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STORM TYPING AND SEEDABILITY IN OROGRAPHIC SNOW/RAIN AUGMENTATION IN THE SIERRA NEVADA OF CALIFORNIA*

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Abstract. The seedability of winter-time storms depends on several meteorological criteria, three of the most important being storm size, temperature, and wind flow characteristics. A storm typing scheme was devised using readily available on-site radiosonde temperature and wind data.

Data from several years of cloud seeding for snow pack enhancement in the Sierra Nevada of California indicate that moderate southerly storms predominated over moderate westerly systems in both seedable and seeded categories.

The lack of seedability was closely related to wind flow characteristics: high wind speeds associated with many of the westerly storms, and some of southerly cases, precluded targeting. Also important in seedability was the size of storm systems: many fast moving westerly cases bring only very small amounts of precipitation over a short period of time. Wind direction and air mass temperature were only third and fourth in importance in the lack of seedability.

1. Introduction

The establishment of storm seedability is extremely important, and depends on several meteorological criteria, including storm size, temperature, and wind flow characteristics. A storm typing scheme, using readily available radiosonde temperature and wind data, allows for easy classification of winter-time storms that affect the Sierra Nevada.

Data from eight years of cloud seeding activity (1977-85) has been summarized for a ground-based orographic snowpack enhancement project undertaken by the Sacramento Municipal Utility District in the Sierra Nevada of California southwest of Lake Tahoe. (Fig. 1).

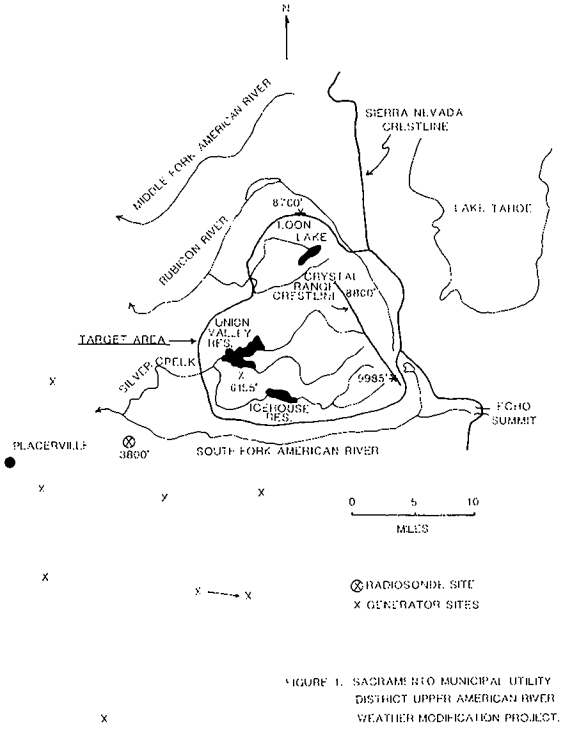

FIGURE 1. SACRAMENTO MUNICIPAL UTILITY DISTRICT UPPER AMERICAN RIVER WEATHER MODIFICATION PROJECT.

This study indicates that moderate southerly storms predominate over moderate westerly systems, in both seedable and seeded categories. Other classes of colder and warmer storms were few. Lack of seedability was closely related to wind flow characteristics: in many westerly cases and some southerly cases, high wind speeds precluded targeting. Of much less importance in seedability was the size of storm systems, with many fast moving westerly cases bringing only very small amounts of precipitation over a short period. Wind direction and air mass temperature were less important in establishing seedability.

2. Storm Typing and Seedability

A storm typing system is useful only if data needed for it are readily available and pertinent. Most cloud seeding projects have on-site or near on-site radiosonde information, so that air masses can be monitored for seedability. Data from these upper air soundings is easily obtainable in real time for forecasting in weather modification. Such information is also very useful after the fact in storm analysis and in establishment of seeding effectiveness. A storm typing system (Table 1) developed by the author for wintertime storms in California and Nevada was discussed in an earlier article by Hannaford & James (1982).

Table 1. California and Nevada Winter Storm Types

Level (mbs)	Wind Direction
500	---
700	-235 +
	SOUTH WEST
850	-230 +

*This paper is similar to one presented at the First European Conference of the Weather Modification Association, at Clermont-Ferrand & Toulouse, France, Sept. 1985.

Table 1. Continued

Level (mbs)	Temperature (C)		
500	-25	-14	
	COLD	MODERATE	WARM
700	-10	0	
850	---	---	

(Temperature at 500 mb takes precedence over that at 700 mb when cloud top is at or above 500 mb. Wind at 700 mb takes precedence over wind at 850 mb.)

Based on wind flow and temperature characteristics at three levels: 850, 700 and 500, storm systems that affect the Sierra Nevada were divided into six categories, southerly or westerly and warm, moderate and cold. The temperature and wind direction criteria were chosen from study of hundreds of Sierra Nevada storm systems, and a review of previous published work by Krick (1943), Williams, Griffith and Smith (1970), and others.

Even though storms were classified beginning in 1968, for quality control purposes only the last eight years of data are utilized in this study. Table 2 indicates that during the eight year study period (1977-85) moderate southerly storm systems easily predominated over the other five categories in both seedable and seeded cases.

seedable storms with 12 each. During 1980-81, of the 12 seedable cases 11 were classified as moderate southerly. The 1982-83 and 1983-84 seasons were the only ones with more seedable westerly storms than seedable southerly ones.

Of the seeded cases, 64% were moderate southerly storms, only 28% moderate westerly, with the other four storm types combined making up only 8% of the seeded storms during 1977-85. (This project operated on a 3 of 4 randomization during most of the eight year period.)

Again, the two-year period 1977-79 stands out as having the most seeded cases, with 37, or 47% of the eight year total. Moderate southerly storms made up 70% of the seeded systems during this two year period. An outstanding winter season was 1980-81 in that all eight seeded storms were moderate southerly. The least productive year was 1983-84, when only two storms were seeded, because it was a very wet year and the project suspended operations much of the time. During the eight year period, 74% of the moderate southerly storms that were seedable were seeded, while only 43% of the seedable moderate westerly cases were treated.

3. Causes for Lack of Seedability

In the 300 cases over the 1977-85 period, the overwhelming cause for lack

Table 2. Seedable and Seeded Storms, Southerly and Westerly Breakdown, Upper American River Project, Sierra Nevada, California, 1977-85.

	Seedable Storms			Seeded Storms		
	Moderate Southerly	Moderate Westerly	Other	Moderate Southerly	Moderate Westerly	Other
1977-78	15	14	1	13	6	1
1978-79	13	4	2	13	4	0
1979-80	7	7	1	5	3	1
1980-81	11	1	0	8	0	0
1981-82	5 1/2	4 1/2	3	4 1/2	1 1/2	1
1982-83	7 1/2	8	1 1/2	2 1/2	4	1/2
1983-84	3	5 1/2	3 1/2	0	1	1
1984-85	6	5	2	4	2	2
8 Year Totals	68	49	14	50	21 1/2	6 1/2
			131			78

PERCENT SEEDED - SOUTHERLY 74%, WESTERLY 43%

Of the 131 seedable storms in the period of study, 68 (52%) were in the moderate southerly class, and 49 (37%) moderate westerly. The other four storm classes had only 14 of the 131 storms. The two years following the drought of 1975-77 had the most seedable cases, with 30 seedable storms in 1977-78 and 19 in 1978-79. This two-year total of 49 seedable storms was 37% of the eight-year total of seedable storms. During the two winters 28 of these storms were in the moderate southerly class (57% of the two-year total), while only 37% were moderate westerly. The 1980-81 and 1983-84 winter seasons had the smallest number of

of seedability was due to strong winds that precluded targeting (Table 3).

Table 3. Percent of Time That Various Factors Caused Lack of Seedability, Upper American River Project, Sierra Nevada, California, 1977-85.

Winds Too Strong for Targeting	62%
Small Size of Storm	14%
Wrong Wind Direction	9%
Too Warm	8%
Too Cold	7%

Almost two-thirds (62%) of the unseedable storms were such because of strong winds during most of their duration. Most of these (2/3) were in the moderate westerly category, usually fast moving due to jet stream proximity, with little troughing to slow them down, they moved past the area after leaving little precipitation.

The second most important reason for lack of seedability, albeit a poor second, was small size (14% of the cases), providing less than two or three tenths of an inch of precipitation in the Project Area. Again, over half of these were moderate westerly cases. Little troughing and a lack of vertical lift, usually results in light amounts of precipitation.

Three minor causes for non-seedability were wrong wind direction, too warm an airmass, or an airmass that is too cold, Each of these reasons occurred in less than 10% of the cases. With fixed ground generators, a westerly, south-westerly, or southerly wind flow is necessary to insure seedability. During only 9% of the time was this criterion not fulfilled. Most of the "too warm" cases occurred in the early portion of the seeding season (October and early November), and most of the "too cold" systems in the spring when hail is a danger in the unstable airmass over the fruit growing area near, but upwind from the Project Area.

4. Conclusion

A storm typing method requiring radiosonde temperature and wind data was useful in establishing seedability of winter time orographic systems that affect the Sierra Nevada of California. Moderate southerly storms dominated over other systems in both the seedable and seeded categories. Most (2/3) of the lack of seedability was caused by wind speeds too strong to allow proper targeting from fixed ground based generators.

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