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FLASH FLOOD EVENT OF 6 FEBRUARY 1998: A CASE STUDY

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[Note: Because of the large number of figures, only the text will be published in hard copy. The figures can be accessed on the Web version at http://www.wrh.noaa.gov under Technical Attachments.

I. Introduction

During the winter of 1997-1998, El Nino was at its peak and several very heavy rainfall events [>10 inches of rain] hammered Southern California. On the morning of February 6, the third most powerful storm of the winter season brought very heavy rains to the region. As a result, flooding was reported from San Luis Obispo south to Los Angeles. Some of the most intense rains occurred in the area surrounding the city of Camarillo, located in Ventura County.

This paper will look at the flash flooding that occurred in the Camarillo-Point Mugu area, which includes the Calleguas Creek River Basin. Specifically, the purpose is to document the Ventura County region's critical dependence on radar coverage from the Sulphur Mountain Doppler radar (KVTX). Following a short meteorological discussion and an analysis of the rapid river response to the event–radar coverage from the Sulphur Mountain Doppler radar will be compared with other network radars in the region. Based on this comparison, it will be shown that the KVTX radar was the only warning tool forecasters had available that provided significant lead time for this potentially life-threatening event–even considering the extensive gage network that serves the area.

II. Event Overview

The storm that hit southern California on the February 6 had all the earmarks of a classic El Nino event. Figure 1 shows the 500 mb pattern associated with the storm. Of particular note is the classic negatively-tilted trough aligned along the coast of southern California. Figure 2 shows a 160 knot jet approaching northern Baja–another classic El Nino feature that puts much of southern California under the favorable left exit region of the jet stream and in an area of enhanced upward vertical motion. The strength of the vertical motion can be seen in Fig. 3, a time-height cross section from the Eta model centered over the Oxnard

Plain of southern Ventura County. Note that the strongest upward vertical velocities, over 15 micro-bars per second, are centered around 06/18Z (10 PST). This is almost precisely when the heavy rains and flooding occurred.

Obviously, this was a very dynamic event capable of producing intense downpours. Orographic rainfall enhancement played a lesser role, if any, in the heavy rains which produced the flooding. In fact, as will be seen below (Section IV), heavy showers and thunderstorms formed over the waters of the Santa Barbara Channel, then moved onshore. Thus, the immediate coastal areas became prone to the flooding.

About mid morning on the 6th, heavy rains moved onshore over the Oxnard Plain and hit the Camarillo-Point Mugu area. Between roughly 9 and 10 PST, the area received over two inches of rain. Significantly, this high intensity rainfall occurred within just a few days of an earlier event [2nd and 3rd of February] that had dropped over 6 inches of rain in the region. Thus, the grounds were already saturated. Due to these antecedent conditions, the February 6th event produced very rapid, widespread flooding in the area. Nearly two-thirds of Camarillo City Hall was flooded, highway 101 southbound was down to one lane, and the Pacific Coast Highway near Malibu was under two feet of mud. On the south side of Camarillo, the Conejo Creek (a tributary to the Calleguas Creek) overflowed its banks, inundating the Camarillo Springs Golf Course. Further downstream, the Calleguas Creek overtopped the Pacific Coast Highway and caused minor flooding at Point Mugu, home of the Navy's Pacific Missile Test Center.

III. Automated Stream Gage Network

The Calleguas Creek is not just any small creek. The Calleguas Creek River Basin is located in southeastern Ventura County at the extreme west end of the Santa Monica Mountains. Figure 4 is a topographic map of the area showing the creek (magenta) running east and south of Camarillo (C). Although it is a small basin–covering only 325 square miles with elevations running from sea level to about 2,800 feet–flooding in this basin threatens much more than just the farmlands of Oxnard and Camarillo. Located near the river's mouth is the Navy's multi-billion dollar Pacific Missile Test Center at the Point Mugu Naval Air Station (P). Other than levees on the lower reaches of the river and around the Navy Base, there are no major flood controls in the watershed. On the morning of February 6, flood waters rose rapidly to within six inches of topping the levee. The flash flood warning issued by the National Weather Service at Oxnard gave Navy personnel advanced notice on the possibility for dangerous flooding along Calleguas Creek–and they were standing by the levee at the time.

Figure 5 shows how the Calleguas Creek responded rapidly to the intense rainfall on the morning of February 6. This graphic was produced using a technique developed by Jonathan Slemmer and Brent Bower (1999). On this graphic, hourly data from two automated rainfall sensors (CSUCI-R and MOR) are overlaid with hourly data from an automated river stage sensor (CSUCI). Sensor MOR is located in the headwaters of the

Calleguas Creek, while sensors CSUCI-R and CSUCI are co-located on Calleguas Creek, near the campus of the California State University-Channel Islands, just north of Point Mugu.

Note that the response of the river was virtually instantaneous, rising immediately with the onset of moderate rain [0.3 inches per hour] between 8 and 9 PST. The heaviest rains [~1.5 inches per hour] reached the gage at CSUCI between 9 and 10 PST. By that time, the river is already most of the way to its peak with flooding in some areas. It is clear that if forecasters had only these gages to rely on, the flood warning would not have been issued until shortly after 10 PST. As it turns out, the initial reports of flooding began streaming in by 1030 PST (see Section IV). It is clear that little lead time would have been provided to the people in the region based on gage reports alone.

During this high intensity rainfall event, automated rain gages and stream sensors played a very important role in monitoring the development of the flash flooding in the Calleguas Creek River Basin. As Fig. 4 demonstrates, they were very effective at capturing and documenting the extremely rapid response of the river. However, automated gage data would have been untimely for supporting the issuance of the flood warning for the event. As will be shown in Section IV, it was data from the Sulphur Mountain Doppler radar that provided forecasters with the necessary information to support the issuance of the flood warning with outstanding lead time.

IV. KVTX Radar Coverage

There are three radars in the national Doppler network that can provide at least some coverage over southern Ventura County, the area of this flood. To the northwest, about 92 NM from Point Mugu, lies the Vandenberg AFB radar – KVBX. About 84 NM to the southeast of Point Mugu lies the Santa Ana radar – KSOX. Finally, just 23 NM to the north-northwest of the area is the Sulphur Mountain radar located near Ojai. Figure 6 shows the relative locations of these radars.

Clearly, KVTX has the advantage in providing radar coverage to the region due to its proximity. Just 23 NM away, the KVTX radar's lowest beam has coverage down to 3,500 feet over Point Mugu. Thus, the Sulphur Mountain radar can detect much more of the storm. However, at 60 to 70 miles further away, the lowest beam height from either the KVBX or KSOX radars is 2 miles or higher above Point Mugu. As will be shown, this is much too high to detect even the most intense winter storms like the ones that occurred on February 6.

Figure 7 is a composite reflectivity (CR) product from the KVTX radar at Sulphur Mountain. This data has a time stamp of 1612 UTC (812 PST). Allowing for processing of the image, the radar operator had access to this data at roughly 1620 UTC (820 PST). This data clearly depicts a band of heavy showers and thunderstorms south of Anacapa Island. The KVTX radar also indicates a forecast movement to the northeast at 19 knots, towards the coastline of southeastern Ventura County. It was solely on the basis of this data that a flash flood warning was issued for southern Ventura County at1635 UTC (835 PST). Note that while the heaviest rains are still located well offshore–south of Anacapa–rainfall over Camarillo and the Calleguas River Basin is much lighter. Light to moderate rain is being reported at this time by the gages at CSUCI-R and MOR (Fig. 5).

Figure 8 is a One-Hour Precipitation (OHP) product taken from KVTX at 1654 UTC (854 PST), almost 20 minutes after the warning was issued. At this time, the rain band is just beginning to move onshore near Oxnard, but the heaviest rains are still located south of Anacapa Island. The radar indicates that the rain in this band has an intensity of 1.8 inches per hour. This is in agreement with subsequent spotter and gage reports taken after the band moves onshore.

At approximately 1800 UTC (10 PST) 6 February, a spotter reported that two inches of rain had fallen in the Camarillo area in about an hour. This report was followed by one of flooding at Camarillo's City Hall at 1830 UTC [1030 PST] Based on this time line, warning lead time would be 90 to 120 minutes, based solely on data from the Sulphur Mountain Doppler radar (KVTX). This compares very favorably to the stated National Weather Service goal of 41 minute lead times for flash flooding events.

V. Performance of Adjacent Radars (KVBX and KSOX)

Could this warning have been issued based solely on data from either of the adjacent network Doppler radars, KVBX and KSOX? Figure 9 displays the CR product from KVBX at 1614 UTC (814 PST), just 2 minutes after the KVTX data that was used to issue the warning. While the rain band that eventually produces the flooding can be seen, its intensity is so weak that the radar does not identify the return as a storm cell, nor predict its future movement. Also note the total lack of rainfall over southern Ventura county, even though moderate rain was fairly widespread at the time. From the opposite perspective, Fig.10 shows the CR data from KSOX at 1618 UTC, or just 6 minutes after the key KVTX data. Once again, notice how innocuous the entire event appears. Again, KSOX shows only very light rain over southern Ventura County. Clearly, neither of these radars would support the issuance of a warning even though the event was one of the strongest and most dynamic to hit the area the entire winter.

Another way to look at radar performance is to examine the storm total precipitation (STP) products from the three radars. The STP is a product that basically summarizes a radar's rainfall estimate for the event. As such, it also provides a good measure of the radar's performance. Figure 11 is the STP from the Sulphur Mountain Doppler radar, KVTX. On this image, the band of heavy showers and thunderstorms that produced the flash flooding is clearly visible, with storm total precipitation estimates up to two inches. Figures 12 and 13 display much lower STP estimates from KVBX and KSOX, respectively. Both these radars severely underestimated the rainfall over southern Ventura County. Thus, the conclusion is again inescapable. Of all the network Doppler radars, only the Sulphur Mountain radar was capable of supporting the warning issued the morning of February 6,

1998. In fact, it was the only data source available to forecasters that was capable of meeting the National Weather Service's stated warning lead time goal for flash flooding events.

VI. Summary and Conclusions

On 6 February 1998, the third in a series of strong Pacific storms swept through coastal Ventura County. This storm displayed characteristics that are typical of the classic El Nino event. Specifically, there was a negatively-tilted trough along the coast of California with an upper level jet located over northern Baja. These dynamic features combined to produce showers and thunderstorms over the waters of the California Bight, which moved onshore over the Oxnard Plain, producing intense rainfall and widespread flooding in the Camarillo-Point Mugu area. This event presented an excellent opportunity to evaluate the performance of the Sulphur Mountain Doppler radar relative to both the adjacent Doppler radars and the dense network of automated gages in the region.

Specific conclusions are as follows:

1. NWS forecasters issued a flash flood warning for southern Ventura County which verified with an estimated lead time of 90 to 120 minutes. This lead time was well in excess of the stated NWS goal of 41 minutes.

2. Radar data from the adjacent network radars, specifically the Vandenberg AFB radar (KVBX) and the Santa Ana Mountain radar (KSOX), was insufficient in coverage to support the issuance of any flood warning.

3. Automated rain and stream gages in the Calleguas Creek River Basin were critical for monitoring the onset of heavy rains, as well as the near instantaneous rise in the river. However, these gages could not have supported the issuance of a timely flood warning for the area.

4. Radar imagery from the Sulphur Mountain Doppler radar (KVTX) was the only meteorological sensor available to the forecasters that could detect the storms far enough over the adjacent waters to permit the issuance of a flood warning for the area with sufficient lead time.

5. Clearly, this event illustrates that when flooding rains approach the growing coastal communities of Ventura County, the Sulphur Mountain Doppler radar is key for storm detection and the protection of life and property.

VII. Acknowledgment

The author wishes to acknowledge the reviewers of this paper, Dave Gomberg and Ben Moyer. In addition, the author would like to thank Brent Bower, Curt Kaplan, and Ray Tanabe for the production of several of the graphics.

VIII. Reference

Slemmer, Jonathan and Brent Bower, 1999: Technique for Analyzing Heavy Rain Events and Associated Stream Responses, Western Region Technical Attachment 99-16 (Available from the National Weather Service, 125 S. State St., Salt Lake City, UT 84138.

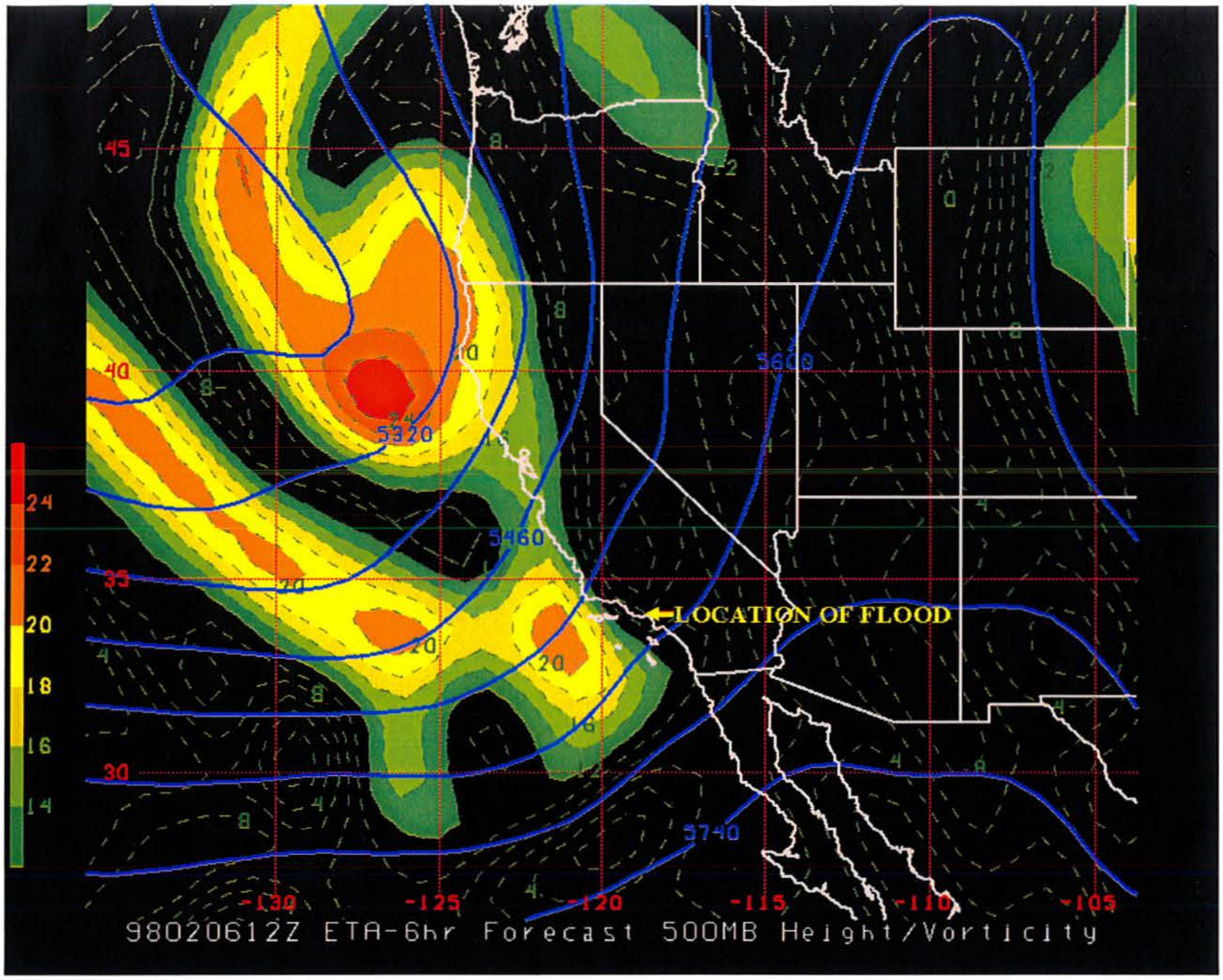

Figure 1. 500 MB Heights and Vorticity

This figure shows the Eta forecast 500 MB heights and vorticity pattern for 18Z on the 6th of February. Note the negatively tilted trough lying along the coast of California.

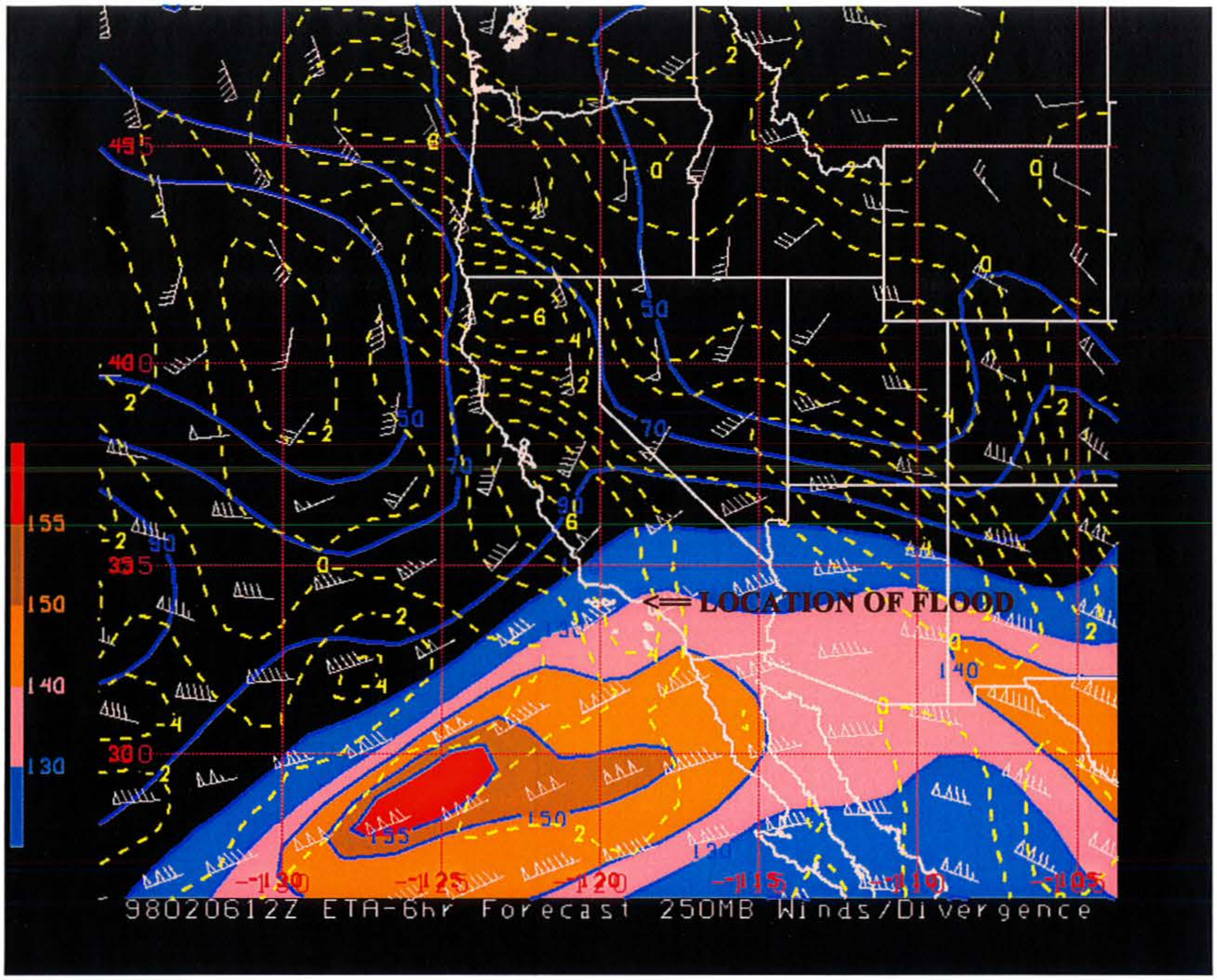

Figure 2. 250 MB Winds and Divergence.

This figure shows the Eta forecast 250 MB wind pattern for 18Z on the 6th of February. A 160 knot jet streak is approaching the coast of northern Baja, Mexico. Note that the flood location is under the left exit region of the jet–an area favorable for enhanced upward vertical motion.

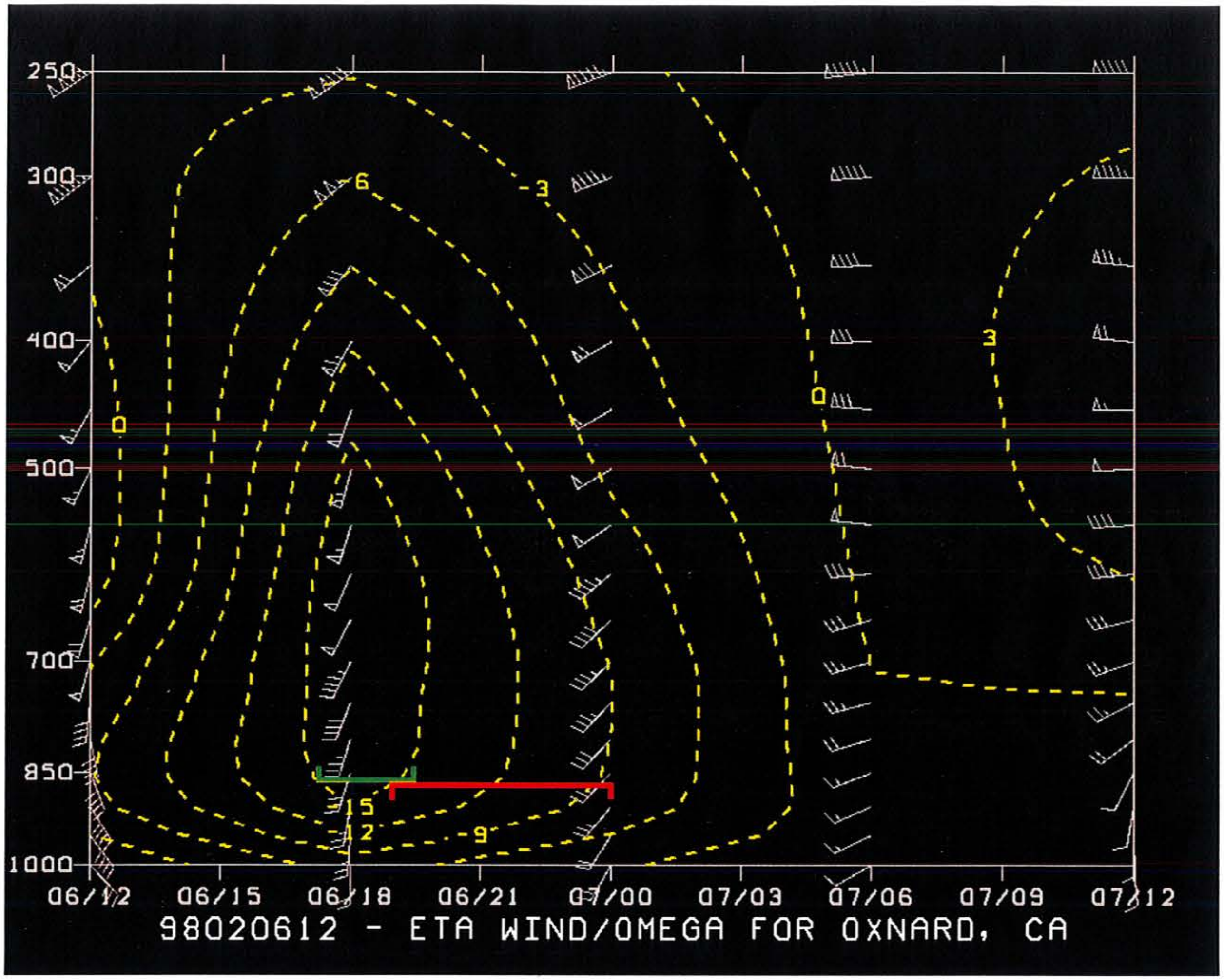

Figure 3. Time-Height Cross Section of Winds and Omega.

This figure shows the Eta forecast time-height cross section of winds and omega for Oxnard, CA from the 12Z model run. Note the area of 15 μ bars/sec upward vertical motion centered near 18Z. The green line indicates the period of the heaviest rains, while the red line indicates the period of highest flows on the Calleguas Creek.

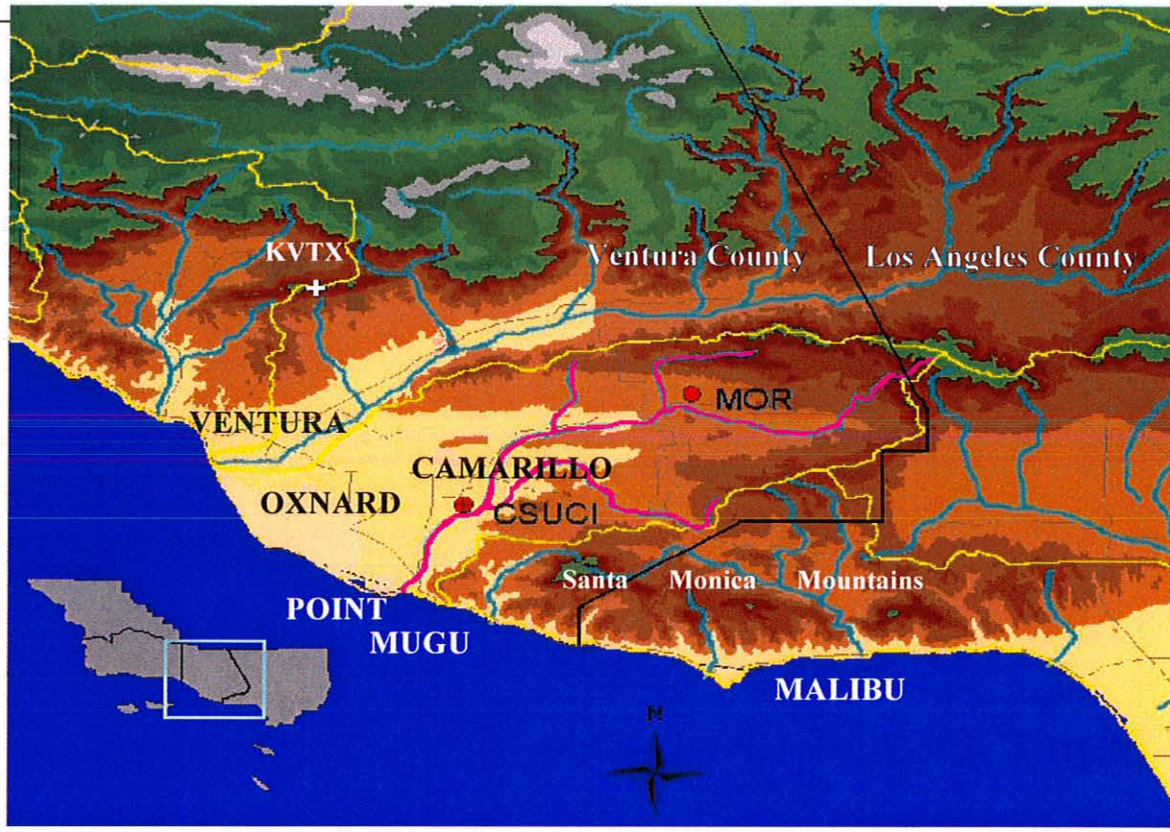

Figure 4. Calleguas Creek River Basin.

This map shows the relative positions of the Sulphur Mountain radar [**KVTX**], the city of Camarillo, Point Mugu, the dual rain gage and river sensor near California State University-Channel Islands [**CSUCI**], and the rain gage at Moorpark [**MOR**]. The Calleguas Creek is colored magenta. The mountain range to the south and east of the river is the Santa Monica Mountains [>3000 feet]. The mountains to the north are the Topa-Topas [>6200 feet].

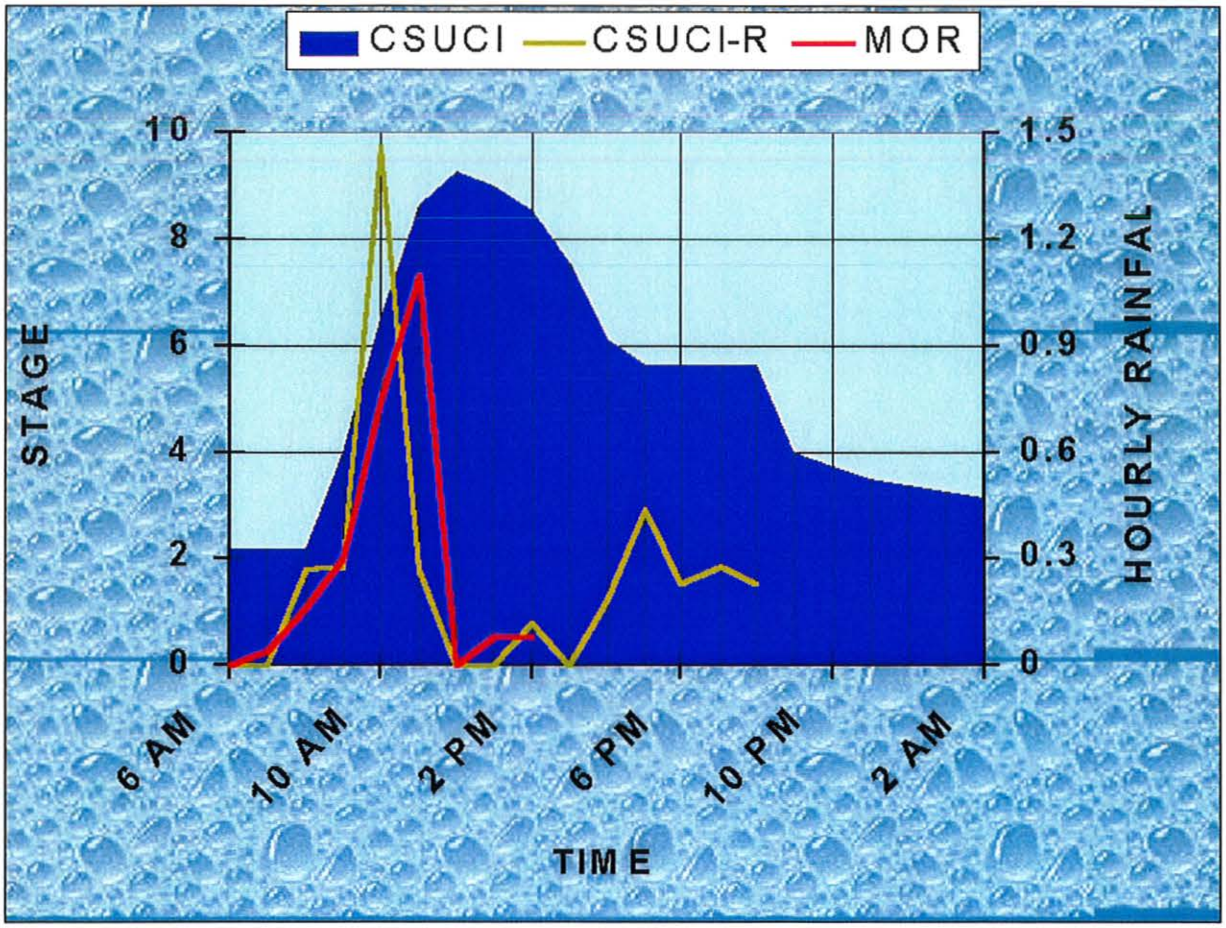

Figure 5. Calleguas Creek Response, 6 February 1998

Figure 6. Next Generation Radar [NEXRAD] Sites.

This figure shows the relative positions of the three NEXRAD sites that have coverage over the area that flooded on 6 February 1998. Note the four-county, county warning area [CWA] supported by the Los Angeles/Oxnard office is outlined in yellow. The Calleguas Creek is highlighted in magenta.

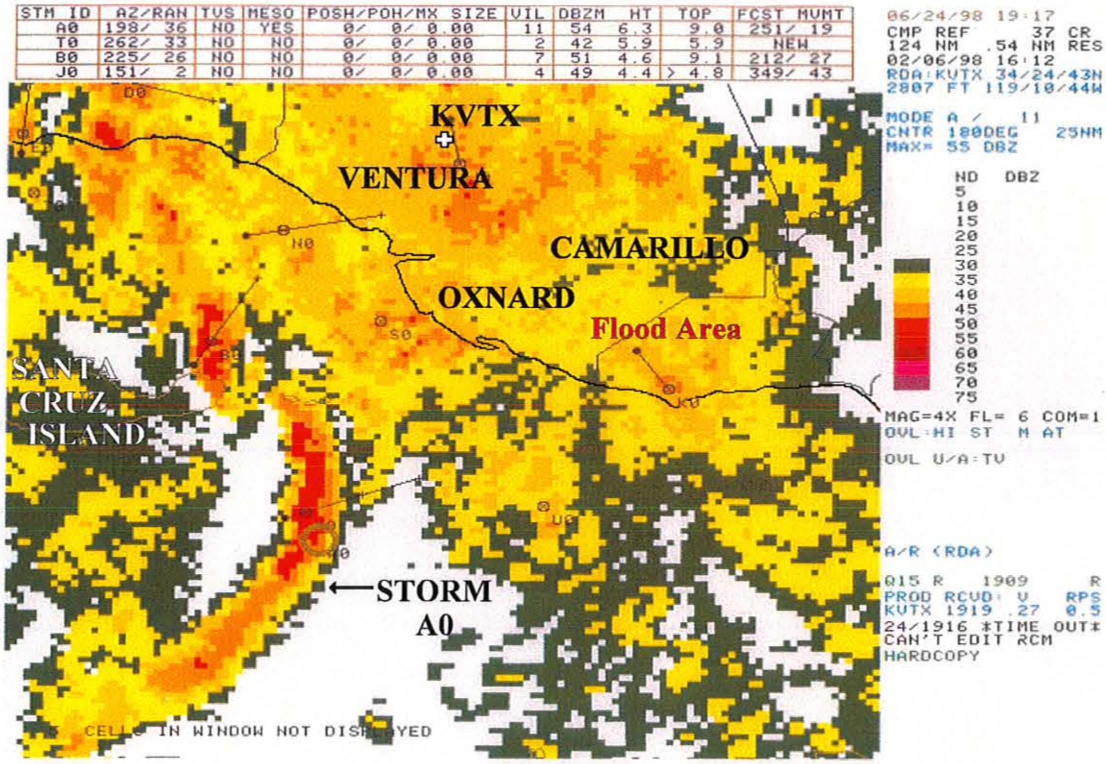

Figure 7. Composite Reflectivity (CR) Product from the
Sulphur Mountain Radar at 1612 Z [8:12 AM PST].

This figure shows the band of heavy rain approaching the area where the flooding occurred. It was based largely on this piece of data that the flash flood warning was issued for southern Ventura County and western Los Angeles County. This band of showers was identified as **Storm A0** by the radar with characteristics as follows: azimuth of 198 degrees, range of 36 NM, no TVS, MESO, no hail, VIL = 11, DBZM = 54, HT = 6.3, TOP = 9.0, FCST MVMNT = 251/19. While the data time is 1612Z, keep in mind that, due to radar processing time, the image was not available to the forecaster until about 1620Z. The warning was issued at 1635Z.

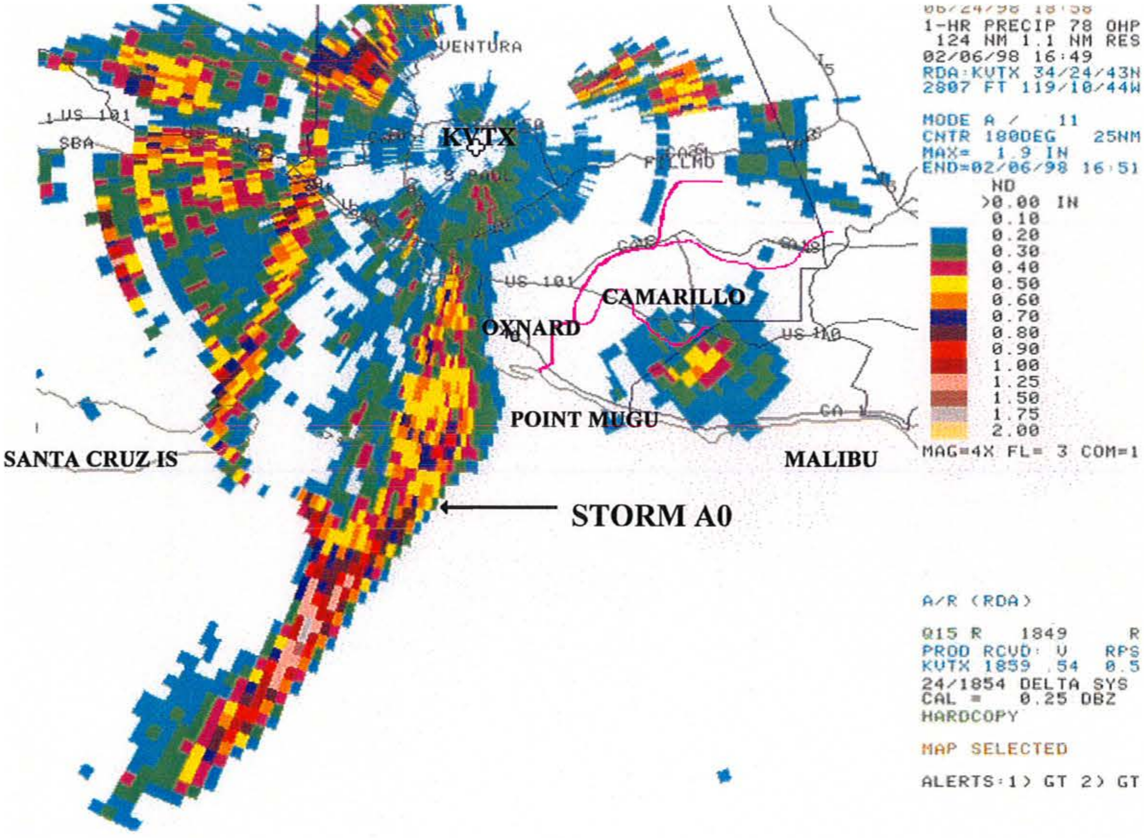

Figure 8. One-Hour Precipitation [OHP] Data from KVTX at 1654Z on the 6th of February 1998.

At this time, the flood warning had been in effect for 19 minutes and the heaviest rains were still 20 to 30 minutes offshore. Note that the heaviest rains [>1.9 inches/hour] are still over 15 miles offshore. Without the KVTX radar data, forecasters would have no way of knowing that flooding rains were approaching Point Mugu and the Calleguas Creek [magenta].

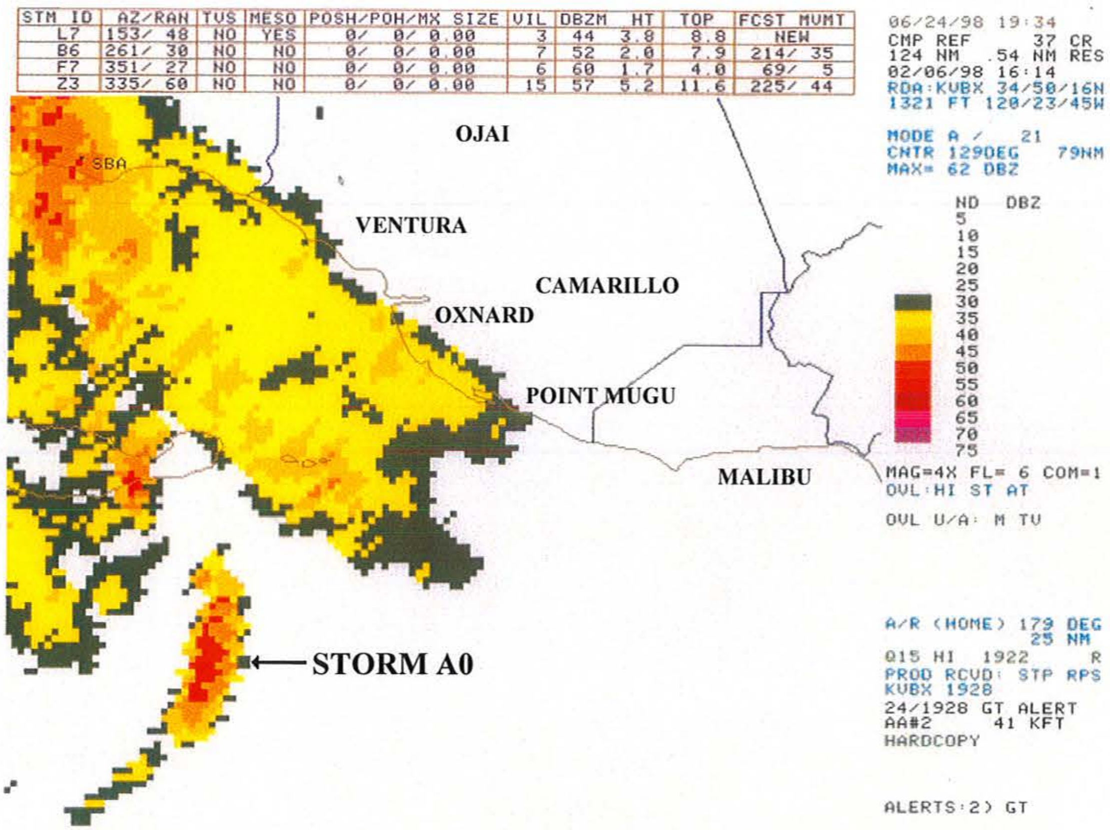

Figure 9. Composite Reflectivity [CR] Data from KVBX.

This figure shows CR data from the Vandenberg radar, KVBX. This data was taken at 1614Z [8:14 AM PST], only 2 minutes after the data from KVTX [Fig 7.] that was actually used to issue the flood warning. Note that beam blockage from the Santa Ynez Mountains prevents effective radar coverage over the communities of southern Ventura County and western Los Angeles County. Also, the band of showers that showed up so well on the KVTX data, **Storm A0**, now appears to be too insignificant to require local flood warnings. In fact, the KVBX data does not even identify the band as a storm cell. This data simply would not have supported the issuance of a timely warning for the flooding that occurred.

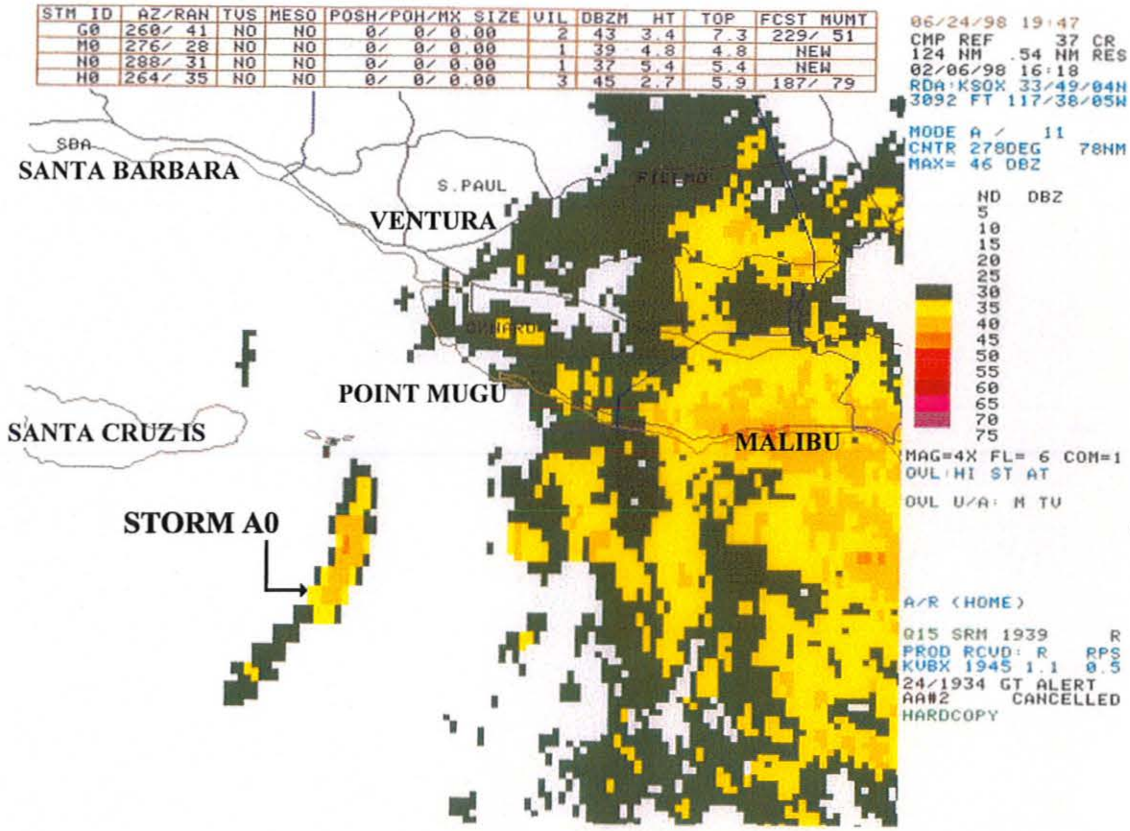

Figure 10. Composite Reflectivity [CR] Data from KSOX.

This figure shows CR data from the Santa Ana Mountain radar, KSOX. This data was taken at 1618Z [8:18 AM PDT]. Note that beam blockage sharply reduces the rainfall coverage over southern Ventura County. Also, due to the range, the heavy band of showers southeast of Santa Cruz Island [**Storm A0**] appears to be insignificant. Again, this data would not have supported the issuance of a timely warning for the flooding that eventually occurred.

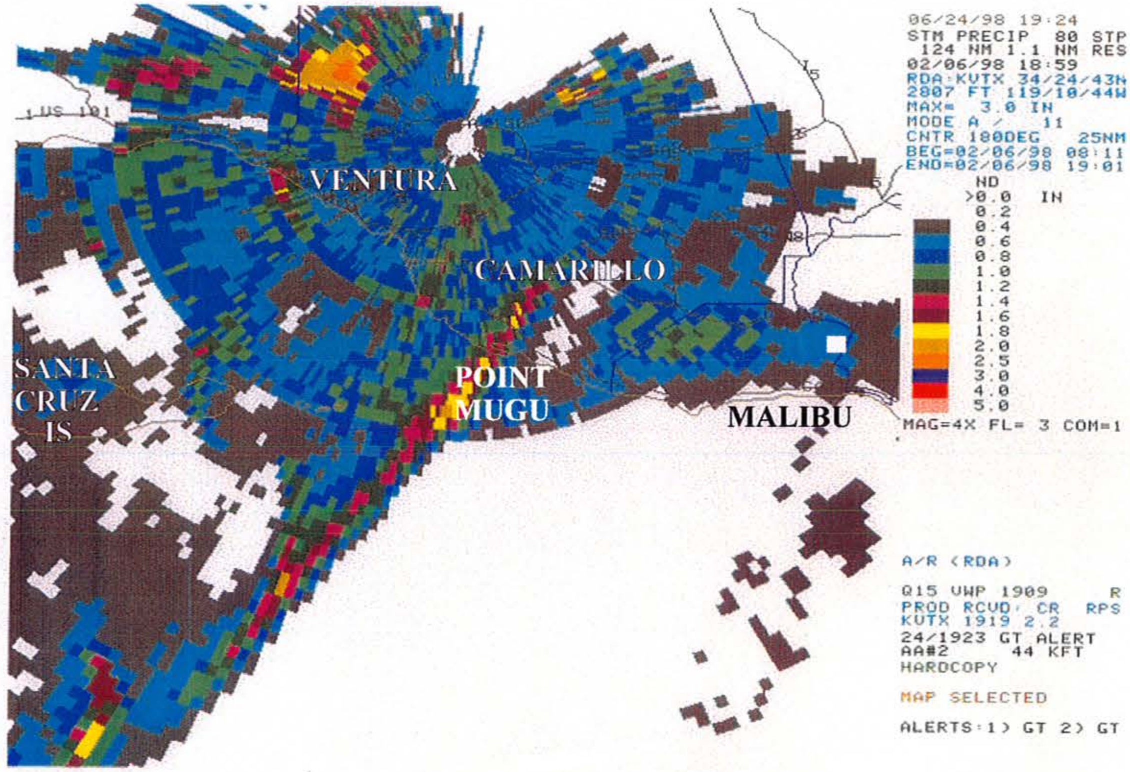

Figure 11. Storm Total Precipitation [STP] Data
from the Sulphur Mountain Radar [KVTX].

This figure shows the KVTX radar estimate of rainfall from 0811Z to 1901Z [12:11 AM PST to 11:01 AM PST] on the 6th of February 1998. Note the path of heaviest rains that moved from south of Santa Cruz Island directly towards the city of Camarillo. Note that the heaviest rains in the Camarillo area, approximately 2 inches, agreed well with spotter reports from the vicinity.

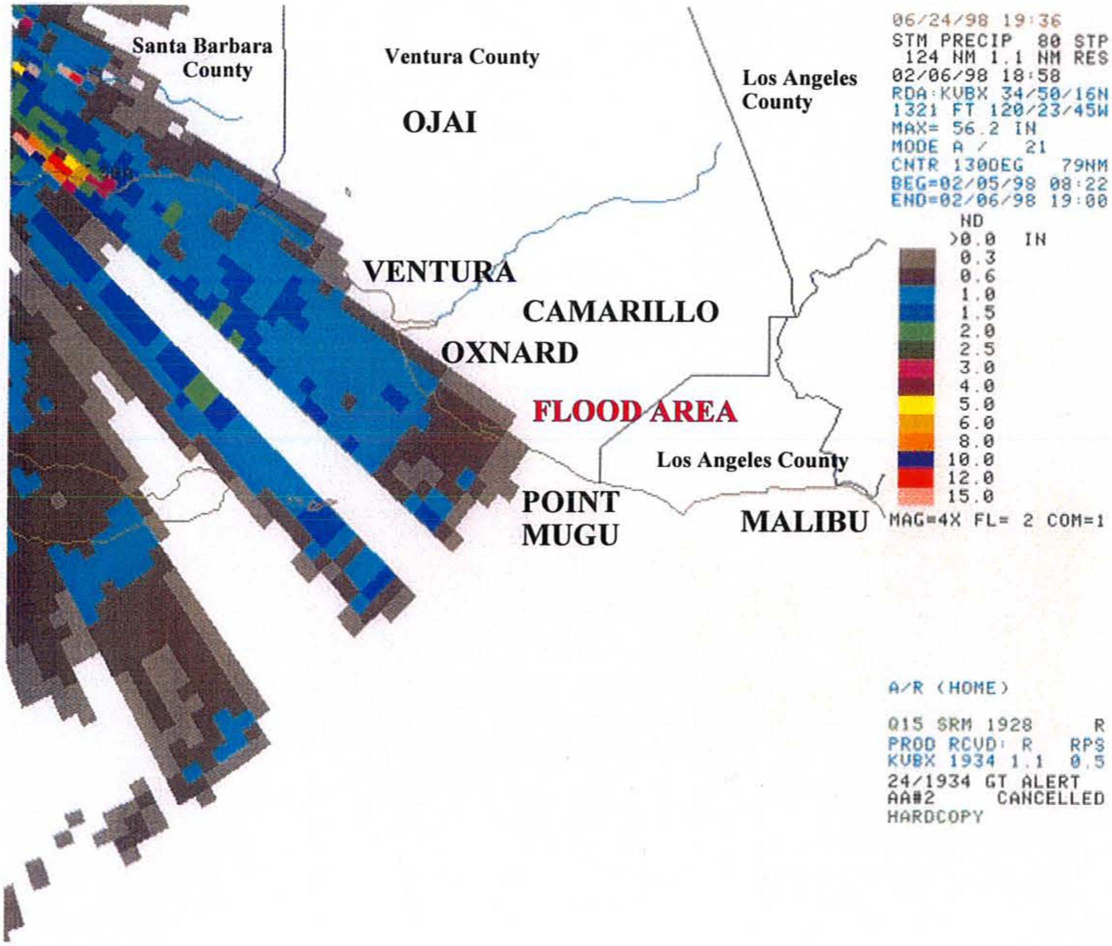

Figure 12. Storm Total Precipitation [STP] Data
from the Vandenberg Radar [KVBX].

This figure shows the KVBX radar estimate of rainfall from 0822Z to 1909Z [12:22 AM to 11:09 AM PST] on the 6th of February 1998. This figure clearly illustrates the Vandenberg radar's near total lack of coverage over most of Ventura County and portions of western Los Angeles County–including the area that suffered from the flash flooding.

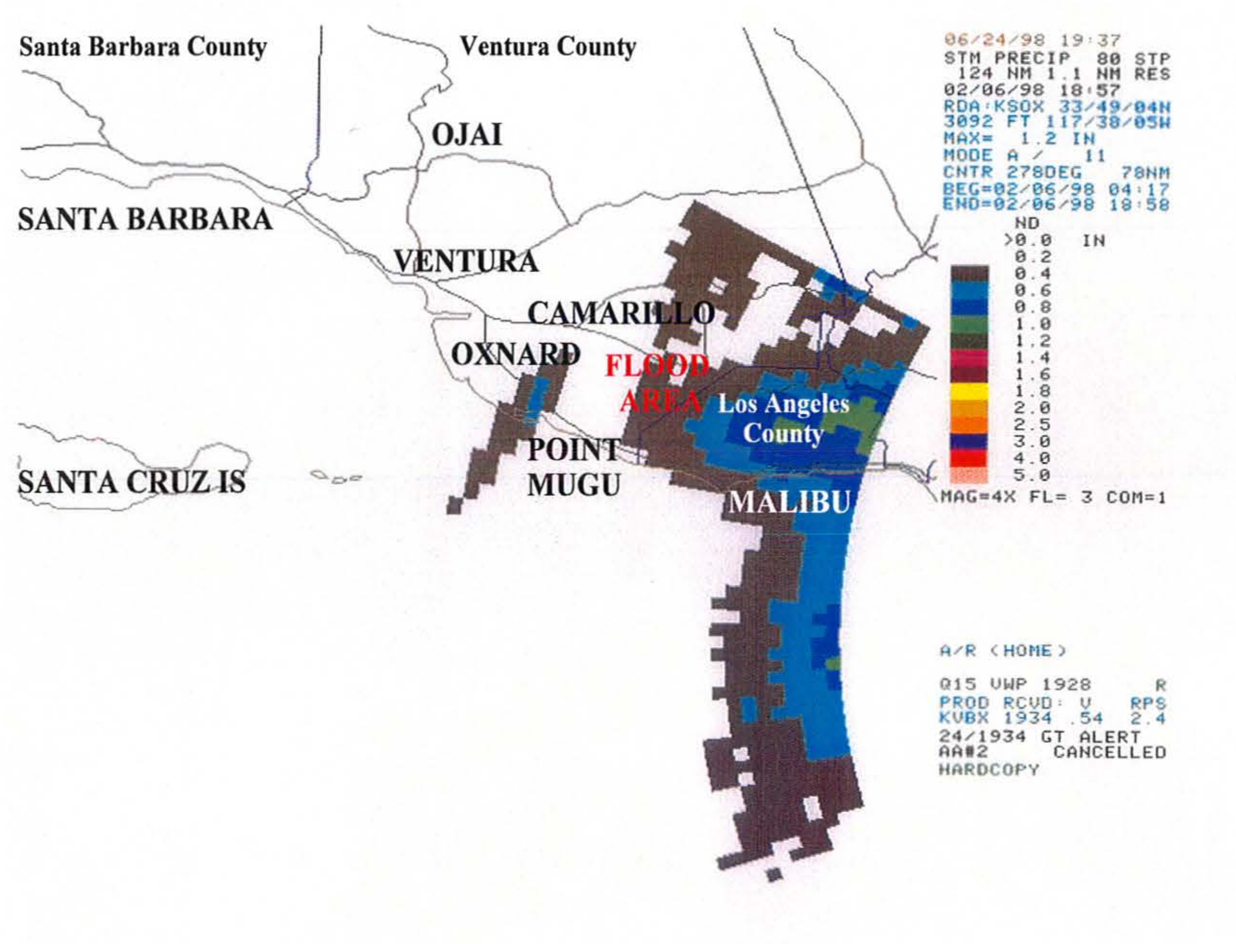

Figure 13. Storm Total Precipitation [STP] Data
from the Santa Ana Radar [KSOX]

This figure shows the KSOX radar estimate of rainfall from 0417Z to 1858Z [8:17 PM on the 5th to 10:58 AM PST on the 6th] on the 6th of February 1998. What little coverage this radar provides over Ventura County and western Los Angeles County does not begin to reflect the flooding rains that occurred.