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THUNDERSTORMS IN SAN DIEGO AND ASSOCIATED EASTERLY WAVE OF 20 JULY 1998

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[Note: The figures and tables will not be printed in hard copy, but can be accessed in the Web version of the TA.]

Introduction

An easterly wave moved west across New Mexico, Arizona and southern California from 18-20 July 1998. During the afternoon of 20 July 1998, when the easterly wave was near San Diego, CA, thunderstorms occurred in the coastal sections of San Diego County, including the city of San Diego. This is somewhat unusual, as summer thunderstorms have occurred at the coast in San Diego on average only about once every two years (Evans and Halvorson, 1998). The thunderstorms on 20 July 1998 were short-lived, not lasting more than one hour at any one location. However, the thunderstorms were strong enough to give San Diego Lindbergh Field 0.21 inches of precipitation, which was ten times the average rainfall for the entire month of July. This was the third largest daily precipitation amount ever recorded in July at the official observation location in San Diego. It was the largest daily precipitation value in July since 31 July 1991, when 0.23 inches of precipitation occurred during an easterly wave. Not all easterly waves that move through southern California produce precipitation in San Diego. An easterly wave (which occurred on 11 July 1999) did not produce precipitation in coastal San Diego County, despite producing flooding in the San Bernardino County mountains and deserts. An examination of these waves will show that there were two major differences between the 20 July 1998 and 11 July 1999 systems.

Mechanisms for Summer Precipitation in Southern California

The Mexican monsoon, during which easterly waves can occur, affects much of northwestern Mexico and the southwestern United States each summer (Douglas et al., 1993). Climate data show that while the winter is by far the season with the most precipitation across southern California, there is a secondary monthly precipitation maximum across most desert and a few mountain locations during summer. Table 1 shows monthly precipitation for selected mountain and desert locations (Fig. 1) in southern California. Unlike the winter precipitation, which comes from Pacific storms, the summer precipitation over much of the southwestern United States, including southern California, comes primarily from moisture from the Gulf of California through gulf surges (Brenner, 1974). Tubbs (1972) linked the Mexican monsoon (then called Sonoran summer monsoon) to the summer increase in thunderstorms over southern California (except in September, when other mechanisms contribute to thunderstorms). Tropical cyclones can also account for summer precipitation, mainly in September, but this is sporadic as an average of only one east Pacific hurricane or tropical storm impacts the southwestern United States per year (Garza, 1999). Furthermore, these often result only in precipitation east of southern California.

While the Gulf of California moisture can combine with the unstable atmosphere during the hot days of summer to produce thunderstorms over the mountains and deserts of southern California, this process is difficult to reproduce west of the mountains since the air is usually much more stable due to the marine influences and blocking of low-level gulf surges by the mountains. Thus, most of the time, summer thunderstorms only occur west of the mountains when east winds aloft allow them to drift west into the valleys after they form. Seldom will thunderstorms actually form west of the mountains, but this occurred on 20 July 1998.

Synoptic Pattern from 18-20 July 1998

From 18-20 July 1998, strong high pressure aloft was nearly stationary over the interior western United States. The 500-mb pressure height exceeded 5940 meters throughout the period from most of the Four Comers region of Utah, Colorado, Arizona, and New Mexico, west into parts of southern California, as can be seen in Fig. 2 for 1200 UTC 19 July 1998. This produced easterly winds at 500 mb over most of Arizona, New Mexico, southern California, and northwestern Mexico. Easterly winds were also occurring at 850 mb (or about 1500 meters) over northwestern Mexico. Small vorticity maxima were circulating clockwise around this high pressure system, including minor westward-moving disturbances on the south side of the high.

GOES-10 water vapor images showed an area of cyclonic circulation over eastern New Mexico at 1900 UTC 18 July 1998. By 1500 UTC 19 July 1998, this area of cyclonic circulation drifted west-southwest into extreme southwestern New Mexico. The tight cyclonic circulation continued and gradually moved west. It reached extreme southern California at 2100 UTC 20 July 1998 (Fig. 3) when the thunderstorms were erupting along the coast of San Diego County. Figure 4 shows a movie of the water vapor images at two-hour intervals from 1900 UTC 18 July 1998 through 2300 UTC 20 July 1998. The westward progression of the easterly wave is best visible through this movie.

WSR-88D Analysis of Thunderstorms on 20 July 1998

Thunderstorms developed during the morning of 20 July 1998. Late morning Doppler weather radar images showed that thunderstorms of moderate intensity had already developed near Riverside and were beginning to develop over the Apple Valley in San Bernardino County. Shortly before noon, the Riverside cells were dissipating as they moved southwest into the Santa Ana Mountains, and the thunderstorms over San Bernardino County had intensified. Figure 5 shows that by 1924 UTC (12:24 PM PDT), the thunderstorm activity had developed further south over the Riverside and San Diego County mountains. Some isolated precipitation over extreme northwestern San Diego County and nearby coastal waters was all that remained due the remnants of the former Riverside convection.

Numerous showers and thunderstorms continued to develop over the mountains of San Diego County during the early afternoon on 20 July 1998. This typically occurs when monsoonal moisture moves into southern California. At 2024 UTC (1:24 PM PDT), the San Diego KNKX Doppler weather radar showed that convection, with reflectivities of numerous cells reaching 50 dBZ, was widespread over the higher terrain of the San Diego County mountains (Fig. 6). At that time, convection was beginning to develop over coastal sections of northwestern San Diego County. The trigger for this convection was possibly an outflow boundary from earlier thunderstorms over the mountains and foothills of north-central San Diego County and Riverside County interacting with the weak onshore flow and the sea breeze near the surface.

By 2059 UTC (Fig. 7), the thunderstorms over coastal northwestern San Diego County had intensified and were moving south. Heavy rain and thunder were reported with these storms. At 213 4 UTC (Fig. 8), an area of thunderstorms extended north-south along and just inland from the coast from Del Mar to downtown San Diego. It was at this time that Lindbergh Field received 0.21 inches of rain, which set the record for the day, and portions of nearby Interstate 5 experienced local flooding. In these areas, storm reflectivities were 50 dBZ or greater. The thunderstorms continued to move south and southwest, and by 2209 UTC, the cluster of strongest convection had moved into the coastal waters off San Diego.

Figure 9 shows the KNKX WSR-88D vertical wind profile over San Diego during the peak of the storm at 2134 UTC. The precipitation in the area provided ample targets for viewing the winds aloft. The easterly wave appears to have made a strong impact on the winds aloft as they were from the north between 8000 and 20000 feet MSL. Above 20000 feet, winds became more easterly, which provided a good east-to-west steering current for the easterly wave. The Doppler radar winds were similar to the winds aloft from the Miramar (NKX) sounding taken about two hours later at 0000 UTC 21 July 1998 (Table 2). After 0000 UTC, the easterly wave moved west and southwest of San Diego, and by 1200 UTC 21 July 1998, the NKX sounding indicated that winds between 8000 and 20000 feet MSL were mostly from the east.

Figure 10 shows the KNKX WSR-88D estimated storm total precipitation along with the reported 24-hour precipitation (20 July) amounts greater than a trace. The areal coverage of precipitation was not that large, though some values between Del Mar and Lindbergh Field may have been underestimated despite radar composite reflectivity values greater than 50 dBZ in that area. While no precipitation reports greater than 0.21 inches were reported, radar estimated that values in excess of 0.6 inches were detected just off the coast west and southwest of San Diego. Local precipitation values over an inch were reported in the mountains and deserts of San Diego County; however, this occurs several times per summer during monsoonal flow over southern California.

Model Performance

The Meso-Eta (29-km grid) model data from 1800 UTC 19 July 1998 and from 0300 UTC and 1800 UTC 20 July 1998 were analyzed. This was found to be the best performing model as all three model runs predicted vorticity maxima at 500 mb within about 200 miles east of San Diego for 0000 UTC 21 July 1998. Other models, such as the NGM and the AVN correctly had easterly flow at 500 mb but were more variable with the locations of the vorticity maxima.

The 1800 UTC 19 July 1998 Meso-Eta model output consistently tracked the easterly wave west, as was evident by the 500 mb heights and vorticities. Figure 11 shows the position of the vorticity maxima 30 hours after initialization, valid at 0000 UTC on 21 July 1998, when a significant vorticity maximum was located near the Arizona-California border. The 0300 UTC 20 July 1998 model run was somewhat less consistent. It showed that while the easterly wave appeared to be moving smoothly west in the first 12 hours, the vorticity maximum moving west into extreme southeastern California dissipated rapidly between 12 and 18 hours while a new vorticity maximum formed over central Arizona. It was not until the 21 -hour forecast, that the vorticity maximum moved west and strengthened. The 1800 UTC 20 July 1998 Meso-Eta run depicted the vorticity maximum at 0000 UTC 21 July 1998 further north and west than the previous two model solutions. Nevertheless, this position hinted at potential development of convection by this time period.

The 700 mb flow was progged by the three Meso-Eta runs from different initialization times, to be cyclonic around an area just southwest of San Diego at 0000 UTC 21 July 1998. The three different model outputs had similar results. However, it was found that the flow was too easterly in the model output, while the sounding and the WSR-88D wind profile showed more northerly winds. Therefore, with current resolution (including display resolution), the Meso-Eta was best used for determining if an easterly wave would be in the region but would only be able to provide a rough estimate of the timing or location of the easterly wave.

Moisture (originating mostly from the Gulf of California) was aloft over mountain and desert sections of southern California before the 20 July 1998 easterly wave but was most prevalent over Arizona. On 20 July 1998, winds aloft associated with the easterly wave shifted the most abundant moisture west into the mountains of southern California and also increased the moisture strongly near the coast. At both 700 mb and 500 mb, the relative humidity values at 0000 UTC 21 July 1998 (Figs. 12 and 13) were forecast to be high over southern California (including the coastal areas) by the 1800 UTC 20 July 1998 Meso-Eta model guidance. Relative humidity values near the coast were 55 percent at 700 mb and 70 percent at 500 mb. Earlier Meso-Eta runs predicted lower relative humidity values for 0000 UTC 21 July 1998 at those levels. The Meso-Eta values for vertical motion (omega) at those levels showed nothing unusual (at those levels) as it showed moderate upward vertical motion over the southern California mountains at 700 mb at 0000 UTC (Fig. 12) and little or no upward motion at 500 mb (Fig. 13). Typically, Meso-Eta has been more valuable with its vertical motion fields during winter storms than during easterly waves.

11 July 1999 Easterly Wave Example

Easterly waves are quite variable and unique, and many do not produce thunderstorms at the coast. Whether or not coastal precipitation in San Diego occurs, depends largely on the location of the vorticity maximum as it moves west across southern California. Even if moisture aloft is abundant, a dynamic trigger appears to be necessary for precipitation near the coast, since surface heating by itself is almost never sufficient for convection there in summer. The strength of a vorticity maximum will certainly provide a good clue to the magnitude of the dynamics available for convection, but the location of the vorticity maximum will ultimately determine whether or not thunderstorms can form in coastal areas.

The easterly wave that moved through southern California on 11 July 1999 contributed to major flooding over the mountain and desert areas of San Bernardino County. The strong convection which developed resulted in one fatality in the Forest Falls area as heavy rainfall produced flash flooding. However, despite the strength of this easterly wave, no precipitation occurred over coastal sections of San Diego County.

In reviewing the 11 July 1999 case, it became evident that the track of the vorticity maximum associated with the easterly wave played a major role in defining the areas of precipitation. The vorticity maximum associated with the easterly wave was depicted by the zero-hour analysis of the 0000 UTC 12 July 1999 ETA to be further north, near the south tip of Nevada (Fig. 14), instead of over extreme southern California as it was on 20 July 1998. Thus, more energy would have been directed into San Bernardino County instead of San Diego County. Also, the 0000 UTC 12 July 1999 NKX sounding (Table 3) showed that all wind speeds above the surface and below 300 mb (approx. 30000 feet MSL) were less than 10 knots. While this atmospheric profile is quite favorable for flash flooding over the mountains and deserts due to the slow movement of thunderstorms, it appears less favorable for thunderstorms near the coast. This is because the transport of moisture towards the coast is less, and the thunderstorms that form over the mountains are much less likely to move west towards the coast.

Summary

When an easterly wave moves into southern California during summer, especially one that is identified clearly by model guidance forecasts and satellite imagery for 24 to 48 hours, meteorologists should expect at least a slight chance of thunderstorms at the coast. In reviewing this case which produced coastal precipitation, it was found that probabilities for development of showers and thunderstorms at the coast increase when easterly waves moving west are accompanied by (a) a vorticity maximum moving west directly toward San Diego; (b) winds aloft from the north or northeast greater than 10 knots between about 700 mb and 300 mb and (c) relative humidity greater than 50 percent between 700 mb and 500 mb extending west to the coast, if not beyond.

Even on 20 July 1998, when the thunderstorms affected coastal San Diego County, most of the precipitation occurred over the southern California mountains. Monthly precipitation averages are low enough at the coast during the summer months that cases like these are clearly an anomaly and not the norm. Usually when precipitation occurs west of the mountains during summer, it is a result of thunderstorms transported by easterly winds from the mountains to the foothills and inland valleys, sometimes in conjunction with an easterly wave, but not always. These thunderstorms rarely reach the coast. Thus, it takes the proper combination of ingredients to produce thunderstorms at the coast during summer, and an easterly wave, with the proper positioning of its vorticity maximum, is one of these ingredients.

References

Brenner, I. S., 1974: A surge of maritime tropical air-Gulf of California to the southwestern United States. *Mon. Wea. Rev.,* **102**, 375-389.

Douglas, M.W., R.A. Maddox, and K. Howard, 1993: The Mexican Monsoon. J *Clim.,* **6**,1665-1677.

Evans, T.E., and D.A. Halvorson, 1998: Climate of San Diego, California. *NOAA Technical Memorandum, NWS* WR-256.

Garza, A.L., 1999: 1985-1998 North Pacific tropical cyclones impacting the southwestern United States and northern Mexico: An updated climatology. *NOAA Technical Memorandum,* NWS WR-258.

NOAA, 1998: *Daily Weather Maps.* Weekly Series, July 13-19,1998.

Tubbs, A.M., 1972: Summer thunderstorms over southern California. *Mon. Wea Rev.,* **100**, 799-807.

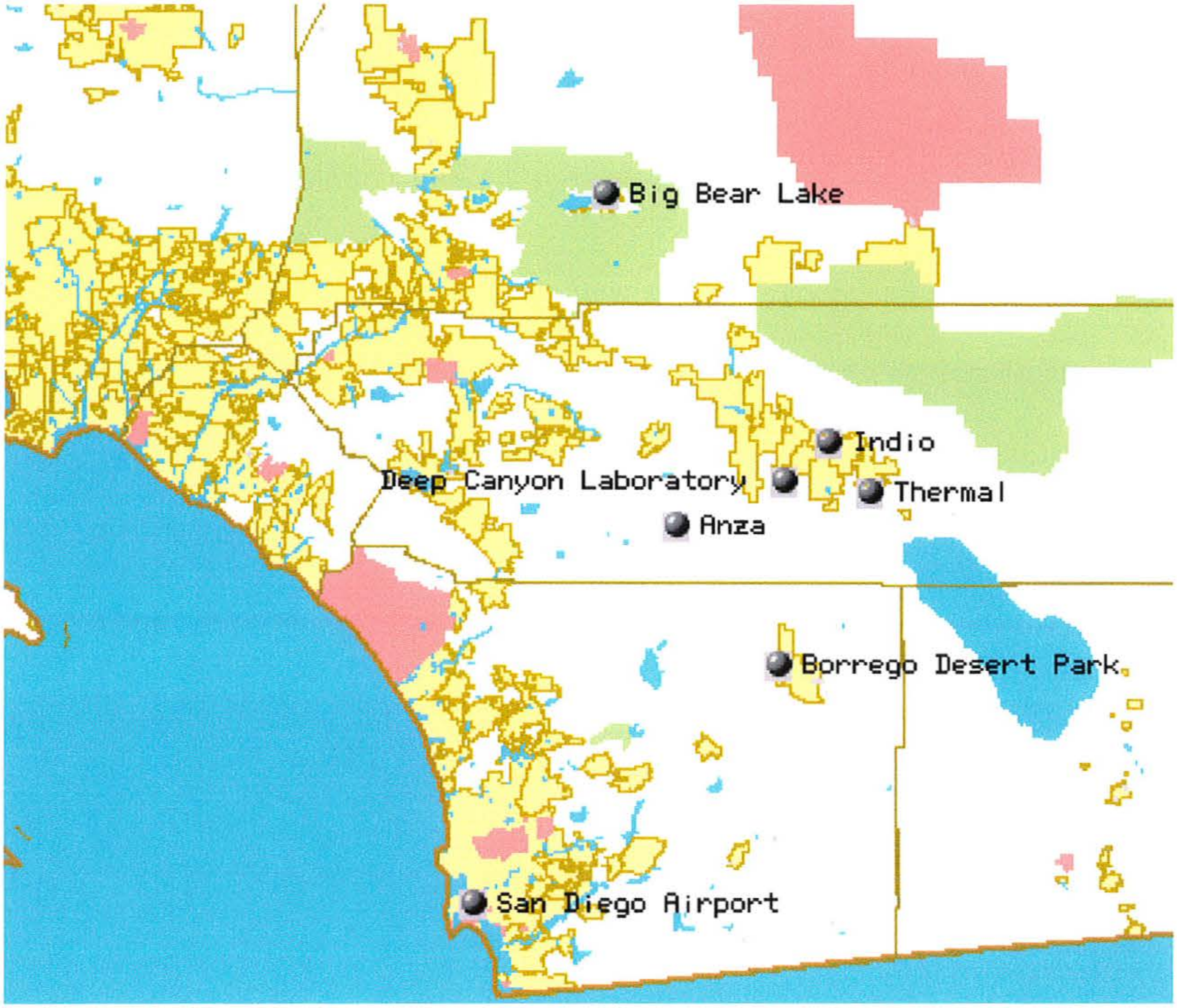

Figure 1. Locations of stations listed in Table 1.

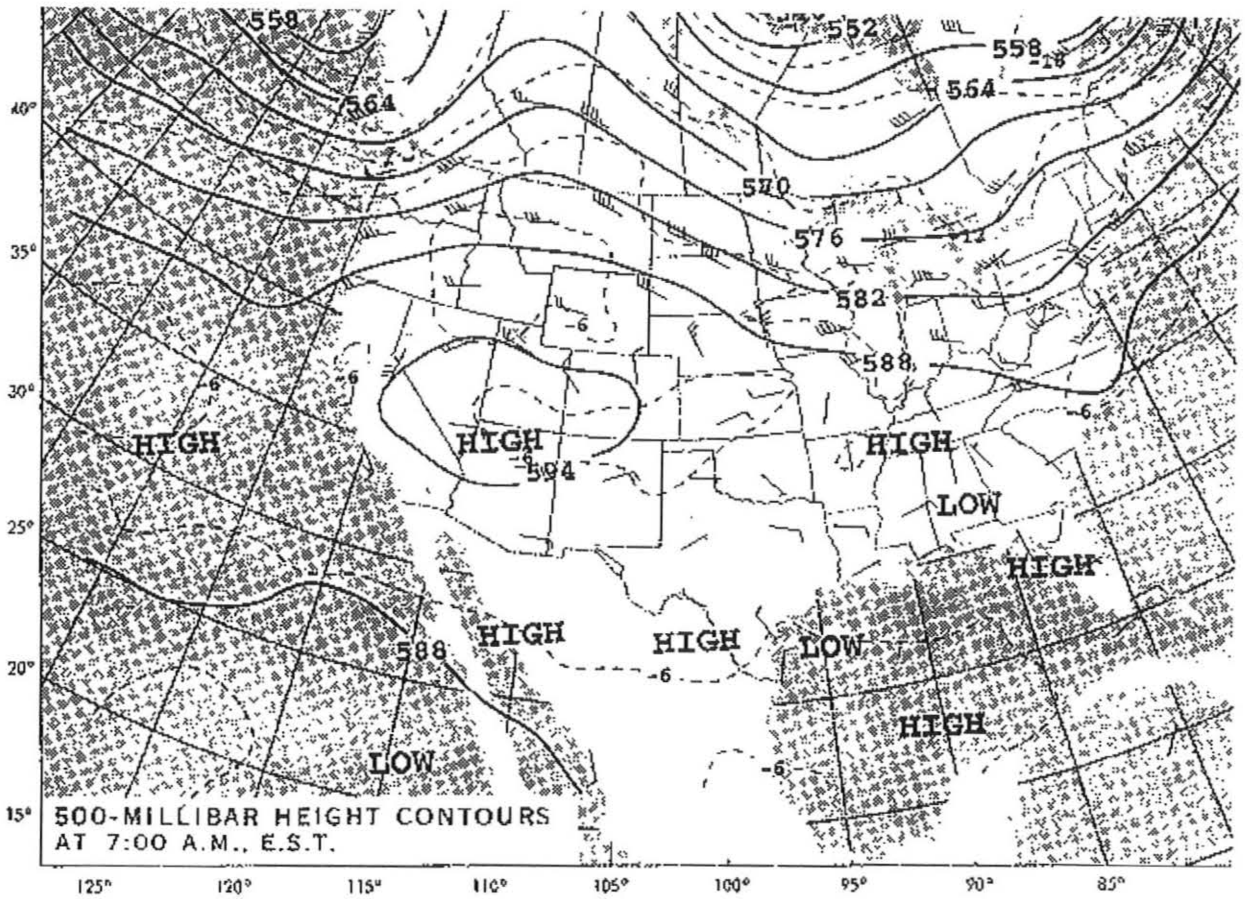

Figure 2. 500-mb height contours at 1200 UTC 19 July 1998 (from NOAA, Daily Weather Maps).

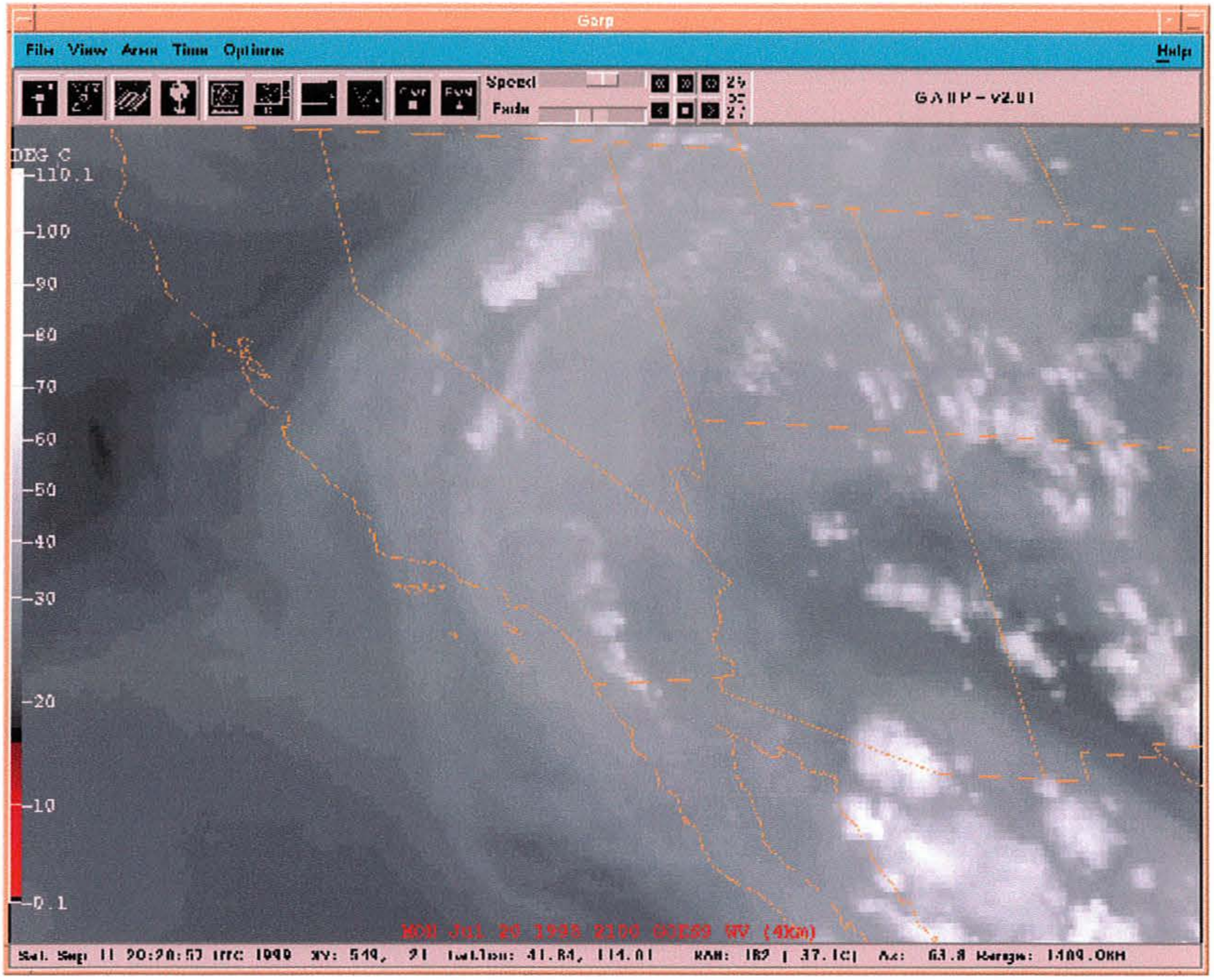

Figure 3. GOES-10 water vapor image for the southwestern U.S. at 2100 UTC 20 July 1998.

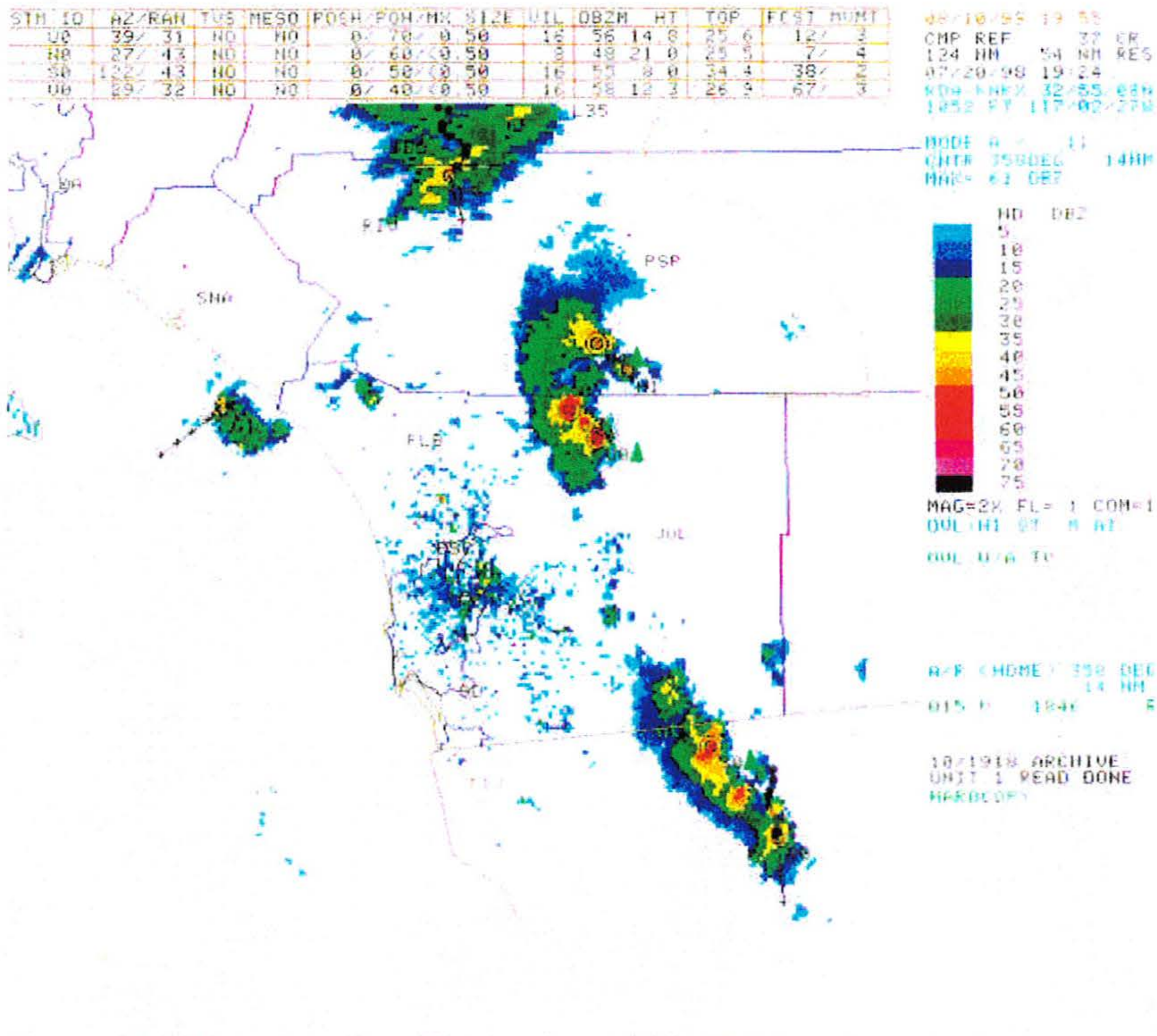

Figure 5. KNKX (Miramar) WSR-88D composite reflectivity image at 1924 UTC 20 July 1998.

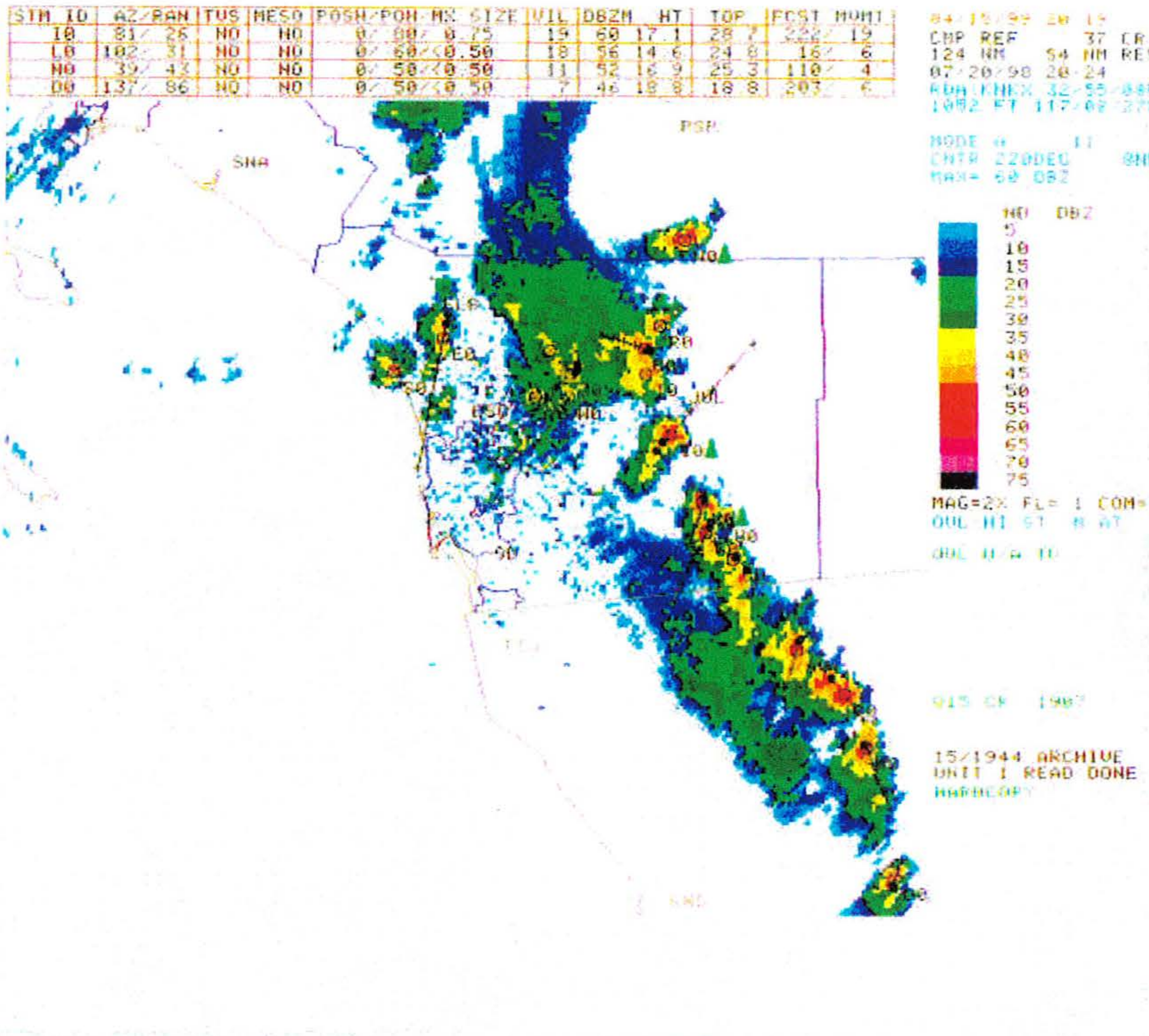

Figure 6. Same as Fig. 5, except for 2024 UTC 20 July 1998.

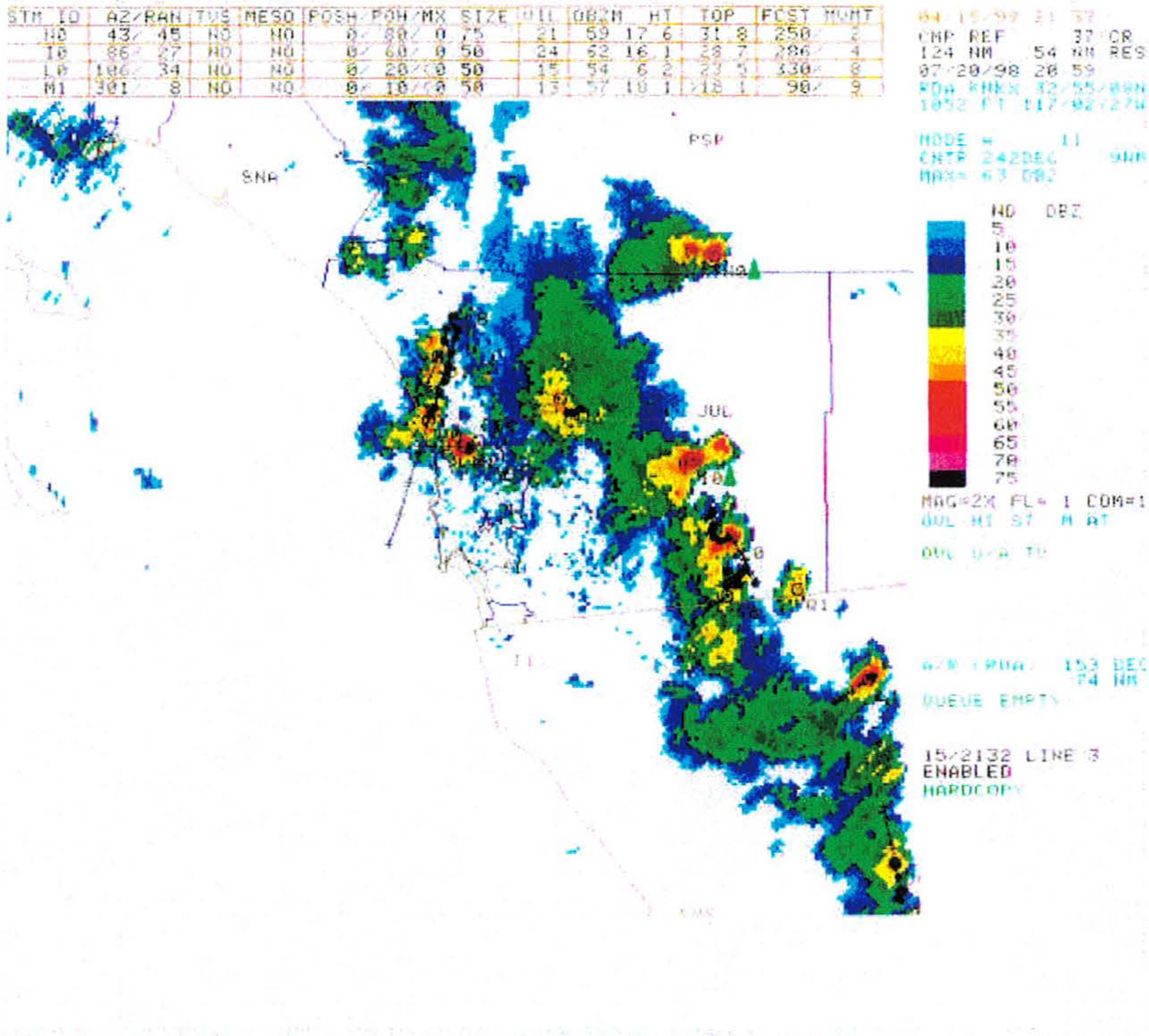

Figure 7. Same as Fig. 5, except for 2059 UTC 20 July 1998.

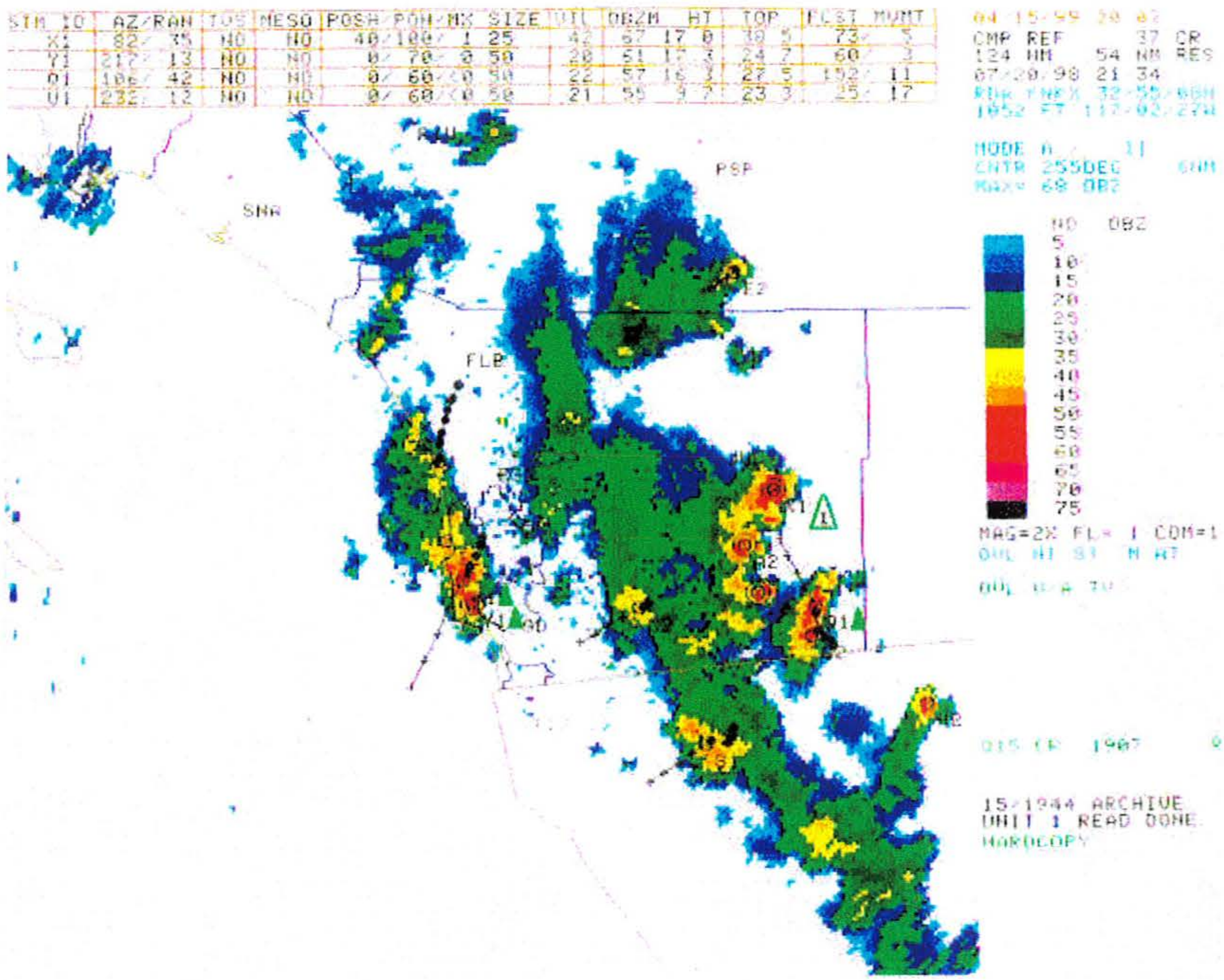

Figure 8. Same as Fig. 5, except for 2134 UTC 20 July 1998.

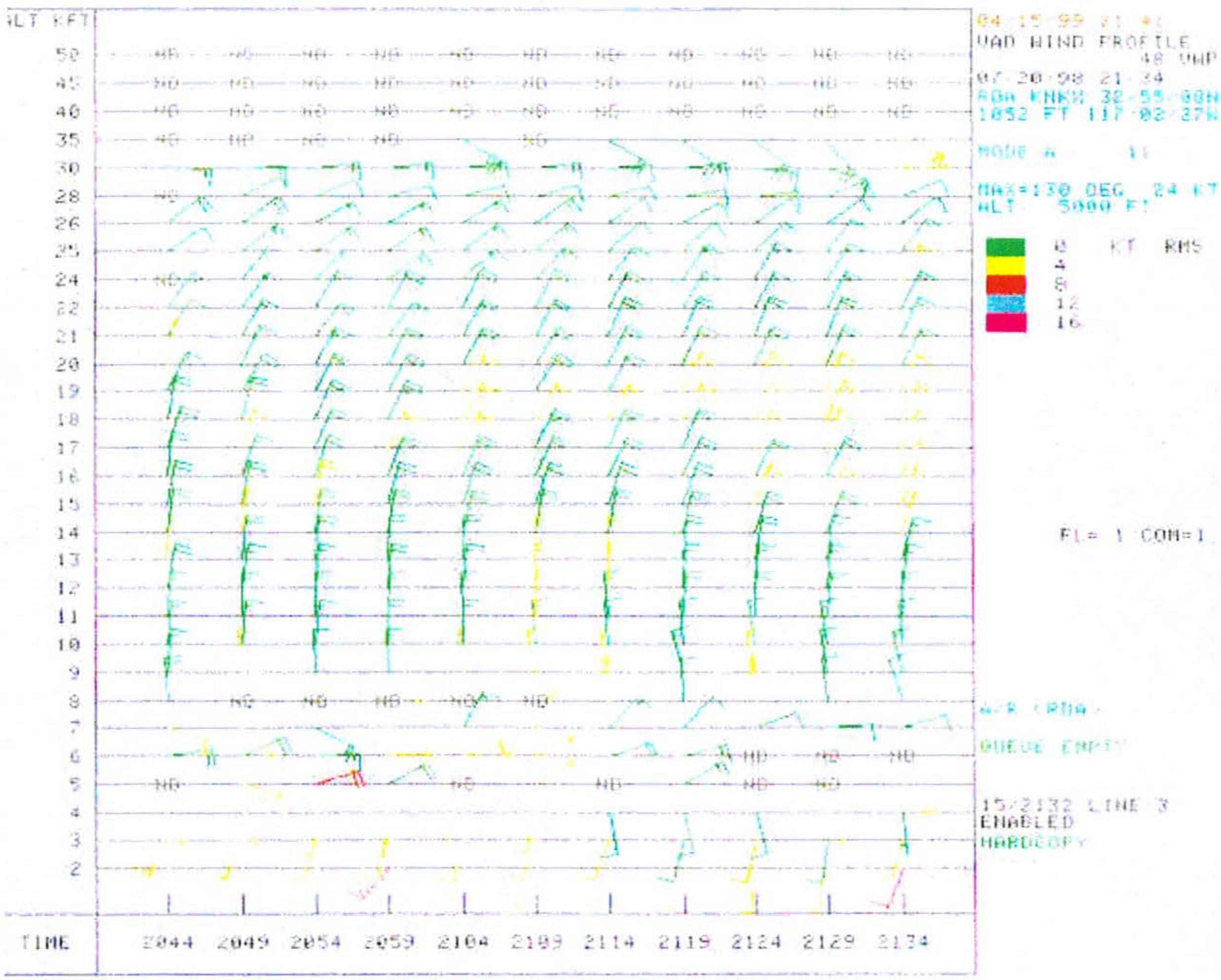

Figure 9. KNKX (Miramar) WSR-88D vertical wind profile at 2134 UTC 20 July 1998.

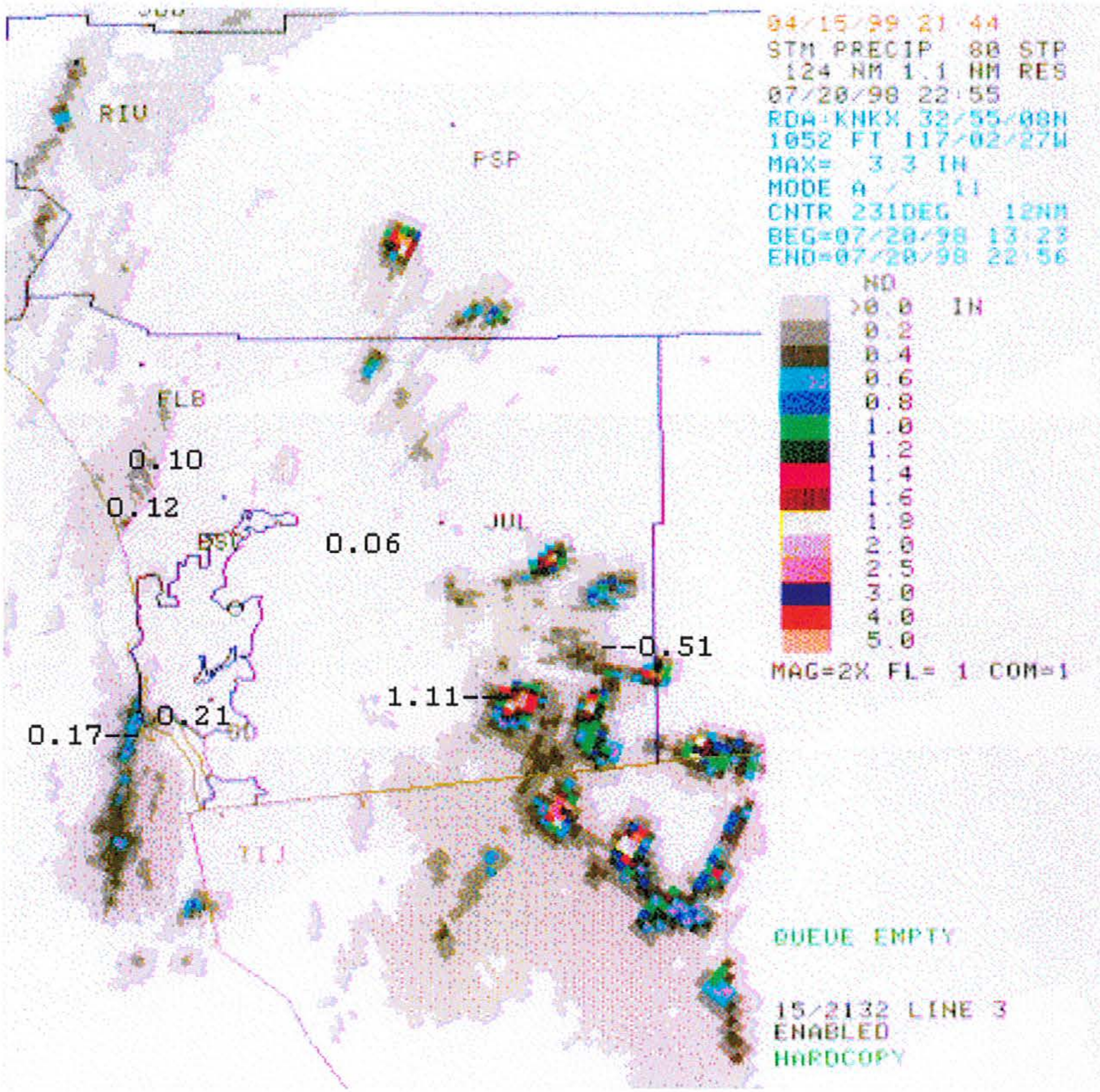

Figure 10. KNKX (Miramar) WSR-88D storm total precipitation for 20 July 1998 with measured totals overlaid.

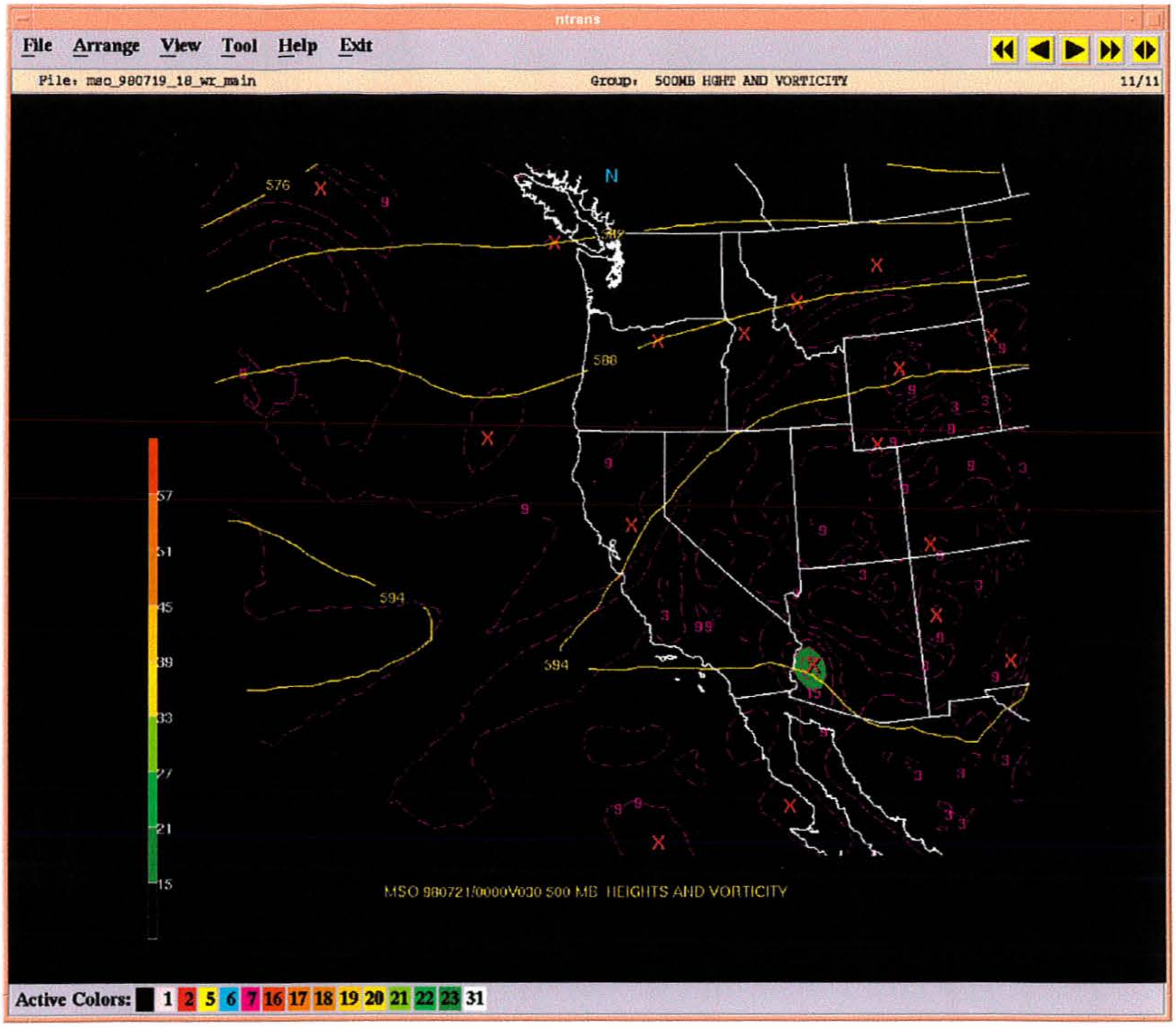

Figure 11. 500-mb height and vorticity contours for 0000 UTC 21 July 1998 as predicted by the 1800 UTC 19 July 1998 Meso-Eta model (30 hours after initialization).

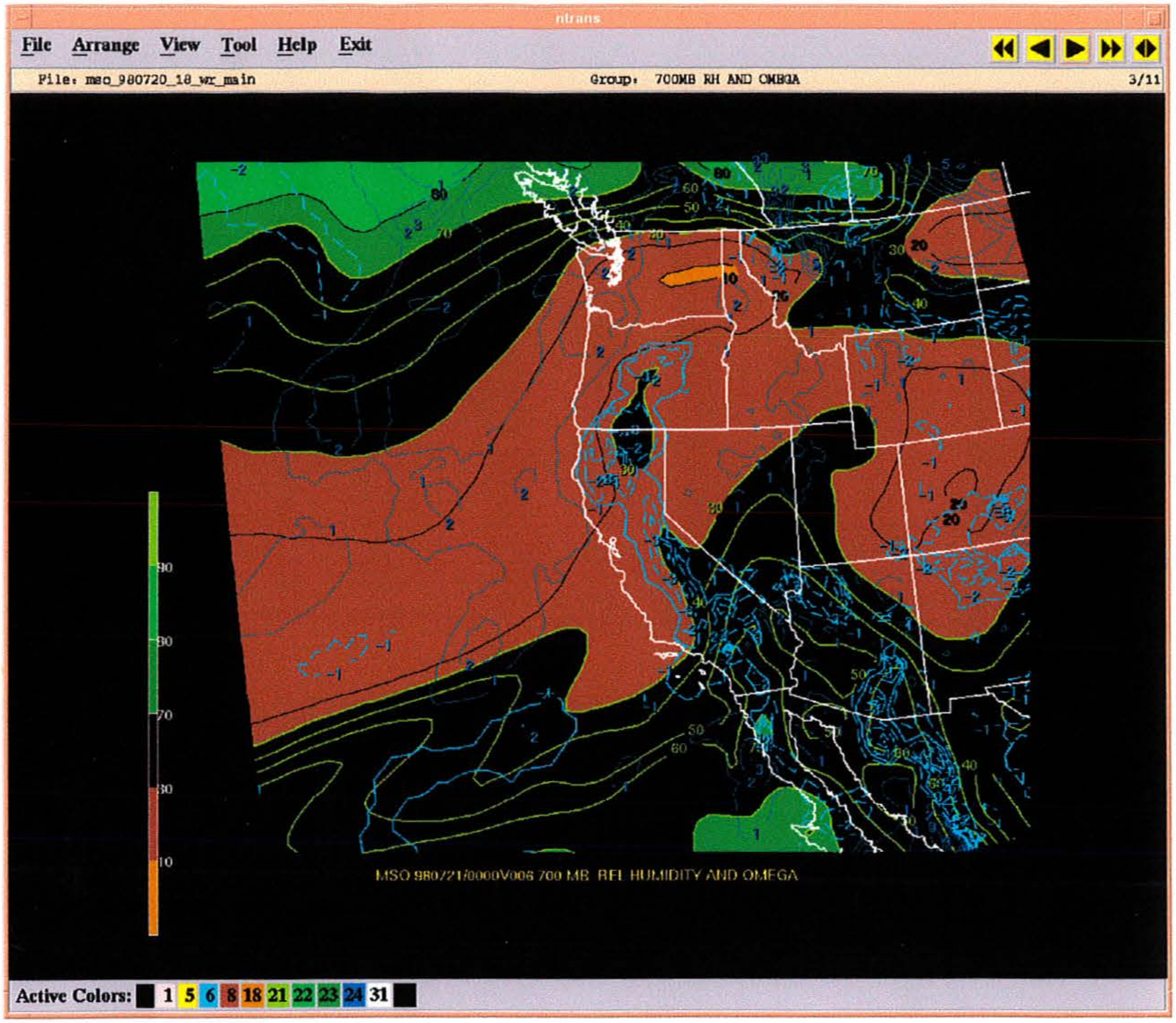

Figure 12. 700-mb relative humidity and omega contours for 0000 UTC 21 July 1998 as predicted by the 1800 UTC 20 July 1998 Meso-Eta model (6 hours after initialization).

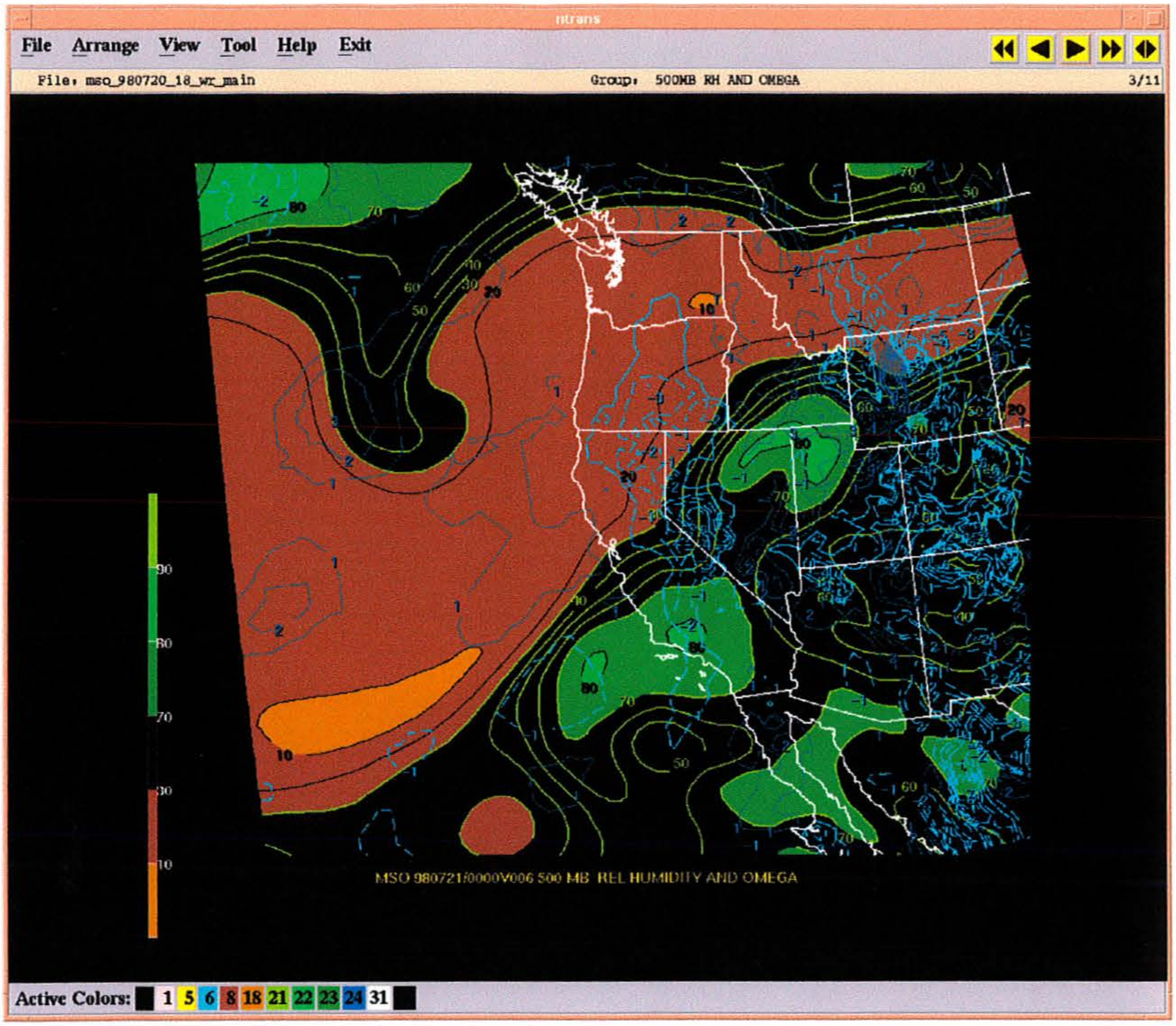

Figure 13. Same as Fig. 12, except at 500 mb.

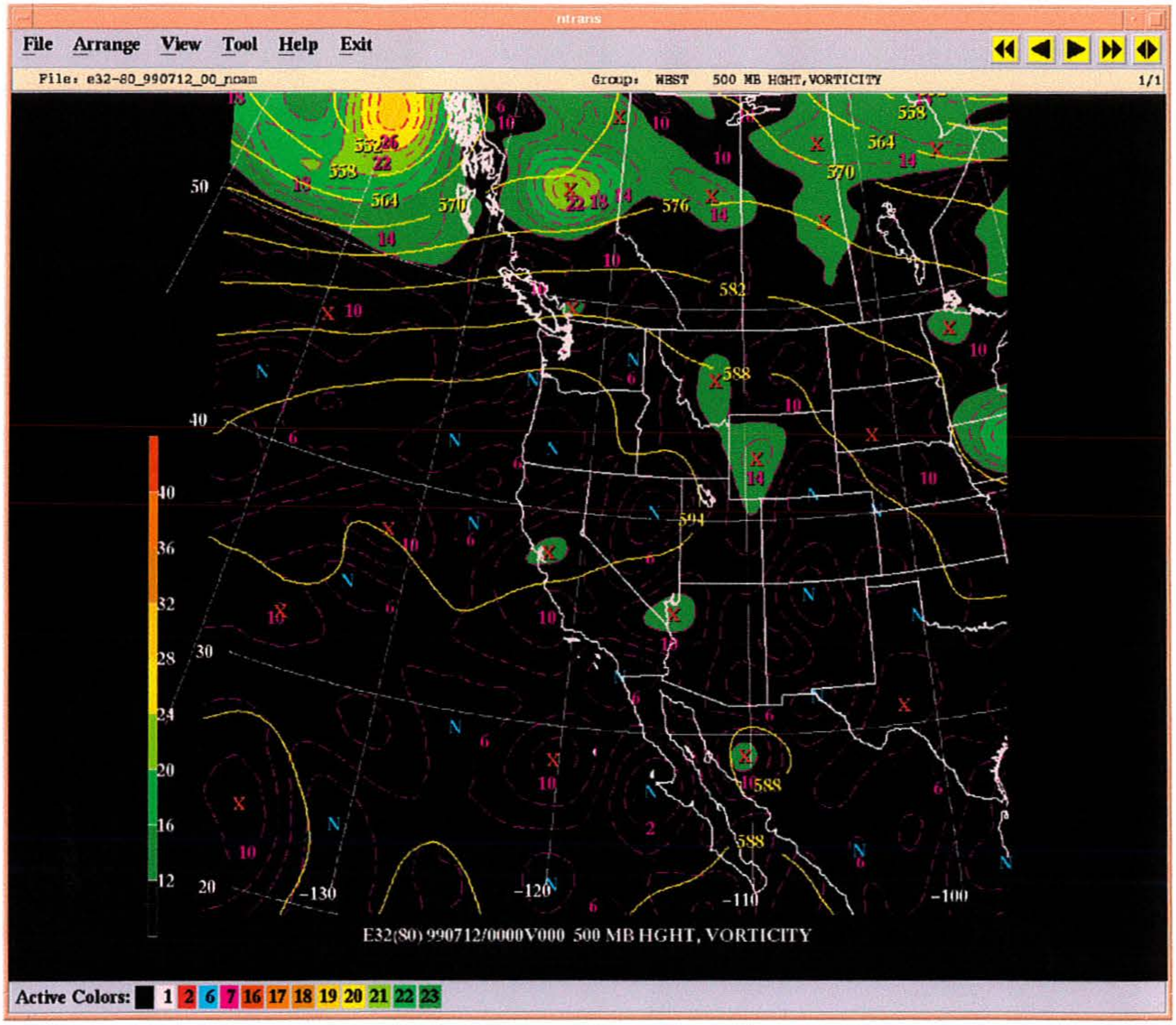

Figure 14. 500-mb height and vorticity contours for 0000 UTC 12 July 1999 (as initialized by the ETA model).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Anza	2.29	2.40	2.33	.99	.42	.07	.46	.77	.82	.46	1.47	1.97	14.45
Big Bear Lake	4.01	3.75	3.53	1.53	.58	.12	.82	.99	.62	.68	2.54	3.48	22.65
Borrego Dsrt Park	1.04	1.01	.81	.23	.09	.02	.35	.67	.44	.31	.69	.86	6.52
Deep Canyon Lab	.79	.71	.56	.15	.10	.03	.46	.79	.63	.25	.55	.64	5.66
Indio	.58	.53	.42	.07	.07	.01	.22	.51	.42	.19	.38	.41	3.81
San Diego Airport	1.80	1.53	1.77	.79	.19	.07	.02	.10	.24	.37	1.45	1.57	9.90
Thermal Airport	.47	.45	.32	.05	.07	.02	.18	.40	.36	.20	.32	.32	3.16

Table 1. Average monthly precipitation totals for selected southern California locations. Locations of these stations are provided on a map in Figure 1.

Height (Feet, MSL)	Wind Dir. (Deg.) 0000 UTC	Wind Speed (Kt.) 0000 UTC	Wind Dir. (Deg.) 1200 UTC	Wind Speed (Kt.) 1200 UTC
400 (surface)	170	8	100	3
1000	180	7	135	4
2000	190	7	175	5
3000	185	10	180	4
4000	170	8	245	2
6000	195	8	295	6
7000	210	6	310	5
8000	345	5	10	5
9000	355	12	35	7
11000	--	--	60	12
12000	20	21	90	9
14000	30	17	95	14
16000	30	22	105	13
17000	--	--	105	13
19000	45	22	--	--
20000	40	19	95	12
21000	--	--	80	11
22000	25	14	--	--
24000	--	--	110	13
25000	60	12	110	15
28000	--	--	120	11
29000	100	13	--	--
30000	95	17	150	9
32000	110	11	--	--
34000	145	14	--	--
35000	140	16	120	15

Table 2: NKX sounding winds at 0000 UTC and 1200 UTC 21 July 1998 between the surface and 35000 feet MSL.

Height (Feet, MSL)	Wind Direction (Deg.)	Wind Speed (Kt.)
400 (surface)	290	11
1000	295	7
2000	325	5
3000	340	4
4000	315	1
5000	160	3
6000	150	5
12000	105	7
13000	55	2
14000	165	3
20000	215	7
25000	280	5
30000	215	9
32000	210	12
35000	190	13

Table 3. NKX sounding winds at 0000 UTC 12 July 1999 between the surface and 40000 feet MSL.