3.14

TOPOGRAPHIC AND SYNOPTIC INFLUENCES ON COLD SEASON SEVERE WEATHER EVENTS IN CALIFORNIA

Ivory J. Small* and Greg Martin
NOAA/NWS, San Diego, CA

Steve LaDochy
Department of Geography and Urban Analysis
California State University, Los Angeles CA

Jeffrey N. Brown
Department of Geography
California State University, Northridge CA

1. INTRODUCTION

Understanding and forecasting severe weather in California continues to be a challenge for forecasters as well as for researchers. Rugged terrain coupled with oceanic influences are key components of the forecast problem. (Figs. 1 and 2). Investigators have been able to compare and contrast severe weather events in California with those that occur in the midwest. Halvorson (1970) noted that in Southern California, at times, tornadoes formed during conditions that were markedly different than conditions normally seen during tornado outbreaks in the midwest. Hales (1985) investigated the tornado problem in the Los Angeles Basin, connecting the effects of enhanced helicity in the Basin to the enhanced frequency, compared to other areas in California. Monteverdi and Quadros (1994) also looked at rotational parameters as well as convective parameters during a study of northern and central California tornadoes. Blier and Batten (1994) compiled a climatology of California tornadoes, and Ladochy and Brown (submitted) added other severe weather events for a more complete picture of California severe weather. In this paper, we take a look at synoptic and mesoscale forcings that can result in favorable conditions for the development of severe weather in California. Case studies will be presented to show the effects of terrain on the development of a tornado, funnel clouds, golf-ball sized hail, microburst winds, and a line of waterspouts. Composite maps for the State of California will be included to show the conditions generally associated with severe weather statewide, with some discussion on the difference between those that produce tornadoes and those that do not.

2. POWAY TORNADO

Between 1730 UTC and 1800 UTC on 10 November 2000 precipitation bands were generated by the islands. This phenomena is known locally as "Island Effect" (Fox 1978; Small 1999a). Also during this time, a tornado occurred in the city of Poway, about 30 km (20 miles) northeast of downtown San Diego (SAN). In this case, as opposed to cases where waterspouts move onshore as small tornadoes, this tornado formed on a cloud band that extended downwind from the islands (basically an "island effect" or "IE" tornado), and did not experience any time as a waterspout. At the surface, open cell convection covered much of the Southern California Bight Region. A weak California Bight Coastal Convergence Zone (CBCCZ) had formed around Point Conception (Small, 1999b). There was even an Island Effect band downwind of the Channel Islands (just south of SBA), extending inland over Orange County (SNA). To the north of Orange County, the low level moisture had been swept out of the northwesterly flow at the lower levels by the Santa Ynez mountains, but was still largely unaffected west of the CBCCZ. As the day progresses, the

FIG. 1. Map of California showing the 4 areas.

*Corresponding author address: Ivory J. Small, NOAA/NWS San Diego. 11440 W. Bernardo Ct., Ste. 230, San Diego, CA 92127-1643; e-mail; ivory.small@noaa.gov

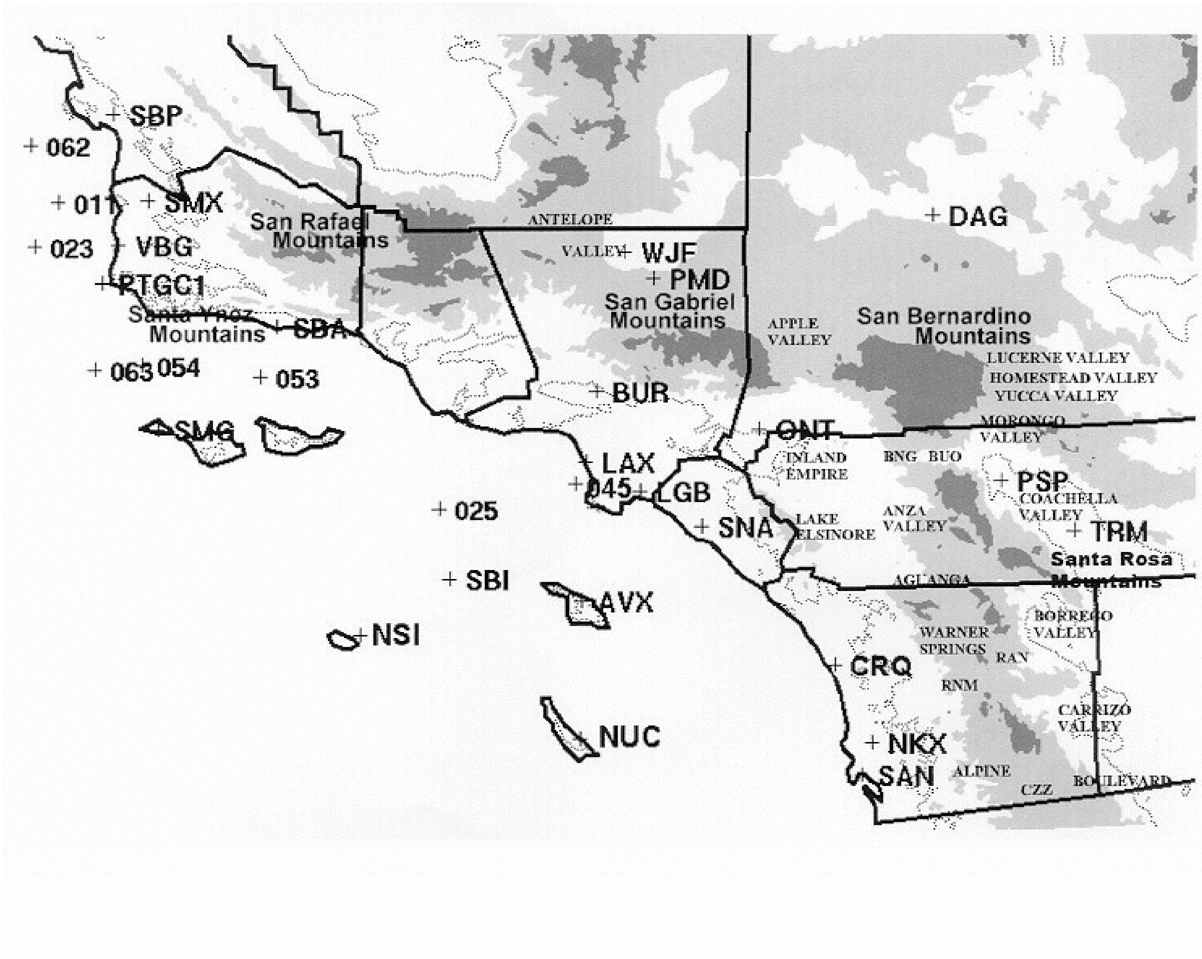


FIG.2. Map showing the terrain of southern California.

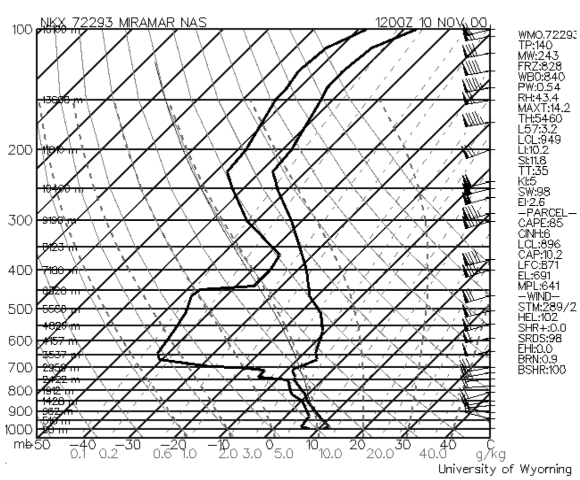


FIG. 3. 1200 UTC 10 November 2000 NKX raob

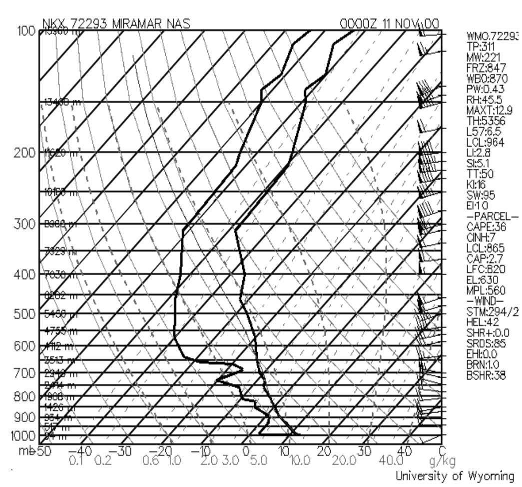


FIG.4. 0000 UTC 11 November 2000 NKX raob

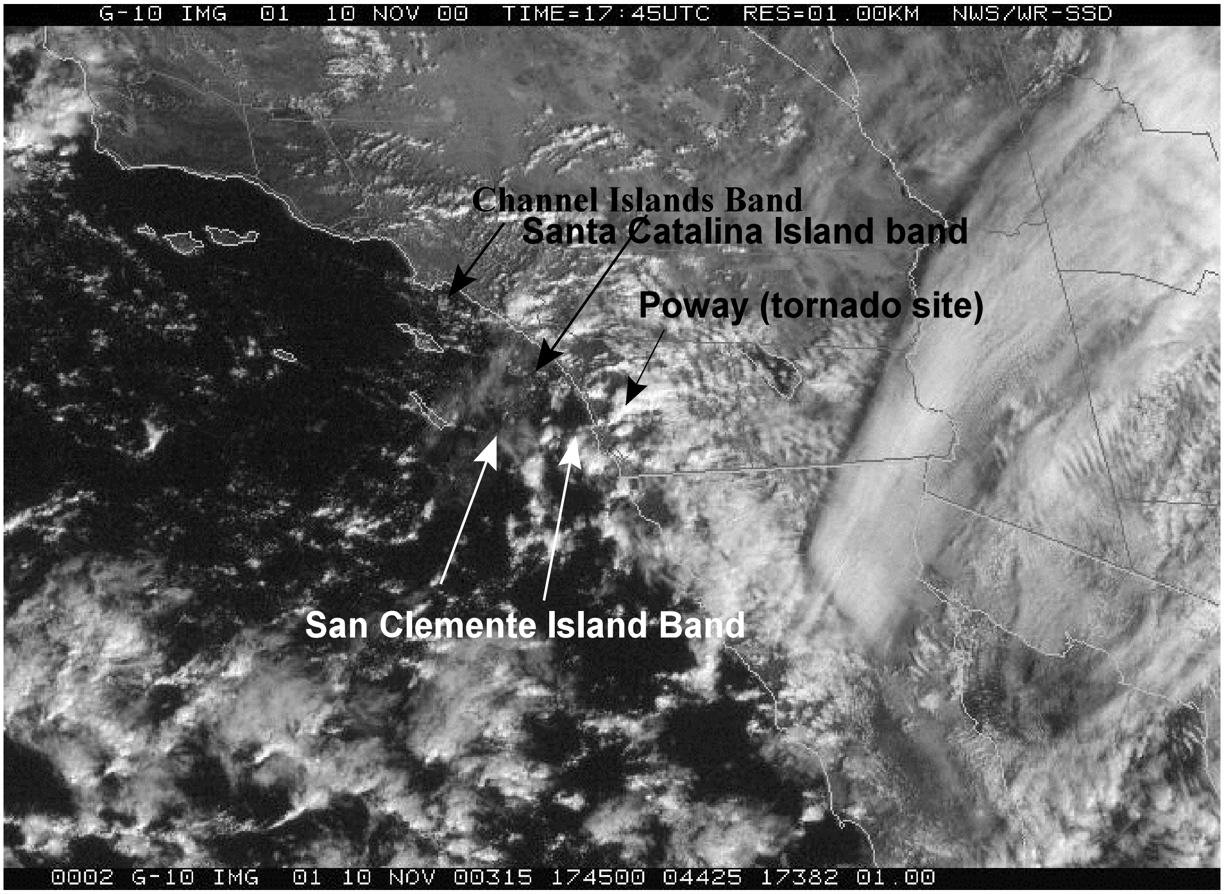


FIG. 5. 1745 UTC 10 November 2000 visible satellite imagery

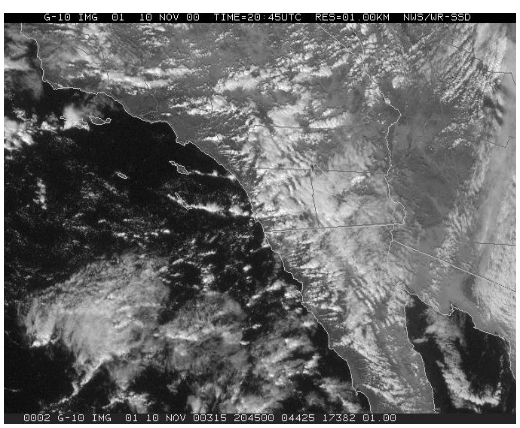


FIG. 6. 2045 UTC 10 November 2000 visible satellite imagery.

low level winds [at approximately 1000 meters (3000 feet) and below] fall below about 10 ms^{-1} (20 knots) (see Figs. 3 and 4). This results in changes for IE bands, as they are made up of more cellular, separated elements when the winds are fairly strong, and organize into a continuous lines of convective elements when the winds weaken (similar to the transition from open cell convection to horizontal roll convection behind a cold front). The 1745 UTC 10 November 2000 1 km visible imagery (Fig. 5) showed the tornadic cell. It appeared to be due to the interaction of a cell that developed on an IE band generated by San Clemente Island with an IE band generated by Santa Catalina Island. The bands connecting the tornadic cell and the islands can be seen in the visible imagery. Also the midday surface heating had resulted in rapid development at about 1800 UTC (also this is about the time that IE bands normally experience rapid strengthening). By 1930 UTC (not shown) a train-track pattern had developed downwind of San Clemente Island. This train track pattern (two convective bands with a cloud free zone) generally forms when the lifting condensation level (LCL) is quite low. (When the LCL is as low or lower than that of the higher terrain on an island, the dual band train track pattern will often develop). This usually occurs overnight. Also, like the Santa Ynez Mountains, there is a reduction in clouds downwind of an island, with shear zones on either side of the island, resulting in convection along the shear lines. Usually daytime convection indicates a very moist and unstable airmass at the lower levels. This can also be seen on the NKX raobs at 1200 UTC 10 November 2000 and 0000 UTC 11 November 2000 (Figs 3 and 4). It has been noted that when a strong cold front passes, open cell convection develops, and may also result in a strong CBCCZ, but conditions are not yet favorable for the development of easily identifiable, linear, well organized IE bands in the visible satellite imagery, (until heating results in a well mixed boundary layer, higher LCL, low level inverted V sounding profile, and a single band pattern). At night the low level airmass becomes more moist with only a few degrees difference between the temperature and dewpoint below the height of the highest island peaks. This also corresponds to a low LCL, that is lower than the highest terrain on the island. This profile is usually associated with an increase in convection over the ocean at night, and dual IE bands developing downwind from an island, with a cloud free zone between them. In this case, a train - track pattern does form briefly during the day. The 2045 UTC 10 November 2000 1 km visible imagery (Fig. 6) shows well developed IE bands extending downwind from both Santa Catalina Island and San Clemente Island. The train-track pattern is a bit more discernable due to the lack of small cumulus downwind, especially in the lee of Santa Catalina Island and the pattern evolves into a single island band downwind from an island by midday. The bands continued well into the night. There is even a well developed band downwind of Palos Verdes Peninsula [(500 m (1500 foot) peak near LAX], extending over Orange County. [This feature is also suspected of being a potential tornado producer (no tornadoes were produced during this event, however 1.25 cm (½ inch) hail did develop over Orange County later in the evening].

3. TERRAIN FORCED FUNNEL CLOUDS

At approximately 1657-1701 UTC 15 April 1998 2 funnel cloud reports were received (from the SAN area and from CRQ) The 1200 UTC 15 April 1998 NKX raob (not shown) showed a conditionally unstable, nearly saturated post-frontal flow with a light northwest surface wind. The flow was unidirectional and steadily increasing with height for unidirectional shear. Mesoscale cellular convection was occurring over the outer waters. Enhanced lines of convection were noted southeast of Santa Catalina (AVX) and San Clemente (NUC) Islands. The lines formed overnight, and a cloud-free region was apparent. There were showers with small hail. The 1652 UTC 15 April 1998 KNKX composite reflectivity (Fig. 7) showed two bands, both of which originated from Santa Catalina Island. At about that time, the funnel cloud reports were received. After the lower levels warmed and dried later in the afternoon a single band pattern developed.

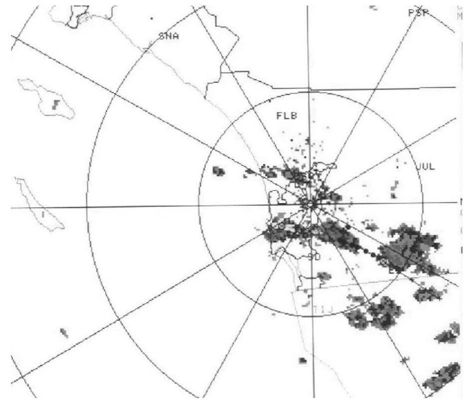


FIG. 7. 1652 UTC 15 April 1998 KNKX composite reflectivity.

4. TERRAIN-FORCED SEVERE HAIL EVENT

At 2300 UTC 5 March 2000 a terrain-forced thunderstorm produced golf-ball sized hail over the San Bernardino Mountains southeast of Lake Arrowhead. The pattern was a very cold upper level low over the area. At 2207 UTC 5 March 2000 a comma-shaped bow echo was moving east toward the San Bernardino Mountains (not shown). The bow echo contained cells with 55-60 dbz echoes, but the VIL was only about 9, and the VIL density was well below the Amburn and Wolf (1996) threshold of 3.5. No hail was reported. By 2252 UTC 5 March 2000 a severe thunderstorm formed over the mountains. The VIL peaked at 15. There was a strong, fairly broad reflectivity core including about 14 pixels of 50 dBZ or more extending downwind about 6 miles, with 3 pixels of 55 dBZ. Spotters reported golf ball sized hail. The storm VILs peaked at 15 with this cell. VILs in the mid teens or stronger with a broad reflectivity core [possibly about 7 km (4 miles) of 50 dBZ in the direction of storm movement, including a few pixels of 55 dBZ], along with a freezing level of 1800 m (6000 feet) or less have proven to be prolific producers of large hail in southern California, especially if a steady state, well developed updraft/downdraft couplet and/or mesocyclone can be seen via radar. The following day another thunderstorm fitting at least some of these characteristics produced golf-ball size hail near SNA in Orange County. The maximum VIL was 20, and the VIL density peaked at less than 3.5.

5. TERRAIN - FORCED MICROBURST EVENT

Between 2050 UTC and 2100 UTC 29 March 1998 a microburst struck in the Lake Elsinore area of southern California. The thunderstorm uprooted a tree and damaged roofs. Later there was flooding in the area. The 1200 UTC 29 March 1998 NKX raob (not

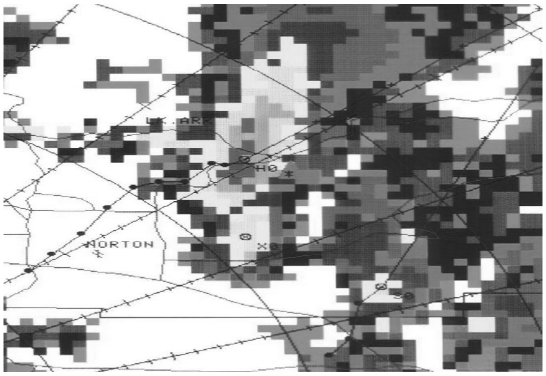


FIG. 8. 2252 UTC 5 March 2000 KNKX composite reflectivity.

shown) showed a nearly saturated, conditionally unstable airmass up to just above 700 mb, with steadily increasing winds with height near the surface, and unidirectional shear. The wind near 1000 m (900 mb/3000 feet) were 10 to 12 ms^{-1} (20 to 24 knots), which is just low enough in speed to support mildly organized IE bands (broken up into some cells). The 0000 UTC 30 March 1998 raob (not shown) showed winds that have decreased below the 10 ms^{-1} (20 knot) threshold (the approximate highest value for well - organized IE bands) to 5 ms^{-1} (10 knots), which supports a more continuous string of convective elements (This can result in bands with an appearance

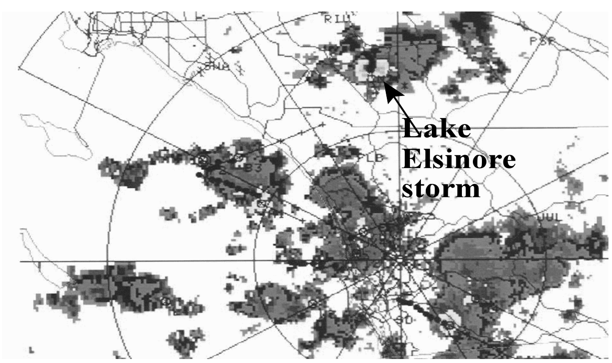


FIG. 9. 2052 UTC 29 March 1998 KNKX composite reflectivity.

similar to "pearls on a string" downwind from isolated higher terrain features such as islands and mountains ranges such as the Santa Ana Mountains). The 2052 UTC 29 March 1998 KNKX composite reflectivity (Fig. 9) showed a pair of IE bands extending southeast from the islands, which supports convergence bands downwind from terrain features on the mainland as well. This convective band appears to have been generated by converging flow in the lee of the Santa Ana Mountains, thus considered to be an Elsinore Convergence Zone (Small et al. 2000). Over the life of the cell, the maximum intensity was between 50 and 55 dbz. The maximum VIL was 18 and the maximum echo top was 8500 m (28 thousand feet). This placed the VIL density at less than the 3.5 value Amburn and Wolf found for the production of large hail. The storm was basically locked on the convergence zone, and steady state. The 2052 UTC 29 March 1998 0.5 degree base velocity (not shown) showed a well-developed mesocyclone associated with the cell, which illustrates the fact that a mini-supercell may have developed along the Elsinore Convergence Zone.

6. A TERRAIN - FORCED MULTIPLE WATERSPOUT EVENT

At about 0110 - 0137 UTC 14 March 1998 a pilot reported 5 waterspouts lined up between LGB and Santa Catalina Island. This phenomena was mainly caused by "enhanced convection due to the flow interacting with the islands". To a lesser extent, there was also convergent flow between the westerly flow from the Pacific and the southerly flow due to the coastal ranges creating a barrier jet. The preference for waterspouts to develop along lines of cumuli has been well documented. There was an upper level low over the area, with a surface low approaching the Southern California Bight. By 0000 UTC 14 March 1998 the circulation was between the Channel Islands and Santa Catalina Island. The 0000 UTC 14 March 1998 and 1200 UTC 14 March 1998 NKX raobs (not shown) showed a moist, conditionally unstable airmass at the lower levels with onshore winds less than 20 knots. Temperatures aloft were favorable for the development of IE bands. The 0029 UTC 14 March 1998 KSOX 0.5 degree base velocity showed southwest winds with well developed wake regions extending northeast of Santa Catalina and San Clemente Islands. These regions later combined into one strong shear area, resulting

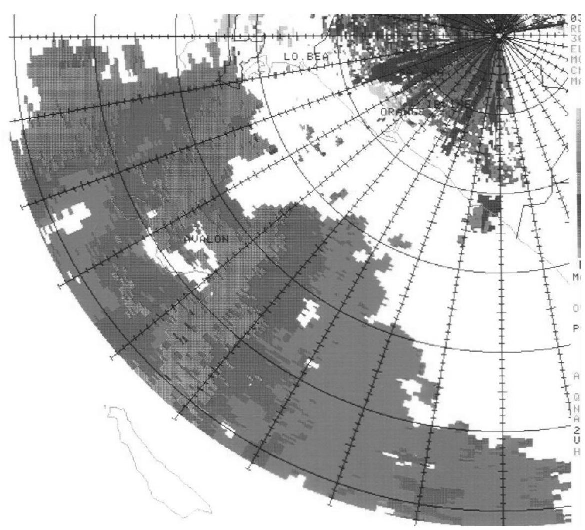


FIG. 10. 0029 UTC 14 April 1998 KSOX composite reflectivity.

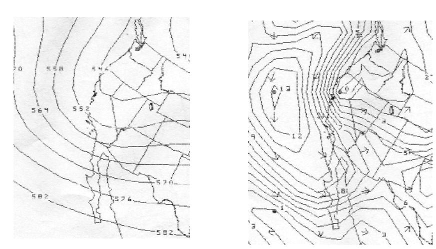
in multiple waterspouts.

7. SEVERE WEATHER COMPOSITE MAPS

Fig. 11 is a composite of all tornado events in the Southern area for the period 1975-1989, and Figs. 12-15 are composites of all tornadoes, funnel clouds, waterspouts, and downburst winds in California for the same period. We selected the raob time that was closest to the time of the reported event, and also 24 hours prior. [A few events that occurred in May or October were more “monsoonal” than “winter weather” type events (Small et al. 2000), and were dropped]. It was seen that rapidly falling heights (and corresponding thickness/ temperature falls) along with a landfalling low level jet were key for the development of shears and boundaries that can focus severe weather. The figures are composite figures of 500 mb heights and 850 mb winds for 4 key areas of California. All 4 composites show a negative tilt difluent trough on the west coast with a negative tilt ridge to the east. Severe weather further south favored a more “V” shaped trough than northern areas. The 850 mb winds show a well developed low-level jet for all 4 areas, with winds much stronger behind the upper level trough, signifying a deepening negative tilt trough. The areas of concern are clearly seem to be in the left front quadrant, as is expected for many severe weather events. There is also a tight gradient in wind speed over the areas where the severe weather occurs. This strong low level jet is important, since it provides the low level shear necessary for terrain forced boundary development as well as development of rotating supercells. The composites clearly show that the area of maximum winds associated with the low level jet is quite variable and rather small. This has resulted in composited mean wind speeds of 5 to 7 ms^{-1} (10 to 15 knots), even though during strong events, 850 mb wind speeds of 15 to 20 ms^{-1} (30 to 40 knots) are not uncommon. These strong low level jets are excellent producers of heavy rain as well since there is abundant moisture advection and moisture convergence during these negative tilt troughing events. When combined with 1000 to 500 mb relative humidity exceeding about 85 percent, it can result in 2.5 to 5 cm (1 to 2 inches)of rainfall in the coastal areas. [With orographics , 5 to 10 cm (2 to 4 inches) can occur in the mountains]. Also, based on the data, it is rare for any area to experience tornadoes on consecutive days, and nearly as rare to see funnel clouds on consecutive days. Therefore, after a day with tornadoes, usually the threat of further tornadic activity is reduced. Waterspouts, and to a lesser extent, funnel clouds are more apt to develop on consecutive days, however, they must be watched as they can move onshore or touch down as a tornado. Based on the composites, 24 hours before a severe weather event, the 558 dam 500 mb height contour is generally north of or at the very northern fringe of an area (the 1000 to 500 mb thickness is generally about 100 meters or so lower). By the time the event occurs at H + 00, the 558 dam height contour has swept south over the area, usually falling some 40 - 60 meters in response to strong cold advection during the period. During very strong events, these values can be exceeded in less than 12 hours. At 558 dam, the corresponding 1000 to 500 mb thickness is in the 540 to 550 dam range, where severe weather can occur. During many days when severe weather occurred, the lowest level of the sounding was very moist and unstable. The temperature difference between the surface dewpoint and the 850 mb temperature (a variation on the “cross total) of between 7 and 10 degrees Celsius can often be achieved, which can exceed than the 6 to 8 degree Celsius moist adiabatic lapse rate. Also, often times the low level winds exceeded 10 ms^{-1} (20 knots) during severe weather events. Temperatures at 500 mb are generally at most -15 degrees C with about -25 being very common for severe weather events.

8. DISCUSSION AND CONCLUSION

It has been shown that the low level jet at around 850 mb interacting with the highly variable terrain in California can result in very complex flows. When combined wtih rapidly falling heights, thicknesses, and temperatures, favored areas for terrain-forced severe weather occurs. In an effort to assist the forecaster in recognizing these patterns, composites have been made to show the positions of the upper level trough and low level jet prior to and during severe weather. There are some factors that the forecaster can look for. One is an upper level trough with 500 mb heights falling into the 550 to 560 dam range or lower (which results in 1000 to 500 mb thicknesses of about 540 to 550 dam). Falls of 40 to 60 meters or more over the 24 hour period are usually necessary, especially for tornadoes. For the stronger activity, the left front quadrant of the low level jet should be nosing into the area [generally around 850 mb, with a core of maximum wind speed of at least 12 to 15 ms^{-1} (25 to30 knots)] offshore. The 850 mb winds reaching the area in question should be 7 to 10 ms^{-1} or higher with a tight speed gradient over the area. The low level airmass should be should be moist and



(a) (b)

Fig. 11. Mean values for tornadic weather in the Southern area at raob time closest to occurrence of event: (a) 500 mb heights in dekameters. (b) 850 mb wind speed in knots.

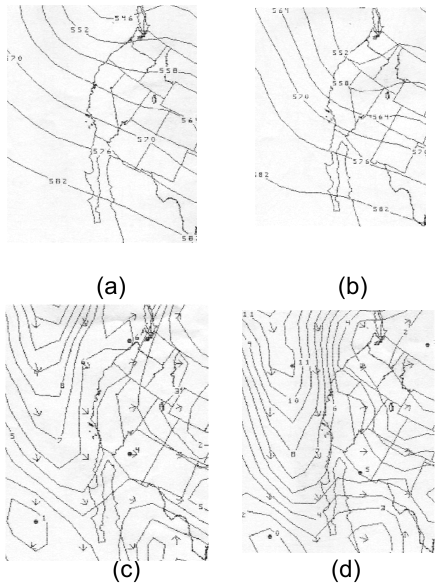


Fig. 12. Mean values for severe weather in the Northern areas where T = raob time closest to occurrence of an event: 500 mb heights in dekameters for (a) T - 24 hours and (b) T - 00 hours. 850 mb winds in knots are for (c) T - 24 hours and (d) T - 00 hours.

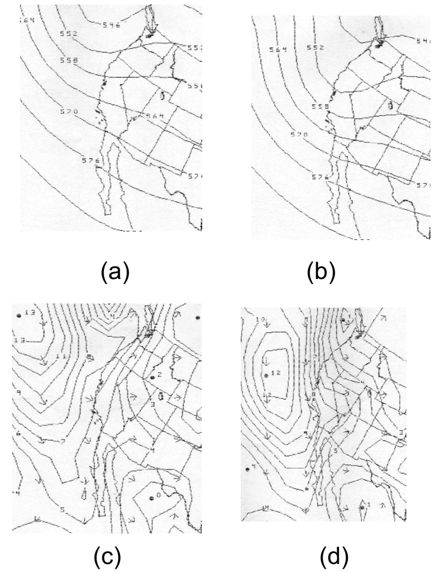


Fig. 13. Mean values for severe weather in the Sacramento Valley and adjacent areas where T = raob time closest to occurrence of an event: 500 mb heights in dekameters for (a) T - 24 hours and (b) T - 00 hours. 850 mb winds in knots for (c) T - 24 hours and (d) T - 00 hours.

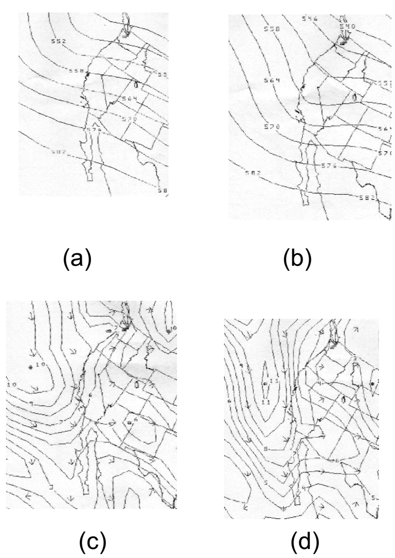


Fig. 14. Mean values for severe weather in the San Joaquin Valley and adjacent areas where T = raob time closest to occurrence of event: 500 mb heights for (a) T - 24 hours and (b) T - 00 hours. 850 mb winds are for (c) T - 24 hours and (d) T - 00 hours.

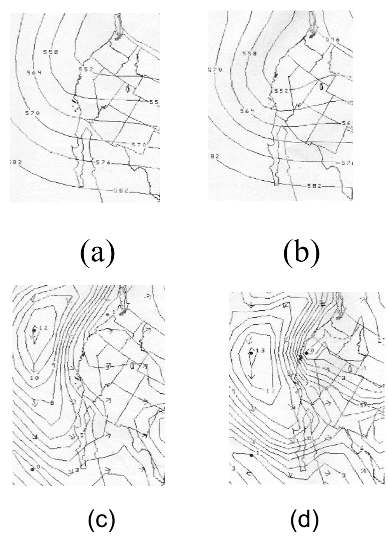


Fig. 15. Mean values for severe weather in the Southern area where T = raob time closest to occurrence of event: 500 mb heights for (a) T - 24 hours and (b) T - 00 hours. 850 mb winds are for (c) T - 24 hours and (d) T - 00 hours.

unstable, with surface to 850 mb cross totals at or above the moist adiabatic lapse rate (about 6 to 8 degrees Celsius) from the surface to 850 mb. (When moisture levels are very high near the surface, the lifting condensation level can be so low that the difference between the surface to 850 cross total and the moist adiabat through the surface temperature evaluated at 850 mb can be comparable to an 850 mb lifted index. This can also be done at any height. It can show high instability below 700 mb, even when 700 and 500 mb values indicate stable conditions). The 1200 UTC 10 November 2000 NKX raob (Fig. 4) shows the importance of looking at instability at non-mandatory level heights (such as 750 mb in this case). A surface based lifted index would give a more unstable value at 750 mb than at 700 mb. So it is best to look for the most unstable value. When the freezing level lowers to below about 1800 m (6000 feet, which places 850 mb temperatures near 3 degrees Celsius), hail production becomes more likely. Large cores of 50 dBZ echos (with some 55 dBZ) that show an organized updraft/downdraft couplet (or even a mesocyclone) along with VIL values in the teens can be large hail producers (even if the VIL density remains below 3.5). Boundaries (IE, CBCCZ, thunderstorm outflow, and those formed to the lee of higher terrain) should always be scrutinized for possible development of severe weather. The cold, moist unstable airmass overriding the warm ocean becomes quite unstable overnight. Upslope flow is also a good prospect for generating instability. Finally, Fig. 15 shows composites for the Southern area consisting of dates during which all severe weather occurred, and for comparison, Fig. 11 shows only days when tornadoes occurred in the Southern area. It shows that the trough has 500mb heights about 30 meters lower along with stronger winds on tornadic days versus non-tornadic days (558 dam versus 561dam at SAN). This indicates that the stronger frontal systems are more apt to generate tornadoes, and weaker weather systems are less likely to produce tornadoes, but still produce funnel clouds, waterspouts, and large hail. Also noted was after a tornado occurs, usually there is little, if any, tornadic activity the next day. This probably has something to do with the tornadoes being more closely related to rapid height/thickness/temperature falls, cold advection, and stronger winds at or just behind the cold front, as opposed to the cold unstable airmass with weaker winds and milder height/thickness/temperature falls well behind a front where non-tornadic severe weather can still thrive. Future plans are to further investigate the differences between the types and severity of events in more detail in order to obtain more reliable tools for more accurate severe weather forecasts in California.

9. Acknowledgements

This paper is funded (in part) by a cooperative agreement between the National Oceanic and Atmospheric Administration (NOAA) and the University Corporation for Atmospheric Research (UCAR). The views expressed herein are those of the author(s) and do not necessarily reflect the views of NOAA or any of its sub-agencies, or UCAR. We would like to thank Dan Atkin for graphical assistance. NMCdraw (Leblang) was used for composites.

10. BIBLIOGRAPHY

Amburn, S. A., and P. L. Wolf., 1996: VIL density as a Hail Indicator. *Wea. Forecasting,* **12**, September 1997 473-478

Blier, W. and K. A. Batten, 1994: On the incidence of tornadoes in California. *Wea. Forecasting*, **9** 301-3

Fox, A. D., 1978: A study of a Southern California coastal storm using satellite imagery. Preprints, Conference on Weather Forecasting and Analysis and Aviation Meteorology, Amer. Meteor. Soc., Boston, 125-131.

Hales, J. E., Jr., 1985: Synoptic features associated with Los Angeles tornado occurrences. *Bull. Amer. Meteor. Soc*., **66**, 657-662

Halvorson, D. A., 1971 Tornado and Funnel Clouds in San Diego County. Western Region Technical Attachment No. 71-33. Available from : NWS Western Region, P. O. Pox 11188, Salt Lake City, UT 84147

LaDochy, S. and J. N. Brown (submitted): The Climatology of California Severe Weather: Population Bias or Geographic/climatological Influences?

Monteverdi, J. P. and J. Quadros, 1994: Convective and rotational parameters associated with three tornado episodes in northern and central California. *Wea. Forecasting*, **9**, 285-300.

Small, Ivory J., 1999a: An observational study of Island Effect Bands: Precipitation producers in Southern California. Western Region Technical Attachment No. 99-18, 11pp. (Available from the National Weather Service, 125 S. State St., Salt Lake City, UT 84138).

Small, Ivory J., 1999b: An observational study of a California Bight Coastal Convergence Zone: Precipitation producer in Southern California. Western Region Technical Attachment No. 99-19, 11 pp. (Available from the National Weather Service, 125 S. State St., Salt Lake City, UT 84138).

Small, Ivory J., Mackechnie, and B. Bower, 2000: Mesoscale Interactions Triggering Severe Thunderstorms and Flash Flooding in Southern California - July 1999. Western Region Technical Attachment No. 00-01, 18 pp. (Available from the National Weather Service, 125 S. State St., Salt Lake City, UT 84138).