findings to optimize any advantageous artificial effects.

A feasibility study was initiated in the vicinity of Climax, Colorado, from 19 February to 12 May 1960. During this period prodecures and equipment were tested and developed. This pilot study has been continued and expanded somewhat during the current winter season.

A. Area

The Climax area where the study is being carried out (Fig. 1) is located in Central Colorado in a section of the Rockies where the Continental Divide is oriented east-west for a short distance.

Three passes, Tennessee (10,424'msl), Fremont (11,318'msl) and Hoosier (11,542'msl) traverse this section of the Continental Divide separated by distances of around 8 miles. These passes are all kept open throughout the winter so that the area is readily accessible for observations at various elevations despite snow accumulations of 6-8 feet by late winter. Roads over these passes are oriented generally north-south. An additional pass in the study area, Vail (10,603'msl), is oriented generally east-west. Elevations in the study area vary from around 8,000 feet to near 12,000 feet msl with peaks going to over 14,000 feet. The area is covered by coniferous forests. There are numerous clearings in the forested area.

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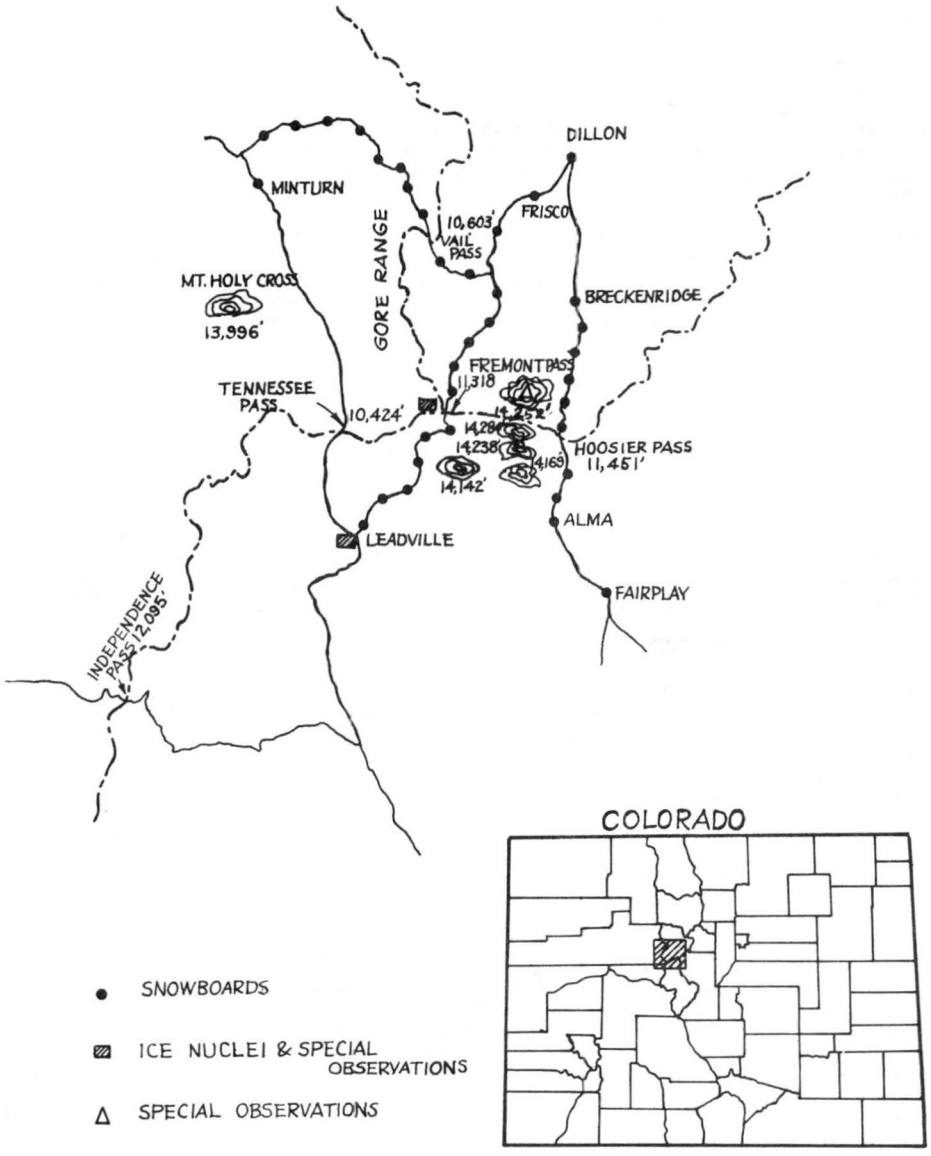


Figure 1. Snow Project - Observation Network

Lodging and laboratory facilities are available at the top of Fremont Pass at the Climax Molybdenum Company and at the High Altitude Observatory of the University of Colorado

B. Climatology

Climatological data for Climax is given in Table 1.

TABLE 1

CLIMATOLOGICAL DATA FOR CLIMAX, COLORADO, FOR THE PERIOD NOVEMBER THROUGH APRIL, BASED ON RECORDS FROM NOVEMBER 1953 TO APRIL 1960

Average number of days with precipitation	85
Median number of days with precipitation	88
Maximum observed daily precipitation	0.81 inch
Range of precipitation amounts for 80 percent of all cases	0.04 to 0.51 inch
Free air velocity:	
10,000 ft msl: 85 percent of time less than	25 mph
20,000 ft msl: 75 percent of time less than	40 mph

The large number of days with the range of precipitation within one order of magnitude is very desirable for statistical analyses.

For practical purposes all clouds occur at temperatures below freezing are consequently in the temperature range where the "ice process" can be expected to be the primary process for the formation of precipitation.

C. Procedure

The procedure being followed in carrying out the study involves snowfall and atmospheric observations and ground-based seeding operations.

1. Snowfall Observations

Daily snowfall observations were made at 33 sites spaced at about one-mile intervals along Highway 91 from Leadville over Fremont Pass to Frisco during the spring of 1960. Daily observations are being made at 65 sites over Fremont, Hoosier and Vail passes during the current winter season. Observation of snowfall and water content are made at each site daily and a sample of new snow is collected for laboratory analysis to determine the freezing point depression of the snow water.

2. Ice Nuclei Observations

Since weather modification operations are based on the assumption that there is a deficiency of natural ice nuclei in the atmosphere, observations of atmospheric ice nuclei from the upper part of the mountain range is an essential part of the project. Ice nuclei observations (1,2)* have been made daily at the High Altitude Observatory at Climax since the fall of 1954 and are being continued. Several observations are made daily.

3. Local Weather Observations

Local weather observations are obtained a number of times each day at the High Altitude Observatory and at each of several silver iodide generator sites. These observations include information of wind, temperature and clouds.

4. Special Observations

Special observations are taken periodically when CSU personnel are in the area. These include

* Numbers refer to appended references.

observations, both visual and photographic, of the cloud forms (Figs. 6 and 7), structure and movement, snow crystal structure, and snowfall characteristics. In future phases of the program these observations will be made on a routine basis. It is planned that observations will include stereo-cloud photographs obtained with K-24 stereo-camera pairs that have been developed at CSU and crystal structure, mass and fall velocities obtained from different mountain elevations.

5. Free-Air Observations

Limited observations have been made of wind, temperature and humidity from nearby Quandary Peak (14,252'msl) which is an isolated peak in the project area. Plans are being made to obtain routine observations from this mountain peak in future years.

6. Artificial Cloud Seeding

Seeding is carried out on a random basis using hypodermic needle type silver iodide generators. Determination of suitable experimental days for seeding is currently being made independently by the U. S. Weather Bureau of Denver. Investigations are underway which are designed to make this determination completely objective in the future. A system of "straight randomization" (as opposed to "random pairs") is used for obtaining the random decision to "seed" or "not seed" on days which have precipitation potential. Clear days are of course not considered. Snowfall and atmospheric observations for the "seed" and "no seed" days are being compared.

INVESTIGATIONS IN PROGRESS AND PRELIMINARY FINDINGS

The program during the spring of 1960 was designed primarily to investigate the feasibility of such a project during the wintertime in a high mountaineous area. Primary considerations are the obtaining of reliable precipitation data, the operation of seeding equipment and the facilities for obtaining the desired atmospheric observations.

A. Snowfall Observations

Commercial weather modifications have been carried out periodically in the High Mountains in Colorado since 1950. Evaluation of the operations was not made by Thom (3) of the President's Advisory Committee on weather control due to the sparsity or non-existence of precipitation observations. This lack of data presents one of the greatest problems in studying snowfall and its modification at high elevations. Other problems concern design and exposure of instrumentation.

1. Precipitation Gage

Warnick (4) and others have considered the problem of precipitation gages and the shielding of these gages to assure proper catch. Various reports in the literature uniformly report deficiencies in catch on unshielded gages, and improved catch with various types of shieldings. Precipitation during the snow season as observed at the Weather Bureau station operated by the High Altitude Observatory (Fig. 8) is substantially different for shielded and unshielded gages. During the period of the study during the spring of 1960 the standard 8" gage had an accumulated catch of 5.98" while the adjacent shielded recording gage had a catch of 8.58". The deficiency amounts to 30 percent of the shielded gage collection. Problems of expense, installation, maintenance, and reading a large number of shielded gages, as are required for detailed aerial snowfall investigations, suggest that other techniques should be considered.

2. Snowboards

Snowboards from which daily observations can be taken are being used for field observations. These boards consist of a square of painted plywood. V-shaped runners are attached to the underside for stability in deep snow. A dowel extends upward from the board surface as an aid in locating the board in deep snow. Snow-depth measurements are taken at several positions on the boards. For depth of water in the new snow a sample core is obtained and weighed. Figures (9) and (10) are of boards which are being used. These boards are placed 50-200 feet from the highway. Considerable effort has been expended in selecting sites in clearings where protection from severe winds can be expected.

Several tests, as are listed below, have been made of the reliability of data obtained with these boards.

Fig. 6 - Time lapse photography of associated clouds

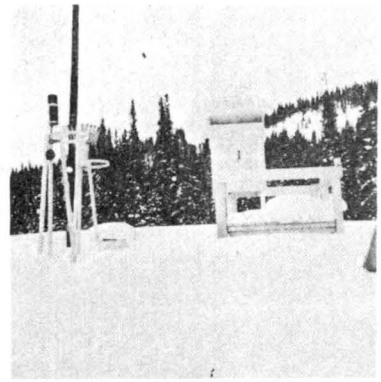


Fig. 8 - Climax observation station of U. S. Weather Bureau

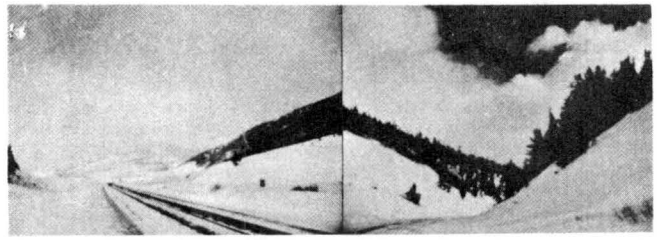


Fig. 7 - Both water droplet (right) and ice crystal clouds (left) were observed

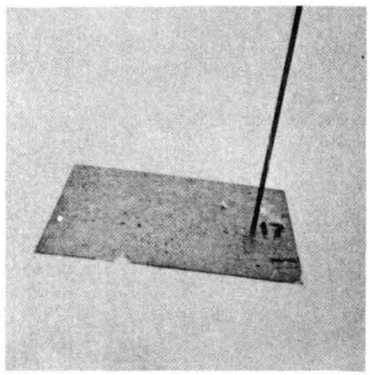


Fig. 9 - Snowboard used for daily collection of snowfall at 24 observation sites

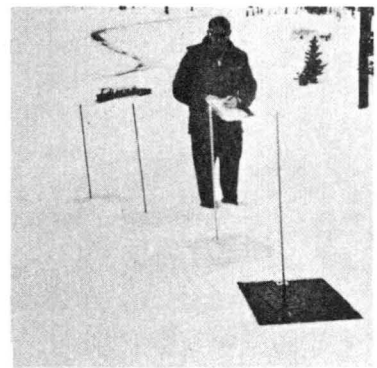


Fig. 10 - Comparative study of snowboards

a. Gage and Snowboard Comparisons

A snowboard is operated immediately adjacent to the shielded and unshielded precipitation gages at Climax. The day-by-day comparisons show little difference in the case of the shielded gage. The accumulated catch from the snowboard and from the shielded gage are nearly the same for the test period during the spring 1960. The accumulated seasonal catch on this snowboard was 9.04 inches or 5 per cent in excess of the 8.58 inches collected in the shielded gage. This is considered to be good agreement. It is noted from Warnick's data (4) in which shielded gages were compared with snowboard readings, taken over extended periods for several years, that snowboard readings were in excess of the shielded gages by about the same magnitude.

b. Snowboard Color

The catch on four boards of different colors was observed daily at the same site during the spring of 1960. These boards were white, black, silver, and burlap covered. The accumulated depth of the snow water for the season showed little variation between these boards. The catch on the white was the greatest, being 5 percent greater than obtained on the black board, 2 percent greater than the burlap, and less than 1 percent greater than the silver-colored board. White boards are being used for the regular network observations. Some melting was observed on all boards. This is minimized by making morning observations.

c. Observer Comparisons

Visual comparisons made by snowboard observers for the large number of observations made during the spring 1960 season have been carefully reviewed. In these the observers have made observations of the amount of new snow on the respective boards and the mean of the new snow in the surrounding area. These observations are of assistance in determining the representativeness of snowboard observations and also of the site characterisitics. From these observations it is apparent that under extreme wind conditions in completely exposed locations that satisfactory readings cannot be obtained. For conditions that existed during the spring of 1960 representative readings were reported even at exposed locations during approximately 55 percent of the snow events. At a number of protected sites observations of new snow were representative of the new snowfall in the area even for the most severe wind conditions experienced.

d. Comparison of Observations at the Respective Sites

The representativeness of the observations of the respective boards has been checked by correlating the daily snowfall on each board and the sum of the snowfall on the four adjacent boards, two on either side. Due to the large number of correlations required for this comparison graphical correlations have been used. It is planned that correlations will be computed and definite limits established for the acceptance of readings from the various sites when the IBM 1620 computer becomes available at CSU this summer. With three exceptions out of the 30 sites, these relationships are considered satisfactory. In the three cases where this relation is bad, other tests also indicate these sites are unsatisfactory and the affected snowboards have been relocated for the current season.

e. Pattern of Snowfall

The consistency of the pattern of snowfall observed over the snowboard network for individual storms and accumulated over the

season in itself forms a basis for considerations of the representativeness of the data. Fig. 2 shows a cross section of Fremont Pass, the respective observing stations, and the accumulated observed precipitation. The pattern of accumulated precipitation is consistent and forms a pattern that might be reasonably expected. From the various tests of the data that have been carried out the data from stations 1, 8, and 21 is considered to be doubtful. Vandalism and tampering occurred at station No. 8.

It is of interest to note in Fg. (2) that snowfall increased with elevation despite the altitude of 11,300' msl. Precipitation for corresponding elevations is considerably greater on the northern slope. Studies of snowfall distribution are being made for each storm situation.

The determination of the representativeness of the snowboard readings at various observation sites forms the basis for describing the characteristics of satisfactory observing sites. Each site over Fremont Pass has been described with regard to the slope of the land and the tree-line elevation in all directions. These characteristics are being studied in relation to the efficiency of catch with various wind conditions. It is intended that characteristics which define good sites will be described and used as a basis of network refinement in future installations.

Indications to date are that satisfactory daily snowfall observations can be obtained at high elevations if adequate attention is given to site selection.

B. Ice Nuclei Observations

A cold box type counter which has been used since 1954 and an Australian-type expansion counter are being used to observe ice nuclei. Readings were taken with these during the spring of 1960 and a comparison of the readings has been prepared (2). This indicates that observations with the two instruments are comparable although individual sample variation can be substantial.

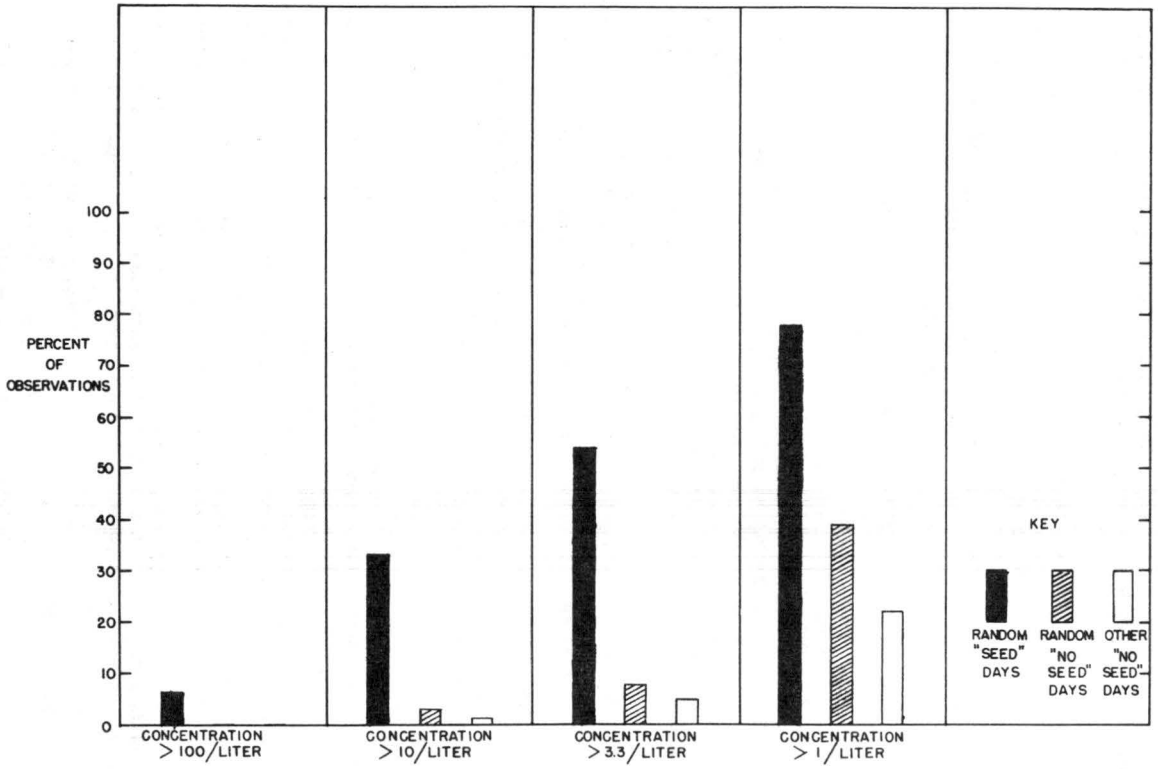
Ice nuclei concentrations observed at Climax since 1954, with a few exceptions, have consistently been about 1 to 2 per liter at -20 degrees C. This is an order or more less than has been calculated by most workers to be the concentration desired for making optimum utilization of available orographic cloud moisture for the production of precipitation.

A better understanding of the optimum concentrations is one of the ultimate objectives of the current investigation. Only a few significant variations from past observations were observed during the spring of 1960. Large increases did occur for short periods following two of the randomly selected seeding operations. These were not consistent and limited operations make it difficult to draw conclusions. The situation has been quite different during the current season. Ten to a hundred-fold increases in concentrations have been consistently observed on the seeding days in comparison to the control days left unseeded. A third of all observations made during the current season on seeding days have given concentrations greater than 10 per liter. Less than 3 percent of the control observations have been this high. Figure 3 shows a comparison of the concentrations observed on "seed" and "no seed" and "other days". "Other days" are those on which no random decision was made and no seeding was carried out. Most of these days were cloudless.

Figure 4 shows a comparison of concentrations observed from 12 through 17 January 1961. Seeding was carried out on 14 January. Figure 5 shows the same comparison for 23 February - 1 March 1961, during which 25 and 26 February were "seed" days. It can be noted for January 14 and February 26 (Figs. 4 and 5) that the concentrations on these "seed" days were in some cases 100 times greater than for other days. Concentrations on February 25, a "seed" day, were of the same order of magnitude as observed on other non-seeded days. It has not yet been possible to make a detailed wind analysis for this day but it is to be expected that on certain of the seed days that the artificial nuclei will not be carried directly over the counter.

These data indicate that artificial ice nuclei which have been released ten to forty miles upwind are being observed in concentrations of 10 to 100 per liter.

Since observations can be made only periodically during the day with present equipment, study of the detailed time distribution of concentration increases is not possible. It is planned that a continuously recording nuclei counter will be utilized during the 61-62 season. No observations of the vertical distribution of nuclei concentrations are possible at the present time. It is planned that, as a minimum



COMPARISON OF ICE NUCLEI CONCENTRATIONS OBSERVED ON DAYS OF PRECIPATION WHEN SEEDING "WAS" AND "WAS NOT" CARRIED OUT AS DETERMINED BY RANDOM DECISION, AND FOR OTHER DAYS OF "NO SEEDING." CLIMAX, COLORADO, 26 DECEMBER 1960 - 10 MARCH 1961

FIG. 3

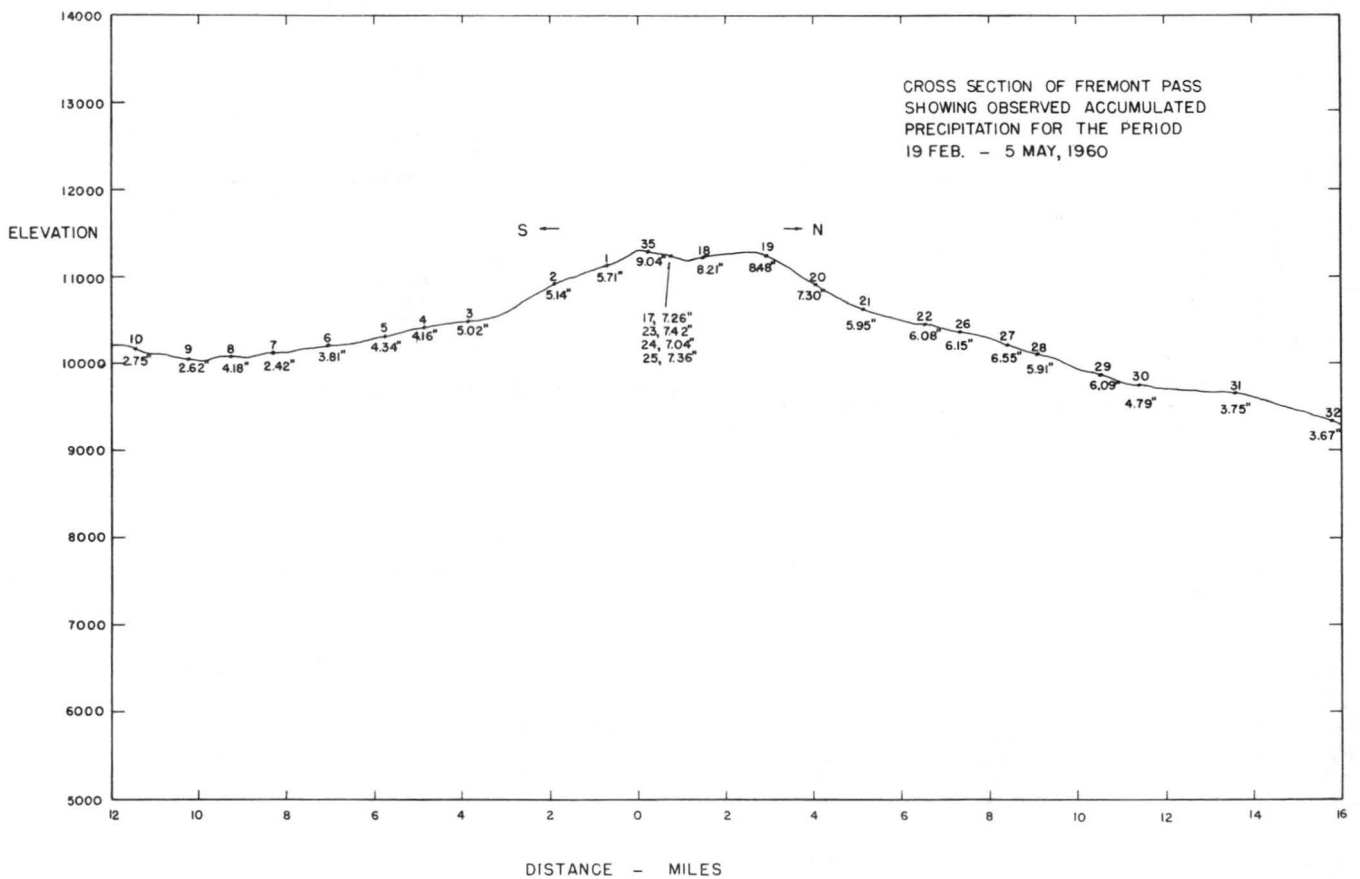
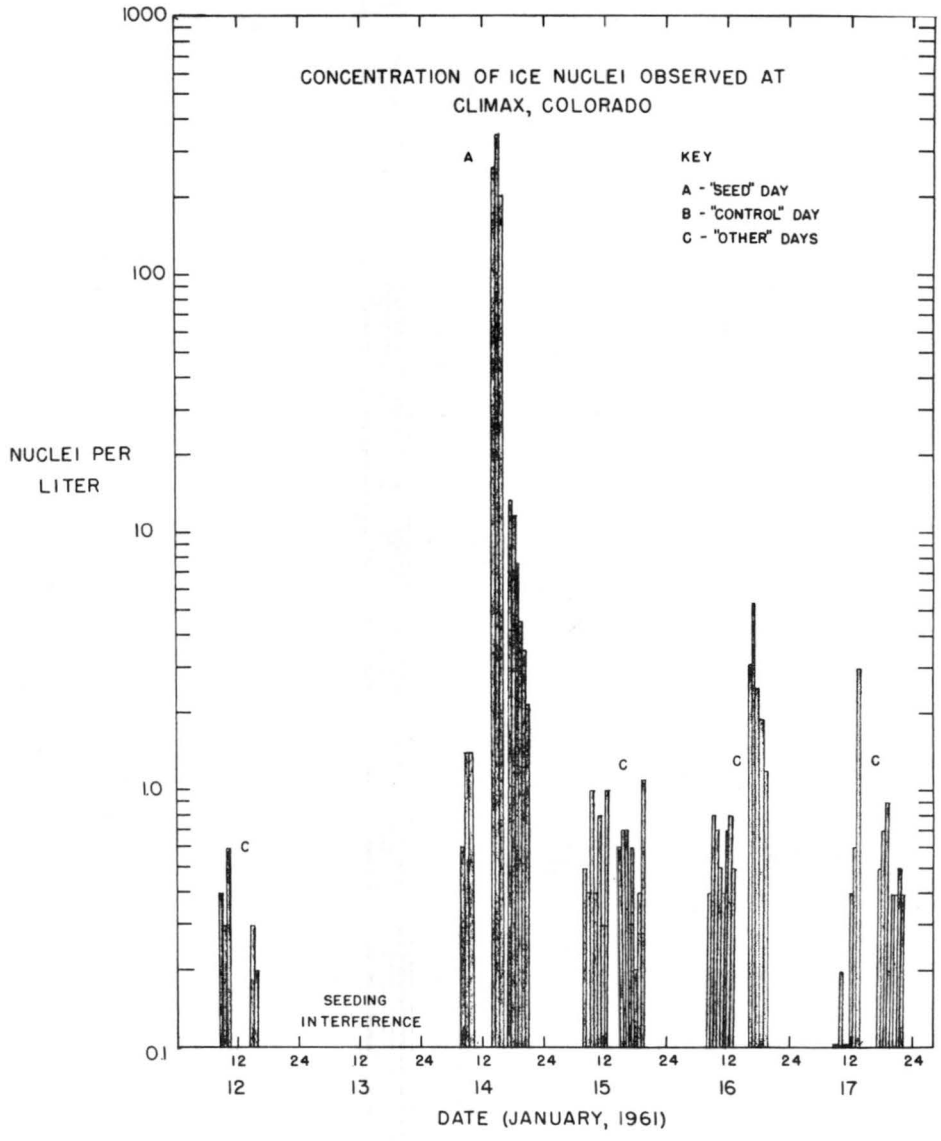

CROSS SECTION OF FREMONT PASS
SHOWING OBSERVED ACCUMULATED
PRECIPITATION FOR THE PERIOD
19 FEB. – 5 MAY, 1960
ELEVATION
S ←
→ N
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
10 2.75"
9 2.62"
8 4.18"
7 2.42"
6 3.81"
5 4.34"
4 4.16"
3 5.02"
2 5.14"
1 5.71"
35 9.04"
17, 7.26"
23, 7.42"
24, 7.04"
25, 7.36"
18 8.21"
19 8.48"
20 7.30"
21 5.95"
22 6.08"
26 6.15"
27 6.55"
28 5.91"
29 6.09"
30 4.79"
31 3.75"
32 3.67"
12 10 8 6 4 2 0 2 4 6 8 10 12 14 16
DISTANCE – MILES

FIG. 2


CONCENTRATION OF ICE NUCLEI OBSERVED AT
CLIMAX, COLORADO
KEY
A - "SEED" DAY
B - "CONTROL" DAY
C - "OTHER" DAYS
NUCLEI PER
LITER
1000
100
10
1.0
0.1
A
C
C
C
C
SEEDING
INTERFERENCE
12
24
12
24
12
24
12
24
12
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12
24
12
13
14
15
16
17
DATE (JANUARY, 1961)

FIG. 4

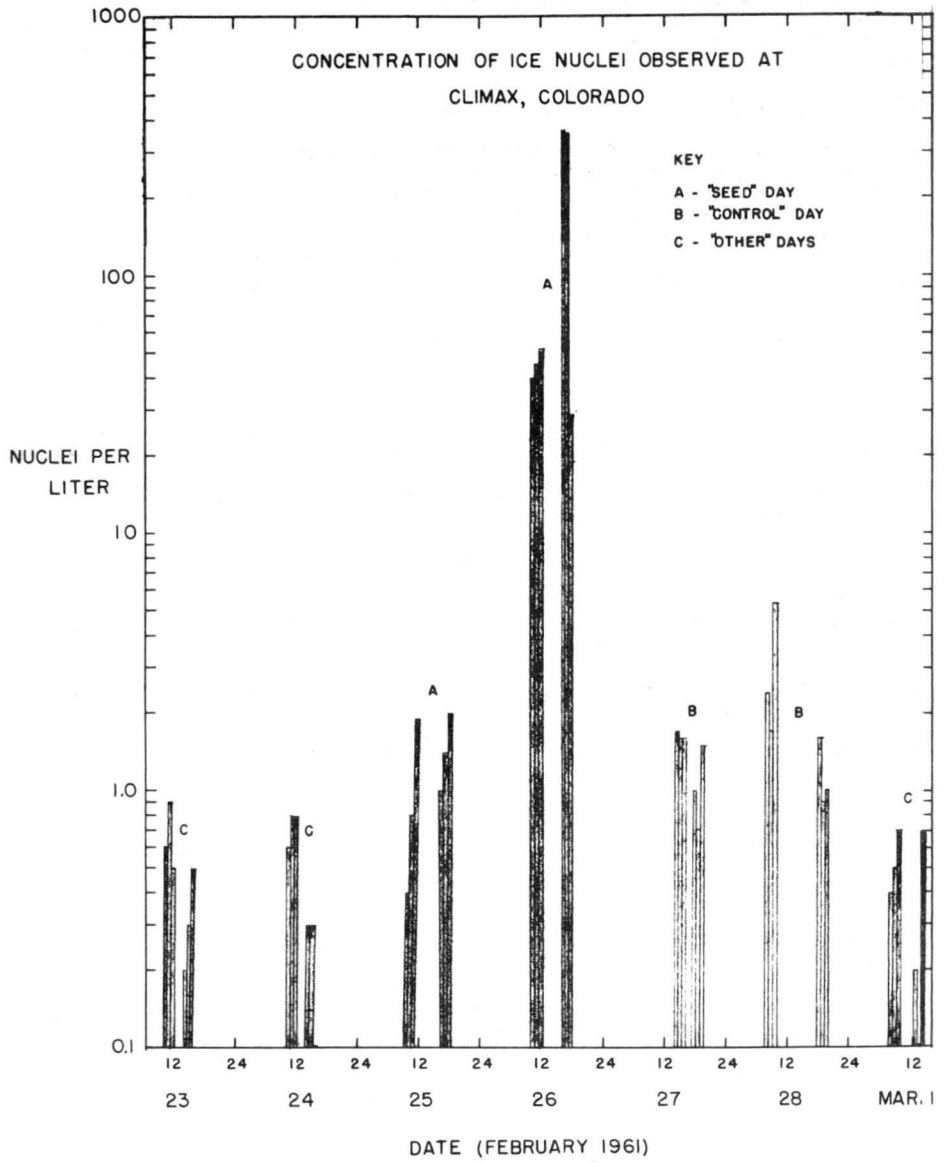
CONCENTRATION OF ICE NUCLEI OBSERVED AT
CLIMAX, COLORADO
KEY
A - "SEED" DAY
B - "CONTROL" DAY
C - "OTHER" DAYS
NUCLEI PER LITER
1000
100
10
1.0
0.1
A
B
C
12 24 12 24 12 24 12 24 12 24 12 24 12
23 24 25 26 27 28 MAR. 1
DATE (FEBRUARY 1961)

FIG. 5

observations will be made at varying mountain elevations during the future program with portable equipment.

Work is also in progress to attempt to establish the presence of silver iodide nuclei in new snow. Samples of new snow are saved in a frozen state from each board during each snowfall. These are being analyzed to determine the depression of temperature below freezing required for each sample before small droplets of this water will freeze. Samples of snowwater which contain silver iodide nuclei can be expected to freeze at a warmer temperature than those which do not. The effect has been observed in control samples and the routine checking of field samples is now in progress.

C. COMPARISONS OF SNOWFALL ON SEEDED AND UNSEEDED DAYS

Since this comparison must be made by statistical means a sizeable sample will be required before analysis can be made. Twenty-eight events, 12 seeded and 16 unseeded, were accumulated during the spring of 1960. Thirty-two additional events have been accumulated during the present season, for a total of 60, 28 seeded and 32 unseeded, through 5 April 1961. Most snowfall data is not available from the field observers and analyzed for the current season and the cases for the spring of 1960 are too few in number to draw conclusions as to precipitation differences with any degree of confidences. Looking just at the observation from the High Altitude Observatory at Climax through 51 events, 23 seeded and 28 unseeded, it is apparent that the snowfall on the seeded days has been substantially greater. An analysis of the significance of this variation and that for the entire network will be made at the completion of the current season which will be completed at the end of April.

FUTURE PLANS

It is planned that the present studies will be continued for several seasons to establish with high confidence just what the effects of the present ground seeding is on high elevation snowfall and on the cloud and precipitation characteristics. From changes which might be observed in cloud and atmospheric conditions it is hoped that techniques can be engineered that will make possible efficient utilization of available atmospheric moisture for providing increased water supplies.

ACKNOWLEDGMENTS

The initiation of this study was made possible through a research grant from the Climax Molybdenum Company. The continued support of this group in providing assistance and facilities during the second operating season is also gratefully acknowledged.

Support from the National Science Foundation for continuation of these investigations during the 1960-61 winter season is gratefully acknowledged.

The encouragement and assistance in taking observation by the High Altitude Observatory personnel has made possible many observations that could not otherwise have been obtained.

Support from the Rocky Mountain Forest and Range Experiment Station, U. S. Forest Service, for obtaining additional snowfall observations is also gratefully acknowledged.

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