

**Summary of Operations for a Winter Cloud Seeding Program for the
Upper Santa Ynez Drainage in Southeastern Santa Barbara County
and the
Huasna-Alamo Drainage in Northern Santa Barbara
and Southern San Luis Obispo Counties
Water Year 2013**

Prepared for

**Santa Barbara County
Public Works
Department
Water Agency Division**

By

**Don A. Griffith, CCM
David P. Yorty**

**North American Weather Consultants, Inc.
8180 S. Highland Dr., Suite B-2
Sandy, UT 84093**

**Report No. WM 13-4
Project No. 12-319**

June 2013

**Summary of Operations for a Winter Cloud Seeding Program for the
Upper Santa Ynez Drainage in Southeastern Santa Barbara County
and the
Huasna-Alamo Drainage in Northern Santa Barbara
and Southern San Luis Obispo Counties
Water Year 2013**

Prepared for

**Santa Barbara County
Public Works
Department
Water Agency Division**

By

**Don A. Griffith, CCM
David P. Yorty**

**North American Weather Consultants, Inc.
8180 S. Highland Dr., Suite B-2
Sandy, UT 84093**

**Report No. WM 13-4
Project No. 12-319**

June 2013

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
1.0 INTRODUCTION	1-1
2.0 OPERATIONS.....	2-1
2.1 Summary of 2012-2013 Rainy Season Rainfall.....	2-1
2.2 Hydrologic Conditions during the 2012-2013 Rainy Season	2-6
2.3 Summary of Seeding Operations	2-6
2.4 Significant Storm Events of the 2012-2013 Season	2-8
November 29-30, 2012	2-9
December 2, 2012	2-11
December 12-13, 2012.....	2-12
December 14, 2012	2-15
December 22, 2012	2-16
December 23-24, 2012.....	2-21
December 25-26, 2012.....	2-22
December 28-30, 2012.....	2-25
January 5-6, 2013	2-31
January 23-25, 2013	2-32
February 7-8, 2013.....	2-33
February 19-20, 2013.....	2-34
March 7-8, 2013.....	2-37
3.0 THEORY OF CLOUD SEEDING FOR PRECIPITATION AUGMENTATION AND RESULTS OF PREVIOUS RESEARCH CONDUCTED IN SANTA BARBARA COUNTY	3-1
3.1 Precipitation Processes.....	3-1
3.2 Ice Nucleation	3-2
3.3 Impacts of Silver Iodide Seeding.....	3-3
3.4 Santa Barbara II Research Program.....	3-4
4.0 PROJECT DESIGN	4-1
5.0 EQUIPMENT, PROCEDURES AND PERSONNEL.....	5-1
5.1 Weather Radar	5-1
5.2 AHOGS Ground-Based Seeding Systems	5-2

Table of Contents (continued)

<u>Section</u>	<u>Page</u>
5.3 Weather Forecasts and Meteorological Data Acquisition	5-12
5.4 Seeding Procedures	5-12
5.5 Suspension Criteria	5-13
5.6 Personnel.....	5-13
 6.0 COMPUTER MODELING	 6-1
6.1 WRF Model	6-2
6.2 HYSPLIT Model.....	6-8
 7.0 SUMMARY AND RECOMMENDATIONS	 7-1
 REFERENCES	
APPENDIX A	BACKGROUND ON CLOUD SEEDING IN SANTA BARBARA COUNTY
APPENDIX B	2012-2013 CLOUD SEEDING PROGRAM SUSPENSION CRITERIA
 <u>Figure</u>	<u>Page</u>
2.1 Project areas, topographic features and ground-based high-output flare site locations.....	2-2
2.2 Santa Maria daily rainfall, October 1, 2012 to March 31, 2013	2-4
2.3 Bald Mountain daily rainfall, October 1, 2012 to March 31, 2013	2-4
2.4 San Marcos Pass daily rainfall, October 1, 2012 to March 31, 2013	2-5
2.5 Gibraltar Dam daily rainfall, October 1, 2012 to March 31, 2013	2-5
2.6 Discharge, Sisquoc River near Sisquoc, October 1, 2012 to April 30, 2013.....	2-6
2.7 Rainfall totals for November 29-30, 2012	2-10
2.8 Rainfall totals for December 2, 2012.....	2-11
2.9 Infrared satellite image at 2030 PST, December 12, 2012	2-12
2.10 Radar reflectivity at 2048 PST, December 12, 2012	2-13
2.11 Vandenberg VAD wind profile ending at 2048 PST, December 12, 2012.....	2-14
2.12 Rainfall totals for December 12-13, 2012.....	2-15
2.13 Infrared satellite image at 0700 PST, December 22, 2012	2-17
2.14 Radar reflectivity at 1003 PST, December 22, 2012	2-18
2.15 Wind profile ending at 0958 PST, December 22, 2012.....	2-19
2.16 Rainfall totals for December 22, 2012.....	2-20
2.17 Rainfall totals for December 23-24, 2012.....	2-21

Table of Contents (continued)

<u>Figure</u>	<u>Page</u>
2.18 Infrared satellite image at 2200 PST, December 25, 2012	2-22
2.19 Radar reflectivity at 2325 PST, December 25, 2012	2-23
2.20 Wind profile ending at 2320 PST, December 25, 2012	2-24
2.21 Rainfall totals for the December 25-26 storm event	2-25
2.22 HRRR 4-hour forecast for 0100 PST, December 29, 2012	2-26
2.23 Infrared satellite image at 0345 PST, December 29, 2012	2-27
2.24 Radar reflectivity at 0302 PST, December 29, 2012	2-28
2.25 Wind profile ending at 0302 PST, December 29, 2012	2-29
2.26 Rainfall totals for the December 28-30 storm event	2-30
2.27 Rainfall totals for January 5-6, 2013	2-31
2.28 Rainfall totals for January 23-25, 2013	2-32
2.29 Rainfall totals for February 7-8, 2013	2-33
2.30 Visible spectrum satellite image at 1600 PST, February 19, 2013	2-34
2.31 Radar reflectivity at 1609 PST, February 19, 2013	2-35
2.32 Wind profile ending at 1609 PST, February 19, 2013	2-36
2.33 Rainfall totals for the February 19-20 storm event	2-37
2.34 GOES-West satellite image at 2000 PST, March 7, 2013	2-38
2.35 Infrared satellite image at 1945 PST, March 7, 2013	2-39
2.36 Radar reflectivity at 2118 PST, March 7, 2013	2-40
2.37 Wind profile ending at 2118 PST, March 7, 2013	2-41
2.38 Rainfall totals for March 7-8, 2013	2-42
3.1 Santa Barbara II Project Map	3-6
3.2 Seeded/not-seeded ratios of band precipitation for Phase I ground operations, 1967-71 seasons	3-7
3.3 Annual Average Precipitation, Southern California	3-8
3.4 Seeded/not-seeded ratios of band precipitation for Phase II aerial operations, 1970-74 seasons	3-9
3.5 Approximate percentage of winter precipitation occurring in convection bands, 1970-74 seasons	3-10
3.6 Frontal convection band passing over Santa Barbara County on April 11, 2010	3-12
4.1 Project areas, topographic features and ground-based high-output flare site locations	4-1
4.2 Comparison of Effectiveness of the LW-83 verses the ICE Burn-in-Place Flare, CSU Cloud Chamber results	4-6
5.1 Photograph of the Mt. Lospe AHOGS Site	5-5
5.2 Photo of the Harris Grade AHOGS Site	5-6
5.3 Photo of the Sudden Peak AHOGS Site	5-7
5.4 Photo of the Gaviota AHOGS Site	5-8
5.5 Photo of the West Camino AHOGS Site	5-9

Table of Contents (continued)

<u>Figure</u>	<u>Page</u>
5.6 Photo of the Gibraltar Road AHOGS Site	5-10
5.7 Close-up photo of spark arrestors	5-11
5.8 Flare burning inside a spark arrestor.....	5-11
6.1 HRRR model ten-hour forecast of composite radar reflectivity on March 25, 2012	6-4
6.2 Vandenberg AFB PPI radar display valid at 1426 PDT, March 25, 2012.....	6-5
6.3 HRRR model ten-hour forecast of one-hour precipitation on March 25, 2012	6-6
6.4 Observed hourly precipitation at Sudden Peak, March 25, 2012	6-7
6.5 Observed hourly precipitation at Santa Maria, March 25, 2012	6-7
6.6 HYSPLIT Model output for Sudden Peak, December 22, 2012.....	6-9
6.7 HYSPLIT Model output for Sudden Peak, Harris Grade, and Mt. Lospe on December 25-26, 2012.....	6-10
6.8 HYSPLIT Model output for Sudden Peak and Harris Grade on March 7, 2013	6-10
6.9 Vandenberg NEXRAD vertical wind profile at 0907–0958 PST, December 22, 2012 ..	6-11

<u>Table</u>	<u>Page</u>
2-1 Seasonal Rainfall and Percentage of Normal through March 11, 2013	2-3
2-2 Ground-Based Seeding by Location.....	2-7
3-1 Short Duration Rainfall Amounts at the Santa Maria Airport During Storm Event in Figure 3.6	3-13
4-1 CSU Cloud Chamber Test Results for Ice Crystal Engineering Flare	4-4
4-2 Comparison of LW-83 and ICE Burn in Place Flares	4-8
5-1 AHOGS Site Locations	5-3
6-1 HRRR Forecast Parameters of Interest.....	6-3

**Summary of Operations for a Winter Cloud Seeding Program for the
Upper Santa Ynez Drainage in Southeastern Santa Barbara County
and the
Huasna-Alamo Drainage in Northern Santa Barbara
and Southern San Luis Obispo Counties
Water Year 2013**

NAWC Report WM 13-4

1.0 INTRODUCTION

North American Weather Consultants (NAWC), with headquarters in Sandy, Utah, conducted a cloud seeding program for the Santa Barbara County Water Agency (Agency) from December 1, 2012 through March 15, 2013. Originally the contract called for seeding for a four month period; December 1, 2012 through March 31, 2013. The operational period was shortened by the Agency due to the low amounts of rainfall that had occurred during the months of October through February. The Agency indicated that due to the low soil moisture content there was little likelihood of the generation of any significant runoff from any rainfall that might occur in the latter half of March or early April.

The target areas consisted of the upper Santa Ynez drainage located in the southeastern portion of Santa Barbara County and the Huasna-Alamo target area (Twitchell Reservoir drainage) located in portions of northern Santa Barbara and southern San Luis Obispo Counties. Figure 1.1 provides the location of the two target areas. Cloud seeding suspension criteria for this past season included a provision to avoid any negative impacts in recent burn areas during high intensity rainfall periods. Suspensions were also specified whenever the National Weather Service (NWS) issued a severe storm, precipitation, or flood warning that affected any part of the project area. As in previous seasons, there was a generic exclusion of creating any seeding impacts along the south coast of Santa Barbara County.

Only ground based seeding was conducted during the 2012-2013 rainy season. Six previously established ground based seeding sites were activated for the season. These sites were

Mt. Lospe, Harris Grade, Sudden Peak, Gaviota, West Camino Cielo and Gibraltar Road. The cloud seeding equipment located at these sites provided the ability to fire high output seeding flares from these remote locations in real time on a 24/7 basis. All seeding decisions were made by WMA certified project meteorologists operating from NAWC's home offices located in Sandy, Utah or from the project meteorologist's residences. All seeding decisions included consultation with Santa Barbara County Water Agency project personnel prior to and during the seeding periods.

This report contains discussions on project operations, a short theory of cloud seeding, project design, equipment and personnel, and summaries and recommendations. An historical background of cloud seeding activities conducted in Santa Barbara County is provided in Appendix A.

2.0 OPERATIONS

The locations of the two seeding target areas; the upper Santa Ynez and the Huasna-Alamo, are shown in Figure 2.1. Seeding was accomplished from six ground sites: Mt. Lospe, Harris Grade, Sudden Peak, Gaviota, West Camino Cielo and Gibraltar. These locations are provided in Figure 2.1. Further details on the design of the project are provided in Section 4.0.

All operations were conducted in accordance with established suspension criteria contained in Appendix B. Suspension criteria were developed for a variety of situations (e.g., high intensity rainfall, flood warnings, forecasted high streamflow and high intensity rainfall for one burn area. Refer to Appendix B for more details regarding all of the different types of suspension considerations.

2.1 Summary of 2012-2013 Rainy Season Rainfall

The 2012-2013 rainy season was much below average in terms of precipitation, as was the previous season. Table 2-1 provides rainfall statistics as of March 11th which was near the end of the seeded period, when the county-wide percentage of normal rainfall for the season was 54%. December was the only month with above average precipitation during the 2012-2013 season, with the cumulative percentage of average for the county improving from 67% as of December 1, 2012 to 92% as of January 1, 2013. This percentage then dropped to 71% by February 1, 53% by March 1, 49% on April 1 and 46% as of May 1, 2013. This May 1st value compares to 66% for the previous (2011-2012) season. The current season was classified as ENSO-neutral (neither an El Nino nor a La Nina year).

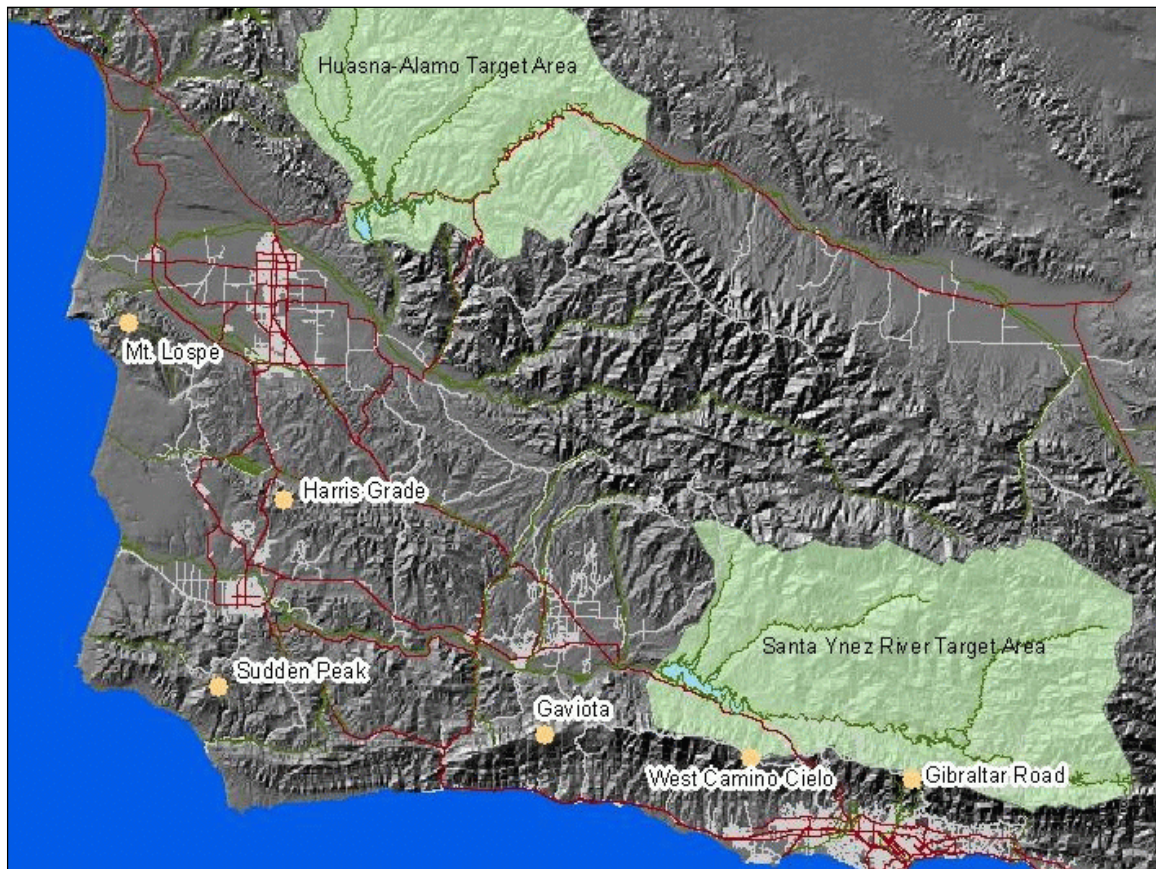


Figure 2.1 **Project areas, topographic features and ground-based high-output flare site locations.**

Table 2-1 Seasonal Rainfall and Percentage of Normal through March 11, 2013
(Data from the Santa Barbara County Flood Control District)



Santa Barbara County - Flood Control District

130 East Victoria Street, Santa Barbara CA 93101 - 805.568.3440 - www.countyofsb.org/pwd

Rainfall and Reservoir Summary

Updated 8am: 3/11/2013

Water Year: 2013

Storm Number: NA

Notes: Daily rainfall amounts are recorded as of 8am for the previous 24 hours. Rainfall units are expressed in inches. All data on this page is from automated sensors, is preliminary, and subject to verification.

*Each Water Year (WY) runs from Sept 1 through Aug 31 and is designated by the calendar year in which it ends
County Real-Time Rainfall and Reservoir Website link > <http://www.countyofsb.org/pwd/pwwater.aspx?id=3582>

Rainfall Location	ID	24 hrs	Code	Storm 0 day(s)	Month	Year*	% of Norm.	AI
Buellton (Fire Stn)	233	0.00		0.00	1.11	7.46	54%	
Cachuma Dam (USBR)	332	0.00		0.00	0.93	7.76	48%	
Carpinteria (Fire Stn)	208	0.00		0.00	0.68	7.53	48%	
Cuyama (Fire Stn)	436	0.00		0.00	0.28	2.28	39%	
Figueroa Mtn (USFS Stn)	421	0.00		0.00	1.05	13.28	76%	6.9
Gibraltar Dam (City Facility)	230	0.00		0.00	0.79	7.67	35%	9.1
Goleta (Fire Stn-Los Carneros)	440	0.00		0.00	0.94	10.18	67%	
Lompoc (City Hall)	439	0.00		0.00	0.97	6.77	56%	8.4
Los Alamos (Fire Stn)	204	0.00		0.00	0.92	6.18	51%	
San Marcos Pass (USFS Stn)	212	0.00		0.00	1.23	16.67	57%	
Santa Barbara (County Bldg)	234	0.00		0.00	0.64	8.19	56%	
Santa Maria (City Pub. Works)	380	0.00		0.00	0.76	6.17	57%	
Santa Ynez (Fire Stn /Airport)	218	0.00		0.00	0.62	6.70	52%	
Sisquoc (Fire Stn)	256	0.00		0.00	1.15	7.81	65%	

County-wide normal-to-date rainfall percentage: 54%

Figures 2.2 - 2.5 provide graphical depictions of rainfall events for the period of Oct. 1, 2012 through March 31, 2013, for four different sites; two in or near the Huasna-Alamo target area and two in or near the upper Santa Ynez target area.

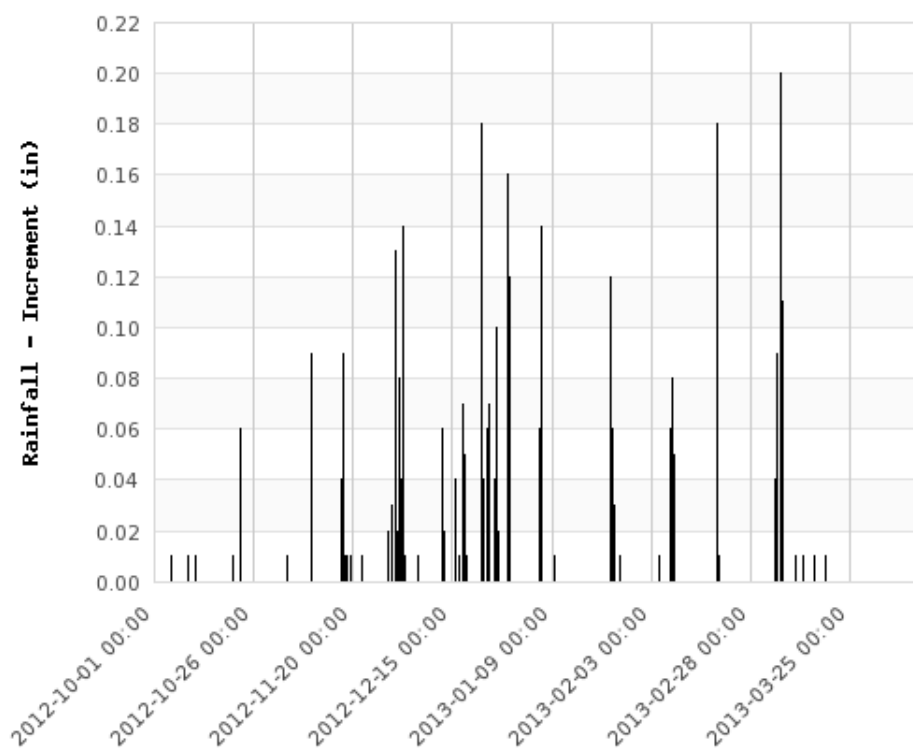


Figure 2.2 Santa Maria Daily Rainfall (8 am to 8 am), October 1, 2012 to March 31, 2013

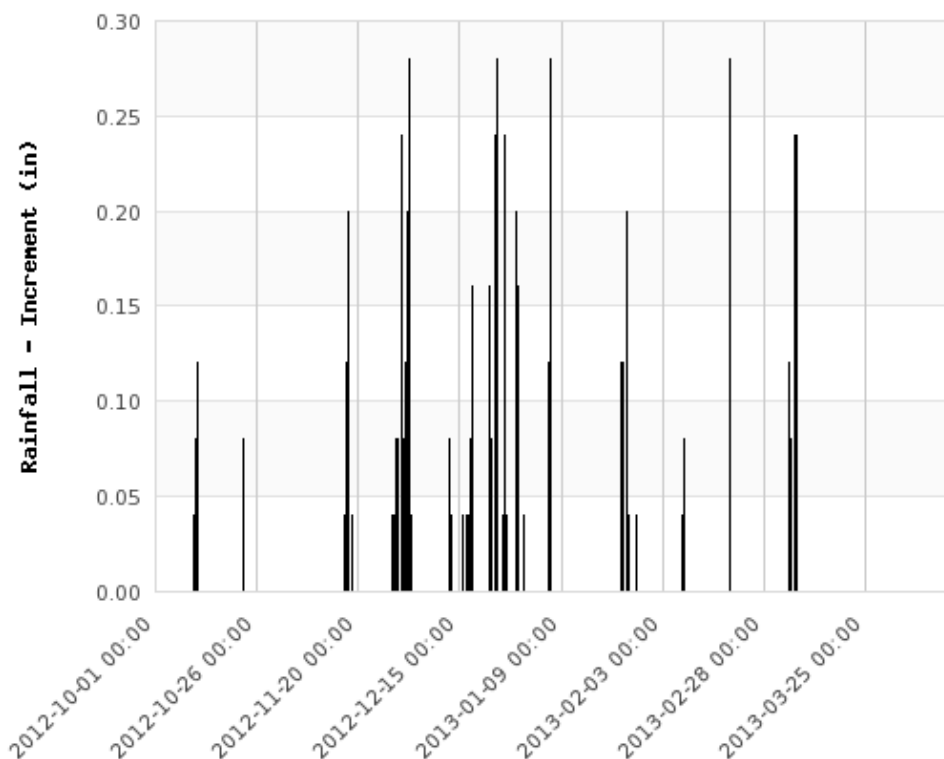


Figure 2.3 Bald Mt. Daily Rainfall (8 am to 8 am), October 1, 2012 to March 31, 2013

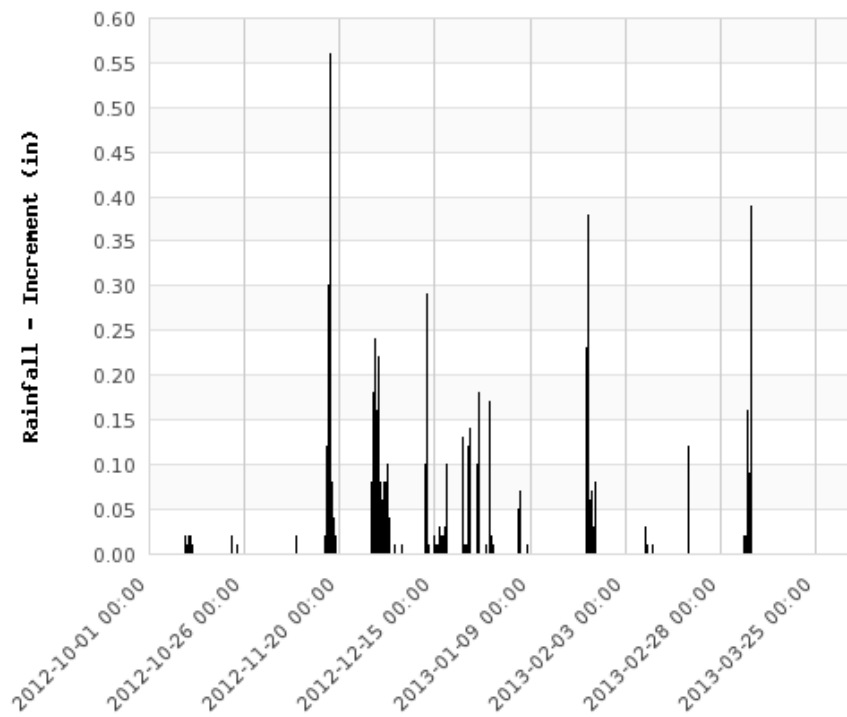


Figure 2.4 San Marcos Pass Daily Rainfall (8 am to 8 am), October 1, 2012 to March 31, 2013

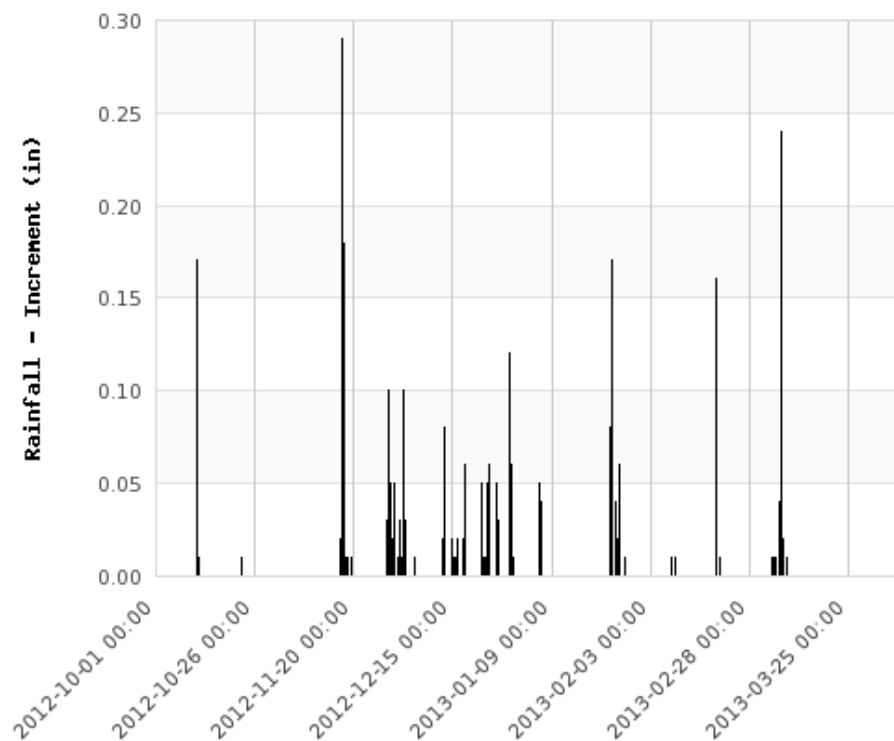


Figure 2.5 Gibraltar Dam Daily Rainfall (8 am to 8 am), October 1, 2012 to March 31, 2013

2.2 Hydrologic Conditions During the 2012-2013 Rainy Season

There was very low runoff in local area streams due to the dry rainy season. Figure 2.6 provides the Sisquoc River discharge near Sisquoc for the period of October 1, 2012 through April 30, 2013. None of the Santa Ynez River gaging sites showed any runoff during this time period.

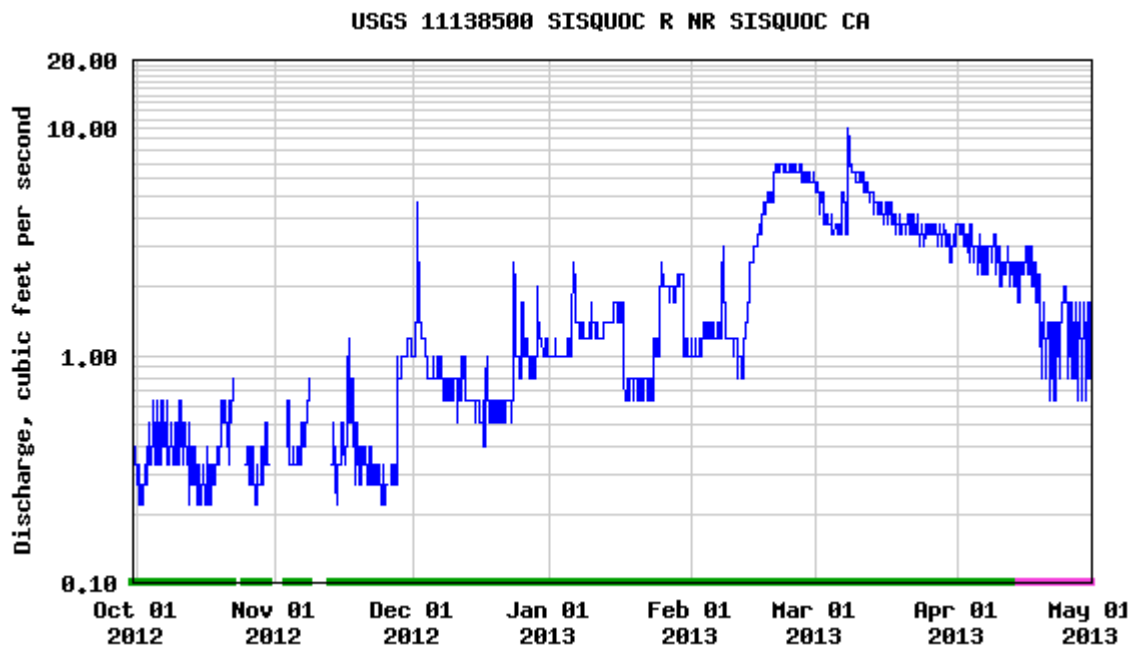


Figure 2.6 Discharge, Sisquoc River near Sisquoc, October 1, 2012 to April 30, 2013

2.3 Summary of Seeding Operations

The contract period ran from December 1, 2012 – March 15, 2013. Seeding opportunities occurred on eight days during the season. There were a total of six seeded storm events, including four in December, one in February and one in March. Table 2-2 summarizes the ground-based seeding operations for the season. A total of 49 flares were successfully

burned at the three ground sites, releasing an estimated 735 grams of seeding material. Individual operational periods are discussed in more detail in the following section.

Table 2-2 Ground-Based Seeding by Location
(Time references are PST for all of this season's storm events)

Date	Mt. Lospe	Harris Grade	Sudden Peak	Gaviota	West Camino Cielo	Gibraltar Rd.
Dec. 12	1622(17),1626 (18)	1627(32) ³ ,1634 (31)	1639(17)	1718(17)	1938(17)	2052(17)
Dec. 22	0650(19)	0719(30)	--	1004(18)	1117(18)	--
Dec. 25	2200(20)	2327(29)	2225(18)	2238(19)	--	--
Dec. 26	--	--	--	--	--	0032(18)
Dec. 29	0305(21),0349(22)	0354(28)	0315(19),0457(20)	0450(20) ²	0515(19)	--
Feb. 19	1409(17),1606(18)	1617(32) ^{3?} ,1639(31)	1629(17),1647(18)	--	--	--
Mar. 7	--	1837(30),1854(29),2006(28),2027(27),2104(26),2156(25)	1632(19),1738(20),1840(21) ³ ,1954(22),2016(23)	1848(17),1956(18),2023(19),2101(20),2121(21),2144(22)	1829(30),2200(18),2234(19),2316(20)	2353(17)
Mar. 8	--	--	--	--	--	0019(18)
Total Flares	8	11	10	9	7	4

¹ PST unless otherwise noted

² Misfire, bad flare

³ Misfire, flare tested good

2.4 **Significant Storm Events of the 2012-2013 Season**

This section describes significant storm events in the Santa Barbara project area during the 2012-2013 operational period (December 1, 2012 to March 15, 2013). A general discussion of the meteorology accompanying each event is given, followed by a description of the seeding operations (if any). Wind directions, when provided, are always reported in the direction from which the wind is blowing (e.g., a southerly wind means the wind is blowing from the south

toward the north). Wind speeds are usually reported in nautical miles per hour (knots), with 1 knot equal to 1.15 miles per hour. Figures shown in the storm summaries may include the following:

- 1) Satellite images; infrared (IR), water vapor (WV), or visible. IR images provide information both day and night and also provide information on cloud top temperatures. Visible images are only available during daylight hours but the resolution on the images is better than the resolution on the IR products.
- 2) National Weather Service NEXRAD radar images, showing reflectivity values associated with precipitation near the times when seeding occurred. These displays are called Plan Position Indicator (PPI) images which are horizontal depictions of the radar reflectivity values within range of the radar. These images give an indication of the type, intensity, and extent of precipitation during seeding periods. Wind direction and velocity are also observed by the NEXRAD radars through the Doppler feature, which is part of the NEXRAD design. Plots of winds in the vertical in 1000-foot increments are available with a 6-minute time resolution from NEXRAD radars. These displays are called Velocity Azimuth Displays (VAD).
- 3) Skew-T upper-air soundings from Vandenberg AFB. The skew-T sounding is a plot of temperature, dew point, and winds vs. height, observed by a radiosonde (balloon borne weather instrument). This sounding information is useful for analyzing various parameters of the atmosphere including temperature and moisture profiles, and convection potential. Soundings are available twice daily at 0400 and 1600 PST. The 700 mb (approximately 10,000 feet) temperatures are frequently reported in the following storm summaries. NAWC typically prefers to see these temperatures at -5°C or colder during seeded periods since silver iodide becomes effective as a seeding agent between -4 and -5°C . The closer the height of the -5°C level is to the ground seeding, the quicker a seeding effect will begin to be produced as the convection elements embedded in the convection bands. These convective elements vertically transport the seeding material from the ground seeding sites to colder temperatures aloft.

4) Rainfall maps of Santa Barbara County are presented, showing approximate storm rainfall totals at various county stations. These totals are based on data obtained from the Santa Barbara County Flood Control District, which contains 24-hour accumulated totals.

Times are in PST or Greenwich Mean Time (GMT) for all of the storm events described in this season's report (PST = GMT - 8 hours).

November 29-30, 2012

A large system in the eastern Pacific pushed a frontal precipitation band through the area on November 29-30, 2012. Although the season had not officially started, NAWC communicated with Dennis Gibbs, Senior Hydrologist for the Agency, on November 30 stating that seeding sites were ready and seeding could be conducted on November 30 if conditions became favorable. However, this event proved to be unfavorable for seeding due to warm temperatures (freezing level near 700 mb) and lack of organized convective bands. NAWC usually prefers for the temperatures at the 700 mb level (~ 10,000 feet) be at or below -5°C . The reason for this being -5°C is generally considered to be the activation threshold of silver iodide. Seeding material released from the ground needs to be transported vertically to this effective level in order to start the formation of ice crystals. This vertical transport can be accomplished by the updrafts contained within and below the convection bands but the higher the -5°C the less certain this transport becomes plus increasing vertical transport distances diminish the concentration of the seeding material. Once ice crystals are formed, they need time to grow into snowflakes before their terminal velocities will become high enough to begin falling to the ground. All of the above processes are time dependent; the longer the time, the further downwind any effects likely to be produced will occur since the convection bands are moving generally in a west to east direction at velocities anywhere from 10-15 nautical miles per hour (knots) to perhaps 30-40 knots. This event did bring significant rainfall amounts to the southeastern portion of the County (e.g., San Marco Pass recorded over 4" of rainfall during the event). Figure 2.7 shows rainfall totals recorded with this system.



Figure 2.7 Rainfall totals for November 29-30, 2012

December 2, 2012

The same general system responsible for the November 29-30 rainfall brought another round of precipitation on December 2. However, this system had tapped into a plume of tropical/subtropical moisture originating from another system near Hawaii. As a result, temperatures were very warm aloft with a 700-mb temperature near +2 C. Although the December 2 precipitation event was too warm for seeding, it brought some moderate rainfall totals to the County as shown in Figure 2.8.



Figure 2.8 Rainfall totals for December 2, 2012

December 12-13, 2012

A frontal passage on December 12 brought the first seeding opportunity of the season, during the afternoon and evening hours. The 700-mb temperature dropped from about -2 to -8° C with the frontal passage. A total of 8 flare firings were attempted, with 7 of those burning successfully. Flares were burned from all 6 sites as the convective frontal precipitation band moved across the area. Figure 2.9 is a satellite image at 2030 PST, and Figure 2.10 is a radar image shortly after this as the convective band moved through the eastern portion of the County. Scattered showers are visible in the colder air mass to the west. The accompanying vertical wind profile is shown in Figure 2.11, depicting a shift to northwesterly winds with the frontal passage just after seeding operations had ended. Rainfall totals for this event are shown in Figure 2.12.

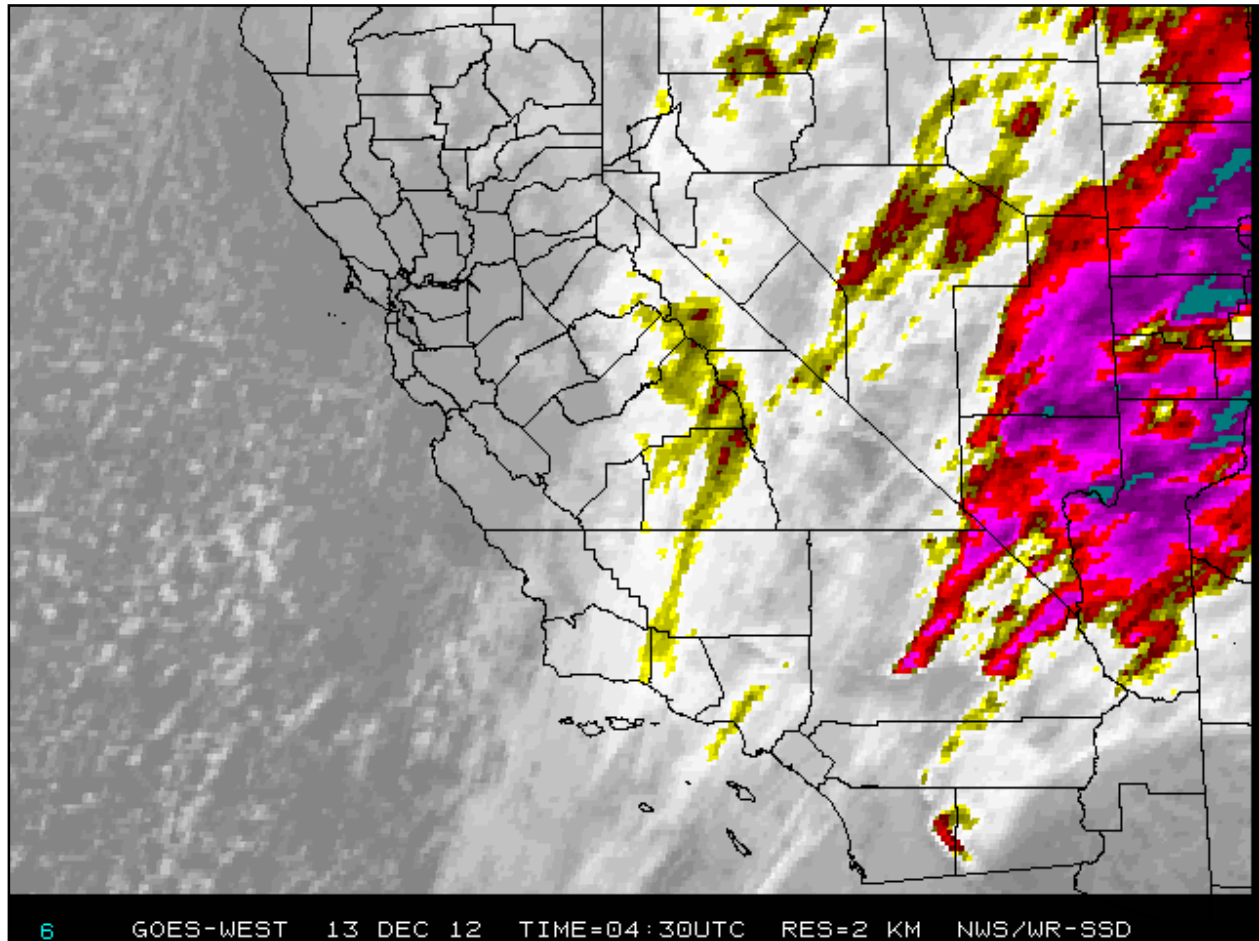


Figure 2.9 Infrared satellite image at 2030 PST, December 12, 2012

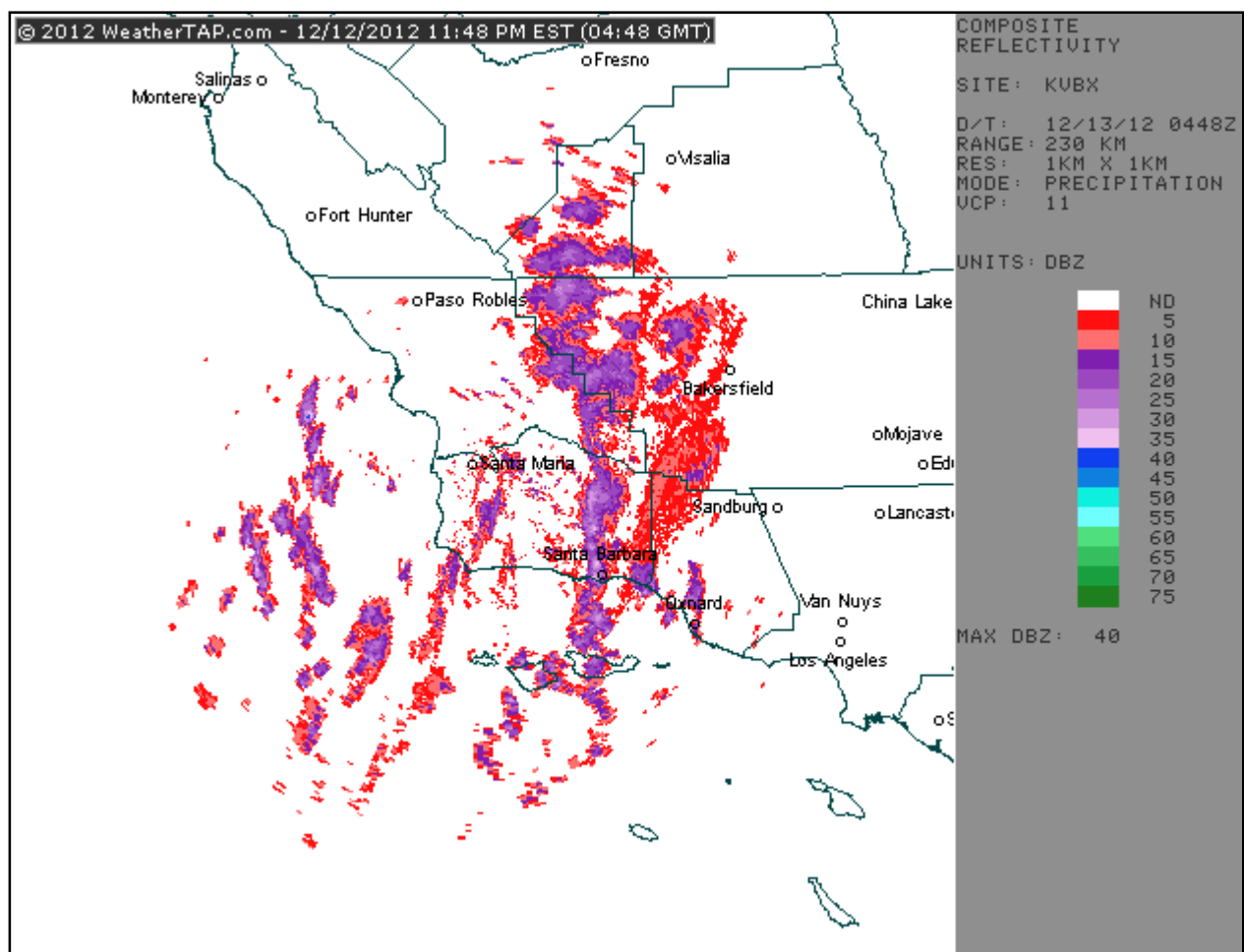


Figure 2.10 Radar image at 2048 PST, December 12, 2012

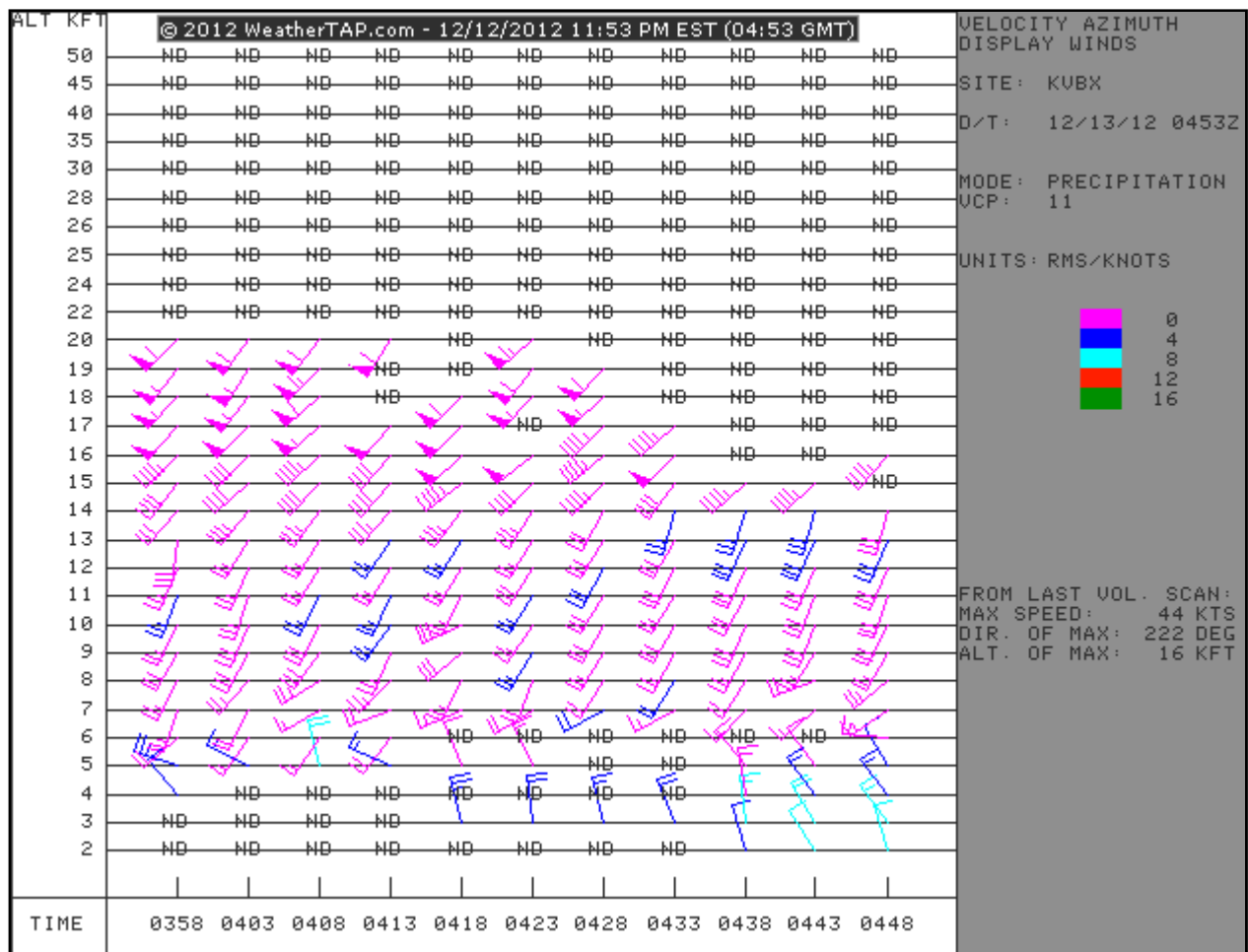


Figure 2.11 Vandenberg VAD wind profile ending at 2048 PST December 12



Figure 2.12 Rainfall totals for December 12-13, 2012

December 14, 2012

A weak embedded wave in northwesterly upper-level flow on December 14 produced only very light precipitation amounts, less than 0.1". Winds and other weather conditions remained unfavorable for seeding.

December 22, 2012

A large system moved onshore over the Pacific Northwest on December 22, with the most significant storm activity remaining to the north. However, a weak precipitation band passed through the County during the morning hours of the 22nd, and seeding was conducted from four sites (Mt. Lospe, Harris Grade, Gaviota, and West Camino Cielo with 1 flare each). Figure 2.13 is a satellite image at 0700 PST as the band began moving into the County. Cloud tops were relatively low (warm) as seen in this infrared image. Figures 2.14 and 2.15 are the radar reflectivity and wind profile, respectively, around 1000 PST as the band moved across the County. The wind profile plot indicated that the precipitation band extended to about 14,000 feet in elevation. The 700-mb temperature was around -3°C , so the cloud tops were likely in an ideal temperature range for seeding.

Rainfall amounts ranged up to around a half inch in some areas, as shown for the County gage sites in Figure 2.16. Totals for the day were highest in the northwestern portion of the County, and in the mountains.

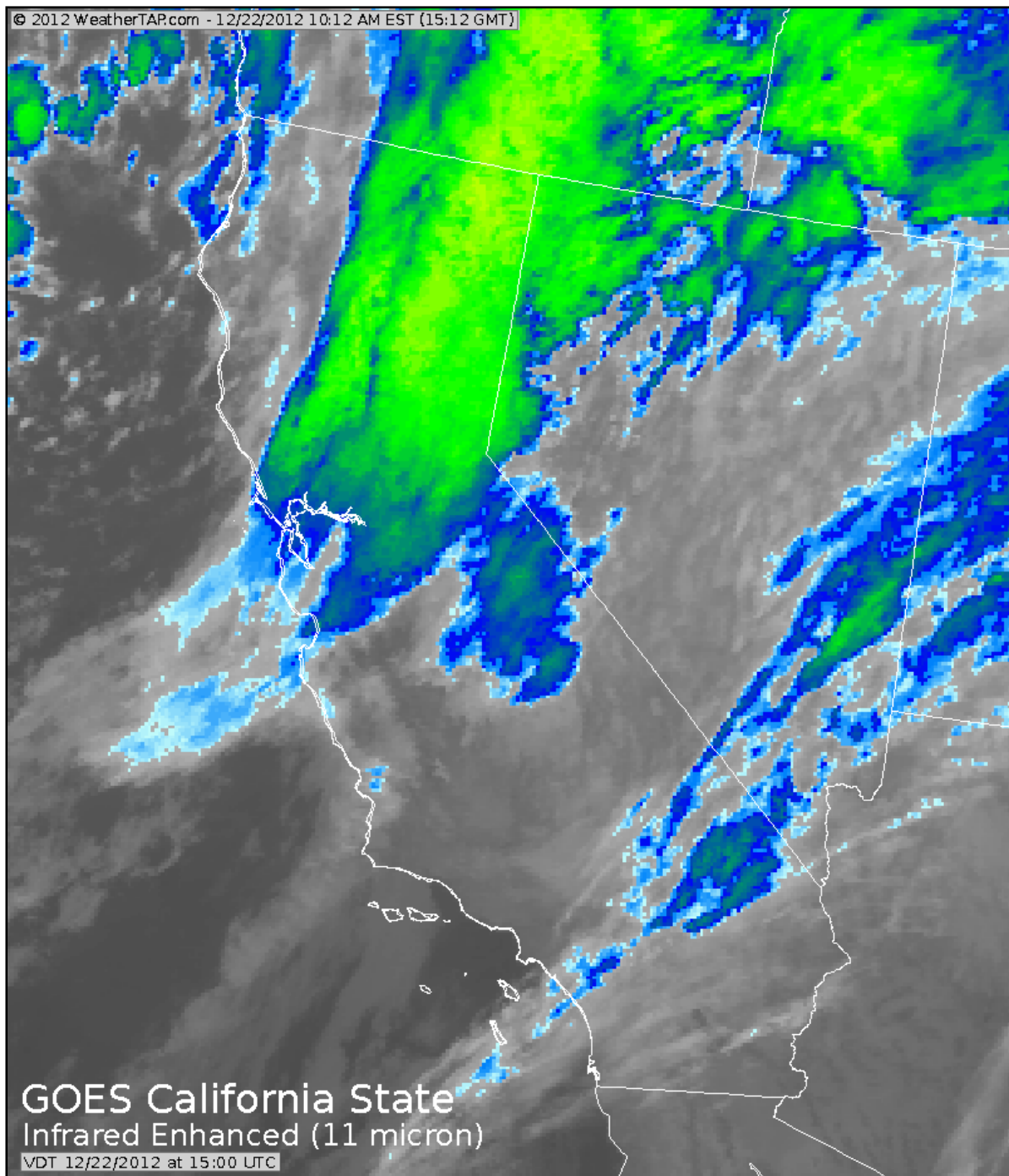


Figure 2.13 Infrared satellite image at 0700 PST, December 22, 2012

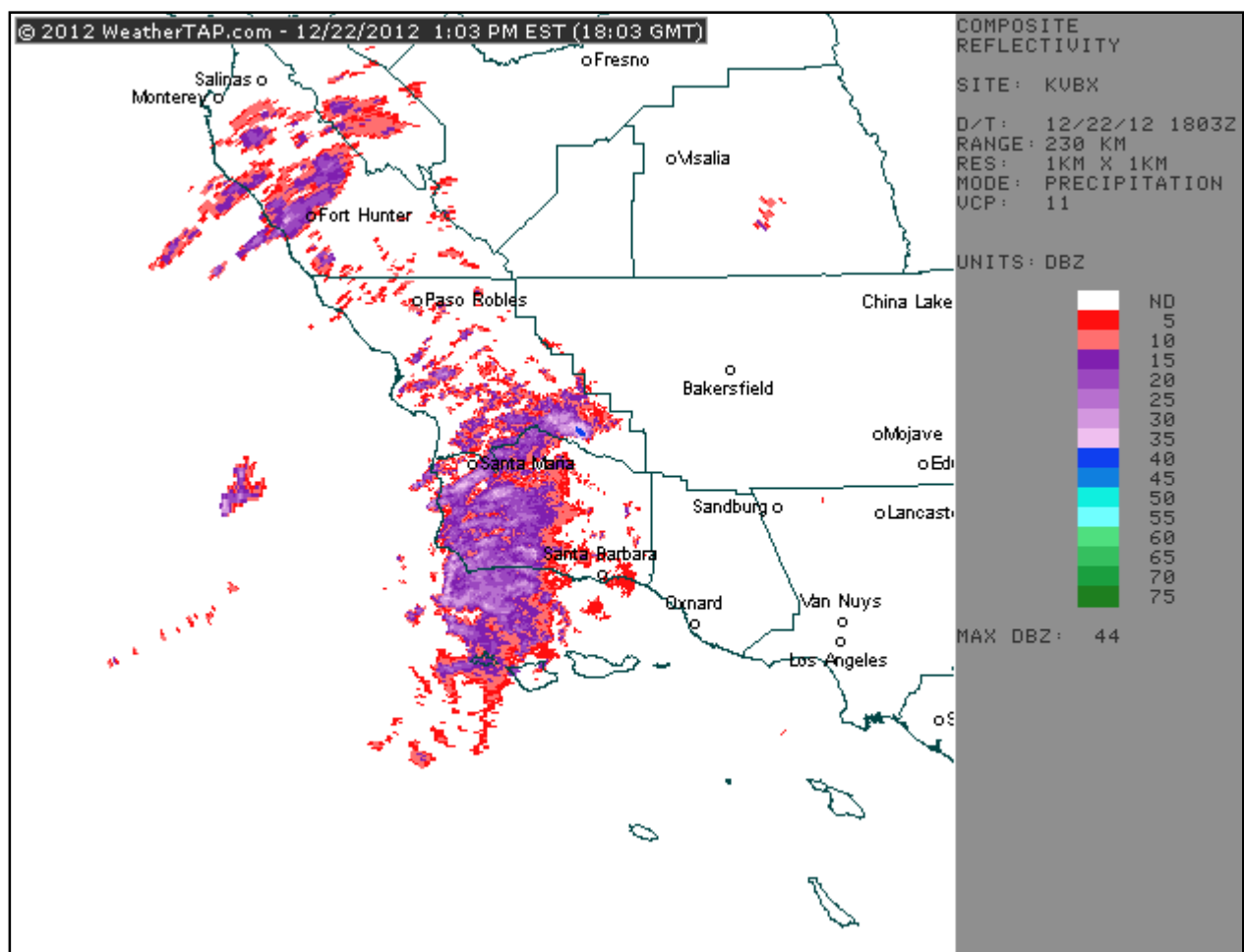


Figure 2.14 Radar reflectivity at 1003 PST, December 22, 2012

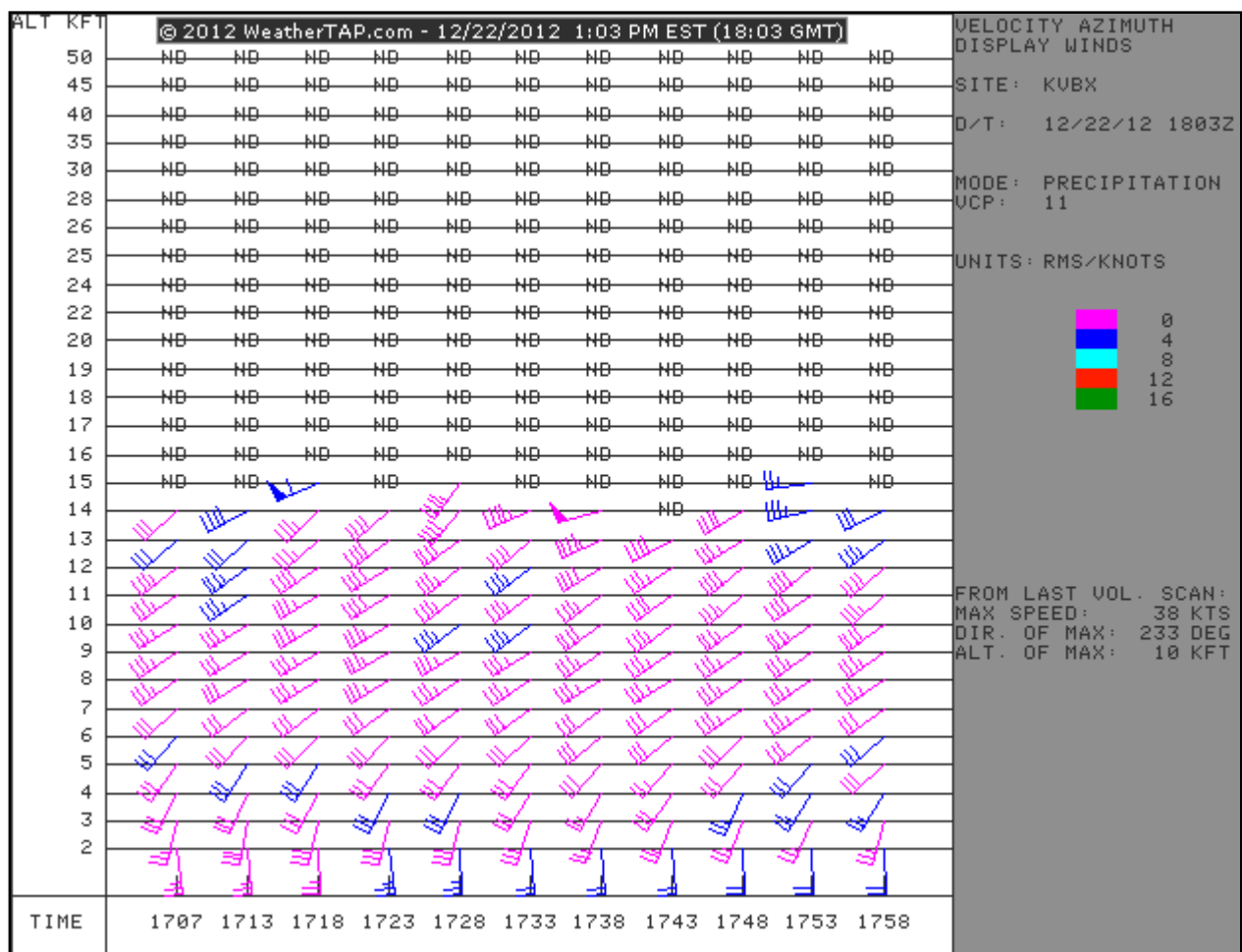


Figure 2.15 Wind profile ending at 0958 PST on December 22, 2012



Figure 2.16 Rainfall totals for December 22, 2012

December 23-24, 2012

A frontal system brought light to moderate rainfall to the area on December 23-24. Temperatures were too warm for seeding operations, with the 700-mb temperature around -1 to -2°C . Figure 2.17 shows rainfall totals from this event.



Figure 2.17 Rainfall totals for December 23-24, 2012

December 25-26, 2012

A fast-moving cold front brought a precipitation band across the area during the evening of December 25. The 700-mb temperature cooled to around -5°C with the frontal passage, resulting in a brief window of seeding opportunity. A total of 4 flares were burned, one each from Mt. Lospe, Harris Grade, Sudden Peak, and Gaviota. An infrared satellite image, radar image, and radar wind profile are shown in Figures 2.18 – 2.20, near the time of seeding operations. Rainfall totals for this event are shown in Figure 2.21.

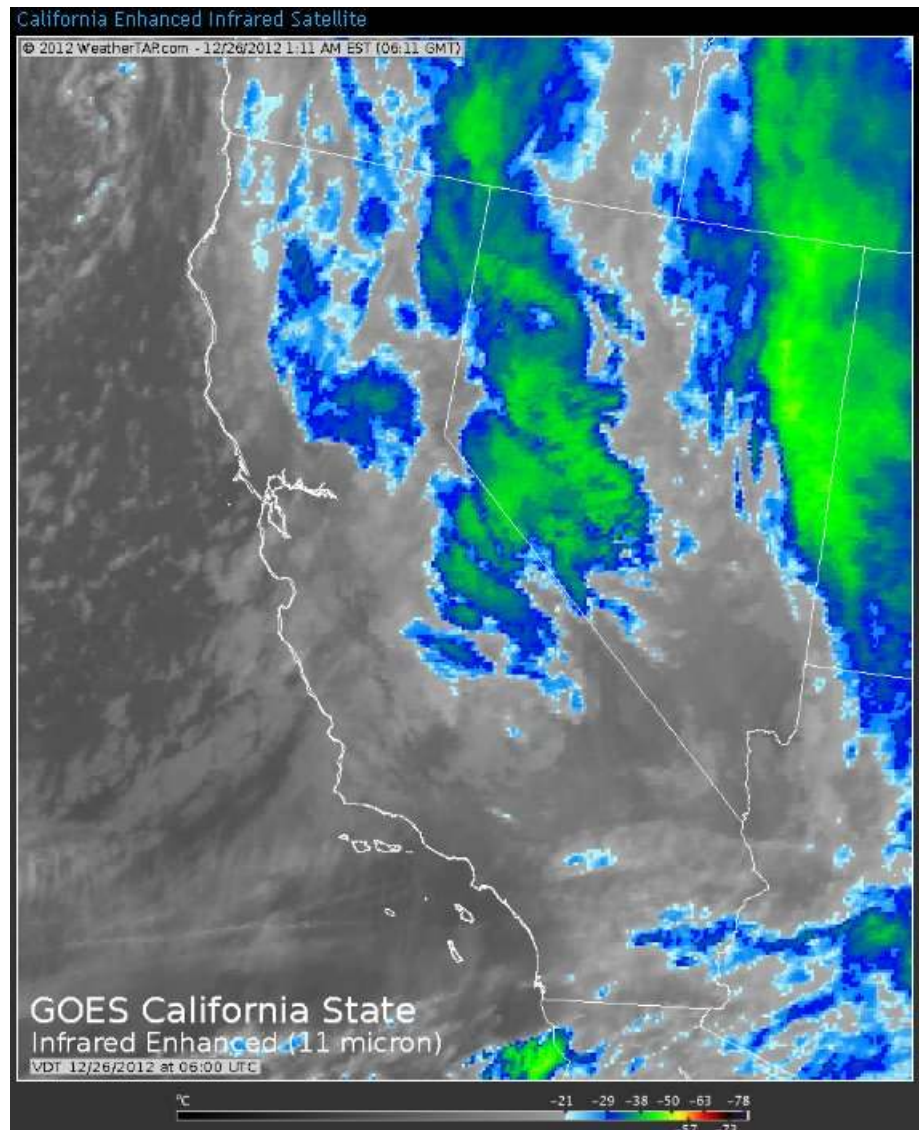


Figure 2.18 Infrared satellite image at 2200 PST December 25, 2012

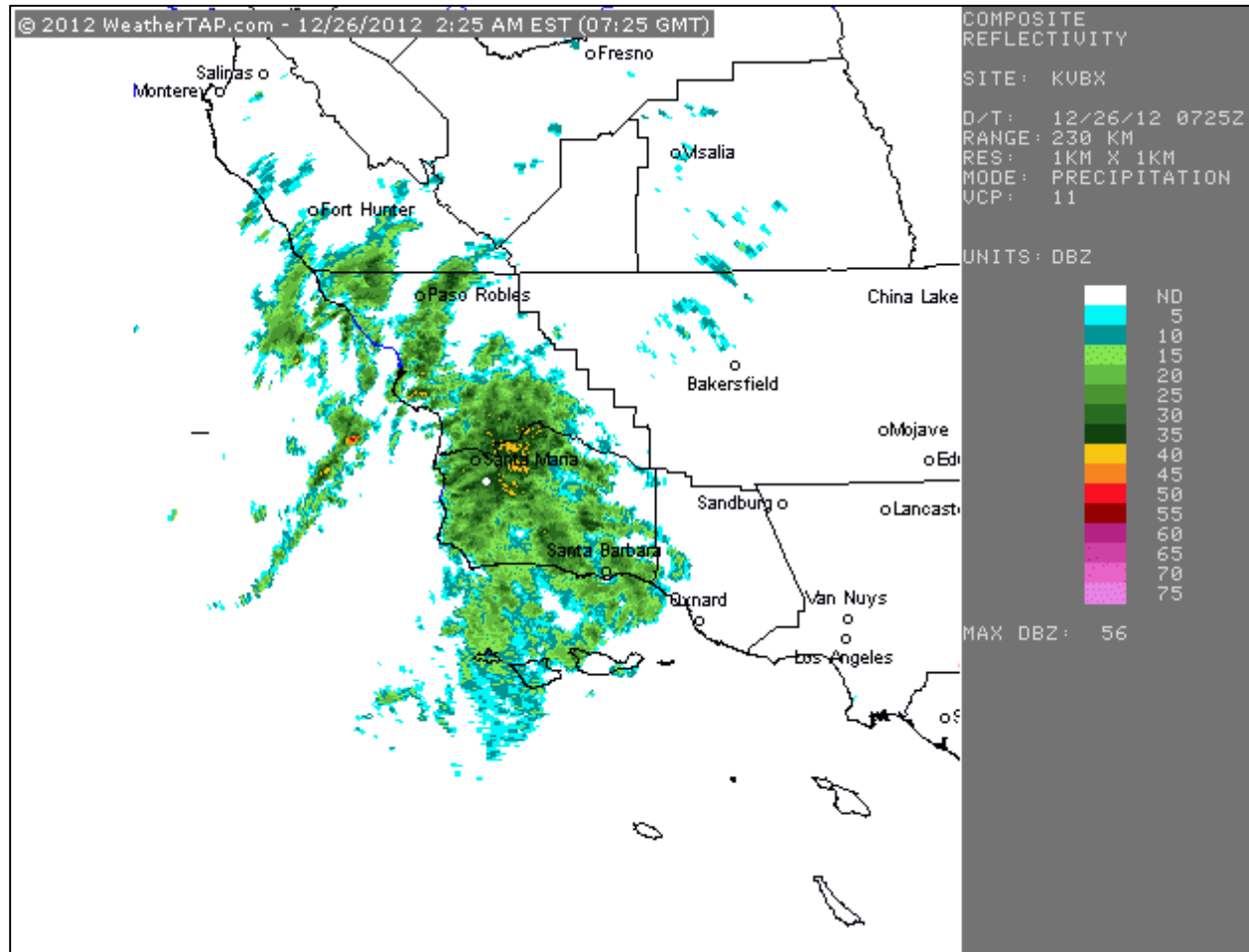


Figure 2.19 Radar image at 2325 PST December 25, 2012

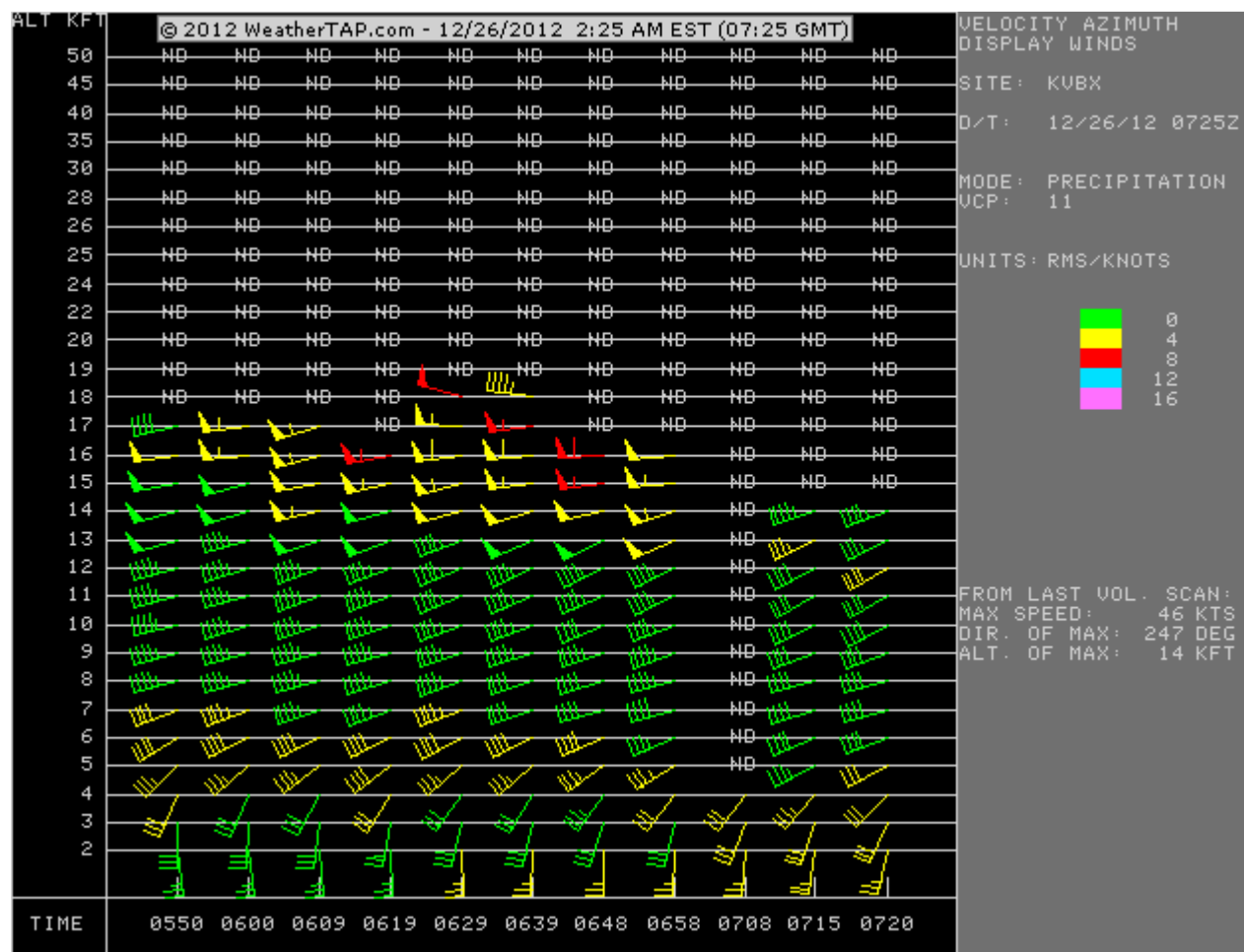


Figure 2.20 Wind profile ending at 2320 PST, December 25, 2012



Figure 2.21 Rainfall totals for the December 25-26 storm event

December 28-30, 2012

A cold frontal system affected the area during the December 28-30 period, with the bulk of the precipitation (as well as the seeding operations) occurring with a band passage during the early morning hours of the 29th. The 700-mb temperature was in the -5 to -7° C range during most of this period. Seven flares were programmed to burn between 0305 and 0515 PST, with six of these actually burning. These six were located at Mt. Lospe (2), Harris Grade (1), Sudden Peak (2), and West Camino Cielo (1). Figure 2.22 shows a 4-hour HRRR model forecast for 0100 PST, as the band was approaching the County. The HRRR is one of the short-range, higher resolution models used as a forecast tool for these convective bands (more details provided in

Section 6). Figure 2.23 provides an infrared satellite image at 0345 PST, and Figures 2.24 and 2.25 are radar reflectivity and wind profile images, respectively, during the time of seeding operations. Figure 2.26 shows rainfall totals for this event.

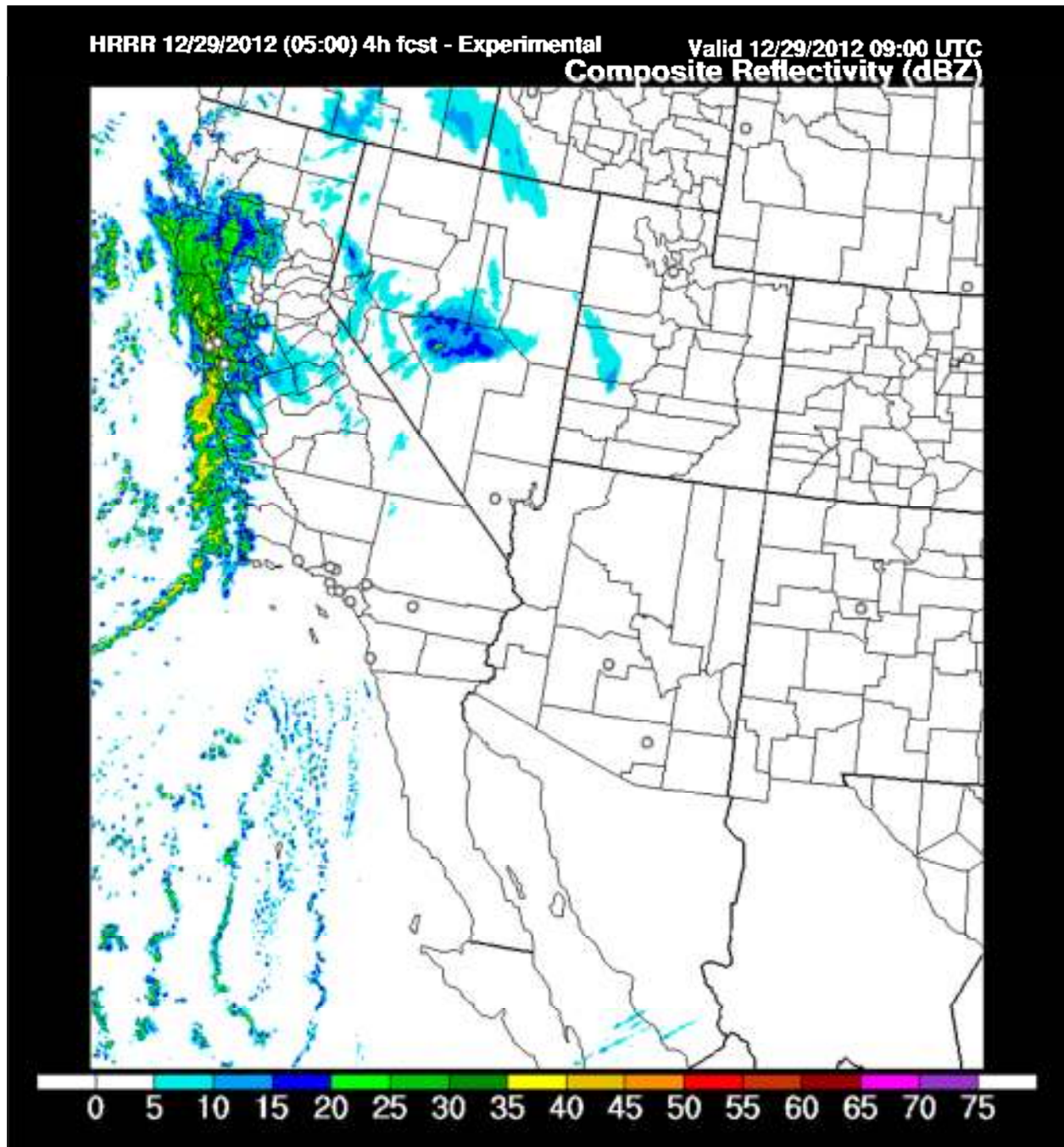


Figure 2.22 HRRR 4-hour forecast for 0100 PST, December 29, 2012

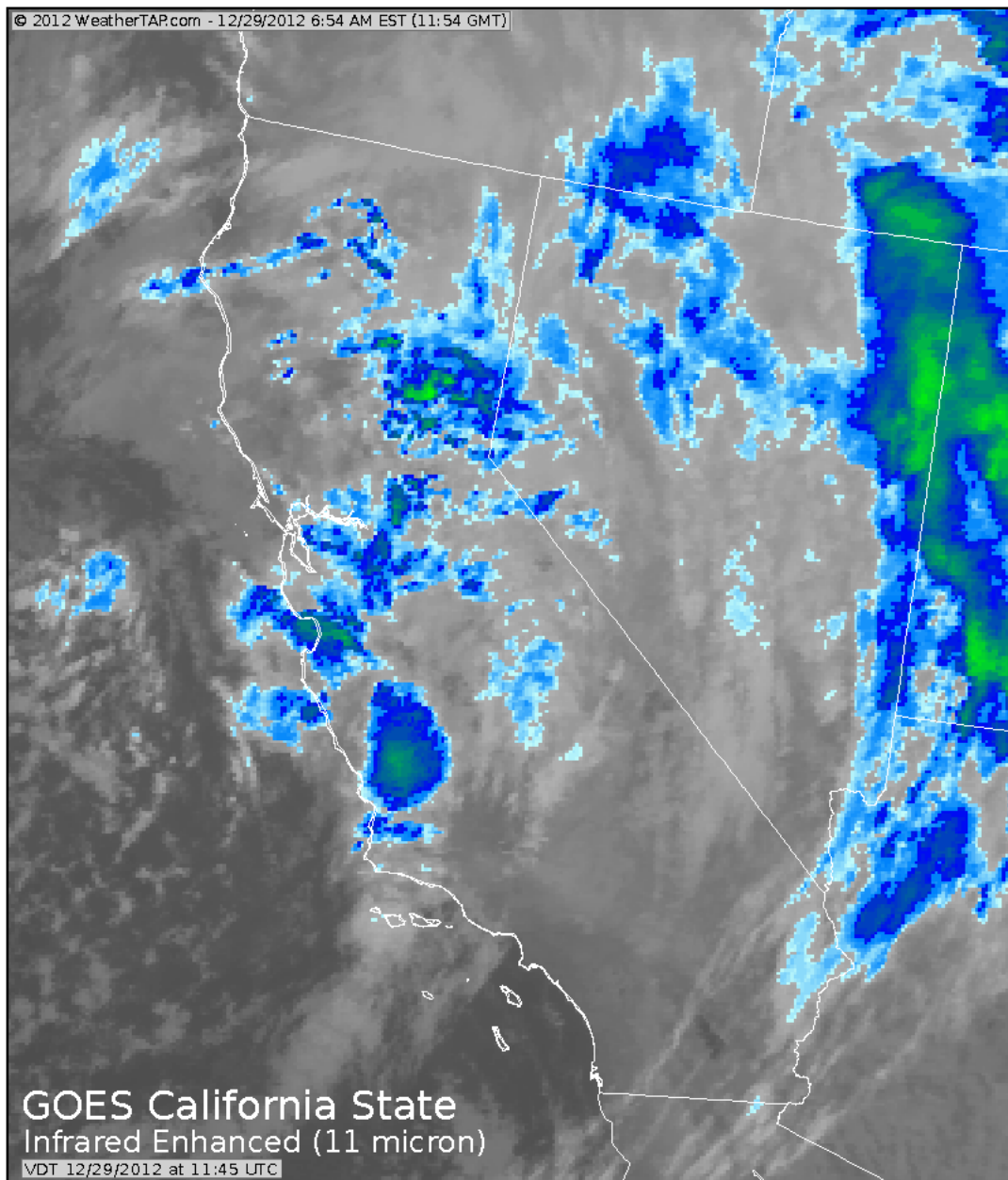


Figure 2.23 Infrared radar image at 0345 PST, December 29, 2012

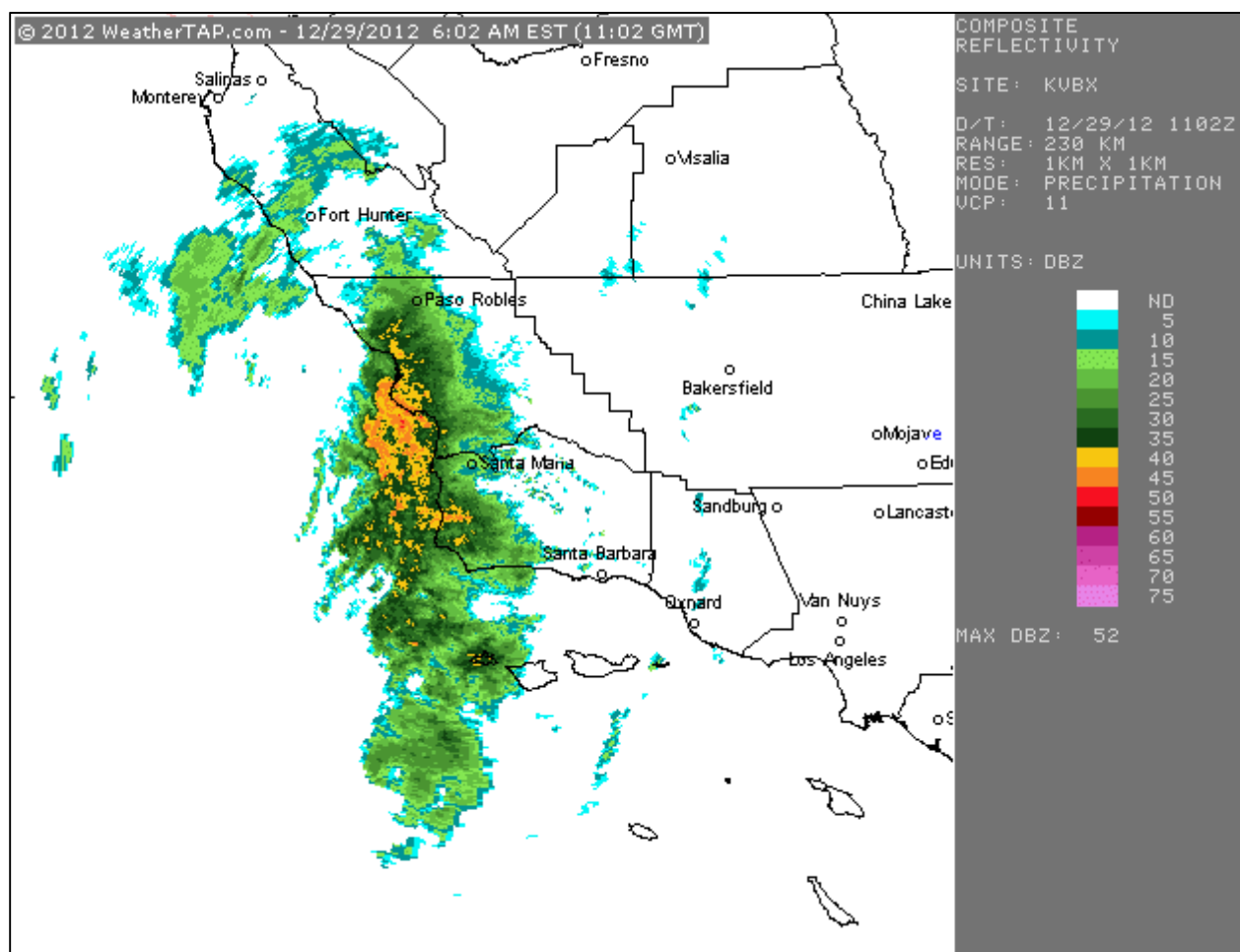


Figure 2.24 Radar reflectivity at 0302 PST December 29, 2012

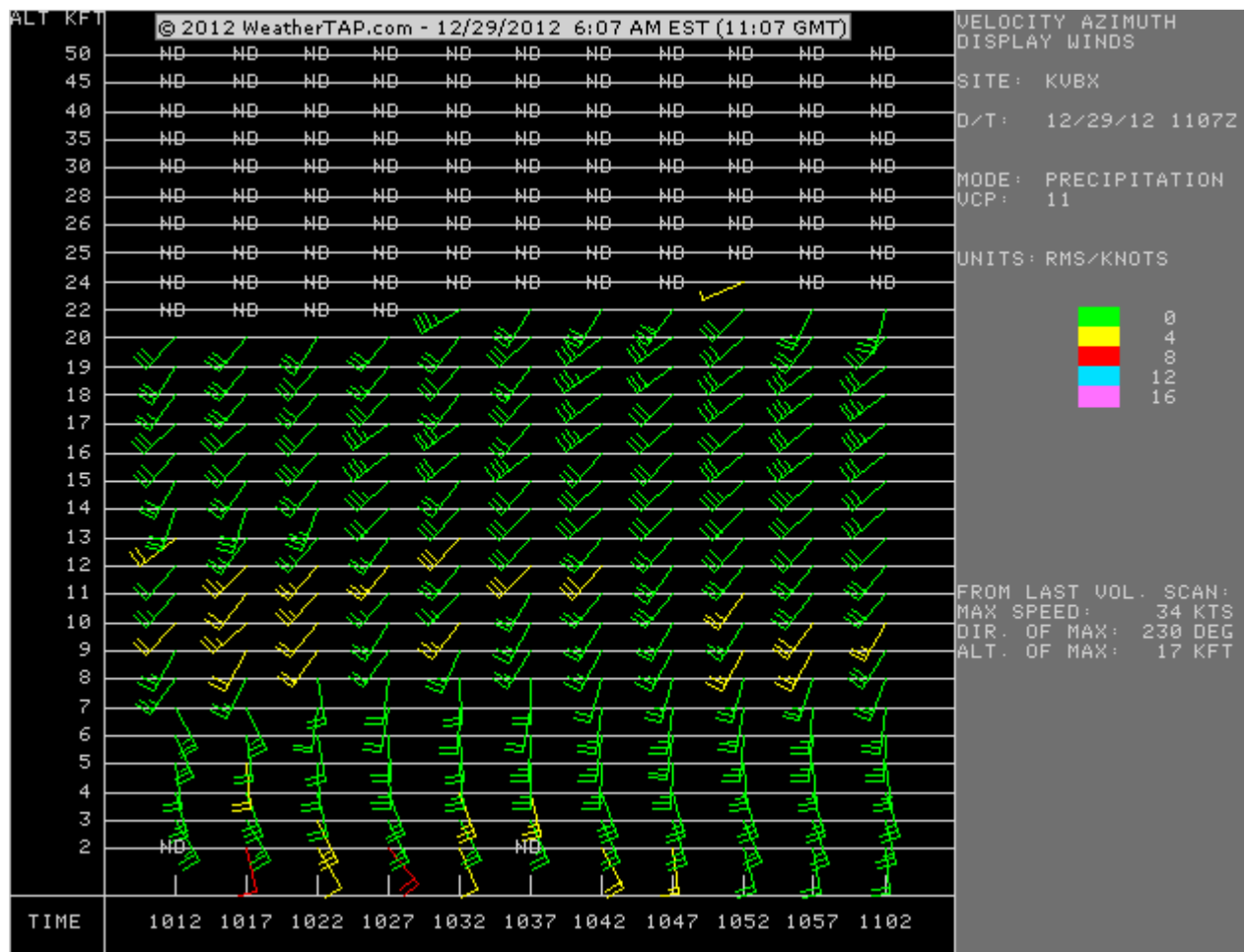


Figure 2.25 Wind profile ending at 0302 PST December 29, 2012



Figure 2.26 Rainfall totals for the December 28-30 event

January 5-6, 2013

A weak frontal system began to develop as a closed upper-level circulation approached the County late on January 5. Precipitation was light and scattered, with no organized band activity. Winds shifted to the northwest around midnight on the night of January 5-6. No seeding opportunity occurred with this system. Figure 2.27 shows rainfall totals for this event.



Figure 2.27 Rainfall totals for January 5-6, 2013

January 23-25, 2013

Two storm systems merged over the area during the January 23-24 period. A weakening low-pressure center from the mid-latitudes remained offshore during the period, gradually moving to a position south of Santa Barbara County by January 25. Meanwhile, a warm subtropical system from off the coast of Mexico was drawn northward into California on January 24 by the southerly flow ahead of the first storm system. The result was a period of rainfall over the County, primarily late on January 23 and on the 24th. Temperatures were very warm in association with this event, due to the tropical and subtropical origin of much of this moisture, with the 700-mb temperature near or above 0 C during much of the precipitation period. Some precipitation lingered near the southern portion of the County on January 25, with the main low center position to the south of the County. Although this system produced reasonably good rainfall totals (Figure 2.28), no seeding opportunities developed because of the very warm temperatures and lack of organized band development.



Figure 2.28 Rainfall totals for January 23-25, 2013

February 7-8, 2013

A cold upper-level trough moved southward along the California coast during the February 7-8 period, with disorganized shower activity that remained mostly offshore. The western portion of the County received the most precipitation; with totals near a half inch common there. The 700-mb temperature dropped to -12°C at Vandenberg AFB by the morning of the 8th. No seeding opportunity developed, due to the position of the trough and lack of convective band organization. Figure 2.29 shows precipitation totals with this event.



Figure 2.29 Rainfall totals for February 7-8, 2013

February 19-20, 2013

A very cold system moved southward along the northern/central California coast on February 19, then inland across the southern half of the state by the morning of the 20th. The 700-mb temperature dropped from -10° C during a frontal precipitation band on the 19th, to -15° C as the core of the trough passed over the area by early on the 20th. Seeding was conducted during the afternoon hours of the 19th with the frontal band passage. A total of 6 flares were burned, 2 each at Mt. Lospe, Harris Grade, and Sudden Peak. Figures 2.30 – 2.32 show a visible spectrum satellite image, radar reflectivity, and radar wind profile, respectively, during the seeded band passage around 1600 PST. Rainfall totals with this event are shown in Figure 2.33.

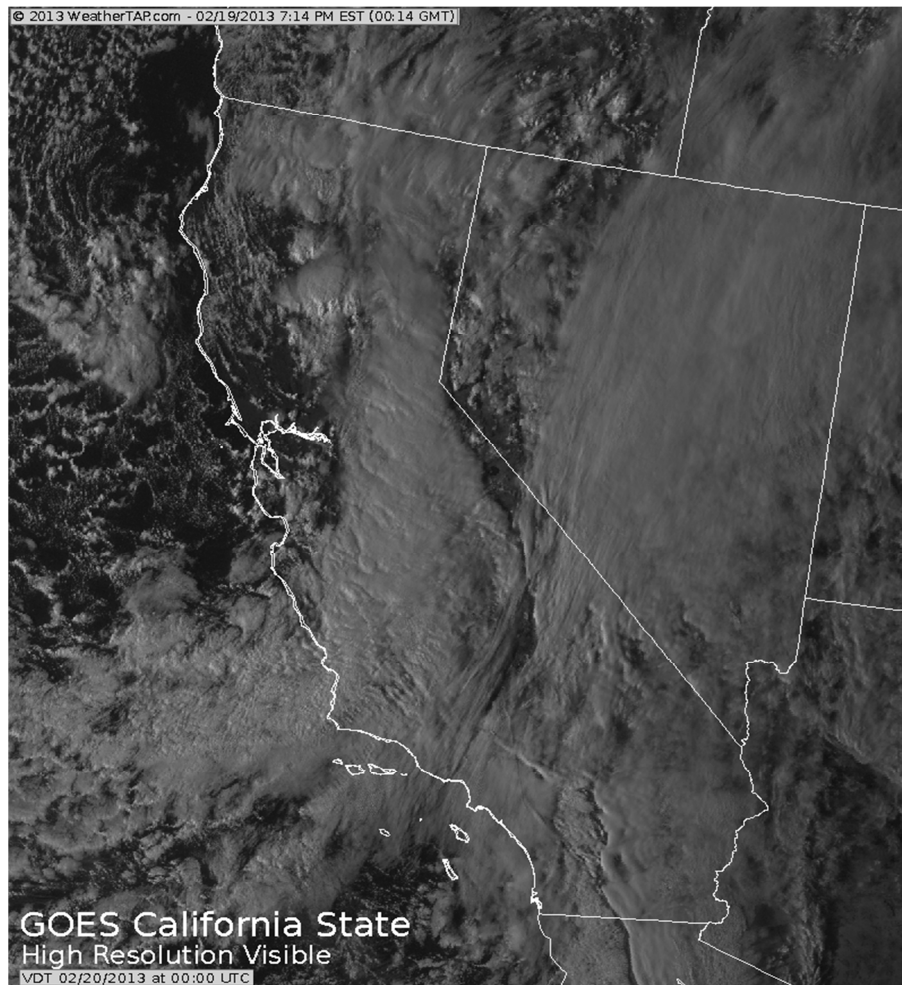


Figure 2.30 Visible spectrum satellite image at 1600 PST, February 19, 2013

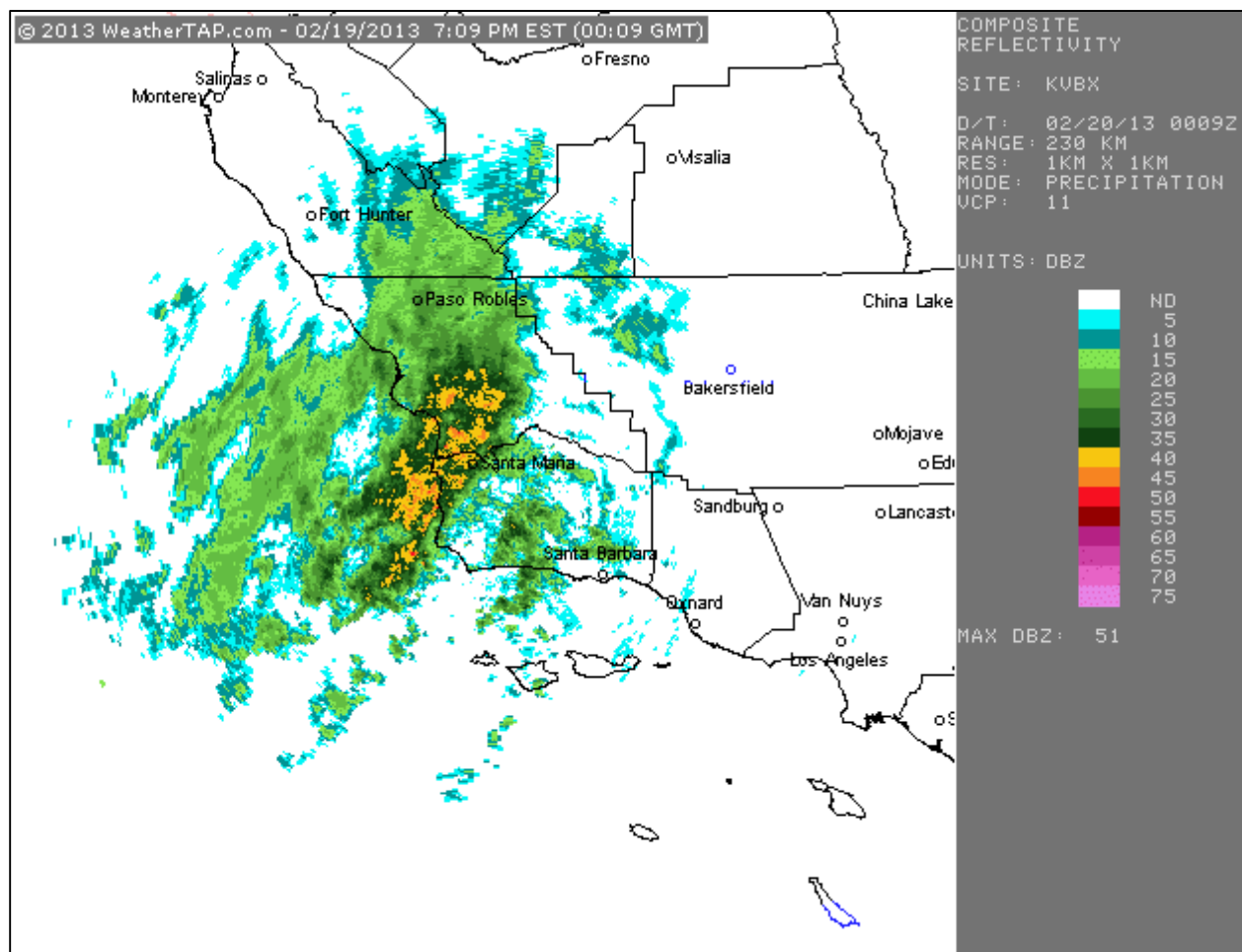


Figure 2.31 Radar reflectivity at 1609 PST, February 19, 2013

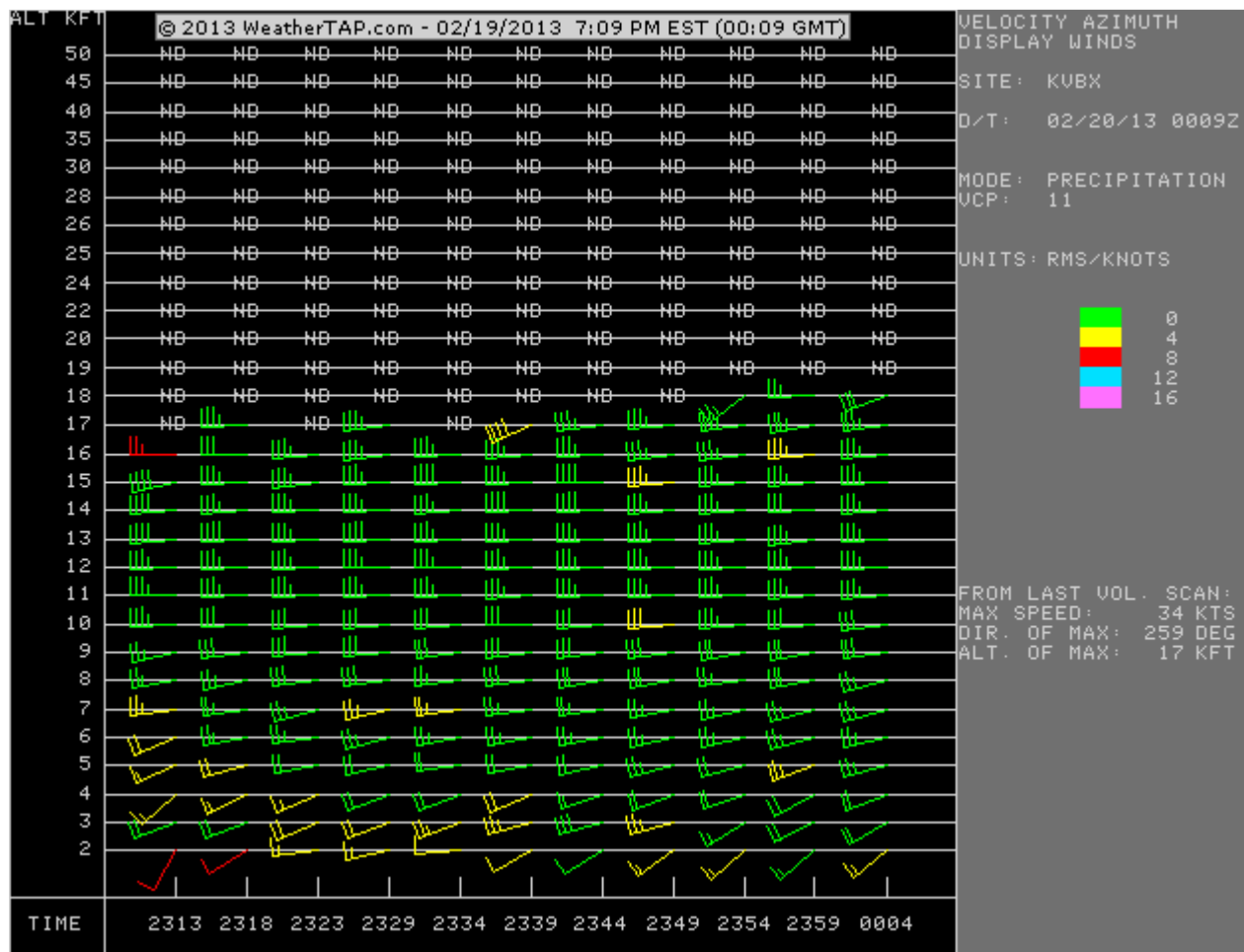


Figure 2.32 Wind profile ending at 1609 PST, February 19, 2013



Figure 2.33 Rainfall totals for the February 19-20 storm event

March 7-8, 2013

A low pressure trough situated off the California coast moved southward on March 7, developing a closed circulation as it moved to the south of Santa Barbara County. It remained offshore to the south of the County through much of the 8th before moving inland in far southern California late on March 8. This trough resulted in a broad, slow-moving precipitation band over the County on the evening of March 7 and during the overnight hours. The 700-mb temperature was between about -7 and -10° C during this period, providing a good seeding opportunity in nearly due southerly flow with this event. A total of 22 seeding flares were programmed to burn during this period, and 21 actually did burn. Seeding flare totals include 6 at Harris Grade, 4 at

Sudden Peak, 6 at Gaviota, 4 at West Camino Cielo, and one at Gibraltar Road. This was the last seeding opportunity of the season, and by far the most heavily seeded storm event of the season as well.

Figure 2.34 is the GOES-west entire area infrared satellite image map at 2000 MST on March, showing the low pressure center positioned off the California coast. A closer view satellite image near this same time (Figure 2.35) shows the main frontal band positioned near Santa Barbara County.

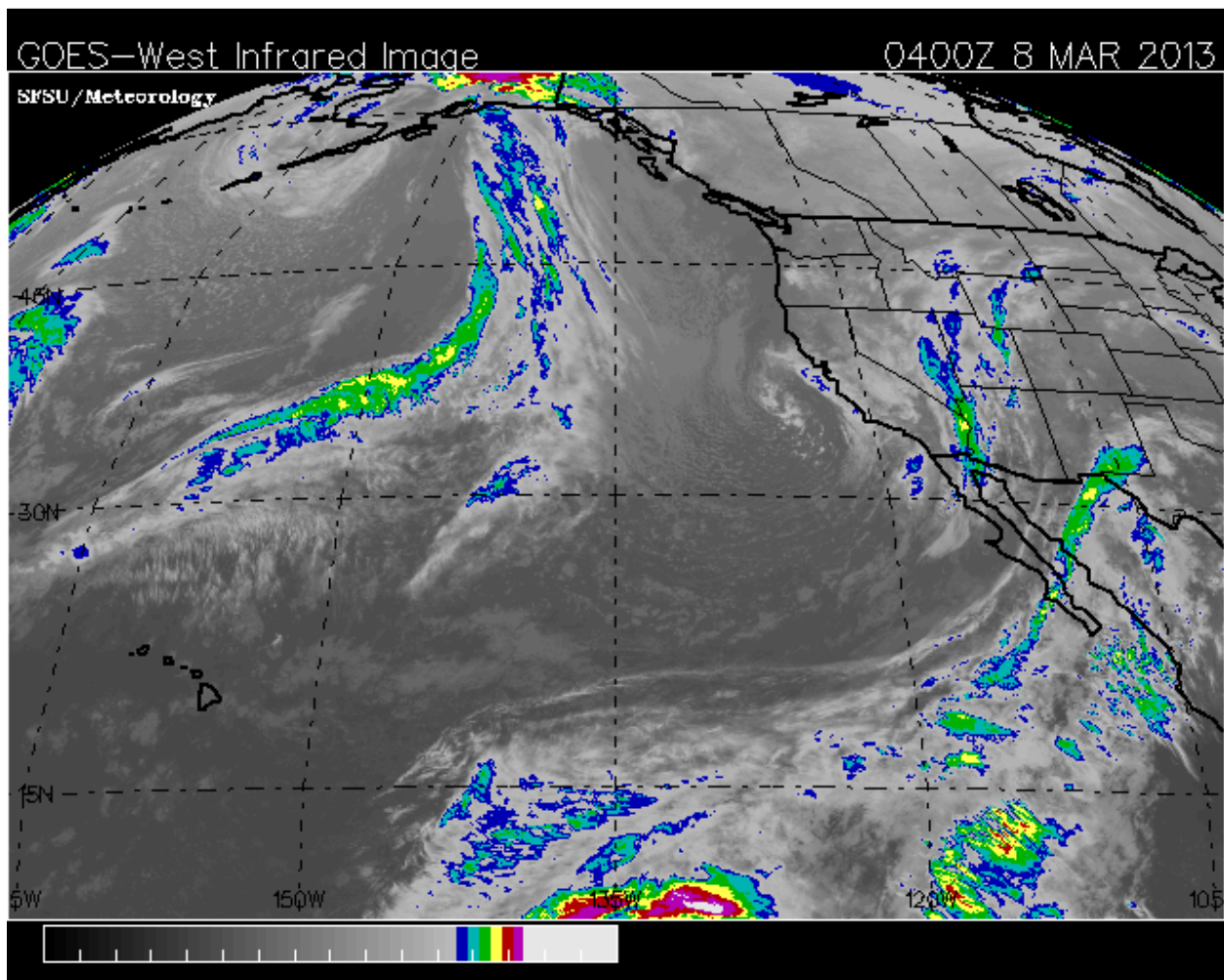


Figure 2.34 GOES-west entire area satellite image at 2000 PST, March 7, 2013

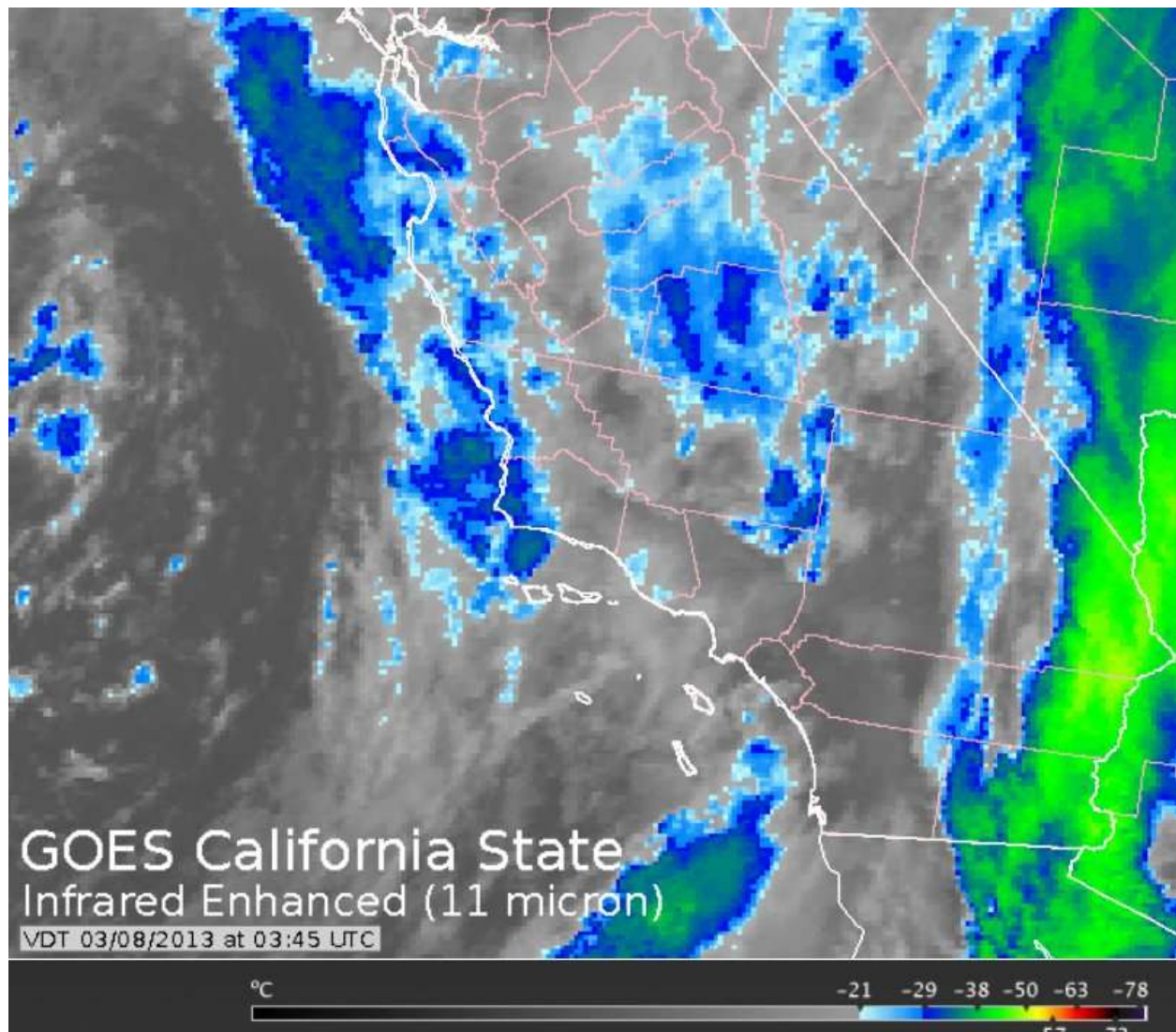


Figure 2.35 Infrared satellite image at 1945 PST on March 7, 2013

Figures 2.36 and 2.37 show the radar reflectivity and wind profile during the middle of the seeded band passage, shortly after 2100 PST on the evening of March 7. The wind profile shows essentially due southerly winds of about 20 knots, with a slight easterly component at low elevations. Eventually, the band began to align in a more southeast – northwest direction as the system became a closed low and continued to move slowly southward. The band weakened and winds became less favorable, with seeding ending early on March 8. Rainfall amounts were

relatively generous with this storm event compared to many this season, with the March 7-8 event totals show in Figure 2.38.

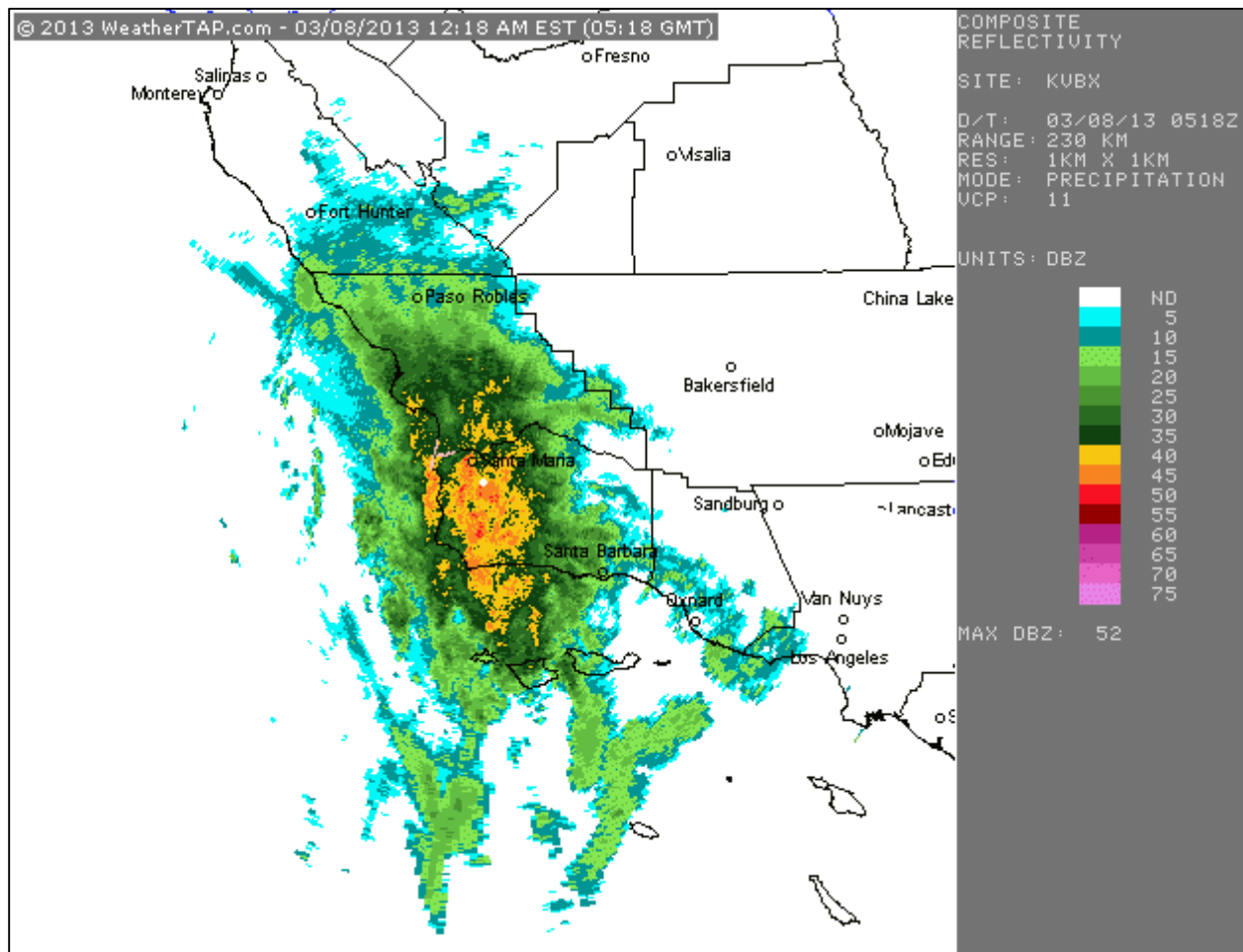


Figure 2.36 Radar reflectivity at 2118 PST on March 7, 2013

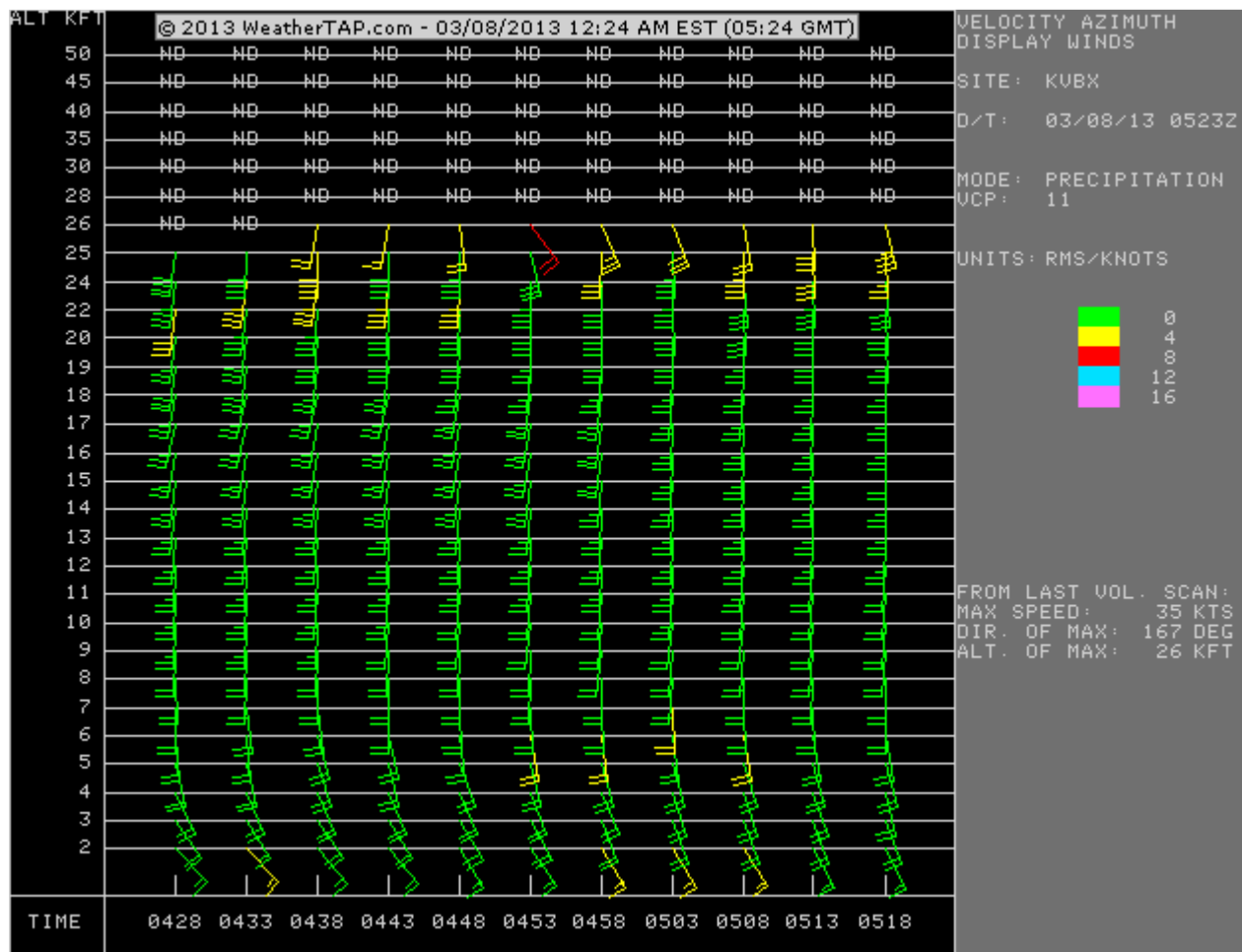


Figure 2.37 Wind profile ending at 2118 PST, March 7, 2013



Figure 2.38 Rainfall totals for March 7-8, 2013

3.0 THEORY OF CLOUD SEEDING FOR PRECIPITATION AUGMENTATION AND RESULTS OF PREVIOUS RESEARCH CONDUCTED IN SANTA BARBARA COUNTY

Two theories have evolved concerning the potential to augment precipitation. One theory postulates that a natural cloud's efficiency in producing precipitation can be increased, while the other theory postulates that seeding can enhance cloud development, leading to additional precipitation. The first theory has often been referred to as the *static* seeding hypothesis while the second relies upon *dynamic* effects of cloud growth. In many situations processes could be operative, whereby a cloud's precipitation efficiency is increased and the cloud is made to grow larger due to the seeding.

Clouds contain water vapor, water droplets and frequently ice crystals if cloud temperatures drop below freezing. Discoveries in the late 1940's established that minute particles of silver iodide, when injected into a cloud that contained supercooled water droplets, would cause those droplets to freeze (Vonnegut, 1947). Supercooled water droplets (droplets in a cloud at temperatures below freezing) frequently exist in clouds, as evidenced by icing on aircraft. These supercooled water droplets are the normal targets of most modern day cloud seeding programs.

3.1 Precipitation Processes

There are two basic mechanisms that produce precipitation: coalescence and ice formation. Coalescence is defined as “The growth of raindrops by the collision and coalescence of cloud drops and or small precipitation particles.” This process is especially important in tropical locations in the production of rainfall but it can also be a factor in the production of rainfall in more temperate climates like those found in Santa Barbara County. Ice nucleation (as described in the Bergeron-Findeisen theory) consists of a process in which precipitation particles may form within a mixed cloud (ones composed of both ice crystals and liquid water drops). In such clouds the ice crystals will gain mass by sublimation (formation of a solid phase directly from a vapor phase) at the expense of the liquid drops surrounding the ice crystals lose mass by evaporation. Upon attaining sufficient weight, the ice crystals (by this time they would be

snowflakes) would fall to the ground as snow if the surface temperatures are at or below freezing, but would melt and fall as raindrops if the surface temperatures are warmer than freezing. Of interest to this discussion is the fact that cloud drops often exist in portions of clouds that are colder than freezing. In fact, pure water droplets in a very clean laboratory environment can be cooled to -39°C before they will freeze through a process known as homogeneous nucleation). This Bergeron-Findeisen process is important in the production of snow and rain in the more temperate climates like those found in Santa Barbara County. The presence of supercooled water droplets in clouds is often the focus of attempts to artificially modify clouds.

3.2 Ice Nucleation

As discussed in the above, clouds often have cloud droplets present at sub-freezing temperatures. These droplets are termed “supercooled”. The natural tendency is for these droplets to freeze, but to do so at temperatures warmer than -39°C they need to encounter an impurity. There are particles present in our atmosphere that possess the ability to cause these supercooled droplets to freeze; they are known as freezing or ice nuclei. Research has demonstrated that certain natural particles (e.g., soil particles, and a certain type of bacteria) in the atmosphere serve as freezing nuclei. The conversion of a supercooled water droplet into an ice crystal is referred to as nucleation. It is known that the efficiency of these naturally occurring freezing nuclei increases with decreasing temperatures. It has also been established that naturally occurring freezing nuclei active in the temperature range of approximately -5 to -15°C are relatively rare. Research has also shown that minute particles of silver iodide begin to act effectively as freezing nuclei at temperatures colder than -5°C (Dennis, 1980). Some more recently developed seeding formulations show nucleation at temperatures as warm as -4°C . Silver iodide (sometimes a silver iodide complex) is the agent most commonly used to “seed” clouds, a process often referred to as “cloud seeding.”

There are two types of ice nucleation: condensation-freezing and contact. In condensation freezing, a nucleus first serves as a condensation nucleus in forming a cloud droplet. At temperatures of approximately -5°C or colder this same nucleus can serve as a freezing nuclei. In other words, under the right conditions, a nucleus can a) cause condensation, forming a cloud

droplet and b) then promote freezing on the same nucleus, forming an ice crystal. Contact nucleation, as the name implies, means that a freezing nucleus must come in physical contact with a supercooled water droplet, thus causing it to freeze (as long as the temperature of the cloud droplet is cold enough for the freezing nuclei to be active). Contact nucleation can be a relatively slow process (from a few to tens of minutes) compared to condensation-freezing nucleation, which can be quite rapid (on the order of one to a few minutes).

3.3 Impacts of Silver Iodide Seeding

Since a sparsity of natural ice nuclei commonly exists in the atmosphere at temperatures in the range of -5 to -15⁰ C, many clouds may be inefficient in converting water droplets into ice crystals. The addition of silver iodide nuclei to these cloud regions can produce additional ice crystals, which, under the right conditions, grow into snowflakes and fall out of the cloud as either snow or rain. Rain is produced by the melting of such snowflakes when they fall through warmer air near the ground. This increase in efficiency is usually referred to as a *static* seeding effect.

In the process of converting supercooled water droplets to ice, additional heat is added to the cloud due to the release of the latent heat of fusion. This additional heat may invigorate the circulation of air within the clouds, resulting in a *dynamic* effect. This postulated *dynamic* effect was the basis for a National Oceanic and Atmospheric (NOAA) research program conducted in Florida known as the Florida Area Cumulus Experiment (FACE). Two different phases of FACE 1, 1970-76 and FACE 2, 1978-80 (Woodley, et al., 1983) indicated increases in area wide rainfall, but results fell short of strict statistical acceptance criteria. Rainfall increases from seeded convection bands in the Santa Barbara II research program (Brown, et al., 1974) were attributed to both *static* and *dynamic* effects. NAWC conducted this research program in Santa Barbara County with funding from the Naval Weapons Center at China Lake.

3.4 Santa Barbara II Research Program

The Santa Barbara II research program consisted of two primary phases. Phase I consisted of the release of silver iodide from a ground location near 2,600 feet MSL located in the Santa Ynez Mountains northwest of Santa Barbara. These silver iodide releases were made as “convection bands” passed overhead. The releases were conducted on a random seed or no-seed decision basis in order to obtain baseline non-seeded (natural) rainfall information for comparison. A large network of recording precipitation gauges was installed for the research program (Figure 3.1). The amount of precipitation that fell from each seeded or non-seeded convection band was determined at each precipitation gauge location. Average convection band precipitation for seeded and non-seeded events was calculated for each rain gauge location. Figure 3.2 shows the results of seeding from the ground as contours of the ratios of average seeded band precipitation versus the non-seeded band precipitation.

Ratios greater than 1.0 are common in Figure 3.2. 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 non-seeded) rapidly lose intensity as they enter the San Joaquin Valley. In other words, a high percentage applied to a low base amount does not yield much additional precipitation. These apparent effects may be due to delayed ice nucleation which would be expected with the type of seeding flares used in this experiment that operated by contact nucleation which is a relatively slow process (see Section 4.2).

The low amounts of natural precipitation in southwest Kern County results from evaporation in “downslope” flow in the winter storms that affect this area. Such predominant “downslope flow” areas are frequently known as rain-shadow areas in the lee of mountain ranges. Figure 3.3 dramatically exhibits this feature from the coastal mountains in Central and Southern California, which are wet, to the San Joaquin and Imperial Valleys, which are dry. The 1.5 ratios along the backbone of the Santa Ynez Mountains are, however, significant in terms of rainfall amounts since this area receives higher natural precipitation during winter storms due to “upslope” flow. This upslope flow is also known as an orographic effect and accounts for many

mountainous areas in the west receiving more precipitation than adjoining valleys (especially downwind valleys). It was concluded that convection band precipitation was increased over a large area using this ground-based seeding approach.

In a similar experiment, phase II employed an aircraft to release silver iodide (generated by silver iodide - acetone wing tip generators) into the convection bands as they approached the Santa Barbara County coastline west of Vandenberg Air Force Base. The convection bands to be seeded were also randomly selected. Figure 3.4 provides the results. Again, a larger area of higher precipitation is indicated in seeded convection bands compared to non-seeded convection bands. Notice the westward shift of the effect in this experiment versus the ground-based experiment. This feature is physically plausible since the aircraft seeding was normally conducted off the coastline in the vicinity of Vandenberg AFB (i.e., west of the ground-based release point).

A study of the contribution of "convection band" precipitation to the total winter precipitation in the Santa Barbara County and surrounding areas was conducted (in the analysis of the Santa Barbara II research program). This study indicated that convection bands contributed approximately one-half of the total winter precipitation in this area (Figure 3.5). If it is assumed that all convection bands could be seeded in a given rainy season and that a 50 percent increase was produced, the result would be a 25 percent increase in rainy season precipitation if we assume the convection bands would have contributed one half of the rainy season's rainfall. Two NAWC reports (Thompson, et al., 1988 and Solak, et al., 1996) provided a more precise quantification of the optimal seeding increases that might be expected at Juncal and Gibraltar Dams (i.e., 18-22%) from seeding convection bands.

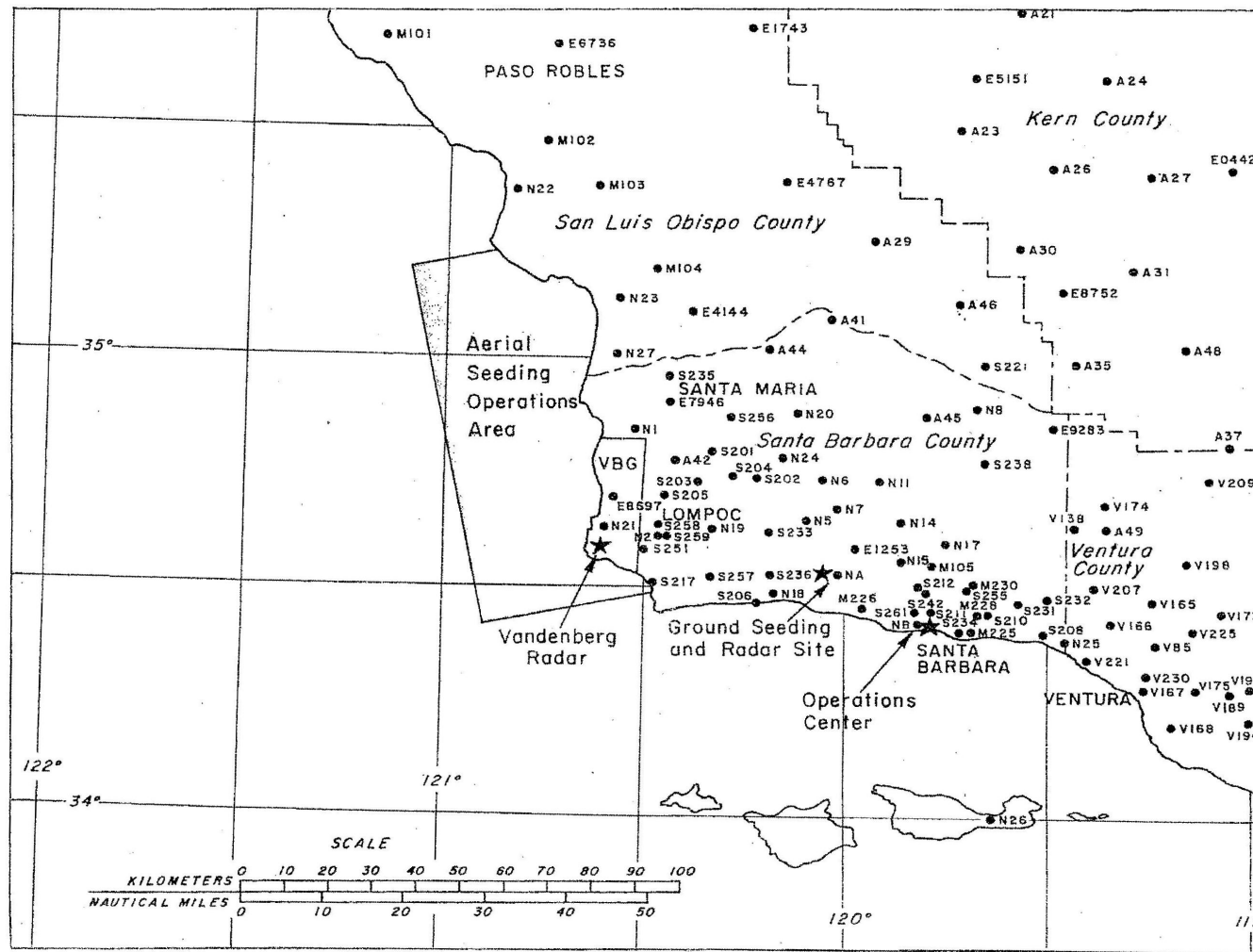


Figure 3.1 Santa Barbara II project map showing rain gage locations, radar, and seeding sites.

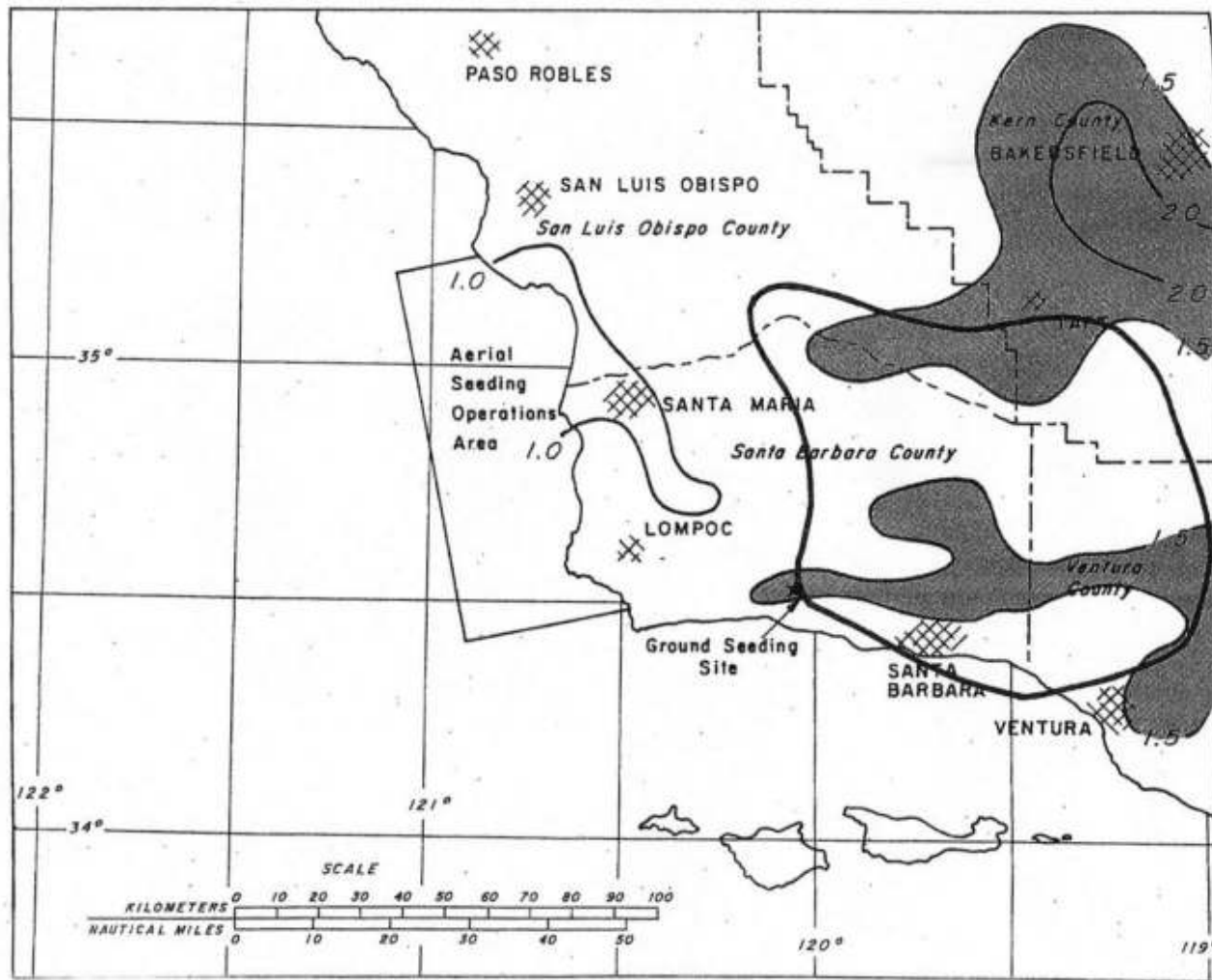


Figure 3.2 Seeded/not-seeded ratios of band precipitation for Phase I ground operations, 1967-71 seasons; 56 seeded and 51 not-seeded bands.

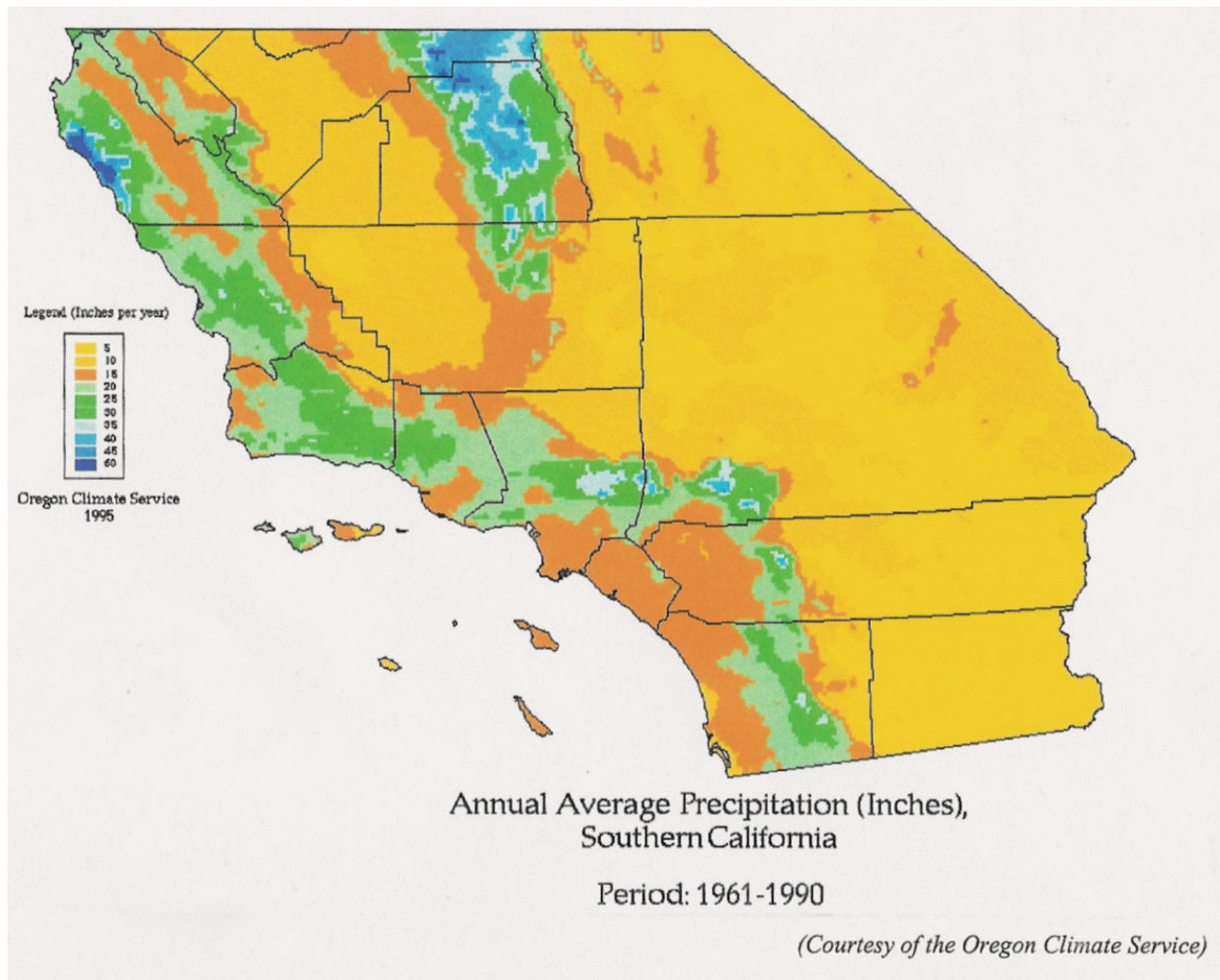


Figure 3.3 Annual Average Precipitation (inches), Southern California - Period: 1961-1990.
(Courtesy of the Oregon Climate Service)

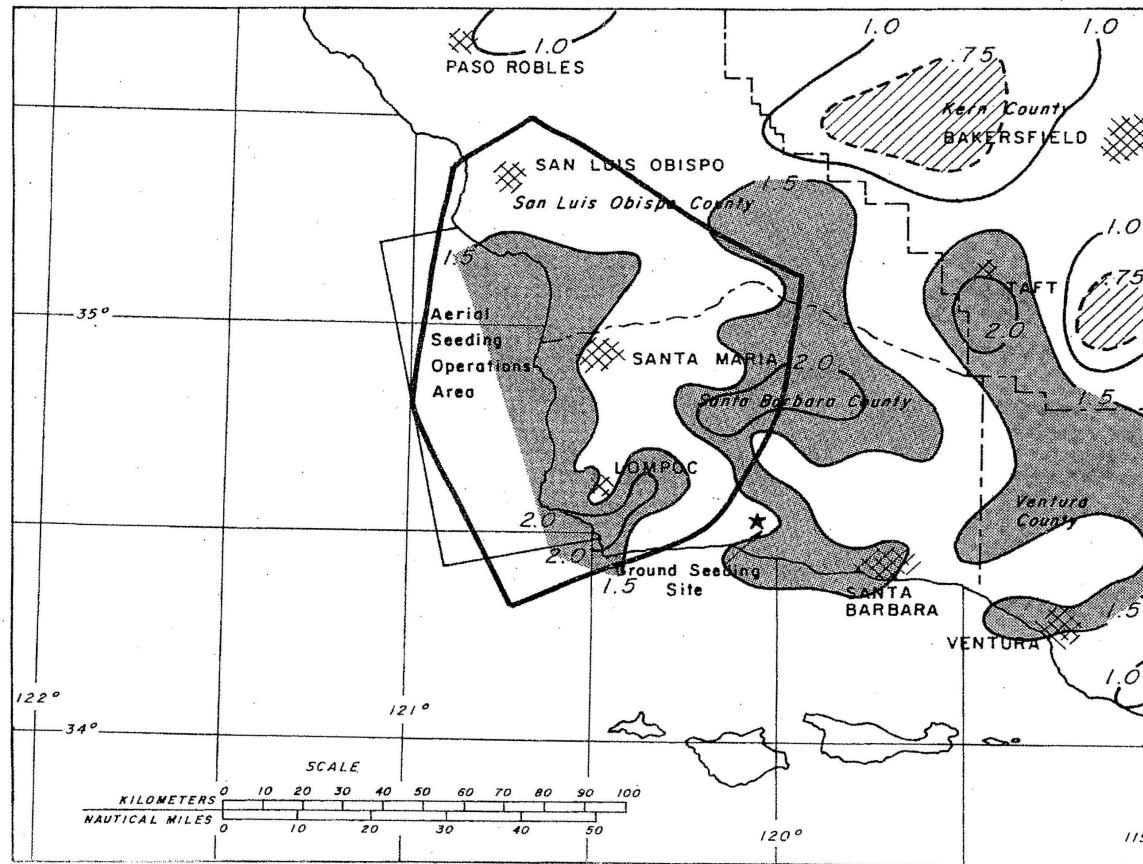


Figure 3.4 Seeded/not-seeded ratios of band precipitation for Phase II aerial operations, 1970-74 seasons; 18 seeded and 27 not-seeded bands.

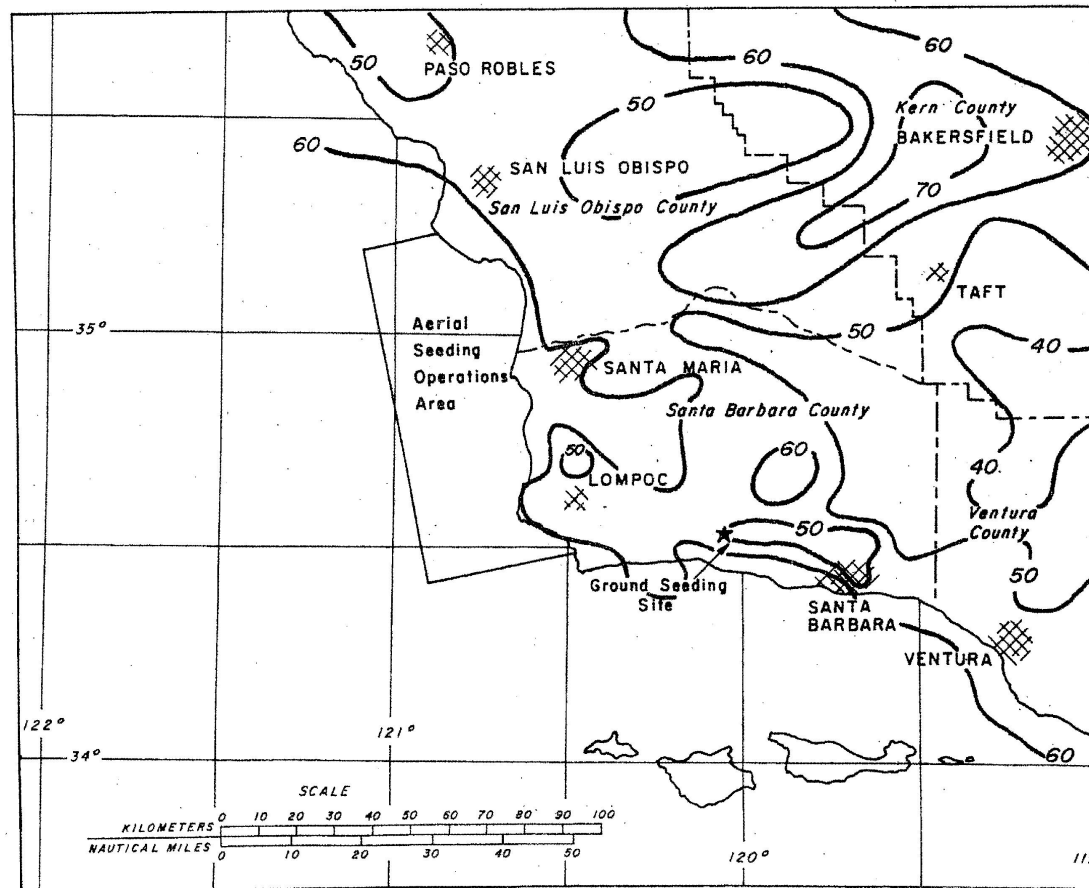


Figure 3.5 **Approximate percentage of winter precipitation occurring in convection bands, 1970-74 seasons.**

For illustration purposes, Figure 3.6 provides a sequence of six radar images of a convection band as it moved into Santa Barbara County on April 11, 2010. The radar images are from the Vandenberg AFB NEXRAD radar site. Table 3-1 provides short interval rainfall values observed at Buellton during the passage of this convection band.

More recent research conducted in Texas (Rosenfeld and Woodley, 1993; Rosenfeld and Woodley, 1997) and in Thailand (Woodley and Rosenfeld, 1999) has also indicated additional rainfall being produced from silver iodide seeding of convection cloud elements. These increases appear to occur due to increased duration of the seeded entities rather than increases in precipitation intensity. These indications are in agreement with the results observed in the Santa Barbara II research program.

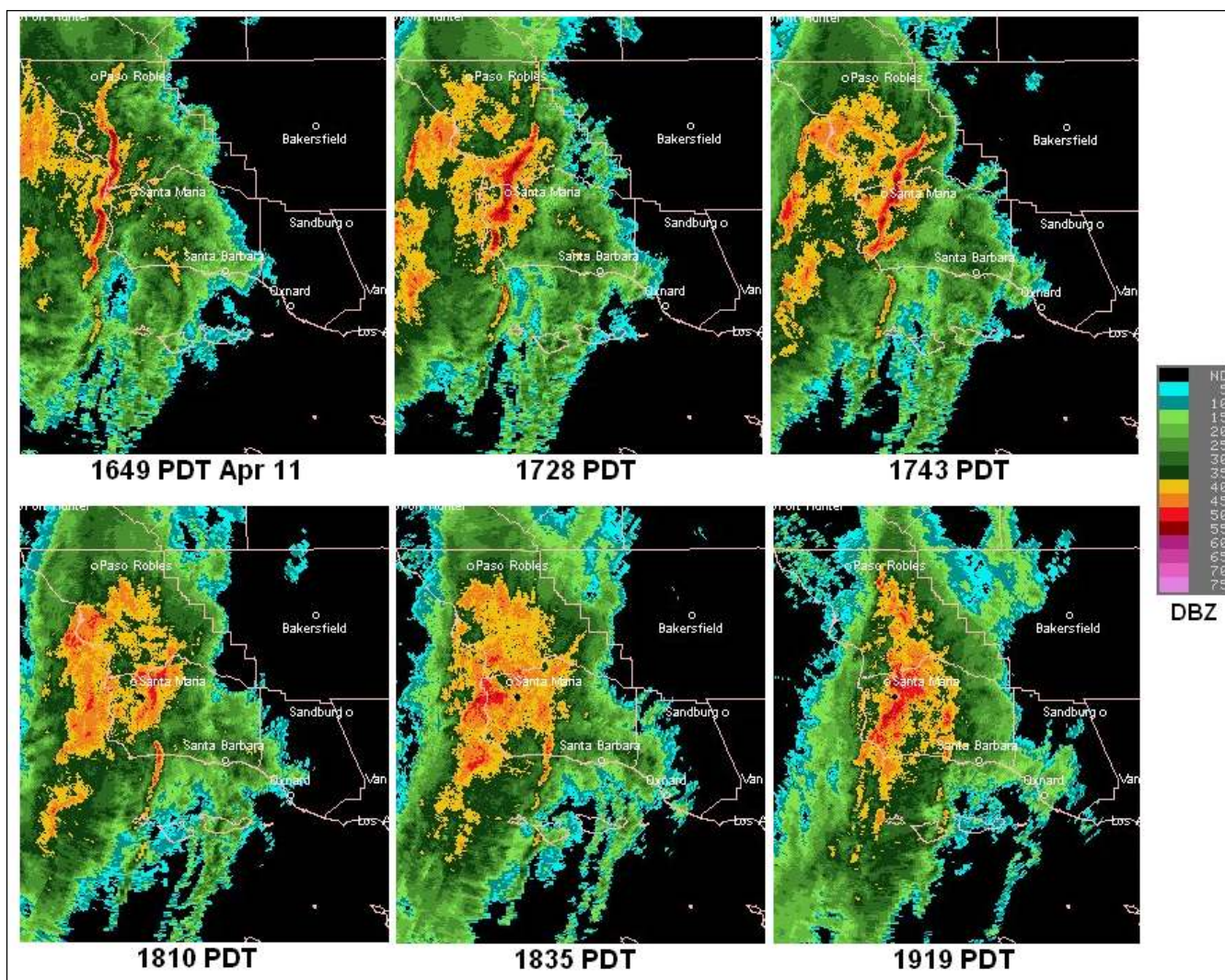


Figure 3.6 Frontal convection band passing over Santa Barbara County on April 11, 2010

**Table 3-1 Short Duration Rainfall Amounts at the Santa Maria Airport
During Storm Event in Figure 3.6**

Period (PST)	1651- 1716	1716- 1730	1730- 1741	1741- 1750	1750- 1851	1851- 1914
Precipitation (in)	0.06	0.21	0.42	0.46	0.21	0.08

In summary, earlier research conducted in Santa Barbara County indicated that “convection bands” are a common feature of winter storms that impact Santa Barbara County and that those bands contribute a significant proportion of the area precipitation. In addition, research has indicated that these bands contain supercooled liquid water droplets; the target of most modern day cloud seeding activities (Elliott, 1962). Seeding these bands with silver iodide either from the ground or air increases the amount of precipitation received at the ground. These bands are typically oriented in some north to south fashion (e.g. northeast to southwest, northwest to southeast, etc.) as they move from west to east. It is common to have at least one convection band per winter storm with as many as three or four per storm being fairly common. One band is usually associated with cold fronts as they pass through the county. Frequently these frontal bands are the strongest, longest lasting bands during the passage of a storm. Other bands may occur in either pre-frontal or post-frontal situations. The duration of these bands over a fixed location on the ground can vary from less than one hour to several hours duration.

4.0 PROJECT DESIGN

The winter cloud seeding program was to be conducted over portions of northern and southeastern Santa Barbara and southern San Luis Obispo Counties. The target areas were the upper Santa Ynez drainage and the Huasna-Alamo Target area (Twitchell Reservoir drainage). These target areas are depicted in Figure 4.1. The objective of the program was to seed all suitable storm systems affecting the target areas, especially organized convective bands, except as precluded by previously established suspension criteria.

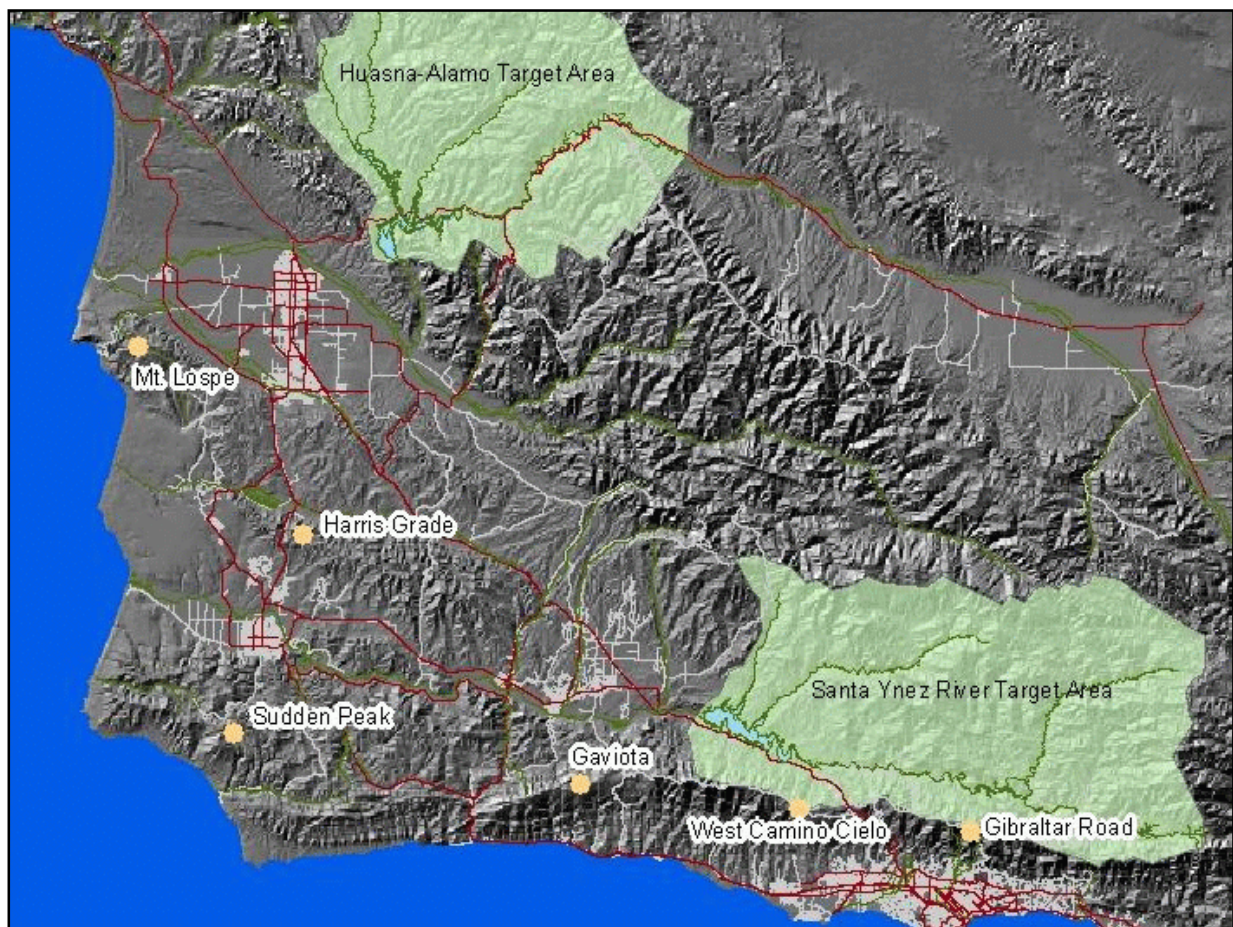


Figure 4.1 Project areas, topographic features and ground-based high-output flare site locations.

It has always been NAWC's philosophy that the design of our operational programs should be based upon prior research programs that provided positive indications of increases in precipitation, to the extent that the research results are considered to be representative of the operational programs' conditions (e.g., are research results from one location transferable to the operational program's target area). The Santa Barbara area has a unique advantage in this respect since successful winter research program was conducted during the winters of 1967-1973 within Santa Barbara County. The research program was known as Santa Barbara II and is summarized in Section 3.0.

Even though Santa Barbara II was conducted about 40 years ago, it is NAWC's professional opinion that it offers the most relevant information for the design of precipitation enhancement programs for this area at the present time. There has not been any winter weather modification research programs conducted in representative coastal areas of the United States since Santa Barbara II. This is a prime example of technology transfer from research to operations.

As a consequence of the above, NAWC believes the best project design for a winter cloud seeding program in Santa Barbara County and southern San Luis Obispo County to be one that replicates, as much as possible, the design of the Santa Barbara II Research Program, since it documented the successful results of randomized seeding experimentation and analysis. In fact, the combination of the research program's phase I (ground-based) and phase II (airborne) seeding modes should constitute the optimized method for capitalizing on the seeding potential for the area. Our project design is based upon this approach.

The project design, reintroduced by NAWC in 2001-2002, was utilized in the conduct of this past season's program. Six automated high-output ground-based pyrotechnic firing sites were used to seed suitable convection bands as they passed over these sites with consideration given to targeting of the effects of seeding and seeding suspension criteria. These sites were

located at: Mt. Lospe, Harris Grade, Sudden Peak, Gaviota, West Camino Cielo and Gibraltar Road. All of these sites had been used in previous programs (Figure 4.1 provides locations).

NAWC initially used this ground-based pyrotechnic seeding approach in the operational Santa Barbara program following the completion of the research program (1982-1985), but this seeding mode was discontinued since the manufacture of high output flares (400 grams each) was discontinued. The basic concept of both the aircraft and ground seeding in the Santa Barbara II research program was to place as much seeding material as possible into the warmer updraft regions of the convective bands with cloud tops colder than freezing (i.e., -4 to -10 or -12⁰ C). High output silver iodide generators were flown on the aircraft and 400-gram output ground flares were fired every 15 minutes during the passage of convective bands over the seeding sites. The 400-gram flares (known as LW- 83's) were considered very high output at the time, but have been replaced by even more effective (in terms of nuclei production) flares in programs conducted beginning with the 2001-2002 program. The pyrotechnic flares used at the AHOGS sites are high output, each emitting 15 g of fast-acting silver iodide complexes during a burn time of approximately four minutes. These flares are referred to as 150 g flares but this weight includes all the components of the flare (e.g., oxidizer, reduction agent, binder etc.) These flares release 15 grams of seeding material when burned. These flares are manufactured by Ice Crystal Engineering (ICE).

The output of these ICE flares has been tested at the Colorado State University Cloud Simulation Laboratory. Table 4-1 provides the results of this testing. These flares exhibited activity up to temperatures of -4⁰ C, which is considered very desirable since activity at these warm temperatures can result in the creation of more artificially generated ice crystals at lower altitudes in the clouds. A couple of advantages can result:

- 1) Ground releases of seeding material can activate more quickly since the -4⁰ C level will be reached sooner than say -6 to -8⁰ C which may have been the case with earlier generation flares.

- 2) Conversion of water droplets to ice crystals at the -4°C level can release additional latent heat of fusion at lower altitudes within the seeded clouds, which should enhance the dynamic response of the clouds to seeding (refer to section 3.0 for a discussion of this dynamic response).

A second important outcome of the testing of these flares at the Cloud Simulation Laboratory was that, when the seeding material was introduced into the cloud chamber, 63% of the ice crystal nucleation was produced within the first minute of introduction of the material into the chamber. It was therefore concluded that these flares were operating by the condensation-freezing mechanism as discussed in Section 3.0. This is also considered to be an advantage over the earlier generation flares that likely operated by the contact nucleation process, which is much slower. This implies that nearly all of the seeding material that reaches temperatures of -4°C within target clouds should be utilized in producing ice crystals. The contact nucleation flares, due to the slowness of the process, could mean that some of the seeding material was not activated in time to produce a seeding effect in the intended target areas. In fact, this characteristic may partially explain the extended downwind effects shown in southwest Kern County during the conduct of Santa Barbara II, Phase I (see Figure 3.2).

Table 4-1 CSU Cloud Chamber Test Results for Ice Crystal Engineering Flare

Pyro type	Temp ($^{\circ}\text{C}$)	LWC (g m^{-3})	Raw Yield ($\text{g}^{-1}\text{ Agl}$)	Corr. Yield ($\text{g}^{-1}\text{ Agl}$)	Raw Yield ($\text{g}^{-1}\text{ pyro}$)	Corr. Yield ($\text{g}^{-1}\text{ pyro}$)	Yield (per pyro)
ICE	-3.8	1.5	3.72×10^{11}	3.87×10^{11}	4.01×10^{10}	4.18×10^{10}	6.27×10^{12}
	-4.0	1.5	9.42×10^{11}	9.63×10^{11}	1.02×10^{11}	1.04×10^{11}	1.56×10^{13}
	-4.2	1.5	1.66×10^{12}	1.70×10^{12}	1.80×10^{11}	1.84×10^{11}	2.76×10^{13}
	-4.3	1.5	2.15×10^{12}	2.21×10^{12}	2.32×10^{11}	2.39×10^{11}	3.53×10^{13}
	-6.1	1.5	6.01×10^{13}	6.13×10^{13}	6.49×10^{12}	6.62×10^{12}	9.93×10^{14}
	-6.3	1.5	5.44×10^{13}	5.56×10^{13}	5.87×10^{12}	6.00×10^{12}	9.00×10^{14}
	-6.4	1.5	6.22×10^{13}	6.34×10^{13}	6.72×10^{12}	6.85×10^{12}	1.03×10^{15}
	-10.5	1.5	2.81×10^{14}	2.85×10^{14}	3.03×10^{13}	3.07×10^{13}	4.61×10^{15}
	-10.5	1.5	2.34×10^{14}	2.37×10^{14}	2.87×10^{13}	2.91×10^{13}	4.37×10^{15}
	-4.2	0.5	1.41×10^{12}	1.45×10^{12}	1.53×10^{11}	1.57×10^{11}	2.36×10^{13}
	-6.0	0.5	7.42×10^{13}	7.73×10^{13}	8.01×10^{12}	8.34×10^{12}	1.25×10^{15}
	-10.5	0.5	2.38×10^{14}	2.41×10^{14}	2.91×10^{13}	2.96×10^{13}	4.44×10^{15}

It should be noted that the Cloud Simulation Laboratory at Colorado State University (CSU) was placed into an inactive status a few years ago. There are no other similar facilities available in the United States or in the world with the possible exception of some facilities in Europe. As a consequence, there are no facilities that can test new flare formulations that would be comparable to the results of the many years of testing performed at the CSU facility.

The newer ICE flare can be compared to the earlier LW-83 flare based upon tests conducted at the CSU Cloud Simulation Laboratory. Figure 4.2 provides a visual comparison of the nucleating characteristics of the ICE and the LW-83 flares. The figure demonstrates that the ICE flare is more effective in the warmer temperature regions of -4°C to -10°C . This temperature region is of prime importance to seeding-induced increases in precipitation in Santa Barbara County. Freezing supercooled water droplets in the upper (colder) portions of the bands may not necessarily contribute substantially to the production of increased rainfall at the ground.

Figure 4.2 demonstrates that the ICE flare can produce more ice crystals (per gram of seeding material) in these critical temperature regions (as much as two orders of magnitude higher at -4°C) than the older LW-83 flare, although the latter flare contained more seeding material.

Some information concerning the flare manufacturer ICE is as follows: ICE was incorporated in 1999. ICE primarily manufactures three types of flares; an ejectable 20-gram silver iodide flare, a burn in place 150-gram silver iodide flare and a burn in place 1000-gram hygroscopic flare. ICE supplies flares to 20 different countries on 5 continents. Over 90% of ICE sales are to customers outside the United States.

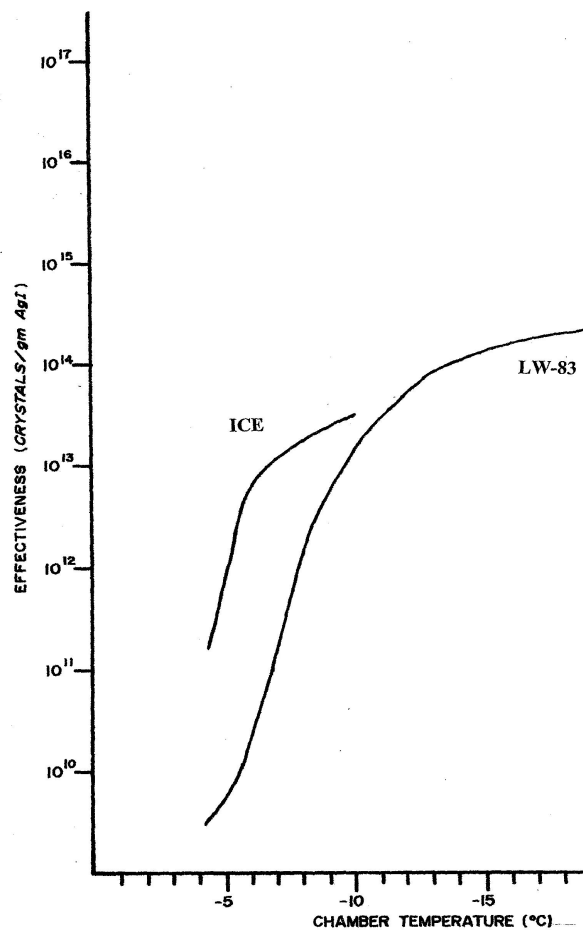


Figure 4.2 Comparison of Effectiveness of the LW-83 versus the ICE Burn-in-Place Flare, CSU Cloud Chamber results

Figure 4.2 demonstrates that the ICE flare can produce more ice crystals (per gram of seeding material) in these critical temperature regions (as much as two orders of magnitude higher at -4°C) than the older LW 83 flare, although the latter flare contained more seeding material.

The cloud seeding program was expanded from a three-month period (December 15 - March 15) in 2001-2002, to a five-month period (November 15 - April 15) during the 2003

through 2005 seasons. This was accomplished by conducting ground seeding operations during the full five-month period, while aircraft seeding was limited to the original three-month period. Combined aircraft and ground seeding would be conducted for three months in the climatologically most productive rainfall period in the County; the period from December 15th to March 15th. In 2005-2006, the original program (November 15 - March 15) was extended through April 5th. The 2006-2007 program ran from November 15 through March 31st. The program was originally scheduled to continue through April 15th, but was terminated effective March 31st due to extremely low rainfall amounts during the preceding winter months that led Agency personnel to conclude that there was little potential for any benefit to be generated via additional seeding since the watersheds in the target areas were far from reaching a point that would produce runoff. Both the 2008-2009 and 2009-2010 programs, which only used ground based seeding, ran from November 15th through April 15th. Both a ground based and aerial program was conducted from November 15, 2010 through March 31, 2011 for both target areas. A ground based program was conducted from December 1, 2011 through April 22, 2012 for the Huasna-Alamo target area. A ground based program was scheduled to be conducted from December 1, 2012 through March 31, 2013, but was shortened to end on March 15, 2013 due to the very dry rainy season with little likelihood of any significant runoff occurring.

Operationally, as seedable convective bands passed over Santa Barbara County, flares were fired from one or more of the pyrotechnic ground sites at ~15-minute intervals as the leading edge of the bands passed over each site. Six ground seeding sites instead of the one used in Santa Barbara II should produce significant seeding effects.

5.0 EQUIPMENT, PROCEDURES AND PERSONNEL

Seeding operations during the December 1, 2012 through March 15, 2013 period were directed from NAWC's main offices located in Sandy, Utah. Some operations were conducted from project meteorologist's residences since operations were conducted on a 24/7 basis. The following sections describe the equipment, procedures and personnel used in the operation of the cloud seeding project.

5.1 Weather Radar

NAWC provided its own dedicated project radar to direct operations during the seeded seasons of 1988-1989 through 1996-1997. These project-dedicated radars were sited at former President Reagan's ranch located on the Santa Ynez ridgeline north of Gaviota. This step was taken to avoid the necessity of travel to Vandenberg AFB's radar to direct operations (as was done in the 1982-1988 period). Scheduling the use of the Vandenberg AFB radar was difficult at times due to other activities at that facility. Another reason for dedicated project radar during those earlier years was the lack of usable weather radar information from the National Weather Service (NWS) in this area. This was a common shortcoming of NWS radar products in the western United States prior to the mid-1990s. This situation changed dramatically when the NWS, through a modernization effort in the 1990s, installed a network of very sophisticated 10-cm wavelength weather radars throughout the U.S. These sites are known as NEXRAD (Next Generation Radar) installations. Each installation cost on the order of \$1,000,000, with approximately 160 NEXRAD sites now in service. One of the NEXRAD radars is located at Vandenberg AFB, providing excellent coverage of the project area. Each NEXRAD radar site provides information on precipitation location and intensity, as well as wind speed and direction within the precipitation echoes. The radars step-scan through 14 different elevation angles in a 6-minute period. The maximum range for the detection of precipitation echoes is 143 miles from each site. The NWS provides all the necessary support for these systems: operation, calibration, spare parts, and maintenance. NEXRAD radar data have been utilized for the

operation of the cloud seeding program since 2001.

An upgrade to the Vandenberg AFB NEXRAD radar was completed during the 2011-2012 rainy season. This upgrade consisted of adding a dual polarization capability. This upgrade greatly enhances NEXRAD radars by providing the ability to collect data on the horizontal and vertical properties of weather (e.g., rain, hail) and non-weather (e.g., insect, ground clutter) targets. Four new products began to be provided from this upgrade during this past season: Correlation Coefficient, Differential Reflectivity, Specific Differential Phase and Hydrometeor Classification. Other products may be available on line in the future. For those that may be interested, the National Weather Service offers training guides for using these products at: <http://wdtb.noaa.gov/courses/dualpol/Outreach/index.html#nonmets>.

5.2 AHOGS Ground-Based Seeding Systems

The Automated High Output Ground Seeding Systems (AHOGS) allows automated, focused, high-output seeding releases from strategic ridgeline locations under program control from the project operations center with the proper computer software and password. These systems give the project meteorologist the ability to conduct intensive seeding of convection rain bands as they track into and across the project area under different wind flow regimes. Each AHOGS consists of the following primary onsite components:

- Two flare masts, which hold a total of 32, fast-acting AgI flares.
- Spark arrestors that enclose each flare.
- An environmentally sealed control box containing a cellular phone communications system, digital firing sequence relays/controller, data logger and system battery.
- A solar panel/charge regulation system to maintain site power.
- Cellular phone antenna.
- Lightning protection.

Each site is controlled via a modem-equipped PC at the operations center, running custom software to manage the flare seeding operations. The meteorologist has the option of firing flares individually in real time, or to order batch firing of any number of flares at selectable intervals at each site, e.g., three flares at 15-minute intervals, beginning at any selected time. The software allows monitoring and reporting of AHOGS site status information, such as flare inventory and battery voltage.

NAWC utilized six custom (AHOGS) sites for the 2012-2013 rainy season, to affect both the upper Santa Ynez and Huasna-Alamo target areas. These sites are designated as Mt. Lospe, Harris Grade, Sudden Peak, Gaviota, West Camino Cielo, and Gibraltar Road. All AHOGS sites were previously selected by considering site elevation and geographic location. NAWC believes higher elevation sites to be more effective since the base of the convection bands may not reach lower elevations during their passage over the target area. Such conditions could result in the lack of transport of the seeding agent into effective regions within the bands. Location is important since the effects of seeding will generally occur to the east through northeast of the site location. Locations are shown in Figure 4.1 of the previous section. The six sites were selected as ones that would offer potential targeting of seeding effects in the Huasna-Alamo and upper Santa Ynez target areas under different lower-level wind flow regimes commonly experienced with the passage of convection bands over Santa Barbara County. Table 5-1 provides location and elevation information for the six AHOGS sites.

Table 5-1 AHOGS Site Locations

Location	Latitude (N)	Longitude (W)	Elevation (ft.)
Mt. Lospe	34° 53.8'	120° 35.7'	1570
Sudden Peak	34° 34.5'	120° 30.5'	1540
Harris Grade	34° 43.8'	120° 24.8'	1204
Gaviota	34° 31.9'	120° 05.5'	2580

Location	Latitude (N)	Longitude (W)	Elevation (ft.)
West Camino Cielo	34° 30.3'	119° 51.1'	2790
Gibraltar Road	34° 27.9'	119° 40.7'	2204

These systems were designed for intensive seeding of convection bands using high output pyrotechnic flares. AHOGS was a new design developed specifically for this project in the fall of 2001. It represents an updated version of electro-mechanical systems used by NAWC in Santa Barbara County and elsewhere for cloud seeding operations and research in previous years. Incorporation of the AHOGS into the project design serves to help replicate the seeding systems used to achieve the strongly positive results shown in NAWC's Santa Barbara II cloud seeding research program.

The pyrotechnic flares used at the AHOGS sites are high output, fast-acting silver iodide complexes produced during a burn time of approximately 3-4 minutes (additional details regarding these flares are provided in Section 4.2). Ice Crystal Engineering (ICE) manufactures these flares. NAWC upgraded these sites for the 2005-2006 rainy season through the addition of spark arrestors placed over each flare. The spark arrestors were developed during the fall of 2005. They are stainless steel cylinders with a large number of small holes drilled in the cylinders' walls. The spark arrestors were designed to eliminate any concerns about sparks, produced during flare combustion, falling to the ground. Even though the cloud seeding program is conducted during the rainy season, there can still be periods when the ground cover can be dry (e.g. at the start of the program in the fall, or a dry spell that occurs during the operational period). Figures 5.1 - 5.6 provide photos of the six sites. Figure 5.7 shows a close up of the spark arrestors, and Figure 5.8 a flare burning inside a spark arrestor.



Figure 5.1 Photo of the Mt. Lospe AHOGS site



Figure 5.2 Photo of the Harris Grade AHOGS site



Figure 5.3 Photo of the Sudden Peak AHOGS site



Figure 5.4 Photo of the Gaviota AHOGS site



Figure 5.5 Photo of the West Camino AHOGS site



Figure 5.6 Photo of the Gibraltar Road AHOGS site



Figure 5.7 Close-up photo of spark arrestors



Figure 5.8 Flare burning inside a spark arrestor

5.3 Weather Forecasts and Meteorological Data Acquisition

NAWC meteorologists were responsible for the determination of when seedable conditions were present and whether seeding suspension criteria were met. Coordination between NAWC's project meteorologist and Mr. Dennis Gibbs of the Santa Barbara Water Agency typically occurred before each potential seed event and sometimes during these events. NAWC's project meteorologist was also responsible for saving relevant weather information from each event. Examples are shown in Section 2, which discusses last winter's operations.

A variety of weather information is available via the internet that was used to forecast approaching storms, forecast and observe weather conditions during storms as they passed through Santa Barbara County and document conditions of interest like criteria relating to suspension criteria. Examples of useful products include upper-air constant pressure charts (e.g. 700 and 500 mb levels); weather balloon observations; forecasts of pressure, temperature, winds and precipitation patterns from a few hours to several days in advance, NEXRAD weather radar displays of echo intensities (related to rainfall intensities) and upper-level winds at 6 minute intervals; hourly weather reports from surface stations (cloud cover, temperature, precipitation, winds, etc.); hourly observed precipitation from networks like the Alert networks in San Luis Obispo and Santa Barbara Counties; stream flow observations and satellites. Satellite imagery is a particularly valuable data type for operations in the Santa Barbara County area since weather typically moves from west to east at Santa Barbara County's latitude, which means there are often no surface reports of weather conditions associated with approaching storms. Available satellite imagery consisted of a variety of visual, infrared, and water vapor presentations updated at intervals ranging from 15 minutes to one hour.

5.4 Seeding Procedures

NAWC's conceptual model of the dynamics of the convection bands is that they are similar to summer squall lines in the Great Plains. NAWC believes that the primary low to mid-

level inflow to these bands is along the leading edge of the bands. The inflow regions are thought to be the likely accumulation zones of supercooled liquid cloud droplets water, which are the targets of the seeding. Consequently this is the desired region for the introduction of the seeding material. This would mean that flares burned at the ground sites would be timed to occur as the leading edge of the bands, as determined by the 6-minute PPI Vandenberg AFB NEXRAD radar, approached the ground sites. Low-level winds were considered in terms of targeting of effects as well as the avoidance of seeding over suspension areas. The HYSPLIT model, discussed in Section 6 was used in real time to help predict the plume dispersion from flares burned.

5.5 Suspension Criteria

Suspension criteria were implemented to serve as safeguards to protect against claims of negligence, and the loss of property and/or life due to the cloud seeding program. Since 1989, different types of suspension criteria for this project have been adopted and amended annually as needed. The 2012-2013 suspension criteria are contained in Appendix B. There were no seeding suspensions during the season.

5.6 Personnel

The following agencies and personnel were responsible for the conduct of the 2012-2013 cloud seeding program.

Santa Barbara County Flood Control & Water Conservation District and Water Agency

Mr. Matt Naftaly, Water Agency Manager

Mr. Dennis Gibbs, Senior Hydrologist/Project Coordinator

Mrs. Fray Crease, Senior Program Specialist

North American Weather Consultants

Mr. Don Griffith President, Project Manager and Project Meteorologist, Sandy, Utah

Mr. David Yorty, back-up Project Meteorologist, Sandy, Utah

Mr. Victor Lee, Local Equipment Technician, Orcutt, California

6.0 Computer Modeling

NAWC utilized specialized computer models in the conduct of this program. These models were of two basic types: 1) those that forecast a variety of weather parameters useful in the conduct of the cloud seeding program (e.g. NAM or WRF) and 2) those that predict the transport and diffusion of seeding materials (e.g., HYSPLIT).

In previous rainy seasons NAWC had used the standard National Oceanic and Atmospheric Administration (NOAA) atmospheric models: NAM (formerly ETA) and GFS in forecasting seedable events and associated parameters of interest (e.g. temperatures, winds, precipitation). NAWC continued to use the NAM and GFS models, especially for longer range forecasts. A more sophisticated model was used for shorter range forecasts. This was the Weather Research and Forecasting (WRF) model developed by the National Center for Atmospheric Research (NCAR) and NOAA. Recently this model has shown considerable skill in predicting precipitation, pressure fields, wind fields and a variety of other parameters of interest in conducting the cloud seeding operations.

The GUIDE model (Raubert, et al, 1988) had been used for many years to predict the transport and diffusion of seeding material and fallout of seeded precipitation. There has been significant advancement in computer models that predict the transport and diffusion of particles released either from the ground or aircraft since the GUIDE model was developed. NAWC recognized that newer, more sophisticated computer models would provide more accurate predictions than those produced by GUIDE. For example, the HYSPLIT model developed by NOAA provides forecasts of the transport and diffusion of either ground or aerial releases of some material, which in our case would be silver iodide seeding particles. NAWC utilized predictions from the HYSPLIT model to assist in making seeding decisions during the 2012-2013 rainy season.

The WRF and HYSPLIT models will be discussed separately in the following.

6.1 WRF Model

The Weather Research and Forecasting (WRF) Model is a next-generation mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. It features multiple dynamical cores, a 3-dimensional variational (3DVAR) data assimilation system, and a software architecture allowing for computational parallelism and system extensibility. WRF is suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometers.

The effort to develop WRF has been a collaborative partnership, principally among the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (the National Centers for Environmental Prediction (NCEP) and the Forecast Systems Laboratory (FSL), the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA). WRF allows researchers the ability to conduct simulations reflecting either real data or idealized configurations. WRF provides operational forecasting a model that is flexible and efficient computationally, while offering the advances in physics, numerics, and data assimilation contributed by the research community.

NAWC utilized NOAA's Earth Systems Research Laboratory's High Resolution Rapid Refresh (HRRR) version of the WRF model during the 2012-2013 rainy season. This model has a 3km grid spacing compared to the more standard grid model spacing of 13km (e.g. NAM model), plus it is re-initialized every hour using the latest radar observations. The NAM and GFS models are currently re-initialized every 6 hours. Hourly forecast outputs from the HRRR model are available for a variety of parameters out to 15 hours. Table 6-1 provides a summary of forecast parameters of interest in conducting the cloud seeding program.

Table 6-1 HRRR Forecast Parameters of Interest

Parameter	Application
1km above ground level reflectivity	Forecast of convection band locations based on radar returns 1km above ground
Composite reflectivity	Forecast of convection band locations using reflectivity values from different scan elevations. This is useful when bands approach the radar site since low elevation scans may go underneath the bands.
Maximum 1km above ground level reflectivity	Forecasts that pinpoints the location of the heart of the convection bands
1 hour accumulated precipitation	Forecasts of radar derived estimates of precipitation reaching the ground in a one-hour period (QPF).
Total accumulated precipitation	Forecasts of radar derived estimates of precipitation reaching the ground for a specified time period, for example 1-6 hours in the future (QPF).
850 mb winds	Forecasts of the 850 mb (~4,000 feet) wind direction is useful in determining if and when wind directions may go out of bounds in regards to suspension criteria.(e.g., avoiding burn areas)
700mb temperature	NAWC uses this level, which is ~10,000 feet, to indicate whether silver iodide will activate. Temperatures < -5 ⁰ C are desirable at this level
700mb vertical velocity	Forecasts the strength of the upward or downward movement at ~the 10,000 foot level. Stronger updrafts favor transport of seeding material to colder, more effective cloud regions.
Echo top height	Forecasts of cloud echo tops. Can be useful in determining whether the cloud tops are forecast to be cold enough for silver iodide to be effective (~-5 ⁰ C) and perhaps too cold <-25 ⁰ C to produce positive seeding effects.

Figure 6.1 is a ten-hour forecast from the HRRR model of composite radar reflectivity over the southwest valid at 1600 PDT, March 25, 2012. This model predicts a west-east oriented convection band over Santa Barbara County associated with an upper closed low located off the coast of Santa Barbara County. This HRRR forecast agrees

well with the radar image in Figure 6.2, which is the Vandenberg AFB PPI radar display valid at 1530 PDT March 25th. Figure 6.3 provides a ten-hour forecast of the one hour accumulated precipitation over California valid from 1500-1600 PDT March 25, 2012. This forecast also seemed to verify, for example, the HRRR forecast indicated approximately 0.10" of precipitation in the Sudden Peak vicinity. Figure 6.4 provides hourly precipitation values from Sudden Peak, which indicates 0.20" of precipitation fell from 1400-1500 PDT, about an hour earlier than forecast. Examination of the rainfall at Santa Maria indicated that the band apparently rotated northward with 0.11" from 1500-1600 PDT being observed there about an hour earlier than predicted; (Figure 6.5). More comparisons like this, conducted in future seasons, will help determine how well this model is performing. The precipitation that was forecast to occur over Santa Barbara County during this period was associated with a convection band that did develop and that was seeded from ~ 1400-1500 PDT.

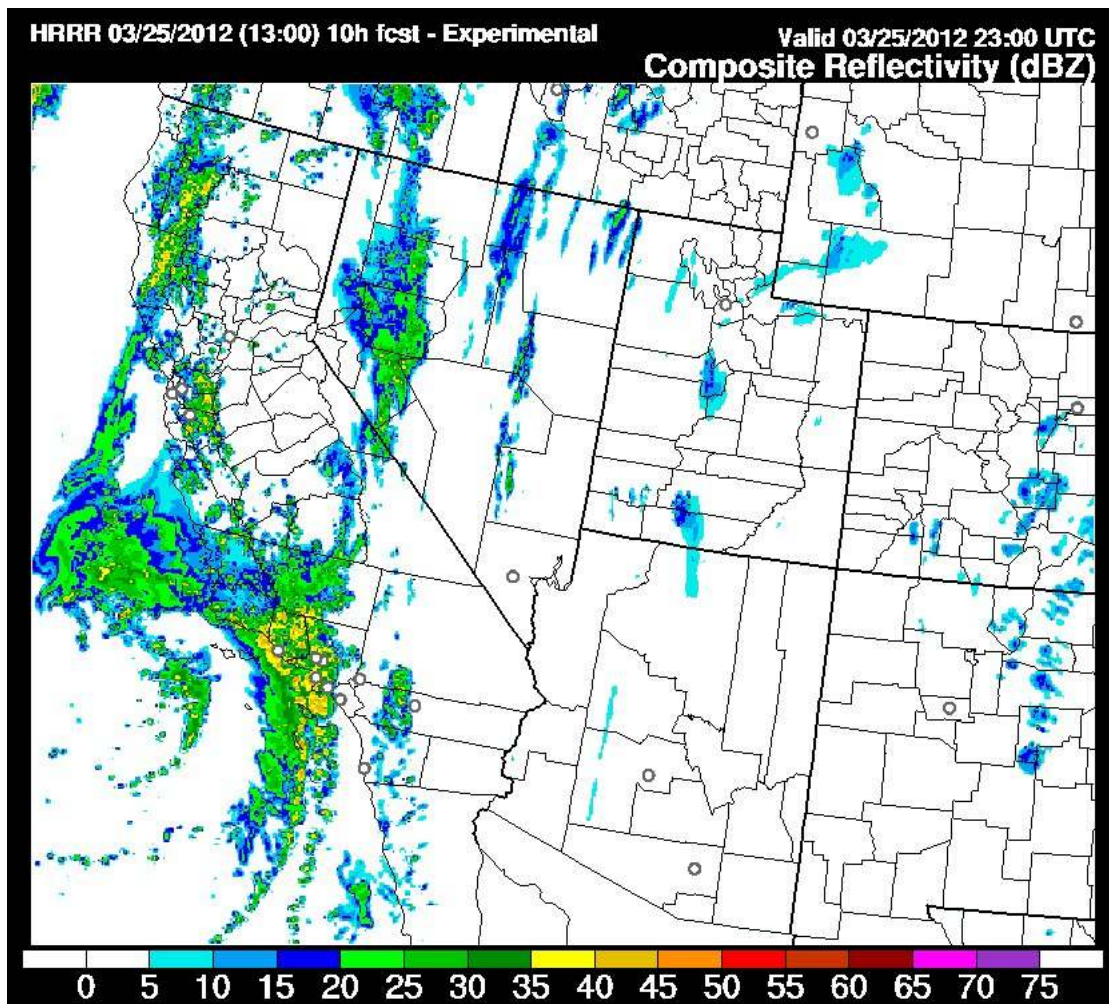


Figure 6.1 HRRR model ten-hour forecast of composite radar reflectivity, valid at 1600 PDT on March 25, 2012



Figure 6.2 Vandenberg AFB PPI radar display valid at 1530 PDT, March 25, 2012

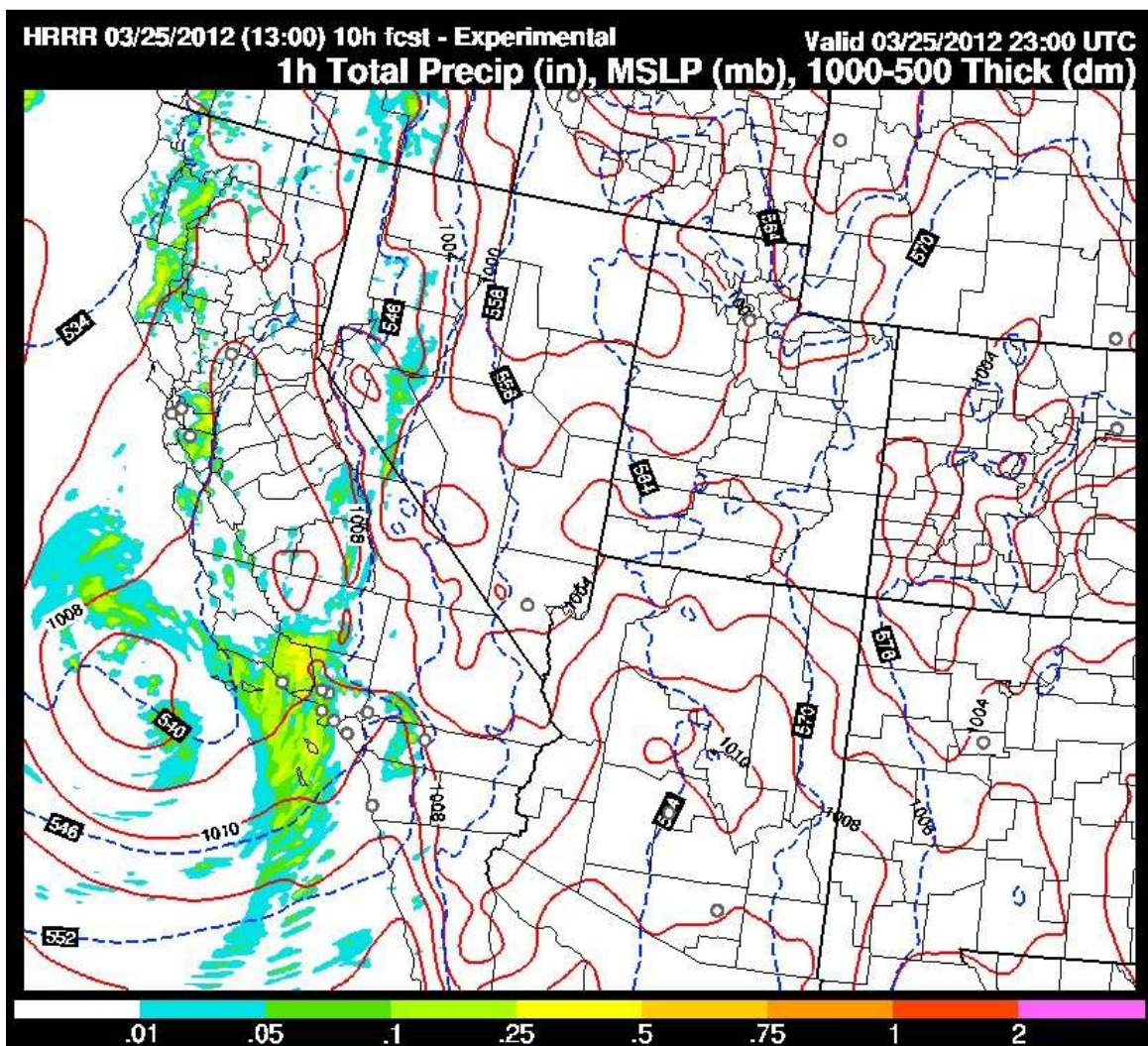


Figure 6.3 HRRR model ten-hour forecast of one-hour precipitation from 1500-1600 PDT March 25, 2012

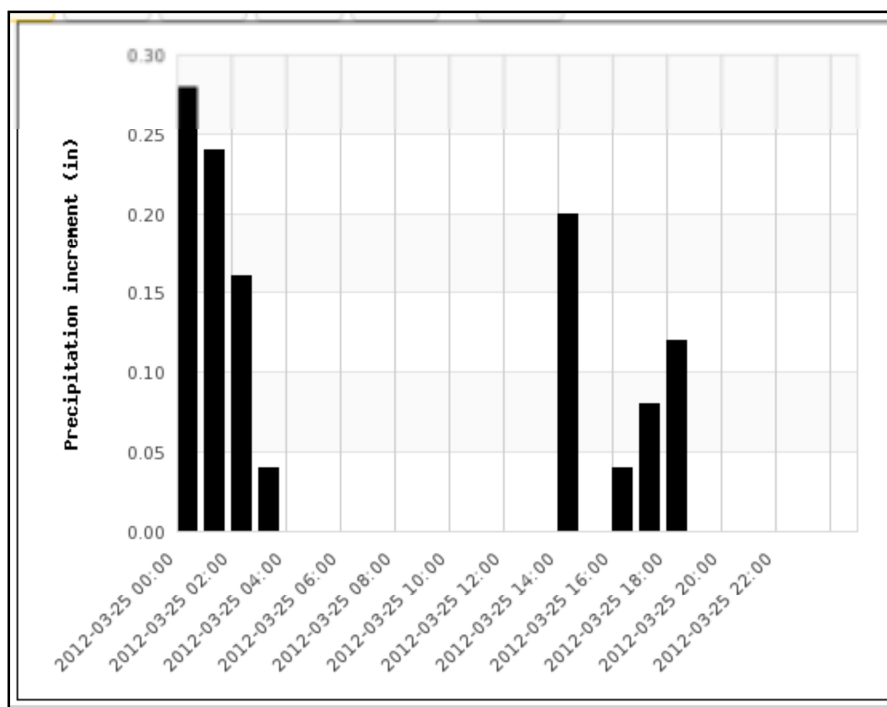


Figure 6.4 Observed hourly precipitation at Sudden Peak, March 25, 2012

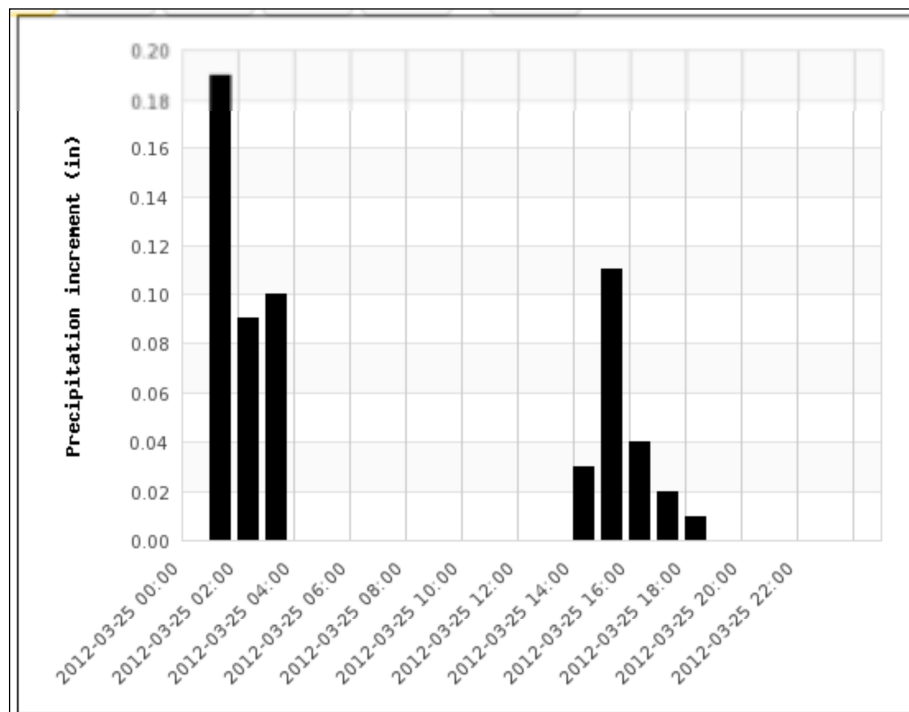


Figure 6.5 Observed hourly precipitation at Santa Maria, March 25, 2012

Based on the design of the program (Section 4) which is focused upon seeding convection bands, and the seeding techniques as described in Section 5.4, it can be seen that forecasts of convective band locations are not a requirement but are useful when using the ground-based seeding sites. Seeding decisions for ground-based sites can be made using real-time radar information indicating when a convection band is approaching a particular seeding site. These forecasts become more useful in airborne operations in order to provide lead time in filing flight plans to coincide with convective band passages. The precipitation type forecasts (e.g., Figure 6.3) are useful when considering suspension criteria.

6.2 HYSPLIT Model

The HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model is the newest version of a complete system for computing simple air parcel trajectories to complex dispersion and deposition simulations. As a result of a joint effort between NOAA and Australia's Bureau of Meteorology, the model has recently been upgraded. New features include improved advection algorithms, updated stability and dispersion equations, a new graphical user interface, and the option to include modules for chemical transformations. Without the additional dispersion modules, HYSPLIT computes the advection of a single pollutant particle, or simply its trajectory.

The dispersion of particles released into the atmosphere is calculated by assuming either puff or particle dispersion. In the puff model, puffs expand until they exceed the size of the meteorological grid cell (either horizontally or vertically) and then split into several new puffs, each with its share of the pollutant mass. In the HYSPLIT particle model, a fixed number of initial particles are advected about the model domain by the mean wind field and a turbulent component. The model's default configuration assumes a puff distribution in the horizontal and particle dispersion in the vertical direction. In this way, the greater accuracy of the vertical dispersion parameterization of the particle model

is combined with the advantage of having an ever-expanding number of particles represent the pollutant distribution.

The model can be run interactively on the Web through the READY system on the NOAA site, or the code executable and meteorological data can be downloaded to a Windows PC. The Web version has been configured with some limitations to avoid computational saturation of the web server. The registered PC version is complete with no computational restrictions, except that the user must download the necessary meteorological data files. The unregistered version is identical to the registered version except that it will not work with forecast meteorology data files.

NAWC has utilized the HYSPLIT model to predict the transport and diffusion of silver iodide seeding material during storm situations in Santa Barbara County during the past three seasons of operations. The model can also be run using archived NAM model data, which is available back to 2007. Figures 6.6 to 6.8 provide HYSPLIT model output for three separate seeded storm events during the 2012-2013 season.

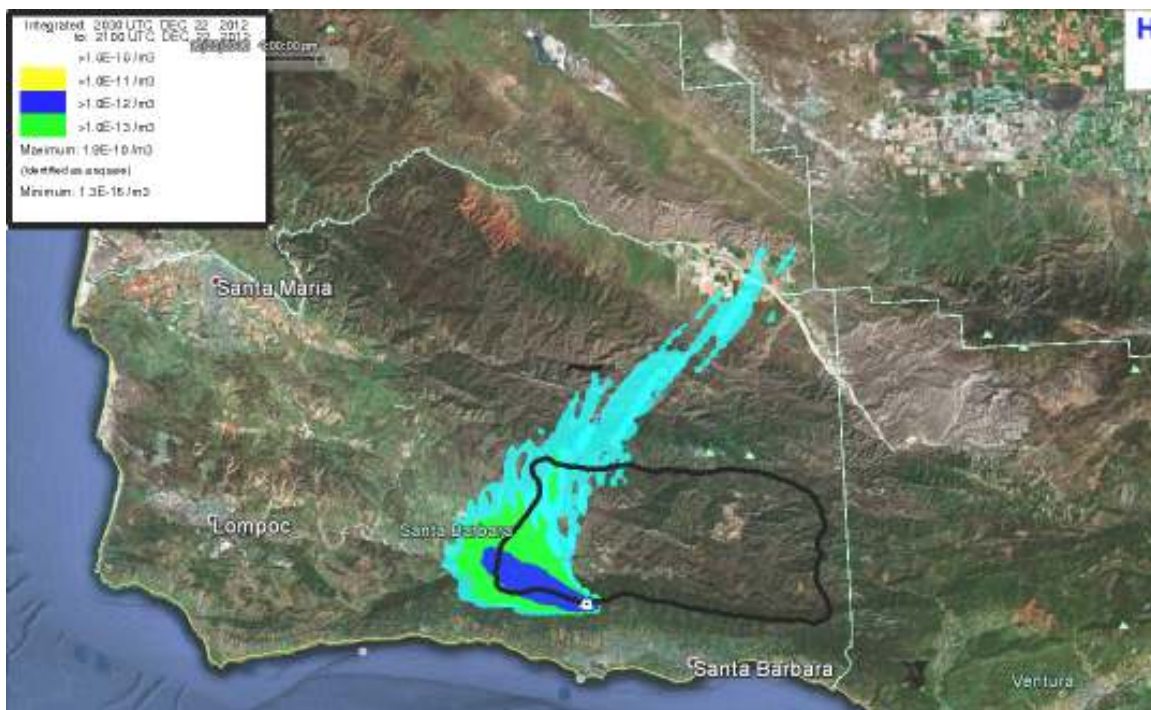


Figure 6.6 HYSPLIT Model output for West Camino Cielo, December 22, 2012.

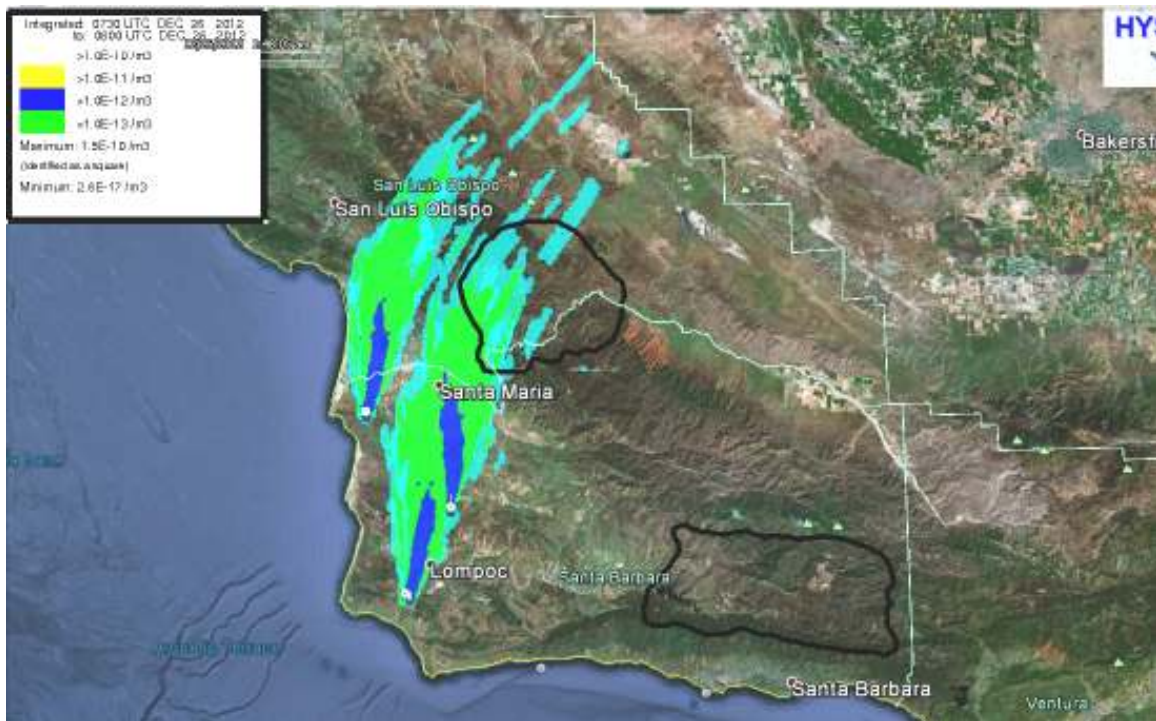


Figure 6.7 HYSPLIT output for Sudden Peak, Harris Grade, and Mt. Lospe on December 25-26, 2012

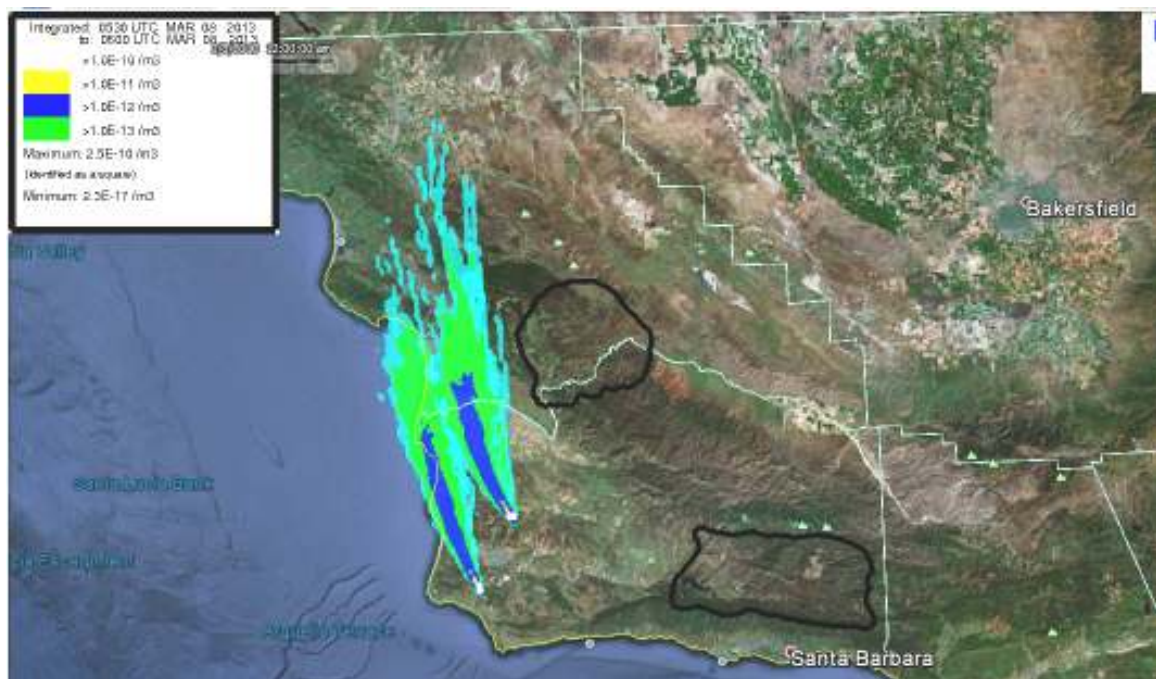


Figure 6.8 HYSPLIT output for Sudden Peak and Harris Grade on March 7, 2013

The depictions provided in Figures 6.6 through 6.8 are of the transport of the seeding plumes. The seeding material needs to interact with the convection bands forming ice crystals which grow into snowflakes which then fall to the ground changing into rain drop as they pass through the freezing level. These processes occur as the band moves downwind in time. Consequently, these depictions are of the initial transport and diffusion phase of the plumes while the resultant fallout of augmented precipitation would occur downwind of these plume depictions (typically to the east or northeast of these plume depictions). Although the plumes predicted by HYSPLIT may pass over urbanized areas (e.g., Santa Maria), there would be no or minimal impact in these areas since the upper portions of the plume are just reaching activation levels near the tail end of these predicted plume locations.

Another very useful tool in avoiding seeding impacts in areas identified in the suspension criteria is the vertical wind displays from the Vandenberg AFB NEXRAD radar. Figure 6.9 provides an example. Winds in the vertical at 1000 foot intervals are displayed over approximately a one hour period in ~6 minute time steps. NAWC has frequently used the winds at the 850-mb level (~5,000 feet) as an indicator of the mean direction that a seeding plume would transported. For example, in Figure 6.9 the 5,000 foot wind is from the southwest (about 235 degrees), with more southerly winds below this height and more westerly winds higher up. This would mean that the seeding material released from a burning flare at lower elevations under these conditions would be transported to the north, then northeast, and subsequently to the east-northeast as the plume rises above the surface.

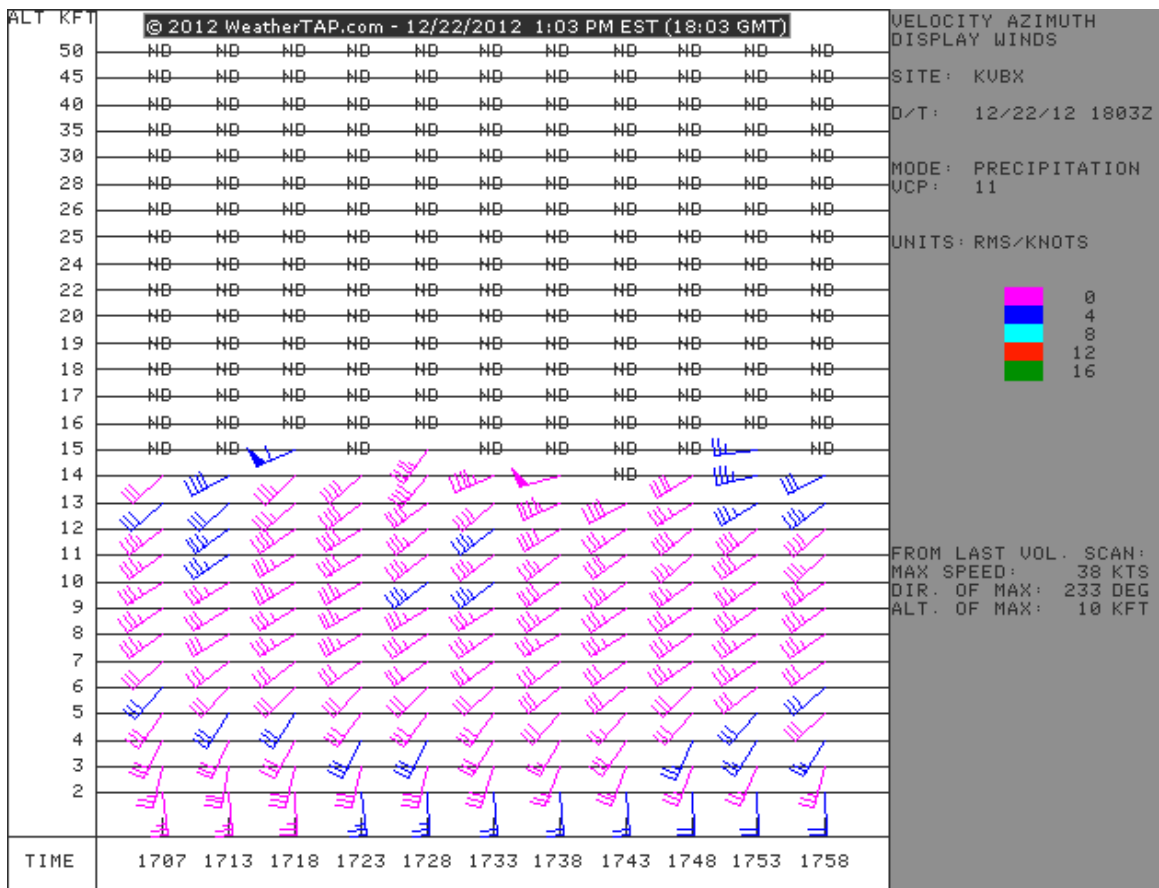


Figure 6.9 Vandenberg AFB NEXRAD vertical wind profile at 0907 – 0958 PST on December 22, 2012

7.0 SUMMARY AND RECOMMENDATIONS

For the 2012-2013 rainy season, operations were conducted to affect the upper Santa Ynez Drainage in Southeast Santa Barbara County and the Huasna-Alamo Drainage located in northern Santa Barbara and southern San Luis Obispo Counties. Six previously established ground-based seeding locations were utilized. These sites were located at Mt. Lospe, Sudden Peak, Harris Grade, Gaviota, West Camino Cielo, and Gibraltar Road. The operational period ran from December 1, 2012 to March 15, 2013. The operational period was originally scheduled to end on March 31, 2013 but was shortened due to the dry conditions in the watersheds and the low likelihood of any runoff occurring.

The cloud seeding equipment at the ground-based sites provided the ability to fire high output silver iodide complex seeding flares from these remote locations. Operations were directed by NAWC WMA certified project meteorologists located in Utah, with close coordination of activities with Mr. Dennis Gibbs or Mrs. Fray Crease of the Agency.

The ENSO (El Nino / La Nina) phase was essentially neutral during the 2012-2013 rainy season. Nevertheless, precipitation in the southwestern United States was once again well below normal this season. Rainfall from the beginning of the water year (September 1, 2012) through May 1, 2013 averaged 46% of normal in Santa Barbara County, with percentages ranging from 30% to 63% of average at the County gage sites.

In all, seeding opportunities occurred on eight days during the 2012-2013 operational season. There were a total of 6 seeded storm events, including four in December, one in February and one in March. A total of 49 flares were burned, releasing an estimated 735 grams of seeding material.

We conclude that the project design, including the current seeding systems, procedures, and flexibility are well suited to the meteorological and physiographic characteristics of the region, and are of genuine benefit to the project sponsors.

It is recommended that the Agency continue the operational cloud seeding project with

the basic design that was implemented during the 2001-2002 rainy season and has been enhanced during ensuing seasons. It is recommended that any aircraft operations be based at the Captain G. Allan Hancock Field in Santa Maria. The basic project design can be modified for a specific rainy season to account for special circumstances such as burn areas.

REFERENCES

- Brown, K.J., R.D. Elliott, J.R. Thompson, P. St. Amand and S.D. Elliott, Jr., 1974: The seeding of convective bands. AMS Preprints 4th Conf. on Weather Modification, Nov. 18-21, 1974, Ft. Lauderdale, FL.
- Dennis, A.S., 1980: Weather Modification by Cloud Seeding. International Geophysics Series, 24, Academic Press, New York, New York.
- DeMott, D.J., A.B. Sawyer, G. Langer, D.C. Rodgers and J.T. McPartland, 1995: Comparative Characterizations of the Ice Nucleus Ability of AgI Aerosols by Three Methods. WMA, Journal of Weather Modification, Vol. 27, No. 1, pp. 1-16.
- DeMott, P.J., 1999: Report to Ice Crystal Engineering on Tests of Ice Nucleating Ability of Aerosols Produced by New Formulation Pyrotechnics-July 1999. Publication of Department of Atmospheric Sciences, Colorado State University, Ft. Collins, Colorado.
- Elliott, R. D., 1962: Note on Cloud Seeding Evaluation with Hourly Precipitation Data. AMS Journal of Applied Meteorology, Vol. 1, pp. 578-580.
- Elliott, R. D. and E. L. Hovind, 1964: On Convection Bands Within Pacific Coast Storms and Their Relation to Storm Structure. AMS Journal of Applied Meteorology, Vol. 3, pp. 143- 154.
- Elliott, R. D. and E. L. Hovind, 1964: The Water Balance of Orographic Clouds. AMS Journal of Applied Meteorology, Vol. 3, pp. 235 - 239.
- Finnegan, W. G., 1999: Generation of Ice Nucleus Aerosols by Solution and Pyrotechnic Combustion. WMA, Journal of Weather Modification, Vol. 31, No. 1, pp. 102- 108.
- Griffith, D.A., M.E. Solak, R.B. Almy and D. Gibbs, 2005: The Santa Barbara Cloud Seeding Project in Coastal Southern California, Summary of Results and Their Implications. WMA, Journal of Weather Modification, Vol. 37, pp. 21-27.
- 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. AMS, Journal of Applied Meteorology, Vol. 27, No. 7, pp. 811-828.
- Reynolds, D.W., 1994: Further Analysis of a Snowpack Augmentation Program using Liquid Propane. WMA, Journal of Weather Modification, Vol. 26, No. 1, pp. 12-18.

- Rosenfeld, D. and W.L. Woodley, 1993: Effects of Cloud Seeding in West Texas, Additional Results and New Insights. AMS, Journal of Applied Meteorology, Vol. 32, pp. 1848-1866.
- Rosenfeld, D. and W.L. Woodley, 1997: Cloud Microphysical Observations of Advance to the Texas Cold-Cloud Conceptual Seeding Model. WMA, Journal of Weather Modification, Vol. 29, No. 1, pp. 56-69.
- Solak, M. E., J. Girdzus, D. A. Griffith, 1996: Precipitation Augmentation Potential from Convection Band Cloud Seeding in Santa Barbara County. Prepared for Santa Barbara County Flood Control & Water Conservation Dist. and Water Agency NAWC Report WM 96-3, May 1996.
- Thompson, J. R., K. J. Brown, and R. D. Elliott, 1975: Santa Barbara Convective Band Seeding Test Program. NAWC final report 6-135 to U. S. Naval Weapons Center.
- Thompson, J. R. and D. A. Griffith, 1988: Precipitation Augmentation Potential from Convective Band Cloud Seeding in Santa Barbara County. NAWC report WM 87-7 to Santa Barbara County Water Agency.
- Vonnegut, B., 1947: The Nucleation of Ice Formation by Silver Iodide. American Meteorological Society, Journal of Applied Physics, 18, pp. 593-595.
- Woodley, W.L., A.G. Barnston, J.A. Flueck, and R. Biondini, 1983: The Florida Area Cumulus Experiment's Second Phase. Part II: Replicated and Confirmatory Analyses. Journal of Climate and Applied Meteorology, Vol. 22, 1529-1540.
- Woodley, W.L., D. Rosenfeld, P. Sudhikoses, W. Sukarnjanaset, S. Ruangsuttinaruparp, and W. Khantiyanan, 1999: The Thailand Cold- Cloud Seeding Experiment; Results of the Statistical Evaluation. Seventh WMO Scientific Conference on Weather Modification, Chiang Mai, Thailand, Feb. 17-22, 1999.

APPENDIX A

BACKGROUND ON CLOUD SEEDING IN SANTA BARBARA COUNTY

There is a long history of cloud seeding programs being conducted in Santa Barbara County. Some of these have been research programs, while others have been operational programs. The research programs have been conducted to better understand winter storm systems that impact Santa Barbara County and also to attempt to evaluate the potential impacts of cloud seeding, especially in terms of any additional rainfall that can be attributed to the cloud seeding activities. Some of these research programs employed randomization techniques whereby approximately one-half of the seedable events were deliberately left unseeded in order to provide data for comparison with the seeded events. Operational programs have been conducted with the primary objective being to maximize the amount of rainfall produced through the cloud seeding activities. As a consequence, randomization is typically not employed on operational programs since the goal is to produce the maximum impact, not to demonstrate that cloud seeding “works” or to document the amount of the cloud seeding increases. Programs in the County date back to the early 1950's which were the result of the pioneering work done in the field of weather modification in the late 1940's by Drs. Vincent Schaefer and Bernard Vonnegut.

Table 1-1 provides a summary of the research programs conducted in Santa Barbara County. There were also some early operational programs conducted in the 1950's and a later program in 1978. The 1978 program was conducted due to drought conditions. The design of the current program is based upon the results obtained from the Santa II Phase I research program. Table 1-2 provides a summary of some of the earlier operational programs.

Table A-1 Summary of Santa Barbara Research Programs

Name	Time Period	Study Area	Sponsor(s)	Design	Results
Santa Barbara	1957-1960	Higher Elevations of Santa Barbara and Ventura Counties	State of California, University of California, Santa Barbara County, Ventura County, National Science Foundation, U.S. Weather Bureau, U.S. Forest Service	Randomized seeding using ground based silver iodide generators	Indications of a 45% increase, but results were not statistically significant (Neyman, et al, 1960) (Elliott, et al, 1962)
Water Balance of Orographic Clouds	1960-1963	Santa Ynez and San Gabriel Mountain Ranges	National Science Foundation	Analysis of Precipitation and Rawinsonde data during winter storms	Approximately one quarter of the orographically produced condensate fell as precipitation in the two mountain areas. More precipitation is produced in unstable versus stable air masses
Convection Band Study	1960-1963	Santa Barbara County	National Science Foundation	Analysis of Precipitation and Rawinsonde data during winter storms	The discovery that convection bands are a common feature of winter storms. Bands 20-40 miles wide centered some 30 to 60 miles apart Elliott and Hovind, 1964
Santa Barbara II Phase I	1967-71	Santa Barbara County	Naval Weapons Center, China Lake, California	Randomized seeding of winter convection bands from a single ground site using high output silver iodide flares	Increases in convection band precipitation as high as 50%, several sites statistically significant Brown et al, 1974

Santa Barbara I Phase II	1970-1974	Santa Barbara County	Naval Weapons Center, China Lake, California	Randomized seeding of winter convection bands using aircraft	Increases in convection band precipitation as high as 100%, several sites statistically significant Brown et al, 1974
-----------------------------	-----------	----------------------	---	--	---

Table A-2 Summary of Earlier Santa Barbara Operational Programs

Time Period	Target Area	Sponsor	Design	Results
1950-1953, 1955	South Coast, Santa Ynez Basin, Cuyama Valley	Santa Barbara County Water Agency	Ground Based Silver Iodide Generators	Estimated 1.35 to 5.09 inch increases for 1955 program
1978	North-east portion of Santa Barbara County	Santa Barbara County	Ground based, high output silver iodide flares	Estimated increases of approximately 40%

The Santa Barbara County Water Agency (Agency) completed a number of tasks during 1981 designed to reactivate cloud seeding activities within the County. These tasks included: 1) preparation of a Negative Declaration Statement (#81-ND-87), 2) conducting a public hearing (December 10, 1981), and 3) obtaining a Weather Resource Management permit from the California Department of Water Resources. North American Weather Consultants (NAWC) was awarded an initial contract from the Agency (dated January 11, 1982) to conduct an operational cloud seeding program during the remainder of the 1982 winter season. Periodic contracts were awarded to NAWC by the Agency to continue these operational programs in a nearly continuous fashion through the 1997 Water Year.

Atmospherics, Inc. of Fresno, California was awarded a contract to conduct an operational program during the 1998 Water Year. Weather Modification, Inc., of Fargo, North Dakota, was awarded a contract by the Agency to conduct operational programs for the 1999 through 2001 Water Years. NAWC, under contract with the Agency, resumed its conduct of operations for the County during the winter of 2001-2002. This program utilized a revised project design based upon the highly successful results of earlier research conducted by NAWC (e.g., Santa Barbara II phase I and phase II experiments). The Agency renewed NAWC's contract to conduct the cloud seeding operations for the 2002-03 winter season. The Agency released an RFP for another three-year program during the early summer of 2003. NAWC was awarded this contract, which resulted in operations being conducted during the 2003-2004, 2004-2005 and 2005-2006 rainy seasons. The revised design, originally implemented during the 2001-2002 rainy season, was utilized in conducting these programs. The Agency released another RFP for a three-winter program during the spring of 2007. NAWC was again selected to perform this work, which would include both ground and airborne seeding. A large fire impacted substantial portions of the upper Santa Ynez watershed during the summer of 2007 (the Zaca fire). As a consequence, the Agency decided that no cloud seeding would be conducted during the 2007-2008 winter season. The Agency decided to conduct a program designed to only affect the

Twitchell watershed. The Agency expanded the program for the 2009-2010 program to include both the Huasna-Alamo and Upper Santa Ynez watersheds although restrictions were in place to avoid seeding impacts in some recent burn areas (La Brea, Jesusita, Gap and Tea fires). The Agency released another RFP for a three-winter program during the summer of 2011. NAWC was again selected to perform this work, which would include both ground and airborne seeding. Only ground seeding was conducted during the 2011-2012 and 2012-2013 rainy seasons. Table 1-3 provides a summary of NAWC operations for the 1981 through 2013 period.

Research has demonstrated that properly conducted cloud seeding programs offer an environmentally safe and cost-effective means of augmenting precipitation from winter storms. NAWC conducted a study for the Santa Barbara County Water Agency (Thompson and Griffith, 1987), which assessed the precipitation augmentation potential from seeding wintertime cloud bands moving over Santa Barbara County. That assessment covered a sixty-one (61) year period (1920-1980). A follow-on study (Solak, *et al.*, 1996) covered the period from 1981 through 1994, applying the same analysis methods. A key conclusion of these studies was that, under average conditions, seasonal precipitation could be optimally enhanced by 18 to 22 percent at Juncal and Gibraltar Dams through seeding of all appropriate precipitation bands from October through April. Seasonal increases of that magnitude could add as much as 4.5 to 5.0 inches of precipitation to the average seasonal total. Realizing the importance and benefit of this additional rainfall, the water purveyors of Santa Barbara County, under the administrative leadership of the County's Water Agency and/or the Flood Control District have sponsored a cloud seeding program in all water years since 1982, with the exception of 1985-1986 and 2007-2008. The 1985-1986 and 2007-2008 programs were canceled due fires, which produced large burn area in the project areas, which, in turn, created concerns about the potential for excessive erosion and mudslides.

Availability of fresh water in adequate supplies is obviously of paramount importance. Local precipitation has been the major source of water for most areas of California. As part of Santa Barbara County's water resource development and management strategies, cloud seeding operations have been routinely utilized to augment natural precipitation, helping to stabilize

annual fresh water supplies. Cloud seeding for precipitation enhancement has been shown to be an effective tool, which carries a very attractive long-term benefit/cost ratio.

Table A-3

Historical Operational Cloud Seeding Periods in Santa Barbara County, Water Year 1982 to Present

(All NAWC programs unless indicated otherwise)

OPERATIONAL PERIOD	TARGET AREA	REMARKS
Jan 15-Apr 15, 1982	Santa Barbara County except South Coast	Airborne seeding, weather radar support provided by Vandenberg Air Force Base. Ground based pyrotechnic flare firing at Tranquillon Park.
Dec 1, 1982-Jan 26, 1983	Santa Barbara County except South Coast	Airborne and ground based pyrotechnic seeding suspended in late January due to heavy rainfall and Lake Cachuma approaching capacity.
Mar 1, 1984-Apr 30, 1984	North County	Airborne seeding and ground based pyrotechnic seeding.
Nov 1, 1984-Apr 30, 1985	Santa Barbara County except South Coast	Airborne seeding and ground based pyrotechnic seeding.
1985-1986		No program due to burn areas in San Luis Obispo and Ventura Counties
Nov 1, 1986-Mar 31, 1987	Santa Barbara County except South Coast	Airborne seeding. Ground based pyrotechnic seeding replaced with two ground based silver iodide generators (Mt. Lospe and Sudden).
Nov 1, 1987-Mar 31, 1988	Santa Barbara County except South Coast	Airborne seeding. Implementation of remotely controlled ground based silver iodide generators began (Mt. Lospe). The use of a computerized targeting model (GUIDE) began.
Nov 1, 1988-Apr 30, 1989	Santa Barbara County except South Coast	Provision of a project specific weather radar was initiated. Airborne seeding. Four manual generator sites (Gaviota, La Cumbre, Sudden, Graham Ranch) and one remote site (Mt. Lospe). Dedicated weather radar.
Nov 1, 1989-Apr 30, 1990	Santa Barbara County except South Coast	Airborne seeding. Four manual generator sites and one remote site. Special project suspension criteria developed for lower Santa Ynez River flow below Bradbury Dam. Dedicated weather radar.

Nov 1, 1990-Apr 30, 1991	Santa Barbara County except South Coast	Special targeting criteria adopted for Painted Cave burn area. Lower Santa Ynez flow suspension criteria continued. Airborne seeding. Three remotely controlled ground generators (Sudden, La Cumbre and Graham Ranch). One ground based manual site (Gaviota). Dedicated weather radar.
Nov. 1, 1991-Apr 21, 1992	Santa Barbara County except South Coast	Targeting restrictions continued for Painted Cave burn area plus Santa Ynez River flow. Airborne seeding. Four remotely controlled and one manually operated ground based silver iodide generators. Dedicated weather radar.
Dec. 1, 1992-Mar 31, 1993	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Cachuma Reservoir spilled for the first time since the 1982-83 winter season. Santa Ynez River flow restrictions continued. New suspension criteria for Twitchell Reservoir inflow adopted. Provision made for acquisition of weather satellite information. Dedicated weather radar.
Dec. 17, 1993-Apr 18, 1994	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Targeting restrictions imposed for the Marre burn area. Santa Ynez River flow and Twitchell Reservoir inflow restrictions continued. Airborne seeding. Six remote generators. Dedicated weather radar.
Nov. 15, 1994-Mar 24, 1995	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Targeting restrictions continued for the Marre burn area. Santa Ynez River flow and Twitchell Reservoir inflow restrictions continued. Airborne seeding. Six remote generators. Cachuma spilled. Dedicated weather radar.
Dec. 14, 1995 - Mar. 13, 1996	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Targeting restrictions for Marre burn area removed. Santa Ynez River flow and Twitchell Reservoir inflow restrictions continued. Continued airborne seeding. 6 remote and 2 manual generators. Dedicated weather radar.
Dec. 9, 1996 - Mar. 22, 1997	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Santa Ynez River flow and Twitchell Reservoir inflow restrictions continued. Airborne seeding. Six remote generators. Two manual generators. Dedicated weather radar.
Nov. 15, 1997-Apr. 30, 1998	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Work performed by Atmospheric, Inc. of Fresno, California. Program onset delayed, operated Jan. 1-Feb. 1, 1998. Program suspended on Feb. 2, 1998 and terminated Mar. 15, 1998 (extremely wet watersheds)
Dec. 15, 1998-Mar. 31, 1999	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Work performed by Weather Modification, Inc. of Fargo, North Dakota

OPERATIONAL PERIOD	TARGET AREA	REMARKS
Dec. 15, 1999-Apr. 5, 2000	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Work performed by Weather Modification, Inc. of Fargo, North Dakota
Dec. 8, 2000-Mar. 31, 2001	Santa Barbara County except South Coast plus a portion of the Twitchell Drainage in southern San Luis Obispo County.	Work performed by Weather Modification, Inc. of Fargo, North Dakota
Dec. 20, 2001 - Mar. 22, 2002	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Revised project design implemented, including airborne seeding and three automated high-output ground-based flare seeding (AHOGS) sites. Custom software utilized to combine NEXRAD and aircraft track data for use in operations.
Nov. 7, 2002 - May 2, 2003	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Airborne seeding and three automated high-output ground-based flare seeding (AHOGS) sites. Custom software utilized to combine NEXRAD and aircraft track data for use in operations.
Nov. 15, 2003 - Apr. 15, 2004	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Airborne seeding and three automated high-output ground-based flare seeding (AHOGS) sites. Custom software utilized to combine NEXRAD and aircraft track data for use in operations.
Nov. 15, 2004 - Apr. 15, 2005	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Airborne seeding and four automated high-output ground-based flare seeding (AHOGS) sites. Custom software utilized to combine NEXRAD and aircraft track data for use in operations. WxWorx display in aircraft cockpit of aircraft location, underlying terrain and current NEXRAD radar data.
Nov. 15, 2005 - Apr. 5, 2006	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Airborne seeding and five automated high-output ground-based flare seeding (AHOGS) sites. Custom software utilized to combine NEXRAD and aircraft track data for use in operations. WxWorx display in aircraft cockpit of aircraft location, underlying terrain and current NEXRAD radar data.

OPERATIONAL PERIOD	TARGET AREA	REMARKS
Nov. 15, 2006 - Mar. 31, 2007	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Airborne seeding and five automated high-output ground-based flare seeding (AHOGS) sites. WxWorx display in aircraft cockpit of aircraft location, underlying terrain and current NEXRAD radar data.

2007-2008 Winter Season	No Operations	Zaca Fire
Nov. 15, 2008 – Apr. 15, 2009	Twitchell watershed located in portions of northern Santa Barbara and southern San Luis Obispo Counties.	Revised project design partially implemented consisting of three high-output ground-based flare-seeding (AHOGS) sites. No aircraft seeding.
Nov. 15, 2009 – Apr. 15, 2010	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Revised project design partially implemented consisting of five high-output ground-based flare-seeding (AHOGS) sites. No aircraft seeding.
Nov. 15, 2010 – Mar. 31, 2011	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Revised project design implemented consisting of airborne seeding and six high-output ground-based flare-seeding (AHOGS) sites.
Dec. 1, 2011 – Apr. 22, 2012	Portions of northern Santa Barbara and southern San Luis Obispo Counties	Revised project design targeting only the northern (Huasna – Alamo) area, using three high-output ground-based flare seeding (AHOGS) sites.
Dec. 1, 2012 – Mar. 15, 2013	Portions of Santa Barbara and southern San Luis Obispo Counties, emphasizing upper and middle Santa Ynez watershed and lower Twitchell watershed	Revised project design implemented consisting of six high-output ground-based flare-seeding (AHOGS) sites.

APPENDIX B

2012-2013 Cloud Seeding Program Adopted Suspension Criteria:

A. General Criteria for the Entire Project Area in both Santa Barbara and San Luis Obispo Counties

Criteria in this category apply to the entire project area including all of Santa Barbara County and the Twitchell Reservoir Drainage of Southern San Luis Obispo County.

1. Whenever the National Weather Service (NWS) issues a severe storm, precipitation, or flood warning that affects any part of the project area, the project meteorologist shall suspend operations which may affect that part. Operations will be suspended at least for the period that the warning is in effect.
2. The Project Meteorologist or District/Agency personnel shall retain independent authority to suspend cloudseeding operations for any part, or all of the project area in the event that unforeseen conditions develop during storm events which in their best judgment have the potential to cause flooding or other adverse conditions anywhere within the project area.

B. Specific Criteria for Individual Areas/Watersheds

South Coastal Areas:

1. No targeting of or seeding operations which affect the South Coast of Santa Barbara County south of the Santa Ynez Mountains Ridgeline will be conducted.

Santa Ynez River Watershed including the Zaca Fire Area:

1. Due to the ongoing recovery of the Zaca Fire area, high intensity storms will not be seeded that would impact recovering areas since high intensity events may cause accelerated sediment flux. If the NWS predicts 0.8" per hour or greater rainfall intensity, seeding will not be conducted in project areas where such intensities are predicted. If 0.8" per hour intensities are observed anywhere in the Santa Ynez River Watershed, seeding activities shall be immediately suspended for the remainder of that storm event.
2. Prior to and during each storm event the District will make stream flow runoff forecasts for the Santa Ynez River using a hydrologic computer model, Alert telemetered rainfall data, radar, and quantitative precipitation forecasts. If, prior to any storm event the model indicates that the storm has the potential to generate a 15,000 cubic feet per second (cfs) or greater flow in the Santa Ynez River near Lompoc, the storm may be seeded *only* if; (1) both the District/Agency and Project meteorologist concur, and (2) measures are taken to continuously monitor the storm event. If stream flow runoff forecasts predict flows of over 15,000 cfs in the Santa Ynez River near Lompoc based on **observed** rainfall data, seeding

operations which may impact the Santa Ynez River flow below Bradbury Dam shall be immediately suspended.

3. Should it be predicted that Lake Cachuma entirely fill and/or spill based on the Flood Control's Santa Ynez River computer flow model, seeding operations to target the Santa Ynez Watershed will be suspended for the remainder of the season.

The La Brea Fire Area:

1. The La Brea Fire Area is not a targeted area of the cloudseeding program. However, due to ongoing recovery and the fact that this area is *adjacent* to the Twitchell Reservoir target, if the NWS predicts 0.8" per hour or greater rainfall intensity for the La Brea Fire Area, seeding would not be conducted in the adjacent project area (Huasna and Alamo drainages). If 0.8" per hour intensities are observed in the Twitchell target area, seeding activities shall be immediately suspended for the remainder of that storm event.

Twitchell Reservoir and the Cuyama River Watershed:

1. Cloud seeding operations shall be suspended in the Twitchell Watershed when District/Agency project that the conservation pool of Twitchell Reservoir will fill. The conservation pool is full at elevation 622.30' (108,758 acre-feet of storage). This leaves 89,000 AF of Flood Control capacity.
2. Seeding operations shall be suspended if the current or projected flow on the Cuyama River is 15,000 cfs or greater, as determined by the District/Agency.
3. Seeding operations shall be suspended if the NWS or NOAA predicts a storm of 6" or greater over any 24-hour period to occur in any location within the Sisquoc Watershed. The Sisquoc River has no control facilities on it and significant flows emanating from it can affect the Santa Maria River levee.

Note: All suspension criteria are subject to revision should hydrologic conditions warrant it. All revisions must be documented in writing and be approved by District/Agency representatives with notification provided to the project meteorologist.

***North American
Weather Consultants, Inc.***

8180 S. Highland Dr., Suite B-2
Sandy, Utah 84093

801-942-9005