EFFECT ON CLOUD SEEDING EVALUATION OF ERRORS IN PRECIPITATION MEASUREMENT DUE TO VARIATIONS IN THE WATER CONTENT OF THE PORTION OF THE TOTAL PRECIPITATION WHICH FALLS AS SNOW.

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INTRODUCTION

The problem dealt with in this paper concerns errors in methods of snow measurement. It has come to light as a result of an evaluation of extensive cloud seeding operations in western Quebec.

Section 1: Cloud seeding evaluation. The target area for this cloud seeding project comprises approximately 8,000 square miles on the Upper Gatineau and Upper Lievre watersheds in western Quebec. The seeding has been carried on since 1955 and continuously since April 1957 to-date. The purpose of the operations was increase of precipitation for hydro-electric power generation for Gatineau Power Company and Maclaren-Quebec Power Company. The seeding was done from ground based generators using silver iodide as the seeding chemical. The evaluation is based on a regression comparison (1) between the target precipitation as measured at Mercier Dam and Cabonga Dam (the only 2 target stations with long term precipitation records); and 12 control, or unseeded, stations in an arc from west through south to southeast. These control stations comprise all of the available stations without any possibility of contamination by the seeding and with long term precipitation records. All data used are from the Monthly Records of Observations, Meteorological Branch, Department of Transport. The general evaluation method used was that of the Advisory Committee on Weather Control (2).

The target and control precipitation are normalized by the cube root transformation. Since these are monthly totals, it was found by testing that the more laborious gamma transformation recommended by Thom of the Advisory Committee was unnecessary.

The regression analysis for the period September 1955 through November 1958 was carried out (figure 1). The average percentage departure attributable to cloud seeding for the months, April through November, was found to be 17.7% to 21.7%. The probability is .04 to .012, that is, significant at the 4% and the 1.2 % levels respectively.

A test of the validity of the regression equation was made by feeding into the equation the unseeded months between 1955 and 1959. Figure 2 shows the results of testing the unseeded months, April to November, as though they had been seeded. It can be seen that no significant variation from zero effect was found. The positive departure of approximately 6% occurred with a probability of only 0.48 that is, approximately 50% or a purely chance variation.

Seeding was carried on during certain winter months, December through March. Equations were set up for these winter months exactly the same as for April through November. Figure 3 shows the results for the seeded winter months, 5 in all, that were tested. It can be seen from the figure that a substantial increase was found of 35.0% significant at the 5% level.

Figure 4 shows the results of testing the reliability of the winter regression relationship by feeding in 14 unseeded winter months. A most remarkable result was obtained; namely, a positive departure of 25.3%, significant at over the 1% level. Since these months were in fact unseeded and a small departure of low probability should have been found it is obvious that the winter equations are completely unreliable.

Figure 5 shows a combined tabulation, the results of all the tests of regression which were made. It can be seen that by omitting the winter months the equations are found reliable and the results conform with those obtained by the Advisory Committee for the most northerly projects it evaluated. That is, an increase in precipitation of 17.7% during the seeded months and a non-significant departure of 8.1% during the unseeded months. However, it is obvious that something very unusual happens in the winter months both seeded and unseeded.

Section 2: In an attempt to track down the cause of the irregularities in the regression equations some thought was given to possible synoptic weather anomalies which might be acting; i.e. wet or dry cycles, or warm or cold spells.

It was decided to examine the historical winter months on which the regressions were based by computing the theoretical target precipitation for the historical months, and then relating the percentage departure of each month's actual precipitation from the theoretical to the temperature and precipitation anomalies which prevailed during the month.

A combined contingency table for all months was prepared (figure 6). This shows clearly that warm dry winter months tend to produce an apparent increase of precipitation in the target.

Since the winter months in test periods, both seeded and unseeded, 1954 to 1958, had slightly above normal temperatures and well below normal precipitation part of the apparent unseeded increase seems to be explained.

Section 3. Snow Density. With evidence pointing to some effect of temperature and the amount of precipitation as the cause of the irregularities in the winter regression it was concluded that the most likely source of the trouble might be in the measurement of snow since the main part of the winter precipitation in the area falls as snow. Furthermore, the density of the snow is directly related to the temperature at level of formation in the atmosphere which in turn shows some correlation with the surface temperature anomalies. Also the relative snow density target to control must be quite variable from storm to storm and from month to month.

In Canada all snow precipitation measurements are obtained by measuring the depth of newly fallen snow and converting to equivalent rainfall using the standard 10 : 1 conversion factor. It was decided to investigate this aspect of the problem.

The history of snow measurements in Canada has been dealt with by Bruce and Potter [3]. They indicate that the 10 : 1 ratio is based on an average of water equivalent as measured in Toronto. Landsberg in Physical Climatology[4] reports on very extensive measurements of densities of newly fallen snow at Burlington, Vermont, covering 295 storms from 1914 to 1948 from work done by Wilson. It indicates an average snow density of 7.7%, however, extreme values range from 2.0 to 21.0%. Extreme values found elsewhere range up to 30.0%; i,e, a possible relative error of 200 to 400% in precipitation measurements.

Since monthly snowfall amounts are the sum of several storms, the range of density variations in monthly totals is not so high as in individual storms. A conservation estimate of the density range for monthly totals is from 8.0% to 12.0%

Such wide variations from month to month indicate that precipitation figures derived from a 10% density assumption can be greatly in error, so that the accuracy of regression equations based on them is very doubtful. Even assuming that with a long enough historical period these errors would tend to cancel out in the regression there is still the problem of the effect on the individual months being tested.

For example, the December regression equation is:

$$Y = 0.3614 + 0.4382X$$

where Y is the cube root of the sum of the precipitation at two target stations and X is the cube root of the precipitation at 12 control stations. Now assuming that the average actual measured depth of snow in the controls is 25 inches (about normal for December) then the following table shows the expected value of Y for various values of control snow density.

Control Snow Density	Expected Target Precipitation (water equivalent)	Percentage Error
.08	4.29"	19.3%
.10	5.12"	-
.12	5.91"	13.4%

Thus the error in the expected target precipitation due to the variations of snow density are of the same order of magnitude as the true seeding increases we are trying to detect.

Section 4. Discussion. These findings we feel are of interest to hydrologists for the following reasons: a) Such snow measurements make impossible the use of the data for regression evaluation of cloud seeding operations in the winter months. b) Evaluations based on such data are most probably seriously in error and should be re-examined. A case in point is the British Columbia Research Council's investigations of commercial cloud seeding operations on the west coast of Canada [5]. The report found seeding to have increased precipitation by some value in excess of 0.33% with a very high probability that the true increase was less than 10%. These findings are in conflict with the evaluation by Thom of the Advisory Committee in which increases of 9% to 22% on the west coast south of the border were found. The British Columbia report used yearly regressions correlating stream flow in the target and precipitation for the water year, (October through September) on the control. Most of these control stations have an appreciable fraction of their total annual precipitation in the form of snow. The data used in the B.C. report were abstracted from the Monthly Record of Observations, Meteorological Branch, Department of Transport. A preliminary check on the data indicated that the inaccuracies in the control precipitation are probably of the same order of magnitude as the seeding increases which the report was endeavouring to detect. c) The problem also applies to hydrological studies using the same type precipitation measurements, since precipitation during the spring run-off season is an important factor in some prediction schemes, such as that of Cavadias, presented to the Eastern Snow Conference in 1955 and to the Western Snow Conference in 1958 [6,7]. An improvement in the accuracy of snow measurements would undoubtedly result in an increase in the accuracy of the run-off predications. d) While using the 10% density figure over a long period may result in average errors in the annual precipitation of about 6% [8], the errors in any one period, such as a month, may be as much as 25%, and in any one storm much more than that. It is questionable whether such data, therefore, have much value for purposes other than long term means. Serious errors can undoubtedly arise in certain hydrological studies based on such data.

REFERENCES

(1) Evaluation of Cloud Seeding Results in Western Quebec 1955-1958. Weather Engineering Corporation of Canada Ltd., Montreal, Canada.

(2) Thom, H.C.S., 1957: A statistical method of evaluating augumentation of precipitation by cloud seeding. Final Report of the Advisory Committee on Weather Control, Vol. II. Superintendent of Documents, Washington, D.C., pp. 5-25.

(3) J.P. Bruce and J.G. Potter. The accuracy of precipitation measurements. Proceedings of the Third National Meeting, Royal Meteorological Society. Canadian Branch, Toronto, June 3, 1957.

(4) Landsberg, H. Physical Climatology. pp. 180.

(5) The British Columbia Research Council, 1957: The evaluation of rain making operations in British Columbia - Phase 2, pp. 59.

(6) Cavadias, G.S. Reappraisal of Snow-Melt as a Factor in Quebec Streamflow. Eastern Snow Conference, February 1955.

(7) Cavadias, G.S. An Approach to Forecasting the Spring Run-off in Quebec. Western Snow Conference, 1958.

(8) Currie, B. W. Water content of snow in cold climates. Bulletin of the American Meteorological Society. Vol. 28, pp. 150-151, March 1947.

TEST OF REGRESSION

(15) Non-History Unseeded Months
(Excluding December, January, February, March)

Month	Year	Departure	Percentage Departure	Variance
April	1954	-.0982	-14.0	.02723
	1955	.1730	+38.8	.02420
	1956	.0556	- 8.7	.02425
May	1954	+.1201	-21.6	.02994
	1955	-.0113	- 2.0	.02966
	1956	-.2188	-31.2	.03159
June	1954	-.0606	- 8.2	.04008
	1955	+.3246	72.6	.03891
July	1954	+.1960	37.7	.06230
	1955	-.0121	- 1.8	.06304
August	1954	+.0185	2.7	.05603
	1955	+.0915	14.6	.05567
September	1954	-.0061	- 0.9	.01883
October	1954	-.1957	-27.4	.02173
November	1954	+.0379	6.3	.01750
		+.3032	+ 6.4	.52521

Mean Departure $\bar{d}_m = \frac{.3032}{15} = .02021$

Variance $= \frac{.52521}{15^2}$

Standardized departure $(S\,\bar{d}_m) = \sqrt{\frac{.52521}{15}} = \frac{.7247}{15} = .04831$

Standardized Departure $t - \frac{\bar{d}_m}{S\,\bar{d}_m} = \frac{.02021}{.04831} = .418$ (Less than 50% probability)

Figure 2

(5) SEEDED WINTER MONTHS

	Departure	Percentage Departure	Variance
December 1956	.1994	41.8	.02477
December 1957	.1076	18.0	.02428
January 1958	.1486	30.2	.01171
February 1958	.2496	51.6	.01902
March 1958	.1223	33.0	.02383
	.8275	35.0	.10361

Standardized Departure $t = \frac{.8275}{\sqrt{.10361}} = 2.57$ (Probability approximately 95%)

Figure 3

TEST OF REGRESSION

(14) Unseeded Non-History Winter Months

		Departure	Percentage Departure	Variance
January	1954	.1728	33.0	.01160
February		.0342	6.3	.01905
March		.1191	23.0	.01996
December		.0628	10.5	.02330
January	1955	.1351	29.2	.01230
February		.0983	21.1	.01955
March		.2682	49.5	.02038
December		.3456	85.3	.02828
January	1956	.0971	-17.2	.01180
February		.2923	70.4	.01857
March		.1936	44.5	.02071
January	1957	-.0281	- 5.0	.01160
February		-.1508	32.7	.01905
March		-.1282	-29.7	.02441
		+1.6194	25.3	.26056

Standardized Departure $t = \frac{\bar{d}_m}{S\,\bar{d}_m} = \frac{1.6194}{\sqrt{.26056}} = 3.17$

(Probability greater than 99%)

Figure 4

SUMMARY OF REGRESSION RESULTS

	Percentage Departure	t Value	Significance
SEEDED MONTHS			
All 28 Months	+21.6	2.64	S_2
5 Winter Months	+35.0	2.57	S_5
23 Non-Winter Months	+17.7	1.83	S_5
UNSEEDED MONTHS			
All 29 Months	+16.4	2.17	S_5
14 Winter Months	+25.3	3.17	S_1
15 Non-Winter Months	+ 8.1	0.42	NS_5

S_1 = Significant at 1% level

S_2 = Significant at 2% level

S_5 = Significant at 5% level

NS_5 = Not significant at 5% level

Figure 5

COMBINED CONTINGENCY TABLE

(75) Winter Months
(December, January, February, March)

Departures of actual precipitation (y) from expected precipitation (y) for historical months (1930-1953).

	WARM	COLD
Wet	- 1.0	+ 2.4
Dry	+10.3	-4.0