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Synoptic Features Associated with Los Angeles Tornado Occurrences

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Abstract

Historically, tornadoes have not been a meteorological concern to California. There has never been a tornado-related fatality recorded in the state, and those tornadoes that do occur are believed to be of the weak variety.

Upon closer examination of the tornado data it is found that there is a small region in the highly populated Los Angeles area that has a tornado incidence disproportionately higher than the rest of California. This coastal zone is about 75 km long by 35 km wide. It is hypothesized that this region is a favorable location for tornadoes because the shape of the coastline and the inland location of the mountains enchance the low-level convergence field.

The tornado occurrences all seem to have very similar synoptic patterns. Low centers extending from the surface to 500 mb are located off the coast of California northwest of Los Angeles. In all cases, a very strong upper-tropospheric jet is located along the California/Mexico border. Many of the tornadoes occurred several hours after the passage of a cold front when the lower troposphere was destabilized and the low-level moisture increased as a result of the long overwater trajectory of the air mass. Several other tornado cases occurred at approximately the same time that cold fronts passed the area. A case study of the 9 November 1982 tornado outbreak is presented. During this particular episode, there were a record-setting seven tornadoes, all of which occurred in or near the tornado-prone zone.

1. Introduction

One of the many reasons for the growth of California this century is the unusually tranquil climate. The coastal regions where much of the population resides is favored by mild winters and pleasantly warm summers. Severe weather conditions that are experienced in other sections of the country, such as blizzards, severe thunderstorms, and hurricanes, are not a real concern to much of this area. In particular, the southern California environs have the reputation of having one of the most livable climates in the United States.

Tornadoes, one of nature's most feared storms, are generally not associated with the climate of California. There has never been a tornado-related fatality recorded in the state. However, in recent years, there has been a noticeable increase in tornado occurrences reported in the coastal areas of southern California. A relatively narrow zone in the coastal area of the Los Angeles basin has been found to have a tornado frequency not unlike parts of the central United States.

In the past 22 years there have been 14 separate episodes of tornadoes in the coastal region near Los Angeles, resulting in 28 individual tornadoes. The largest number reported in one episode was on 9 November 1982, when seven were observed.

While the tornadoes in California are not of the intensity of the large midwestern storms, their impact is increased severalfold due to the high population density. In the central United States, tornadoes can track for several miles with negligible effect on the populace, but a tornado can hardly touch down around Los Angeles without hitting something.

The purpose of this paper is to determine typical atmospheric conditions that are observed during tornado occurrences in the Los Angeles area. A brief analysis of the 9 November 1982 case is presented. Favorable conditions are contrasted with those in the Plains states and the Midwest.

2. Data and approach

Figure 1 depicts the locations of confirmed California tornadoes during the period 1962–1983. All of the tornadoes were tabulated in *Storm Data* (U.S. Department of Commerce, 1962–83), the log maintained at the National Severe Storms Forecast Center, or the California wind-storm report (California Department of Water Resources, 1979).

There are three identifiable areas in California where tornadoes occur most frequently. The first one, the Central Valley region from the Red Bluff area southward to near Fresno, has a predominantly cool season maxima associated with cold upper troughs and a low-level moist onshore flow of Pacific air. Local convergence effects due to the flow through the coastal range near San Francisco and the interaction with the Sierra Nevada Mountains may contribute to the maxima near Fresno and Sacramento.

The second area is the deserts of southern California, which have a predominantly warm season maxima. These tornadoes are associated with the periodic intrusions of moist unstable tropical air masses from the south.

The focus of this study is the third area, which is the area of southern California near Los Angeles (Fig. 2), where the frequency of tornadoes far exceeds that of any other location in the state. It has one of the highest incidences of tornadoes of any location in the United States west of the Continental Di-

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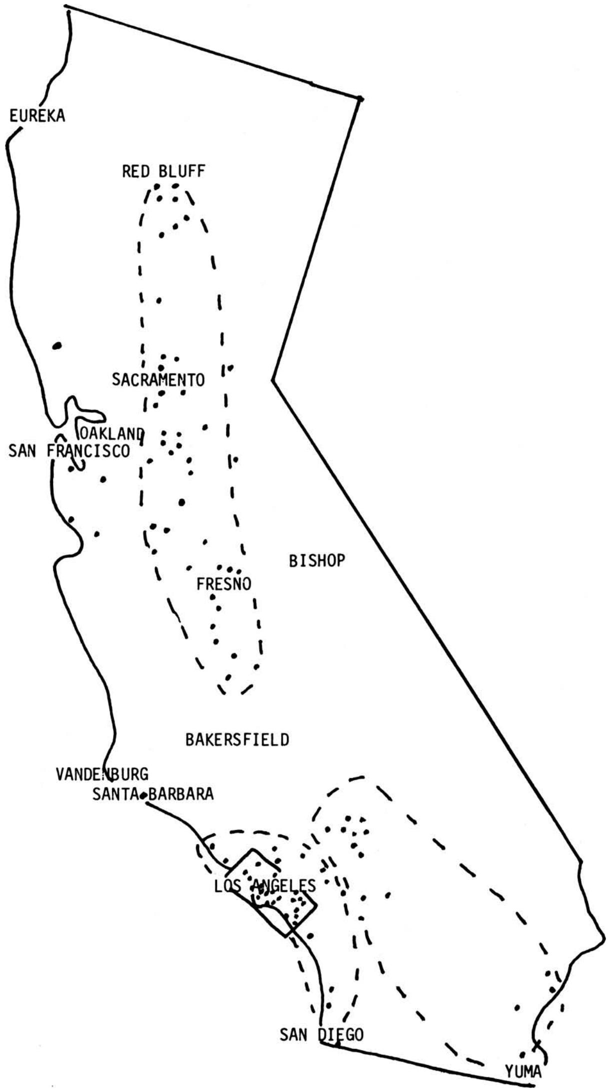

FIG. 1. California tornadoes, 1962–1983. Dots are tornado locations. Dashed line indicates tornado-prone zones. Rectangle encloses an area of frequent tornado occurrence.

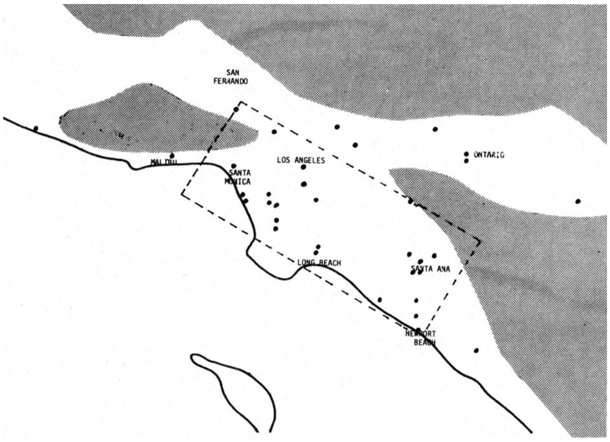

FIG. 2. Los Angeles Basin tornadoes. Stippling indicates elevations greater than 700 m (2000 ft.). Dots are individual tornadoes with the dashed box the region of greatest tornado frequency.

TABLE 1. Los Angeles area tornadoes.

Date	Time (PST)	Location	Description
09/30/83	0600	Maywood	Trees uprooted, roof damage
09/30/83	2230	Hawthorne	Minor injuries, 10 homes major damage
03/01/83	0740	Los Angeles	50 homes and business damage, convention center roof damaged, $5 million+, 4-mile path
03/01/83	0815	San Marino	One injury, car blown across highway
11/09/82	0930	Malibu	Major damage to a few homes
11/09/82	1130	Van Nuys	Severe damage major department store
11/09/82	1200	Long Beach	Serious damage to homes, businesses, 10-mile path
11/09/82	1200	Inglewood	
11/09/82	1300	Garden Grove	Uprooted trees, roof damage
11/09/82	1300	Mission Viejo	
11/09/82	1515	Point Mugu	Minor damage
01/28/80	1315	Gardena	Minor damage
01/31/79	1530	Santa Ana	Roof damage, car overturned, 2-mile path
01/31/79	1530	Universal City	$1 million damage to movie sets
01/31/79	—	Anaheim	
02/10/78	0030	El Segundo	Downed power lines and trees
02/10/78	0355	Huntington Beach	6 injuries, $3 million damage
05/08/77	1000	Long Beach	Major damage to homes, businesses, $500,000 to $5 million
03/16/77	1830	Fullerton	4 injuries, 80 homes, 19 businesses damaged, 8-mile path
04/18/77	1730	Santa Monica	Minor damage
11/07/66	0909	Newport Beach	Minor damage
11/07/66	1300	Costa Mesa	Building damage
11/07/66	1300	Lennox	10 injuries, 8.5-mile path, Lawndale to Inglewood
11/07/66	1515	Willowbrook	Minor damage
04/08/65	1000	Costa Mesa	Minor damage
11/09/64	0700	El Segundo	Trees/power lines down, buildings damaged
05/14/62	1200	Gardena	Building damage
02/19/62	0730	Santa Ana	Minor damage

vide. This small area shown by the rectangle covers about 2600 km^2. Table 1 lists all known tornado occurrences since 1962 in this area, their locations, and a description of their associated damage.

With the objective in mind to develop mean synoptic maps, the NMC surface and upper-air analyses were gathered together for the 14 identified episodes. From these analyses and data a table was prepared to compare pertinent parameters (Table 2).

3. Common case characteristics

Several characteristics were common to most of the tornado cases examined. These include:

TABLE 2. Selected variables associated with Los Angeles tornadoes.

		San Diego[a] Observations						Low Offshore[e]		
No.	Tornado Date	SFC T/Td[b]	SFC Wind[c]	850 T/Td	500 Wind	300 Wind	LIS[d]	SFC	850	500
1	09/30/83	21/15	18007	8/6	22028	23045	−2	Yes	Yes	Yes
2	03/01/83	19/11	15015	6/6	22029	23031	0	Yes	Yes	Yes
3	11/09/82	19/12	16013	4/−1	24028	23053	−4	Yes	Yes	Yes
4	01/28/80	17/13	17010	6/3	25028	25028	+3	No	Yes	No
5	01/31/79	13/11	20008	2/1	23020	26053	−7	Yes	Yes	Yes
6	02/10/78	18/13	16013	7/6	22033	24065	−4	Yes	Yes	Yes
7	05/08/77	19/11	18008	3/2	21030	23050	−6	Yes	Yes	Yes
8	03/16/77	13/11	23005	1/−2	26055	27085	−6	Yes	Yes	Yes
9	04/18/67	16/10	18005	4/0	23040	24038	−3	No	Yes	Yes
10	11/07/66	17/14	16010	6/2	22023	22025	−1	Yes	Yes	Yes
11	04/08/65	14/10	16003	2/0	21025	22040	0	Yes	Yes	Yes
12	11/09/64	15/12	10002	6/4	22030	23045	−2	Yes	Yes	Yes
13	05/14/62	17/9	25008	3/2	28035	26050	0	No	No	No
14	02/19/62	12/8	15003	3/2	24030	24058	0	Yes	Yes	Yes
Avg.[f]		16/11	17008	4/2	23031	24050	−2			

[a] The observations at San Diego were taken at the surface (SFC), 850, 500, and 300 mb. [b] T/Td: temperature and dew point temperature in degrees Celsius. [c] Wind: The first three digits represent wind direction based upon a 360° compass and the last two digits are wind speed in meters per second ($\mathrm{m \cdot s^{-1}}$). [d] LIS: surface-lifted index. [e] Low Offshore: Yes or no indicates whether the center of a cyclonic wind circulation was located in the hatched area of Fig. 3. [f] Avg.: the average of the wind and temperature observations for the 14 cases.

1) There was a closed cyclonic circulation at all levels from the surface to 500 mb;
2) the centers of the cyclonic circulations at the 850-, 700-, and 500-mb levels were offshore and generally confined to the area indicated in Fig. 3;
3) the surface low centers were generally along or just offshore, as indicated in Fig. 3;
4) a strong 300-mb west-southwest jet crossed the coast (Fig. 3) very near San Diego with speeds equal to or greater than 60 $\mathrm{m \cdot s^{-1}}$;
5) surface dew points at San Diego were 11°C or greater, which is typical for this maritime location;
6) 500-mb temperatures at Vandenberg were −20°C or lower, a fairly frequent occurrence in the colder months; and
7) surface-lifted indices at Los Angeles were zero or less (Hales and Doswell, 1982). The surface-lifted index is computed the same as the lifted index (Galway, 1956) except instead of using a mean mixing ratio in the lower 100 mb of the sounding, the observed surface temperature and mixing ratio are used. Typically, the surface-lifted index is somewhat more unstable than the standard lifted index.

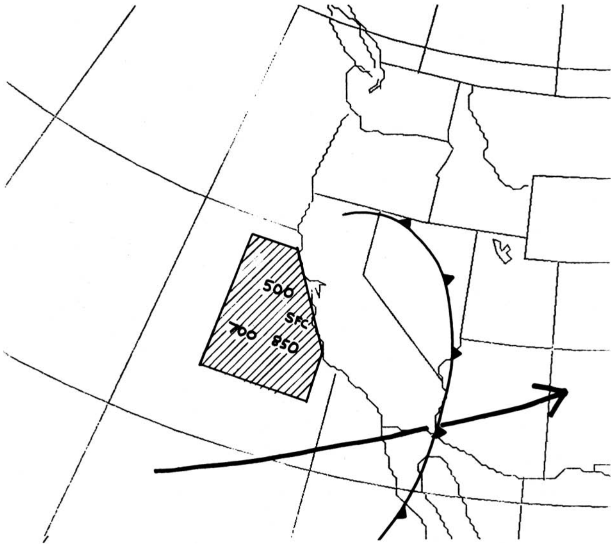

FIG. 3. Mean position of jet stream (arrow) and cold front at the time of tornado occurrences. The hatched area indicates the typical location of the low centers at the surface, 850, 700, and 500 mb.

The majority of tornadoes occurred well behind the cold front. The mean position of the cold front (Fig. 3) was along the California/Arizona border at the time of the tornadoes. The mean positions of the surface to 500-mb low centers were well northwest of the Los Angeles area off the central California coast in the area bounded by the box in Fig. 3. The tornadoes in all cases occurred on the cyclonic shear side of a west-southwesterly jet. The time of occurence in the majority of the cases was between 1200 and 1500 PST, or near the peak period of solar heating.

Figure 4 is a composite sounding at San Diego. There is veering of the wind up to 700 mb, with most veering occurring in the subcloud layer below 850 mb. The moisture profile reflects the initially cold dry air mass associated with the upper low circulation offshore being warmed and moistened as it passes over the progressively warmer water during its cyclonic trajectory around the low. The mixing ratio gradually decreases with height up to 850 mb, with a more rapid decrease to quite low humidities at 700 mb.

As a result of the shallow nature of the moisture field, the average Showalter index (Showalter, 1953) is a relatively stable +5. However, computing a lifted index using the surface dew point and temperature (Hales and Doswell, 1982), a lifted index of −3 is obtained.

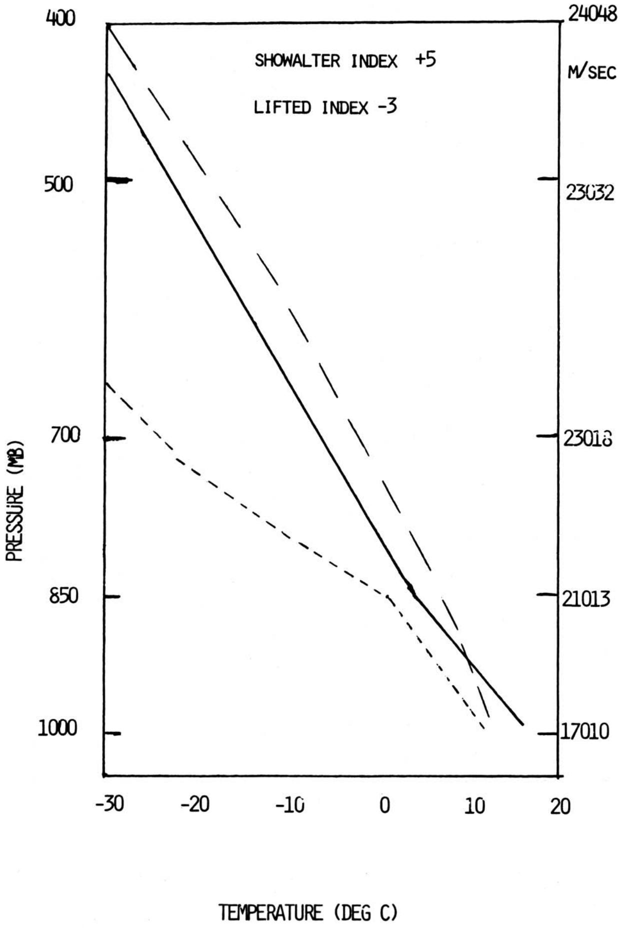

FIG. 4. Mean San Diego sounding for observing times nearest the tornadoes. The solid line is temperature, the short dashed line is dew-point temperature, and the long dashed line is a representative moist adiabat. The five-digit number at the right of the diagram indicates wind speed and direction. The first three digits are wind direction on a 360° compass, and the last two digits are wind speed in meters per second ($m \cdot s^{-1}$).

There is a strong increase in wind speed with height from 700 to 300 mb, a characteristic common to severe-thunderstorm wind profiles in the central United States. It is noteworthy that all the tornadoes in the Los Angeles area occurred from the end of September to the middle of May. The lack of tornado activity in the summer months can be directly attributed to the stabilizing influence of the adjacent relatively cool Pacific waters and the lack of any significant dynamic forcing mechanism.

4. Case study—9 November 1982

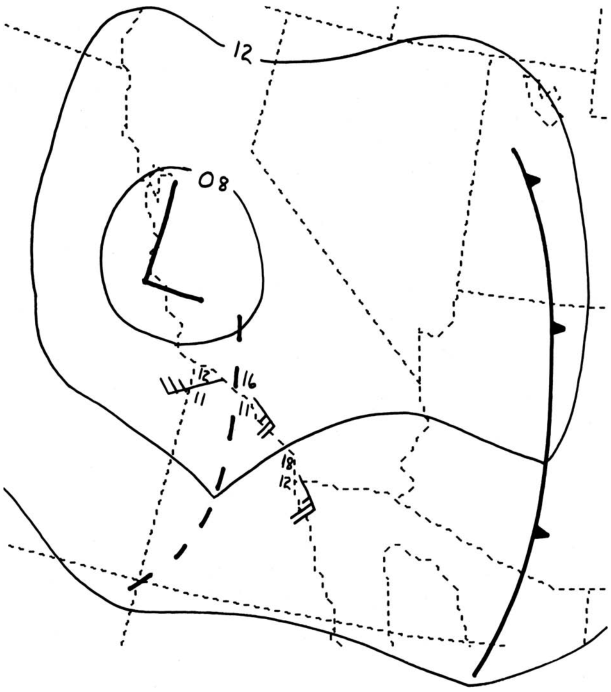

FIG. 5. Surface analysis at 1100 PST 9 November 1982. Solid lines are isobars at intervals of 4 mb. The cold front is represented by a solid barbed line, and the confluence or trough line is indicated by a dashed line. Wind speeds of 5 $m \cdot s^{-1}$ are represented by a full barb and speeds of 2.5 $m \cdot s^{-1}$ by a half barb. Wind speeds of 25 $m \cdot s^{-1}$ are represented by a flag. Temperature and dew-point temperature in degrees Celsius are plotted to the upper left and lower left, respectively, of the station locations.

The 9 November 1982 case is typical of the pattern that produces tornadoes in the Los Angeles area. The surface chart for 1100 PST, a short time before the tornadoes began to develop, shows that the initial cold frontal boundary had moved well east into Arizona (Fig. 5). A vigorous confluence zone, located just to the west of Los Angeles in the postfrontal air mass, formed in response to the proximity of a strong upper low and approaching 500-mb vorticity maximum. The surface winds were south-southeasterly 8–12 $m \cdot s^{-1}$ (15 to 25 kts) ahead and southwest 12 $m \cdot s^{-1}$ (25 kts) after passage of the line. The tornadoes occurred in very close proximity to the instability line, which was embedded in the broad enhanced baroclinic cloud zone on the 1015 PST infrared satellite photo (Fig. 6).

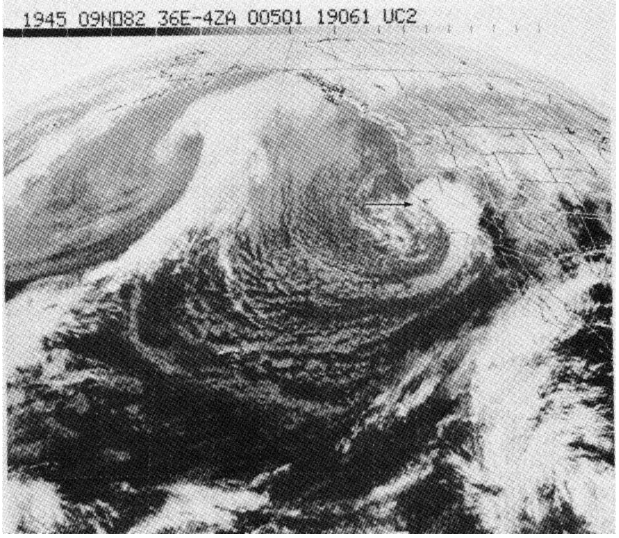

FIG. 6. Infrared satellite at 1015 PST 9 November 1982.

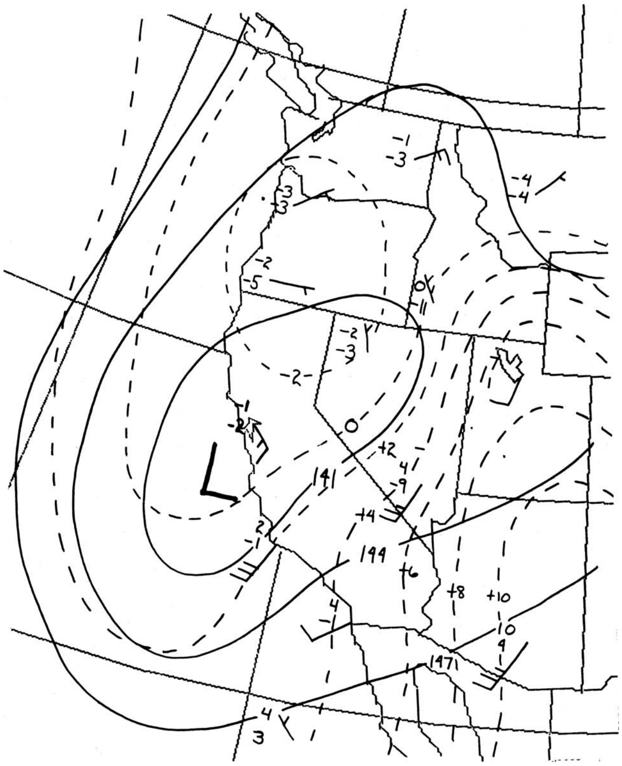

FIG. 7. 850-mb analysis at 0400 PST 9 November 1982. The plotting convention for the winds and temperatures is the same as that in Fig. 5. The solid lines are height contours in decameters at 30-m intervals, and the dashed lines are isotherms at intervals of 2°C.

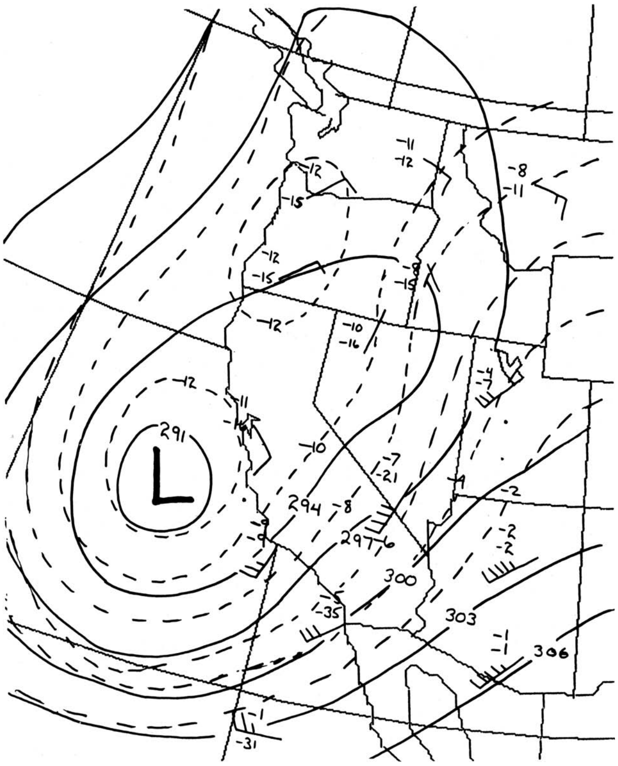

FIG. 8. Same as Fig. 7, except for 700 mb.

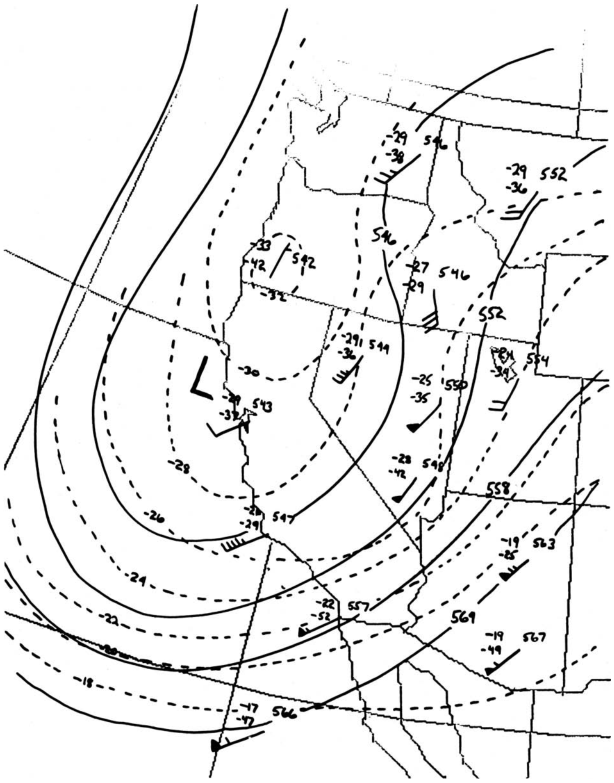

FIG. 9. Same as Fig. 7, except for 500-mb. Geopotential heights in decameters are shown to the right of the locations of each station. The solid lines are height contours in decameters at 60-m intervals.

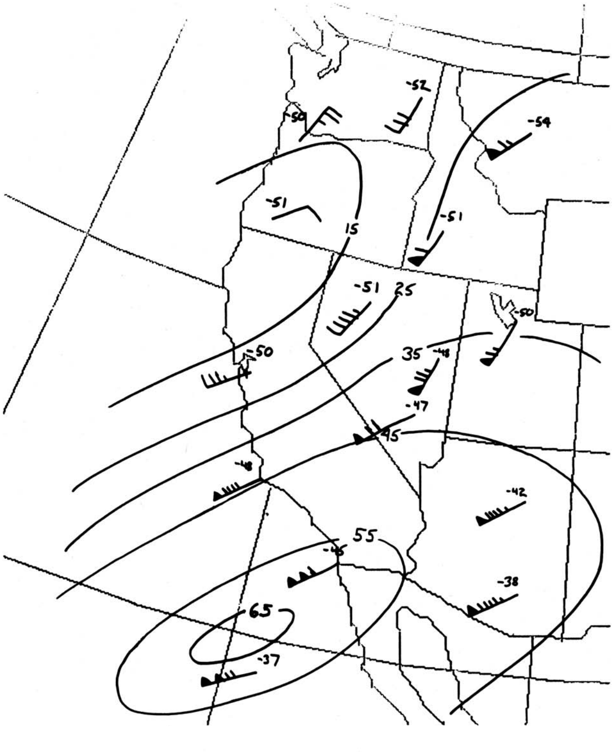

FIG. 10. 300-mb map. The plotting convention is the same as in Fig. 5 except that dew-point temperature is not shown. Solid lines are isotachs, which are presented in units of meters per second and are at intervals of 10 m·s^{-1}.

The 1015 PST infrared satellite photo indicated a classical comma cloud off the south-central California coast. Reed (1979) found that comma clouds are associated with an upper vorticity maxima on the cyclonic side of polar jets. In this case, southeasterly winds at 850 and 700 mb at Oakland (Figs. 7 and 8) at 0400 PST provide support for the location of a low center at those levels near the northwestern tip of the comma cloud (see the arrow in Fig. 6; the same cloud feature in the satellite image at 0400 PST was about 100 km to the west). The southwesterly wind at Oakland at 500 mb (Fig. 9) suggests that the center of the cyclonic circulation in the middle troposphere was north of the center in the lower troposphere. Another interesting feature of Fig. 6 is the fetch of unstable cold air that is implied by the very pronounced area of convective clouds to the west of the comma head.

The 300 mb analysis (Fig. 10) shows that the left front quadrant of a strong jet maximum was over the Los Angeles area. McNulty (1978) found that the left front quadrant is usually characterized by high-level divergence and upward vertical motion in the upper troposphere.

The 0400 PST radiosonde at San Diego indicated that the air above 850 mb was quite dry and that relatively moist air was present below 850 mb. Although the 0400 PST Showalter indices were somewhat stable (Vandenberg +1, San Diego +5), the computed surface-lifted index at Los Angeles at the time of the passage of the instability line was a rather unstable −4. This surface-lifted index is computed from the observed surface temperature and dew point at Los Angeles and the 500 mb temperature interpolated subjectively from the most recent upper-air soundings in the southern California area. Certainly there was adequate instability to support strong thunderstorms in view of the favorable upper-tropospheric pattern.

5. Conclusions

Tornadoes occur in the Los Angeles area during the cooler months from September to May. Typical conditions that favor the formation of the tornadoes are:

1) centers of cyclonic wind circulations from the surface to 500 mb located in an offshore area to the northwest of Los Angeles;
2) increasing winds with height to speeds in excess of 50 $\mathrm{m \cdot s^{-1}}$ with the strongest winds south of Los Angeles;
3) surface frontal or postfrontal confluence zone in the area;
4) moist onshore low-level flow with dry air aloft; and
5) surface-lifted indices ≤ 0.

The combination of the curvature of the coastline and the nearby mountains that are parallel to the coast appear to favor strong frictional convergence in onshore flow in the area of maximum coastal curvature near Los Angeles. It is speculated that frictional convergence caused by the unique juxtapositioning of the coastline and mountains may be the cause of the enhanced tornado activity.

Comparisons of meteorological conditions associated with tornadoes in the central United States and Los Angeles reveal several similarities. In both areas, typical kinematic conditions include large vertical shear of the horizontal wind and a strong polar jet. There are, however, significant thermodynamic differences. In the central United States tornadoes tend to form in a maritime tropical (MT) air mass that originates over the Gulf of Mexico, while maritime polar (MP) air is involved in California. The MP air is inherently the more stable of the two. Also, the Midwest tornadoes generally occur in the warm sector, while Los Angeles tornadoes develop with and after cold fronts.

Though the frequency and intensity of tornadoes in the Los Angeles area is less than in the central United States, the tornadoes are of significance. The population density of the Los Angeles area justifies an increased awareness of those meteorological conditions favorable for the formation of tornadoes.

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