

THE SANTA BARBARA CLOUD SEEDING PROJECT IN COASTAL SOUTHERN CALIFORNIA, SUMMARY OF RESULTS AND THEIR IMPLICATIONS

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1. INTRODUCTION

Interest in weather modification in Santa Barbara County (County), California, USA dates back to 1950. This interest developed shortly after the discoveries of Drs. Schaefer and Vonnegut in the late 1940's that established a scientific basis for weather modification (commonly referred to as cloud seeding). Two weather modification research programs have been conducted in the County. Numerous winter season operational cloud seeding projects have been conducted in the County dating back to 1950.

This interest in cloud seeding has been driven by two primary water needs in the County: drinking water supplies and agriculture. Water is a valuable commodity to both groups due to the amounts and seasonality of rainfall in the County. The months of November through March typically produce most of the rainfall in the County.

Operational winter seeding projects were conducted in the County from 1950-1955 utilizing ground based silver iodide generators. Analyses of the effectiveness of these non-randomized projects indicated an average 16% increase in precipitation. Figure 1 provides the location of Santa Barbara County relative to the State of California.



Fig. 1 Location of Santa Barbara County

2. EARLY RESEARCH EFFORTS

A research program, Santa Barbara I, was conducted from 1957-1960. This program involved randomized seeding from ground based silver iodide generators. Participants included the State of California, University of California, and North American Weather Consultants (NAWC). Funding was provided by Santa Barbara County, Ventura County (an adjoining county to the east), the National Science Foundation, the U.S. Weather Bureau and the U.S. Forest Service. The analyses of the program indicated considerably more precipitation from the seeded cases but the results were not statistically significant (Neyman, *et al*, 1960) (Elliott, 1962).

NAWC was funded by the National Science Foundation to conduct studies of winter storms that affected Santa Barbara County from 1960-1963. This work utilized sequential rawinsondes at several locations, airborne cloud physics measurements, and an extensive rain gage network. One of the significant results of this work was that most of the precipitation, updrafts and supercooled liquid water (inferred to be related to upward vertical velocities) suitable for cloud seeding occurred in relatively narrow traveling "convection bands" embedded within the winter storm systems (Elliott and Hovind, 1964a and b).

3. SANTA BARBARA II RESEARCH PROGRAM

A second winter weather modification research program was conducted in the County in the period from 1967 through 1973 (Brown, *et al*, 1974). This program was funded by the Naval Weapons Center at China Lake, California and conducted by North American Weather Consultants. The design of this program was based upon the work conducted in the 1960's which identified "convection bands" as the primary target of opportunity for winter cloud seeding precipitation augmentation activities in the County.

The research program was known as Santa Barbara II phases I and II. Phase I consisted of the release of significant amounts of silver iodide from a ground location near 1,200 m MSL located in the Santa Ynez Mountains north of Santa Barbara. Silver iodide pyrotechnics (400 gram units) were ignited every 15 minutes as the convection bands passed over the release site. Each pyrotechnic burned approximately 3 minutes. The seeding of selected convection bands was conducted on a random basis in order to derive some not seeded (natural) information. A large network of recording precipitation gages (112 sites) was available for the research program (Figure 2).

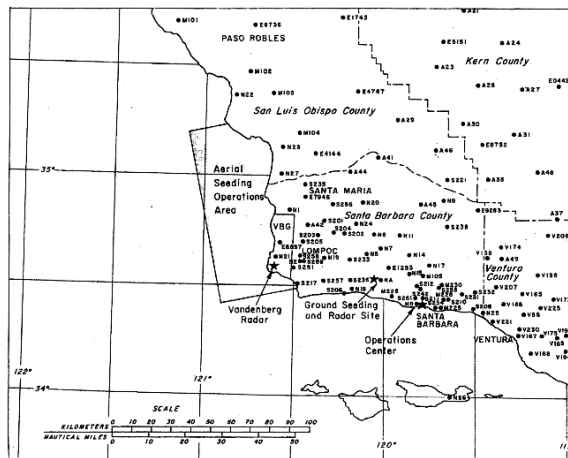


Fig. 2 Locations of Precipitation Gages

The amount of precipitation that fell from each seeded or not seeded "convection band" was determined at each precipitation gage location (the analyst did not know which bands were seeded or not seeded). Average convection band precipitation for seeded and not seeded events was calculated for each rain gage location. Contours of the average ratios of seeded band precipitation versus the not seeded band precipitation for Phase I are plotted in Figure 3. Ratios over 1.0 are common in this figure. A ratio of 1.50 would indicate a 50 percent increase in precipitation from seeded convection bands. The high ratios in Southwestern Kern County are not significant in terms of amounts of additional rainfall since the convection bands (both seeded and not seeded) rapidly lose intensity as they enter the San Joaquin Valley due to a "rainshadow" effect. In other words, a high percentage applied to a low base amount does not yield significant additional precipitation. The 1.5 ratios along the backbone of the Santa Ynez Mountains east of the release site are, however, significant in terms of amounts of rainfall since this area receives higher natural precipitation

during winter storms due to "orographic" lift. It was concluded that convection band precipitation was increased over a large area using this high output silver iodide ground based seeding approach. Figure 4 provides the statistical significance of these results. See also Elliott *et al* (1971a) which shows increases of $\geq 50\%$ via randomized ground-based seeding in Phase I, significant at some precipitation gage sites at the 5% level.

In a similar experiment, phase II employed an aircraft to release silver iodide generated by high output (silver iodide - acetone wing tip generators dispensing 900 grams of silver iodide per hour) into the "convection bands" as they approached western coastline of Santa Barbara County. The aircraft was

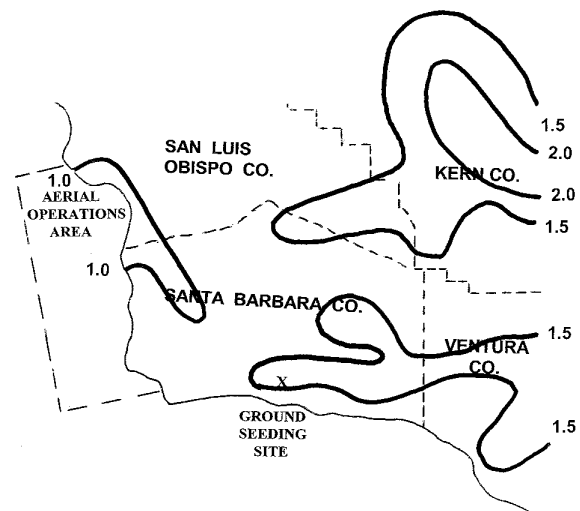


Fig. 3 Seed/no-seed Ratios, Phase I (ground)

flown at the freezing level near the leading edge of the convection bands in 30 to 60 km flight legs. The convection bands to be seeded were again randomly selected. Figure 5 provides the results. Again, a large area of higher precipitation in seeded convection bands compared to not seeded convection bands is indicated. Figure 6 provides the statistical significance of these results. This figure indicates a number of precipitation stations where the indicated 50% increases in convection band precipitation are significant at the 0.01 to 0.05 significance level which indicates these results are not due to chance. Rather, they are interpreted to be the result of the seeding activities.

A study of the contribution of convection bands to the total amount of winter precipitation in Santa Barbara and adjoining counties was conducted as part of the Santa Barbara II research program for the winter seasons of 1971-74 (Brown, *et al*, 1974). This

study indicated that approximately 50-60% of the winter precipitation is due to the passage of convection bands through these coastal California counties (Figure 7).

Various aspects of the research programs (Santa Barbara I and II) are also described in Hess (1974), providing additional perspective and information.

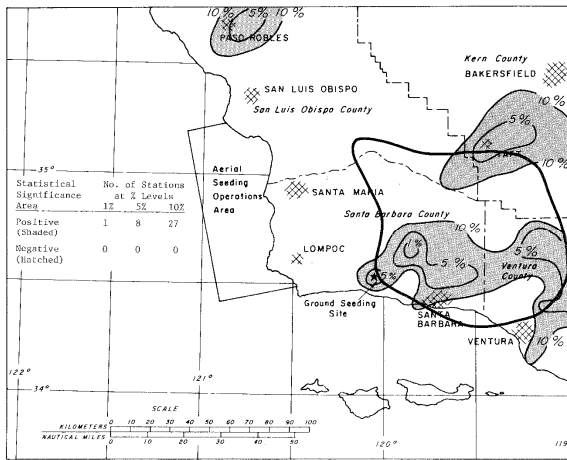


Fig. 4 Statistical Significance of Ground Seeding

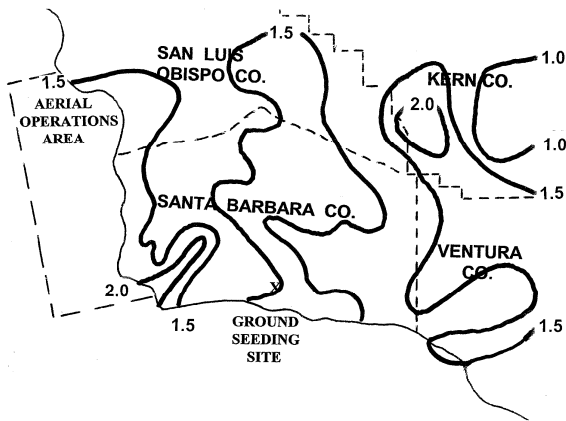


Fig. 5 Seed/no-seed Ratios, Phase II (aerial)

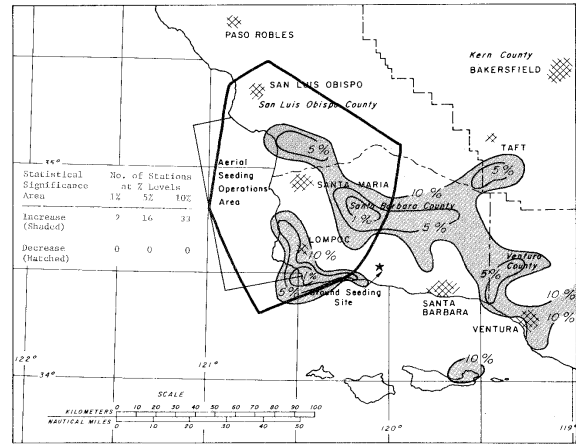


Fig. 6 Statistical Significance of Airborne Seeding

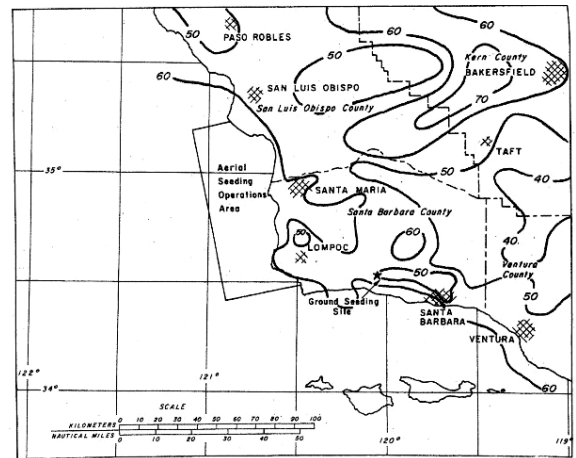


Fig. 7 Percentage of Winter Precipitation Associated with Convection Bands

Detailed analyses of this research program were conducted. Some of conclusions reached as a result of these analyses are as follows (Brown, *et al*, 1974):

- 1). Seeding convection bands is an efficient means of augmenting water supplies from wintertime cyclonic storms in the County.
- 2). The magnitude of the precipitation increase is on the order of 50 to 100% within the seeded bands and 25 to 50% for the storm total.
- 3). Three distinct areas of increased precipitation have been identified. The first area might be called “the primary seeding zone”. This area is within 50 km of the seeding source. The second area of significant increase has been termed a “downwind area”. This region occurs about 100 km from the seeding site in the direction of the 700 mb flow. This second area is probably caused by a direct transport of either silver iodide nuclei or very small particles of ice or water.

This “downwind effect” is only observed during the Phase 1 – ground based seeding and occurs in a semi-arid region where most of the unseeded bands do not produce precipitation. The third area of augmented precipitation has been termed the “Mesoscale Dynamic Effect Area”. This effect is found 100 to 150 km east of the seeding source in the direction of the band movement. There is no known way that seeding material could be transported to this region in sufficient concentrations to produce seeding effects. The cause of the increased precipitation is apparently a dynamic intensification of the bands.

4). The bands tend to widen and possibly slow after seeding.

5). Rawinsonde observations within the seeded bands indicate a significant backing in the 700 mb wind direction.

6). The atmospheric pressure at the surface beneath the seeded bands decreases on the average of 1.0 mb about 100 km downwind from the seeding site.

7). Moving the location of the seeding site causes a corresponding shift in the location of the seeding effects, both precipitation increases and pressure changes.

Project seeding test results have also been reported in Elliott, *et al* (1971a) and downwind effects presented in Elliott, *et al* (1971b).

4. ON-GOING OPERATIONAL SEEDING PROJECTS

The County, through its Flood Control and Water Agencies, resumed support of operational seeding projects during the 1977-78 winter season. High output, ground based seeding of convection bands was conducted. After three seasons without any seeding, operations resumed in the 1981-82 winter season. Operational projects have been conducted routinely up to the present since 1982 with the exception of no seeding during the 1985-86 winter season due to concerns about fire damaged areas in and near the County. These projects have utilized both airborne and ground seeding capabilities.

The design of the operational cloud seeding projects in Santa Barbara County have been based primarily upon the design of the Santa Barbara II research program. As a consequence, the focus has been on seeding convection bands. The design of the program has, however, evolved since the early 1980's to incorporate changing technologies.

In the late 1980's dedicated project weather radar was incorporated into the program instead of relying upon the Vandenberg AFB radar which had been

utilized in the conduct of the Santa Barbara II research program. Remotely controlled, ground based generators were incorporated into the program design to augment the cloud seeding conducted from aircraft. This ground seeding capability replaced the earlier use of silver iodide flares ignited from a single ground based location as had been done during the Santa Barbara II, Phase I research program due to the unavailability of the high output pyrotechnic flares (400g units). The installation of the ALERT (automated local evaluation in real time) precipitation *gage* network by the County provided additional information which was provided to the project meteorologist in a real-time computer call up mode in the weather radar operations center. The project radar and ALERT precipitation data were incorporated into specialized cloud seeding suspension criteria to address special areas of concern such as the streamflow in the lower Santa Ynez River and fire damaged areas. Provisions were made to acquire weather satellite imagery at the weather operations center beginning in the 1992-93 winter season. NAWC began using a computerized targeting model, GUIDE, in the 1990's to assist in real-time seeding decision-making (Raubert, *et al*, 1988).

Two other weather modification contractors were selected to conduct the cloud seeding program for the County in the 1997 through 2001 winter seasons. NAWC was again selected to conduct the program beginning with the 2001-02 winter season. NAWC instituted several program design changes beginning in the 2001-02 winter season that included:

1). Dropping the provision of a project-dedicated weather radar and shifting to reliance upon U.S. National Weather Service NEXRAD radars (Vandenberg AFB and Ojai) to provide information for the direction of the operations. NEXRAD data and products are available at approximately 5-7 minute update intervals. This time scale has proven to be adequate for the direction of seeding activities. Figure 8 provides an example of a convection band impacting Santa Barbara County as depicted by the NEXRAD radar at Vandenberg AFB.

2). Development of a custom software tracking package that overlays aircraft location and altitude information on the NEXRAD PPI displays.

3). A return to the use of high output pyrotechnics at three remote ground sites (a fourth site was added for the 2004-2005 winter season), replacing the use of remotely controlled acetone-silver iodide generators (made possible through the development of efficient, high output pyrotechnics in the latter 1990's; such pyrotechnics were unavailable after the early 1980's). Figure 9 provides photographs of one of these ground based pyrotechnic sites. NAWC has utilized 150g

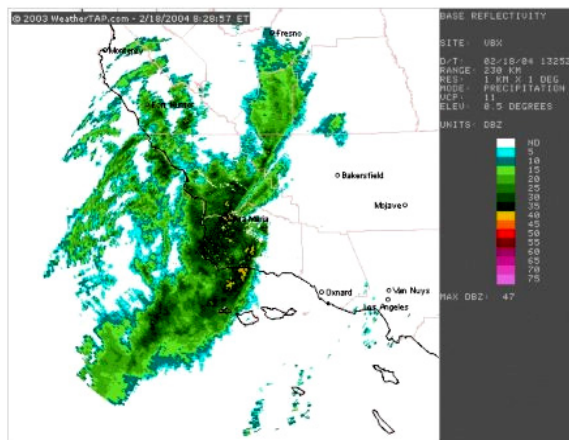


Fig. 8 Example of a Convection Band Impacting Santa Barbara County from Vandenberg AFB NEXRAD Radar Depiction

flares manufactured by ICE, Inc. of Fargo, North Dakota at these sites. Flares are fired remotely using a cellular phone internet connection as programmed by the project meteorologist. Timing of flare firings are based upon anticipated passage of the convection band over each ground based flare site as indicated from the NEXRAD radar display.

4). Aircraft flights at the freezing level along the leading edge of the convection bands as they approach and pass over the western portion of the County (flight levels in previous seasons had typically been conducted at the -5 to -10 ° C level). Flying at the freezing level allows time for the seeding material to diffuse before it reaches its activation threshold temperature which is approximately the -5 ° C level. Flying at the freezing level also duplicates the approach used in the conduct of the Santa Barbara II, phase II research program.

The latter two changes were made in an attempt to more closely duplicate the design used in the conduct of the Santa Barbara II research program. The combination of multiple ground based flare sites plus airborne seeding should result in an optimization of seeding effects through the combination of the two seeding modes that were shown to produce positive effects in the County during the conduct of the Santa Barbara II research program. Figure 10 provides the location of the two target areas used in recent years in the conduct of the operational projects. The x symbols mark the locations of the three ground based flare sites.

5. POTENTIAL BENEFITS / IMPLICATIONS

The results of cloud seeding are difficult to ascertain on operational cloud seeding projects. There are a variety of reasons why this is the case including: lack of randomization procedures being used (which would provide not seeded samples that could be compared to seeded samples), the high natural variability in precipitation in time and space and different responses of seeding in different storm conditions.

Santa Barbara County presents an especially challenging situation regarding evaluation of the operational seeding projects. A traditional method used to evaluate operational seeding projects is through a target/control historical regression analysis. Using this approach involves selecting a historical period without any seeding and establishing relationships between “target” and “control” measurements (i.e. precipitation data). The control area(s) is selected upwind or cross-wind of the target area so that it will not be contaminated during any subsequent seeding operations. The historical relationship, (typically a linear regression equation) can then be used to predict the amount of natural precipitation (streamflow, etc.) expected within the target area during the seeded periods. Such predictions can then be compared with observations from the target area during the seeded period to determine if there are any systematic differences. Since the Pacific Ocean is located on the southern through western coastlines of the County and the majority of the winter storms that impact the County approach the County from these directions, there are no “upwind” areas with observations that can be used as control areas.

The County attempted to partially address this dilemma by contracting with NAWC in 1987 to make an assessment of the potential of augmenting precipitation in the County through seeding of convection bands (Thompson and Griffith, 1988). This assessment utilized the results from the Santa Barbara II research program to extrapolate results for a 61 year period (1920-1980) at two strategic precipitation gage sites (Juncal and Gibraltar Reservoirs) in the Santa Ynez River drainage. The study concluded that October-April precipitation could optimally be increased by 21-22%. This percent increase would provide an average 11.5 to 12.7 cm of additional precipitation to the seasonal totals.

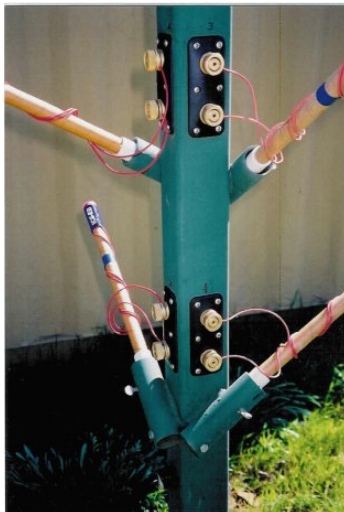


Fig. 9 Ground Based Flare Site at Rancho Dos Vistas

The two targeted watersheds in the County (Figure 10) cover approximately 1810 km². If the winter precipitation in a wet winter was increased by 11.5 cm, the additional precipitation over the targeted watersheds would amount to ~ 207,800,000 m³. This would result in ~ 140,000,000 m³ of additional runoff into the County reservoirs. The annual program costs of approximately \$300,000 U.S. are cost shared on a 50/50 basis between the County and the local water purveyors. The cost of this additional runoff would be approximately \$0.002/m³. Since there are fewer seedable storms in normal and drier winters, the average cost of the additional runoff may be on the order of \$ 0.07/m³. This cost is still considerably less

than the other supplemental sources of water such as water from the California State water project (~\$0.32/m³) and desalinated water (~\$0.80/m³), and even less expensive than pumping ground water (~\$0.16 - \$0.24/m³).

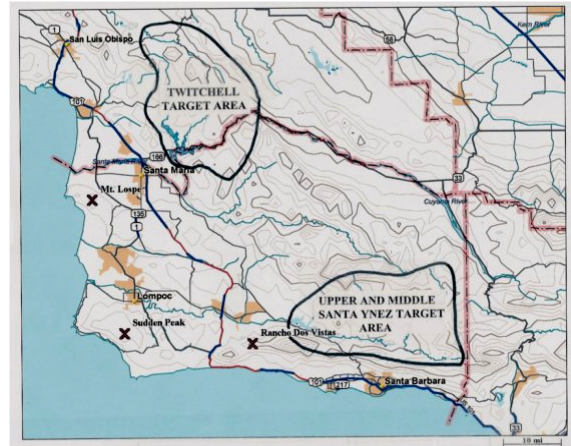


Fig. 10 Target Areas for Recent Cloud Seeding Projects in Santa Barbara County

6. REFERENCES

Brown, K.J., R.D. Elliott, J.R. Thompson, P. St. Amand and S.D. Elliott, 1974: The Seeding of Convection Bands. *Preprints, 4th Conf. on Wea. Mod.*, Amer. Meteor. Soc., p.7-12.

Elliott, R.D., 1962: Note on Cloud Seeding Evaluation With Hourly Precipitation Data. *J. Appl. Meteor.*, **1**, 578-580.

Elliott, R.D. and E.L. Hovind, 1964a: On Convection Bands within Pacific Coast Storms and their Relation to Storm Structure. *J. of Appl. Meteor.*, Amer. Meteor. Soc., **3**, 143-154.

Elliott, R.D. and E.L. Hovind, 1964b: The Water Balance of Orographic Clouds. *J. of Appl. Meteor.*, Amer. Meteor. Soc., **3**, 235-239.

Elliott, R.D., P. St. Amand, and J.R. Thompson, 1971a: Santa Barbara Pyrotechnic Cloud Seeding Test Results 1967-70. *J. Appl. Meteor.*, **10**, 785-795.

Elliott, R.D., and K.J. Brown, 1971b: The Santa Barbara II Project – Downwind Effects. *Proceedings of the International Conference on Weather Modification*, Canberra, Australia, 1971, 179-184.

Hess, W.N. (editor), 1974: Weather and Climate Modification. John Wiley and Sons, Inc., New York.

Neyman, J., E.L. Scott, and M. Vasilevskis, 1960: Statistical Evaluation of the Santa Barbara Randomized Cloud Seeding Experiment. *Bull. Amer. Meteor. Soc.*, **41**, 531-547.

Rauber, R. M., R. D. Elliott, J. O. Rhea, A. W. Huggins, and D. W. Reynolds, 1988: A diagnostic technique for targeting during airborne seeding

experiments in wintertime storms over the Sierra Nevada. *Journal of Applied Meteorology*, Vol. **27**, No. 7, pp. 811-828.

Thompson, J.R. and D.A. Griffith, 1988: Precipitation Augmentation Potential from Convection Band Seeding in Santa Barbara County. North American Weather Consultants report # WM87-7 to Santa Barbara County Water Agency, 73pp.