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Analysis of the 22-23 July 2006 Extreme Heat In San Diego County

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Introduction

One of the hottest days in recent San Diego County history occurred on 22 July 2006. Nine daily record high temperatures were set (plus one which tied the record). This includes three all-time record high temperatures, and an additional location tying the all-time record. On the same day, eight stations reached daily highest minimum temperatures. This unusually hot weather covered the entire county. San Diego Lindbergh Field (KSAN), a coastal site, reported a high temperature of 99 degrees (F), which has not occurred since 9 October 1994 (Fig. 1). Anomalous heat covered other parts of Southern California, including the Inland Empire (an inland valley), the Coachella and Imperial Valleys (in the lower deserts west of KIPL), and most of Orange County (west of the Inland Empire). 23 July 2006 was sharply cooler near the coast, with maximum temperatures 10 to 20 degrees lower than on 22 July 2006.

Mesoscale model output depicting the analysis for the hottest day (22 July 2006) and the subsequent cooling on the following day is shown from the locally-generated Workstation-WRF model. The Workstation-WRF is a 4-km (approximately) horizontal resolution model (NMM/Non-hydrostatic Mesoscale Model core) covering a domain from just west of Point Conception to the northwestern extent of the Gulf of California (Fig. 1). The national WRF model sets the initial and boundary conditions. The model run time of 0000 UTC 22 July 2006 was used in this analysis for the daytime period on 22 July because forecasters could use this output as early as around 2:30 AM (shortly before the issuance of the midnight shift zone forecast product). The 0000 UTC 23 July 2006 run time was used for the daytime hours on 23 July 2006.

Synoptic Pattern

Strong high pressure aloft covered the western United States. 500 mb heights exceeded 600 decameters at the center of the high over northern Utah (Fig. 2) at 1800 UTC 22 July 2006. 500 mb heights exceeding 597 dam extended from southern California to Montana. Salt Lake City, Utah had the highest 500-MB height (599 dam) recorded among all their 1200 UTC soundings between 1998 and 2006, while the 500-MB heights at other stations in the southwestern United States were between the 91st and 97th percentile for 1200 UTC July soundings. East to southeast flow occurred over most of the southwestern United States between 850 MB and 300 MB, including the Miramar (KNKX) sounding at 1200 UTC 22 July 2006 (Fig. 3) near San Diego. The flow was bringing in moisture aloft, mainly between 700 MB and 500 MB, and resulted in scattered to broken cloud cover over most of the southwestern United States. A weak inverted short wave had moved west through southern California, resulting in isolated thunderstorms and somewhat enhanced cloud cover, which helped to keep nocturnal temperatures high. Also, the Miramar sounding showed a low-level inversion which was surface-based (more like a desert nocturnal inversion) and not elevated (like marine inversions usually are). Summer days when the inversion is surface-based are often anomalously hot near the Pacific coast.

Temperatures aloft were unusually high, above 30 degrees C over most of southern California, Nevada and Utah (Fig. 4). While this almost always results in a very hot day over inland parts of southern California, this is not necessarily the case near the coast as strong inversions (especially those with bases above the surface) can result in below-normal temperatures despite abnormally high temperatures and heights aloft. For example, on 8 July 2002, the high temperature at KSAN was 72 degrees F (22 degrees C), yet the 850-MB temperature at Miramar (0000 UTC 9 July 2002) was 84 degrees F (29 degrees C), and the 500-MB height was at its highest recorded value between 1998 and 2006, 599 dam. However, a temperature inversion with a base of 480 meters above sea level occurred that morning (1200 UTC 8 July 2002) in the Miramar sounding (Fig. 5). This elevated marine inversion had an inversion strength of over 12 deg C between the base and the top of the inversion. This value is much stronger than the normal inversion strength for summer of around 8 degrees C (Small, 2006), and also much stronger than any other time of year.

Mesoscale Analysis of 22 July 2006 (Peak Heat)

Atkin and Dandrea (1998) stated that during summer heat events in coastal southern California (July-September), subsidence is the most important ingredient for record heat, versus foehn-type winds flowing from the mountains to the coast. In the case of the 22 July 2006 heat, mesoscale dynamic subsidence occurred over the coastal waters, causing compressional heating below 900 MB to force the marine inversion to the surface. This was not the case over land, as the vertical motion was upward. Minor foehn-type winds helped to supplement the heat in the valleys of western San Diego County, but these winds did not extend to the coast.

An offshore flow pattern (where the wind trajectories were from land to sea) occurred on 22 July 2006 between 925 MB and 300 MB. This was evident on the 1200 UTC Miramar sounding (Fig. 3). The flow at 925 MB was from the north-northwest near the coast during the morning with an offshore trajectory. Fig. 6 shows the 1500 UTC output of the 0000 UTC (22 July 2006) run of the Workstation-WRF (which verified well). Temperatures at 925 MB were unusually high at the coast (34 deg. C), which was almost as high as the 36-37 deg. C readings found in the deserts. The morning sea-level pressure gradients were weakly onshore (the sea level pressure at KSAN was 4.0 MB higher at 1200 UTC than that in Imperial, a location in the desert about 100 miles east of San Diego), but the prevailing wind at the coast was from the northwest (with light east winds occurring in a few locations).

Fig. 7 shows the 2100 UTC output of the 925 MB wind and temperatures from the same 0000 UTC Workstation-WRF model run. This showed a strong surge of southeast flow in the deserts, typical of a summer-monsoonal pattern which often brings scattered thunderstorms to the mountains and deserts of southern California. That surge was strong enough to cause easterly winds over the mountains of Riverside and San Diego County and the adjacent valleys to the west, effectively acting as a foehn-type or downsloping wind. There was a convergence at 925 MB in southwestern Riverside County; not surprisingly, thunderstorms formed there in the afternoon. The 925 MB temperatures were slightly higher on the west slopes of the mountains versus on the east slopes, something seldom seen during a summer afternoon. Near the coast, north to northwest flow continued to parallel the coastline. This kept the afternoon sea breeze surface-based and weak. When the temperature peaked at 99 degrees F at San Diego Lindbergh Field, there was actually a west wind occurring, which displays how ineffectively a sea breeze can cool the land surface when the marine inversion is surface-based.

Strong dynamic subsidence over the coastal waters can best be seen in Fig. 8, a Workstation-WRF cross-section extending west to east across the northern San Diego County coast (the geographical location of the cross section can be seen in Fig. 9). The coastal waters subsidence extended to near the surface at Points A and B, bringing warm air from aloft almost to the surface. At 850 MB, impressively high omega values of 8 microbars per second were being modeled for 2100 UTC 22 July 2006 by the Workstation-WRF over Point B, just off the coast. Subsidence dominated the region just inland from the coast (Point C). Further inland along the coastal mountain slopes (Point D), strong upward vertical motion occurred, with omega values stronger than -20 microbars per second in the 850-700 MB layer.

Mesoscale Analysis of 23 July 2006 (Rapid Coastal Cooling)

Despite similar heights, temperatures and wind flows above 850 MB, 23 July 2006 was sharply cooler in coastal areas of extreme Southern California than on 22 July 2006. The maximum temperature at San Diego Lindbergh Field was only 83 degrees F (a decrease of 16 degrees) and at Brown Field (near the Mexican border about 10 miles from the coast) only 91 degrees (a decrease of 19 degrees). Most locations in western San Diego County (coastal and valley locations) were 10 to 20 degrees cooler than on 22 July. The surface wind pattern was substantially different as a weak coastal eddy had formed, resulting in southerly winds near the coast. Southerly winds occurred during 10 of the 12 hours from 0200 UTC to 1300 UTC (7:00 PM to 6:00 AM PDT) 23 July 2006 at Lindbergh Field, with wind speeds of 5 knots or greater during 8 of those hours. These southerly winds continued throughout most of the day on 23 July. In contrast, southerly winds did not occur at all between 0200 UTC and 1300 UTC 22 July 2006 at Lindbergh Field.

Fig. 10 shows the sounding for Miramar at 1200 UTC 23 July 2006. A surface-based inversion continued that morning, again more typical of a nocturnal inversion in the desert than of a coastal marine layer. The sounding showed easterly or southeasterly winds of 10 knots or greater at every level (mandatory or significant) from 878 MB to 250 MB. The 850-MB temperature was 30 deg C, even higher than at 1200 UTC 22 July. This is ideal for hot conditions over the mountains and deserts of southern California; however, whether or not the heat extends west to the coast depends more on the low-level flow.

Fig. 11 shows the Workstation-WRF predicted winds for 1500 UTC 23 July 2006. Easterly winds were occurring over the region at 925 MB, unlike the northerly winds seen 24 hours previously. Easterly winds are typical during the latter stages of a heat wave or Santa Ana wind event but do not appear to reliably indicate the end of a heat wave. However, the Workstation-WRF projected winds at 925 MB for the afternoon (2100 UTC 23 July 2006, Fig. 12) tell a different story. South to southwest winds were projected at that level for all coastal locations and southern and western parts of the Inland Empire. The 925-mb flow plus the coastal eddy at the surface allowed cooler marine air to move onto land.

The Workstation-WRF projections of the cross-section of omega and wind (Fig. 13) at 2100 UTC 23 July 2006 (using the same baseline from Fig. 9) shows that the subsidence just inland from the coast (Point C) had ended below 850 MB. Therefore, the subsidence heating that occurred near the coast 22 July was unable to materialize on 23 July. The strongest upward vertical motion still occurred over the coastal slopes of mountains (just east of Point D), but the compensating downward motion over the coastal waters (Points A and B) was weaker and did not extend as close to the surface. This can be seen via the -1 -ubar/s contour. This allowed an inversion to develop above the sea surface. In fact, an inversion had formed with a base at 359 meters above sea level in the afternoon 0000 UTC 24 July 2006 Miramar sounding (Fig. 14).

Conclusions

Some of the keys for getting a heat wave at the coast appear to be the positioning of the subsidence and the low-level wind flow, as well as a surface-based nocturnal inversion. For the anomalous coastal heat of 22 July 2006, the flow between the surface and 925 MB was northerly, while the subsidence was strong over the ocean and over coastal areas. The subsidence almost reached the ocean surface. On 23 July 2006, the low-level wind was from the south or southwest, and low-level upward vertical motion occurred near the coast, which allowed a cooler marine layer to develop. The inversion was surface based both mornings, though this might be because the eddy had not yet had time to elevate the inversion in the morning of 23 July 2006. However, elevated marine inversions usually bring cool weather near the coast (relative to inland areas) in summer. While high temperatures and heights at various pressure levels aloft (850 mb, 700 mb, 500 mb, etc…,) are necessary for a heat wave, they cannot guarantee anomalously hot conditions near the coast as they occurred on both 22 July and 23 July 2006.

References

Atkin, D.V. and J.A. Dandrea, 1998: Composite Maps of Selected Warm Events in San Diego. Western Region Technical Attachment No. 98-09. http://newweb.wrh.noaa.gov/wrh/98TAs/9809/index.html

Small, I., 2006: Forecaster's Handbook for Extreme Southwestern California Based On Short Term Climatological Approximations: Part I - The Marine Layer and Its Effect On Precipitation and Heating. NOAA Technical Memorandum NWS WR-277
http://www.wrh.noaa.gov/wrh/techMemos/TM-277.pdf

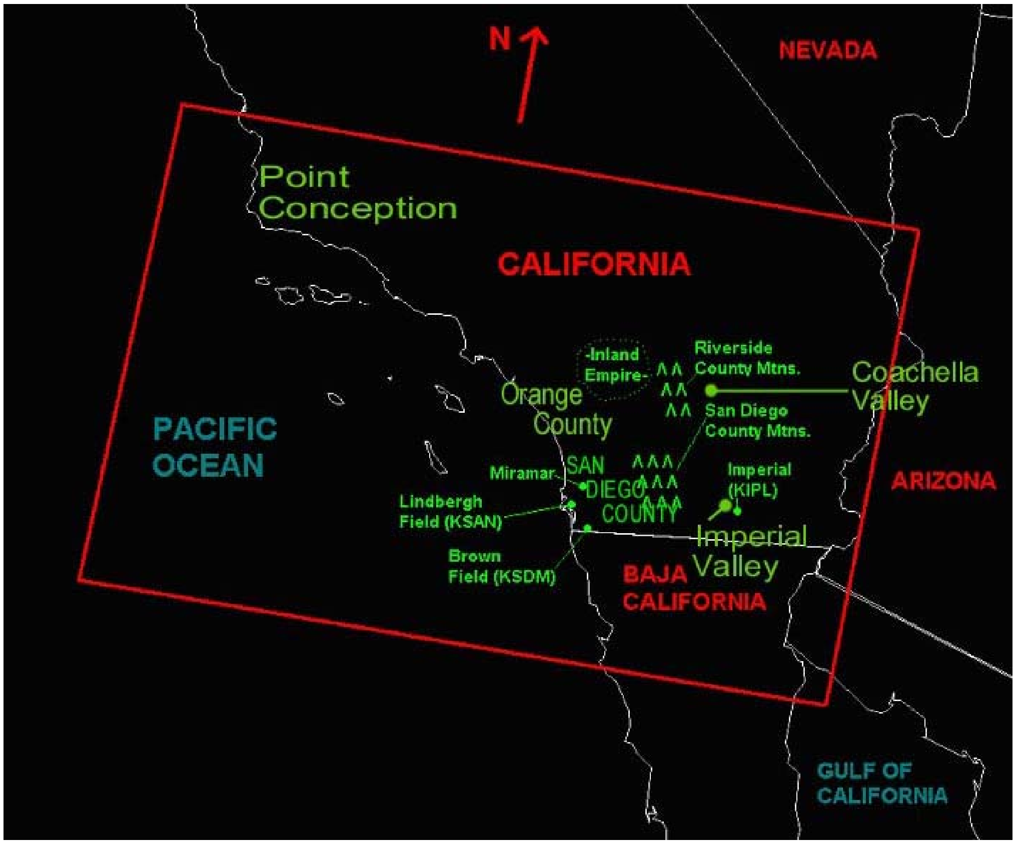

Fig. 1. Map of southern California and Northern Baja California. Also shown is the domain covered by the 4-km resolution Workstation WRF (non-hydrostatic).

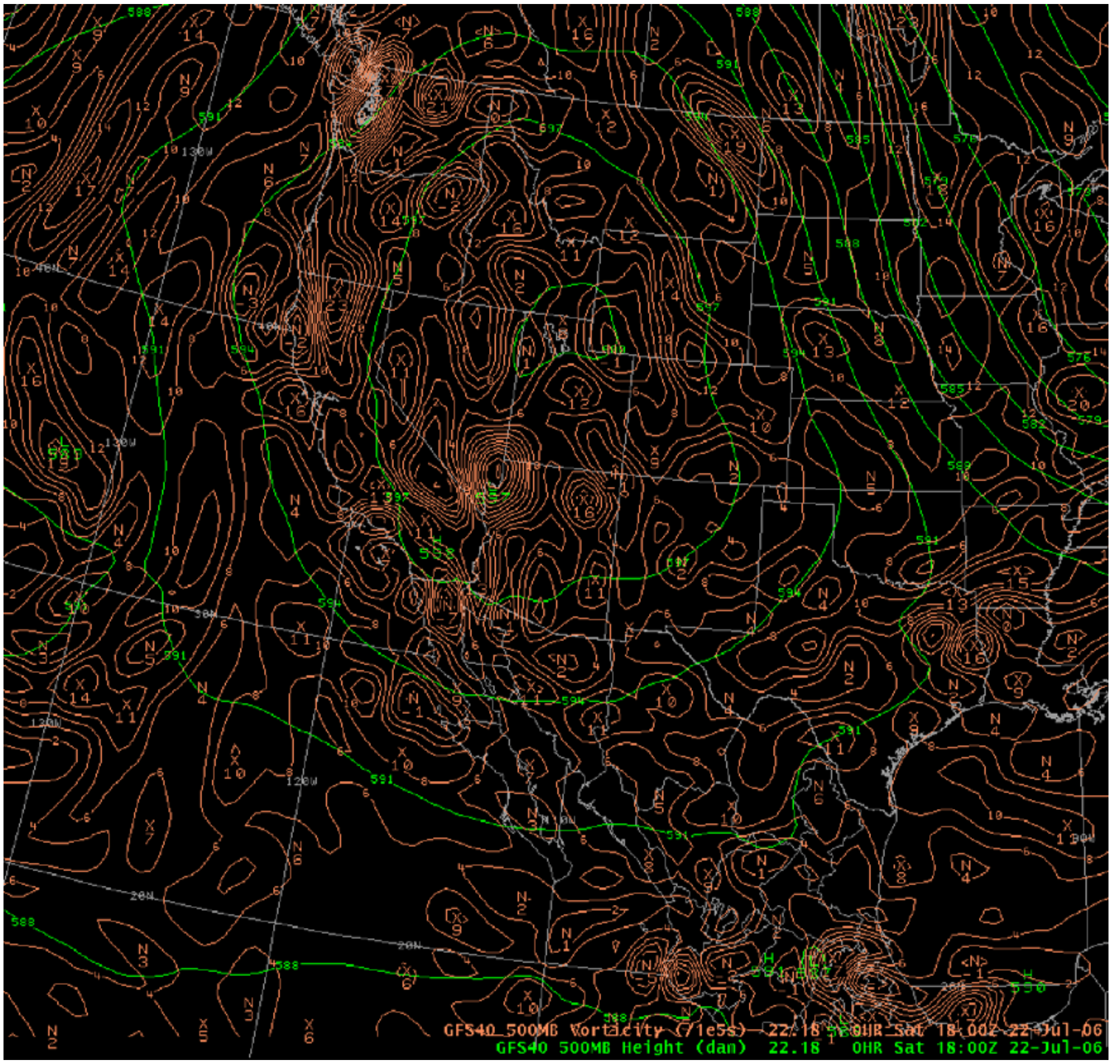

Fig. 2. 1800 UTC 22 July 2006,GFS 500 MB heights (green, in decameters) and vorticity (orange, s^{-1}).

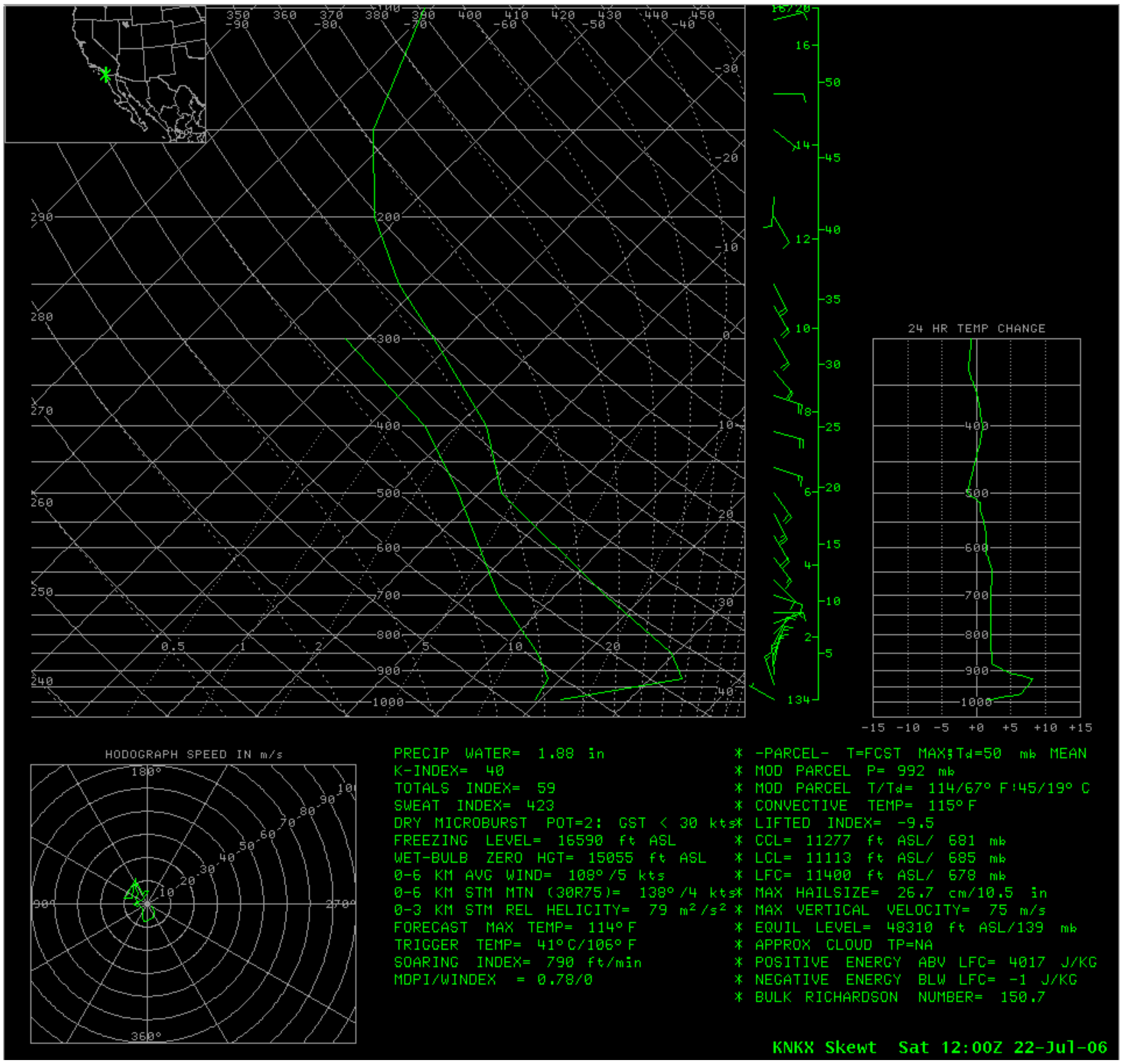

Fig. 3. 1200 UTC 22 July 2006 Miramar sounding (KNKX).

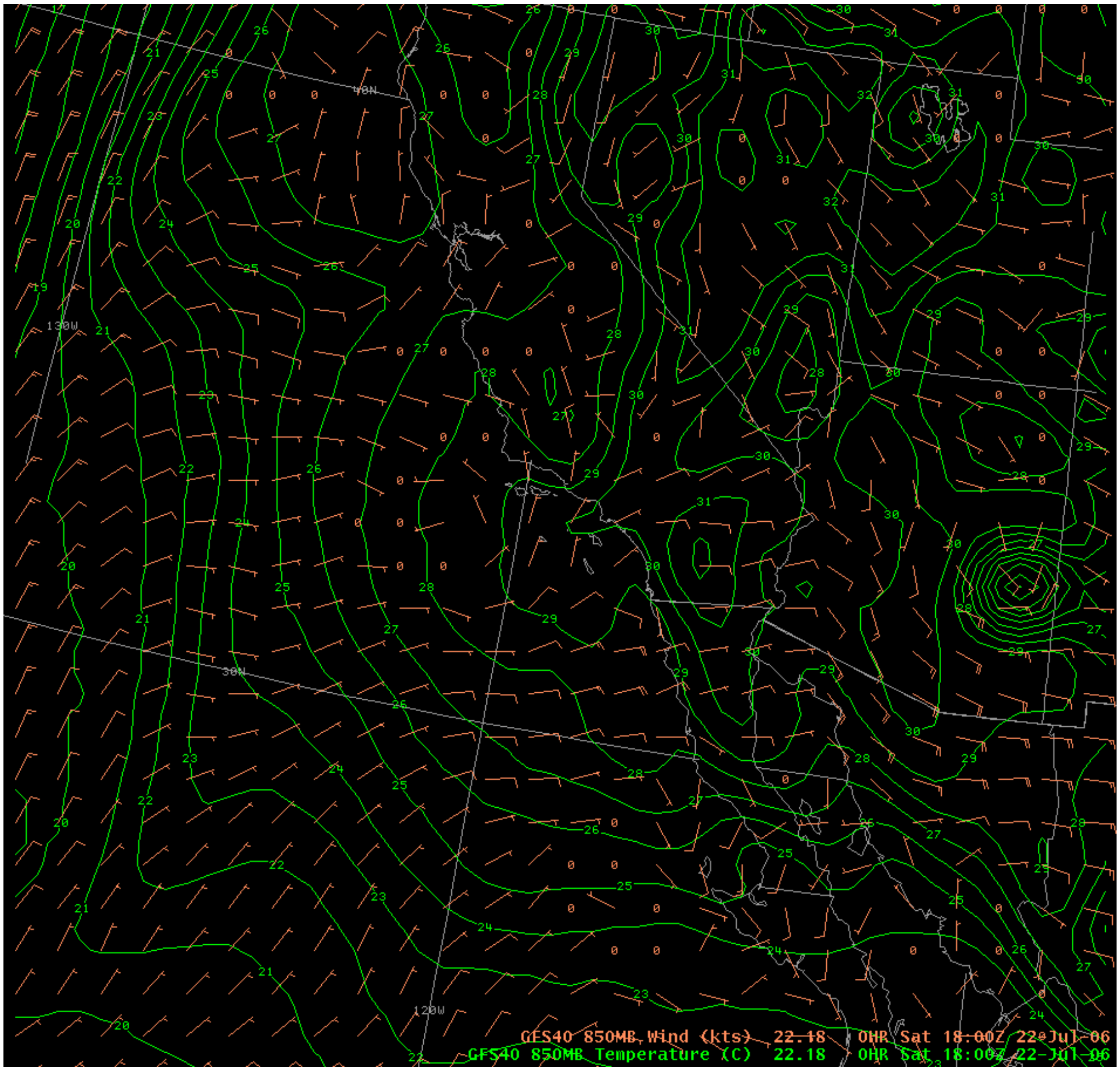

Fig. 4. 00 hour GFS 850 mb temperature (degrees C) and wind (in knots) valid at 1800 UTC 22 July 2006.

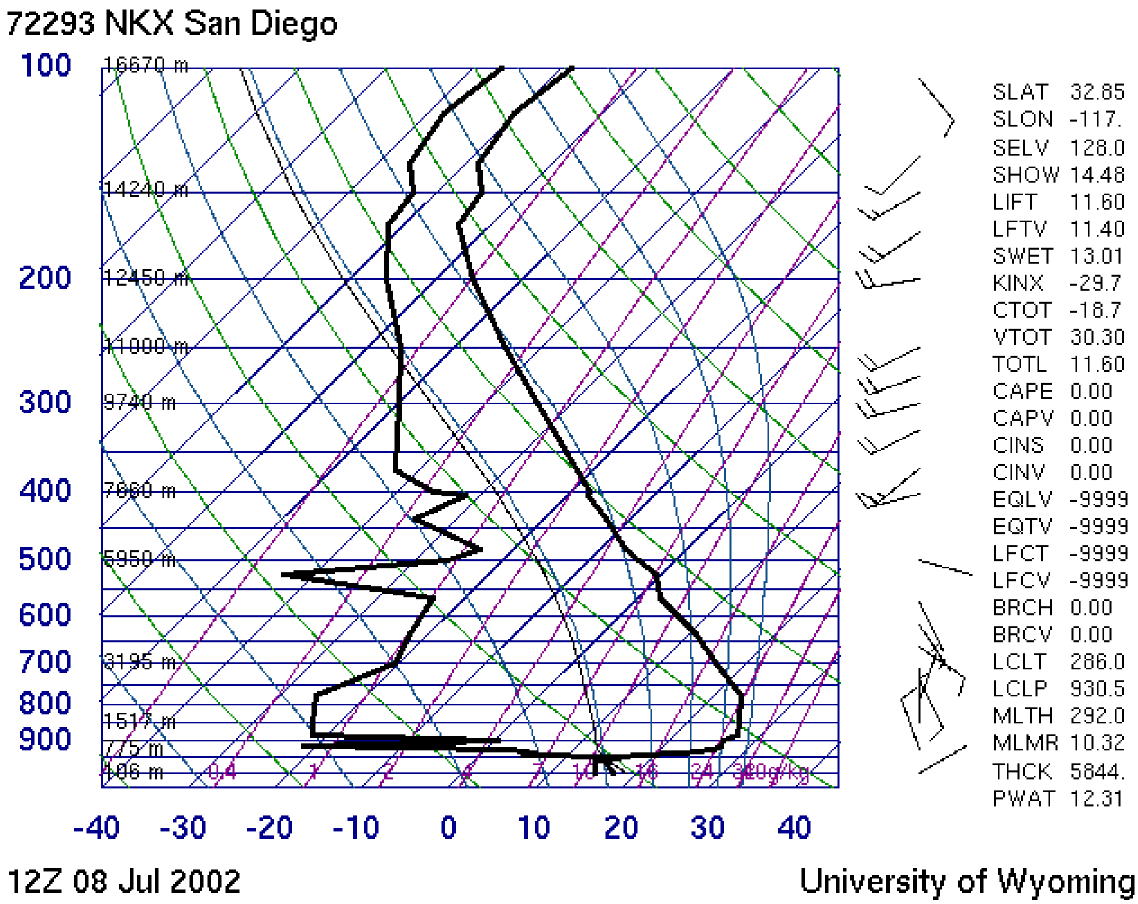

Fig. 5. 1200 UTC 08 July 2002 Miramar sounding (KNKX).

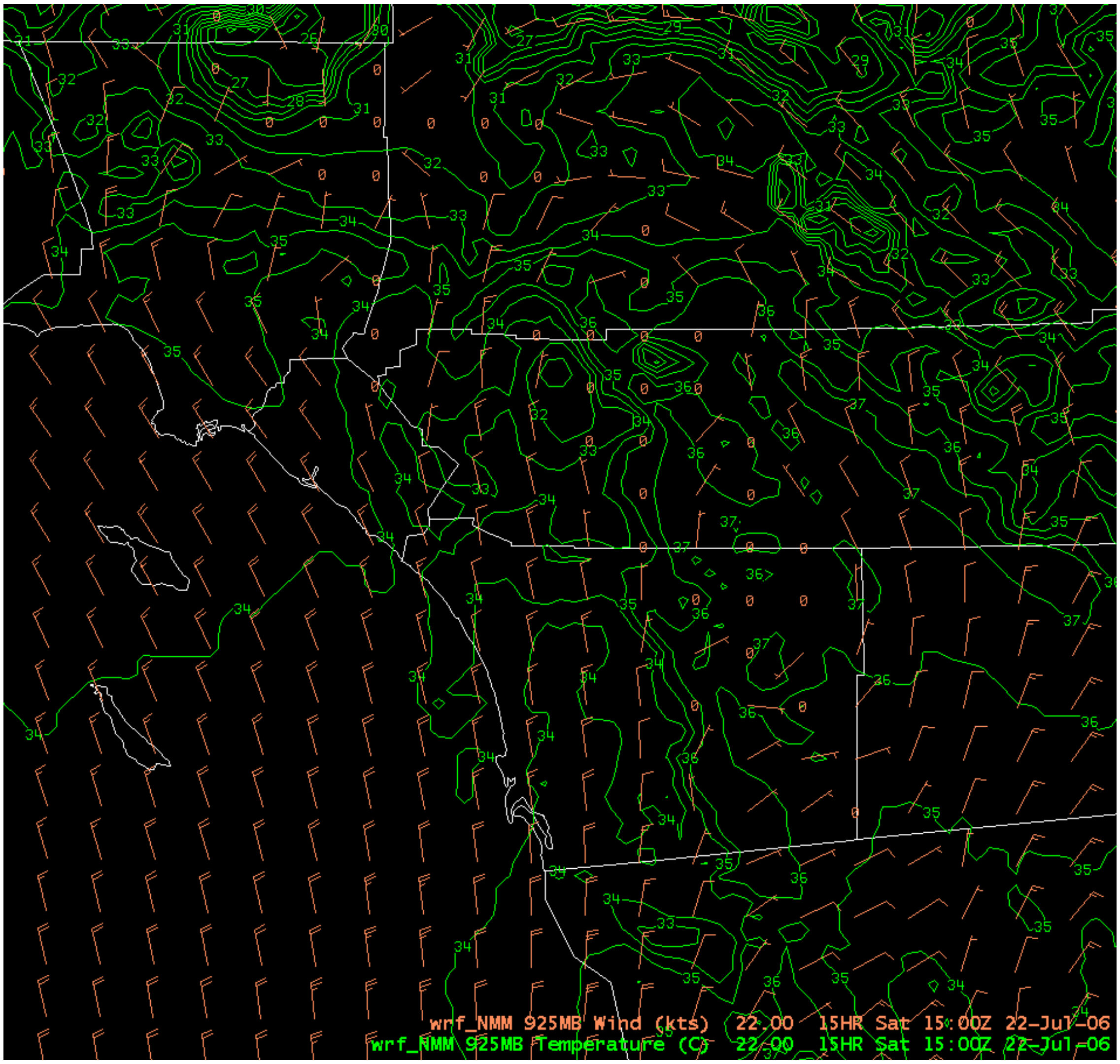

Fig. 6. 15 hour Workstation WRF 925 mb temperature (degrees C) and wind (in knots) forecast valid at 1500 UTC 22 July 2006.

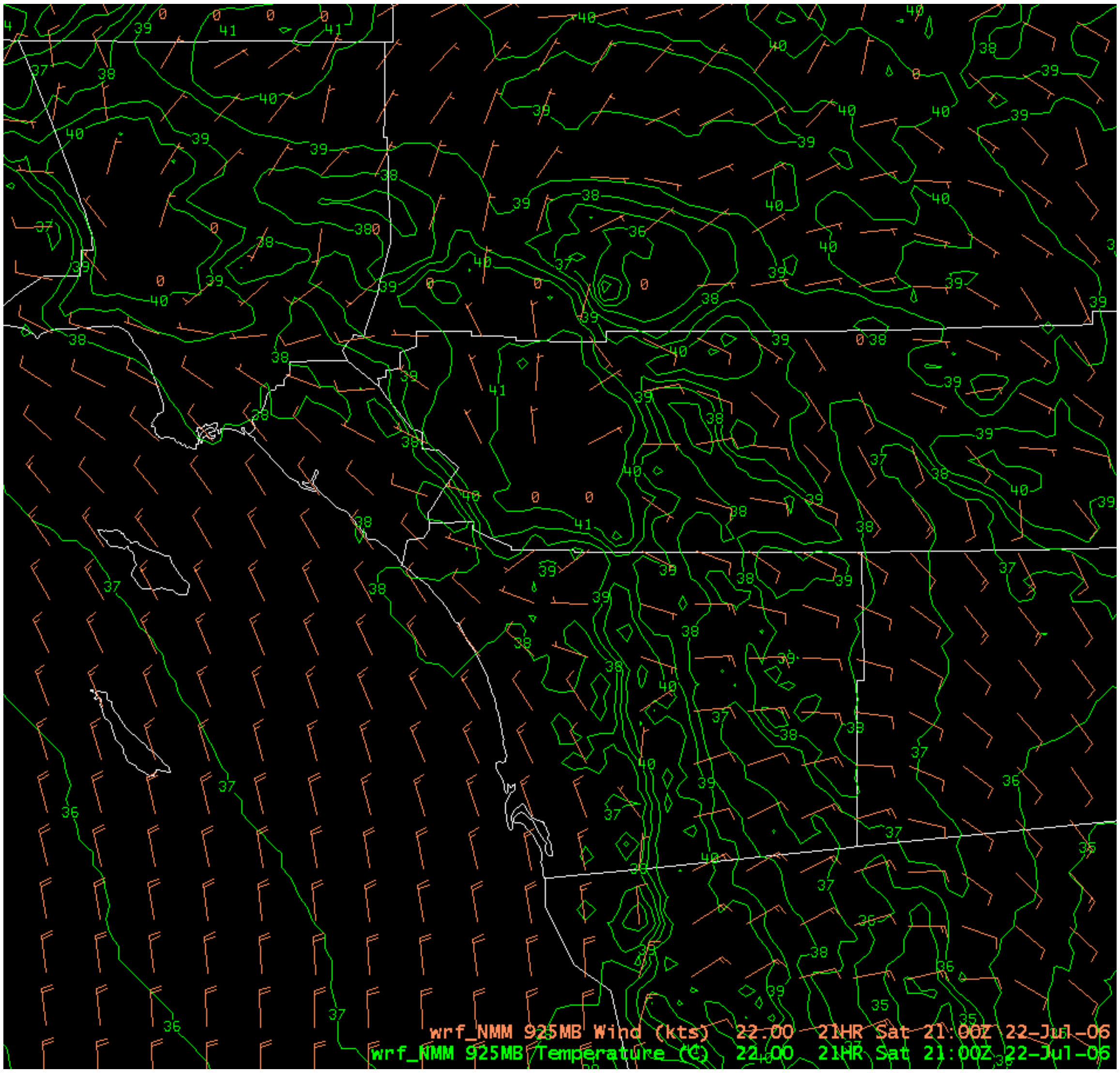

Fig. 7. 21 hour Workstation WRF 925 mb temperature (degrees C) and wind (in knots) forecast valid at 2100 UTC 22 July 2006.

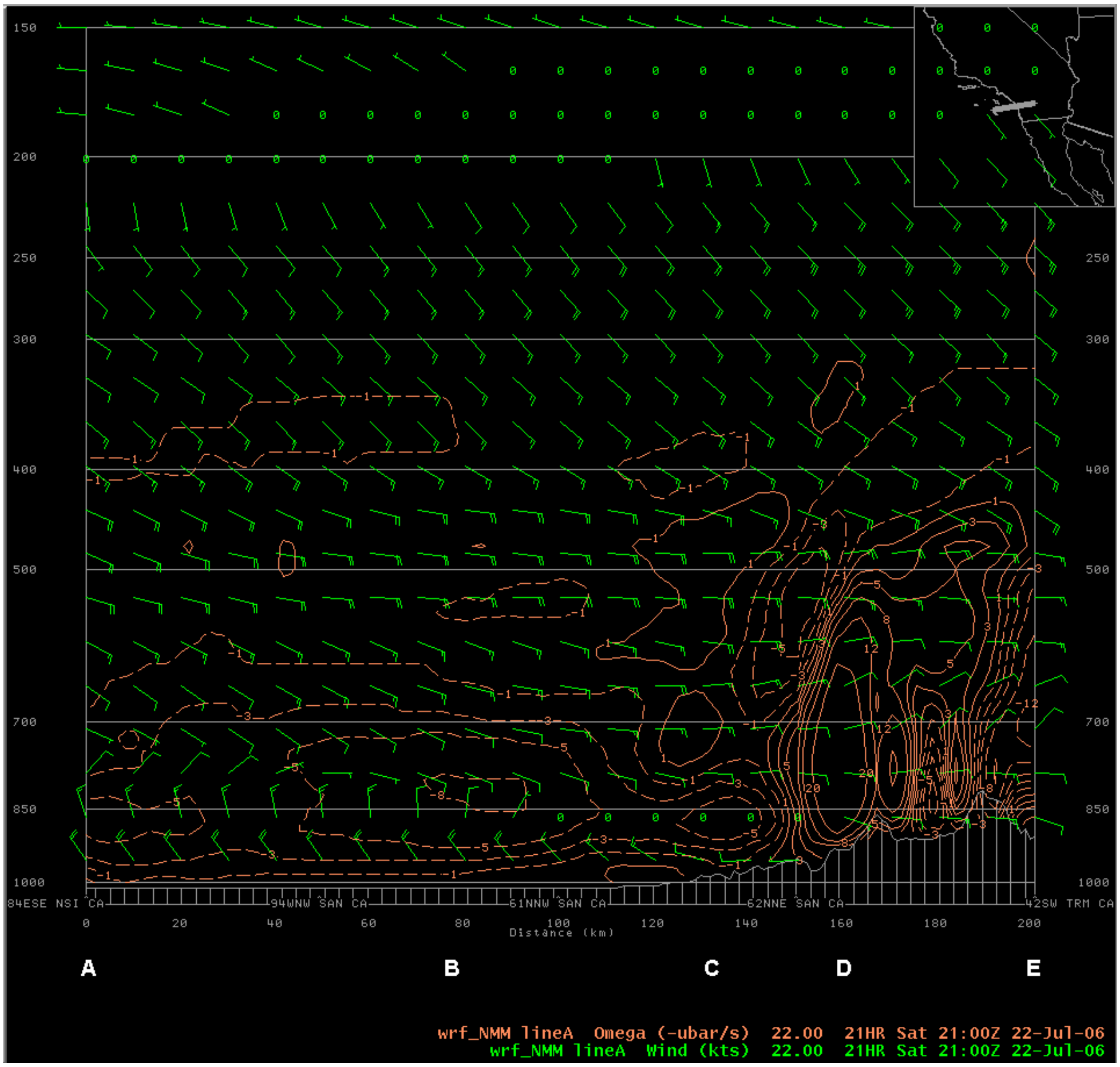

Fig. 8. 21 hour Workstation WRF 925 mb wind (knots) and omega (-ubar/s) forecast valid at 2100 UTC 22 July 2006.

Fig. 9. location of the cross section used in Fig. 8.

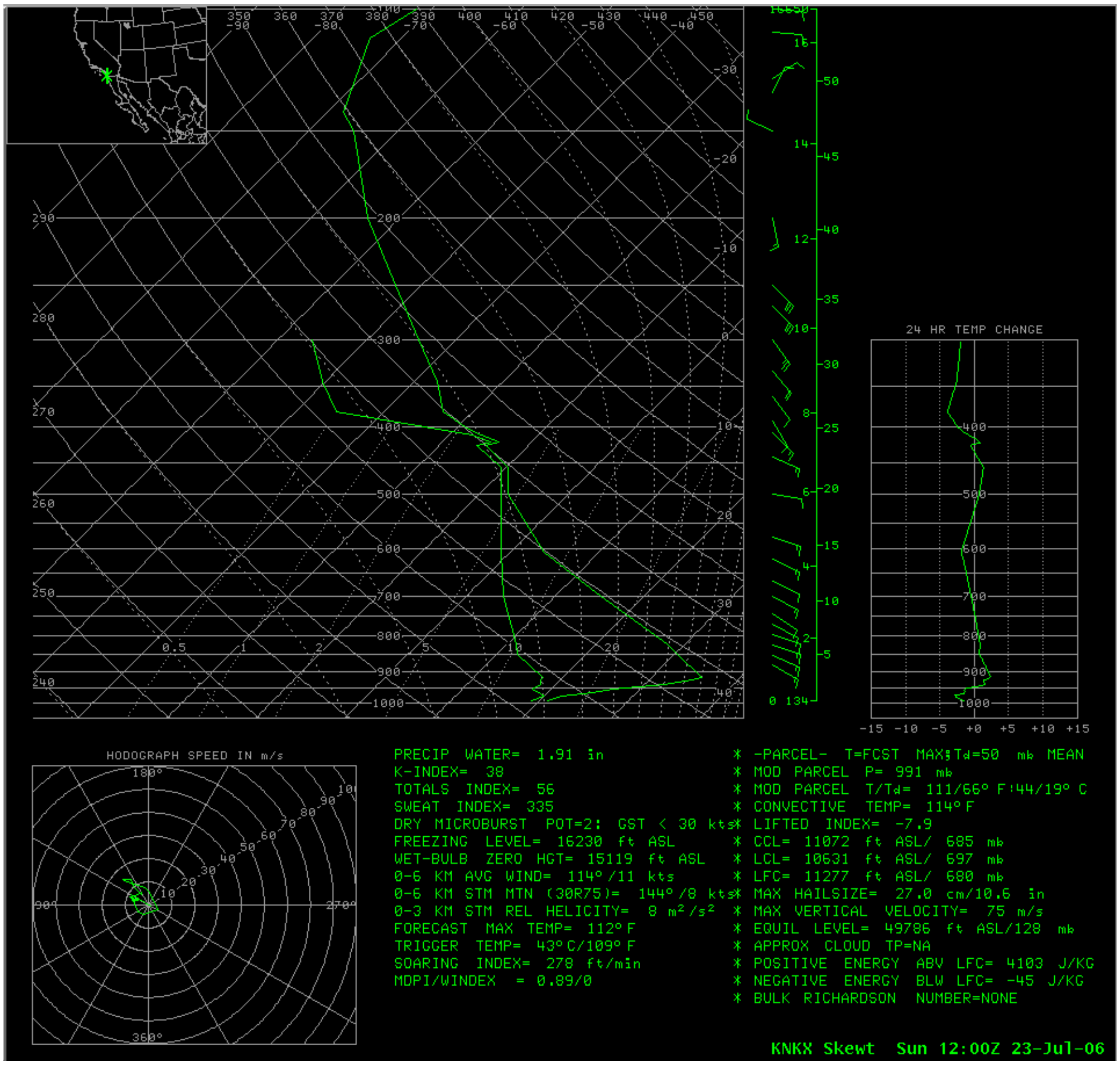

Fig. 10. 1200 UTC 23 June 2006 Miramar (KNKX) sounding.

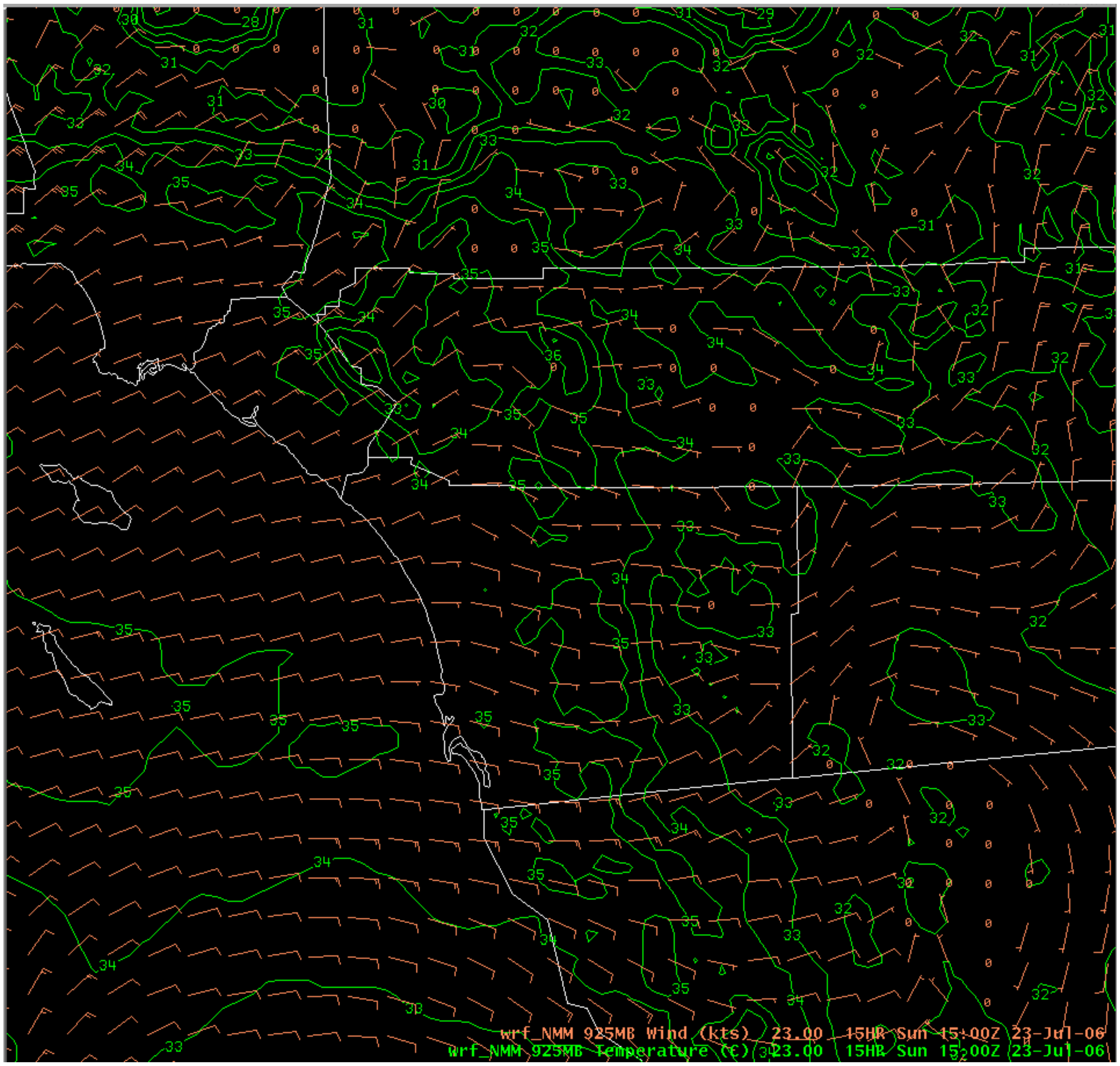

Fig. 11. 15 hour Workstation WRF 925 mb temperature (degrees C) and wind (in knots) forecast valid at 1500 UTC 23 July 2006.

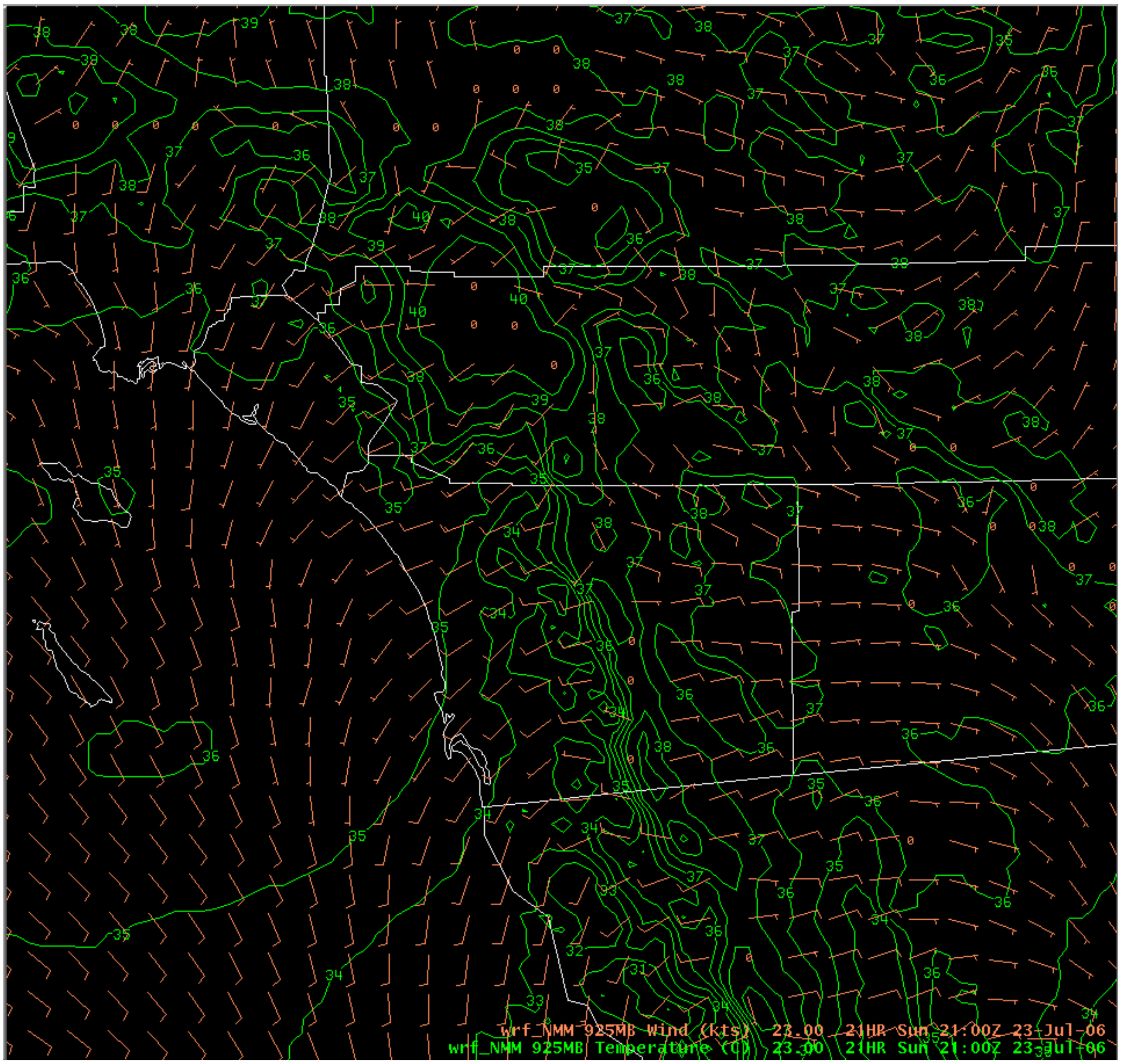

Fig. 12. 21 hour Workstation WRF 925 mb temperature (degrees C) and wind (in knots) forecast valid at 2100 UTC 23 July 2006.

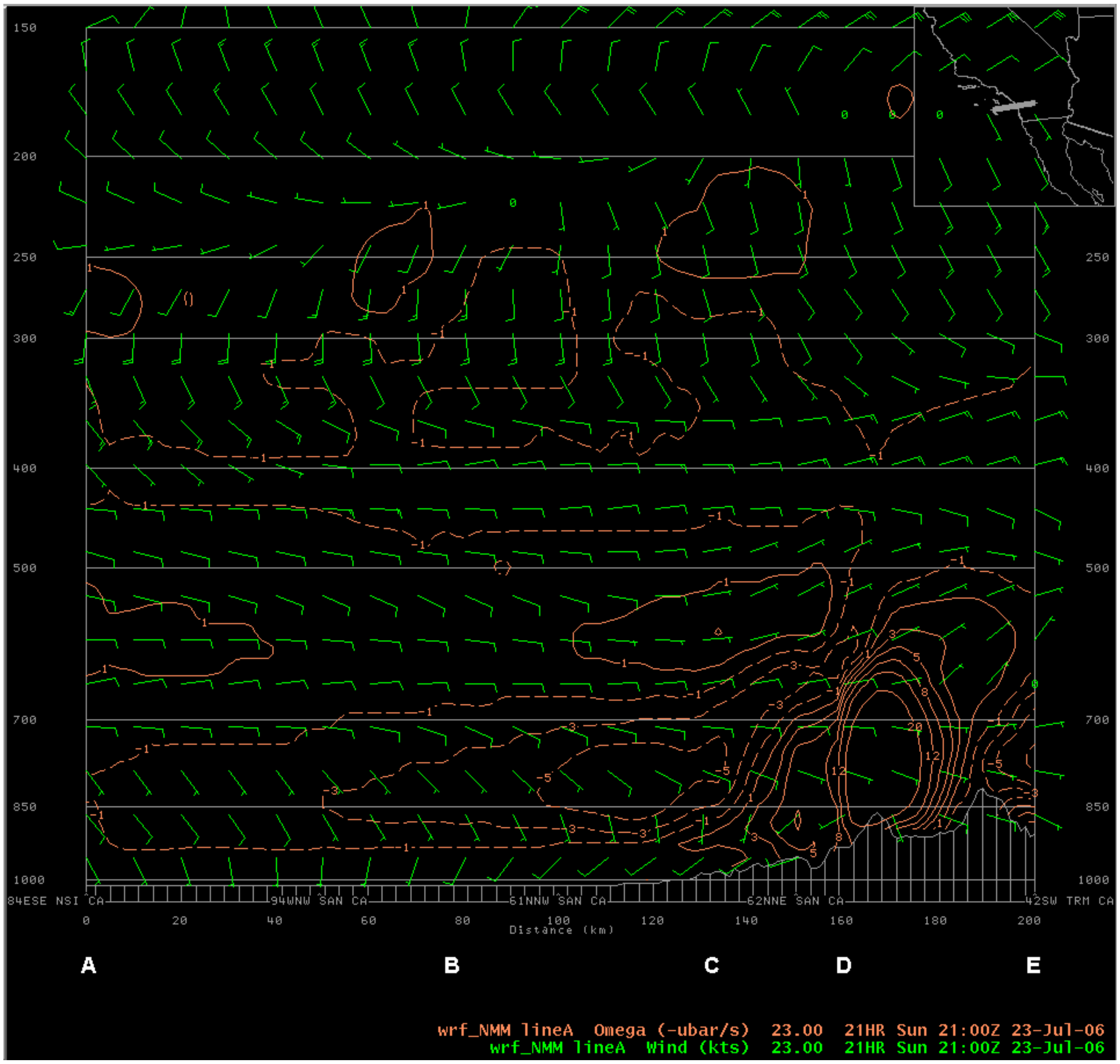

Fig. 13. 21 hour Workstation WRF 925 mb wind (knots) and omega (-ubar/s) forecast valid at 2100 UTC 23 July 2006.

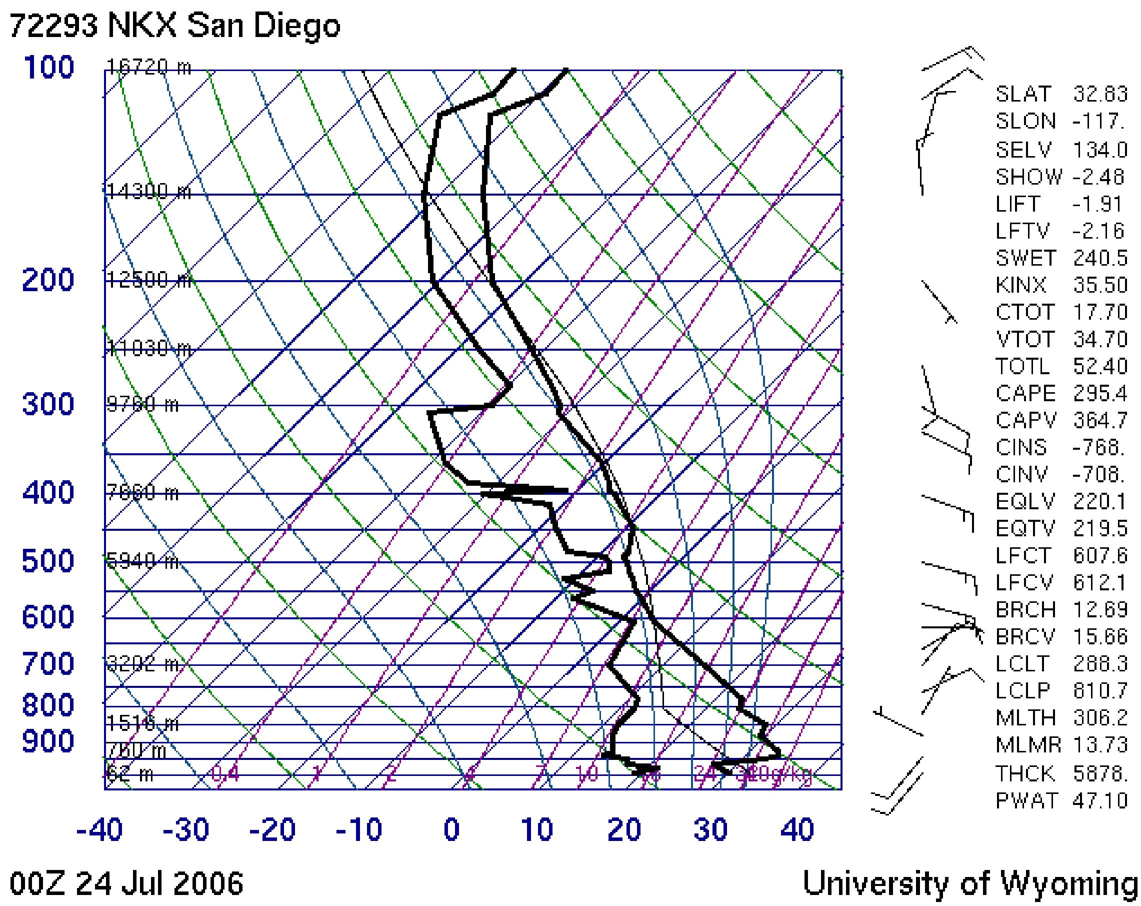

Fig. 14. 0000 UTC 24 July 2006 Miramar sounding (KNKX).