January 1980

Preliminary Study of the Northern Utah Hail Suppression Project

Geoffrey E. Hill

PRELIMINARY STUDY OF THE NORTHERN UTAH HAIL SUPPRESSION PROJECT

by

Geoffrey E. Hill

FINAL REPORT

COOPERATIVE AGREEMENT 80-5257

December 1980

UWRL/A-80/02

for the

Division of Water Resources

231 East 400 South

Salt Lake City, Utah 84111

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Table | Page

1.0 INTRODUCTION

This study represents an examination of the possibilities for evaluating the northern Utah summertime rain-enhancement hail-suppression project. This study is not an evaluation of the project.

In this report available data are reviewed with the purpose of making known what data are useful and what additional data are required for evaluating the project.

In summary none of the existing (radar) data can be used to evaluate the hail suppression project. Although data quality appears to be a factor, the primary reason is that neither hail measurements nor suitable treatment controls are available. Thus, if an evaluation of the hail suppression project is desired both hail measurements and suitable treatment controls will be required.

Evaluation of the precipitation enhancement project is possible in principle. The method used by the Division of Water Resources in 1978 is basically a sound one. However, the use of monthly precipitation greatly weakens the strength of the method. A parallel evaluation of precipitation enhancement could be made along similar lines as with hail suppression if suitable measurements and treatment controls were employed.

2.0 DATA AVAILABLE

2.1 Precipitation

The primary source of precipitation data in and around the project target area, shown in Fig. 1, is monthly. While daily and hourly data

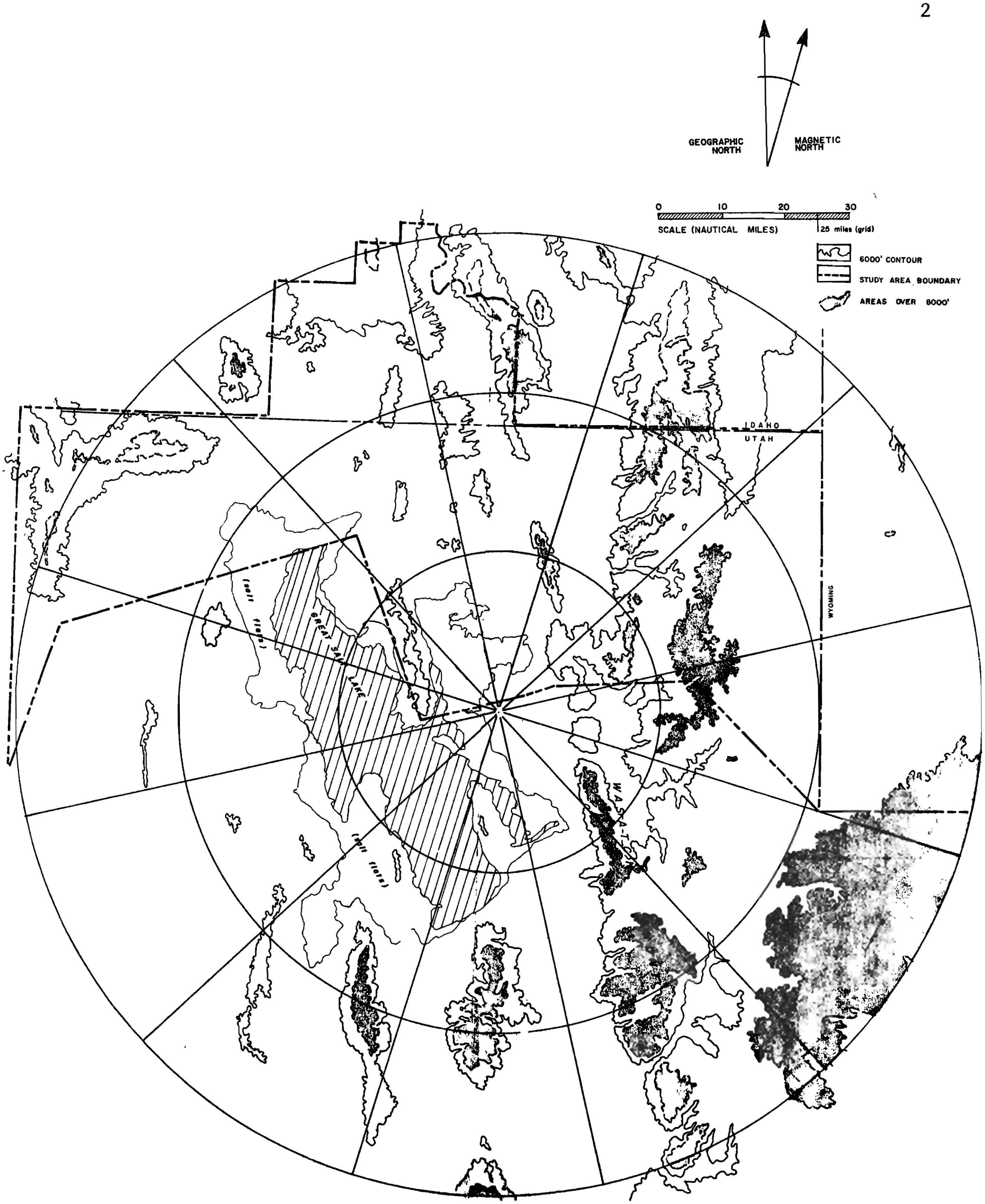

Fig. 1. Target area for Utah-Idaho summer project for precipitation enhancement and hail suppression. Topography is indicated by 6000' contour and 8000' or higher as shaded areas.

do exist, only the monthly data are sufficiently extensive to provide suitable treatment controls. Stations where these monthly data are obtained, with records extending back at least 20 years, are shown on Fig. 2. With these monthly records, seasonal data were derived by the Division of Water Resources (1978) in an evaluation of the first two years of the project. Certainly it would be desirable to add the three remaining seasons to this evaluation.

2.2 Radar echoes

During the course of the hail-suppression precipitation-enhancement project, radar data were collected from the project radar located at Little Mountain, about 15 miles west of Ogden. These data were collected in the target area during conditions when seeding for precipitation enhancement or hail suppression was believed appropriate. Examination of these data are made in a general way herein to aid in the assessment of how an evaluation of the hail suppression project might be accomplished.

While the radar system is an extremely useful tool to assist project personnel to identify or measure clouds with a likelihood of producing hail, their location, movement, and vertical extent, the usefulness of radar to evaluate hail suppression effects depends upon the total project configuration. In the present case, the radar is used in the absence of surface hail measurements; and no suitable treatment controls exist. Therefore, radar data as collected on this project cannot be used for evaluation of changes in hail amounts due to seeding.

Fig. 2. Location of precipitation gages used in evaluation of summer precipitation enhancement by cloud seeding. C1, C2, and C3 are Idaho, Nevada, and Utah controls, respectively. W, C, and E are west, central, and east gages within target.

Whereas an evaluation of precipitation enhancement can be made, even though relatively crude, an evaluation of hail suppression using radar data is not possible, at least, if accepted practices of evaluating treatment effects are followed. What is needed is both actual hailfall data and adequate treatment controls, either based upon historical data or other concurrent data for unseeded clouds taken from the same population (taken from the same type and intensity of clouds as the seeded ones). Neither of these controls exist.

Therefore, we can only review the existing radar data with a view toward gaining further insight as to how treatment controls can be obtained. Based upon this survey of radar data, recommendations will be made as to what measurements will be required to make an evaluation of the hail suppression project.

3.0 RADAR DATA ANALYSIS

3.1 Radar data characteristics

Several aspects of data obtained from the project radar must be considered in the interpretation of cloud echoes and estimation of hail frequency or other aspects of hailfalls. These aspects include radar ground clutter, signal attenuation, elevation angle of signal, topography, and the measured cloud echoes.

Ground clutter occurs when signals are reflected back from terrain features, especially mountains. When the radar is operated at low elevation angles, the ground clutter increases over what it would be at a higher elevation angle. However, for adequate range, a radar is

normally operated at a few degrees elevation, typically 3° in the Northern Utah hail suppression project. A depiction of ground clutter is shown in Fig. 3 for this elevation angle. In all of these areas it is not possible to accurately obtain echo data from the film projections.

In general signal attenuation is primarily caused by intervening clouds rather than a distance squared factor. However, with summertime convection, especially as it occurs in the Intermountain West, attenuation is not a very serious problem. The reason is that heavy convective clouds are scattered over the area, and one cloud will not often obscure another from radar view.

The elevation angle of the radar signal affects the viewing range. The height above ground of the sampled volume of atmosphere increases with increasing range, as shown in Fig. 4. Thus, beyond a range of 75 nautical miles only the very deep clouds (containing precipitation) can be detected by the radar at a scanning elevation of 3°. At higher scanning elevations where ground clutter is reduced, the range of viewing clouds becomes smaller. At lower scanning elevations the effect of the earth's curvature becomes increasingly important; note for example the height of the 0° elevation as a function of range.

The formation of convective clouds and detection by radar are greatly affected by topography. Although convective clouds are frequently widely scattered, there is a strong tendency for clouds to develop and grow over mountains. Subsequently, the clouds may move away from their formative region under the action of the upper level airflow.

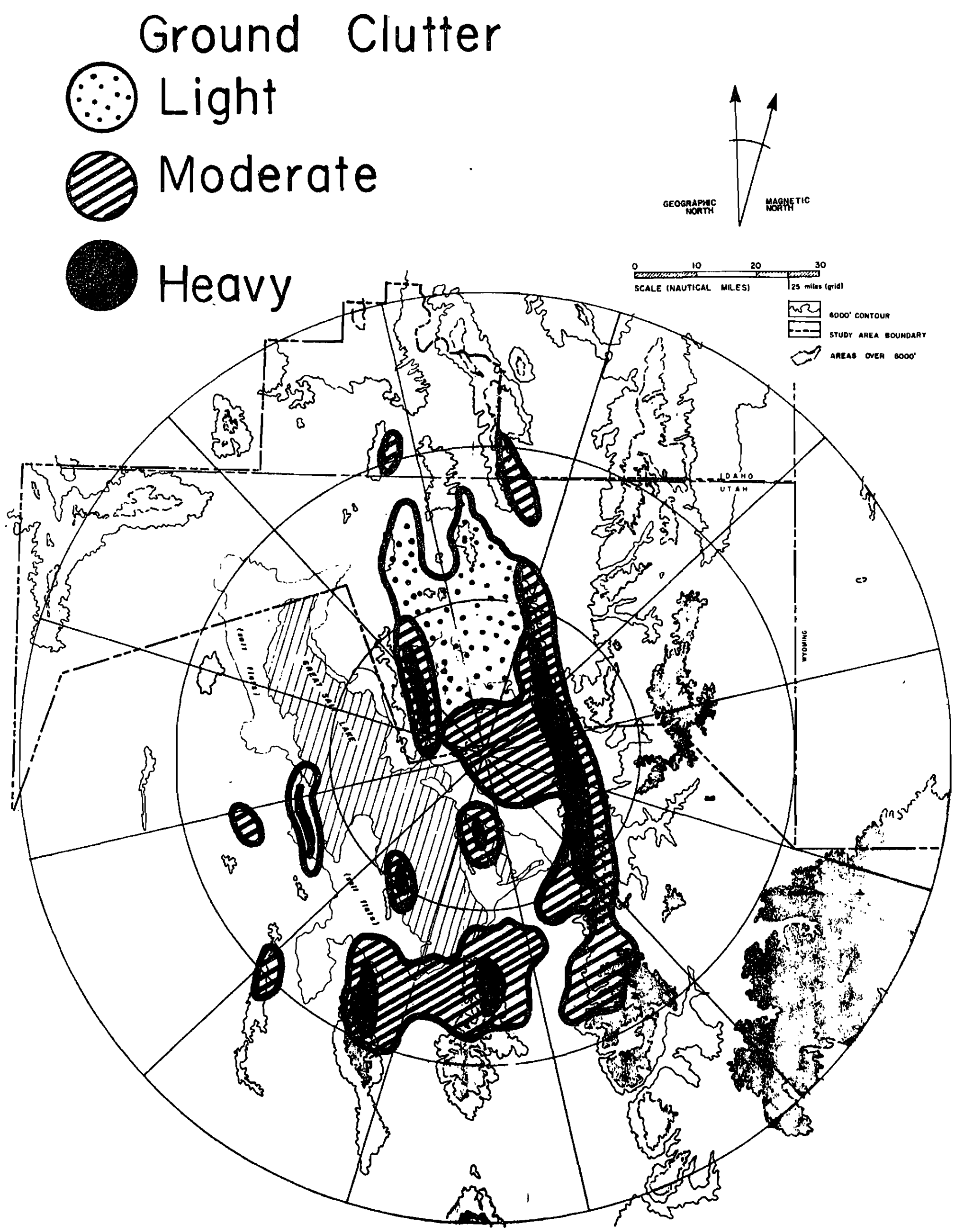

Fig. 3. Radar ground clutter for radar elevation angles of 2 to 3 degrees.

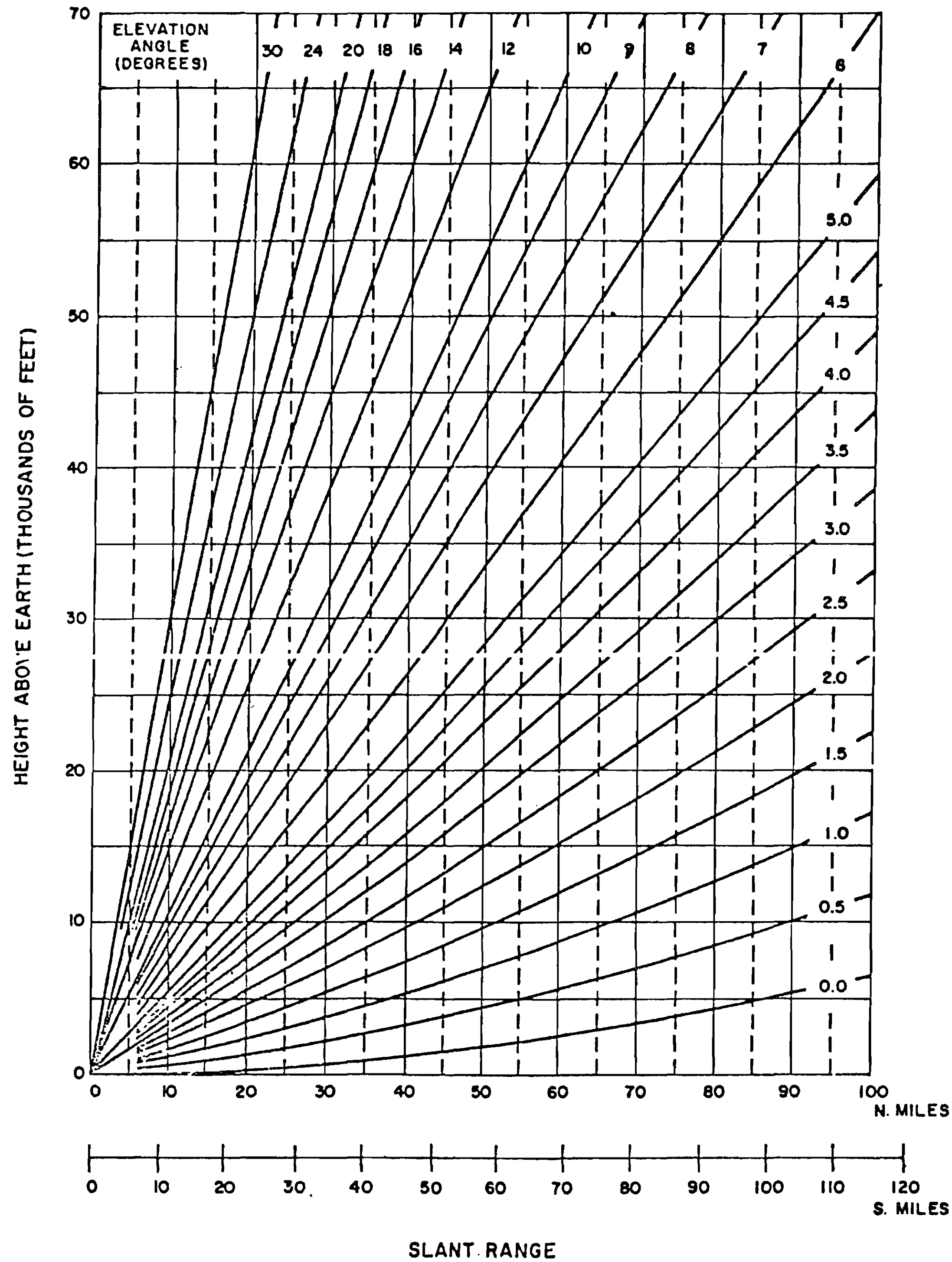

Fig. 4. Height of radar echo as a function of slant range and elevation angle.

3.2 Statistics of echo size and time of occurrence

It is well known that hail occurs often when the intensity of a radar echo is great. On the other hand, the size of an echo does not necessarily indicate its intensity. However, the height of convective storms reveals the potential for hail; that is, convection exceeding 30,000 ft tends to produce hail. Clouds reaching 40,000 ft usually contain hail. In turn, deep clouds are normally at least as large horizontally as tall, and in squall lines or supercells the clouds are somewhat broader than they are deep. Therefore, clouds with horizontal sizes exceeding, for example, 10 n. mi. have a much greater chance of containing hail than do smaller ones.

While echo intensity measurements are by far more valuable than the PPI data, only the latter are available on a somewhat regular basis. From our present discussion it appears that some information on the occurrence of hailfalls can be gleaned from data on radar echo size. These data are compiled for 21 days in 1979 with available radar data. A summary is given in Table 1. Correspondence with hail activity and larger radar cells appears to be valid, according to a comparison with Atmospherics, Inc. brief report dated 1 October 1980. For example, on July 18 there were a very large number of relatively small cells (5-10 mi.); this day is reported as one of weak surges of moisture with scattered shower activity. On the other hand, July 21-23 (with large cells present) was regarded in the report as being a period of hail threat.

In terms of evaluation of the hail suppression program, these data do not appear to be sufficiently quantitative to serve as an

Table 1. Radar-cell average diameter (miles).

Day (1979)		0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45–50	50+
May												
145	25	7	8									
147	27	14	47	22	4	2					1	
148	28	4	7	2	1	1			1			
June												
169	18	7	27	10	8							
172	21	23	26	9	1	1	1				1	1
177	26	11	15	3								
July												
183	2	4	2	1								
184	3	1	5	1			1					
187	6	8	12	3								
197	16	4	18	3	1							
198	17	8	15									
199	18	39	106	30	2				1			1
200	19	11	70	24	6	4	4	6	1	2	2	2
201	20	26	19	3								
202	21	55	90	36	10	8	4	5	4	2	2	6
203	22	15	43	21	9	5	1	1	2	1	1	4
206	25		5	1								
207	26		8	9								
208	27	13	22	9	1	1			1			
Aug.												
218	6	4	17	3	1	1						1
219	7	17	81	35	13	5	4	4	2	3	2	1

evaluation tool. However, some insight into what would be required to evaluate a hail suppression program is gained. The main gap to proceeding with an evaluation is the availability of actual hail data. The radar data taken on a fairly regular basis are not a suitable substitute for hail data. If radar-echo intensity contouring were available, the radar data would be somewhat more useful.

The time of occurrence of maximum radar activity is shown in Table 2 along with the start and end times of radar film data. A reasonable estimate of maximum radar activity is 1600 MST. Thus, data collection in an evaluation program could be concentrated around this time.

Statistics of direction of echo movement are shown in Table 3 for 1978 and 1979. It is clear that the predominant direction of movement of radar echoes is from the WSW to the ENE. The typical duration is a half hour to an hour. With a speed of movement of 20 mph, the track length of an individual hailfall is probably less than 15 miles, probably more like 5 or 10 miles.

Therefore, the measurement of hail on the ground will be difficult, because of the small area affected by hail from any single cell and the short duration of the hailfall. Although high quality radar data can be used to estimate the occurrence of hail, the actual ground based measurement of hail appears to be necessary if an effective evaluation of hail reduction efforts is to be made.

Further examination of project radar data provides some information on where hail is most likely to be found. Statistics of radar echoes are shown in Fig. 5 for 1978 and 1979. The area covered by radar surveillance is divided into squares 12.5 mi. on a side. Half hourly radar maps are used in the compilation; each time an echo is found in a given square, a count is made. All counts for available data during the two summers are shown in the figure. A total of 349 overlays were used in this analysis.

Table 2. Radar data time intervals (1979).

Day	Time		
	Start	End	Maximum
145	1500	1600	1600
147	1500	2030	1830
148	1400	1640	1640
169	1200	1900	1600
172	1400	1830	1730
177	1430	1730	1700
183	1530	1630	1530
184	1930	2100	1930
187	1330	1500	1430
197	1430	1830	1700
198	1330	1700	1600
199	1230	1930	1500(1830)
200	1230	1900	1400
201	1300	1650	1445
202	1000	2000	1430(1700)
203	0600	1430	0900(1430)
206	1600	1630	1600
207	1400	1530	1500
208	1300	1630	1400(1600)
218	1530	1630	1530
219	1330	2100	1600
			1600

Table 3. Radar cell movement (1978,1979).

	Movement from:				
	S	SW	W	NW	N
No. of Days	1	18	17	2	0

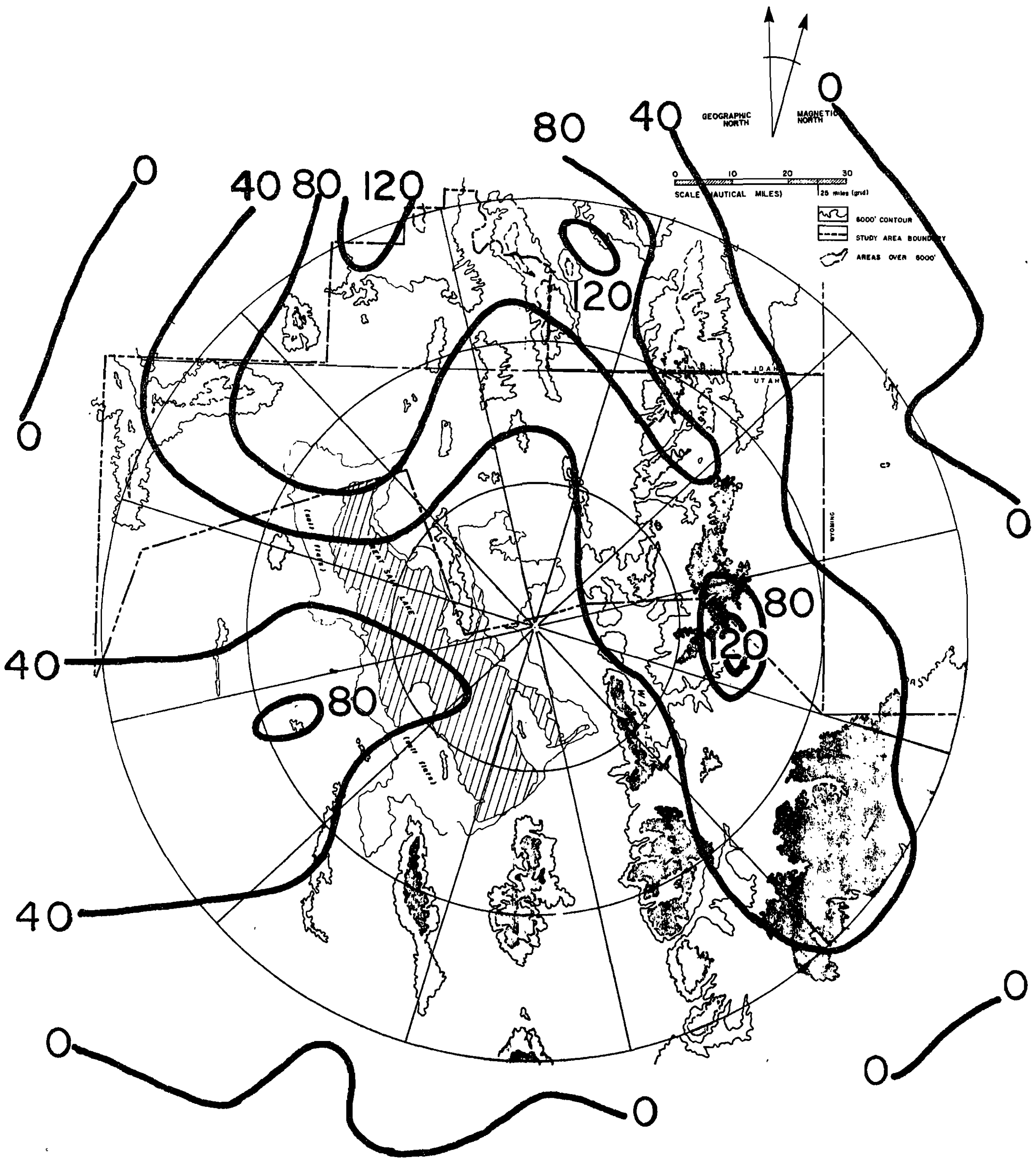

Fig. 5. Statistics of radar echoes from 349 overlays during periods of convection in 1978 and 1979. Contours indicate number of times an echo was found at each location during the combined sampling periods.

Several aspects of convective cloud formation as determined by radar are evident. Inspection of Fig. 5 reveals that beyond about 75 n. mi. the radar does not detect most clouds. Within that range echoes are generally found to be a maximum over the Wasatch Mountains, Raft River Range in NW Utah, and the mountains of Oneida County in Idaho. Also, another apparent maximum appears over the Great Salt Lake Desert, but this is probably an artificial maximum. That is, the band of lower values of echo counts to the north of this apparent maximum is due to a radar "blind" spot caused by the lower end of the Promontory Mountains.

In the southerly direction from the radar site, there appears to be a significant lack of echoes. At least part of this absence of echoes is due to the strong ground clutter from that direction. Also, in these two summers there may indeed have been fewer clouds in the region around Salt Lake City and to the southwest. Whether this pattern is a normal one or a short term anomaly is not known.

Within a range of about 25 miles of the radar, echoes are difficult to distinguish from the strong ground clutter, except at relatively high radar scanning elevations. Because most of the time the scanning elevation is 2 or 3 degrees, the in-close ranges have an apparent minimum of echoes.

Upon inspection of individual radar film sequences, it is evident that most of the time radar echoes are generated in the vicinity of mountains and then move downstream with the prevailing airflow. Because convective clouds may persist for an hour or two, the path of convective

clouds frequently is over the valleys. (It is noted that convective clouds are found over flat terrain and oceans, but in the presence of mountains convection forms more readily over them than elsewhere.)

To summarize, the radar in its present location gives coverage in a range between 25 to about 75 miles from the site. Outside these limits the radar coverage is weak. Also, in a narrow band to the WNW and a wider zone of about 60° azimuth to the south, the radar coverage is also weak. However, the viewing area of the radar does cover the target except for the extreme western portion.

4.0 EVALUATION APPROACHES

4.1 Interpretation of existing radar and precipitation data

The radar data discussed in the foregoing section might be used in an attempt to evaluate effects of seeding. For example, Henderson's 1977 report to the Utah-Idaho Weather Modification Corporation contains an evaluation based upon radar data. Maximum echo intensity, maximum echo height, maximum duration of precipitation, and area coverage were used in the evaluation. Seeded precipitation areas were compared with simultaneously occurring nonseeded precipitation areas adjacent to the target area. The intensity and height of seeded areas ranged from 2 to 12 percent greater than nonseeded echoes in adjacent areas; the duration and area coverage in seeded areas ranged from 43 to 58 percent greater than nonseeded echoes in adjacent areas. While it is possible that such differences are due to seeding, it is also just as possible that seeding was carried out in the target area just because echoes there were of

hail producing type, or were thought suitable for precipitation enhancement. Such systematic differences may well exist in the type of comparisons made in that evaluation. Certainly there is no question that the project personnel chose clouds to seed according to their criteria. But the use of such "uncontrolled" data for evaluation purposes is highly questionable. It is now rather well known in the State of Utah that evaluation of the winter project is difficult indeed. With the very large space and time variability of cloudiness in summer storms and the rather extreme variability of hail, evaluation of seeding effects is likely to be more difficult than with wintertime seeding. However appealing the evaluation described above appears, we are compelled to take the position that based upon measurements made during the project alone, it is not known whether there is a seeding effect on hail suppression at all. Of course, it is hoped that hail is being suppressed, but that is based upon the general knowledge of hail-suppression technology and not an evaluation of this project specifically.

Actual evaluation of this project must utilize similar inputs as is done for evaluations of winter projects. That is, either historical data in the target area and in an outside area, or a randomized type seeding program would be required to make an evaluation. Not only is such radar data unavailable, but hail measurements are totally absent. Only a small amount of actuarial data exist over a period prior and during the project. A preliminary analysis by Hubbard (1977) indicated that hail suppression efforts could be worthwhile. Further review of the data indicates emphatically that no useful evaluation can be made from that data.

In order to make a reasonable evaluation of hail suppression or precipitation enhancement, measurements of these quantities are needed in 1) seeded clouds and 2) in unseeded clouds drawn from the same population, or in other words, unseeded clouds of the same type and strength as the seeded ones if they had been left unseeded. As previously indicated, these measurements could in principle be obtained in two ways; one by use of historical data, the other by use of randomization during the project operation.

Because there is an absence of historical data for hailfall, only some form of randomized seeding will permit an evaluation of this particular project. In addition, direct measurement of hail will be required. While radar data may be used as a covariate to reduce some of the uncertainty of hailfall occurrence and intensity, radar data should not be used as a substitute for hail data. This is so because of a substantial uncertainty or variability in the relationship between radar echoes and hail.

Inasmuch as the northern Utah summer project for hail suppression and precipitation increase is a nonrandomized one, a basic impasse arises in any attempt to evaluate hail suppression. Concerning evaluation of precipitation change, some historical data are available. An evaluation using such data was carried out by the Division of Water Resources in 1978. Thus, to evaluate hail suppression we must turn to an area adjacent to the target area wherein randomization is used, and hail measurements are made. Such an area should not be affected by nonrandomized seeding in the main target.

A test area is set up for evaluation of hail suppression using randomization. The evaluation requirements are summarized in the following list.

1) Area is adjacent or near target area.
2) Randomization is used.
3) Hail measurements are made in test area and in a limited area within the target area.
4) Seeding in target area does not affect test area.
5) Test area is in viewing range of project radar.
6) Optimum choice of test area is downwind (ENE) of a mountain range.

If all of these conditions could be met (#6 is optional), then the basic requirements for an effective, credible evaluation would be satisfied. Probably the best area meeting the above requirements is the region near the Newfoundland and Hogup Mountains west of the Great Salt Lake. Unfortunately, there is a large "Restricted Area" around and to the south of these mountains. Another good location would be in the vicinity of Wendover, but in this case the present radar location is about 90 n. mi. ENE of Wendover. At this distance the radar is nearly out of viewing range and definitely out when it is recognized that storms generally approach from the WSW.

Still another possible test site would be in the vicinity of Morgan (about 30 miles NE of Salt Lake City). However, seeding required upwind of the test target would be in the vicinity of Salt Lake City and its associated air traffic. It is not likely that seeding could be carried out in this location in a similar way as for the main target area.

5.0 RECOMMENDATIONS

We believe that with the present project arrangement, there is no suitable test area which meet the requirements for an effective evaluation. Even with adequate radar coverage the only suitable test area is in the general vicinity of Wendover. Consequently, we recommend that one or more actions be taken as follows:

1) No evaluation of the effectiveness of the hail suppression project in northern Utah be attempted (and that its merits be accepted in accordance with current practices).
2) A new radar be installed with a capability of constant level (intensity) contouring.
3) A radar site be relocated to the west of the Great Salt Lake so that the radar is more centrally located with respect to seeded clouds and that the radar location is such that an evaluation with limited randomization is possible.
4) A second radar with constant level contouring be installed, so that the two radars are placed optimally to cover the target area (possibly expanded in Idaho) and a test area.[1]
5) Hail measurements at the ground are made both in the test area and in a limited area within the target area.

---

[1] The cost of upgrading an existing 5 cm Enterprise radar WR-100-2/77 with interface, digital video integrator processor (DVIP) is $12,000; to produce constant level profiles of echo intensity with complete system including computer and color TV display is $90,000. A new 5 cm radar is $60,000 and $90,000 additional for the constant level contouring.

6.0 REFERENCES

Utah Division of Water Resources, 1978: Northern Project Evaluation. Report to Technical Advisory Committee. 19 pp.

Hubbard, K. G., 1977: Climatology of Hailstorms in Utah--The Hail Suppression Potential by Cloud Seeding. Utah Water Research Laboratory Report PRWG-204-1, Logan, Utah 84322. 22 pp.

Henderson, T. J., 1977: A Summary of Cloud Seeding Activities Conducted Over the Counties of Box Elder, Cache and Rich in Utah and Oneida County in Idaho during the Period March-September 1977. Report for the Utah-Idaho Weather Modification Corp., Cornish, Utah 84308. 47 pp.