"REVIEWED"

SELECTED ANALYSES OF A UTAH/NOAA COOPERATIVE RESEARCH PROGRAM CONDUCTED IN UTAH DURING THE 1982-83 WINTER SEASON

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1. INTRODUCTION

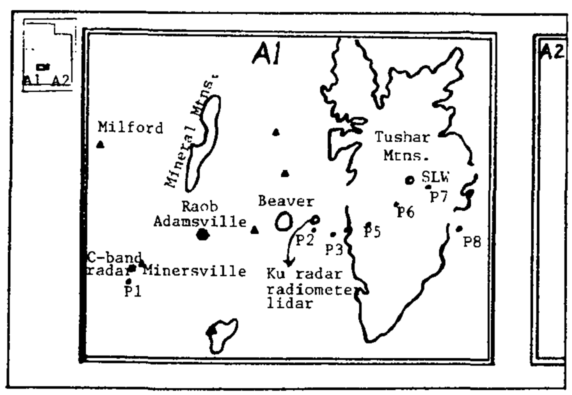
A major weather modification research program was conducted in south central Utah during the 1982-83 winter season. This research was conducted in a "piggyback" fashion upon an on-going operational program being conducted in Utah. The goal of the operational weather modification program in Utah is to increase higher elevation snowpack in much of central and southern Utah to provide augmented streamflow to a variety of irrigation water users.

The piggyback research program was funded by the National Oceanic and Atmospheric Administration (NOAA) as part of an ongoing program designed to evaluate certain state and/or locally supported operational weather modification programs. Such a cooperative research program was first suggested by a special committee appointed by the Department of Commerce in 1976 to address national weather modification policy issues (Cleveland, **et al.**, 1978). The on-going operational program in Utah was selected as one program on which piggyback research would be supported by NOAA. An earlier year of research was funded by NOAA and conducted in the Tushar Mountains region of south central Utah during the 1980-81 winter season.

NOAA awarded a contract to Colorado State University (CSU) in 1979 to develop a design for the piggyback research to be conducted in Utah and North Dakota (Grant, **et al.**, 1982). The research conducted in the 1980-81 and the 1982-83 winter seasons was based upon the recommendations of this earlier CSU design work. This work was conducted in the Tushar Mountains area near Beaver, Utah. A summary of the research field activities has been prepared by NAWC (Swart and Griffith, 1983). NAWC also was awarded some contracts to perform subsequent analysis of some of the data collected in the 1982-83 field program. Other contracts were awarded to other groups to perform different types of analysis. All contracts, both for field activities and subsequent data analysis activities, have been administered by the State of Utah, Division of Water Resources operating under a cooperative agreement with the NOAA-ERL offices in Boulder, Colorado. This paper summarizes the analysis activities of NAWC as related to the 1982-83 field data collected in the Tushar Mountains region. A more in depth technical report has been prepared describing the various analyses (Griffith **et al.**, 1983).

2. DATA ACQUISITION NETWORK AND RESEARCH AREA

The area of intensive research is shown in Figure 1. Table 1 lists all field equipment, suppliers, and operators. The designated primary area (A1) is approximately 40 miles E-W by 30 miles N-S, extending north to south from the northern end of the Mineral range to 10 miles south of Beaver. West to east it encompasses the area from 10 miles west of the Mineral range to 10 miles beyond the crest of the Tushar Mountains. An additional area (A2), 10 miles further east, was used for sampling snow for chemical determination of transport of seeding aerosols and their possible involvement in the precipitation process.



▲ AgI Generator sites
P1 Raingage sites

Fig. 1 NOAA/Utah research equipment locations, 1983.

Table 1 Major Project Equipment.

Type	Supplier/Operator
Ku-band radar	CSU
Dual frequency microwave radiometer	NOAA-WPL/NAWC
C-band radar	WMI
Rawinsonde	UDWR/UDWR
Polarized lidar	Univ. of Utah/U of U
Precipitation gages	UDWR/NAWC
Supercooled liquid water (SLW) detector	AI/NAWC
Cloud physics aircraft	CIC/CIC
AgI generators	NAWC/NAWC
Aerosol generators (indium)	NAWC/NAWC

3. RESEARCH GOALS AND FIELD OPERATIONS

The research program was conducted during the two month period of January 15 - March 15, 1983. The primary goals of the research were to examine: 1) the spatial and temporal distribution of supercooled liquid water and 2) the delivery of seeding material.

There were 20 storm periods that were observed during the two month intensive field period. A storm consisted of any occurrences of middle or lower cloud cover over the Tushars. Some of these storm periods produced little or no precipitation in the research area. Storm periods ranged from 6 to 80 hours in length with an average of 23.8 hours. Data collection during these storm periods was highly successful for most of the instrumentation listed in Table 1. Consequently, a significant data set was acquired upon which a variety of analyses could be performed.

4. NAWC ANALYSES OF THE 1983 DATA

NAWC performed a variety of analyses utilizing data collected by a subset of the total instrumentation available from the research period. The data sets NAWC utilized were acquired from the following: 1) recording precipitation gages, 2) the C band radar, 3) the K band radar, 4) the Adamsville rawinsonde, 5) the dual frequency microwave radiometer, 6) the icing rate meter, and 7) geostationary satellite and other synoptic weather data. Results from these analyses should be tempered by the realization that they are based upon two months of data. Additional data from other years would refine the climatological information described in the following sections. One of NAWC's primary analysis tasks was to classify the Minersville 5 cm weather radar echo patterns into specific types. These types were patterned after an earlier classification scheme developed by NAWC under contract to the Bureau of Reclamation for the Sierra Cooperative Pilot Project (Sutherland and Kidd, 1978). This classification scheme was further refined by Electronic Techniques Inc. on subsequent SCPP contractual work (Huggins, 1981). This scheme came to be identified by the acronym PETS which stands for Precipitation Echo Types. This designation is also utilized in this paper to represent different radar echo patterns.

The half-hourly Plan Position Indicator (PPI) slides and the 16 mm movie films from the 5 cm radar site near Minersville along with the radar operator logs which contained preliminary PET listings at 1/2 hour intervals were used to establish a PET catalog. PET's initially included area echoes, bands, cells, orographic, and none (no echo). The PET catalog was developed for both the Tushar experimental area (roughly the area east of Beaver) and the remaining region of the scope. The radar was operated on the 50 nm range and at a 4^{o} elevation angle (to overshoot ground clutter) during the research period.

After the catalog had been completed, the cell and no echo PET's were subdivided. The two cell categories were embedded and emergent, the difference being whether or not the observed echo tops exceeded the Adamsville rawinsonde-estimated cloud tops. No echo PET's were separated into sub-classes dependent on the occurrence of precipitation at any of the five precipitation gages between Beaver and Mt. Holly (gages P2 to P6 on Fig. 1).

Table 2 provides the hours of PET occurrence over the Tushar experimental area. In general terms, the NP PET (no echo but Tushar precipitation) was the most prevalent. It occurred during 18 of the 20 storms and accounted for 50% of all PET's. The next most frequent PET was cells, which occurred during 15 storms and totaled approximately 25% of all PET observations. No echo (and no precipitation) PETS and area PET's followed, each occurring in about half the storms and about 12% of the time. Bands were very infrequent, occurring during only two storms. Orographic echoes also occurred during only two storms. These results suggest that the no echo but Tushar precipitation PET is probably a shallow orographic cloud situation that was not deep enough

Table 2. Hours of PET occurrence in Tushar experimental area for each storm.

Storm #	AREA	BAND	TUSHAR CELL	ORO	NO PRECIP	PRECIP*	TOTAL
1	4 hrs.	0	9 hrs	0	7 hrs	9 hrs.	29 hrs.
2	0	0	1	0	1	1	0
3	0	0	2	0	0	0	2
4	5	0	1	0	3	0	9
5	3	1	4	0	7	1	16
6	3	0	0	0	1	1	5
7	0	0	0	0	17	0	17
8	0	0	6	0	10	0	16
9	2	0	4	0	1	0	7
10	4	0	3	0	3	1	11
11	0	3	0	1	6	0	9
12	0	0	3	0	1	0	4
13	0	0	3	0	1	0	4
14	0	0	0	0	19	0	19
15	0	0	1	0	2	1	4
16	0	0	0	0	0	2	2
17	0	0	2	1	17	5	25
18	2	0	2	0	1	0	5
19	0	0	5	0	0	1	6
20	2	0	3	0	7	3	15
TOTAL	25 hrs	4 hrs	49 hrs	2 hrs	104 hrs	25 hrs	208 hrs
%	12	<1	24	<1	50	12	

* - Radar echoes elsewhere

to be observed by the 5 cm radar operating at a 4° elevation angle.

4.1 Recording Precipitation Gage Analyses

The recording precipitation gage data were digitized in half hourly precipitation amounts for seven gages. The eighth gage installed for the project provided unreliable data during the field program. Statistics were prepared on storm amounts by gage location. An obvious orographic contribution to storm precipitation was documented over the barrier as depicted in Figure 2.

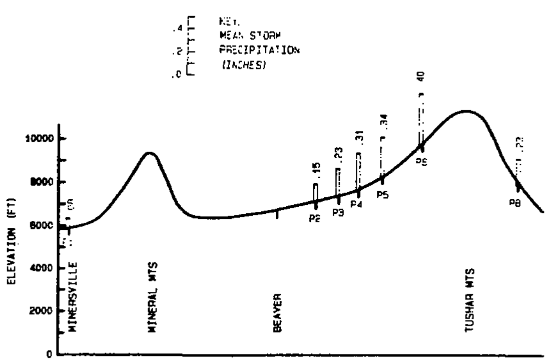


Fig. 2 Mean storm precipitation by gage location (Jan. 15-Mar. 15, 1983).

Precipitation gage data for sites P2 - P6 and P8 were accumulated by PET. The total amount of precipitation that occurred at each site (disregarding the missing data at some of the sites) was used to calculate the percentage of the total precipitation observed during the two month research period by PET. Table 3 provides the results of this summarization. From this figure it is seen that the area PET (A) produces more of the total accumulation in the foothill region of the Tushars and in the lee of the Tushars. Cell precipitation is an important contributor in higher elevations. The no echo precipitation PET (NP) contributed the highest percentage of the two month accumulation in the foothill to mid-elevations.

4.2 Supercooled Liquid Water Analyses

Several different types of supercooled liquid water analyses were performed. A series of time cross-sections utilizing parameters calculated from the Adamsville rawinsonde data were prepared. Indications of liquid water from the radiometer and the Mt. Holly ground based icing rate meter (a Rosemount probe) were related to these cross-sections. Some tentative conclusions were drawn from this analysis which are as follows:

o In stable atmospheric conditions, liquid water is usually associated with a water saturated cloud as indicated on the Adamsville raob with the base of this cloud below the mean crest height and moderate to strong upslope windflow.

Table 3. Precipitation amounts and percentage contribution by PRT for the 1983 research period.

PET	P2		P3		P4		P5		P6		P8	
	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%
A	.47	31	.76	32	.46	21	.83	23	.73	23	.68	45
B	.01	0	.25	11	.20	9	.43	12	.39	12	.22	14
Cell	.27	18	.71	30	.59	27	1.07	29	1.25	39	.45	30
NP	.79	51	.66	28	.93	43	1.34	37	.83	26	.17	11
Total	1.54		2.38		2.18		3.67		3.20		1.52	

o In unstable conditions, with a low level water saturated layer, liquid water seems to occur regardless of wind flow up the barrier.

o Liquid water often occurs with precipitation.

o There is a correspondence between radiometer and ground based indications of liquid water approximately 75 - 80% of the time.

Multiple regressions were developed to predict Mt. Holly liquid water amounts from various Adamsville rawinsonde parameters. The highest correlated parameters were the wind component normal to the barrier at crest height (a positive correlation) and some measure of atmospheric stability (a negative correlation). These results, although the correlations were not exceptionally high, lend support to the earlier tentative conclusions listed above.

A limited direct comparison of the indication of liquid water from the radiometer versus the Mt. Holly measurements was made for two storm periods. Figure 3 provides a plot of the data for the two periods. This comparison indicates that liquid water appears to be observed at the same time by both systems indicating that the liquid water may be distributed through a relatively sizable region of the clouds passing over the Tushars.

The radiometer indicated liquid water was a common component of most storms especially over the Tushars. An examination of the occurrence of liquid water over the Tushars during observation periods from the radiometer indicated liquid water was present 69 percent of the time in area, cell and no echo but precipitation PETS. Liquid water was indicated to occur most frequently in no echo but precipitation PETS. This observation would indicate a potentially seedable event occurs frequently in the Tushars consisting of a shallow orographic cloud.

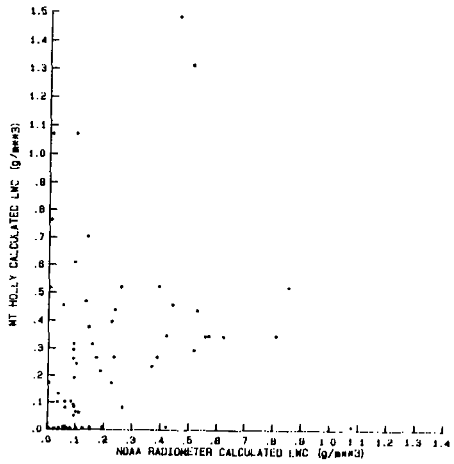


Fig. 3 Comparison of calculated NOAA radiometer vs Mt. Holly liquid water contents (gm^{-3}).

4.3 Guide Modeling

NAWC, in it's work on the Bureau of Reclamations' Sierra Cooperative Pilot Project (SCPP) in California, has developed several computer models to assist in the real-time decision making and subsequent analysis of the SCPP research program. These models have the potential of more general application to other weather modification research programs. The Utah Division of Water Resources contracted with NAWC to apply some of these models to the 1983 Utah/NOAA data analysis effort. Two different versions of GUIDE were utilized in this work. One version deals with the orographic prediction of seeding plume dispersion, interaction with the cloud microphysics, and subsequent predicted fallout locations and differences between natural and seeded precipitation. The other version deals with the prediction of the natural water balance in stable orographic clouds (called OROGWATER). Both versions of the GUIDE model have been described by Elliott **et al.** (1983).

The results of the orographic seeding modeling will be discussed first. Seeding occurred during the research period from January 15 - February 8, 1983. Seeding was terminated on February 9th due to above normal snowpacks and relatively full reservoirs. Seeding decisions during this time were made on a 2:1 seed, no seed randomized basis. Only those storms or storm periods that met NAWC's seeding criteria were randomized.

Consequently, there was not a large amount of seeding conducted during the research period. Of the seeding that was conducted, the GUIDE model indicated limited success in terms of enhanced snowfall at ground level. The primary problems were warm temperatures which restricted silver iodide nucleation and light winds which limited transport of the seeding material. An example of a GUIDE predicted plume transport and precipitation fallout case is provided in Figure 4.

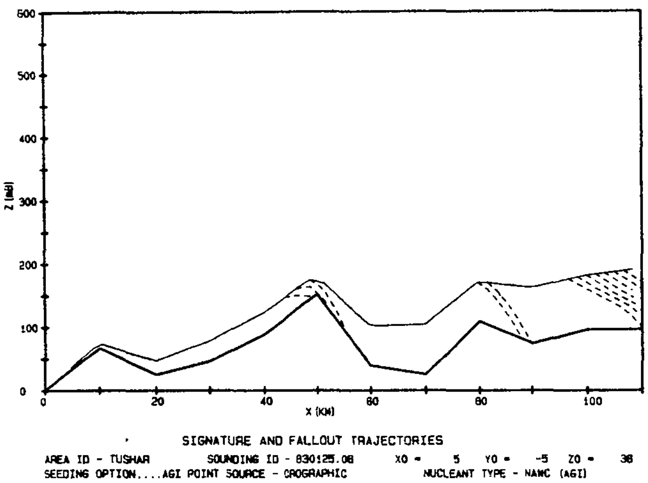


Fig. 4 GUIDE X-Z plot from generator site 17-11 for January 25, 1983, 0600 Z.

The GUIDE modeling indicated an advantage of using high elevation generator locations in certain atmospheric situations versus lower elevation locations. Using activation curves from Colorado State University for a NAWC manual generator utilizing a silver iodide-ammonium iodide-ammonium perchlorate-acetone solution, the GUIDE model indicated a significant advantage in using this solution over that currently used (silver iodide-ammonium iodide-acetone), primarily due to the higher number of active nuclei at warm temperatures (i.e., -4 to -10°C).

The GUIDE orogwater predictions of liquid water indicated an accumulation zone upwind of the Tushars at fairly low elevations for five priority simulation cases. This model calculates the water balance between liquid water and precipitation rates. The predictions of these parameters were compared to liquid water observations from the radiometer and icing rate meter and ground level precipitation. This comparison is depicted in Figure 5. From this figure it is seen that the trends were predicted well but that the relative magnitudes of liquid water and/or precipitation were generally underpredicted.

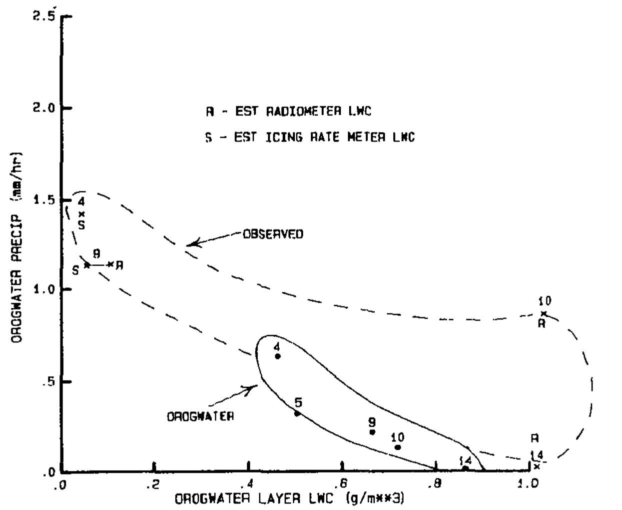


Fig. 5 Comparison of physical measurements of precipitation rate and liquid water vs OROGWATER prediction. (Numbers refer to storm number.)

4.4 Climatological Representativeness of the 1983 Research Period

A study was conducted of the climatological representativeness of the data collected for the 1983 intensive field period. This study was conducted because of a perception that the field period was dominated by upper-level split flow which resulted in fast moving, relatively weak and relatively warm storms. The main indications from this study, which was based upon precipitation and rawinsonde observations for the research period were:

- o wetter than normal.
- o warmer minimum temperatures than normal.
- o there were more storms of short duration and fewer storms of longer duration (> 8 hours) than normal.

- higher than normal heights of constant pressure surfaces on the Ely and Las Vegas rawinsondes when clouds present.
- winds more southerly than normal at Ely and Las Vegas.
- higher than normal freezing levels at Las Vegas.

5. CONCLUSIONS

Various analyses of data collected for a two month period in south central Utah have provided a better understanding of the structure and potential seedability of winter storms. Most of the storm periods observed during the period exhibited at least some periods when supercooled liquid water was present. A storm classification scheme indicated the relative importance of a shallow orographic cloud. This particular type contributed a substantial portion of the research period precipitation and also contained significant periods of supercooled liquid water occurrence. A model of the effectiveness of seeding indicated limited success during a portion of the research period. Limitations to effectiveness included relatively warm airmass temperature, light winds, and low level inversions. High elevation generators were generally indicated to be more effective than low elevation generators. A comparison of the two month research period with longer term records indicated several departures from what could be referred to as "normal" conditions. Collection and analysis of similar data from future seasons would increase the representativeness and therefore usefulness of the climatological analyses presented in this paper.

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