1.1 THE DRAMATIC EFFECT OF TORNADIC SEVERE WEATHER ON A RAPIDLY GROWING URBAN INTERFACE

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1. INTRODUCTION

On 22 May 2008 a late season, upper level low dropped south over Nevada, then slowly drifted west over central California (Fig. 1). Four tornadoes were reported in an inland valley area, rather than near the coast, along with large hail and flash flooding. One of the tornadoes, an EF-2 moved over a crowded freeway and over train tracks during the afternoon rush hour, affecting both rail and freeway traffic. This tornado developed near March Air Reserve Base (KRIV), lifted a tractor trailer rig into the air, and after landing back on the freeway, ended up in a nearby field (injuring the driver). The same tornado also blew 9 rail cars of a train off their track. A couple of years earlier, on 11 March 2006 another large upper level low developed near the west coast, and produced supercells, one resulting in a weak tornado in an inland area [near Ramona (KRNM)]. There were some common features of the two events that pointed toward the potential for supercell development and possible tornadoes. Beyond the moisture and instability, terrain in southern California is often the first place to look when attempting to determine the causative factors of such severe weather. Although, only a small sample, (the 2 cases included in this paper), it appears that unusually strong and persistent synoptic scale forcing in the form of long training vorticity centers may play a major role as well.

2. SYNOPTIC AND MESOSCALE FEATURES ASSOCIATED WITH SOUTHERN CALIFORNIA TORNADO EVENTS

Blocked flow and the associated helicity generation along the southern California coast (Hales 1985), or California Bight Coastal Convergence Zones and Island Effect Phenomena (Small 1999a, 1999b) and Small et al., (2002) have been shown to be key producers of supercells, waterspouts, funnel clouds, severe thunderstorms, and tornadoes over the Los Angeles Basin. Many of the tornado events are over the coastal plain, but have been reported over a large potion of southern California (Blier and Batten, 1994). Of these events, probably the majority are non-supercellular, similar to the events analyzed in Wakimoto and Wilson (1989). It is becoming apparent that there are identifiable patterns and processes that affect the valley areas in regard to such phenomena, including the event that spawned the 22 May 2008 tornado mini-outbreak. There has been an upswing in the number of tornadoes being reported in inland areas. Rapid urbanization of southern California, especially the inland areas may play a huge part in the upswing in the number of tornadoes being reported in these inland areas.

2.1 *Tropospheric Vortex Rivers*

Hales (1985) stated that “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 an attempt to convey the conditions common for such tornadic episodes, he introduced a conceptual model for LA basin tornadoes. It consists of upper level lows parked off the coast of central California (Fig. 2), and south to southwest low level flow which produces a confluence zone over the coastal waters and locally over the coastal plain. Lately, it seems that there are upper air patterns, (some with significant differences from the Hales schematic) that may be alternative setups for the organization/intensification of storms, possibly into long lived supercells, and even produce tornadoes in extreme southwestern California (Fig. 3). This pattern consists of a broad 500 mb trough containing a long ribbon of vortices imbedded in a large thermal gradient aloft. An envelope of vorticity bounded by a 24 x 10^{-5} s^{-1} contour can stretch 750-1000 miles or more, and can reasonably be described as a "Tropospheric Vortex River". Such a pattern may allow long lived supercells to move inland from the coast into the inland valleys, or even develop in the inland valleys. Often such long vortex rivers embedded in longer wave troughs can be slow moving events, and may produce persistent conditions favorable for organized convection, thus resulting in increased probabilities of supercell development and possible tornadoes. These tornadoes may be mesocyclone induced, or even non-mesocyclone type events (possibly induced via stretching along convective or non-convective boundaries with no mesoscyclone).

The 22 May 2008 case showed a prominent Tropospheric Vortex River Pattern. Another prominent Tropospheric Vortex River Pattern occurred on 11 March 2006. There were numerous

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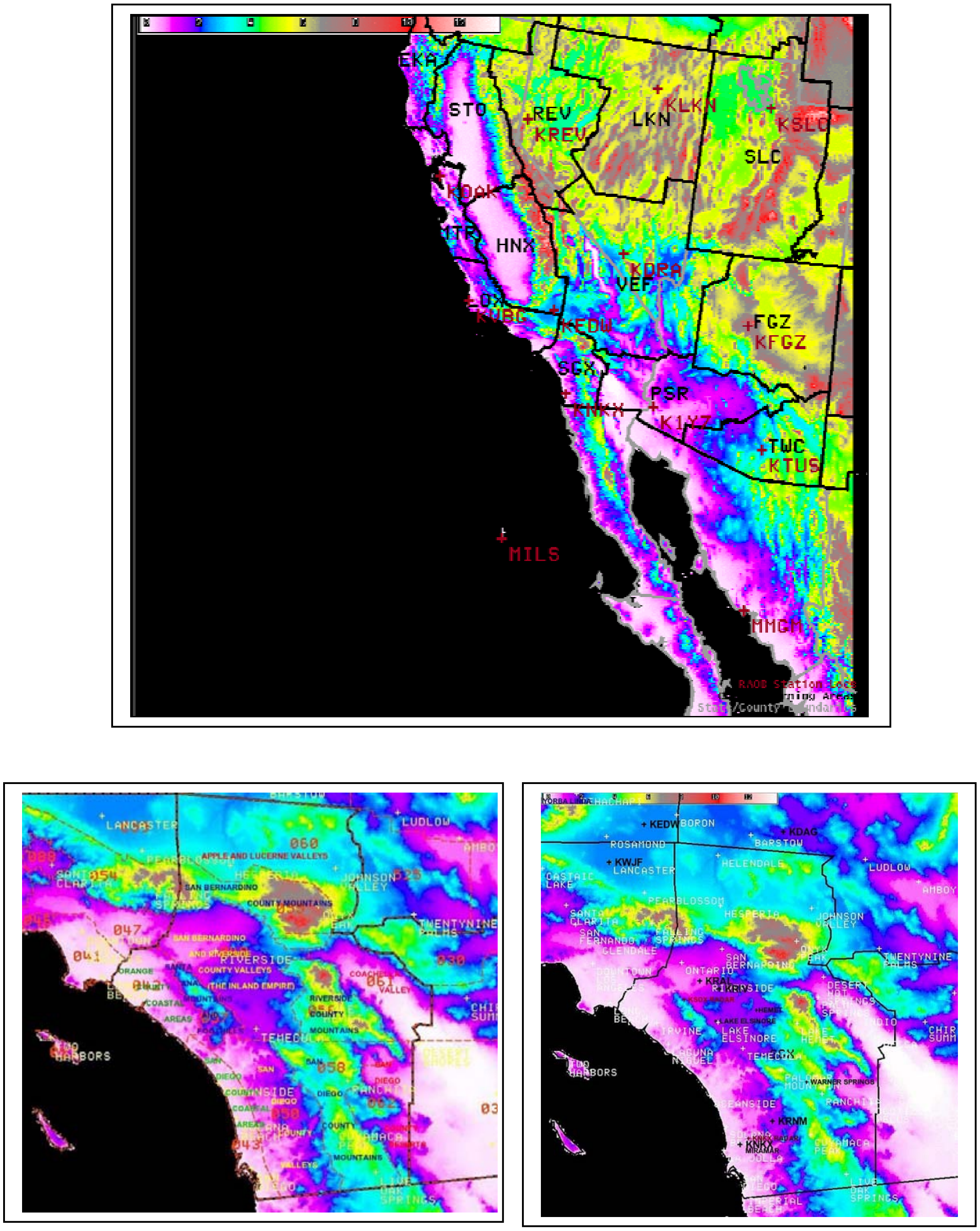

Fig. 1. Terrain map of the WFO SGX CWFA. Color coding in the legend is in thousands of feet MSL. The sounding sites are indicated in red on the upper panel.

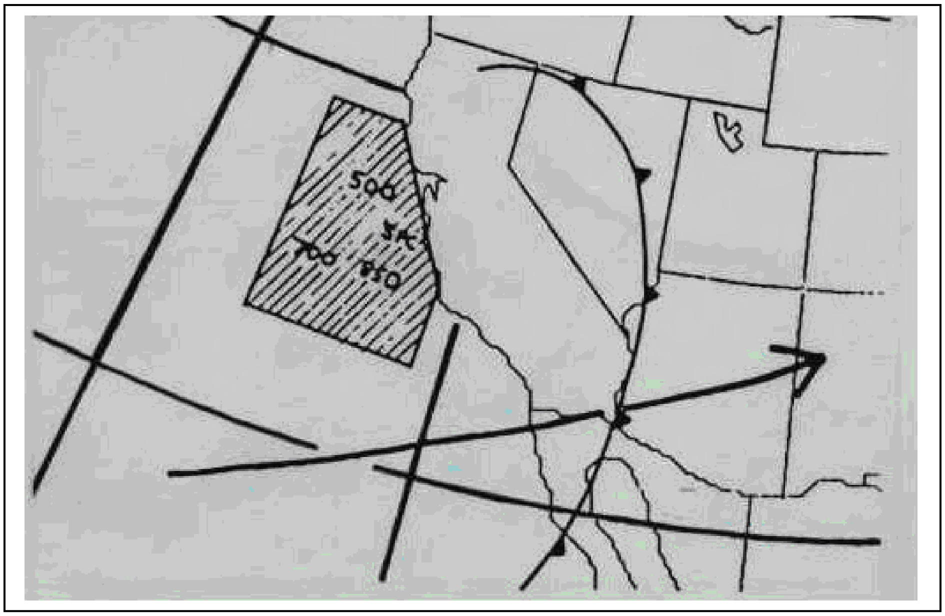

Fig. 2. Hales conceptual model showing the mean position of the jet stream (arrow) and cold front at the time of tornado occurrences. The hatched area indicates the typical location of the low centers at the surface, 850, 700, and 500 mb. (after Hales, 1985).

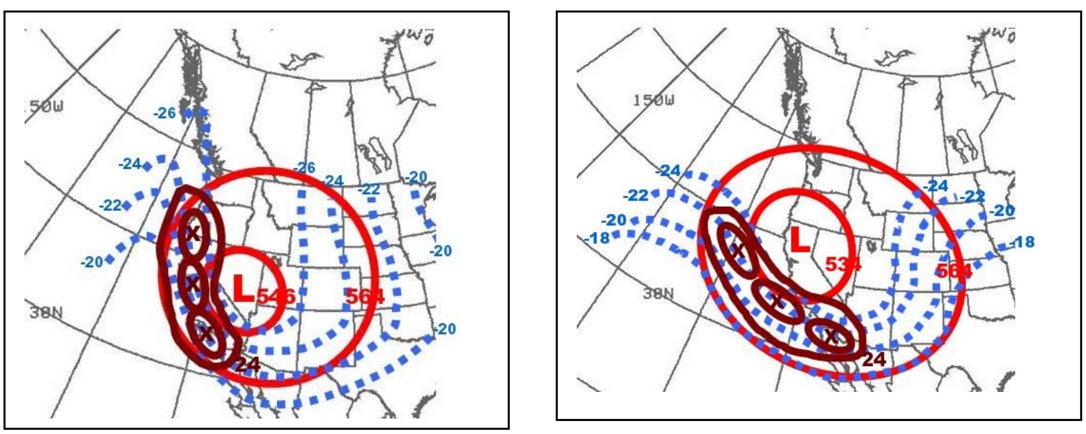

Fig. 3. Conceptual models for very large low pressure systems that may produce supercells and possibly tornadoes. The case with the low center well inland and a northerly flow trajectory is on the left (northerly flow event). The case with the low center slightly inland, with a westerly flow trajectory is on the right (westerly flow event). The red contours (solid) are 500 mb heights, the cyan contours (dotted) are the 500 mb temperatures, and the brown contours along the coast are the "Tropospheric Vorticity Rivers" with imbedded vorticity maxima.

organized cells that day, with large hail, some of it accumulating. One of the cells developed into a near-textbook supercell thunderstorm, rolled past the NWS San Diego Forecast Office into the Inland Valley region near Ramona (RNM), and a tornado developed.

These two fairly recent severe weather outbreaks involving tornadic supercells and "Tropospheric Vortex Rivers" will be investigated and presented. The impact of such events on travel in the rapidly urbanizing inland areas will also be presented. And finally, some insights into the pitfalls of forecasting “northerly flow” events will be visited.

3. THE ELSINORE CONVERGENCE ZONE AND THE MODIFIED ELSINORE CONVERGENCE ZONE

In the Inland Empire, the Elsinore Convergence Zone (Aldrich, 1970), shown in Fig. 4, has been a favored soaring spot for many years during fair weather. However, as of late, the Elsinore Convergence Zone (or ECZ), has been shown to drastically increase the strength of convection in the Inland Empire (Fig. 5), (Small et al., 2000). This convergence zone forms in the San Bernardino and Riverside County Valley Zone, also referred to locally as “The Inland Empire”. The Inland Empire is unique in that it is bordered to the north and east by mountains rising to over 11,500 feet (3504 m) msl, and to the west by the Santa Ana Mountains which extend to close to 5,700 feet (1737 m) msl near Santiago Peak. Late morning and afternoon sea breezes work their way around the northern and southern ends of the Santa Ana Mountains towards Lake Elsinore forming the Elsinore Convergence Zone (ECZ). Occasionally, the ECZ can be modified from the above by mesoscale phenomena. This "Modified Elsinore Convergence Zone", or MECZ (Small et al., 2000) can become established when thunderstorm outflow boundaries modify the flow. This scenario can result in a complex and explosive convergence pattern. It is common for storms to move southwest, but severe weather has occurred with storms moving northeast along the ECZ.

Both the ECZ and the more volatile MECZ can result in enhanced convergence and instability, and initiate strong organized convection over the Inland Empire. The importance of being able to identify such patterns, which may result in the development of severe thunderstorms with heavy rain, becomes much more evident when one realizes that there are nearly 3 million people who live in the Inland Empire. The fear of a rather strong event was realized with the tornado mini-outbreak of 22 May 2008.

4. THE 22 MAY 2008 TORNADO MINI-OUTBREAK

On 22 May 2008 a late season, upper level low dropped over southern California from the interior (Fig. 6). Since it was an upper level low with 700-500 mb relative humidity values in excess of 40 % (and 500 mb temperatures much lower than -20 degrees C helps) thunderstorms developed. Four tornadoes were reported, along with nickel-sized hail and flash flooding. One of the tornadoes, an EF-2, lifted a tractor trailer rig and sent it into a field, injuring the driver. The same tornado also blew 9 rail cars of a train, weighing approximately 63,000 pounds (28,636 kg) each off their track.

The synoptic scale setup was a large upper level low with a low center well inland. This was quite a bit different than the typical position of a strong upper level low for tornado outbreaks, (which is usually off the central California coast). One of the factors supplying the strong energy needed for very strong convection was the baroclinic zone draped over southern California. Baroclinic zones are regions in which a temperature gradient exists on a constant pressure surface, as seen in Fig. 6. Baroclinic zones are favored areas for strengthening storm systems. Also, wind shear is a characteristic of a baroclinic zone. (Both cases contained very strong baroclinic zones. A much larger, boader trough on 11 March 2006 may have helped tornadic conditions to reach southern California, even though the actual low center was further away than is common for typical tornadic events). The baroclinic zone is well represented by what can be called a “Tropospheric Vortex River”, or TVR. This TVR can be seen in the schematics shown in Fig. 3**.** The TVR for the 22 May 2008 event can be seen in Fig. 6 as an enlongated area (embedded in a strong 500 mb thermal gradient) marked by a stream of vorticity centers enveloped by a 24 x 10^{-5} s^{-1} vorticity contour. It is possible that a baroclinic zone with such strong vorticity results in enhanced dynamics and increases the opportunity for severe weather to develop. The shear helps set the stage for rotating supercells.

The 1200 UTC 22 May 2008 KNKX sounding and the 0000 UTC 23 May 2008 KNKX sounding (Fig. 7) shows strong cooling aloft associated with the trough. Also there is some moisture in southerly flow below 850 mb. Overall, the 1200 UTC KNKX sounding, based on the moisture depth, and small capping inversion somewhat resembles the Midwestern loaded gun sounding, however missing the huge convective available potential energy (CAPE) typically associated with Midwestern events. An important point that should be pointed out is the possibility that the KNKX soundings may bear little resemblance to the sounding likely to be resident in the Inland Empire during the tornadoes.

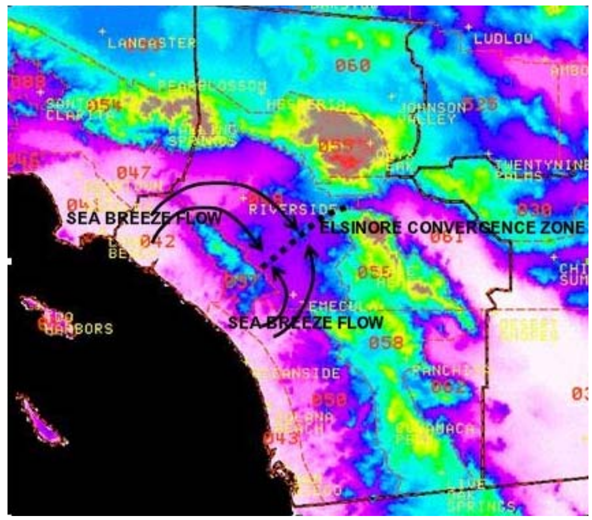

Fig. 4. Example of a typical Elsinore Convergence Zone and the associated wind flow commonly found.

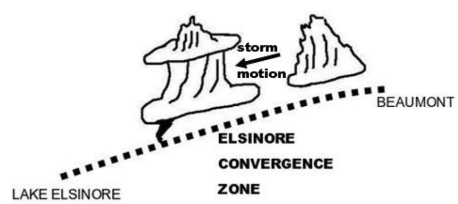

Fig. 5. Conceptual model of an "Elsinore Storm" with a tornado. The tornado may be the result of stretching on the leading edge of a gust front, stretching of circulations along the Elsinore Convergence Zone, a mesocyclone induced tornado, or some combination of the three.

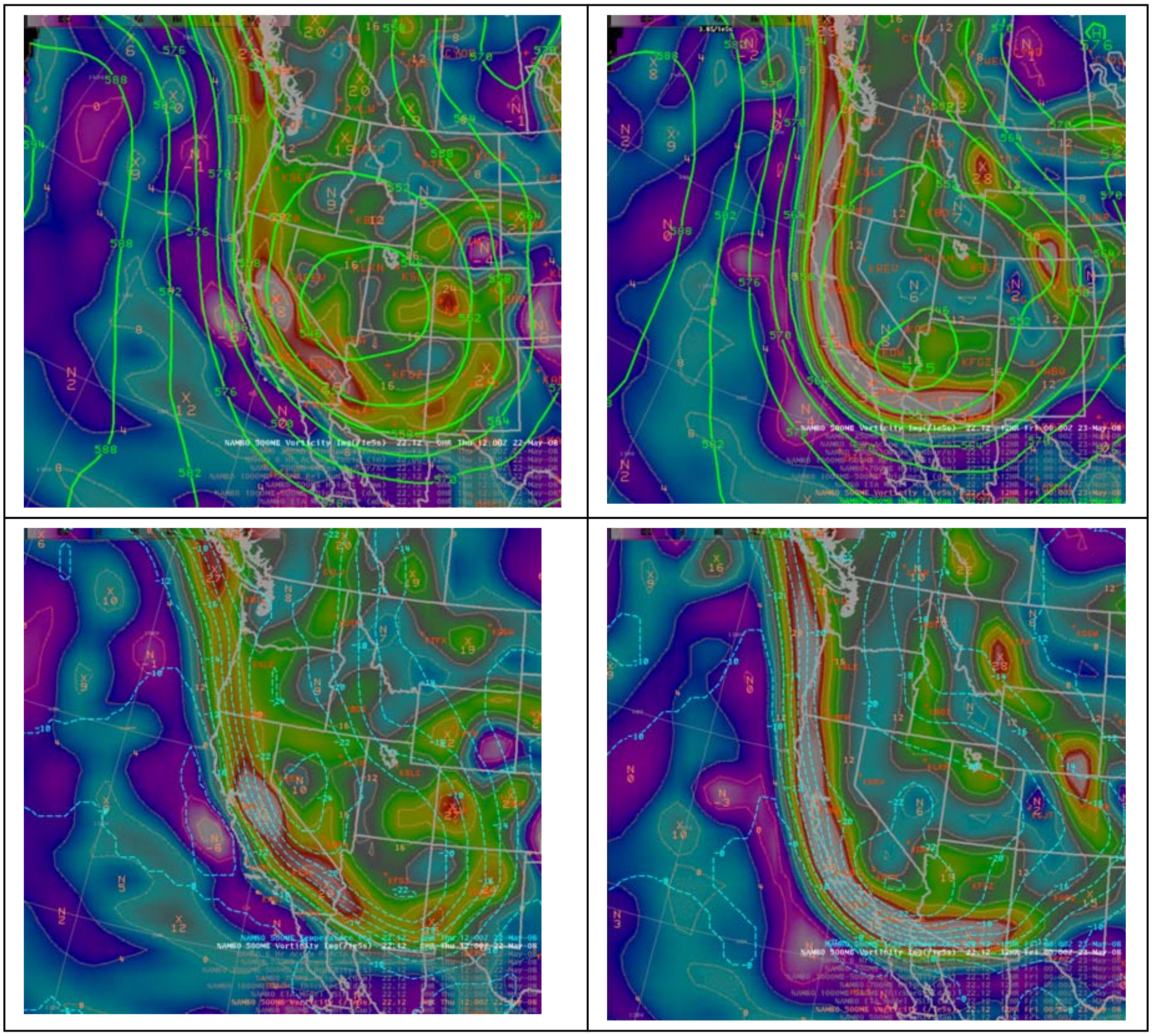

Fig. 6. The upper left panel is the 1200 UTC 22 May 2008 NAM80 500 mb heights (green, contour interval 60 meters) and vorticity (orange contours, intervals of 4 x 10^{-5} s^{-1} and shaded). The panel in the upper right is the same as the upper left, except it is the 12 hour forecast valid at 0000 UTC 23 May 2008. The lower left panel is the 1200 UTC 22 May 2008 NAM80 500 mb temperatures (cyan, intervals of 2 degrees C) and vorticity (orange contours, intervals of 4 x 10^{-5} s^{-1} and shaded). The lower right panel is the same as the lower left panel, except it is the 12 hour forecast valid at 0000 UTC 23 May 2008.

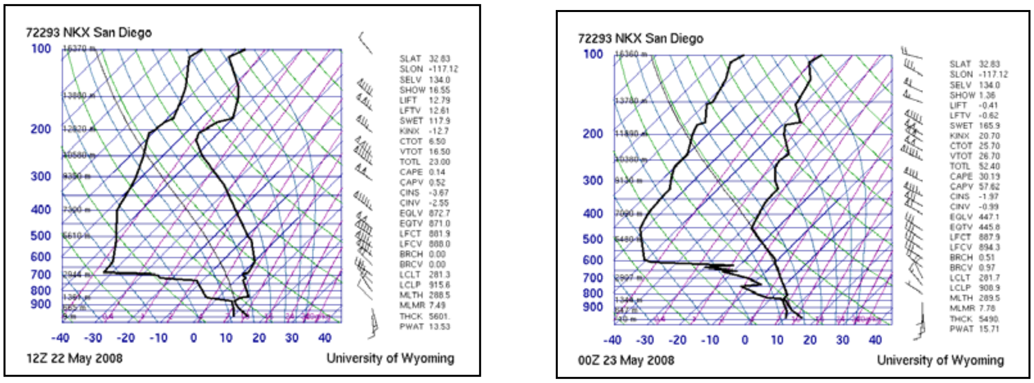

Fig. 7. The 1200 UTC 22 May 2008 KNKX sounding (left) and the 0000 UTC 23 May 2008 KNKX sounding (right).

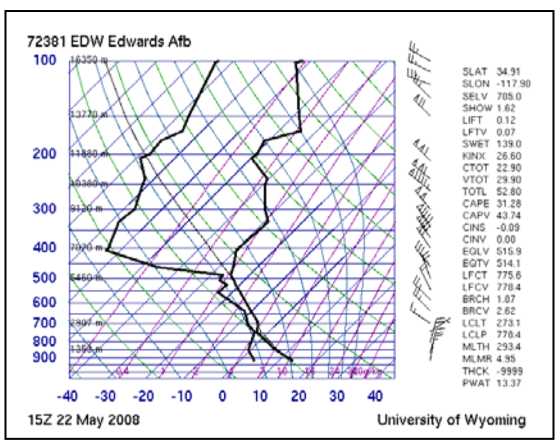

Fig. 8. 1500 UTC 22 May 2008 KEDW sounding.

Figure 8 is the KEDW sounding, just upstream from the Inland Empire. It shows a more volatile setup. There is a low level jet northerly jet of around 20 knots (15 degrees at 20 knots). A low level jet normally supplies shear for tornadic events in southern California, except the northerly jet is in the opposite direction of the low level jets of most tornadic events. The sounding is backing with height indicating cold advection, rather than the warm advection of a Midwestern sounding. There is much more moisture in the KEDW sounding compared to the KNKX sounding, which points toward the KEDW sounding as the more representative sounding for this event.

The soaring parameters from the Soaring Program developed by one of the co-authors (Ted Mackechnie) can be found in Table 1. Although thermal strengths were moderate, their tops far exceeded the convective condensation level (CCL), thus adding a lot of extra energy to the CAPE values of the day, and supporting strong thunderstorm development.

Prior to the EF-2 tornado, a disturbance moved south through the Inland Empire, clearing out the clouds from the center of the valley (Fig. 9). This disturbance set off severe thunderstorms in the southern portion of the valley, which then sent an outflow boundary northward. This northward moving outflow boundary added low level moisture and increased the convergence, thus modifying the ECZ into the more volatile MECZ (Fig. 9). The 15 knot southeast wind at KRIV is a strong indicator of a Modified Elsinore Convergence Zone (MECZ) since it is significantly stronger than the 5-10 knot (2-5 ms^{-1}) speed typically seen at the ECZ. This stronger flow likely enhanced the supercell on the MECZ that produced the EF-2 tornado. Also the deviation to the right as the tornadic storm moved south to the ECZ, and then southwest down the ECZ probably resulted in an increase in the storm relative helicity (SRH).

Figure 10 shows the 2329 UTC 22 May 2008 KSOX radar Composite Reflectivity. The first tornado, an EF-0, was reported at 2330 UTC and lasted 6 minutes. Figure 11 shows the 2333 UTC 22 May 2008 KSOX Composite Reflectivity. Figure 12 is the 2338 UTC 22 May 2008 KSOX Composite Reflectivity just prior to the development of the EF-2 tornado. Figure 13 is the 2342 UTC 22 May 2008 KSOX Composite Reflectivity at the time that the EF-2 tornado was first reported. (The EF-2 tornado was reported to have lasted 21 minutes and was possibly a multi-vortex event. Figure 14 shows the 2355 22 May 2008 UTC KSOX Composite Reflectivity during the EF-2 tornado. The storm has a well defined hook and is an excellent example of a storm with a bounded weak echo region (BWER), an indicator of a very strong updraft.

The 2338 22 May 2008 4-panel reflectivity from the KSOX radar shows a bounded weak echo region in Fig. 15**,** 4 minutes prior to the time that the EF-2 tornado was reported. The 2338 22 May 2008 4-panel SRM from the KSOX radar (Fig. 16) shows a well developed circulation at the same time.

The forcing and vorticity was diving south into the valley areas, with a different sort of condition for the convergence zone than if the dynamics and low level jet was from the more typical westerly direction. This northerly flow may have helped increase the helicity values somewhat, but most likely it was the outflow interacting with the ECZ and the supercell development on the ECZ that was more critical. Small et al (2000) showed how such thunderstorms from the north or east can interact with the ECZ, strengthen rapidly, then propagate southwest down the convergence zone (Fig. 5). It has been noticed that tornadoes can develop rapidly with thunderstorms “bubbling” down or colliding with the ECZ during the warm season, and thunderstorms can quickly become severe. This is especially true when there has been severe thunderstorm activity in southern California earlier in the day (whether it is reported or inferred by convective strength based on radar). The earlier severe thunderstorm around 1900 UTC on 22 May 2008 in the southern portion of the Inland Empire shows that the air mass has a history of severe weather, and storms with additional forcing (such as terrain forced convergence zones and convective boundaries) are good candidates for producing severe weather. Since there was severe activity earlier in the day, there was a good possibility that a tornado would be spawned if a thunderstorm bubbles down the ECZ. An additional component to the equation is that conditions can warm and destabilizes rapidly in late May. The interaction with the MECZ as the storm moved in from the north was very similar to a warm season severe weather scenario (Small et al., 2000).

There was a noticeable pressure trough moving through the area at about an hour before the EF-2 tornado. The mean sea level pressure (mslp) reached a minimum of 29.43 inches at 2255 UTC and 2253 UTC at KRIV and KRAL respectively. The wind shift was notable in the upper deserts. At 2222 UTC the wind shifted at KWJF from 29016G28 knots to 01025G32 knots as the feature went through.

4.1 ***Important points from the 22 May 2008 case***

Previous tornadic events have been analyzed in some detail. A rather unique feature to this event is the trajectory of the synoptic scale forcing and the placement of the upper level low pressure center in general. There are some similarities as well as differences from the Hales conceptual model.

1. This 22 May 2008 event occurred on a modified Elsinore Convergence Zone (MECZ), rather than on a blocking convergence line near the coast (Hales, 1985), or the broader classification such as California Bight Coastal Convergence Zones (Small, 1999b) or Island Effect Rain Bands (Small, 1999a).
2. The upper level low was well inland, rather than off the central California coast, also different from the more common offshore location.
3. Although much further away, this strong low was accompanied by a "Tropospheric Vortex River", which is stronger and longer than most vorticity scenarios. It may have allowed sufficient forcing for severe weather even as far south as southern California to develop. (The low was so large and so strong, it could be centered far from southern California and still bring strong enough forcing to the region to drive a mini-outbreak of tornadoes).
4. With convection arriving from the north, the system used a convergence zone more commonly associated with warm season severe weather phenomena. Storms can develop to the north, move south to the ECZ, and then southwest along the ECZ. (The fact that this was a transition season event may have resulted in the event taking on a sort of "Hybrid" character).

Some interesting similarities as well as differences from the "typical severe weather scenario" can be found in the 11 March 2006 case as well.

5. THE 11 MARCH 2006 CASE

The 11 March 2006 event was somewhat less notable than the 22 May 2008 event. There was only 1 tornado on 11 March 2006, which occurred in an inland valley (however, there was a tornado reported the previous day near the coast in the city of Encinitas, about 15 miles north of downtown San Diego). The synoptic setup (Fig. 17) was a very large upper level low, essentially over the northern California coast, placing the region in cold, moist unstable westerly flow. Overall, it was somewhat closer to the Hales scenario. Similar to the 22 May 2008 case there is an elongated stream of enhanced vorticity surrounded by the 24 x 10^{-5} s^{-1} vorticity contour embedded in a strong 500 mb thermal gradient. It is possible that this baroclinic zone of such strong vorticity results in enhanced dynamics and increases the opportunity for severe weather to develop.

The soaring parameters from the Soaring Program in Table 1 again shows thermal strengths were moderate, with tops far exceeded the CCL, thus adding a lot of extra energy to the CAPES of the day and supporting strong thunderstorm development.

The soundings (Fig. 18) show more typical moisture and wind speed profiles for tornado events. (Actually, the moisture profile of the 0000 UTC 12 March 2006 KNKX sounding is similar to that of the 1500 UTC 22 May 2008 KEDW sounding in the previous case). In Fig. 19 the 1945 UTC 11 March 2006 4-panel reflectivity from the KNKX radar shows a well developed supercell thunderstorm. The actual tornado occurred later, further east in Ramona (KRNM). In Fig. 20 the 1945 UTC 11 March 2006 4-panel SRM from the KNKX radar shows a nice couplet of inbound/outbound velocities, but does not show the type of well-developed circulation seen in the 22 May 2008 storm.

To recap, this event has many similarities to the classic "Hales tornado event" in southern California, but there are some differences that can be pointed out as well.

5.1 *Important* points *from the 11 March 2006 case*

1. Similar to a "Hales tornado event", the main front was well inland (this event occurred about 36 hours after frontal passage).
2. The low was to the north (and even inland at 1200 UTC 11 March 2006, somewhat different than the Hales schematic
3. The flow was somewhat more westerly than the classic Hales case.
4. This event may have occurred via strengthening on a convergence zone as Ramona is in a valley area, but more inspection is required. This event was more likely to be assisted by a convergence features inland rather than at the coast.
5. The "Tropospheric Vortex River" was very strong, long, and persistent.
6. There were back to back days with a tornado being reported (10 March at the coast and 11 March inland). A "possible" small tornado was reported in Encinitas, knocking down a few trees at about 0038 UTC on 10 March 2006. It is a rare occurrence to see 2 tornadoes on back to back days.

Similar to the 22 May 2008 case, near the location of the 11 March 2006 tornado (at KRNM) the mean sea level pressure bottomed out at 29.70 inches, which occurred at 1950 UTC, indicating the passage of a surface trough at least within an hour or so of the tornado.

Table 1. Soaring parameters for selected sites in southern California

SOARING SITE	Max Temp degF	Max Temp degC	Thermal Tops ft-msl	Thermal Tops m-msl	Soaring Index ft/min	Soaring Index m/s	Trigger Temp degF	Trigger Temp degC	CCL ft-msl	CCL m-msl
WARNER SPRINGS (879 m msl)										
1200 UTC 11 MAR 2006	37	2	3477	1087	49	0	36	2	3567	1087
0000 UTC 12 MAR 2006	42	6	7448	2270	380	2	36	2	3595	1096
MIRAMAR (132 m msl)										
1200 UTC 11 MAR 2006	55	13	5439	1657	417	2	45	7	1627	496
0000 UTC 12 MAR 2006	58	14	8866	2702	703	4	50	10	2058	627
HEMET (461 m msl)										
1200 UTC 22 MAY 2008	66	19	4944	1507	286	1	52	11	2864	873
0000 UTC 23 MAY 2008	64	18	6796	2071	440	2	53	12	2901	884
ELSINORE (384 m msl)										
1200 UTC 22 MAY 2008	72	22	7069	2154	484	2	53	12	2751	838
0000 UTC 23 MAY 2008	68	20	8052	2454	566	3	54	12	2788	850
MIRAMAR (132 m msl)										
1200 UTC 22 MAY 2008	63	17	4081	1244	304	2	57	14	2360	719
0000 UTC 23 MAY 2008	63	17	4817	1468	365	2	59	15	2459	749

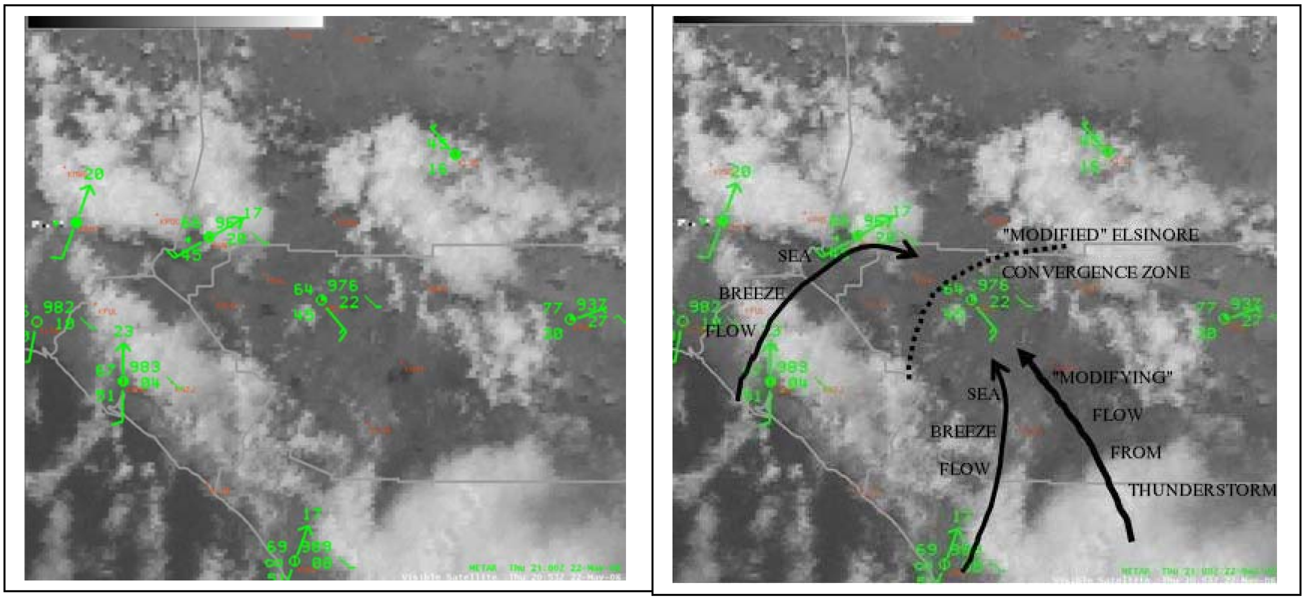

Fig. 9. 2100 UTC 22 May 2008 METAR observation data and the 2053 UTC 22 May 2008 visible satellite imagery. Imagery and observations show a Modified Elsinore Convergence Zone (Modified via strengthening of the convergence zone by a thunderstorm outflow boundary from the southeast, augmenting the convergent flow). The convection along the convergence zone can be seen stretching from the southwest to northeast through KRIV. The clear skies allowed better heating and destabilization of the atmosphere.

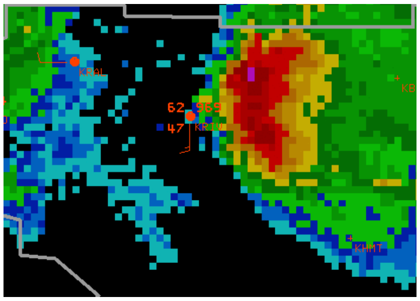

Fig. 10. The 2329 UTC 22 May 2008 KSOX Composite Reflectivity. An EF-0 tornado was reported at 2330 UTC and lasted 6 minutes

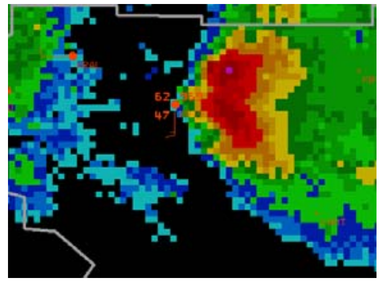

Fig. 11. The 2333 UTC 22 May 2008 KSOX Composite Reflectivity during the EF-0 tornado.

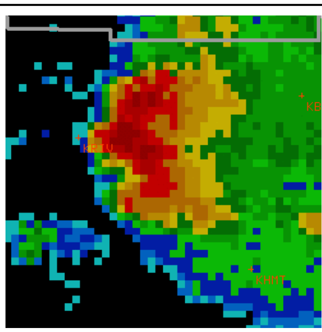

Fig. 12. The 2338 UTC 22 May 2008 KSOX composite reflectivity, just prior to the development of the EF-2 tornado

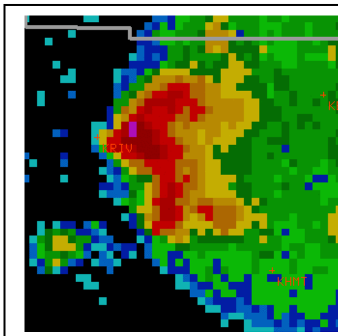

Fig. 13. The 2342 UTC 22 May 2008 KSOX Composite Reflectivity. The EF-2 tornado developed at 2342 UTC and lasted 21 minutes

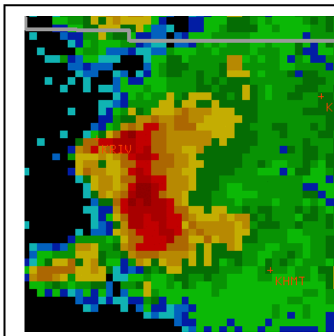

Fig. 14. The 2355 UTC 22 May 2008 KSOX Composite Reflectivity. during the EF-2 tornado. The storm has a well defined hook and is an excellent example of a storm with bounded weak echo region (BWER), an indicator of a very strong updraft.

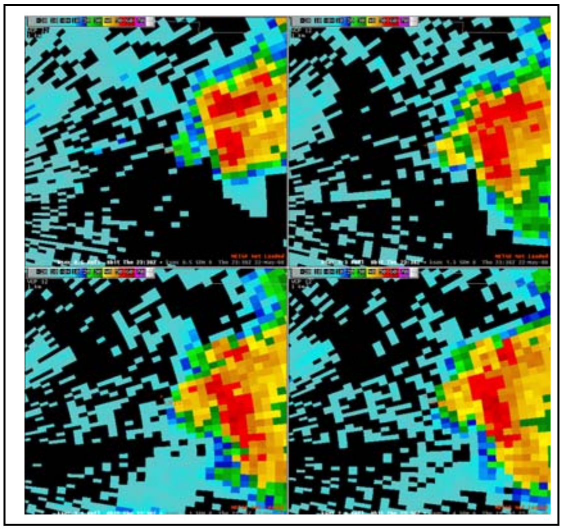

Fig. 15. 2338 22 May 2008 4-panel base reflectivity from the KSOX radar at (clockwise from the upper left) 0.5, 1.3, 2.4, and 3.1 degrees. The 1.3 degree slice shows evidence of a bounded weak echo region.

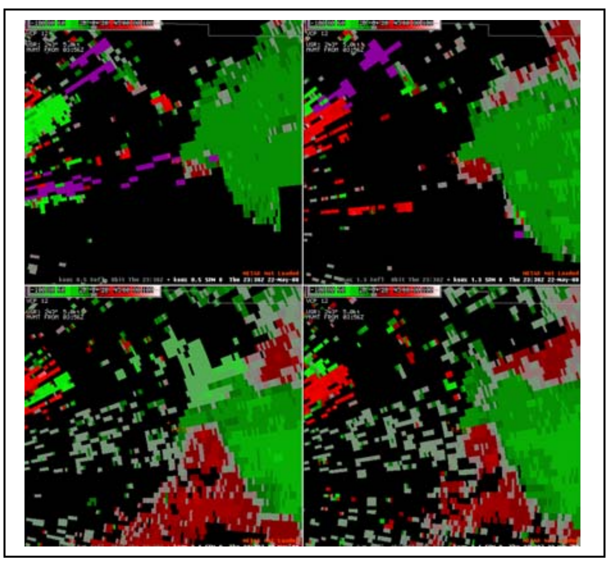

Fig. 16. 2338 22 May 2008 4-panel SRM from the KSOX radar at (clockwise from the upper left) 0.5, 1.3, 2.4, and 3.1 degrees. There is a good circulation signature noted. This was just before the EF-2 tornado was reported.

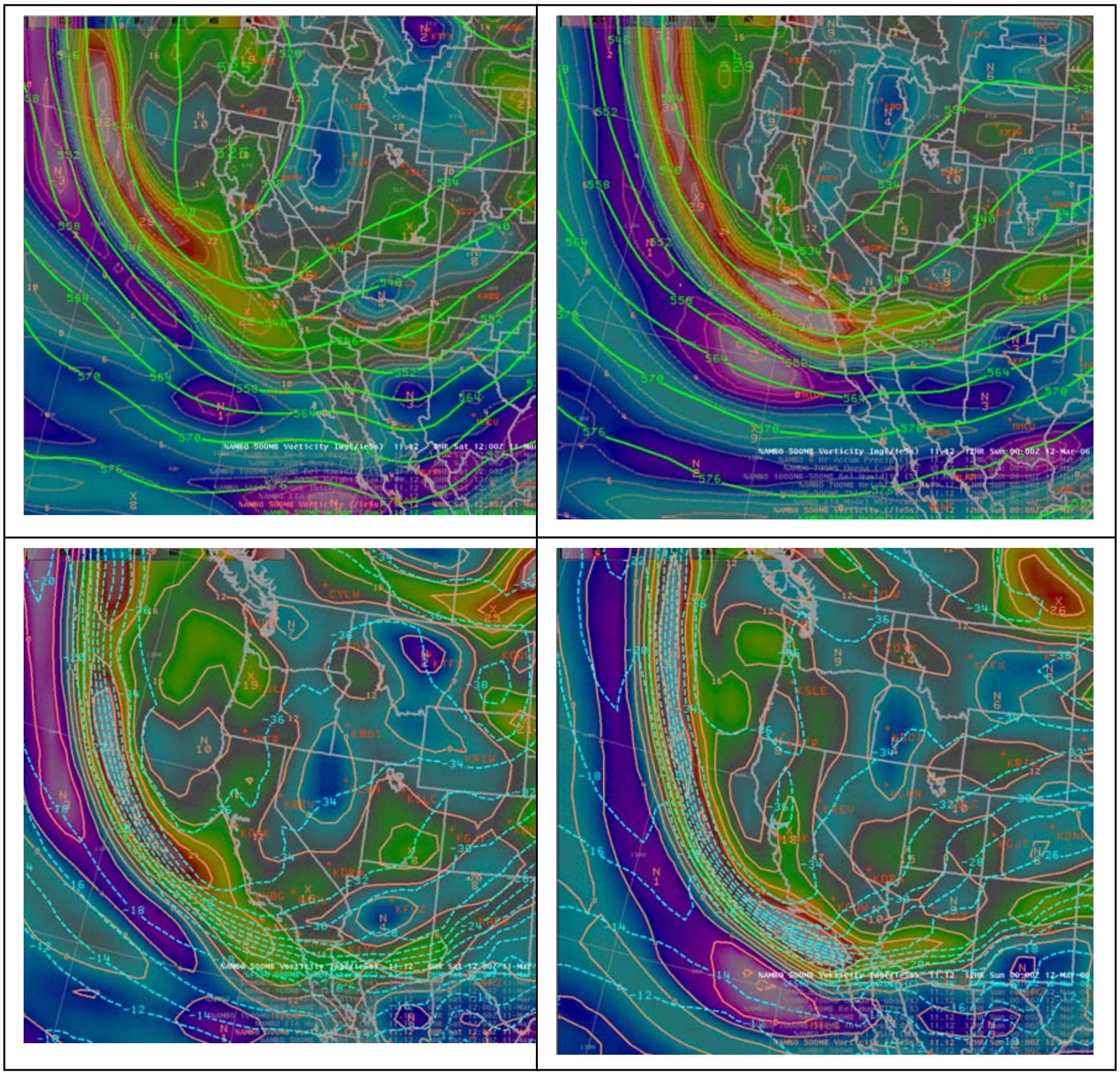

Fig.17. The upper left panel is the 1200 UTC 11 March 2006 NAM80 500 mb hights (green, contour interval 60 meters) and vorticity (orange contours, intervals of 4 x 10^{-5} s^{-1} and shaded). The upper right panel is the same as the upper left panel, except it is the 12 hour forecast valid at 0000 UTC 12 March 2006. The lower left panel is the 1200 UTC 11 March 2006 NAM80 500 mb temperatures (cyan, intervals of 2 degrees C) and vorticity (orange contours, intervals of 4 x 10^{-5} s^{-1} and shaded). The lower right panel is the same as the lower left panel, except it is the 12 hour forecast valid at 0000 UTC 12 March 2006.

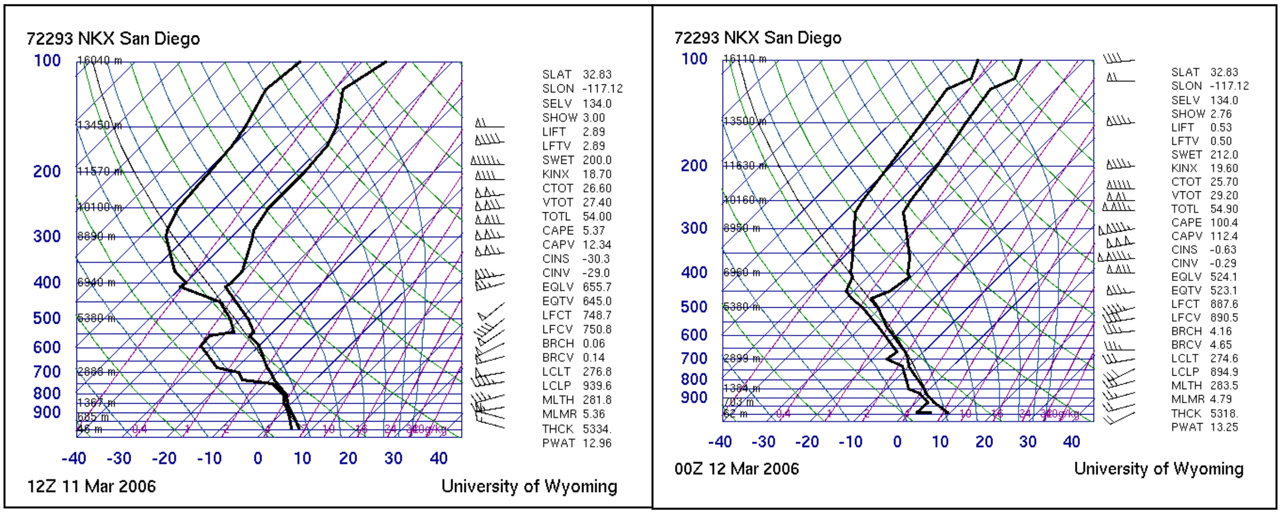

Fig. 18. 1200 UTC 11 March 2006 KNKX sounding (left) and 0000 UTC 12 March 2006 KNKX sounding (right).

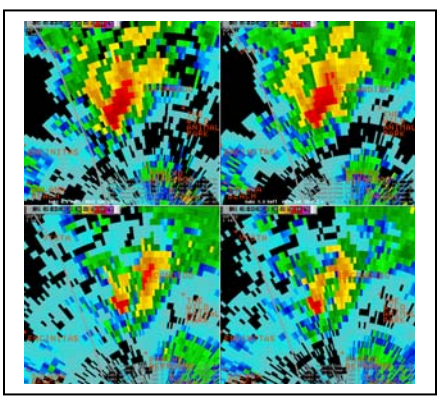

Fig. 19. 1945 UTC 11 March 2006 4-panel reflectivity from the KNKX radar at (clockwise from the upper left) 0.5, 1.3, 2.4, and 3.1 degrees, showing the shape of a near-textbook supercell thunderstorm.

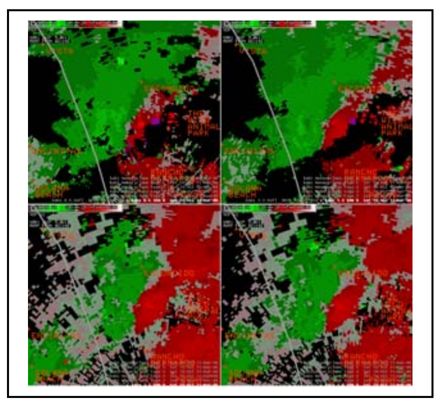

Fig. 20. 1945 UTC 11 March 2006 4-panel SRM from the KNKX radar at (clockwise from the upper left) 0.5, 1.3, 2.4, and 3.1 degrees.

6. DISCUSSION AND CONCLUSION

The 22 May 2008 tornado mini-outbreak was unique in the fact that it did not follow the typical scenario for tornadic convection in southern Califonria associated with strong upper level lows. In the winter, the expected scenario has been a low offshore, a low level jet from a south to southwesterly direction, and well behind a cold front. In this case, the upper level low was well inland and the low level jet flow was north to northeasterly. It seems to occur close to the time of the passage of a back-door cold front or surface trough from the north with the maximum energy in the valleys. This probably shifted the tornado and severe weather maximum from the coast to the valleys. Instead of using convergence features along the coast, (such as the California Bight Coastal Convergence Zone, the Palos Verdes Peninsula, or the Island Effect Bands), the enhancement came from the Elsinore Convergence Zone. This is quite a switch from the norm at the ECZ, since the ECZ typically spawns more severe weather during the summer months during southeast to easterly monsoon flow.(It is unclear at this time whether or not the initiation of the 11 March 2006 event was a convergence feature, but based on the history of such enhancements in rough terrain, there may have been some kind of terrain forced boundary that needs more inspection). The storms in the Inland Empire also produced accumulating hail, which can have major impact on the roads, clogging drains, and creating flooding. Aircraft need to deviate around some of the larger storms, in a region where airspace is already a premium.

"Gustnadoes" or "landspouts" commonly form in the low level shear zones of outflow boundaries and on terrain forced shear zones as well. The probability of a tornado can be significantly increased via stretching of vortices when outflow boundaries interact, terrain forced boundaries and thunderstorm outflow boundaries interact, or convection strengthens on shear boundaries such as the ECZ. Also it appears that boundaries that are oriented in a manner such that propagation along them changes the direction of storm movement, the storm relative inflow, hence its SRH, may be increased, (for example, the deviation to the right seen by the 22 May storm). This may also be the case during some of the thunderstorms during the summer as there are many boundary enhanced thunderstorms. It is also possible that a tornado, complete with a mesocyclone can develop, assuming a mesocyclone development occurs within the storm.

Forecasters should now be diligent in anticipating inland tornadic activity in northerly flow or Tropospheric Vortex River types of events, but one of the challenges of forecasting these "northerly events" in advance is that the track of the storm's energy is critical. If the energy is only slightly further inland than expected, the problems of forecasting a weaker type of event develops as the dynamics over the area are reduced. This decreases the probability of inland valley severe weather. It is also ripe with the issues of forecasting rainfall, considering the serious dry bias in the MOS guidance for this type of event, and the fact that these types of northerly flow events can be rather moisture starved anyway. [From a precipitation standpoint, we have looked at ways to increase PoP accuracy using marine layer depth and mid level moisture (Small 2006). Also there is an effort in the West to use climatology (ClimoPoPs) as a first guess field to help improve forecasts in this regard]. If the storm is even further inland, there are other radical changes to be made to the forecast (for example, the problems associated with precipitation and severe convective weather may be dropped entirely, and the issues transition to dealing with low relative humidities as well as maximum temperatures well above MOS. This is especially true over the inland coastal plain/lower valley temperature maximum during such events. (It was an inland coastal community (the City of Yorba Linda, at the northern edge of the Santa Ana Mountains) that experienced a major urban interface fire this past fall (2008). In these cases it takes MOS a day or so to catch up. [Local programs have been written to help tackle this issue. Also in the west there is an effort to employ bias corrections to battle this problem]. It can be seen that the damage expected can shift from one of tornadoes and convective damaging winds to damage due to down slope winds and wildfires with an inland adjustment of the energy. In the other direction, if the dynamics move offshore and swing by to our west, and it is a colder than usual event, the severe weather problem may be reduced to more of funnel clouds event for the inland areas, but the possibility of low snow develops instead if the drier, northeast flow scenario pulls cold down slope flow out of the desert interior. This is especially problematic during the "low elevation snow maximum" time of the day (the night through morning period prone to lower temperatures, stronger winds, and more advection of cold air, thus there is a higher probability of a low snow event during those times). Again, the use of ClimoPoPs as a first guess field as a minimum should be employed to help improve the precipitation forecasts, and the warning may end up being a winter storm warning rather than a tornado warning. The decision concerning which way to go for such a challenge can be a difficult one, and these potential scenarios would need to be conveyed in briefings to emergency managers and in the forecasts. As a result, they can shift gears to deal with snowy roads and associated closures (and maybe even rescues, similar to what occurred during yet another of our north to northeasterly flow Low Snow Events during the Fall season of 2008). This is just a quick sample of how a seemingly small adjustment in track can swing the message from one of supercells and tornadoes effecting rail, highway, and air traffic, to one of firestorms or even shut-down freeways due to low elevation snow. Sometimes, it is as late as the short term forecast period that confidence in the model solutions improve and a more solid decision on severe weather probabilities can be made.

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