

NORCAL-WMP: 13 FLIGHTS ON 7 DAYS, 1978

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1. CHRONOLOGY

Thirteen seeding flights on seven days, beginning 11 JAN 1978 released a total of only 1.62 kg of AgI before the Northern California Weather Modification Project (NORCAL-WMP) was suspended on 6 FEB because of heavy rains, and then terminated by its sponsor, the California Department of Water Resources (DWR). This report summarizes a detailed study, flight by flight, of this very limited operation (Court, 1978). Precipitation immediately downwind from the seeding was slightly greater than at surrounding gages, although the actual amounts were too small for any practical significance.

On 8 DEC 1977, when a third successive dry winter seemed imminent for California, the DWR sought bids on a program, supported by federal drought-relief funds, "to produce water for storage" in the basins above Oroville, Shasta, and Engle lakes and reservoirs, and generally over most of north-eastern California. From five bidders, Atmospherics Incorporated (AI) of Fresno was selected to dispense AgI from 44 ground generators and three aircraft, operating from Red Bluff Airport and directed by a meteorologist using radar and network weather reports (Atmospherics Incorporated, 1978). But slowness in establishing communications, and in approving insurance coverage, delayed authorization of seeding until 10 JAN 1978.

Meanwhile, a succession of storms raised seasonal precipitation from 50% of average in mid-December to above average by the time of the first seeding flight, on 11 JAN (Fig. 1). These averages are for Brush Creek and Shasta Dam, two recording raingages used routinely at the Federal-State Flood Forecast Center in Sacramento to characterize precipitation over the Feather and Upper Sacramento River basins, respectively. The averages cited here are for the previous 16 years, found in a separate study (by Martha Berg, graduate student) to be adequate predictors of the 17th year's precipitation. After six more flights on three days (13, 14, 15, JAN) and six hours' operation on 14 JAN by two of the four ground generators thus far installed, at 1320 PST on Sunday 15 JAN all operations were ordered suspended. Many rivers, especially the Eel, Yuba and Sacramento, were rising rapidly, and some flooding had begun.

Seeding flights are indicated in Fig. 1 by solid lines showing the amount of silver iodide dispersed on each; ground generator output is shown by dashed lines. The last 10 days of January were dry, except for light rain on the 22nd, and the project suspension continued. Meanwhile, on 26 JAN a strawberry grower near Shasta requested no rain for three weeks. The next day the almond growers' association promised a map of areas not to be seeded.

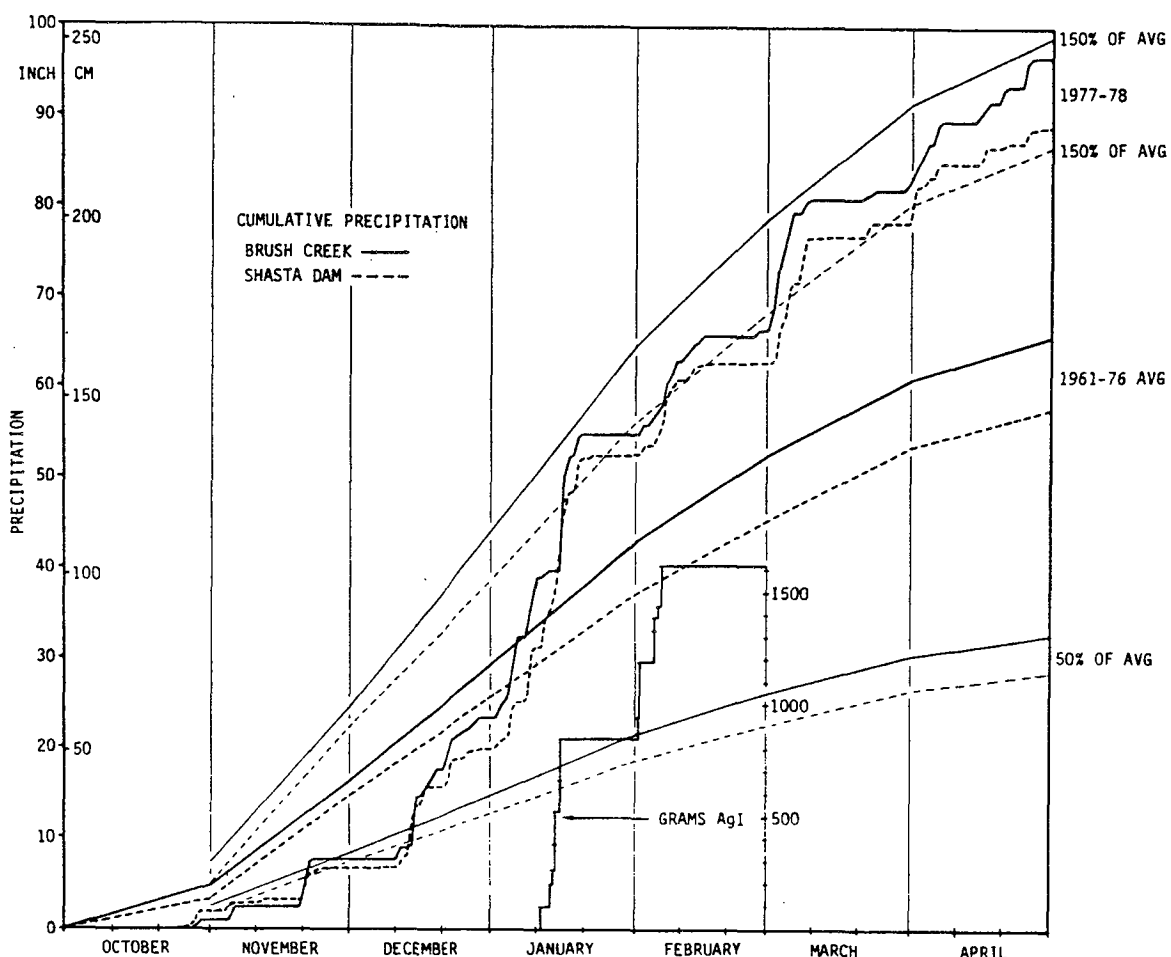


FIGURE 1. Cumulative precipitation, 1977-78, at Brush Creek and Shasta Dam, compared to 50%, 100%, and 150% of 16-year average.

On the 30th, Atmospherics Incorporated was given formal notice of cancellation by the end of February.

As a seedable storm approached on Wednesday, 1 FEB, the suspension was lifted to permit seeding over the Feather Basin, because Oroville Reservoir was not yet full; most other reservoirs (except Engle on the Trinity) were either full or expected to fill when snow melted. Although seeding of Engle by ground generators was specifically authorized on 2 and 3 FEB, no generator had been installed there and none of the 13 flights was over or upwind of it.

Two seeding flights were made over the Feather on the 1st, a flight on the 3rd found only broken clouds and didn't seed. Three flights on the 5th covered the Feather and the far northern and northeastern portions of the target, and two ground generators south and east of Redding were operated for six hours each.

Table 1. Times, consumption, temperatures, and winds of flights, and ground generator output.

DATE (1978)	SEED TIMES PST	AgI GMS	ALT FT MSL	T °C	WIND DEG/KTS	ROAB* TIME, PST	CLOUD TOPS FT MSL	°C
11 JAN	1310-1411	100	10,000	-7	240/30	B/04,16	10K,15K	-6,-16
13 JAN	1655-1748	100	11,000	-6	220/35	B/16	NR	
14 JAN	G1030-1630	120x2						
	1100-1154	60	11,000	-7	190/35	S/10	NR	
	1435-1544	120	11,000	-7	185/42	S/13;B/16		
	1442-1615	140	11,000	-7	190/45	S/16;B/16		
15 JAN	1036-1215	140	11,000	-8	210/42	S/07;A/07		
	1050-1310	190	11,000	-8	210/40	A/07;A/15		
1 FEB	1410-1444	100	11,000	-9	255/28	B/16;S/16	15K,18K	-14,-21
	1621-1753	240	11,000	-9	255/28	B/16;S/16		
5 FEB	0711-1022	140	11,000	-8	190/50	S/10	15K,20K	-15,-26
	0735-0807	60	11,000	-8	190/50	S/07,10		
	G0930-1230	60x2						
	1350-1700	50	17,000	-18	236/35	A/2230		
6 FEB	1200-1300	90	17,000	-20	270/50	A/2230	NR	

* B = Butte County, A = Lake Almanor, S = Sheridan

NR = no report, G = ground generator

At 0730 on Monday 6 FEB limited seeding was authorized, and one plane flew over the headwaters of the Feather River and beyond. But by noon more water was being released from Shasta Dam, and seeding was suspended. The next day, with continued releases from Shasta causing flood warnings on the Sacramento, and Oroville Reservoir forecast to fill within two weeks even without further precipitation, and 3 more inches of precipitation expected that day over the Sacramento and Feather Basins, the project was terminated forthwith.

Thirteen flights on seven days had dispersed 1620 grams of silver iodide, and four ground generators, operated two at a time on two days, emitted 360 grams more, for a grand total of 1890 grams. Only 18 of the planned 44 generators had been installed.

2. ANALYSES

Three other weather modification projects, and one experiment in the tracing of AgI, offered possible overlap into the area of NORCAL-WMP. Fortunately, none of the projects operated either at the same time or close enough to NORCAL-WMP to cause concern. They were:

1. Lake Almanor cloud seeding program of the Pacific Gas and Electric Company, just southwest of the center of NORCAL-WMP.
2. Upper American River project of the Sacramento Municipal Utility District (SMUD), far southeast of NORCAL-WMP but in strong southerly storms possibly affecting its southernmost part, the Yuba Basin.
3. Northern California Precipitation Enhancement Program (NCPEP) to alleviate drought in six counties north and west of San Francisco Bay, and hence possibly reaching the Sacramento Valley portion of NORCAL-WMP.
4. Sierra Cooperative Pilot Project of the Bureau of Reclamation, as part of which silver iodide was released at the ground and traced by aircraft.

Between 11 to 15 JAN and 1 to 6 FEB, the NORCAL-WMP time span, the only near-conflict was on 1 FEB, when the NORCAL-WMP flight stopped seeding near Lake Oroville at 1753 and PGE began at 1800. Between 6 JAN and 2 FEB, PEG operated its west bank of 6 generators for 11 hours each on 6 occasions, releasing a total of 13,200 grams AgI.

On 13 JAN, when NORCAL-WMP operated northeast of Shasta Reservoir, and on the following day, when two flights covered the Feather Basin and one the upper Sacramento, both SMUD and NCPEP operated also, but apparently too far away for any conflict. Similar separation seems to preclude any difficulties on 1 February.

From 20 NOV until termination on 12 FEB, NCPEP dispersed 5,976 grams AgI and 132.3 Kg. of CO₂ on 25 days, 4,156 grams after 1 JAN. No details are available for SMUD. For the American River AgI diffusion studies, Aero-systems, Inc., of Boulder, Colorado, released 3,420 grams AgI from aircraft and 1,153 from the ground between 12 JAN and 9 FEB.

Thus, while NORCAL-WMP was using less than 2 kg of AgI on 7 days during January and February, others released almost 20 kg in and upwind of its operating area. The previous summer, 47 flights over Northern California between 20 July and 28 September in a drought relief program sponsored by DWR spread 7,125 g AgI (Stidd, 1978). With comparatively so little seeding, NORCAL-WMP had little chance of causing substantial precipitation increases, but individual flights could be examined for possible results.

The estimated area of possible effect (EAPE) of the silver iodide released from an aircraft is the area on the ground which is assumed to receive any precipitation induced by the AgI. Nucleation of cloud particles by AgI is considered to require about 20 minutes. Precipitation may fall almost immediately, but may continue for another 30 to 40 minutes. At 4 m/s,

a 1 mm diameter drop will fall 2 km from cloud base to ground in 8 minutes; a 2 mm drop takes only 3 minutes.

Hence the EAPE is computed as the area on the ground 20 to 60 minutes downwind from the aircraft, using the observed or estimated windflow at just below flight level. Three flight tracks are plotted: that of the aircraft as reported by its pilot, and two parallel tracks displaced downwind. The area between these downwind tracks is the EAPE. Examples, for the three flights on the next-to-last operational day, appear in Fig. 2.

To compute the EAPE, two different types of information are needed: a precise flight track, and reliable wind information at and below flight level. Detailed flight tracks, with reference to one of the various VORTAC beacons in the operational area, were available for 11 of the 13 flights. The other two were assumed to have followed the nominal tracks on which they were dispatched. Average duration of a seeding flight was 2.4 hours, of which 1.4 hours was for actual seeding. Each flight had 10 to 20 seeding legs, between identified points, so could be reconstructed readily as an overlay on an aeronautical chart.

Wind information could not be obtained from the aircraft log, for lack of precision navigation equipment. Instead it was estimated in some cases from time-lapse films of the scope of a special radar at the Red Bluff headquarters, but for the most part from rawinsonde flights at one or more sites within or just south of the NORCAL-WMP area.

Wind and temperature conditions during seeding flights, and cloud top heights and temperatures, given in Table 1, were inferred from the nearest available upper air sounding. Such data came from one or more of the three sources:

1. a daily observation at a Butte County site 15 miles south of Chico, part of the environmental impact study of a coal-burning power-plant proposed by the Pacific Gas and Electric Company;
2. a daily observation, around 1330 PST, at Lake Almanor (in the north part of the Feather River Basin) in connection with weather modification activities there by Pacific Gas and Electric Company;
3. irregular observations at Sheridan, 35 miles south of Oroville, by North American Weather Consultants studying winter storms in planning a weather modification program proposed for the American River Basin by the Bureau of Reclamation.

In addition, twice daily observations at Oakland, Medford and Winnemucca were available from the National Weather Service, and occasional flights at Fresh Pond, east of Sacramento, by the East Bay Municipal Utility District in connection with their weather modification activities. These were used to corroborate the PGE and NAWC observations.

The number of times a track was traversed varied from flight to flight, so that the number of times the geographical EAPE would overlap would also vary. To permit quantitative differentiation between the different times

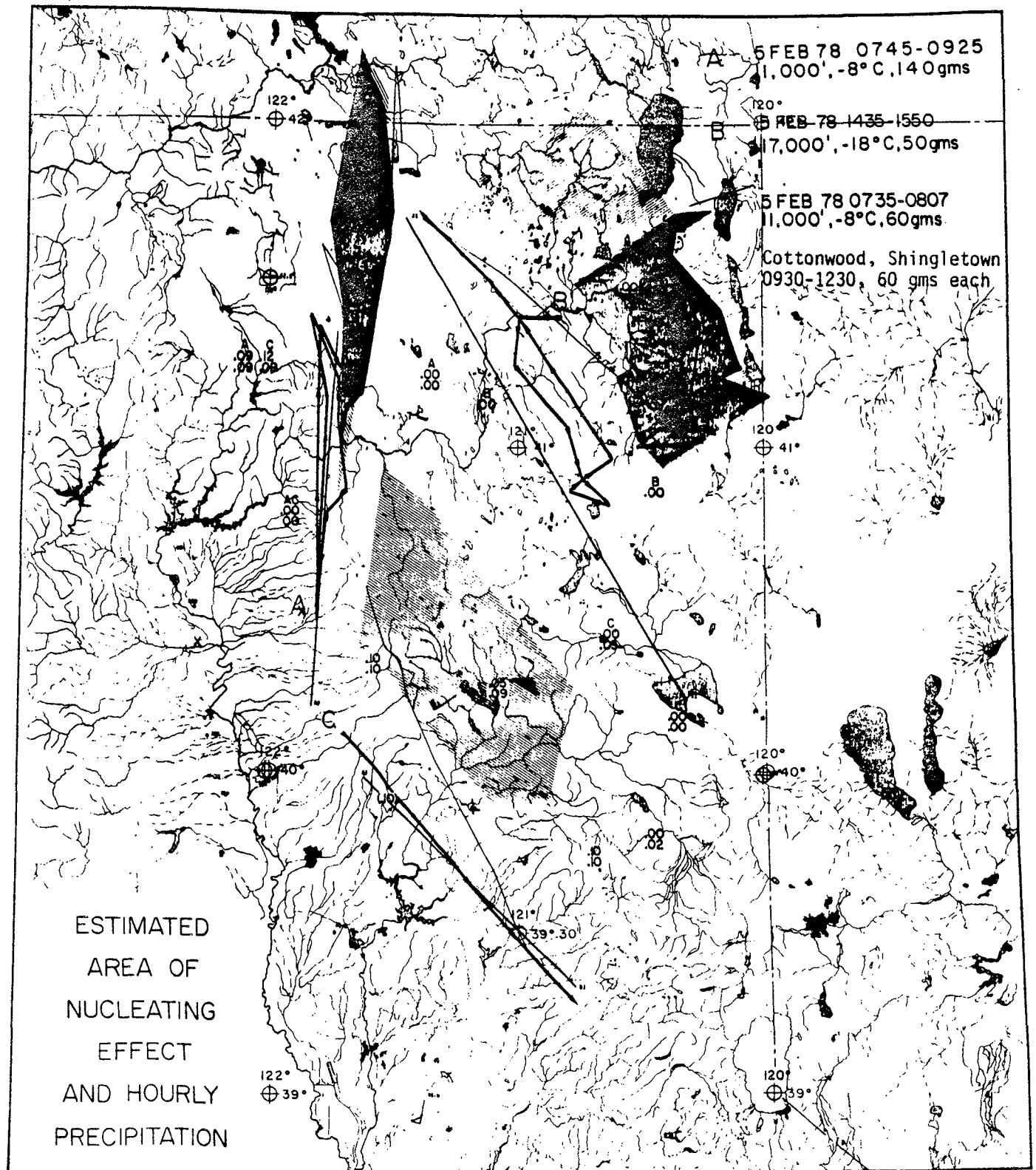


Fig. 2. Flighttracks, estimated areas of effect, and actual precipitation in and around areas on 5 FEB 1978. Upper figure is for hour of seeding, lower for following hour.

that the area of effect overlapped geographically, each pair of points along the 20 and 60 minute plume lines was identified by a sequence number and the local time. In addition, an isochrone of the time of completion of seeding was drawn to represent the position of the AgI released since the start of the seeding run. The geographical dimensions of the areas depend basically on the wind speed and the angle between the track orientation and the wind direction.

No similar display was attempted to the possible results of the operation of ground generators on two days. From 1030 to 1630 on 14 JAN, generators operated at Dunsmuir and Cayton, just downwind from the track of an aircraft seeding from 1442 to 1623. From 0930 to 1230 on 5 FEB, generators operated at Cottonwood and Shingletown, west of one of the seeding flights on that day. Their areas of possible effect cannot be estimated without information on low-level winds and atmospheric stability.

3. RESULTS

Hourly precipitation data obviously were necessary for any evaluation of the results of the Northern California Weather Modification Project. As soon as the evaluation was undertaken, arrangements were started to obtain records, long before publication, from almost thirty recording gages in northeastern California. These are part of the network operated by NOAA, from which data are published in Hourly Precipitation Data (HPD) by the National Climatic Center, usually about six months late. James Goodridge, DWR engineer and State Climatologist for California, arranged to have hourly data for the seven operational days extracted as soon as the charts reached the climatic center.

Precipitation amounts for each hour of seeding flight were plotted on the EAPE diagrams, which had been prepared by Sidney Frank in Santa Barbara before precipitation data were available. Intended originally to document how much of the target area had actually been covered, the diagrams showed a big surprise when Debra Shiroma, geophysical aide, entered the precipitation figures. Stations inside the EAPE seemed to have more precipitation than those around it.

The EAPE actually had been constructed assuming a lag of up to one hour in the precipitation induced by seeding. So precipitation during the hour following seeding was also tallied. Both sets of hourly precipitation amounts (in inches) are entered at the proper locations on each EAPE diagram, the earlier above the later.

Precipitation during flights was greater inside than around the EAPE on eight of the thirteen flights, less on one. For three flights the EAPE contained no rain gauge, and on one no precipitation fell either inside or outside the EAPE. With one-hour lag, five flights showed more precipitation inside than outside the EAPE, two showed less, three had no gages, and for two the proper hourly data had not been obtained.

Statistical significance of these results can be examined in various ways, none completely proper. The simultaneous results may be considered as equivalent to obtaining eight heads and one tail in thirteen coin tosses, with the coin standing on edge once and falling off the table three times. The probability of obtaining as many as eight heads in thirteen tosses is $1093/8192 = 0.133$. But this effectively considers the on-edge and off-table cases as tails. Dividing them equally gives ten heads and three tails in thirteen tosses, for which the probability is $92/8192 = .011$. Ignoring the on-edge (no precipitation) and off-table (no gage) cases gives eight heads and one tail in nine trials, which has a probability of $1/512 = 0.002$. Similar games may be played with the one-hour lag data, with equally varying results, none very convincing.

Many limitations underlie this discussion. The time assumptions underlying the EAPE may not be valid, and the wind information used in computing each EAPE may be erroneous. The graphic presentation permits a reader to adjust each EAPE for different assumptions. Precipitation data are available only for clock-hours, while seeding began and ended at any minute.

How much the precipitation was increased, if at all, by seeding cannot be estimated with any confidence. An hourly amount as great as 0.30 inches was recorded only once; most of the hourly EAPE readings were 0.10 inch or less, and only slightly larger than those at nearby gages outside the EAPE. Differences or ratios of precipitation inside and outside each EAPE cannot be trusted to indicate effects which might have resulted from the prolonged, intensive operation originally intended. But these figures seem to show some desired effects from the release of 1620 grams of AgI during 13 flights on 7 days of the NORCAL-WMP.

4. REFERENCES

- Atmospherics Incorporated, 1978. The Northern California Emergency Weather Modification Program. A summary report of cloud seeding activities conducted by Atmospherics Incorporated for the State of California during the period January-February 1978. Fresno, AI, ii + 45 pp.
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