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FORECASTERS HANDBOOK FOR EXTREME SOUTHWESTERN CALIFORNIA BASED ON SHORT TERM CLIMATOLOGICAL APPROXIMATIONS

PART II –WIND EFFECTS ON TERRESTRIAL AND MARINE ENVIRONMENTS

Ivory J. Small
NATIONAL WEATHER SERVICE SAN DIEGO CA.
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DEPARTMENT OF COMMERCE
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David L. Johnson, Assistant Administrator
for Weather Services

and is approved for publication by
Scientific Services Division,
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Delain A. Edman, Chief
Scientific Services Division
Salt Lake City, Utah

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ABSTRACT

The varied terrain of southern California and its proximity to the Pacific Ocean results in many unique forecast challenges. Therefore unique approaches to diagnosing and forecasting weather conditions in this area are necessary. The purpose of this Forecaster's Handbook is to present a variety of approaches to not only better understand the meteorological processes involved in the area, but to somehow connect them to methods of forecasting for the area. A key component of this study is to employ short term climatological approximations (STCA). Data sets of generally less than 10 years are found to at least give a reasonable approximation of conditions expected with certain meteorological parameters. Forecaster hints are "quick and dirty" guidance for the forecaster to get an initial idea of the types of weather occurrences that are possible for certain parameters, and more information is embedded in the discussions. Also for more detailed information the references can be consulted. Examples of the different types of events are included. (Of course, this information is to be supplemented with computer model guidance). Although not totally comprehensive, it is hoped that this information helps to increase understanding of the phenomena that occurs in the extreme southwestern corner of our nation and helps to improve the ability to forecast them.

1. INTRODUCTION

Synoptic scale windy conditions (sustained 20 mph or higher) are often generated in southern California (Fig. 1), especially during the winter. During the cool season, the low level jet associated with frontal systems can sweep through the area and create strong winds in mainly the mountain and desert areas, below canyons and passes, and occasionally along the coast. Surface high pressure building in to the north typically results in strong, cool winds. It can be coupled with synoptic scale high pressure aloft and mesoscale subsidence (mountain wave/downslope flow) resulting in very low dewpoints for very dry conditions. In these cases the winds can be found in the north-south passes in the northern portion of the forecast area. Sometimes lowering of the jet can be seen in the sounding as an inversion, which can develop in westerly flow as well as easterly flows (fig 2). This inversion can help strengthen a mountain wave, and the drying winds can help erode the marine layer. With the surfacing of the winds in the coastal regions, temperatures can be the warmest in the nation (especially during the winter), and some January coastal record highs are higher than those found in many other southern tier states (Table1). Another aberration in southern California is the fact that numerous sites in southern California [for example Campo (KCZZ) and Ramona (KRNM)] have lower minimum temperatures in December than in January. This is also a deviation from many other sites in the rest of the country. The annual peak in dry flow in December (with associated low dewpoints resulting in low minimums) and the warming affects of cloud cover and rainfall in January (resulting in higher minimums) may be responsible for this.

If the surface high develops to the east [further south over the plateau region of Nevada and Utah (the plateau region of Nevada and Utah is also known as the “Great Basin”)], then a more northeast to east wind develops. The east-west passes will then become very windy, and generally there is less widespread wind along the coast. The switch to northeast almost ensures strong drying to values at or below 40 % relative humidity at the surface. If the winds blow long enough to dry out the airmass (typically by day 2 of an event) the relative humidity can reach the lower teens and even single digits, resulting in a significant firestorm threat. The strongest winds typically develop well before the very low (15 percent) or extremely low (10 percent) relative humidity values occur.

A major challenge in forecasting strong wind is the flow direction aloft and whether the wind will “surface” or remain aloft. The strength of the cold air advection can help determine how widespread a wind event will be. Events with weaker cold advection generally result in mountain wave winds remaining on the ridgelines and lee side slopes, with possibly some localized gusty winds in/below passes and canyons. Strong cold advection tends to allow the winds to spread off the mountains into the lower elevations just about anywhere (even into areas away from canyons and passes and on either side of the mountains). Southwest and northeast are the wind directions for waves in the Cajon Pass area (near DEV) northward since the flow is perpendicular to the mountains. East and west are the best wind directions for waves south of the Cajon Pass since easterly or westerly flow is nearly perpendicular to the mountains south of the Cajon Pass. When the wind is northerly, determining whether a strong wave will surface west of the mountains is very tricky. Just a small difference in wind direction could mean the difference between calm conditions and high winds at times. The wind can be “too northerly” or “too easterly” to surface with the ferocity that the upper level support would suggest. (Upper level support is the height gradient, temperature gradient, thickness gradient, flow speed, and subsidence). The strength of the wind aloft for the same wind direction for 2 different wind events might also be a factor, since with the same northerly flow direction, a very strong wind aloft can briefly drop to the surface, but weaker winds aloft with the same wind direction may not. Sometimes very strong flow will develop in the north-south direction, but only localized strong winds reach the surface at the lower elevations. This can be especially problematic in the Inland Empire. There can be night time cold pooling with plummeting temperatures, which may make it tougher to surface the winds in some locations. At other times or in other nearby areas temperature are held up via mixing if the wave surfaces and remains at the surface in those nearby locations. Even trickier still is if there is intermittent surfacing of the wind aloft (a common problem with northerly flow), temperatures can fluctuate more than 20 degrees F in an hour. It is not uncommon to have calm conditions and temperatures in the 20s in the upper deserts and inland valley locations (for example APL, KVCV, Hemet (KHMT), and Ramona (KRNM), calm conditions and temperatures in the 30s in wind protected coastal and valley areas (for example KOKB and KCNO), nearly calm conditions with temperatures in the 40s along much of the coastal strip (for example, KSNA and KSAN), and temperatures in the 50s at windy, exposed areas below passes and canyons (for example, KRAL). Oceanside (KOKB) is in an area prone to weak, cold drainage flow and is often the coldest coastal site when the winds cannot surface there. KOKB can be colder than many inland valley locations. On some occasions the winds become calm, with plummeting temperatures in areas of efficient cold pooling during the night, followed by a dramatic increase in temperatures as the wind surfaces. The night and morning periods can easily result in such rapid temperature increases, even in the middle of the night. During the warmer times of the year, typical overnight minimums coastal slopes westward during a Santa Ana Wind Event might be 20 to 30 degrees F warmer than the values stated above, with upper 60s and 70s in the foothills and exposed, windier coastal and valley areas. Under extreme conditions, overnight lows west of the mountains can be in the 80s to lower 90s much of the night (if not all night).

Some of the surface highs that move into the Great Basin can be rather dry, especially when the offshore flow (in part due to the surface pressure gradients from the coast to southern Nevada) approach 10 mb [for example, from Los Angeles to Tonopah (KLAX – KTPH]. This can easily result in relative humidities falling into the teens, and possibly into the single digits. To help illustrate some of the relative humidity variations related to winds, a graph showing a comparison between the MesoEta Model 0000 UTC 850 mb relative humidity at Ontario (KONT), the MesoEta Model 0000 UTC 950 mb relative humidity at Ontario (KONT) and the 1600 local standard time surface relative humidity at Devore (DEV) is used. The data is for <u>all MesoEta 850 mb wind speeds and directions at KONT</u> for the period July 2003 – June 2004 out of 288 available days. There were 83 days fitting these criteria. Another graph shows a comparison of the MesoEta Model 0000 UTC 850 mb relative humidity at Ontario (KONT) and the 1600 Local Standard Time surface relative humidity at Devore (DEV) at the base of Cajon Pass, for 850 mb wind gusts of 20 mph or more from any direction. (There were 45 days fitting these criteria between July 2003 and June 2004). Devore (DEV) and Fremont Canyon (FMC) are near 1500 feet MSL, the approximate level of the foothills, (the “especially fire prone” areas). Another graph shows a comparison of the MesoEta Model 0000 UTC 850 mb relative humidity at Ontario (KONT) and the 1600 local standard time surface relative humidity at Devore (DEV) for 850 mb winds with an easterly component of any size. There were 26 days fitting these criteria. “Red Flag Conditions” are when either relative humidity values of 10 percent or less occur for 10 hour, wind gusts to 35 mph with relative humidity of 15 % or less occurs for 6 hours, or sustained winds of 25 mph with relative humidity of 15 % or less occurs for 6 hours. If the humidity and wind speed conditions do not meet the duration criteria, then conditions are better described as “Near Red Flag Conditions”. "Near Red Flag Conditions” for the first 2 descriptions (relative humidity of 10 percent or less, or wind gusts to 35 mph with relative humidity of 15 % or less) are analyzed via a graph of 2 curves. One curve shows the number of occasions when the relative humidity [at Devore (DEV), at approximately 1500 feet MSL in the Inland Empire at the base of the Cajon Pass] fell to 10 percent or less (a total of 257 occurrences). The other curve on the graph shows the number of times that wind gusts of 35 mph occurred in conjunction with relative humidity at DEV of 15 percent or lower (a total of 81 occurrences). In the comparison between events involving relative humidity alone versus conditions involving both relative humidity and strong wind, the conditions with relative humidity and strong wind have been the most volatile conditions for firestorms in the past. These are essentially 2 levels of threat that can be considered “extremely dry conditions” and “very to extremely dry conditions augmented by strong winds”. These conditions are analyzed via graphs in the section on “offshore flow events”.

During the warm season, strong winds are normally southwest to northwest and confined to the afternoons and evenings in the mountains and deserts. During the occasional warm season offshore flow event, rapid temperature jumps can occur mid morning as winds surface, and record high temperatures are a good bet. Because of the lowered dewpoints and overnight “cold pooling”, it is not uncommon to have record low minimum temperatures set on day 1. Due to the continued overnight mixing and the subsidence, record high minimums and maximums can be set on day 2. When the wind drops off, even a more widespread episode of low temperatures (possibly even a frost or freeze) can occur on day 3 (more often during and near the edges of the cool season). During the cool season a big offshore pressure gradient trend (-5.0 mb or so during a 24 hour period) to the plateau is usually a drying flow, and mountain temperatures can plummet into the teens. Also during the cool season, with the stronger storms, strong winds generate large ocean wind waves, which can propagate toward the coast, create large swells, and finally reach the shore as high surf and strong rip currents (one of the most deadly features of southern California weather). During the warm season swells from large southern hemisphere storms can reach the coast, and hurricanes and tropical storms off the southern California coast can also send in high surf and swell. These factors, in addition to others, will be explored in upcoming sections.

2. OFFSHORE FLOW EVENTS

2.1. GENERAL CHARACTERISTICS OF OFFSHORE FLOW

Strong offshore flow events can develop in several ways. The most common upper air patterns are shown in figure 3;

TYPE 1. Gradient Wind Event (Light winds aloft/little upper support above 850 mb)
TYPE 2. Progressive Open Wave in Northwest or Northerly Flow (Positively tilted progressive upper level trough or nearly horizontally tilted upper level progressive trough)
TYPE 3. Cyclonic Northeast flow (Upper low, typically near the Mexican Border)

Examples of the different pattern types can be found in Appendix A. During the summer the Pacific High becomes rather strong just west of North America. During late summer and early fall the high begins to weaken somewhat (but still remains rather strong), and repositions further south. At the same time the sagging jet stream across the Pacific Northwest strengthens, and troughs/lows dive further south, even reaching the plateau region of Nevada and Utah. The contrast between the cooler air behind the early season cold fronts diving into the plateau and the rather warm Pacific high off the southern California coast creates a strong pressure gradient, with offshore flow in the form of strong northerly to easterly winds.

During a typical offshore flow event, offshore wind (basically flow from land to sea) begins by developing in the favored areas. These favored areas (from approximately KONT south) are the Cajon Pass area northeast of KONT, Banning Pass near BUO, Santa Ana Canyon/Fremont Canyon area near FMC (spreading southwest to the coast near Huntington Beach and Newport Beach), and Campo (KCZZ) in the south. There can even be high winds and dense fog in opposite portions of a valley zone early in an event (with winds in the favored areas) during the pattern shift with possibly some low clouds hanging on tenaciously at the coast. Wind speeds of 40 mph with gusts to around 60 mph are rather common for moderate events. Events with wind gusts in the 100-125 mph range occur about once per year, and occasionally twice in a year. Patterns for offshore winds can be quite variable in both time and space. During the weaker events there is a dominant diurnal cycle. During these weaker events in the desert areas there seems to be a mid-day maximum in the offshore winds as the overnight pool of cold to very cold air finally mixes out when the winds surface. A typical speed is 15 mph with gusts to 25 mph. Well to the north, the winds often shift to the northeast at KSDB, followed by Devore (DEV), Riverside/Arlington (KRAL), Fremont Canyon (FMC), then finally descend into the coastal areas near Santa Ana/John Wayne Airport (KSNA) and Huntington/Newport beaches. During most events the winds show up later (possibly much later) at Ontario (KONT) than at KRAL. During some events (or portions of an event) the wind can blow rather strongly from the northeast at KRAL but remain weak or never show up at all at KONT (especially events where the flow aloft is more “northerly” in direction, which can be rather gusty). In the southern half of the forecast area, the winds usually begin in the mountains near Campo (KCZZ) and spread to Ranchita (RAN) and Julian (JUL). Winds can be especially strong in the Pine Valley area northwest of KCZZ. On occasion the wind spreads to Oceanside (KOKB) and Carlsbad (KCRQ) in the northern coastal areas, and the Brown Field (KSDM) and Imperial Beach (KNRS) sites in the southern coastal areas of San Diego County. Due to this wind, temperatures and clouds can be very different for locations only a few miles apart. Where the wind surfaces, it can keep temperatures up all night or result in a rapid rise along with clear skies, while in other areas it can remain much cooler, and even cloudy or foggy. In the valley areas the winds follow a cycle that has a local maximum that occurs sooner than that of the deserts (and sooner than at the coast as well), especially for weaker events. With northeast winds, the wind surfaces below the canyons and passes in the inland areas and spreads out into the valleys before they develop at the coastline. (Surfacing occurs at the coast last during northeast flow). The strongest winds typically develop during the late morning (at around 1600 UTC) corresponding to the most active convective “mixing out” of the morning cold pools/inversions. The “mixing down” of the winds is likely to be easier in the areas from the mountains westward than in the deserts due to a relatively warmer cold pool and stronger northeasterly low level flow than that found in the deserts. From the coastal slopes of the mountains westward there is a mid afternoon minimum when the atmosphere is somewhat “fully mixed”, and the “gusty transfers” of momentum to the surface during this fully mixed period are less efficient than during the active mixing period associated with the mid morning hours. The sea breeze circulation and the afternoon diurnal weakening of the surface pressure gradients play a small role in the afternoon weakening in the offshore flow (but the winds in the afternoon would weaken even if there was no ocean to supply an opposing sea breeze).

Another local wind maximum is at night (possibly due more to a lessening of the forcings that weaken the winds in the afternoon). Also the overnight cooling of the airmass over the plateau continues to strengthen the pressure gradient as it approaches the typical morning peak, correspondingly strengthening the lower/mid level winds aloft, and the flow becomes strong enough to dip into and disrupt the cold pooling process west of the mountains. The natural drainage flow on the mountain slopes may also help drag the flow to the surface in spots. Strong offshore surface pressure gradients to the north (around 6-8 mb or higher at KSFO than at KLAX) supports a more widespread event. Such strong north-south gradients are associated with cold-frontal type patterns with good cold advection and subsidence to "surface" the wind [and this includes the beaches and coastal waters (especially northern beach areas such as Huntington Beach and Newport Beach). During this type of event winds actually surface along the coast first (more of a "northwest wind event"), then drop off for a while as the winds aloft switch from north to a more easterly direction. There might be a little rainfall with these events, but northerly flow is not a favored wind direction for significant rainfall (far less favorable than southerly flow). During the events with weak upper level support [less than 20 knots at 850 mb, less than 30 knots at 700 mb, (and less than a -3.0 C temperature gradient at 700 mb KDRA-KNKX)] localized winds develop in and below passes and canyons. This can be described as more of a "gradient wind event" or "pass/canyon winds". Interestingly, even with little upper level support, gradient wind events can still produce high wind gusts in the 60 to 70 mph range, especially in the favored wind locations.

The terrain configuration in southern California shows a change in the orientation of the passes from a more "north-south orientation" in the northern areas to a more "east-west configuration" in the southern areas. The progression of the surface gradients from north-south on day 1 to a more east-west configuration on day 2 typically results in a peak in the strong winds in northern areas first on day 1 and southern areas later on day 1 or day 2. For example, a more north to northeast flow is the best direction for high winds in extreme southwest California, with the most likely locations of strongest winds in the northern areas, such as below the Cajon Pass (just east of KONT) and the Santa Ana Mountains near Fremont Canyon (FMC). A more east or southeast flow is more favorable for winds in areas such as the Banning/Beaumont area (BUO), the Keenwild/Idyllwild area in the Riverside County mountains just south of BUO, and at Campo (KCZZ) near the Mexican Border. The east-west surface wind patterns (in comparison to a northeast wind pattern) are generally less favorable for high winds in extreme southwest California (northern or southern areas). Areas in the north, (the area most prone to high winds) are likely to see a drop-off in wind speeds when the winds "go east". If there is heavy rain involved, the winds seems to be strengthened at the higher elevations (for example, across ridges), but not as strong at the lower elevations as they would be during a drier event. This is possibly related to the synoptic scale upward motion of the storm since synoptic scale downward motion is absent. When the "1040 line" (the 1040 mb surface pressure contour) crosses the northern Nevada border, placing a portion of northeast Nevada at or above 1040 mb, the wind event can be expected to be in the extreme category (assuming sufficient upper level support in the form of wind speeds, height gradients, and thermal gradient). Surface pressure values that approach or exceed 18 mb offshore KLAX-KWMC along with winds approaching 40 knots or more at 850 mb results in the strongest events. If it hasn't rained in a while, wind gusts approach 40 mph with blowing dust and local visibilities near zero can occur. As for temperature during the winter, interestingly, when the 500 mb heights reach 576 (especially with ridging overhead), to a reasonable approximation, highest coastal plain temperatures can be estimated by simply dropping the first digit (For example, highest coastal plain maximum temperatures exceed 76 for heights of 576, exceed 88 for heights of 588, etc..,), which can easily be picked off a 500 mb map. This value assumes the 500 pattern will be correct, and can give a good estimate of the high temperature without the "skewing to climatology" found in the model forecast values (especially in the extended period). The 850 mb potential temperature (found by lowering the 850 mb temperature along a dry adiabat to the surface, or by add 26-30 F to the afternoon 850 mb temperature), is a very good approximation of the expected inland coastal plain high temperature. This is especially true with the typical day 2 reduction to "wind advisory conditions" at Fremont Canyon (FMC), when gusts fall below 58 mph and the cold advection decreases. The high temperature pattern can be reversed, resulting in a "reverse heating pattern" (especially during the cooler months such as the November – April period). This reverse heating pattern develops when hotter conditions occur near the coast (as opposed to the typical patterns where highest temperatures are in the mountains, valleys and deserts). Some of the reasons for this are the mountains, valleys and deserts are closer to the cold pool of the wave that passes by to our east, there is a higher potential for strong cold advection through the passes into the valley areas during the cooler months, and there is generally slower daytime heating during the cooler months. The cold advection tempers the subsidence heating inland areas on such days. The lack of temperature inversions/clouds can result in temperatures cooling with height based on a more "adiabatic" sounding profile (steady cooling with height of about 5.5 degrees F per thousand feet). Through much of the cool season, events are more likely to be hotter coastal areas than valley areas during the first day that the winds reach the coast. During the early summer and again during the late summer coastal areas are typically cooler than inland areas with weak offshore flow events and the associated very weak cold advection that occasionally occur. On the last couple of days of an event (or during events with only weak cold advection), the temperature patterns typically return to a more "normal" pattern ("standard heating pattern"), with the hottest conditions inland as the coast cools down with the returning marine layer air.

Record low minimum temperatures, record high minimum temperatures, and/or record high maximum temperatures can be reached during the same offshore flow episode. For example, before the winds increase, the temperatures can reach record low minimum temperatures in the morning of the first day due to the initial pulses of dry air signified by fairly low dewpoints. If the winds surface and blow all night during the following night into day 2, record high minimums can be set day 2, and record high maximum temperatures can be reached during the afternoon of day 2. The dewpoints and relative humidity continue to fall, reaching their lowest values near the end of the event since the driest conditions occur slightly out of phase with the wind peak. The drying starts aloft, working its way down the mountain slopes, into the valleys, and possibly through the coastal areas and out over the coastal waters. This lag time usually means that by the time the strong winds begin the decrease, the relative humidity reaches its driest values.

There is a good correlation between the initial 00Z MesoEta model 850 mb relative humidity at Ontario Airport (KONT) and the actual 1600 local standard time relative humidity at Devore (DEV), both in the Inland Empire. Figure 4 shows a comparison (preliminary) between the MesoEta Model 0000 UTC 850 mb relative humidity at Ontario (KONT) the MesoEta Model 0000 UTC 950 mb relative humidity at Ontario (KONT), and the 1600 local standard time surface relative humidity at Devore (DEV). The data is for <u>all wind speeds and directions</u> for the period July 2003 – June 2004 out of a possible 288 available days. There were 83 days fitting these criteria. The 00Z MesoEta model surface relative humidity was not included in the graphic. This is because only Ontario (KONT) area data (lower in the valley near 900 feet MSL) is available, and it shows much wetter values than what would be seen if model data was available for DEV (near 1500 feet MSL). Figure 5 shows a comparison of the initial MesoEta Model 0000 UTC 850 mb relative humidity at Ontario (KONT) and the 1600 local standard time surface relative humidity at Devore (DEV) <u>for 850 mb wind gusts of 20 mph or more from any direction.</u> There were 45 days fitting these criteria. Winds without an easterly component most likely keep the airmass more moist and possibly account for values more toward the right of the graph. Some of the days might be reflecting a wind shift from dry easterly winds to strong west winds, but the recovery to higher relative humidity values lag behind the wind shift. Figure 6 shows a comparison of the initial MesoEta Model 0000 UTC 850 mb relative humidity at Ontario (KONT) and the 1600 Local Standard Time surface relative humidity at Devore (DEV) <u>for 850 mb winds with an easterly component of any size</u>. There were 26 days fitting these criteria. There is a good match between the two graphs for values 25 – 30 percent and below. For model relative humidity values over 30 percent the model relative humidity is somewhat higher than the actual Devore surface relative humidity. Note that there are no 850 mb relative humidity readings above 45 percent at 0000 UTC with an easterly wind component at 850 mb.

Figure 7 shows the number of occasions when at least “near red flag criteria” based on atmospheric conditions (relative humidity of 10 percent or less, or wind gusts to 35 mph with relative humidity of 15 % or less) were met. Fuel moisture is not considered. The red graph with diamonds shows the number of times the relative humidity [at Devore (DEV), at approximately 1500 feet MSL in the Inland Empire at the base of the Cajon Pass] fell to 10 percent or less (a total of 257 occurrences). The red curve shows a preference for near red flag warning conditions to be met based on relative humidity alone at about 1500 local standard time at DEV. The blue graph with circles shows the number of times that wind gusts of 35 mph occurred in conjunction with relative humidity at DEV of 15 percent or lower (a total of 81 occurrences). The blue graph shows a somewhat earlier preference of around 1000 - 1400 local standard time with a peak of 4 occurrences at approximately 1300 local time. This is partly due to the mid morning to early afternoon wind peak, which seems to occur before the relative humidity reaches its lowest point. (During a wind event the wind will typically peak before the relative humidity reaches its lowest point, both on a 24 hour scale and during the course of the wind event). Basically, it was far more common for relative humidity values of 10 percent or less to develop than it was for the combination of relative humidity at or below 15 percent with wind gusts to 35 mph to occur (257 incidences versus 81 incidences). It is probably more common for the 15 percent/35 mph threshold to be reached earlier in the day since the winds are likely to be stronger then. This shows that, at least for the afternoon, it is more likely to reach criteria due to single digit relative humidity values than it is for conditions to fall to 15 percent relative humidity in combination with 35 mph wind gusts at DEV, with a midday peak in occurrences.

The surface dewpoint depression and hence dewpoint can be reasonably approximated from the temperature and relative humidity during rather dry days (45 % relative humidity or lower) by using a simple formula. The dewpoint depression at the surface can be approximated by subtracting the relative humidity from 65, (which, interestingly enough, is the baseline used to calculate “degree days”).

Approximate dewpoint depression in degrees F = 65 – relative humidity in degrees F (1)

Similarly, the relative humidity can be estimated from the temperature and dewpoint;

Approximate relative humidity in percent = 65 – dewpoint depression in degrees F (2)

For example, during the Southern California Firestorms of 2003, the 1400 UTC 26 October 2003 observation at KONT indicated a temperature, dewpoint and relative humidity of 82.4 degrees F, 33.8 degrees F, and 17 % respectively. An estimated relative humidity can be determined via equation 2 by subtracting the dewpoint depression from 65;

Approximate relative humidity = 65 – (82.4 – 33.8) = 16.4 % (3)

The formulas work best for dewpoint depressions between 10 degrees and 55 degrees. (Estimated values tend to be too “dry” for dewpoint depressions below 10 degrees and above 55 degrees F). In addition to being rather dry, these wind events can result in marked overnight warming in the “thermal belts” between 1500 and 4000 feet near the top of the inversion. Low temperatures in the 70s, and occasionally in the 80s are possible during any month of the year, especially if the inversion top temperature is in the 70s or higher. The development time of strong wind during many events is late night in the mountains, reaching the valleys by mid morning, and the coast and deserts by late morning. If the event is more frontal in nature, it can surface almost instantaneously with the front in the deserts and progress along with the front. Another common start time, (for example, if there is a persistent marine layer during the morning through mid afternoon hours west of the mountains), is late afternoon, early evening, and late evening respectively for the mountains, valleys, and coast. Events rarely begin mid afternoon, but often end mid afternoon. During weaker events the wind may make it to KRAL and might make it to FMC, but not reach the coastal areas. During even weaker events it blows in mountain passes such as DEV, BUO, and CZZ, with no wind at KRAL in the mid-valley areas.

The ending time of a wind event of around mid afternoon is rather common. Some events end mid morning. (During events that end mid morning the winds fall off late afternoon of the first day, and do not rise much the following morning as the upper level support moves east). There is a lag time between the peak of the strongest winds, and the best combination of very dry conditions and strong winds. This lag time is approximately 2 hours. This occurs because the period with strong winds <u>and</u> lowest humidities will generally lag behind the period of strongest winds. It takes the relative humidity of the airmass longer to fall to very dry values, and longer to recover (return to a more "normal" value) at the end of an event. Wind gusts to 35 mph along with relative humidity of 15 percent or less can be considered to be "strong winds with very dry to extremely dry conditions". Any wind speed with relative humidity of 10 percent or less can be considered to be "extremely dry conditions". At the end of an event the dry/windy conditions generally end at the coast first then progress inland. The wind speed minimum in the desert is late night (which can result in temperatures dropping rapidly in the dry air during cold pooling). The minimum in the coastal and valley winds is mid afternoon, but there will sometimes be a late night lull. The "morning blast" of winds show up a few hours later in the deserts compared to the valleys at times (partly because it takes a while to scour out the colder air in the deserts). There is a similar delay at the coastline partly due to the time it takes to scour out the morning marine layer air.

The winds during a typical offshore flow event generally peak with the cold advection, then transforms from the "upper level support" stage to more of a diurnally driven "gradient wind" stage. This occurs as the upper level winds driven by dynamics and thermal gradients aloft (upper level support) weakens and/or moves east, starting the "gradient wind stage". Interestingly, the strongest surface pressure gradients from the coast to the plateau are often out of phase with the strongest winds. During many strong to very strong events the surface pressure gradients peak <u>***after***</u> the wind begins to fall off over southern California since the "upper support" may have moved out of the area by the time the surface pressure gradients peak. Therefore, it is important to time the strongest winds with the strongest combination of upper level support <u>**and**</u> pressure gradient rather than just the strongest pressure gradients for the stronger events. During gradient wind events (weaker events, or toward the end of an event), it is more likely for the winds to follow a "typical" diurnal wind cycle ("mid to late morning peak pattern"), with the strongest winds during the mid to late morning hours of the day along with or just after the strongest surface pressure gradient occurs. Temperature patterns respond in a similar fashion. The day when offshore winds at the coast peak and the cold advection is sufficiently strong in the interior, coastal area high temperatures also peak, and are higher than those inland. This is found the first day of an event. On the second day, if the upper level support and high pressure aloft moves inland, the highest temperatures at the coast fall slightly while a weak sea breeze returns. This results in coastal highs being surpassed by the continued rise in high temperature values at the inland sites. If the upper level support and high pressure aloft are still over the coast, the highest temperatures at the coast still rise a degree or so over the previous day. On day 3, as the high moves east and surface pressure gradients trend onshore, all areas cool, except the deserts, where day 3 temperatures may be as high as day 2 temperatures. A variation on this pattern is if the upper level high is nearly quasi-stationary and overhead. In that case, temperatures may rise everywhere through day 3, before the delayed marine layer recovery period ensues. Record low minimum temperatures due to dry morning airmasses, and record highs due to mixing down of the airmass probably occur less in the fall since offshore flow events are so common (especially in the fall when “firestorm season” peaks. During these times the upper level Pacific High, still very warm, strong and residing just offshore, can nose in to raise the temperature, lower the humidity, and increase the wind). The summer months and the edges of the cool season may have an elevated probability of breaking high temperature records during strong offshore flow events since offshore flow events are less frequent.

2.2 FORECASTER HINTS – OFFSHORE FLOW

a. Peak wind gusts in extreme southwestern California (most likely a mountain site or just below a major mountain pass) are approximately 2 times the highest 850 mb wind speed on the KDRA sounding (or the KNKX sounding if it is stronger than the KDRA wind). This is especially true for 850 mb wind speeds between 20 and 50 knots. This is also true for the Vandenberg (KVBG) sounding as long as the 850 mb jet at Vandenberg eventually shifts south over extreme southwest California.

b. The sustained wind at KONT will often match or slightly exceed the upwind 700 mb wind on the Desert Rock sounding (KDRA) for 700 mb winds of 25 knots or more from the northeast during the windstorm peak.

c. For stronger events the winds peak with the strongest upper level support (downward vertical velocity, cold advection, and upper level flow) while the surface pressure gradients are still approaching their peak. For weaker events the winds surface around 1600 UTC, peaking midday, and the peak in winds occur on the day with the surface pressure gradient also peaks. Offshore winds typically show up in the mountain passes (such as DEV) first, before developing in the valleys. Offshore winds in the higher deserts (and KCZZ in the southern mountains) often develop somewhat later than the winds in the northern valleys west of the mountains, and will also have a midday peak. With a cold front, desert winds can begin before they show up elsewhere. Coastal northeast winds also tend to start later than the valleys. Conditions might be calm till 10 AM or so, then gusty winds can suddenly begin, along with low level wind shear, a rapid drop in dewpoints/relative humidity, and on some occasions a 20 - 30 degree F jump in temperatures can occur. Correspondingly, if the wind drops off a huge temperature fall can occur, especially near the coast at any time (partly because of marine air rushing in), or anywhere during the night and very early morning hours (in part due to rapid cold pooling).

d. The winds surface below Cajon Pass in the DEV area with a near neutral (near 0.0 mb) gradient from the coast to KDAG,

e. The winds usually reach KONT with a surface pressure gradient of around -3.5 mb from the coast to KDAG (or with winds around 10 knots or more between 030 and 130 degrees at 850 mb on the KNKX sounding).

f. Sustained mountain wind speeds are approximately the 850 mb wind speed in the mountains, and the 850 mb relative humidity is a reasonable estimate of the surface relative humidity when the 850 mb relative humidity drops below 30 percent or so. (The drier airmass at 850 mb seems to drop to the surface as far west as the valleys, and at times will reach the coast).

g. Strong coastal offshore winds in San Diego County surface easiest in the north county areas near KNFG and KOKB, and may surface in the extreme south near KNZY. (Also KSEE will get the northeast wind at times). Strong winds rarely surface in the coastal areas in the middle of the county, including KSAN. (If the winds drop off at night, KOKB is often the coldest coastal minimum temperature site under cold weak drainage flow).

h. Northeast winds begin in Campo (KCZZ) as soon as the KSAN-KIPL surface pressure gradient reaches +2.0 mb <u>onshore</u>, and are often the first offshore winds (and strongest winds reported) in San Diego County. Wind in the Pine Valley area some 30 miles or so north of KCZZ may actually be the area of strongest offshore winds in the southern areas.

i. High resolution model surface winds in mountain areas, for example the MesoEta model (and the WRF looks similar, but maybe a bit too strong) may be reasonably accurate estimates of sustained winds there.

j. Winds typically start out northerly, first affecting the north-south oriented passes in the northern areas. Winds aloft and gradients generally must become more easterly before the southern areas are affected with strong winds. The “wind peak” for the southern areas might be delayed till day 2 at, for example, KCZZ, since the more east-west oriented passes are prone to wind with a more easterly component, which may not develop until day 2.

k. The winds are very sensitive to the location of the mesoscale features supplying the forcing. For example, if a low cuts off ***over*** the area rather than just ***east*** of it, the strongest flow around the low may end up north and northwest of southern California, with a weaker (than expected) northerly flow developing in southwest California. If the low ends up too far west or northwest, then a northwest, west, or even southwest wind pattern can develop. If the low cuts off too far east, or south of southern California, the upper support may sweep through too fast and/or end up too far downstream. This will result in only brief, moderately strong winds that transition into a gradient wind event. (Events with support “too far east” or “too weak” may have trouble scouring out the marine layer, and may make the marine layer even more persistent if it lowers and strengthens the inversion).

l. “Upper Support” in the form of thermal gradient, height gradient, or flow speed is needed to make the difference between a gradient wind event and a very strong, mountain wave enhanced event.

m. Approximately 18 mb or more of KLAX-KWMC offshore surface pressure gradient, with about 45 knots of northeasterly 700 mb winds (or 45 knot 850 mb winds) are prone to producing sustained 50-60 mph winds (approximately 45 knots sustained winds) at Ontario (KONT). The 850 mb and 700 mb flow has to be "northeasterly enough" to surface at KONT since the winds can be too "northerly" to reach Ontario with 50-60 mph winds, but reach these speeds below Cajon Pass. The winds can also be too "easterly" for 50-60 mph winds at KONT, and instead produce such winds below east-west passes (for example, the passes in the southern areas such as KCZZ and Pine Valley (north of KCZZ).

n. "Inside Sliders" (or lows/troughs that move into the western states north of southern California and slide southward, or develop in Canada then retrograde while sliding south) can be tricky, because if they pick up moisture, a "dry inside slider" becomes a "wet inside slider". Extreme events can produce strong offshore winds, thunderstorms, and unusually low snows in the valleys, with flurries to sea level. In these cases 1000-850 mb thickness values of about 1330 and 1310 may result in snow down to 2000 and 1000 feet msl respectively, with lowest snow levels in windy areas below passes and canyons and in convection. For values below 1300, at least a few snow showers are a good bet at sea level.

o. Developing (deepening) upper level lows in north to south (meridional) flow, typically on the eastern side of a developing high amplitude ridge, often deviate from the model forecast track. Some lows that are forecast to move east through the area as an "inside slider" with west to northwest winds, may tend to develop further west than predicted by most 24 hour model runs. This can change an "inside slider moving through the area" to an "outside slider", clipping the area, with heaviest rain generally in southern areas (or remaining offshore over the coastal waters), and easterly rather than westerly flow. If the low stalls offshore, offshore winds, lower snow levels, and colder conditions than previously expected can develop.

p. During the earlier part of an event, upper support helps drive the winds. During the latter part of the event (possibly corresponding to the peak in the surface pressure gradient) the upper support drops off, and events can become weaker (especially northern areas) and are more "surface gradient driven". The strongest events are accompanied by a more "northeasterly" flow. Events are less likely to be as strong if the flow is "too easterly".

q. There can be high winds below the canyons and passes in the valleys while at the same time dense fog persists in other areas in the valleys and/or at the coast.

r. A mountain wave rotor can suddenly develop at Ontario (KONT) for very erratic winds that may shift from northeasterly to southwesterly at times. The same can occur at Palm Springs (KPSP).

s. Record low and record high temperatures can occur during the same event. Record low minimums can occur at the beginning of an event when the dewpoints are low, but the wind hasn't begun. Record high maximum and record high minimums can occur later in the event when the winds surface, mixing occurs, and an adiabatic temperature profile develops. Record low minimums, and possibly even a frost or freeze at the lower elevations can develop after a wind event if cold dry air settles over the area. This is especially true if 850 mb temperatures are negative.

t. During offshore flow events, the strong easterly flow can blow just above the stable surface layer, or the sea breeze can sneak in under the offshore flow creating dangerous wind shear. KSNA and KONT are especially prone areas for low level wind shear (LLWS).

u. The favored direction for the strongest wind events is northeast. Winds from due east may result in weaker wind events.

v. 850 mb relative humidity is a reasonable estimate of the surface relative humidity in the fire prone regions below passes and canyons as well as the mountain foothills when the 850 mb relative humidity drops below 30 percent, (and especially below 20 percent). When this low relative humidity is combined with the MesoEta model 850 mb wind forecast (and assume peak gusts of twice the sustained speed in the favored areas) an estimate of fire storm potential based only on atmospheric conditions can be made. (Fuel moisture, although not mentioned here, should be added to the results for a final assessment of fire storm potential.)

3. ONSHORE FLOW EVENTS

3.1 GENERAL CHARATERISTICS OF ONSHORE FLOW

Strong onshore flow events can occur in several ways. The most common upper air patterns are shown in figure 8;

TYPE 1. Strong Zonal Flow Patterns (strong sagging jet, possibly with north-south or east-west pressure gradients)
TYPE 2. Open Wave Pattern (upper level progressive trough)
TYPE 3. Cyclonic Pattern (cut-off upper level low)

Examples of the different pattern types can be found in Appendix B. The timing of the "surfacing" of onshore winds (generally south to northwest winds) is counter to that of offshore flow type winds (the mainly north through southeast winds). Most weak onshore winds (about 15-20 mph by mountain and desert standards) only surface over and on the eastern slopes of the mountains and eastward into the deserts. There is an afternoon peak (partially because it combines with the sea breeze flow and/or weak mountain wave flow). Like clockwork, gusts to 25 mph can be expected in many desert locations during the summer. In the morning there is upslope flow via mountain/valley circulations on mountain slopes and locally into some deserts. Southeast morning winds are especially prevalent throughout much of the Coachella Valley in the KPSP and KTRM area. There is westerly flow at night in the upper desert sites, especially away from the mountains. A sort of “onshore flow season”, or “onshore wind season” occurs in the spring due in part to the annual maximum in the surface pressure gradient from the coast to the deserts during the spring. This strong gradient helps to surface strong westerly winds in the mountains and deserts during the spring. This is the opposite of the “offshore flow season” that occurs with the annual coast to desert pressure gradient at a minimum in the fall and early winter.

During strong onshore flow, similar to weak onshore flow regimes, there is still a preference for a mid to late afternoon peak. Strong south winds favor mountain waves north of the east-west ranges in the north [in areas such as the KVCV/Apple Valley/ Lucerne Valley area, the Burns Canyon (BNY) area, and in the Granite Mountain (GAM) area]. As the winds become more westerly, strong west winds and mountain waves favor the east slopes of the north-south oriented mountains from the Burns Canyon area, (and possibly Granite Mountain area) southward to the Mexican Border, and winds slack off in the Apple and Lucerne Valleys. As the winds become northwesterly, the flow favors the region that includes the northern portion of the Coachella Valley, extending through the Pioneer Valley area just north of the Coachella Valley. The winds over and downstream of the north-south oriented mountains from the southern Coachella Valley south to the Mexican Border are weaker in northerly flow than in westerly flow since the perpendicular wind component is small.

During some strong wind events [especially those with west to northwest flow of 20 knots down to 1500 ft (can be seen on the KNTD observation at LAG PK)] a “Palm Springs Rotor” (or “Coachella Valley Rotor”) can bring significant east wind into the northern Coachella Valley, even when winds are west to northwest elsewhere. A common pattern is during a “Nevada Low”, a pattern that is characterized by a strong low pressure area developing over or near southern Nevada. At other times the troughs are fueled by either the Northwest Express (or Aleutian Express) from the Gulf of Alaska or eastern Pacific. If the flow comes from the Arctic, it is more of an “Arctic Express”. The more consistent events are when the lows are still digging or steady state as they move through, producing many of the very strong coastal wind events. Usually a strong (double digit) pressure gradient (for example KLAX-KLAS or KLAX-KTPH) with strong pressure gradient trends is involved. Double-digit 24 hour surface pressure gradient trends have produced some especially damaging events in the past.

Most patterns have an open trough or accompany a strong frontal passage. In these cases the central pressure of the low is to the north, which moves into the Great Basin, resulting in strong onshore gradients and strong onshore (southwest to northwest) flow. If the low position is altered, for example a deep surface low develops near KLAX rather than north of it, there can be a double digit *offshore* pressure gradient with south to southeast winds. These patterns can produce extremely strong winds, even in the coastal areas, especially if there is a secondary wave on the heels of the first wave. Lows that drop that far south bring east to southeast (actually offshore flow type) winds to the coastal airports. This is unlike the vast majority of the weak systems that cut off or pass by further north with only brief south to southwest winds that veer to the west with their associated fronts.

When systems dive into Nevada from the north, the northerly winds can locally bleed over and surface in the Inland Empire as “offshore flow”. Its arrival can be seen at Devore (DEV). [Sandberg (KSDB) in the mountains northwest of Lancaster (KWJF) is a good observation to watch for the wind shift from the northwest quadrant to the easterly (offshore) quadrant] which can result in offshore winds west of the mountains. Thus getting the position of the flow and the low correct can make a huge difference in the surface wind speed, direction, and the locations where the winds develop.

When the direction of the onshore flow is optimal, 850 mb winds of 25 knots, or 700 mb winds around 50 knots almost always result in at least localized mountain/desert high winds. Frequently, when the flow ranges from strong prefrontal southerly to strong post-frontal west to northwest flow, widespread coastal area wind gusts equal to the 850 mb flow can develop. This is especially true during rainstorms/postfrontal conditions in the coastal areas when the inversion is replaced by a large lapse rate, which helps the winds surface. During strong fronts, onshore winds in the coastal and valley areas seem to be strongest in the Orange County area around Huntington Beach and Newport Beach (near KSNA). Possible reasons behind the strengthening are channeling along the mountains (or barrier jet type flow), acceleration around/between the islands, or possibly even a mountain wave downwind of the islands.

As a “first guess” strong wind gusts of approximately 2 times the 850 mb wind speed develop in the favored regions of the mountains and deserts (especially for 850 mb winds that at least reach the 20-25 knot range). The location of the damaging wind is very sensitive to the direction of the winds aloft. When the wind direction becomes more northwest (at or more “northerly” than 320 degrees), the winds generally drop off in the northern deserts, but become strongest along Interstate 10 in the northern Coachella Valley and in Pioneer Valley just north of the Coachella Valley.

With fairly strong cold fronts (and usually south or southwest flow and 850 mb winds at least in the 20-25 knot range), wind gusts of 2 times the 850 mb wind speed will surface at Fremont Canyon (FMC). Occasionally 850 mb winds surface as gusts in the coastal valleys and inland valleys, but are generally associated with huge storms with heavy rainfall. For the most part, gusts are stronger near the coast than in the valleys west of the mountains during strong onshore flow. For the very strong events (about 30 knots or so at 850 mb), the coastal wind gusts can be about 1 ½ times the 850 mb wind speed, especially near the time of the frontal passage. Strong convective elements in the front/baroclinic band can develop into bow echo or strong line segments. They can occasionally “surface” wind gusts equal to 1 ½ times the 850 mb wind speed with lesser 850 mb wind speeds as a sort of combined ambient flow/convective wind gust. Long lived/steady state convective elements with 50-60 dBZ radar returns are very suspect and may surface such winds. A secondary vorticity maxima in the cold air behind a main front are notorious for this.

As for damage, if a wind event follows a period of soaking, heavy rains, or if the winds are very strong during the rain event there can be widespread property damage. Many downed trees can occur with moderately strong winds due to saturated soils. Gusts to only 30-40 mph can uproot trees in saturated soils, especially during the early part of the rainy season when some trees still have their leaves. Also power lines are vulnerable to branches falling on them. Blowing dust is a problem during drier periods and can result in freeway closures during "moderate" wind advisory conditions (generally gusts in the low to mid 40s or stronger). Big rigs and other high profile vehicles can be discouraged or even barred from using certain routes since they can be blown over, with some roads being closed altogether. Air traffic patterns can be reversed (resulting in some airports being "turned around" due to the wind direction), which can reduce the amount of allowable air traffic in and out of the "Southern California Bight Region". (The Southern California Bight Region is the highly populated coastal and valley areas of southern California west of the mountains and deserts and mainly below the 3000 foot contour. Sometimes the coastal waters between the KVBG area and the KSAN area are also referred to as being part of "The Bight"). Airports can even be closed. Flow near the mountains can result in low level wind shear along with strong up and downdrafts and severe to extreme turbulence. Fires can also be fanned by the winds. This is particularly problematic during the fall "firestorm season", characterized by the period of dry, windy weather (onshore or offshore flow) prior to the return of the Pacific storms and their moistening rains.

3.2 FORECASTER HINTS – ONSHORE FLOW

a. South to northwest 850 mb winds around 25 knots or higher, or 700 mb winds around 45-50 knots or more can result in high winds on the desert slopes of the mountains (and rather strong gusts seem to spread to the mountain ridges, even affecting the Santa Ana Mountains if it is raining or strong cold advection is present). Around 20 knots at 850 mb and 40 knots at 700 mb generally results in wind advisory conditions. The strongest onshore winds are typically with the "frontal blast" (around the frontal passage).

b. The western side of the Coachella Valley needs very strong flow (nearly 35 knots at 850 mb and nearly 60 knots at 700 mb) to reach high wind status (gusts to 58 mph). Without strong cold advection, the winds aloft are weaker, and it is tough to get high winds associated with mountain waves to spread off the mountains and into the Coachella Valley. Around 20-25 knots at 850 mb and 45 knots at 700 mb are good enough for reduced visibilities in blowing dust, and possibly wind advisory conditions (gusts to 45 mph).

c. A Palm Springs Rotor (or Coachella Valley Rotor) can bring strong ***east*** winds to Palm Springs (KPSP) during strong ***west to northwest*** flow patterns, especially if sustained winds exceed 15 knots at Point Mugu (KNTD) or wind gusts at Laguna Peak (LAG PK on the KNTD observation) approach 30 knots or more from the west. At this speed blowing dust can develop. A typical rotor will have easterly winds of about 15 to 25 mph.

d. Coastal area gusts for weak to moderate strength fronts are approximately the 850 mb wind speed, (especially during the "frontal blast"). Around 20-25 knots of 850 mb wind generates wind advisory conditions with minor damage, and as little as 25-30 knots at

850 mb can bring more widespread damage since coastal gusts approach the 850 mb wind speed. Coastal area winds are more likely to develop if there is rain at some point during the event. (Strong winds can be brought down to the surface with cold fronts and/or stronger showers and thunderstorms with such strong flow aloft). Even low end wind advisory conditions (surface wind gusts 35-45 mph) can result in uprooted trees when soils are saturated, and damage to power lines is possible from falling trees or large branches. With stronger fronts the wind gusts can approach 1 ½ times the 850 mb wind speed, and produce high winds and widespread wind damage with 850 mb winds reaching at least the 35–40 knot range. (Organized convective storms and long lived strong line segments/small bow echoes can do the same locally with only 20-25 knot 850 mb winds and 50-60 dBZ radar returns).

e. As a first approximation, mountain wave wind gusts are approximately equal to twice the upwind 850 mb wind speed, with sustained values close to the 850 mb winds forecast by high resolution computer models (such as the MesoEta) in the mountains and adjacent deserts.

f. Developing (deepening) upper level lows in north-south flow, typically on the eastern side of a developing high amplitude ridge, tend to develop further west than predicted by the 24 hour model run, with lower snow levels, colder conditions, and strong north to northeast flow instead of the northwest flow that would have occurred had the low developed further east. This is especially true if jet stream winds on the western side of the low (the “back side of the low”) are stronger than those on the eastern side of the low (the “front side of the low”). The same is true for troughs.

4. HIGH SURF AND LARGE SWELLS

4.1 SURF AND SWELL GENERATION

High surf and large swell events develop in several ways. The most common surf/swell generation types are;

TYPE 1. Strong Zonal Flow High Surf and Large Swell Pattern (strong sagging jet)
TYPE 2. Open Wave High Surf and Large Swell Pattern (upper level progressive trough)
TYPE 3. Cyclonic Onshore Flow High Surf and Large Swell Pattern (cut-off upper level low)
TYPE 4. Offshore Flow High Surf and Large Swell Pattern
TYPE 5. Hurricane/Tropical Storm High Surf and Large Swell Pattern
TYPE 6. Southern Hemisphere Storm High Surf and Large Swell Pattern

High Surf and large swell events can generally be separated into 6 types. Examples of the different types can be found in Appendix C. The first 4 types are most commonly seen during the cool season, and the final 2 types are most commonly seen during the warm season. Although most are associated with a south to northwest onshore flow, strong northeast winds below the canyons and passes can push large swell westward over the coastal waters to the offshore islands from the east and create high surf.

Cool season events are characterized by similar conditions at surf generation time. Rather large swells can be generated offshore between 25-40 north latitude and east of 150 west longitude, especially in very strong low latitude storm tracks. It can be seen via large upper level height gradients and associated strong low level flow. Many storms follow the generated swells most if not all of the way to the coast, which continues to build the seas. The swell shows up along the coast as surf. The strong upper level flow, which supports the strong low level flow, also whips up relatively long period wind waves (fresh swell) in addition to the even longer period swells at the coast. Extreme conditions result in coastal flood damage, especially with tides that are near annual maxima (around 7 feet) with high surf on top of the tide. The sum of the tide height and surf height of 14 feet or more may cause coastal flooding. The Pacific Coast Highway, which snakes along the coast from near KSLI to the Mexican Border along with other low lying coastal areas are very susceptible to both high tides (tidal overflow) and coastal flooding (high surf on top of high tides). During borderline coastal flood events rocks can be thrown onto roadways and parking lots along with water from the largest waves, and waves hitting the bottom of and washing over piers can do damage. During extreme events waves can do extensive structural damage, and it is not uncommon to have waves crashing through the windows of some coastal structures.

Warm season swells are generally from the south and southwest, and primarily consists of 2 types. Tropical storms or hurricanes within 1000 nautical miles of the southern California coast (preferably heading toward southern California) can send up large swells that become high surf at the beaches. Swells from a generation region of about 1000 miles away arrive in 2 days with an approximate period of around 12-14 seconds. Whether or not southern California will experience large swells and high surf depends critically on the speed and direction of storm movement. The most favorable situation is one in which the storm is moving at the same speed as the waves formed propagate outward. Watch for the potential of waves generated in the right front quadrant of storm propagating outward toward southern California along a great circle track, and keep a close eye on Wave Watch 3 model predictions. Wave predictions could be off considerably, if the wave energy direction is not handled well. The other source of surf and swell is energy from southern Hemisphere storms. (Storms in the eastern North Pacific are much weaker during the warm season and swell energy from the southern hemisphere can be much larger than that of the northern hemisphere storms). Southern hemisphere storms generate swells that reach southern California in around 7 days with an 18-22 second period. Because of this long period, these swells pack large amounts of energy and can generate high surf, even though actual swell heights may not be very high. Sets of surf at some isolated locations are much larger than what is reported by most of the other stations during an event since it can be amplified by local conditions (such as slope of the bottom or shape/orientation of the coastline). The “Wedge” in Newport Beach is one such location. The variation in the surf size at the various beaches is a problem during the cool season as well.

For inner waters buoy swell heights over 6 feet, the surf height is rather close to the inner waters buoy swell height. [For example, 8 foot swells at Santa Monica Basin Buoy translates to at least an 8 foot surf at the beaches. Max sets can be 33 percent higher, especially for the longer periods (typically 15 seconds or more)]. Surf can be even larger than that for periods around 20 seconds or more. Surf 14 feet or higher can result in coastal flood damage regardless of tide. Wind waves (approximately 1 foot of wave height for every 5 knots of wind) can significantly increase the height of the overall seas.

During the more impressive storms the 850 mb flow increases rapidly near Point Conception [the Vandenberg (KVBG) sounding 850 mb wind exceed 30-40 knots] as the low level jet responsible for increasing surf hits the coastline. The surf/swell generation jets with 30-40 knot 850 mb wind may make it all the way to the coast in the south and show up on the KNKX sounding.

With high surf, rip currents and along-shore currents can be generated. Property damage can result from water washing over jetties, over sea walls, against the bottom of and occasionally over piers, along with flooding of parking lots and frontage roads. Flooding and beach erosion is also a problem. High tides make the problem even worse.

4.2 FORECASTER HINTS – HIGH SURF AND LARGE SWELLS

a. Look for strong packing of the 500 mb height lines between 25 and 40 north at or east of 150 west longitude (a prime large swell generation zone). This is approximately 1000 miles west of the coastline. A 200 meter height change in 5 degrees of latitude is sufficient for high surf. Sometimes, very large storms can generate high surf and swell from locations even further west.

b. Look for 850 mb flow aimed at southern California of 30 knots or more.

c. Usually there is a huge Gulf of Alaska low, (and it is very likely that there are low latitude storms approaching from the west around the south side of the low).

d. Surf should be at least as large as the inner waters buoy swell size, (for example match or exceed swell heights found at Santa Monica Basin Buoy). Long period swells (periods near 15 seconds) can cause high surf of 1/3 higher than the swell (some sets of 6 to 8 feet) with only 4 to 6 foot swells at the local buoys. This is essentially “max surf sets a few feet higher than the swell” for these “relatively small swells”. During optimal conditions, the very long periods (around 20 seconds) may produce max surf sets approaching 7 feet higher than the swell, and extremely long periods (approaching 25 seconds) may generate local surf sets to nearly 10 feet higher than the swells.

e. When the combination of surf and tide is 14 feet or higher, coastal flood damage may occur. Surf of 14 feet or higher can result in coastal flood damage regardless of tide. Even 5 to 7 foot surf can generate strong rip currents.

f. Swell direction 305 degrees or higher is usually too steep (too “northerly”) for swells to move into the area, due to blocking at Point Conception, so high surf is very difficult to generate and typically will not develop. [Although some of the swell, (reduced in size), leak into the outer waters].

g. For swell directions that are west to northwest (up to just under 305 degrees), largest surf and swells are in the south, where the beaches are more “west-facing”. With south to southwest swell, largest surf and swells are in the north, where the beaches are more “south-facing”.

h. Some blocking by the islands will locally lower surf and swell heights behind them.

i. Keep an eye on the Southern Hemisphere for potential wave generation areas that can produce swell that affects southern California. Waves propagate along great circle routes, so having a great circle track overlay centered on southern California (or graphics containing the great circle routes), is helpful.

5. SUMMARY AND CONCLUSION

Strong wind approaching and over southern California can produce a variety of wind effects, based on not only its strength, but its direction as well. If the wind flows from the inland areas out toward the ocean, many locations west of the mountains can get damaging offshore winds. If the flow is from the ocean to the deserts, then conditions are more favorable for mountain and desert locations (and possibly the northern coastal strip) to get strong winds. It is typically the northern coastal areas and northern mountain areas that experience the strongest winds with most events. Besides strong onshore and offshore flow, strong northerly winds (for example, during the transition to offshore flow) can affect the northern portion of the Coachella Valley. Some events begin as northwest wind events with stronger winds at the coast than the valleys, then the winds shift to northeast, resulting in strong winds in the valleys than at the coast.

As for damage, if a wind event follows a period of soaking, heavy rains, or is very strong (from any direction) during the rain event there can be widespread property damage, even west of the mountains. Many downed trees can occur with moderately strong winds due to saturated soils. Gusts to only 30-40 mph can uproot trees in saturated soils. When the ambient winds aloft are strong, squall line type activity (with or without thunder) can locally surface the winds aloft and cause damage. Also power lines are vulnerable to branches falling on them. Blowing dust is a problem during drier periods and can result in freeway closures during moderate to high end wind advisory conditions [generally gusts in the lower to mid 40s (mph)] and certainly during high wind warning conditions (gusts to 58 mph or more). Damaging southeast flow with near zero visibility in blowing dust can also occur, but it is more associated with thunderstorm complexes to the south and southeast during the monsoon season. Big rigs and other high profile vehicles can be discouraged or even barred from using certain routes since they can be blown over or encounter low visibility in blowing dust, sand, and other debris. Some highways are closed altogether. Air traffic patterns can be reversed (resulting in some airports being “turned around” due to the wind direction), which can reduce the amount of allowable air traffic in and out of the Basin. Airports can even be closed. Even light rain (just enough to wet runways) combined with fairly light winds (only 10 knots) can cause a complete reversal in the traffic pattern at major airports in the Los Angeles Basin. During offshore flow events, the strong easterly flow can blow just above the stable surface layer, or the sea breeze can sneak in under the offshore flow creating dangerous wind shear. This is especially true during the beginning an event when an eddy can “prop up” the marine layer and delay the onset of the offshore flow at the surface. An eddy may also develop during an offshore flow event and lift the offshore flow off the surface, which can result in cooler and cloudier conditions than forecast. Wind shear events in which pilots gain or lose 15 knots due to the change in the winds in the lower levels (for example, +/- 15 knots within 2000 feet of the surface) are common. Flow near the mountains can result in strong uprafts and downdrafts and severe to extreme turbulence. Fires can be fanned by the winds, and are particularly problematic during the fall “firestorm season” (the dry, windy offshore flow period prior to the return of the Pacific Storms).

Placement of the upper level low or trough can have a huge impact on the probability and location of strong winds. If the low or trough line is slow moving, directly overhead and fairly “stacked in the vertical” (500, 700, and 850 mb height lines parallel) then the strongest winds miss the forecast area, or the winds temporarily drop off. An error in location can cause a forecast of offshore flow to be changed to an onshore flow forecast, typically determined by the 850 mb flow and surface pressure gradients. Some events have a period of high winds due to onshore flow followed by high winds due to offshore flow. With some storms the stronger upper level jet stream winds are on the western (or “back side”) of a low pressure system, which has a tendency to keep the low digging south, and the low ends up further west and south than originally shown in previous model forecasts. This can have a significant effect on wind forecasts (and also forecasts of other parameters such as rain, snow, thunderstorms, and even severe weather). By diving south along the coast just offshore (an “outside slider”) the storm brings only strong northeast winds and drying rather than the thunderstorms with heavy rain and snow it would bring if it passed directly overhead. If it is somewhat of a hybrid type of windstorm (strong northeast winds but very moist and unstable), it can result in “wet bulb zero effects” with strong low level evaporative cooling. In these cases, along with very strong cold advection, 850 mb temperatures can abruptly fall to values below zero. This results in not only damaging winds, but widespread snowfall down to 2000 feet, 1000 feet, and to near sea level if 850 mb temperatures fall to approximately -1 degrees C, -3 degrees C, and -5 degrees C respectively. The onshore flow patterns can also result in such low snow levels, but they seem to result in less widespread low level snow at the sub 2000 foot level, and typically needs to be colder to produce the same results.

If the onshore winds are strong over the coastal waters, large swells and high surf can develop. Large swells can also develop in strong northeast flow, especially downwind of some of the major canyons and passes, (such as the winds that flow through Santa Ana Canyon toward the Huntington Beach/Newport Beach area). Also the region around Carlsbad and Oceanside (KCRQ and KOKB) as well as the Brown Field area near the Mexican Border (KSDM) can be affected. If there is strong onshore flow, and especially if it is raining or has just rained, strong westerly winds and large waves develop in the coastal areas, with the strongest coastal winds in the Huntington Beach/Newport Beach area (probably due to less friction over water than over land, funneling between the islands, or as a barrier jet forced to flow along the mountains). Although storms between New Zealand and South America are very far away, such Southern Hemisphere Storms have no problem sending up high surf to southern California around a week after being generated. Rip currents and along-shore currents can be generated by high surf. Property damage can result from water washing over jetties, over sea walls, against the bottom of (and occasionally over) piers, along with flooding of parking lots and frontage roads. Flooding and beach erosion is also a problem. High tides make the problem even worse.

Although all is not known about these phenomena, the hints shown above should give some idea of how these phenomena behave under most conditions, but still further examination is necessary to better understand and forecast for them.

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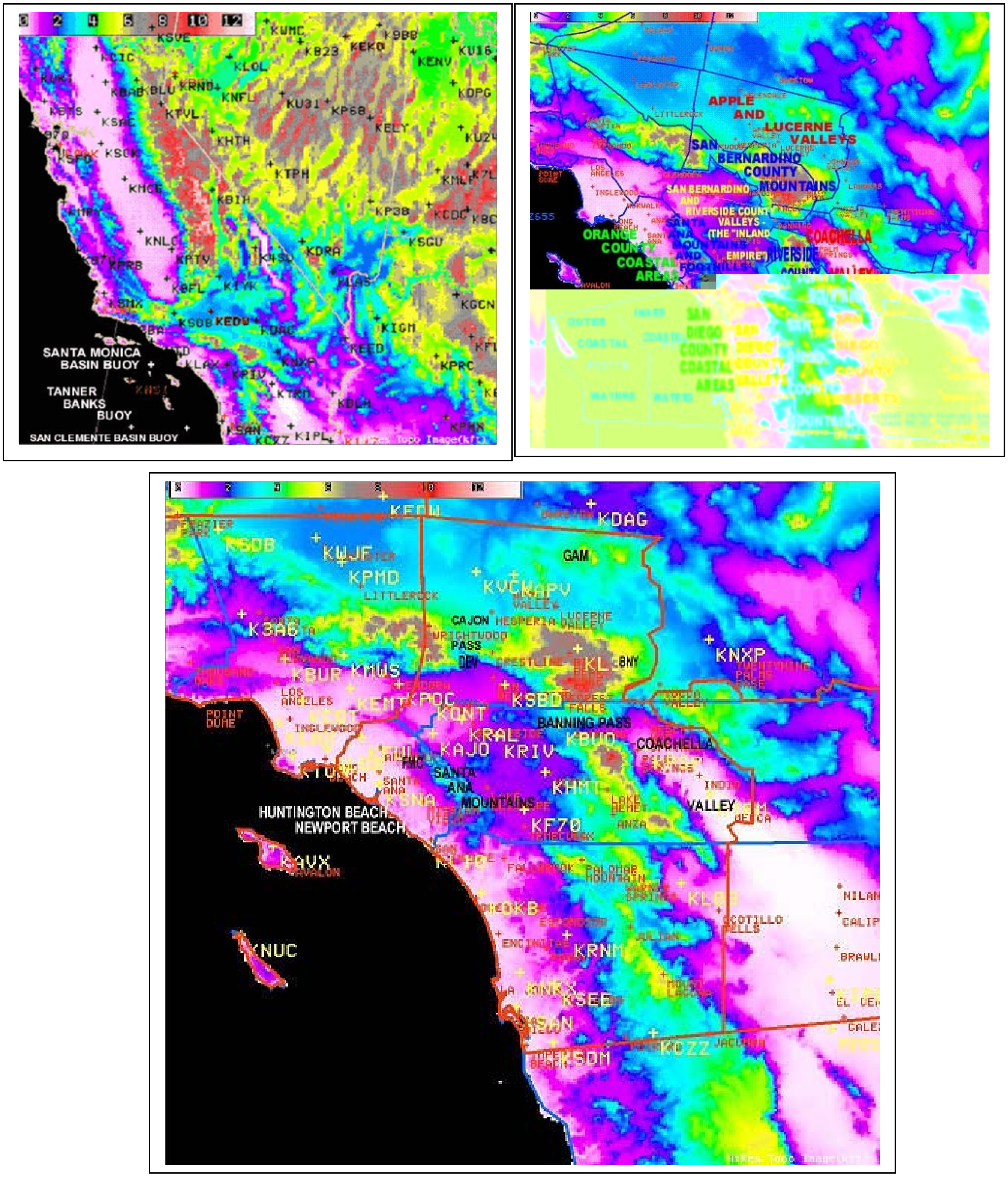


Fig. 1. Terrain map of the WFO SGX CWFA. Color coding is in thousands of feet MSL.

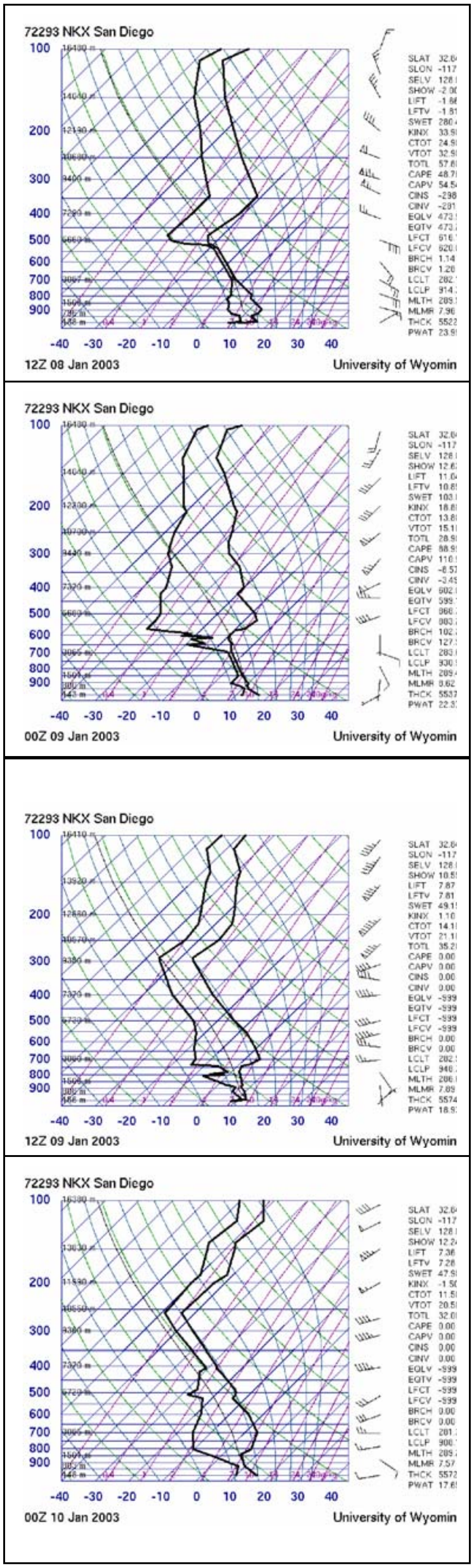


Fig. 2. Example of a lowering jet/windshift aloft and associated inversion wiping out the deep moist layer leading into a “transition day”.

LOCATION	JANUARY RECORD HIGH TEMPERATURE
EL TORO CA	93
BROWNSVILLE TX	93
SAN BERNARDINO CA	91
ONTARIO CA	90
SAN DIEGO CA	88
YUMA AZ	88
PHOENIX AZ	88
MIAMI FL	88
TUCSON AZ	87
HOUSTON TX	83

Table 1. Comparison of record high temperatures for the month of January for selected cities in the southern tier states. The highest temperatures in the nation can easily come from the coastal areas during the cool season and the desert areas during the warm season in southern California.

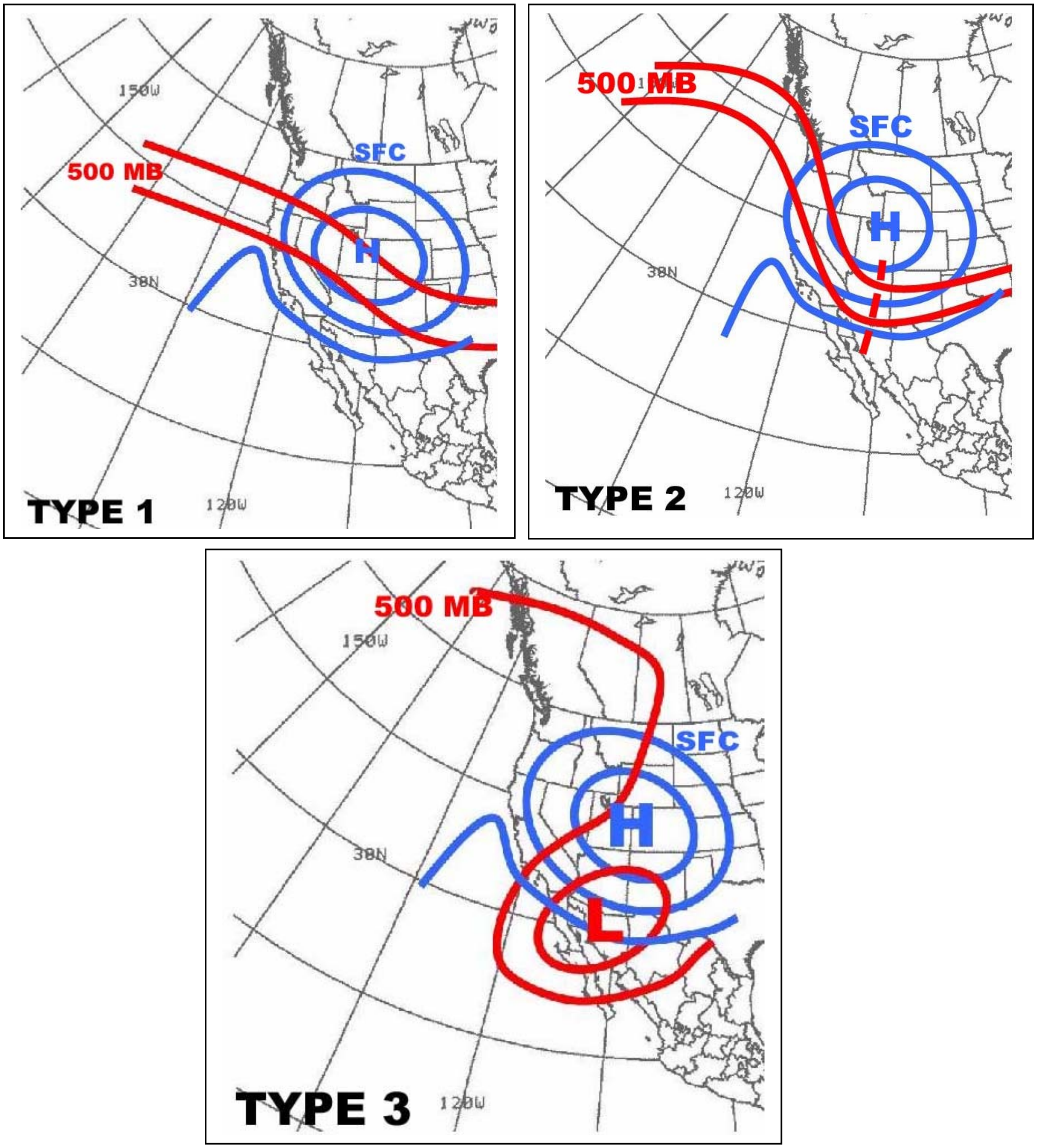


Fig. 3. Three main types of offshore flow patterns. The Type 1 pattern (upper left) is a “gradient wind event”. The upper level flow is not northeasterly, so most of the offshore flow is at 850 mb and below. Still, high winds can develop. The associated upper level trough is minimal. The Type 2 pattern (upper right) is a deep trough pattern when offshore flow is associated with some “upper level support”, but the wave is not “cut off”. Sometimes, the axis of the trough is more “north-south oriented” with the high moving in an east to west fashion. At other times the upper level trough has a strong positive tilt (an “east-west” orientation) and dives down from the north, with the surface high building in from the north behind it. The Type 3 pattern (bottom) is a cut-off low type of pattern. This type of pattern can bring a more widespread wind to the area. Position is very important. If the low develops over or drops into an overhead position, the strongest flow aloft (upper level wind support) will tend to be somewhere offshore. In this case there may be a tendency to have thunderstorms, but a reduction in the wind. If it is simply passing overhead the strong winds are delayed until the back side of the low moves overhead. Very strong high pressure areas (about 1040 mb or higher) that develop over the Yukon have a tendency to eventually slide south west of the Rocky Mountains during some offshore flow events. In this manner, they may produce low snow and frost/freeze events over southern California and should be watched.

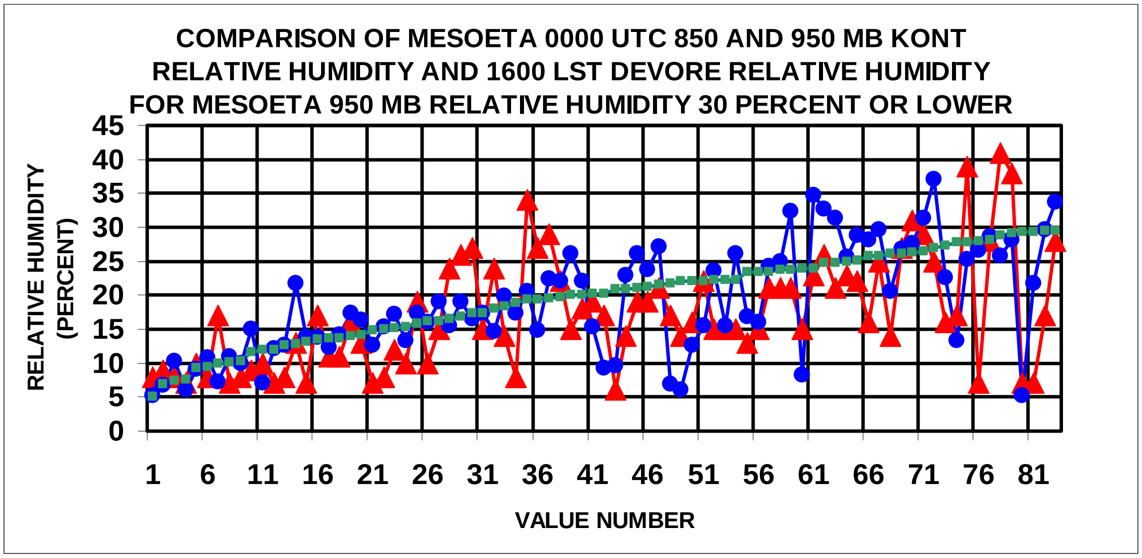


Fig. 4 The graph shows a preliminary comparison between the MesoEta Model 0000 UTC 850 mb relative humidity at Ontario (KONT) in red with triangles, MesoEta Model 0000 UTC 950 mb relative humidity at Ontario (KONT) in green with squares, and the 1600 local standard time surface relative humidity at Devore (DEV) in blue with circles . The data is for <u>all MesoEta 850 mb wind speeds and directions over KONT with a 950 mb relative humidity of 30 percent or lower</u>. The data used was for the period July 2003 – June 2004. There were 83 days out of a total of 288 available days fitting these criteria.

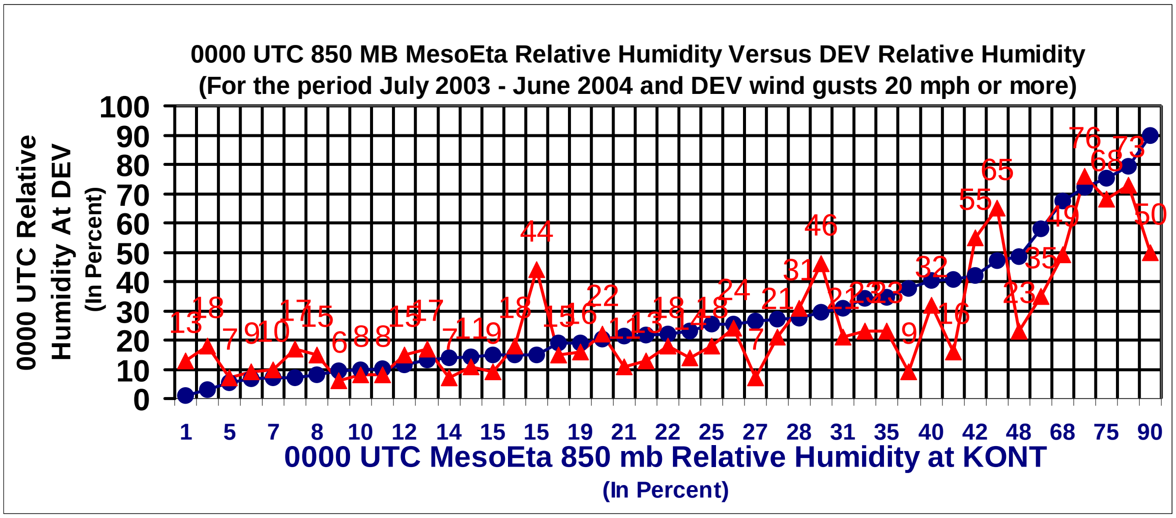


Fig. 5. The graph shows a comparison between the initial MesoEta Model 0000 UTC 850 mb relative humidity at Ontario (KONT) in red with triangles, and the 1600 local standard time surface relative humidity at Devore (DEV) in blue with circles <u>for 850 mb wind gusts of 20 mph or more from any direction</u> for the period July 2003 – June 2004 out of 288 available days. There were 45 days fitting these criteria. Winds without an easterly component most likely keep the airmass more moist and may account for values more toward the right of the graph. Some of the days may reflect a wind shift from dry easterly winds to strong west winds, but the recovery to higher relative humidity values lag. Also 850 mb may be in the dry air above the inversion on some days.

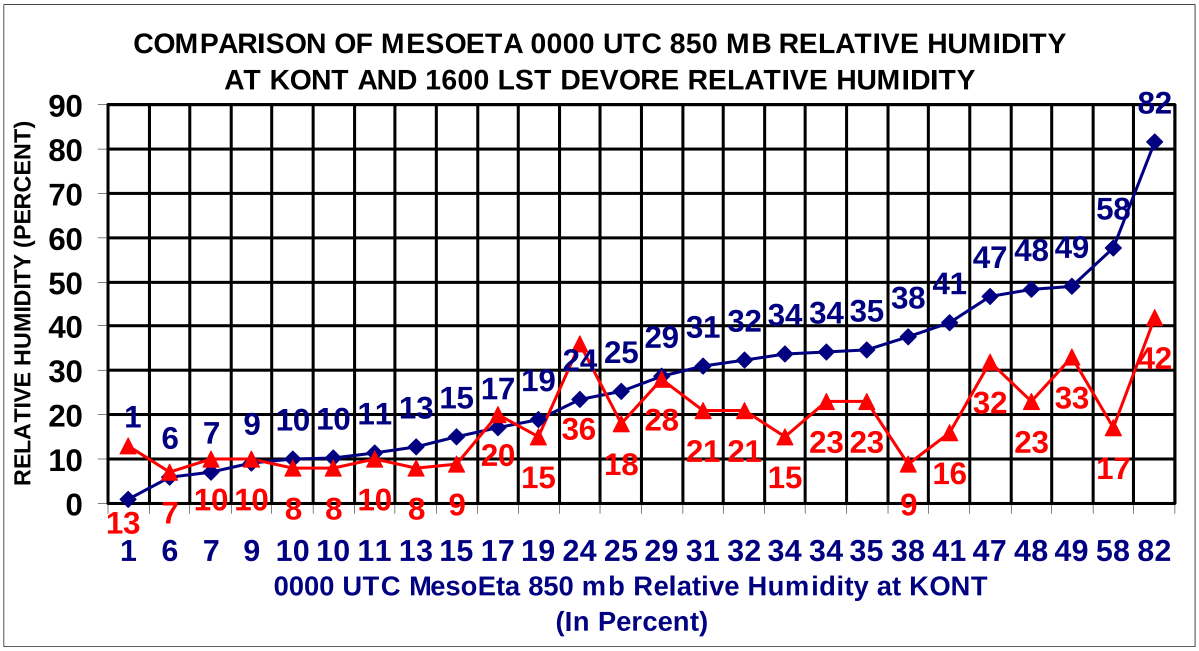


Fig 6. The graph shows a comparison between the MesoEta Model 0000 UTC 850 mb relative humidity at Ontario (KONT) in red with triangles and the 1600 Local Standard Time surface relative humidity at Devore (DEV) in blue with diamonds, for 850 mb winds <u>with an easterly component of any size.</u> There were 26 days fitting these criteria for the period July 2003 – June 2004 out of 288 available days. There is a good match between the two graphs for relative humidity values at 25 – 30 percent and below. For model relative humidity values over 30 percent the model relative humidity is somewhat lower than the actual Devore surface relative humidity. Note that there are no 850 mb relative humidity values above 45 percent at 0000 UTC with an easterly wind component at 850 mb. Also, almost all of the mesoeta relative humidity values below 15 percent resulted in surface relative humidity below 15 percent at DEV.

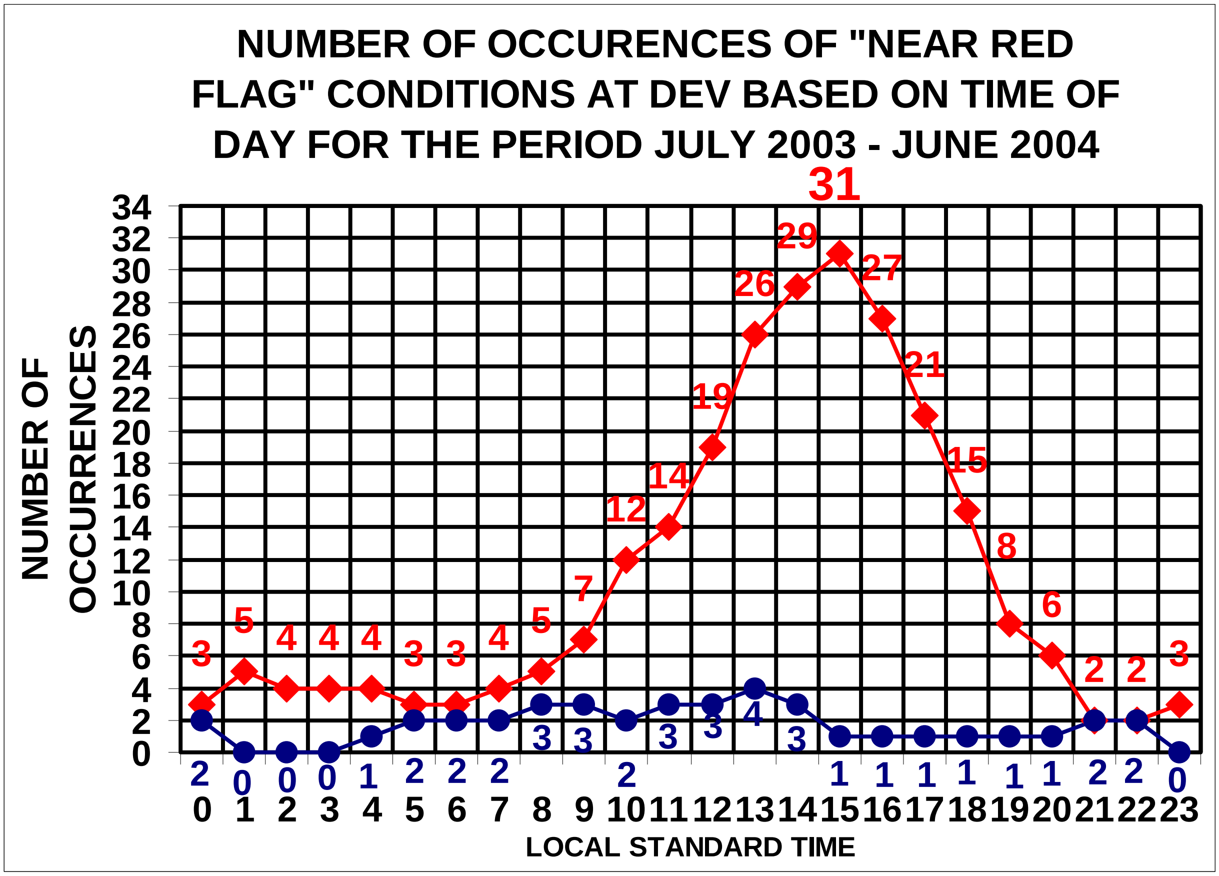


Fig 7. “Red Flag Conditions” are when either relative humidity values of 10 percent or less occur for 10 hours, wind gusts to 35 mph with relative humidity of 15 % or less occur for 6 hours, or sustained winds of 25 mph with relative humidity of 15 % or less occurs for 6 hours. If conditions do not meet the duration criteria, then conditions are better described as “Near Red Flag Conditions”. The graph shows the number of occasions when at least “Near Red Flag Conditions” (relative humidity of 10 percent or less with any wind speed, or relative humidity of 15 % or less with wind gusts to 35 mph) occurred for the hour indicated during the period July 2003– June 2004 (out of 288 available days) for the first 2 conditions. There are essentially 2 levels of threat; “extremely dry conditions” or “very to extremely dry conditions augmented by strong winds”. The latter is the most volatile condition for firestorms. The red graph with diamonds shows the number of times the relative humidity [at Devore (DEV), at approximately 1500 feet MSL in the Inland Empire at the base of the Cajon Pass] fell to 10 percent or less (a total of 257 occurrences). The red curve shows a time preference for near red flag warning conditions based on relative humidity alone of about 1500 local standard time at DEV. The blue graph with circles shows the number of times that wind gusts of 35 mph occurred in conjunction with relative humidity at DEV of 15 percent or lower (a total of 81 occurrences). The blue graph shows a somewhat earlier preference of about 1000 - 1400 local standard time, with a peak of 4 occurrences at about 1300 local standard time. This may be partly due to the mid morning to early afternoon wind peak, which seems to occur before the relative humidity reaches its lowest point later in the afternoon (which is more like mid afternoon). In a fashion similar to the diurnal cycle, during a multi-day wind event the wind will typically peak before the relative humidity reaches its lowest point, and in some cases a day or 2 earlier. Near red flag events and red flag conditions for extremely low relative humidity alone far outnumber near red flag and red flag event for the combination of wind and very low to extremely low relative humidity.

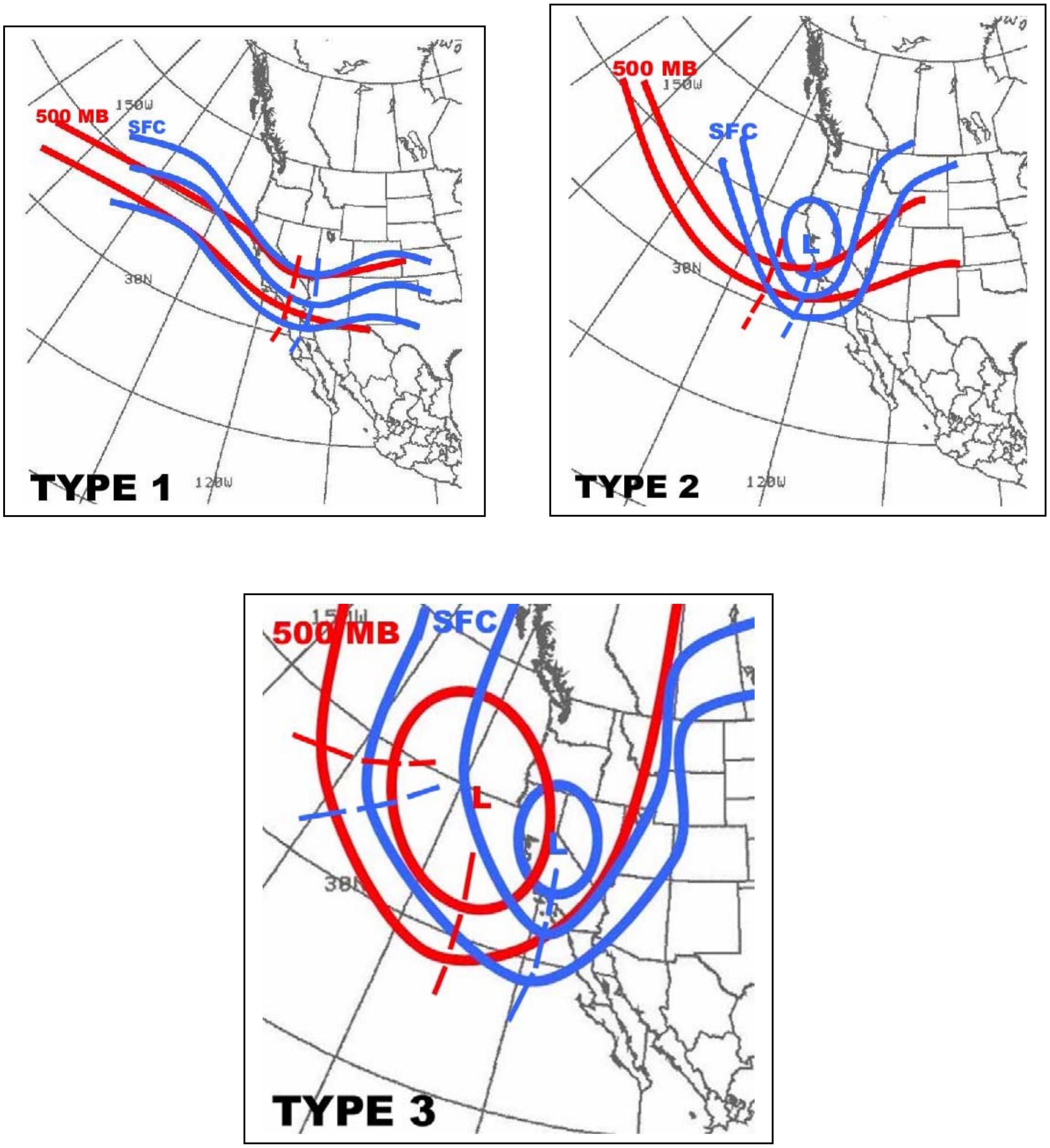


Fig 8. Onshore Flow Schematics. Type 1 patterns (upper left) are characterized by a long fetch of westerlies at 500 mb. The surface pressure pattern can vary from a north-south orientation (lower surface pressure to the north) to an east-west pressure gradient pattern (lower pressure to the east). During some events the upper level trough is barely perceptible. Type 2 patterns (upper right) are characterized by a deeper upper level trough that is better defined. (The surface low may be well north of southern California, but strong winds still develop, as long as the surface pressure gradient is strong over southern California). Type 3 events (bottom) are cut-off lows. Sometimes the first trough is followed by a second trough in rapid succession. The second trough can be stronger than the first, and bring a burst of damaging winds or even severe weather. Negative tilt troughs can be the worst type of events.

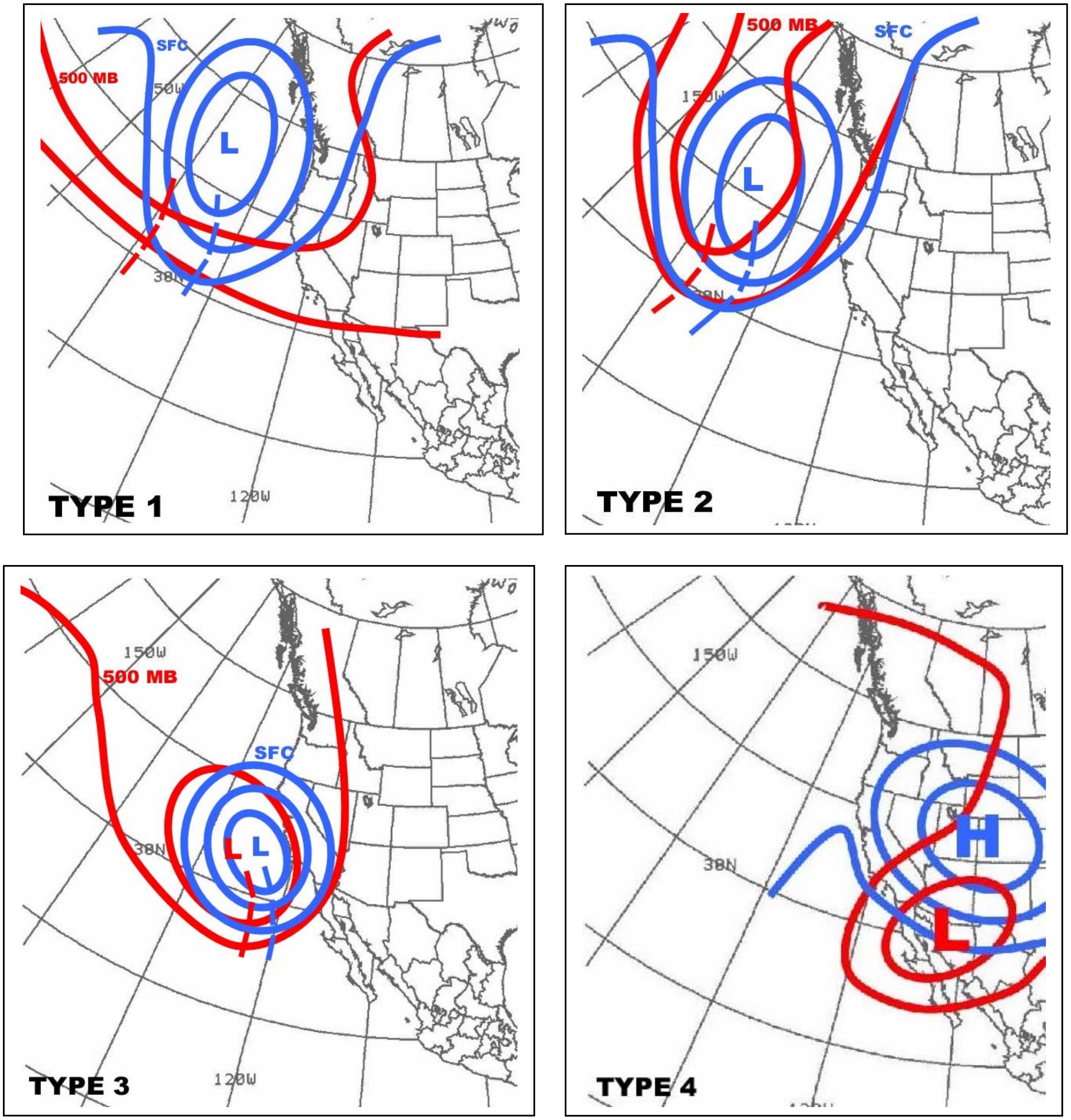


Fig 9. Cool Season High Surf and Large Swell Pattern Types. Type 1 patterns (upper left) are comprised by mainly zonal flow patterns at 500 mb (there may be a hint of a trough). At the surface there is likely to be surface low that could be as far away as the gulf of Alaska or over the 4-corners area of Utah, Colorado, New Mexico, and Arizona. Type 2 patterns (upper right) consist of an upper level trough at 500 mb that contains a nearly stationary storm or one that generates, then "follows the area of swells" to the coast. Type 3 patterns (lower left) are cutoff lows that generate high surf and large swells over the coastal waters of southern California. They are typically stationary enough to remain over one area long enough to build high seas. Type 4 events (lower right) consist of offshore flow that generates easterly swells that propagate eastward from the coast and affect the offshore islands. Many episodes are a mixture of the different types.

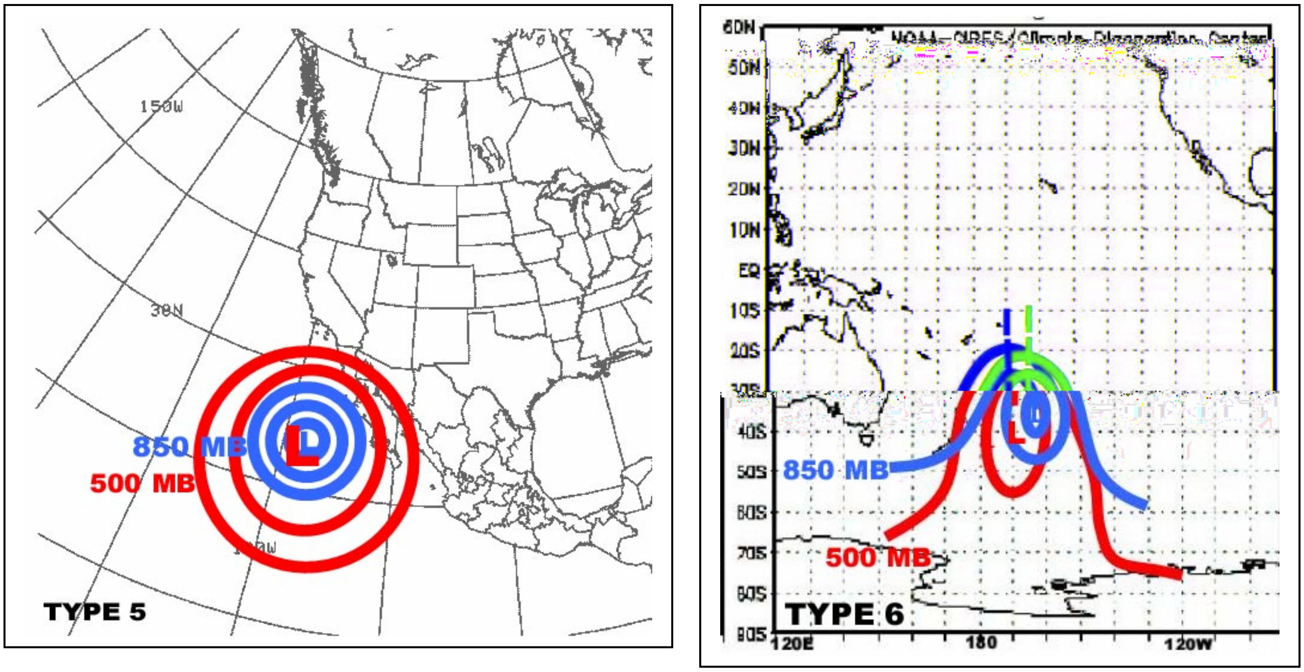


Fig. 10 Warm Season High Surf and Large Swell Pattern Types. Type 5 events (left) are hurricanes and/or tropical storms that develop off Mexico and drift north to within about 1000 miles of San Diego. The best chance of high surf and large swell occurs when the hurricane is moving directly toward San Diego. Type 6 events (right) occur when strong storms develop in the southern hemisphere near to just east of New Zealand during the northern hemisphere summer. The swells take about a week to arrive in southern California. If the storm is just off the coast of Australia the islands east of Australia such as New Zealand can block some of the energy, so it is preferable for the storms to be further east than New Zealand.

Appendix A. Strong Offshore Flow

TYPE 1. Gradient Wind Event (Light or even westerly zonal flow aloft, with little upper level support above 850 mb)

On 14 October 1997 a wind event transitioned to an event driven mainly by surface pressure gradients (“gradient wind event’) as many wind events do. Although the surface pressure gradient from the coast to the plateau was still increasing, the wind was not increasing since there was no upper level support (the 700 mb thermal gradient was small, the thickness and height gradients were weak, and the 850 and 700 mb winds were weak). All that remained was a “gradient wind event” and some warming. The conditions driving gradient wind events are typically quite shallow. In spite of the only 20 knot winds on the soundings, winds in the Santa Ana Mountains gusted to 76 mph, so high winds can still accompany gradient wind events. With 588 decameter 500 mb heights strong warming developed all areas. The sounding at KNKX showed a surface dewpoint depression in excess of 10 degrees C and little inversion, a common characteristic of the classic heat wave sounding. The 500 mb heights above 588 supported estimated high temperatures of at least 88 inland coastal plain. Temperatures reached the 90s all coastal areas the following day, especially since the gradients in the south “went offshore” as much as -3 mb. (Pressure gradient and sounding data are on the next page).

Approximate peak winds in the KONT/KCNO area............NE 20G25 knots (approximately NE 25G30 mph).
Approximate peak winds in the Santa Ana Mountains....NE 42G76 mph

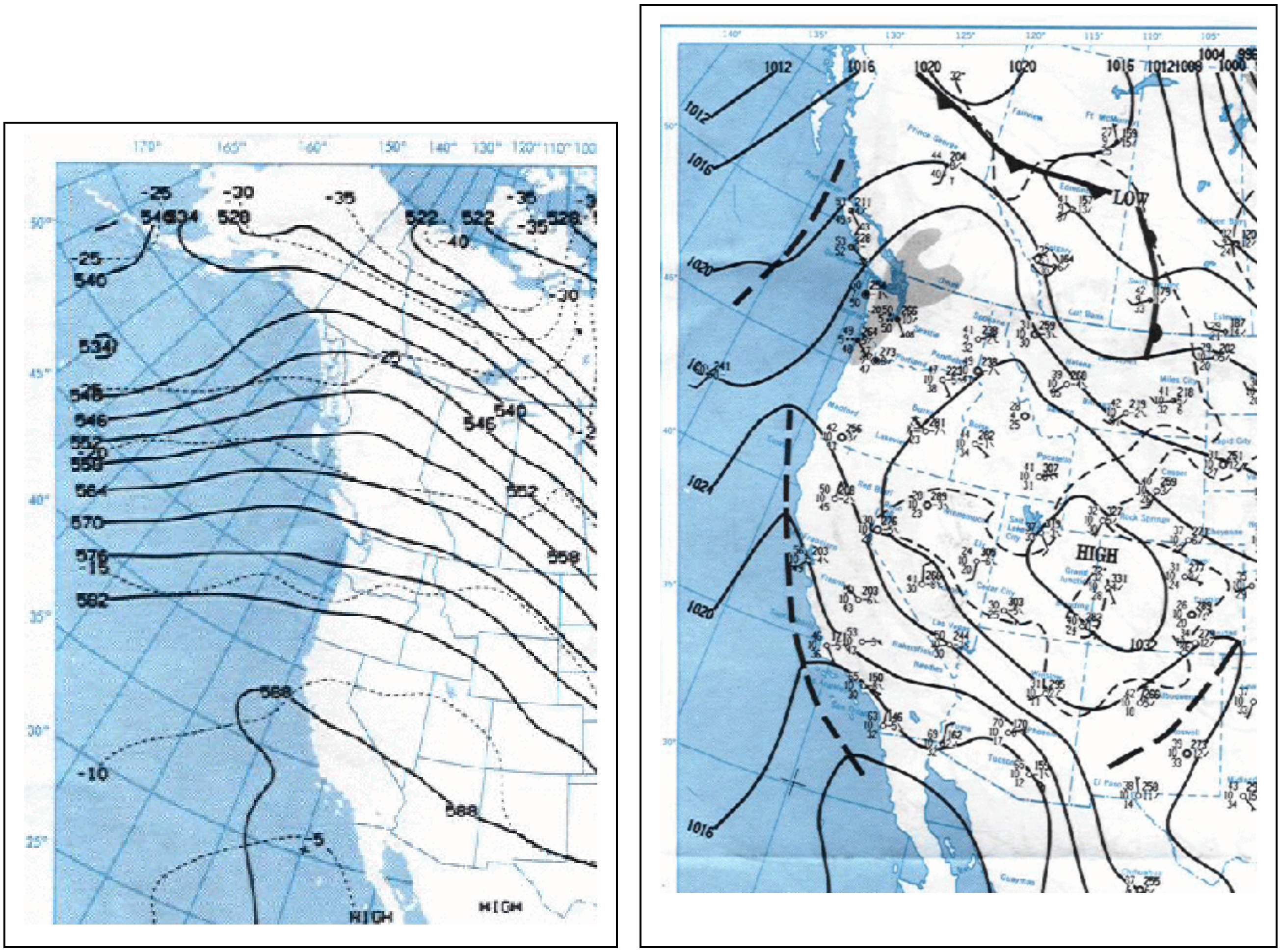
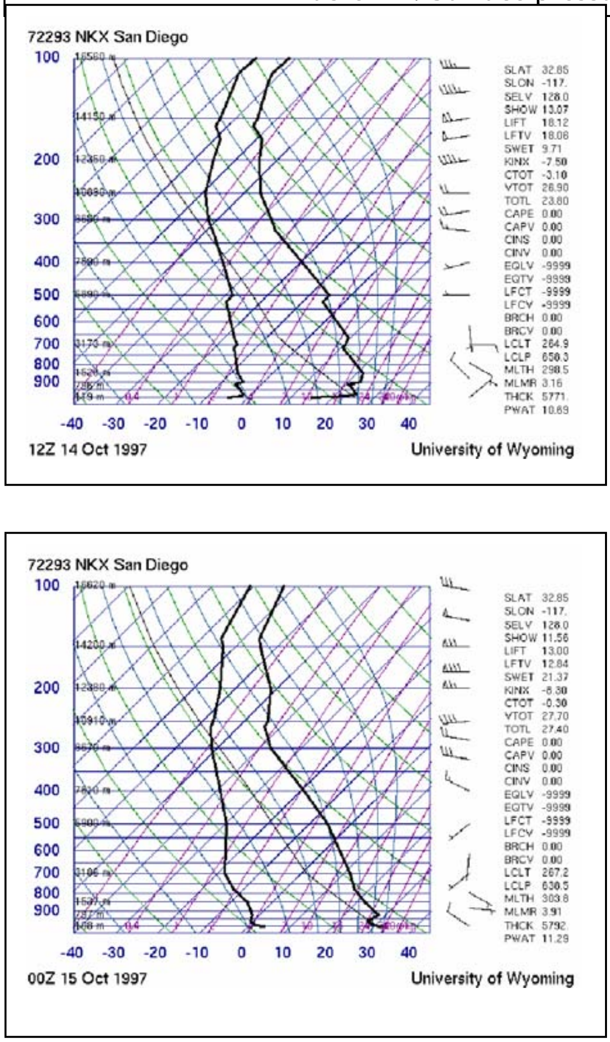


Figure A1. 1200 UTC 14 October 1997 500 mb heights in decameters, temperatures in degrees C, and winds in knots (left), along with station plots and mean sea level pressure in mb (right).

SURFACE PRESSURE GRADIENT (1200 UTC)	DATE: 13 OCT 1997	**DATE: 14 OCT 1997**
LAX-SFO	-4.7	**-5.3**
LAX-WMC	-14.4	**-13.9**
LAX-TPH	-10.5	**-11.6**
LAX-LAS	-8.2	**-9.4**
SAN\-IPL	MISG	**MISG**
SAN-YUM	-3.0	**-1.6**

Table A1. Surface pressure gradient data.



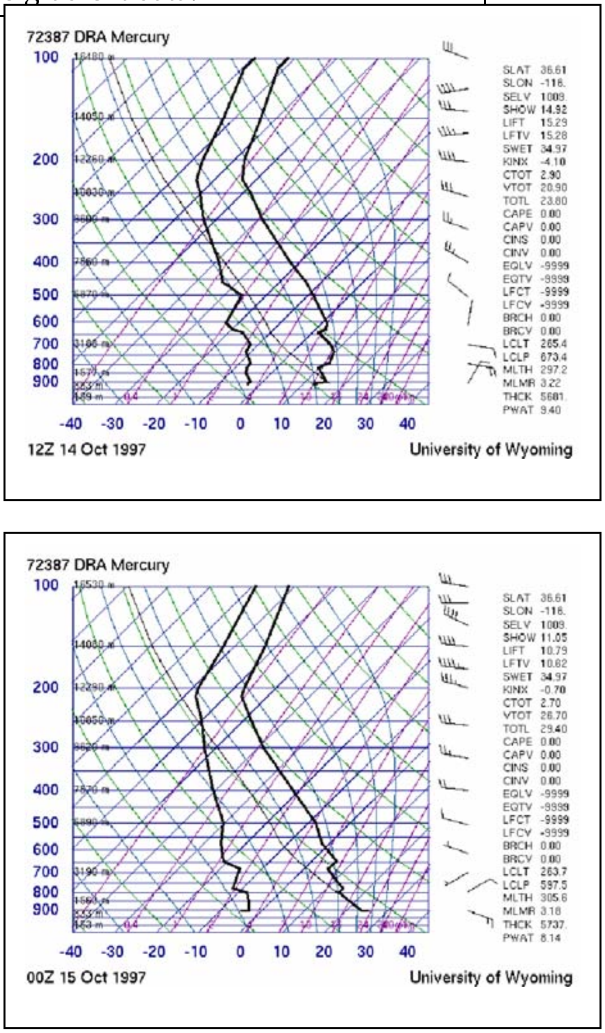


Figure A2. KNKX sounding data.

Figure A3. KDRA sounding data.

TYPE 2. Progressive Open Wave in Northwest Zonal Flow (cold northerly flow pattern)

On **8 December 1994** a moderate-strong offshore wind event developed. The 1033-1035 mb contour crosses the northern Nevada border, rather than the 1040 contour common for extreme events. The surface high tracked east through southern Idaho, with a 12-15 mb offshore surface pressure gradient KLAX-KWMC, below the 18 mb value common for extreme events. This was more of a trough in a hybrid Northwest/Aleutian Express pattern consisting of an open wave as it moved through Nevada and Arizona, (and carried little moisture). Winds at 850 mb reached approximately 30 knots at KNKX. (Pressure gradient and sounding data are on the next page).

Big rig traffic in the KONT/Inland Empire area was affected. Power lines in the Inland Empire below the Cajon Pass (and in Orange County downwind of the Santa Ana Mountains) were also damaged.

Approximate peak winds in the KONT/KCNO area............NE 30G40 knots (approximately NE 35G45 mph)

High winds or wind damage were reported in the “favored locations” (Inland Empire and Santa Ana Mountains).

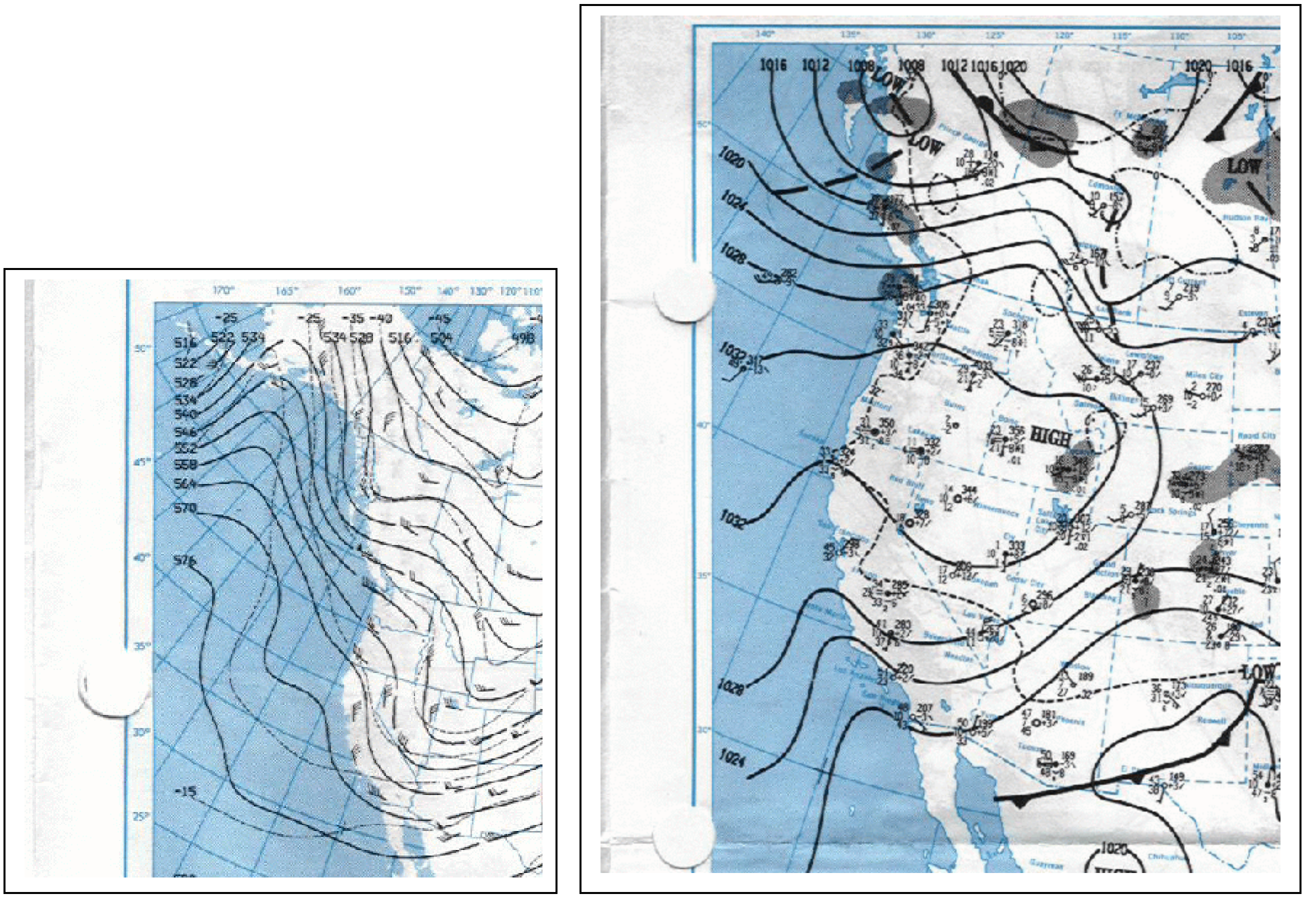


Figure A4. 1200 UTC 8 December 1994 500 mb heights in decameters, temperatures in degrees C, and winds in knots (left), along with station plots and mean sea level pressure in mb (right).

SURFACE PRESSURE GRADIENT (1200 UTC)	**DATE: 8 DEC 1994**
LAX-SFO	**-7.8**
LAX-WMC	**-12.2**
LAX-TPH	**-8.6**
LAX-LAS	**-4.3**
SAN-IPL	**MISG**
SAN-YUM	**-0.8**

Table A2. Surface pressure gradient data.

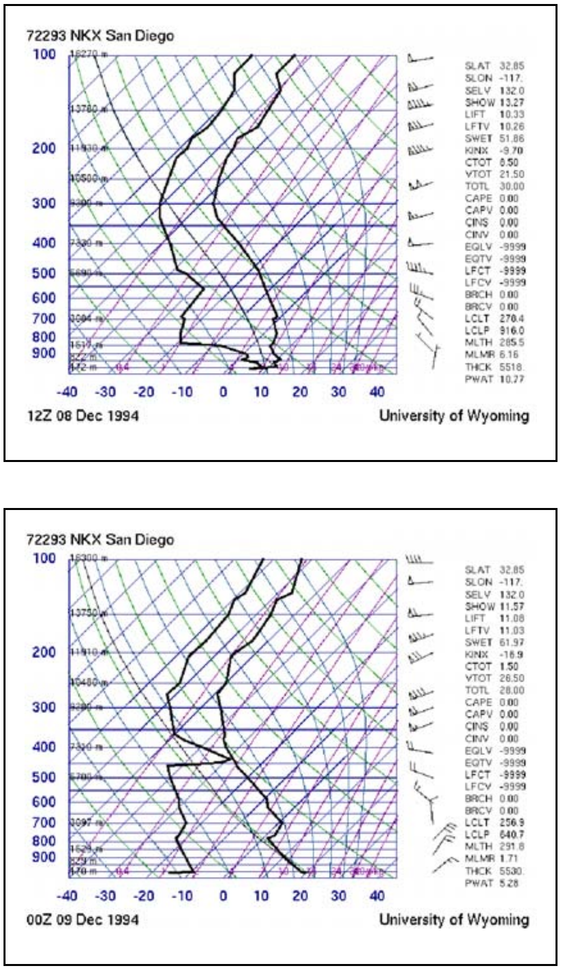


Figure A5. KNKX sounding data.

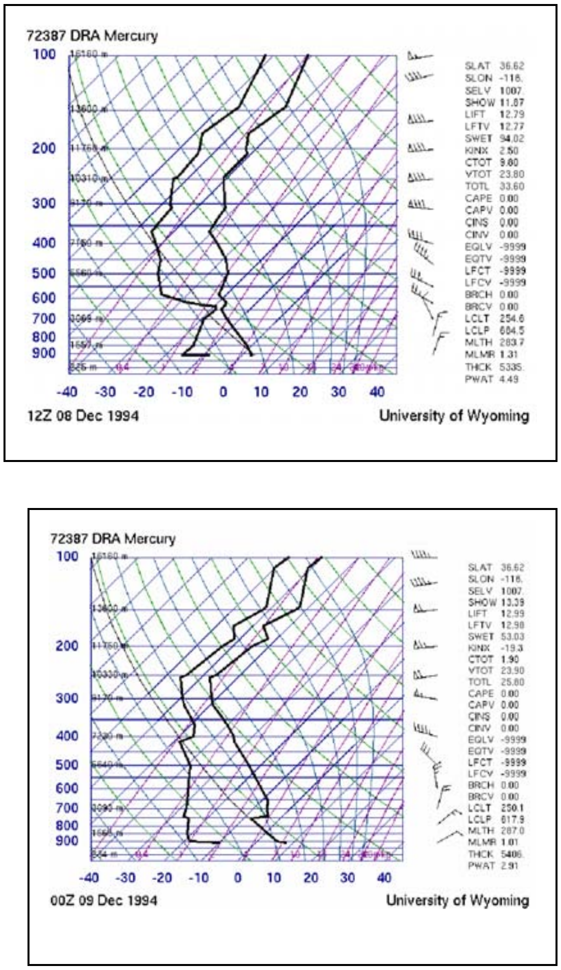
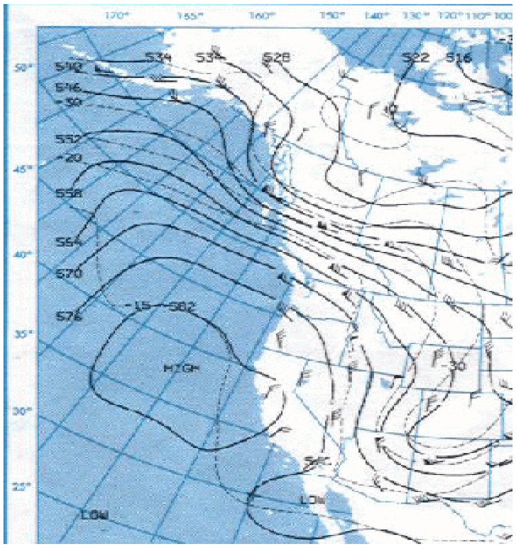


Figure A6. KDRA sounding data.

TYPE 2. Progressive Open Wave in Northerly flow (nearly horizontally tilted upper level progressive trough through Arizona)

On **15 December 1996** extremely strong offshore winds developed. The surface high dropped south into northern Nevada, with an offshore surface pressure gradient of around 18-20 mb KLAX-KWMC, exceeding the 18 mb value common for the extreme events. The 1040 mb surface pressure contour crosses the northern Nevada border, with most of northeast Nevada over 1040 mb. This was a “trough in a Northwest Express” pattern. The trough remained an open wave as it moved south through Nevada and Arizona. The surface pressure gradient from the southern California coastal areas to San Francisco temporarily exceeded the 6-8 mb range, so widespread winds developed, even reaching the beaches. Very strong 850 mb winds also helped the winds become widespread, reaching far below passes and canyons. At 1200 UTC 15 December the wind was backing with height. There was a “cold advection bite” out of the sounding at KDRA as the cold flow capped by an inversion undercuts the warmer air aloft. Wind gusts exceeded 100 mph and bent metal sign posts in some areas. The huge 7 mb offshore pressure gradient trends to the plateau (KLAX-KLAS) and 4 mb offshore trends to the lower Colorado River Valley (KSAN-KYUM) helped drive the strong winds. (Pressure gradient and sounding data are on the next page).

Approximate peak winds in the KONT/KCNO area............NE 45G55 knots (approximately NE 50G65 mph)
Approximate peak winds (east of KSNA) in the Santa Ana Mountains....NE gusting to 111 mph.



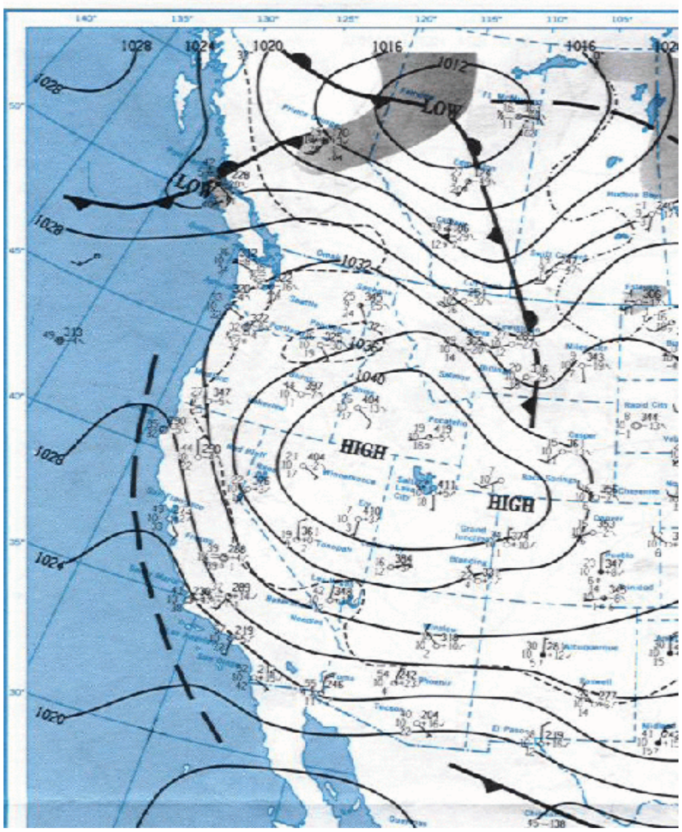
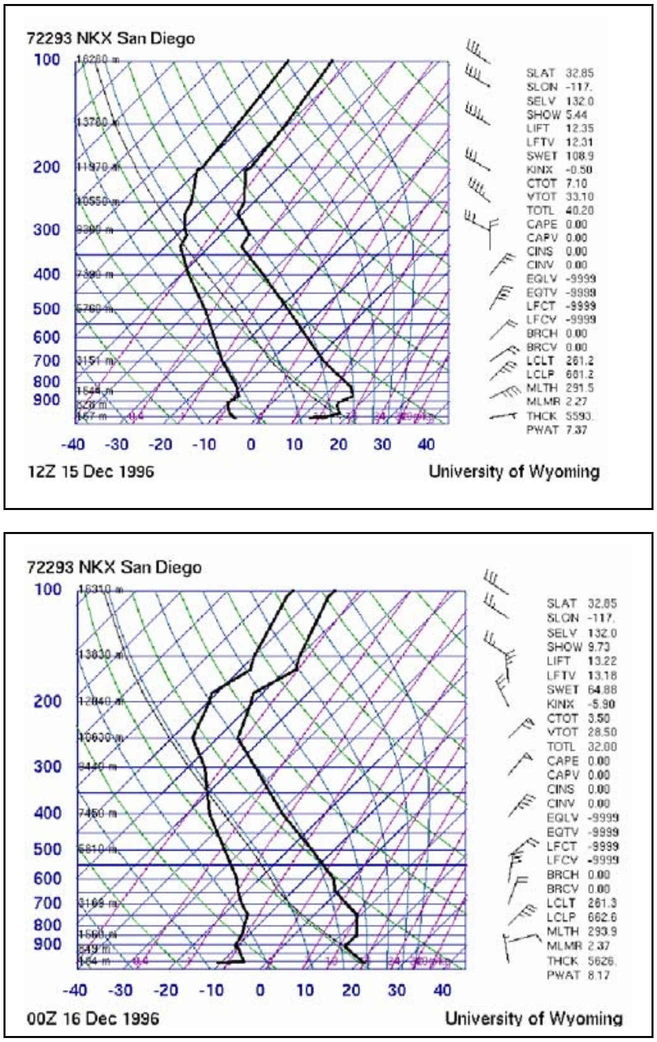


Figure A7. 1200 UTC 15 December 1996 500 mb heights in decameters, temperatures in degrees C, and winds in knots (left), along with station plots and mean sea level pressure in mb (right).

SURFACE PRESSURE GRADIENT (1200 UTC)	DATE: 12/14/96	**DATE: 12/15/96**
LAX-SFO	-9.2	**-5.4**
LAX-WMC	-12.7	**-18.5**
LAX-TPH	-11.4	**-14.2**
LAX-LAS	-5.8	**-12.9**
SAN-IPL	MISG	**MISG**
SAN-YUM	+0.7	**-3.4**

Table A3. Surface pressure gradient data.



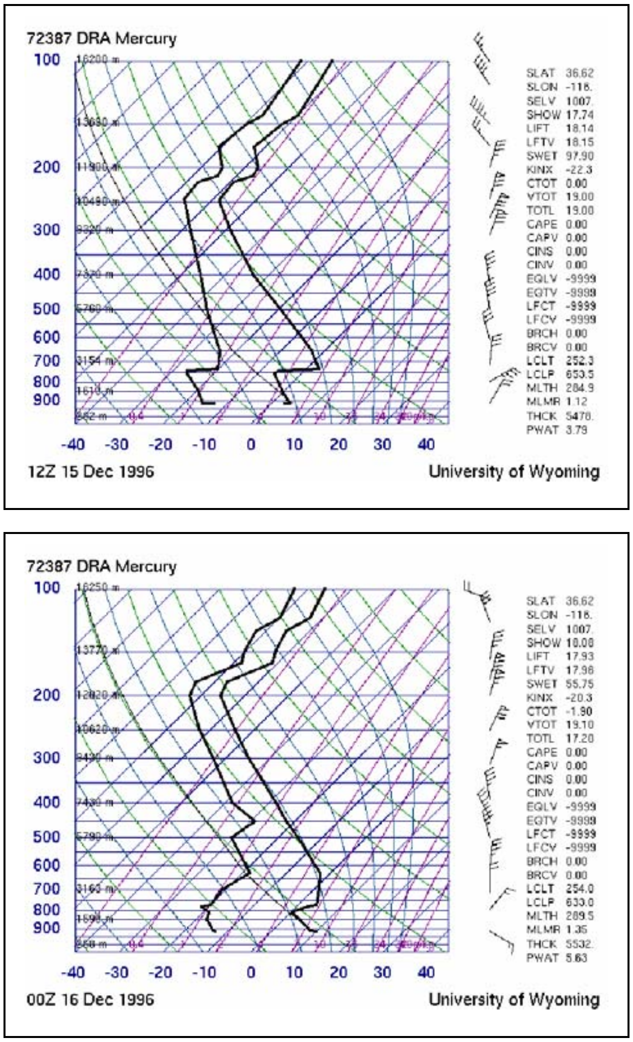


Figure A8. KNKX sounding data.

Figure A9. KDRA sounding data.

TYPE 3. Cyclonic Northeast Flow (Upper Level Low Pattern)

On **6 January 2003** (day 1 of a 2 day event) the strongest offshore wind event in over 25 years developed. The surface pressure gradient of 20-25 mb from the southern California coast to Winnemuca Nevada (KWMC), was well over the 18 mb value common with extreme events. [The 1040 line crosses the northern Nevada border on day 2 (7 January). This generated gradients exceeding 12 mb offshore from the southern California coast to KLAS, and very strong winds coastal areas of San Diego County]. Also on day 2 (January 7), winds up to 45 knots developed as low as 850 and 900 mb on the KNKX sounding, exceeding the 40 knot 850 mb value of many extreme wind events. There was a strong upper level cut-off low involved. Winds gusted to over 100 mph in the mountains, and sustained 65 mph winds with gust to 90 mph developed in the Inland Empire region at KONT. The surface pressure gradient and 850 mb flow, both in the extreme category, helped damaging winds reach well into the coastal areas. (Pressure gradient and sounding data are on the next page).

Approximate peak winds in the KONT/KCNO area............NE 56G78 knots (approximately NE 65G90 mph)
Approximate peak winds (east of KSNA) in the Santa Ana Mountains....NE gusting to 106 mph.

At some time during this event high winds occurred in all areas except the San Diego County Deserts east of KCZZ.

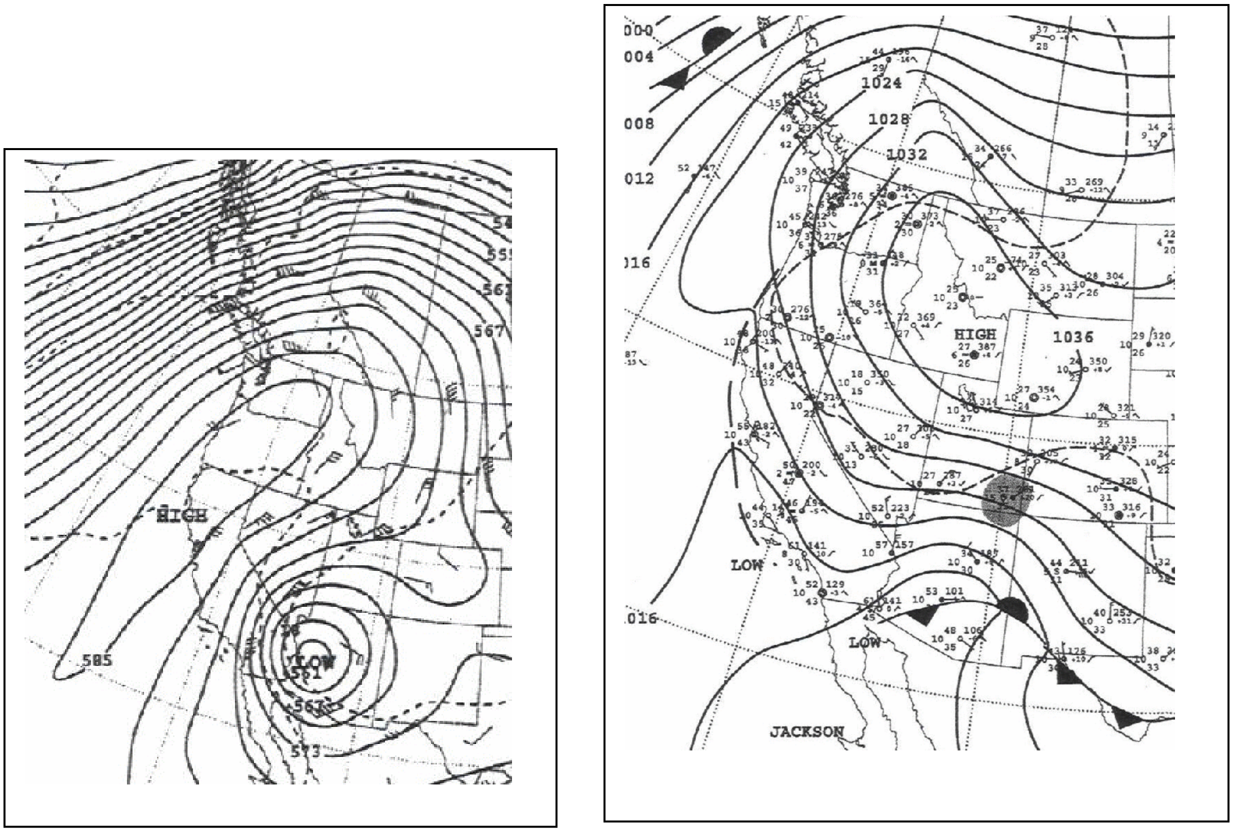


Figure A10. 1200 UTC 6 January 2003 500 mb heights in decameters, temperatures in degrees C, and winds in knots (left), along with station plots and mean sea level pressure in mb (right).

SURFACE PRESSURE GRADIENT (1200 UTC)	**DATE: 6 JAN 2003**	DATE: 7 JAN 2003
LAX-SFO	**-4.1**	-7.7
LAX-WMC	**-20.9**	-18.8
LAX-TPH	**-13.9**	-16.4
LAX-LAS	**-8.2**	-11.8
SAN-IPL	**-3.0**	-4.3
SAN-YUM	**-1.2**	-1.9

Table A4. Surface pressure gradient data.

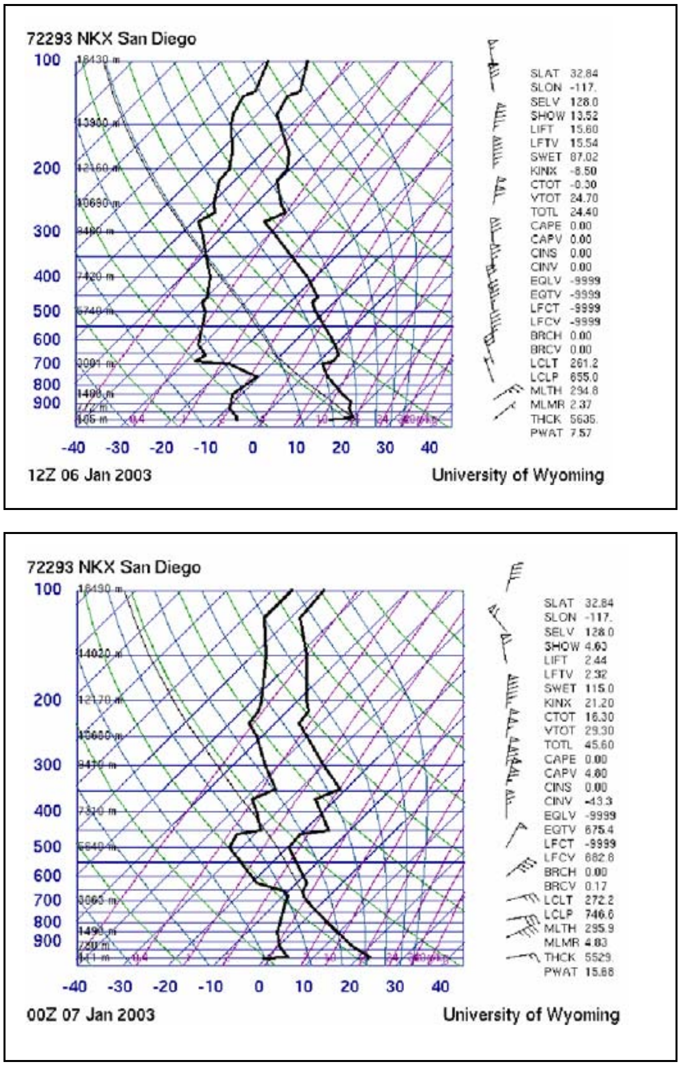


Figure A11. KNKX sounding data.

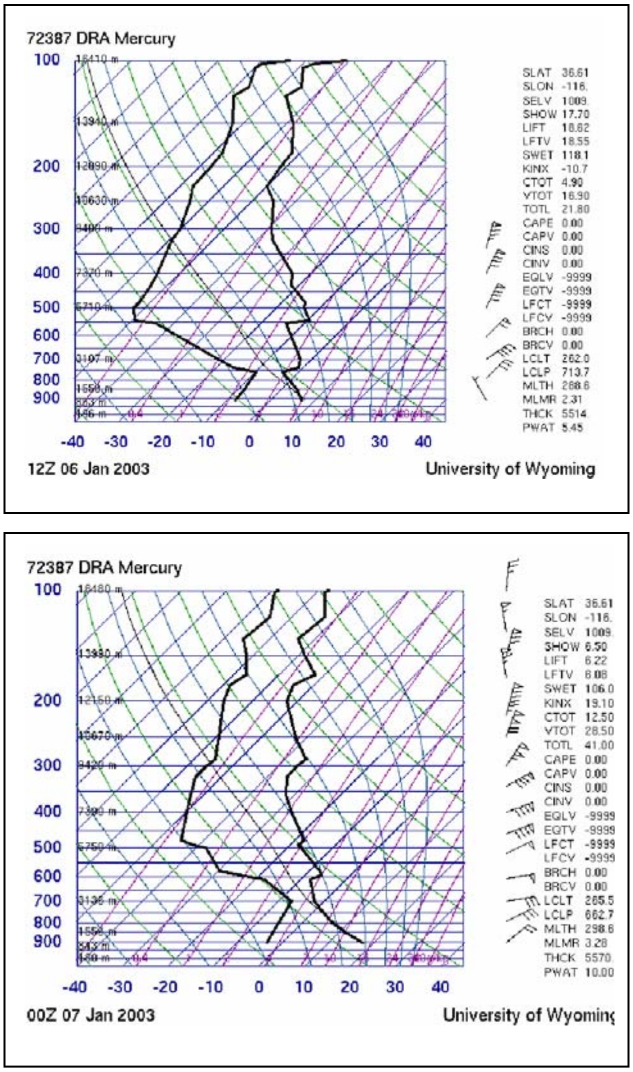


Figure A12. KDRA sounding data.

TYPE 3. Cyclonic Northeast Flow Event (Upper Level Low Pattern)

On **4 January 1949** strong, cold north to northeast flow resulted in a freeze event in southern California. The morning low temperature at San Diego Lindbergh Field (KSAN) was 29 F. One of the key features behind the subfreezing weather was a -6 deg C 850 mb temperature near KNKX. (No sounding or pressure gradient data is available).

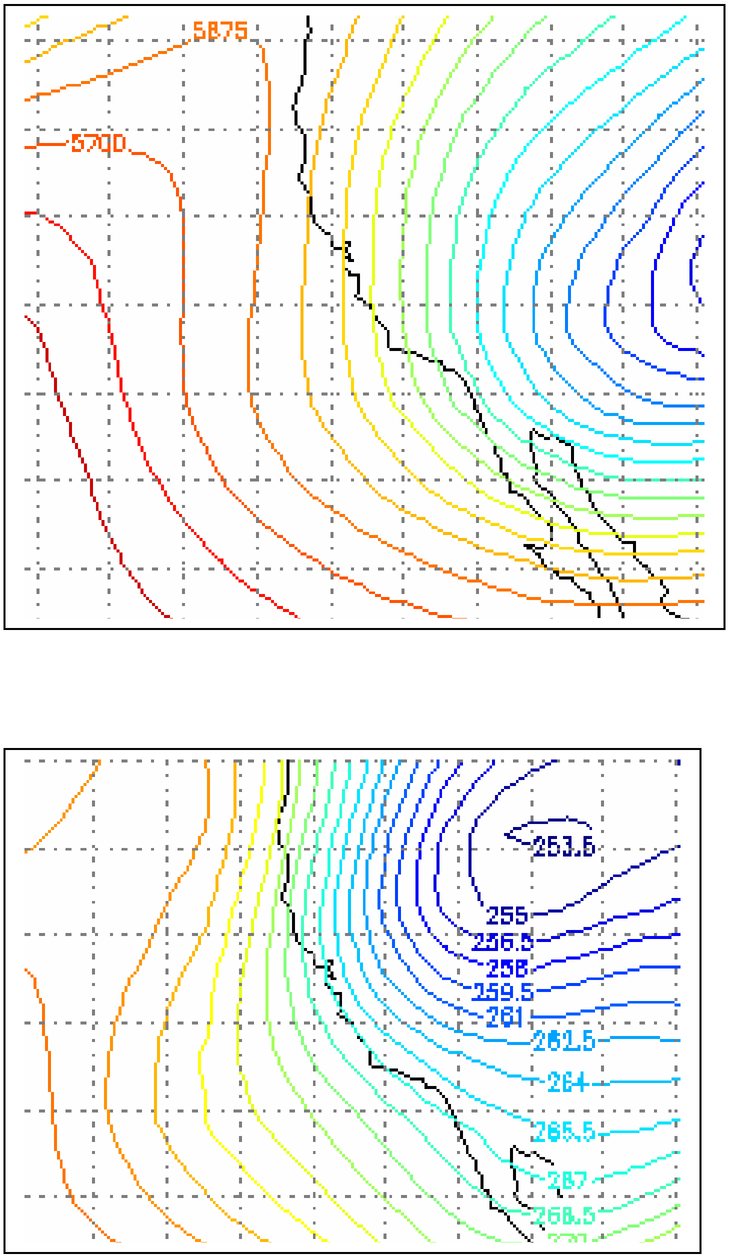


Fig. A13. 1200 UTC 4 January 1949 500 mb heights in decameters (top) and 850 mb temperatures in degrees K (bottom) Notice the - 6 C temperature at 850 mb over San Diego and near -9 C over the San Bernardino Mountains about 50 miles east of Ontario (KONT).

TYPE 3. Cyclonic Northeast flow (Upper Level Low Pattern)

On **11 January 1949** a very cold upper level low dropped south over the area, with the trough line west of San Diego, placing southwestern California in the strong low level offshore flow, with wind speeds reaching 75 mph in the windiest areas. During this event the low was far enough west to pick up moisture from the ocean, and far enough south to supply upward motion on top of the cold offshore flow for snow in all areas. The cold wave on 4 January 1949 brought very low temperatures, with Lindbergh Field (KSAN) dropping to 29 F. The cold air remained in place all week. Temperatures at KNKX fell to -13 deg C at 850 mb near KNKX on the 3rd before rising to -3 deg C at KNKX by the 11th. . Temperatures were only -7 deg C in the San Bernardino Mountains 50 miles east of Ontario (KONT) at 1200 UTC 11 January 1949 resulting in widespread snowfall. (No sounding or pressure gradient data available.

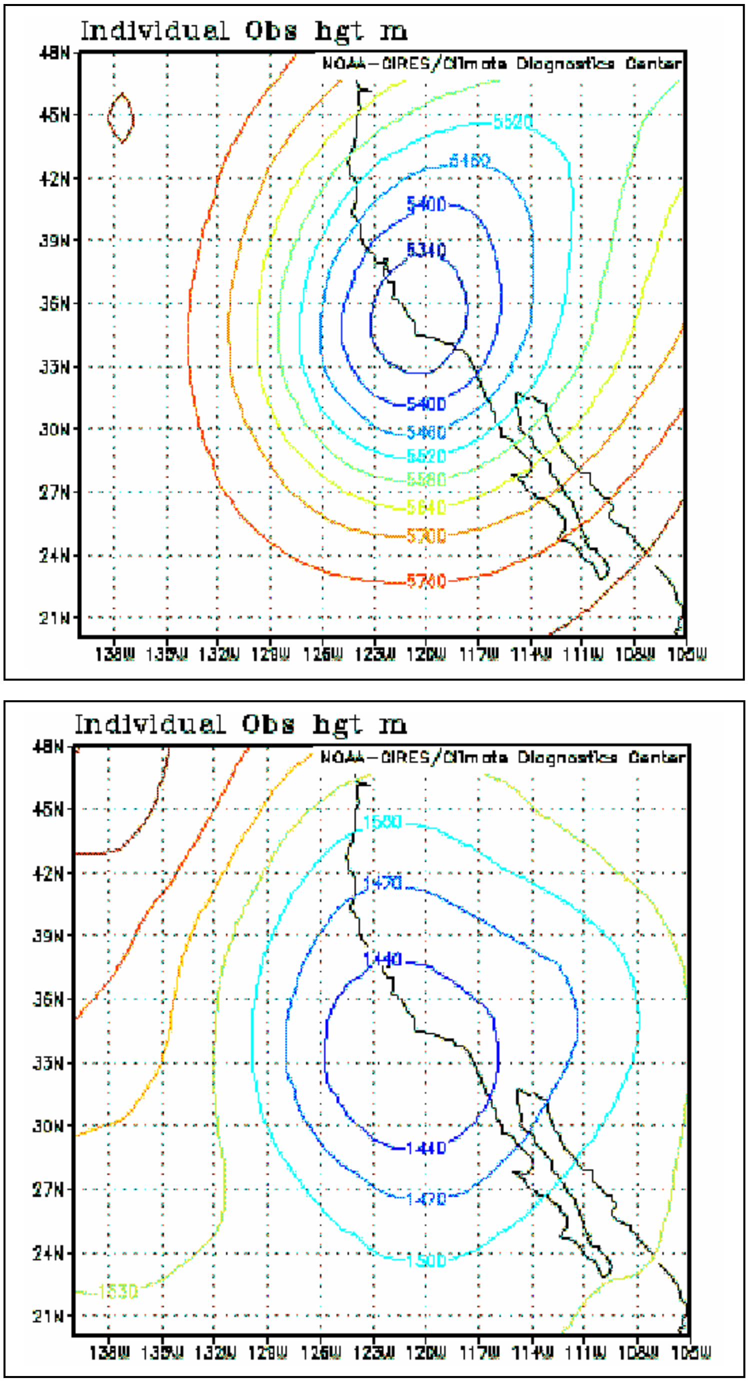


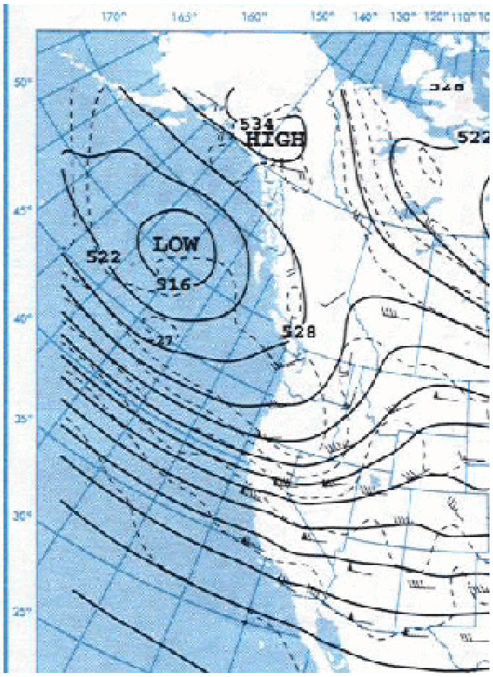
Figure A14. 1200 UTC 11 January 1949 500 mb heights in decameters (top), along with the 1200 UTC 11 January 1949 850 mb heights in decameters (bottom). Heights at the 500 mb level fell to 530 decameters at 1200 UTC 11 January 1949.

Appendix B. Strong Onshore Flow

TYPE 1. Strong Zonal Flow Pattern (Zonal flow with strong north-south gradient, or “West Wind Pattern”)

On **8 November 2002** very strong zonal flow developed over California. There was a strong (516 decameter) anchor low with a very strong (below 968 mb) Aleutian low involved. Southern California was in the right front quadrant of the associated strong anchoring jet, which occasionally oscillated to over 200 knots. With 50-60 knot 700 mb winds, and around 40 knot winds at 850 mb, along with approximately a 10-15 mb onshore surface pressure gradient from the southern California coast to the Las Vegas/Tonopah (KLAS/KTPH) area in southern Nevada, high winds developed at the favored mountain and desert locations. Winds on the eastern slopes of the San Bernardino Mountains at Burns Canyon (BNY) were sustained at over 50 mph with gusts to over 90 mph. There were downed power lines along with damage to roofs and signs. (Pressure gradient and sounding data are on the next page).

High winds developed in the San Bernardino County Mountains near BNY, the Apple and Yucca Valleys near KVCV, and the Coachella Valley.



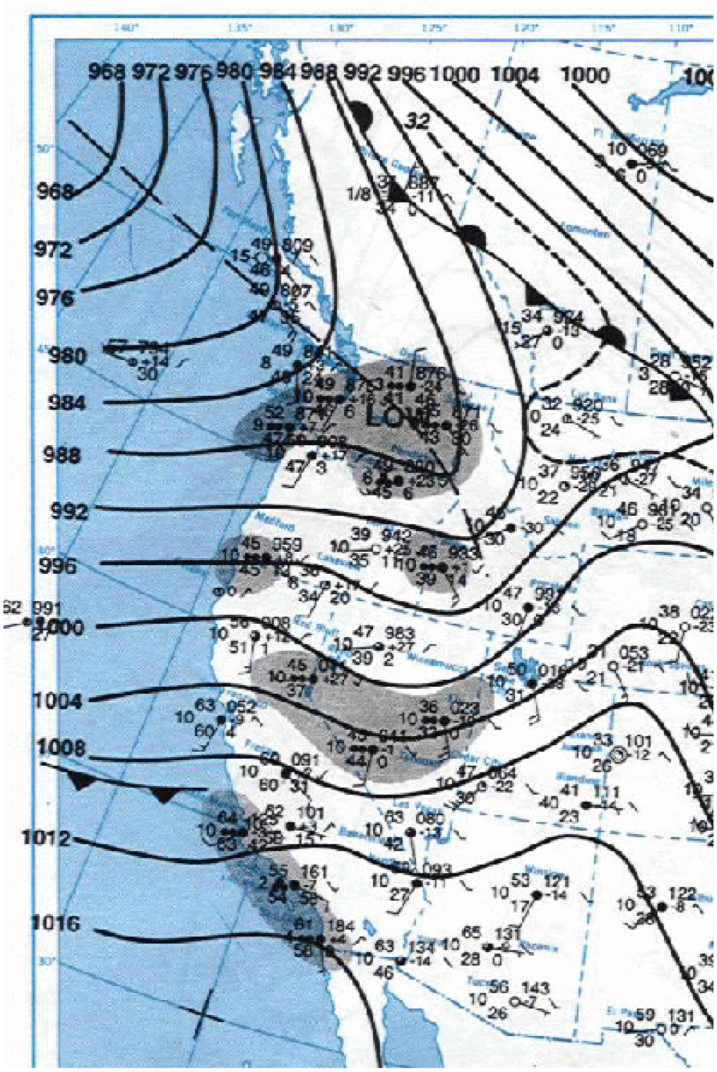
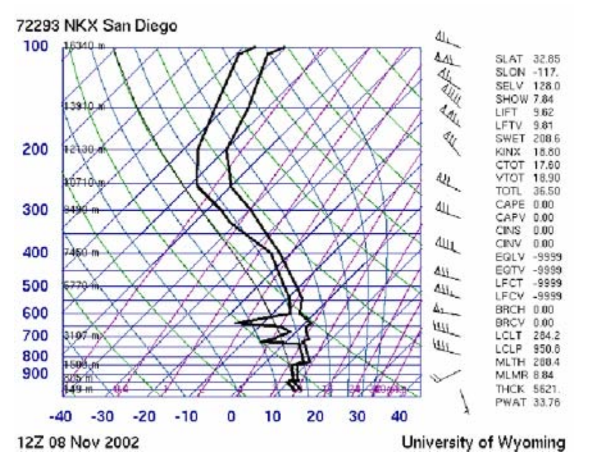
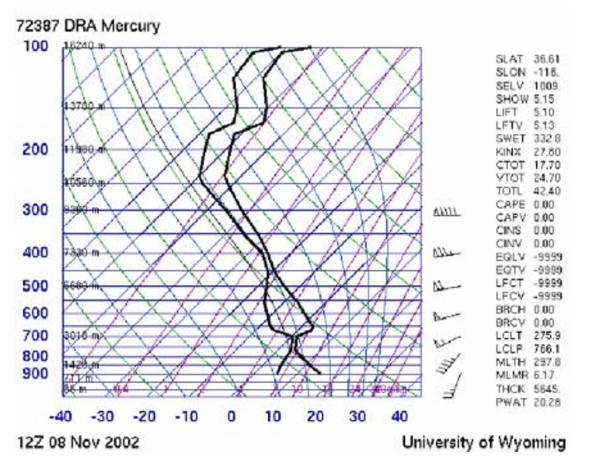


Figure B1. 1200 UTC 8 November 2002 500 mb heights in decameters, temperatures in degrees C, and winds in knots (left), along with station plots and mean sea level pressure in mb (right).

SURFACE PRESSURE GRADIENT (1200 UTC)	**DATE: 8 NOV 2002**	DATE: 9 NOV 2002
LAX-SFO	**+11.9**	+1.4
LAX-WMC	**+17.8**	+7.6
LAX-TPH	**+12.0**	+9.8
LAX-LAS	**+8.0**	+12.6
SAN-IPL	**+4.7**	+6.0
SAN-YUM	**+4.7**	+8.5

Table B1. Surface pressure gradient data.





MISSING

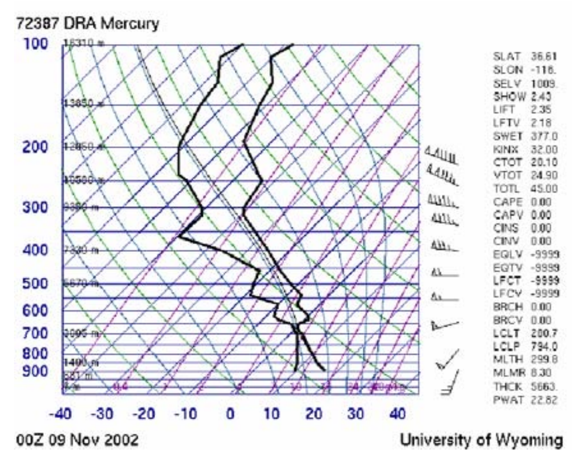


Figure B2. KNKX sounding data.

Figure B3. KDRA sounding data.

TYPE 1. Strong Zonal Onshore Flow Patterns (Zonal flow with strong east –west gradient, or “Northwest Wind Pattern”)

On **21 January 1999** very strong zonal flow developed between a very strong anchoring Aleutian low (528) and a 588 decameter ridge of high pressure. Cold air flowing in behind the surface front resulted in a very strong low level jet. There was a 10-15 mb onshore surface pressure gradient from the coast to the Las Vegas/Tonopah (KLAS/KTPH) area. With northwest flow the strongest wind was mainly southeast of the mountains, which hits the northern Coachella through Morongo Vallley areas especially hard. (Pressure gradient and sounding data are on the next page).

Wind gusts to 71 mph resulted in the closing of the Palm Springs Tram. Highway S22 in the northern portion of the San Diego County Deserts west of Borrego was closed. A Palm Springs rotor developed. The roof on a parking garage was torn off. Winds on the eastern slopes of the San Bernardino Mountains at BNY were 50 mph with gusts to over 80 mph. With over 60 knot 700 mb winds at KNKX, winds gusted to 52 mph at RAN and 42 mph at JUL. Southeast rotor winds at KPSP gusted to over 40 mph.

The areas with high winds were the San Bernardino and Riverside County Mountains, the Apple/Yucca Valleys, and the Coachella Valley. The San Diego County Deserts were at least close.

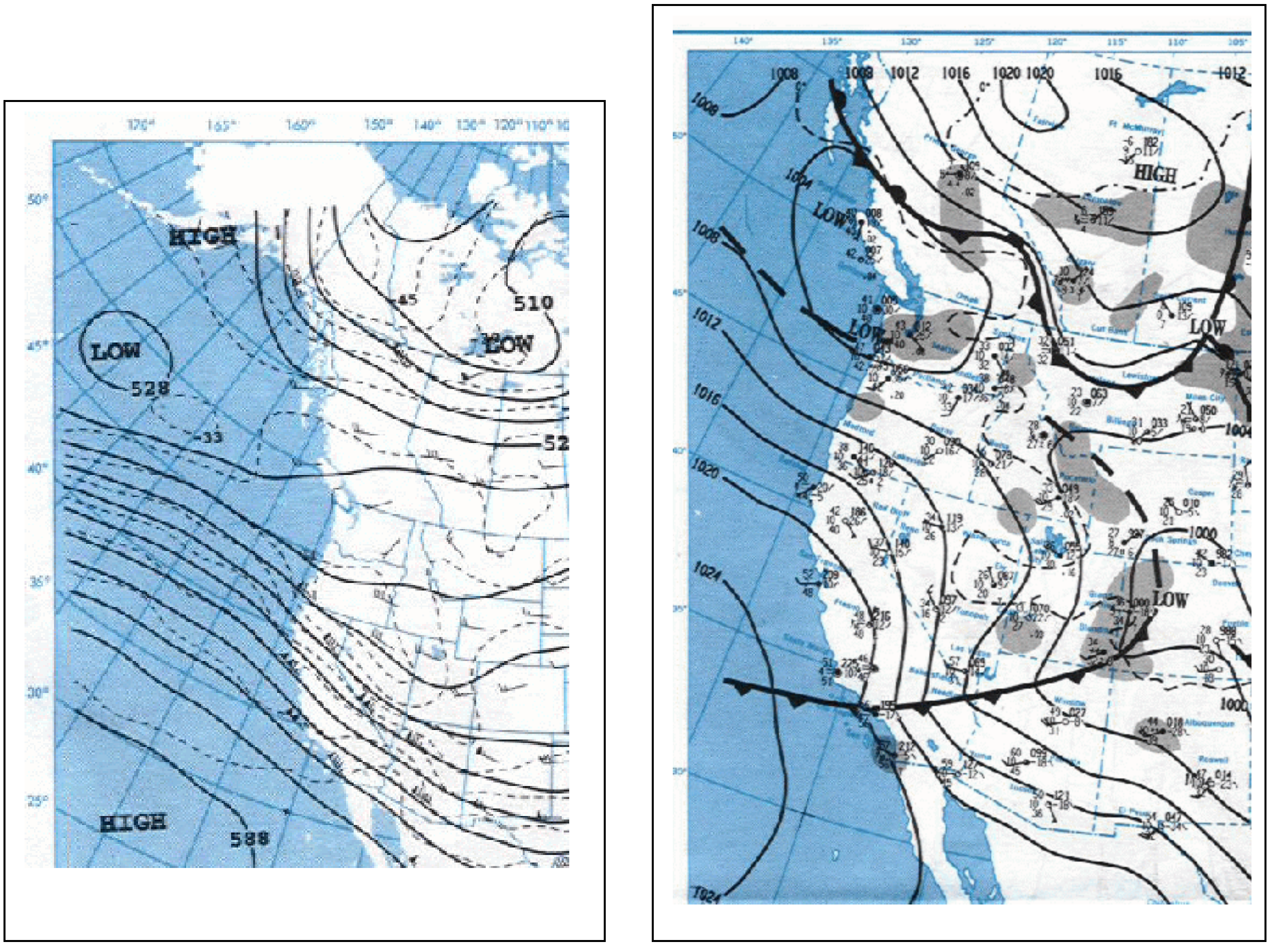
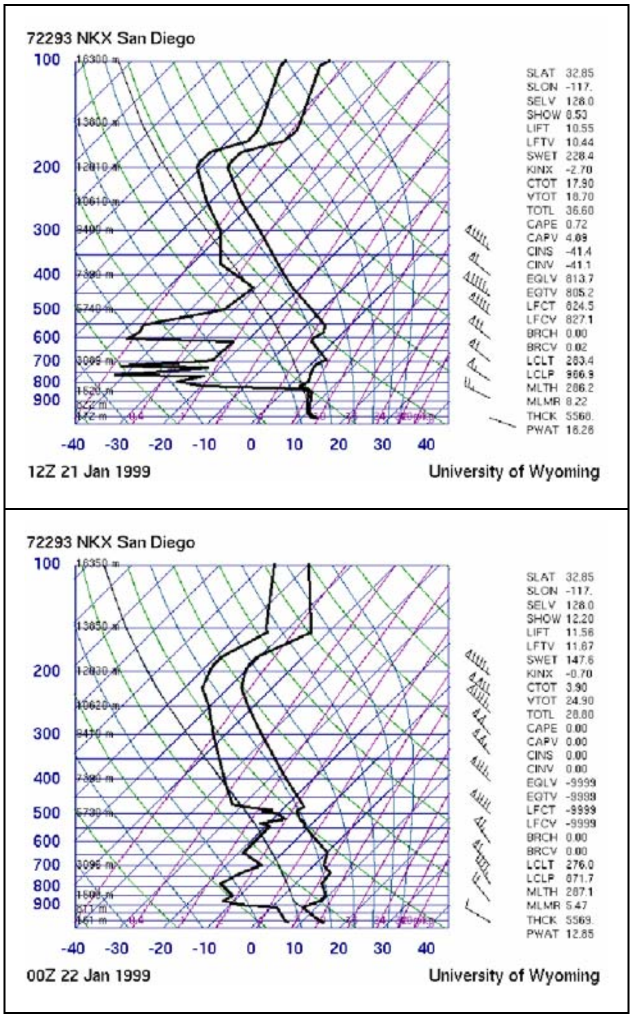


Figure B4. 1200 UTC 21 January 1999 500 mb heights in decameters, temperatures in degrees C, and winds in knots (left), along with station plots and mean sea level pressure in mb (right).

SURFACE PRESSURE GRADIENT (1200 UTC)	**DATE: 21 JAN 1999**
LAX-SFO	**+1.4**
LAX-WMC	**+7.6**
LAX-TPH	**+9.8**
LAX-LAS	**+12.6**
SAN-IPL	**+6.0**
SAN-YUM	**+8.5**

Table B2. Surface pressure gradient data.



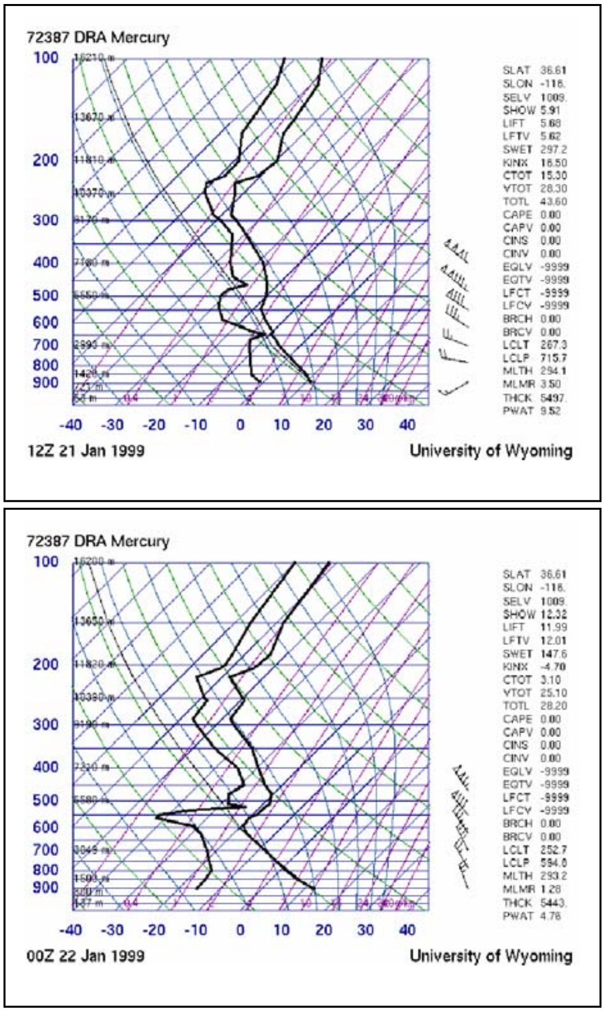


Figure B5. KNKX sounding data.

Figure B6. KDRA sounding data.

TYPE 2. Open Wave Onshore Flow Pattern (upper level progressive trough)

On **17 January 1998** a strong, deep surface low and associated upper level trough moved through southern California. Some all-time low pressure records were set in southern California. As the low deepened and moved through southern California (a common feature of very strong events for strong wind as well as heavy rain) a wind gust to 64 mph was recorded at KSAN (San Diego Lindbergh Field) setting the all time record.

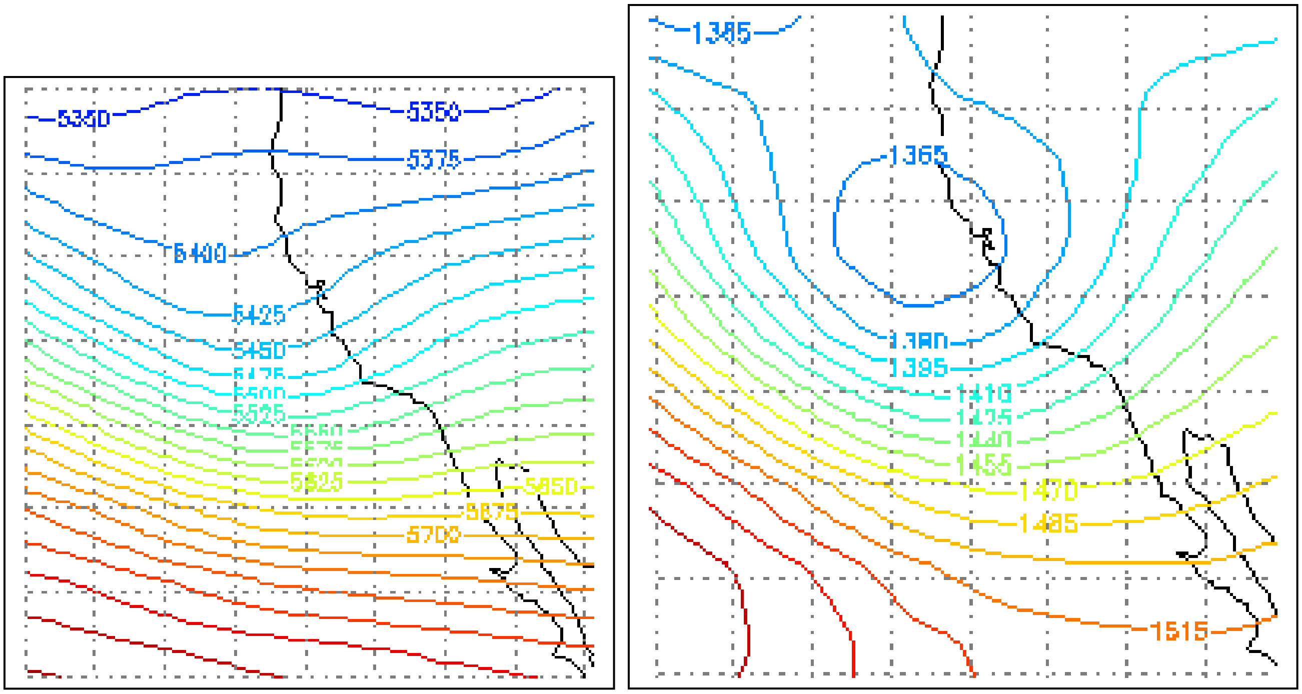
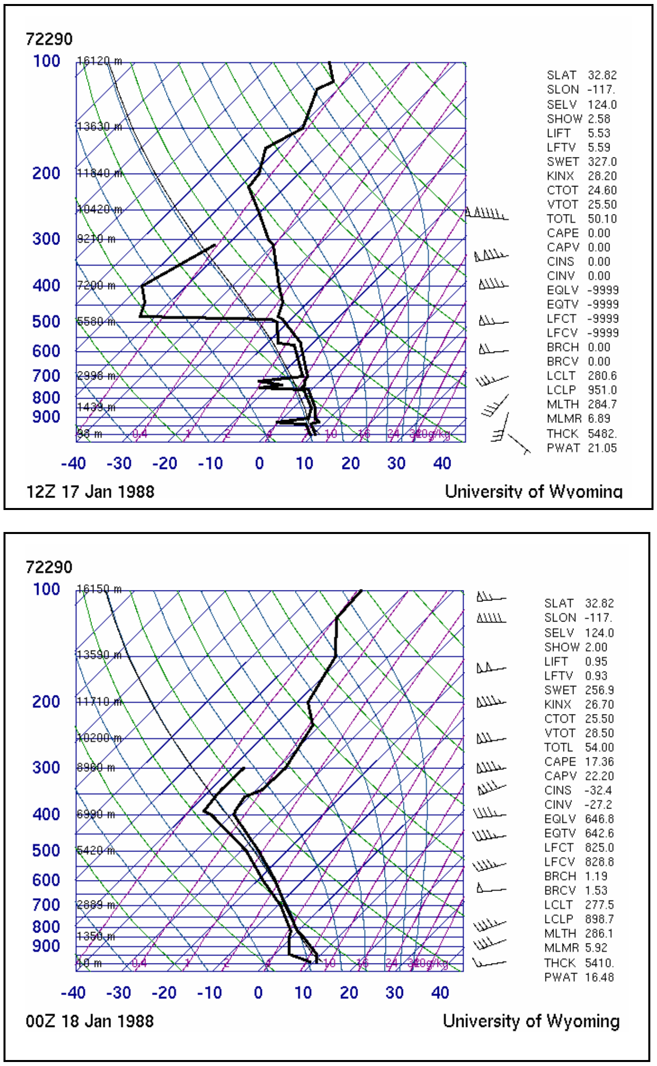


Figure B7. 1200 UTC 17 January 1988 500 mb heights in decameters (left) and 850 mb heights in decameters (right).

NO SURFACE PRESSURE GRADIENT DATA AVAILABLE.



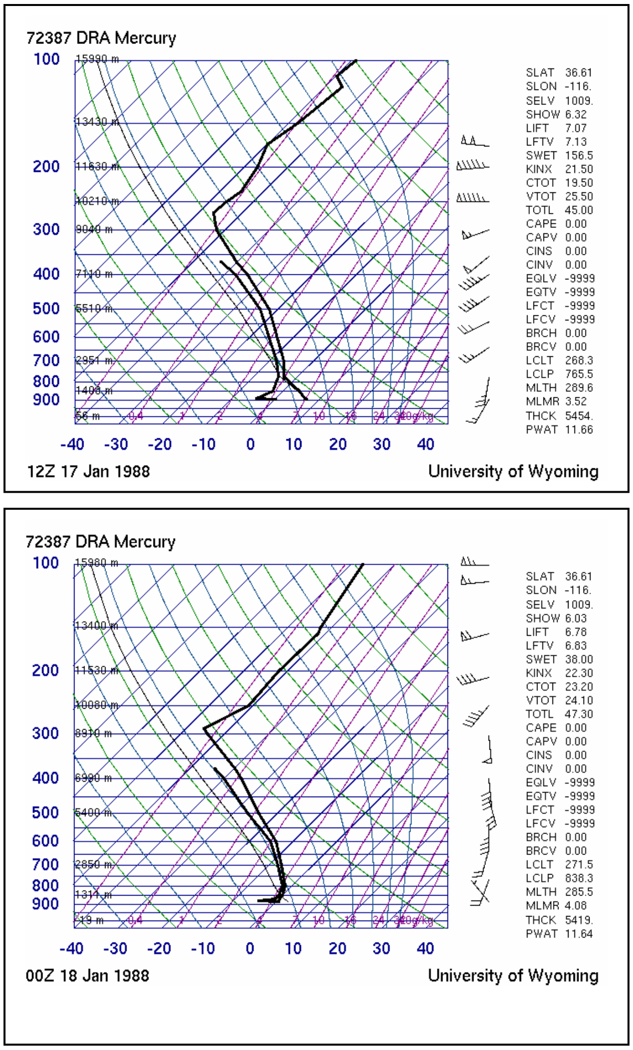


Figure B8. KMYF sounding data.

Figure B9. KDRA sounding data.

TYPE 3. Cyclonic Onshore Flow Pattern (Cut-off upper low/cyclonic pattern, or “Southwest Wind Pattern”)

On **26 November 1997** a low from the gulf of Alaska, fueled with cold air from a Northwest Express, dropped south out of strong zonal flow. The pressure dropped to around 992 mb and generated a surface pressure gradient in the neighborhood of 10-15 mb from the southern California coastal areas to San Francisco Bay Area as the low tracked east. (This is a deviation from the usual strong gradient from the coast to KLAS typically found with strong onshore events). The strong pre-frontal flow generated high winds in the mountains and deserts. The afternoon 850/700 mb wind couplets were 31/45 knots at KNKX and 35/45 knots at KDRA. Winds gusted to over 70 mph in the Victorville/Apple Valley/Yucca Valley areas with trees and power lines down. A section of roof was torn off in the upper deserts, and a middle school was closed. Since 2 times the 850 mb wind speed is approximately 70-80 mph where the wave surfaces, the highest reported gusts are approximately what is expected for the 850 mb wind speed on the soundings. Breezy to windy conditions are usually widespread with these types of events, with high winds over and downwind of the mountains. (Pressure gradient and sounding data are on the next page).

High winds occurred in the Apple and Yucca Valleys zone. High winds may have occurred in the Santa Ana Mountains zone also, with wind advisory level winds coastal areas since there was a gust potential of at least 31 knots in the coastal areas, which was the 850 mb wind speed. Surface gusts could have reached 1 ½ times as large with the frontal passage.

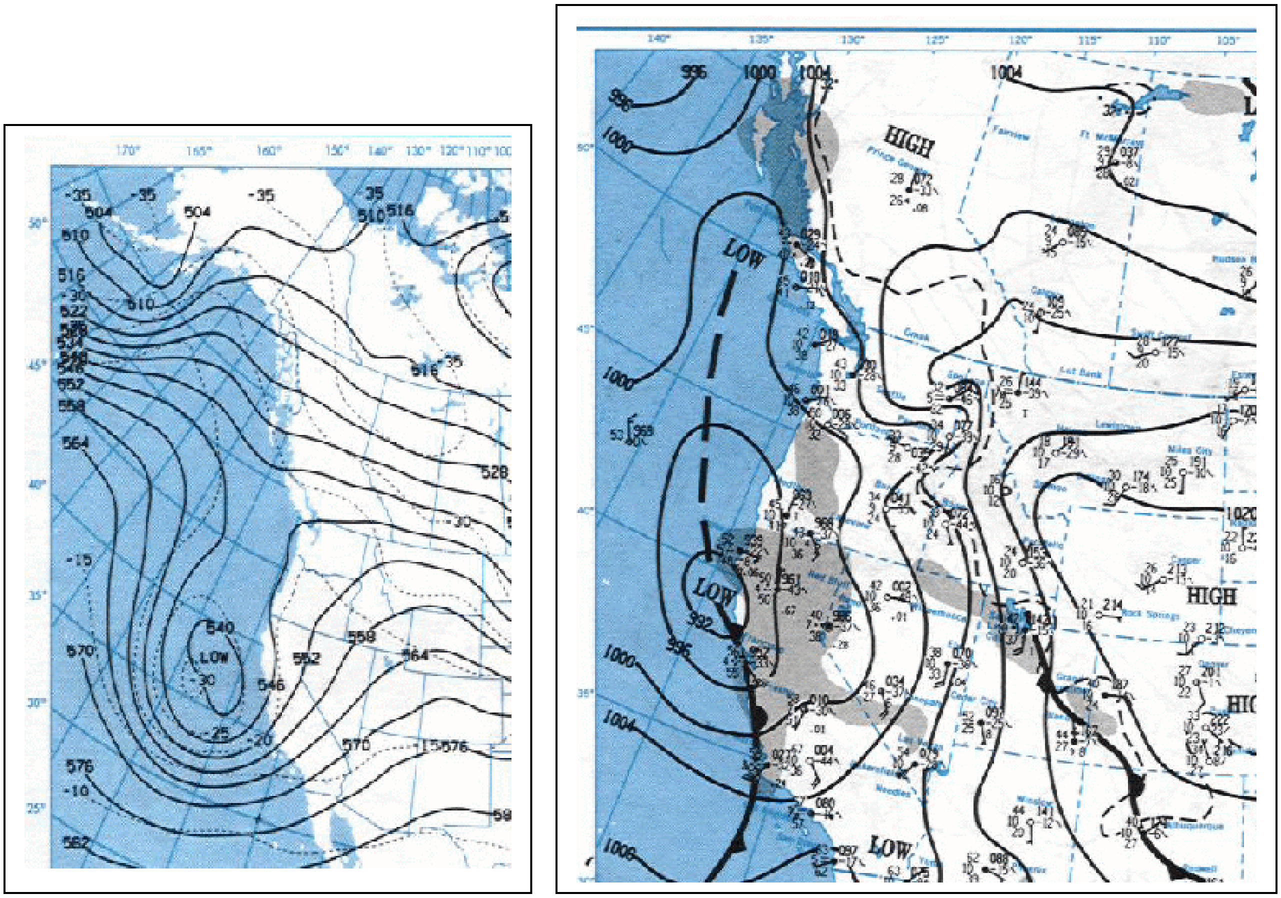
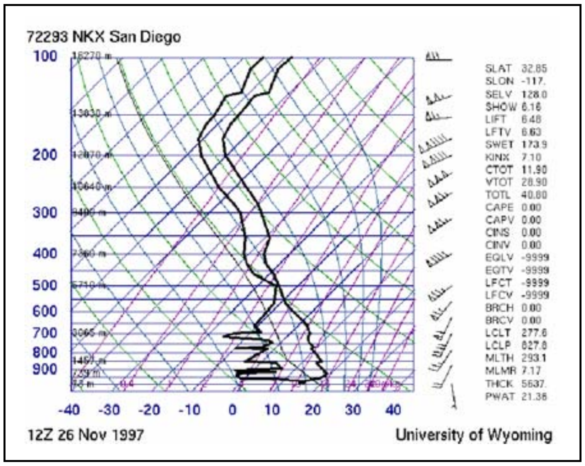


Figure B10. 1200 UTC 26 November 1997 500 mb heights in decameters, temperatures in degrees C, and winds in knots (left), along with station plots and mean sea level pressure in mb (right).

SURFACE PRESSURE GRADIENT (1200 UTC)	**DATE: 26 NOV 1997**
LAX-SFO	**+12.8**
LAX-WMC	**+7.8**
LAX-TPH	**+4.6**
LAX-LAS	**+0.1**
SAN-IPL	**MISG**
SAN-YUM	**+2.0**

Table B3. Surface pressure gradient data.



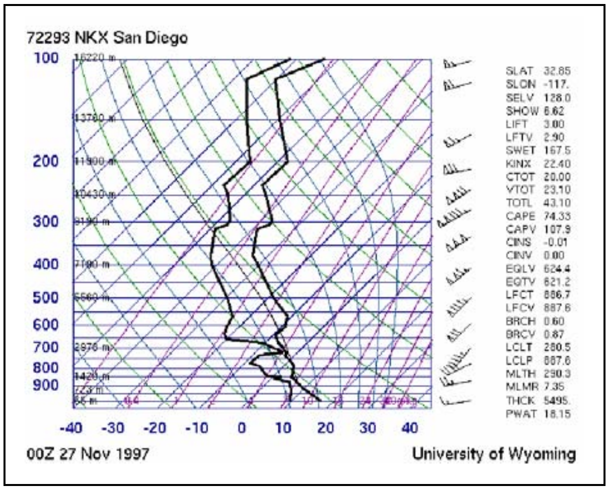
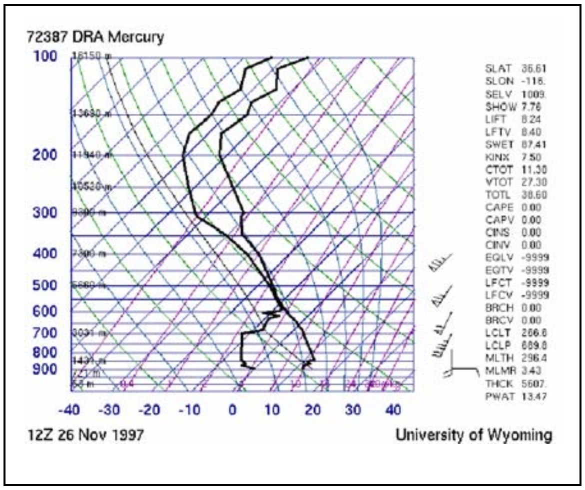


Figure B11. KNKX sounding data.



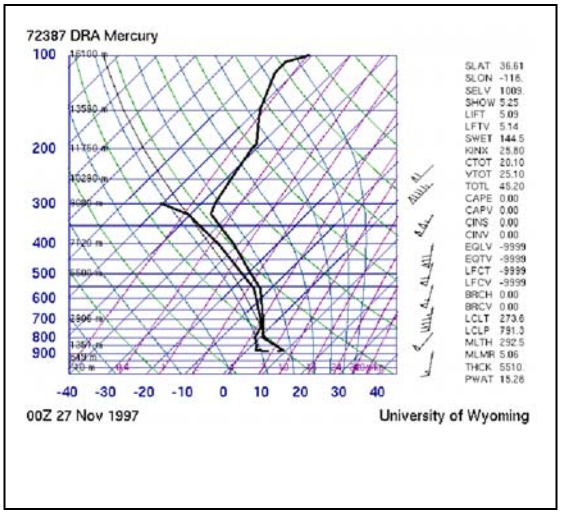


Figure B12. KDRA sounding data.

Appendix C. High Surf and Large Swell Events

TYPE 1. Strong Zonal Flow High Surf and Large Swell Pattern (strong sagging jet)

On **15 December 2002** high surf breaking between 10 and 15 feet caused strong rip currents and 3 feet of beach erosion along Orange and San Diego County beaches (Approximately KSNA to KSAN). Sand berms constructed to block wave "run-up" were overtopped and eroded during high tides. Swell at Tanner Banks Buoy reached 6.68 meters (about 21 feet). The Santa Monica Basin Buoy swells reached about 3.55 meters (11 ½ feet), which corresponds to at least 11 ½ foot breakers. Periods were quite large (up to around 16.5 seconds).

There was approximately a 560 meter 500 mb height gradient near 140 west longitude in the 25-40 north latitude range, near optimal for generating high surf.

Conditions on 14 December 2002 are shown below (The "swell generation period" the day before the event). (Sounding data and maps for the day of the event are on the next page).

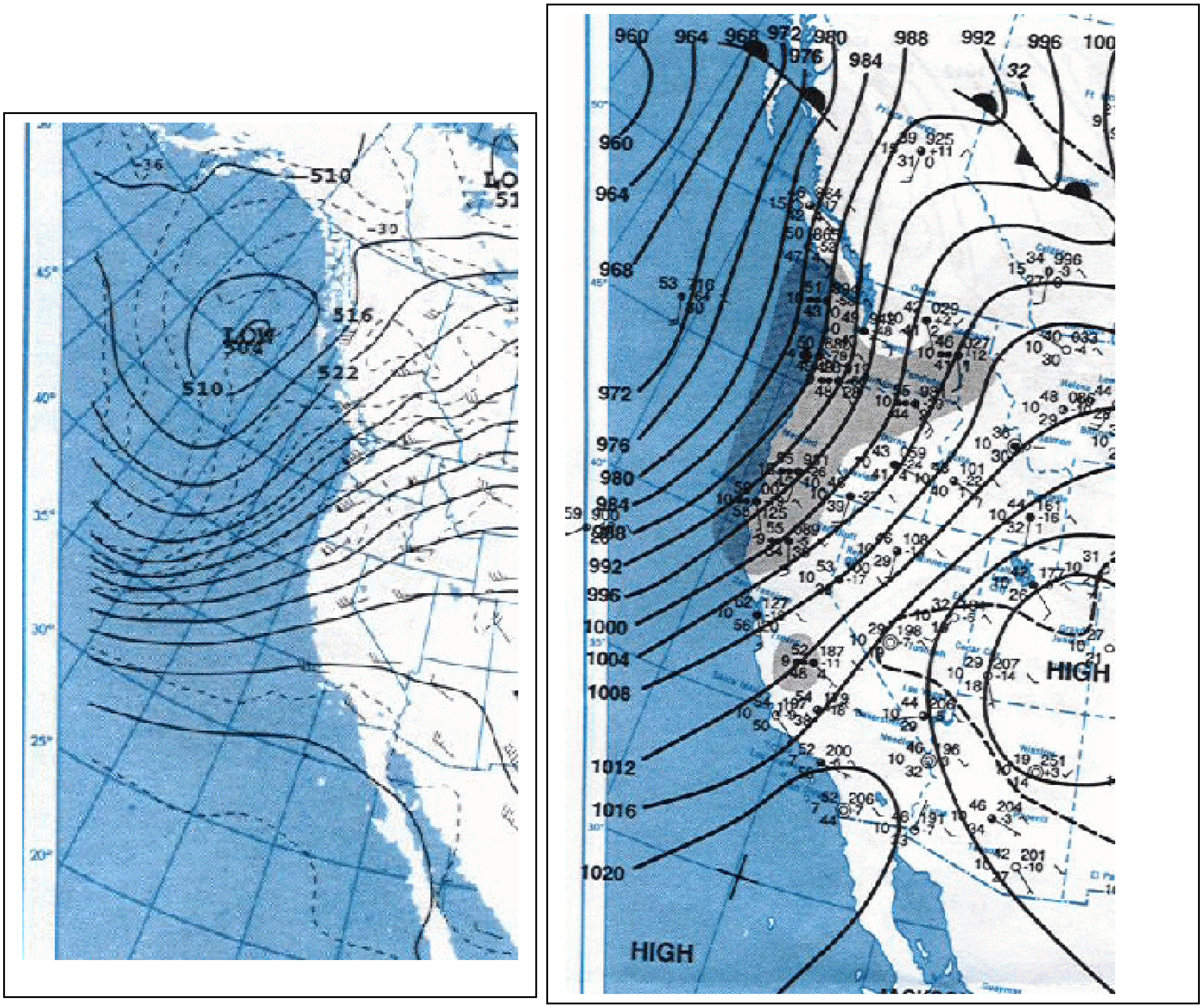


Figure C1. 1200 UTC 14 December 2002 500 mb heights in decameters, temperatures in degrees C, and winds in knots (left), along with station plots and mean sea level pressure in mb (right).

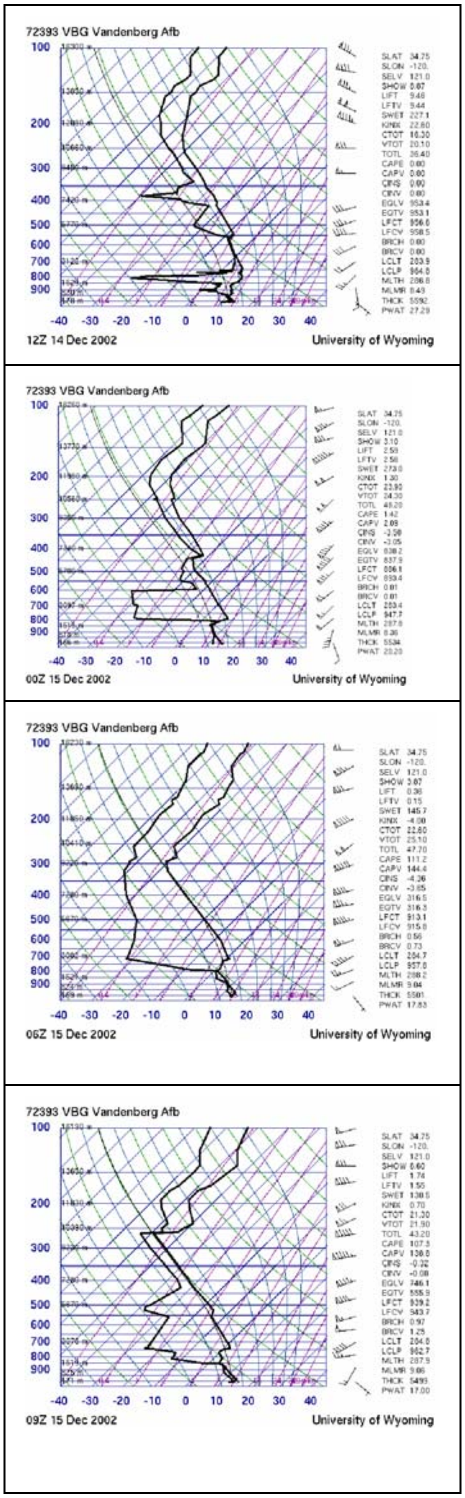


Figure C2. KVBG soundings

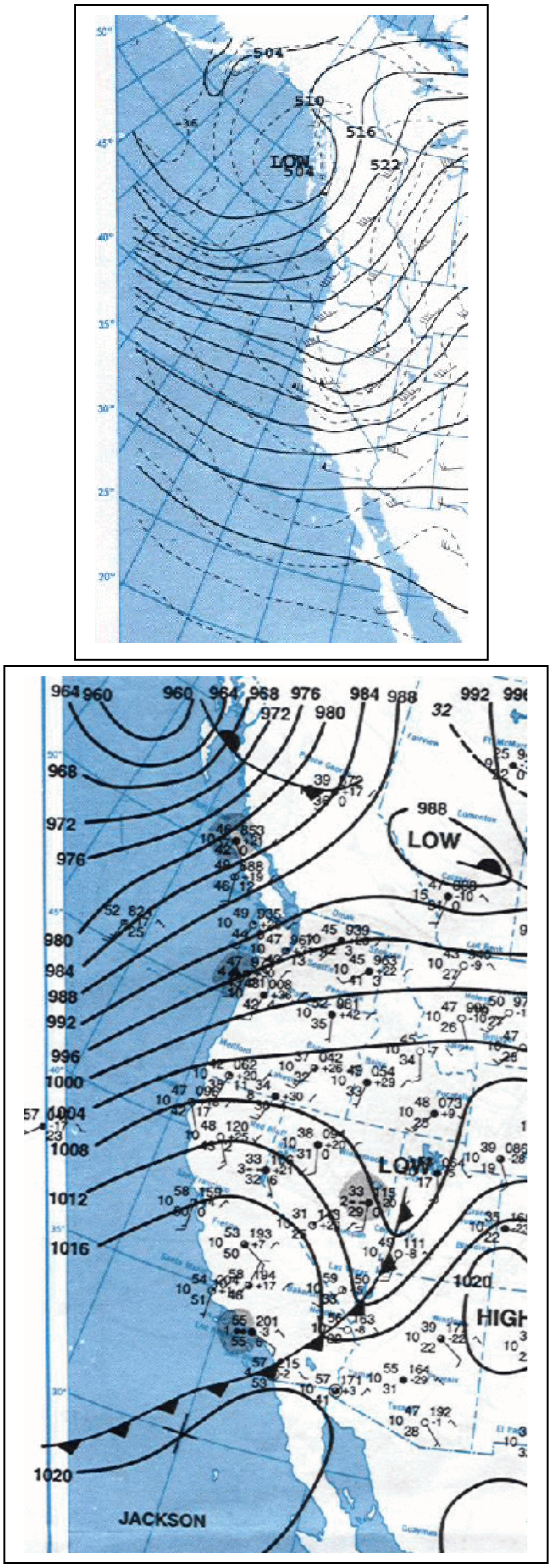


Figure C3. 1200 UTC 15 December 2002 500 mb heights in decameters, temperatures in degrees C, and winds in knots (top), along with station plots and mean sea level pressure in mb (bottom).

TYPE 2. Open Wave High Surf and Large Swell Pattern (upper level progressive trough)

On **3 December 2001** Tanner Banks Buoy reached 5.91 meters or over 19 feet. Santa Monica Basin Buoy reached about 10 feet, which corresponds to at least 10 foot breakers. Periods were quite large (up to around 16.5 seconds). During that evening Ocean Beach Pier near KSAN was slightly damaged by waves over the top of the pier The Crystal Pier in Pacific Beach (KSAN area) was also closed due to high waves.

On 2 December 2001, the day before the high surf and swell event, there was approximately a 500 meter 500 mb height gradient at 140 west longitude in the 25 to 40 north latitude range, near optimal for generating high surf.

The maps below show the conditions on 2 December 2001 (The "swell generation period" the day before the event). (Sounding data and maps for the day of the event are on the next page).

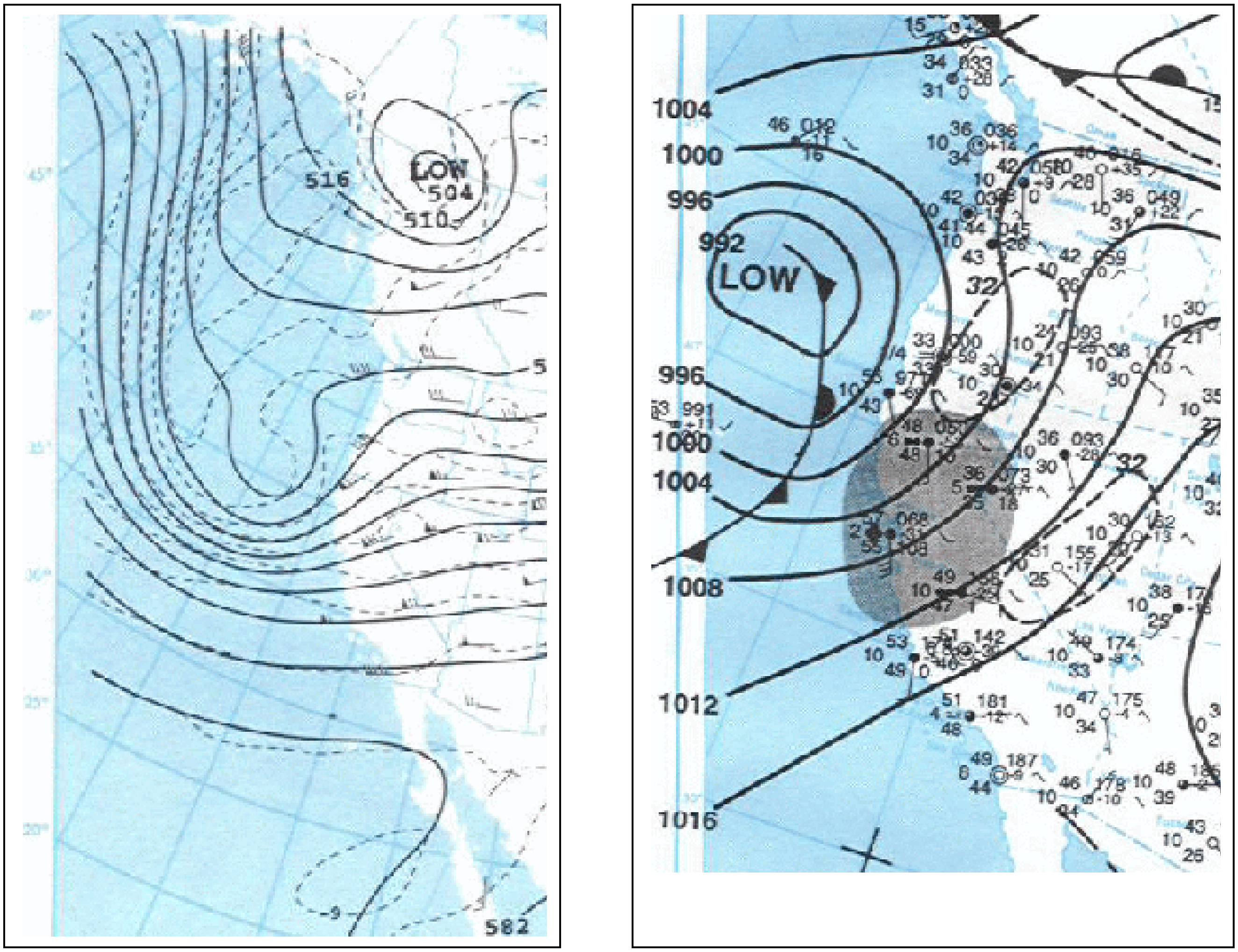


Figure C4. 1200 UTC 2 December 2001 500 mb heights in decameters, temperatures in degrees C, and winds in knots (left), along with station plots and mean sea level pressure in mb (right).

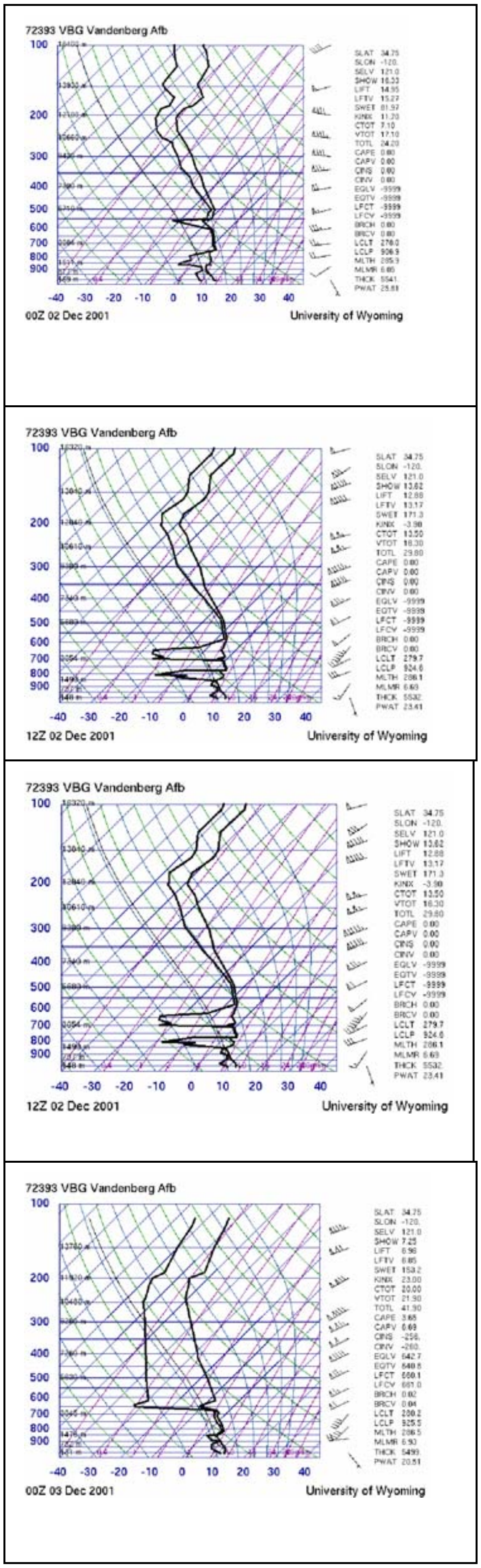


Figure C5. KVBG sounding data.

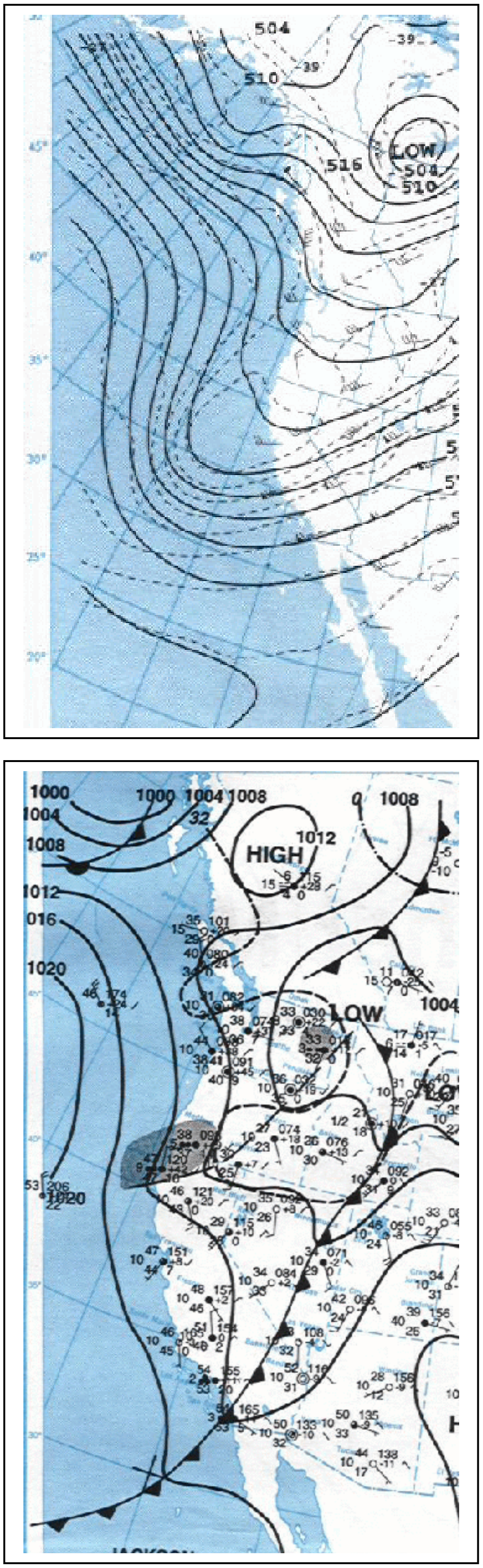


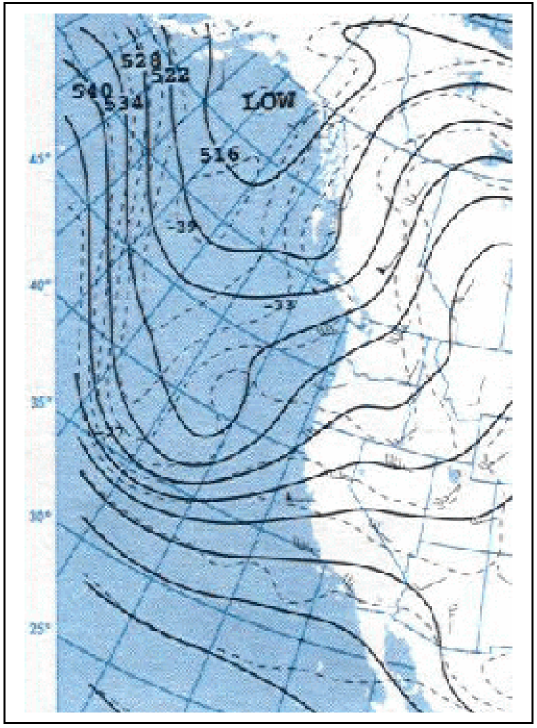
Figure C6. 1200 UTC 3 December 2001 500 mb heights in decameters, temperatures in degrees C, and winds in knots (top), along with station plots and mean sea level pressure in mb (bottom).

TYPE 2. Open Wave High Surf and Large Swell Pattern (upper level progressive trough)

On **11 January 2001** the swell at Tanner Bank buoy was 6.68 meters (about 22 feet). Swells at Santa Monica Basin Buoy rose to around 7 feet, which usually means breakers at least as high, with max sets another 33 % in favored locations. A combination of high tides and very high surf caused a sea wall in Ocean Beach near KSAN to erode, and the foundations of several condominiums were undercut. Piers and the entrance to Mission Bay near KSAN were closed due to large breaking waves, which peaked at about 1800 UTC. (Earlier, on the 9th, a very high tide combined with 4 foot surf eroded a sand berm. The water spilled into a community in Seal Beach near KSNA and flooding (2 feet of water was reported) affected 2 dozen homes. Periods jumped up to between 15 and 20 seconds.

A very deep trough developed with this event. On 10 January 2001, the day before the event, there was approximately a 450 meter 500 mb height gradient near 140 west longitude in the 25 – 40 north latitude range, near optimal for generating high surf.

Conditions on 10 January 2001 are shown on the maps below (The "swell generation period" the day before the event). (Sounding data and maps for the day of the event are on the next page).



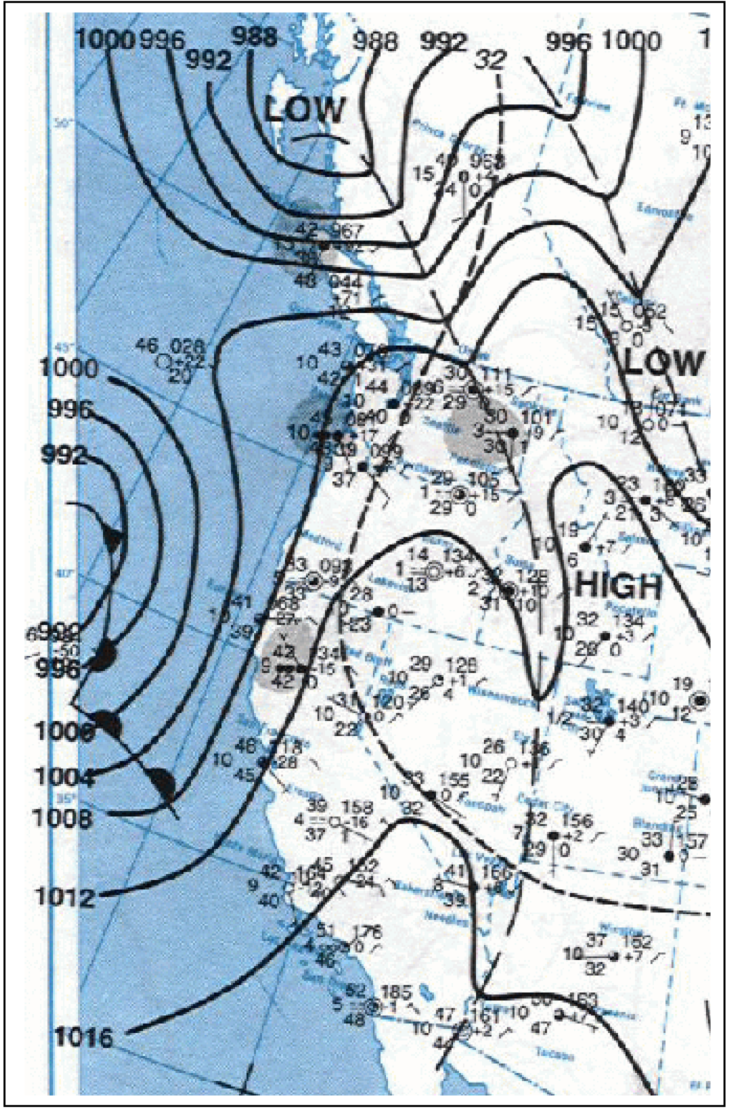


Figure C7. 1200 UTC 10 January 2001 500 mb heights in decameters, temperatures in degrees C, and winds in knots (left), along with station plots and mean sea level pressure in mb (right).

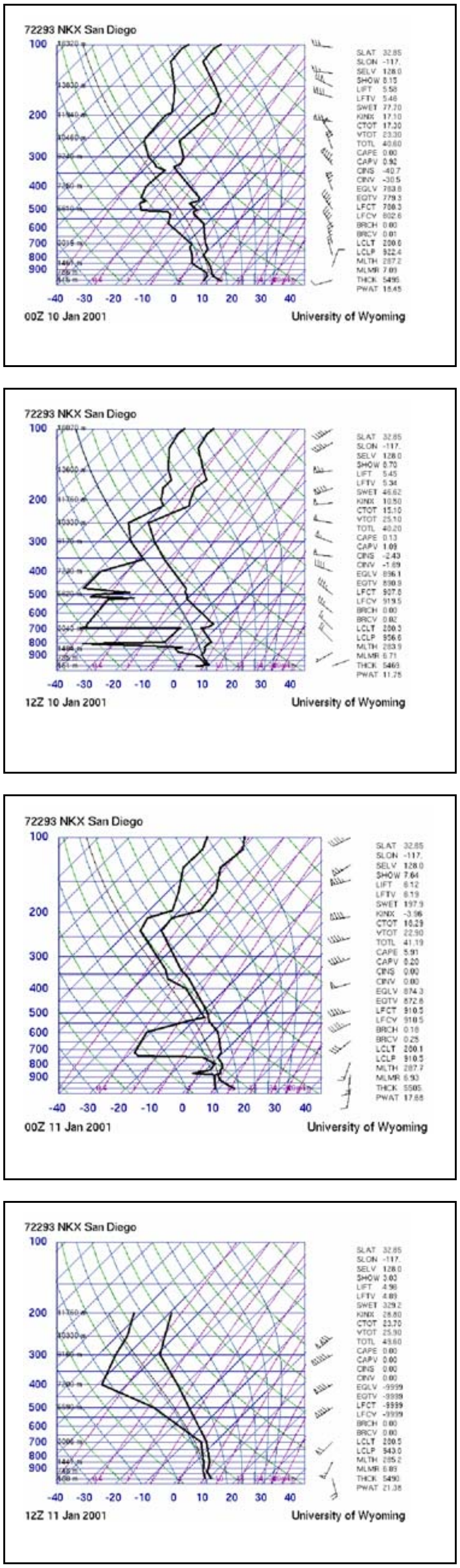


Figure C8. KNKX sounding data.

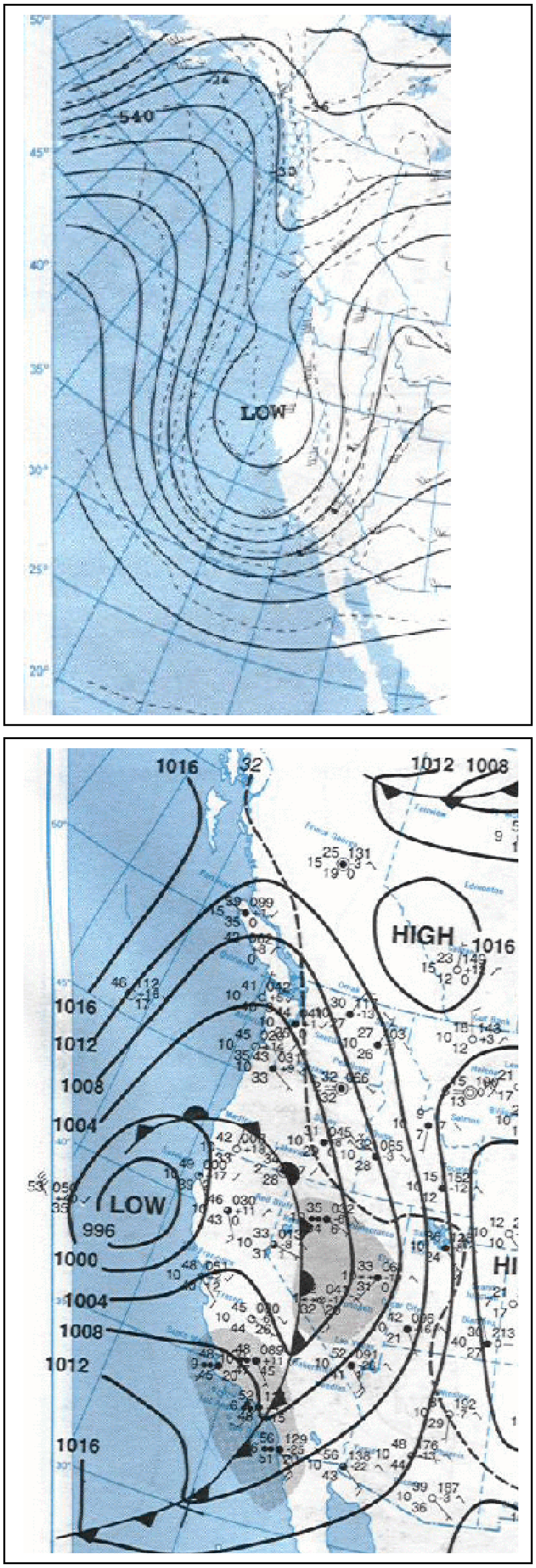


Figure C9. 1200 UTC 11 January 2001 500 mb heights in decameters, temperatures in degrees C, and winds in knots (top), along with station plots and mean sea level pressure in mb (bottom).

TYPE 2. Open Wave High Surf and Large Swell Pattern (upper level progressive trough)

On **17 January 1998** damaging surf was created by 26 foot swells with a 16 ½ second interval as reported at Santa Monica Basin buoy. A strong, deep surface low and associated upper level trough moved through southern California and created the large swells. Some all-time low pressure records were set in southern California. As the surface low deepened and moved through southern California (a common feature of very strong events), the all-time record 64 mph wind gust occurred at San Diego Lindbergh Field (KSAN). On 16 January 1998, the day before the event, there was approximately a 500 meter 500 mb height gradient near 140 west longitude in the 25-40 north latitude range, near optimal for generating high surf with long periods.

Conditions on 16 January 1988 are shown on the maps below (The "swell generation period" the day before the event). (Sounding data and maps for the day of the event are on the next page).

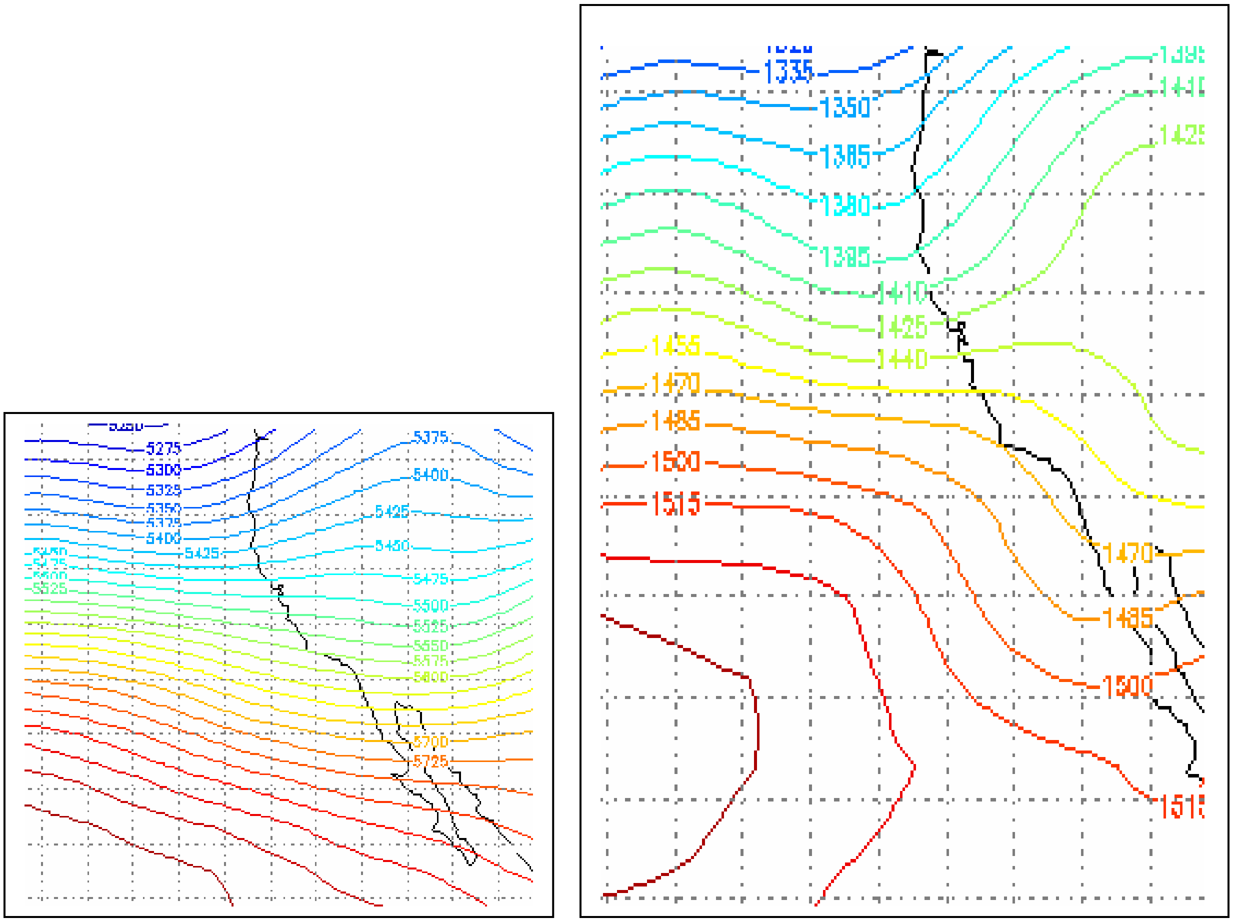


Figure C10. 1200 UTC 16 January 1988 500 mb heights in decameters (left) and 850 mb heights in decameters (right).

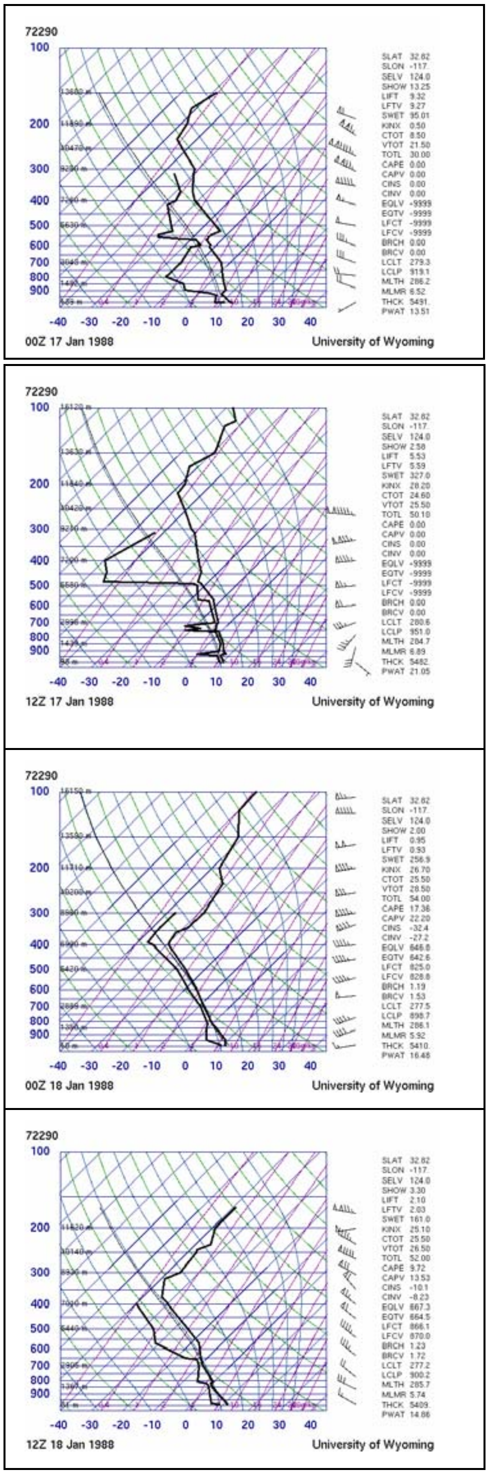


Figure C11. KMYF sounding data.

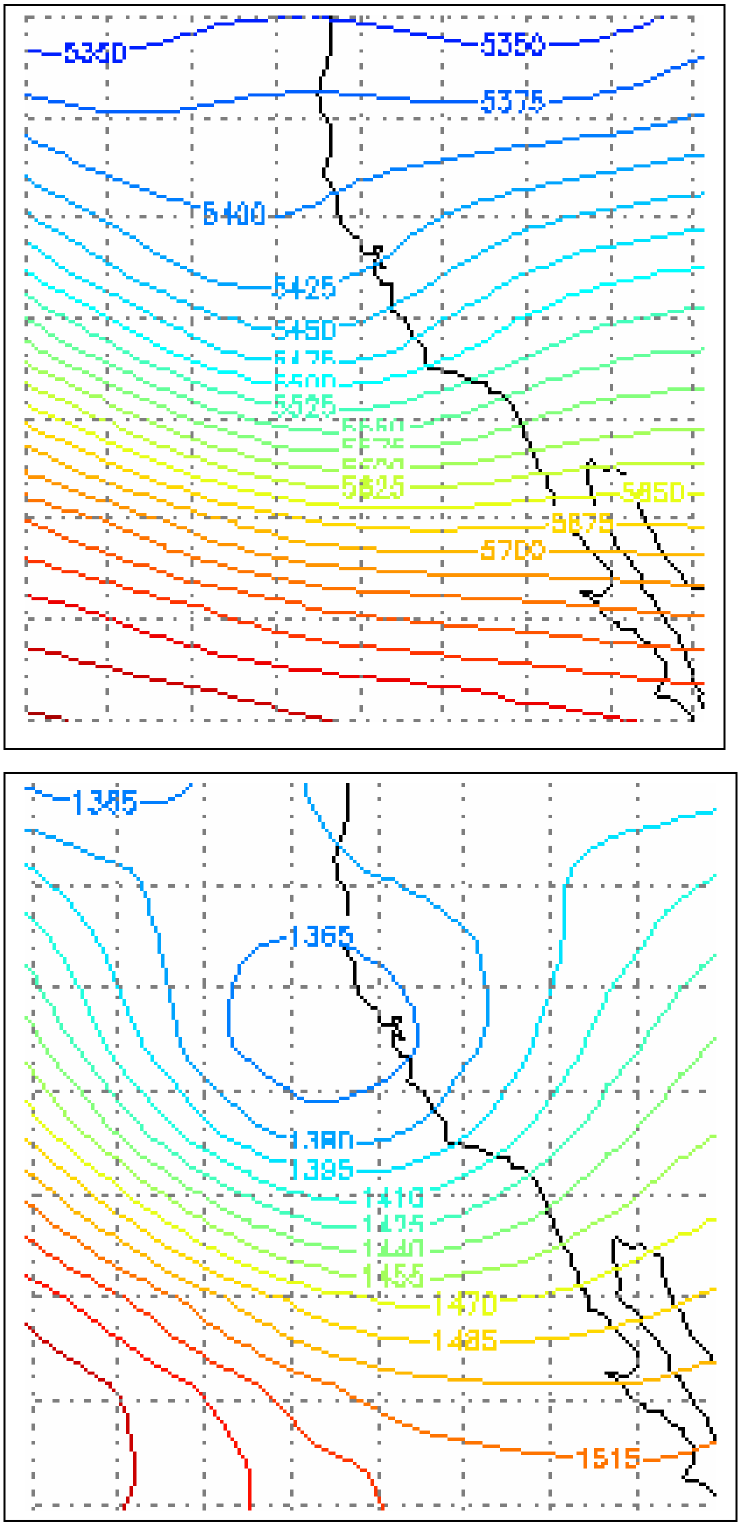


Figure C12. 1200 UTC 17 January 1988 500 mb heights in decameters (top) and 850 mb heights in decameters (bottom).

TYPE 3. Cyclonic Onshore Flow High Surf and Large Swell Pattern (cut-off upper low)

On **12 February 2001** a deep cut-off upper low generated very large swells and high surf. There was approximately a 300 meter 500 mb height gradient at near 130 west longitude in the 25-40 north latitude range, enough for generating high surf. Tanner Banks Buoy reached 6.68 meters (around 22 feet). Swells at Santa Monica Basin Buoy peaked around 14 feet, however the close proximity of the swell generation area resulted in periods of approximately 9 seconds (fresh swell). This storm was reported to have generated at least 12 foot seas in some areas.

Conditions on 11 February 2001 (the "swell generation period" the day before the event) are shown on the maps below. (Sounding data and maps for the day of the event are on the next page).

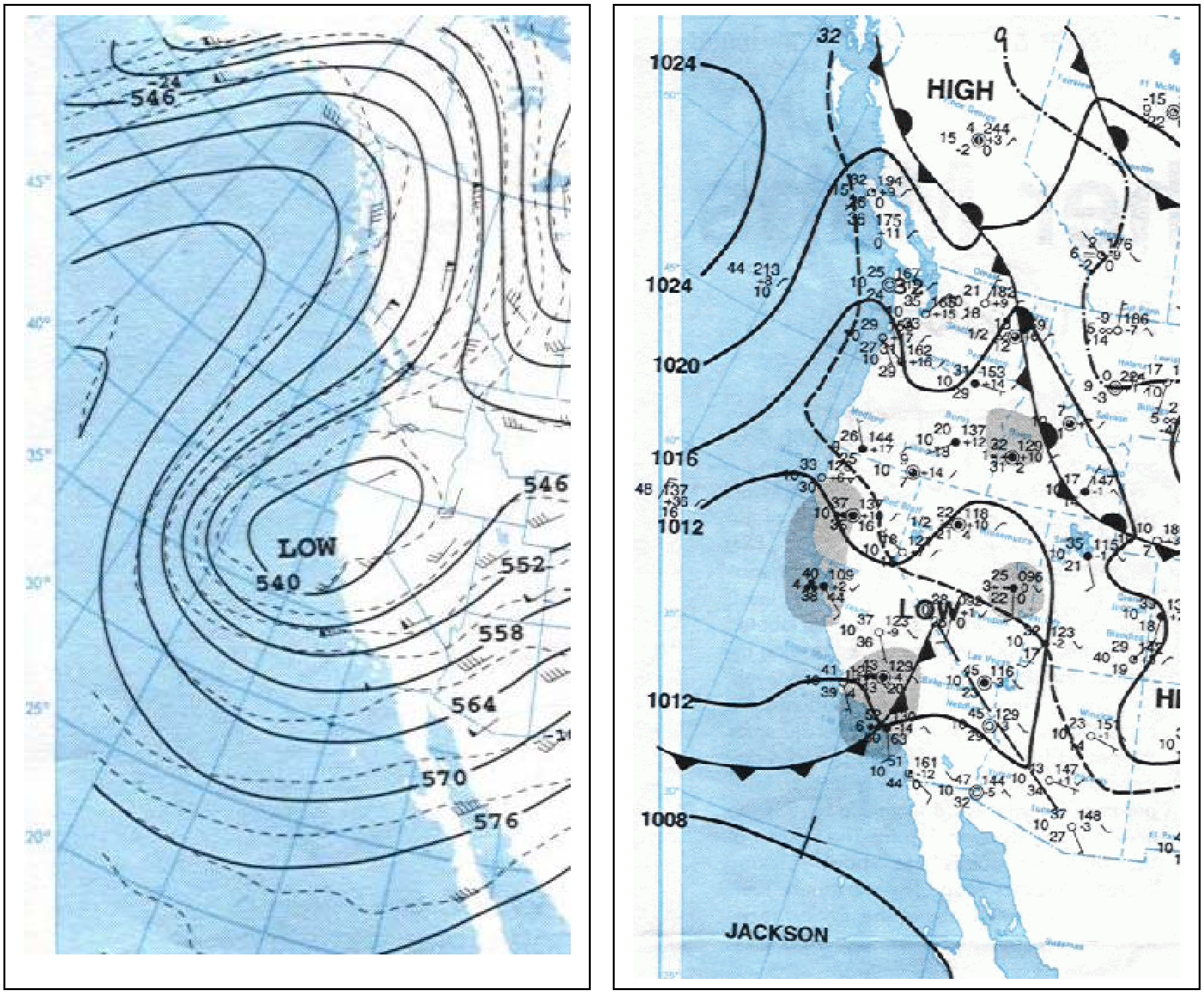


Figure C13. 1200 UTC 11 February 2001 500 mb heights in decameters, temperatures in degrees C, and winds in knots (left), along with station plots and mean sea level pressure in mb (right).

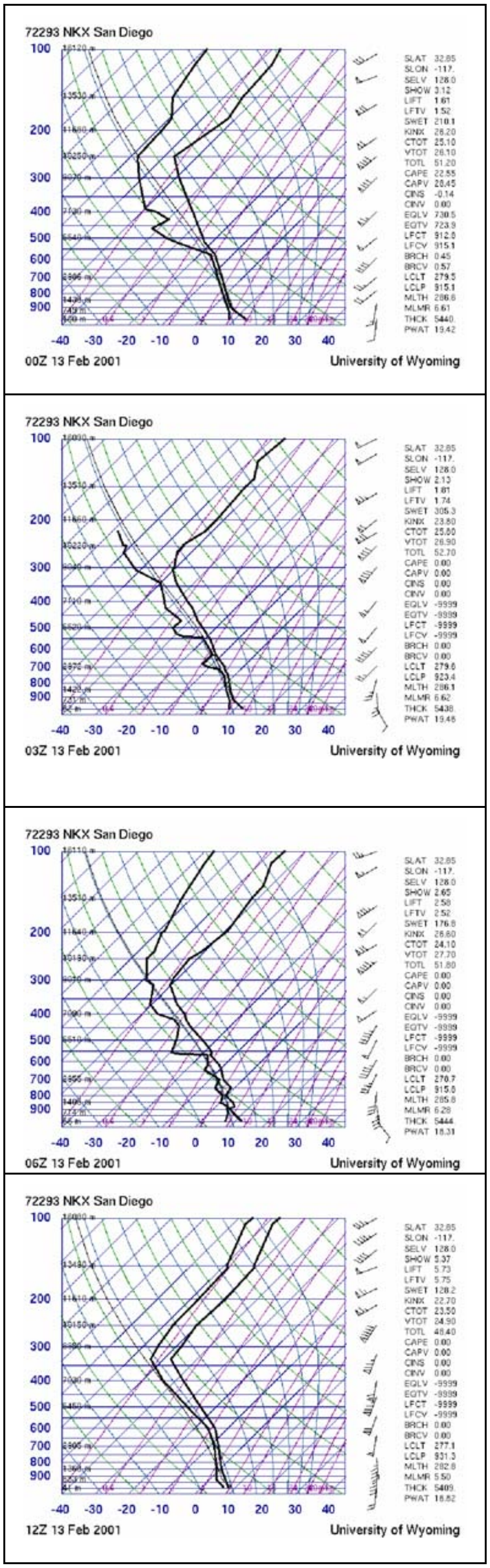


Figure C14. KNKX sounding data..

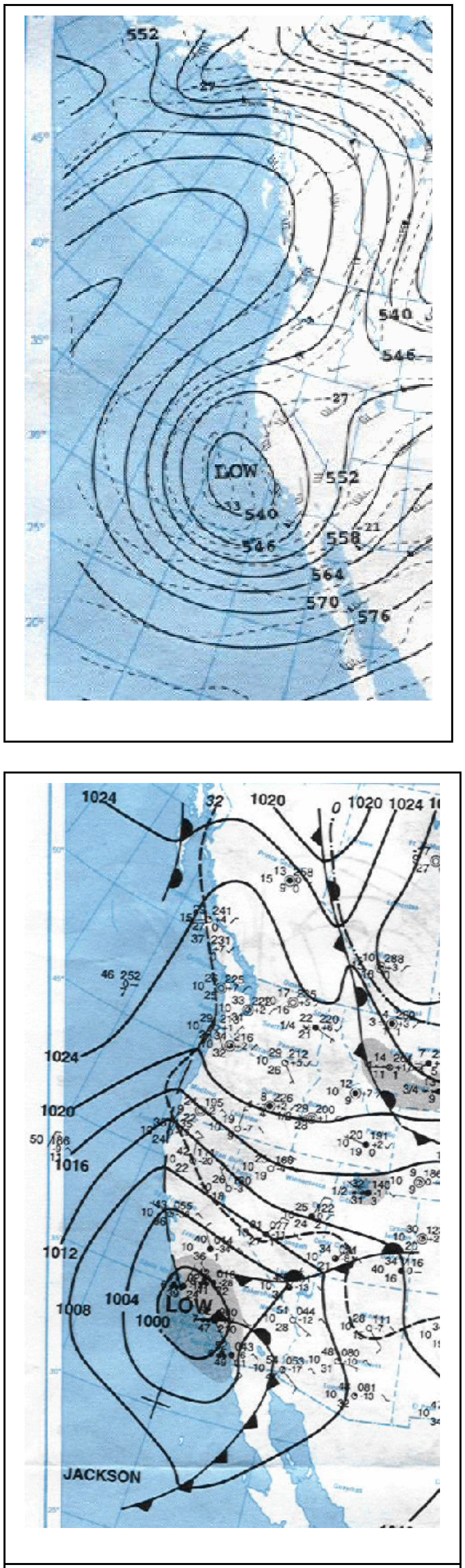


Figure C15. 1200 UTC 12 February 2001 500 mb heights in decameters, temperatures in degrees C, and winds in knots (top), along with station plots and mean sea level pressure in mb (bottom).

TYPE 4. Offshore Flow High Surf and Large Swell Pattern (Low Level Easterly Flow)

On **9 December 1998** an offshore wind pattern developed at 850 mb. Since the fetch was in the coastal waters, rather large wind waves were generated with very short wave periods.

East winds at Santa Monica Basin buoy began at 1000 UTC 9 December 1998 with swells at only 1.09 meters (only about 3 1/2 feet) with a 5 second period (essentially a wind wave). By 1600 UTC 9 December 1998 the sustained 12-15 knot winds at Santa Monica Basin Buoy (but much stronger closer to the coast) resulted in swell heights of 2.39 meters (approximately 8 feet). Swells of this size and period have a tendency to batter the offshore islands and adjacent waters with choppy seas and swells from the east, along with high surf.

Conditions below are shown for 8 December 1998 just prior to the event [Sounding data and maps for the day of the event (when very short period swell is actually generated) are on the next page].

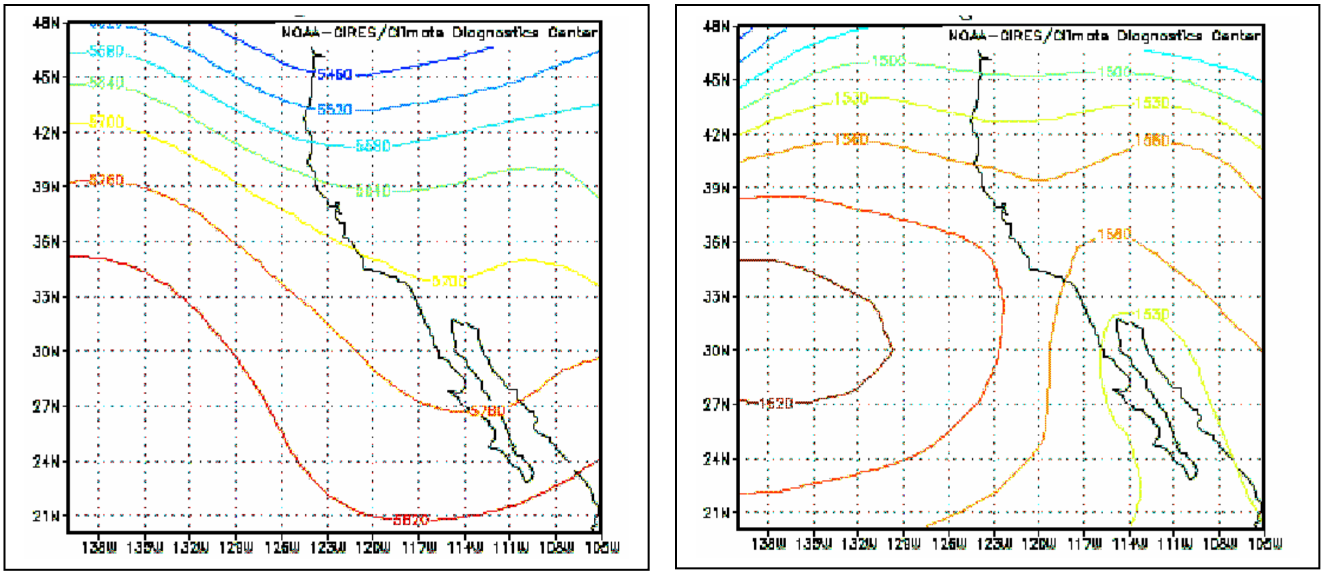
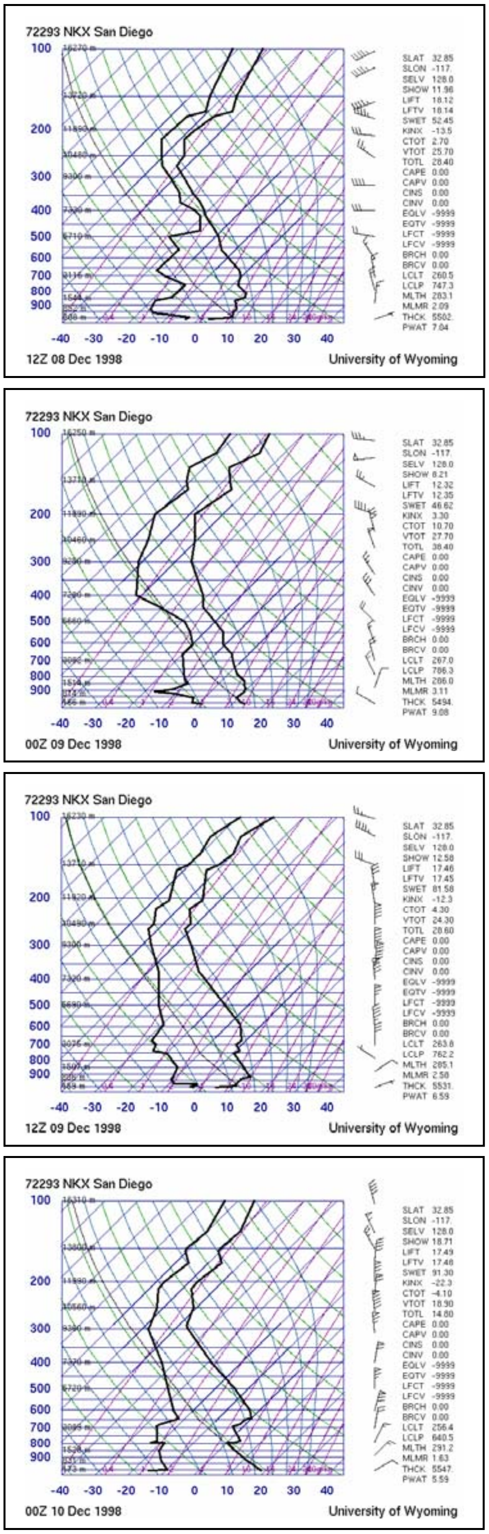


Figure C16. 1200 UTC 8 December 1998 500 mb heights in decameters (left), along with 1200 UTC 8 December 1998 850 mb heights in decameters (right).



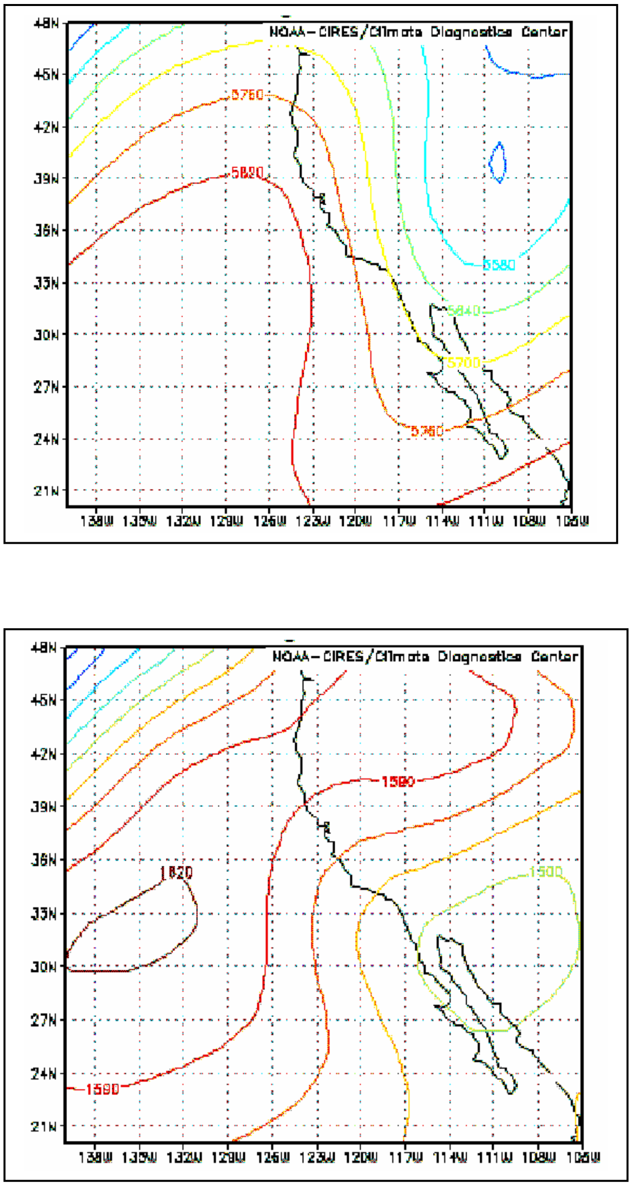


Figure C17. KNKX sounding data.

Figure C18. 1200 UTC 9 December 1998 500 mb heights in decameters (top), along with 1200 UTC 9 December 1998 850 mb heights in decameters (bottom)

TYPE 5. Hurricane/Tropical Storm High Surf and Large Swell Pattern

On 5 September 2004 swells and associated surf from the south ranging from 6 to 12 feet, generated by Hurricane Howard. The combination of an early season surface high building over the plateau and lowered surface pressure off the coast due to tropical depression Howard resulted in offshore flow and afternoon high temperatures reaching the 90s in the coastal areas (96 at San Diego Lindbergh Field). There may have been some residual subsidence around Howard as well helping to increase temperatures. The southerly flow around Howard was the dominant swell generation mechanism since the offshore flow was weak and produced little if any swell. The maps below are for 4 September 2004, the day before the event. The maps for 5 September 2004 are on the following page.

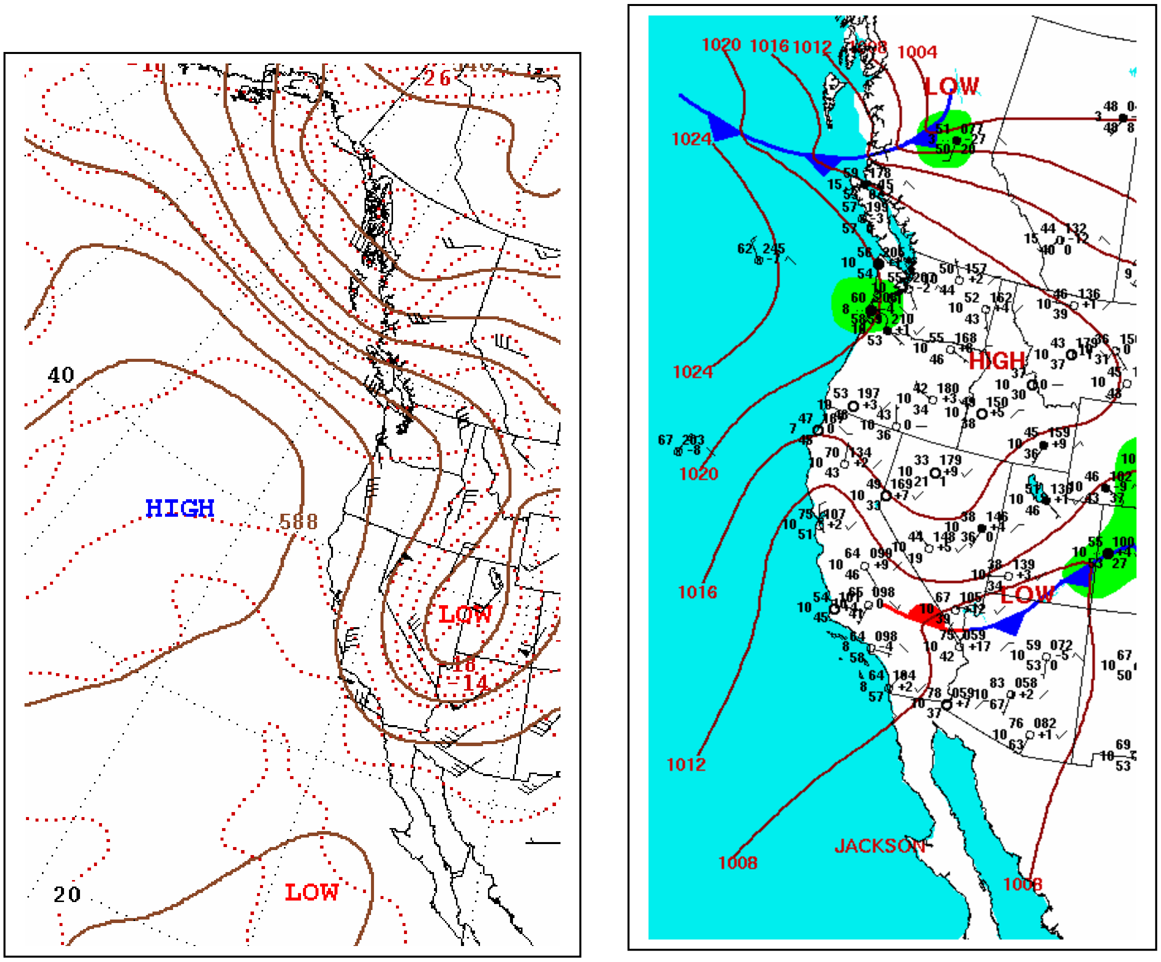


Figure C19. 1200 UTC 4 September 2004 500 mb heights in decameters, temperatures in degrees C, and winds in knots (left), along with station plots and mean sea level pressure in mb (right).

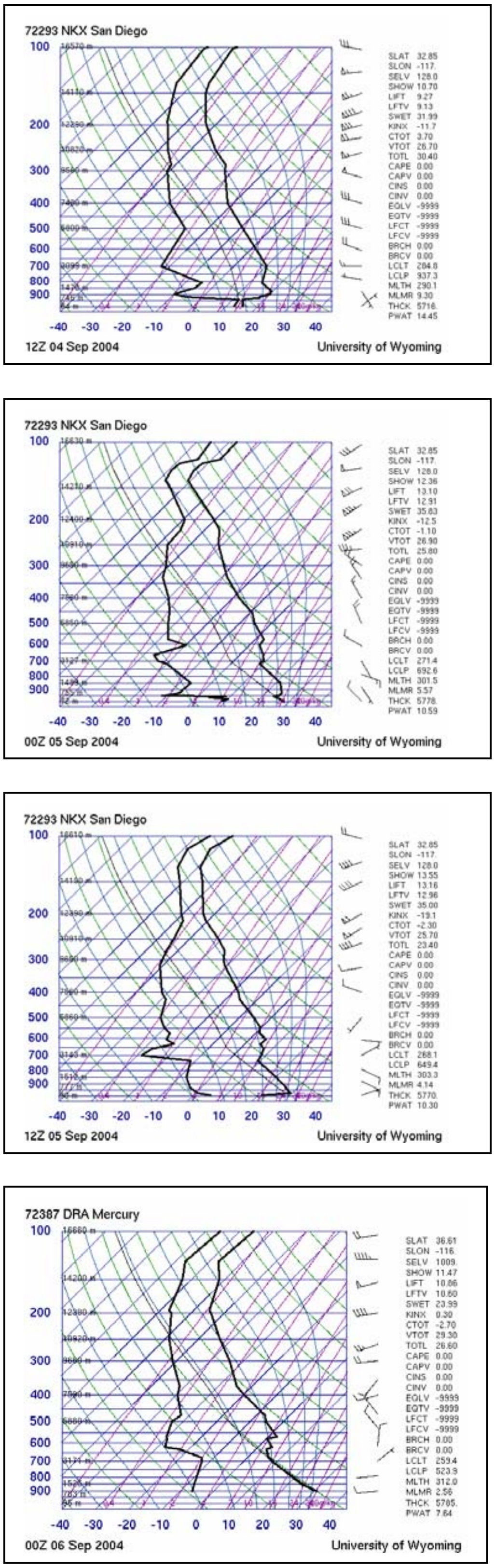


Figure C20. KNKX sounding data.

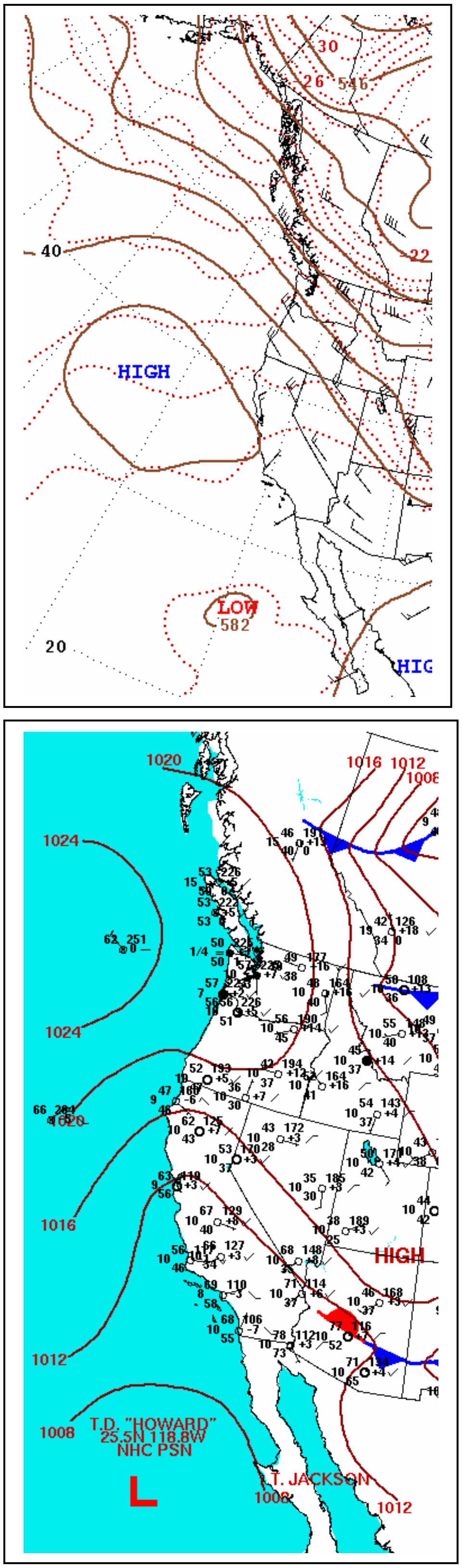


Figure C21. 1200 UTC 5 September 2004 500 mb heights in decameters, temperatures in degrees C, and winds in knots (top), along with station plots and mean sea level pressure in mb (bottom).

TYPE 6. Southern Hemisphere High Surf and Large Swell Pattern

At 1200 UTC on **16 September 2005** the swell at Santa Monica Basin Buoy, some 40 miles west of Los Angeles (KLAX), reached 1.56 meters (5 feet) with a very long period (19 seconds). The swell at San Clemente Basin Buoy, around 20 miles west of San Diego (KSAN) reached 2.44 meters (8 feet) with a 19 second period. The swell at Tanner Banks Buoy (approximately 60 miles west of KSAN) reached 1.95 meters (6 feet) with a 19 second period.

A very strong, slow moving Southern Hemisphere Storm developed east of New Zealand on 8-9 September 2005 and was responsible for the large swells. The strong southerly flow behind the storm was aimed at southern California. It kicked up large swells that traveled along a Great Circle Route through the south Pacific, eventually arriving in southern California about a week later. (Swell typically takes around a week to arrive in southern California from Southern Hemisphere Storms). The swell peaked in southern California on the 16th. The maps shown below are for the swell generation period on the 8th and the maps on the following page shows the continued generation of swells on the 9th to give some idea of how long the winds acted on the ocean to produce such large swells in southern California.

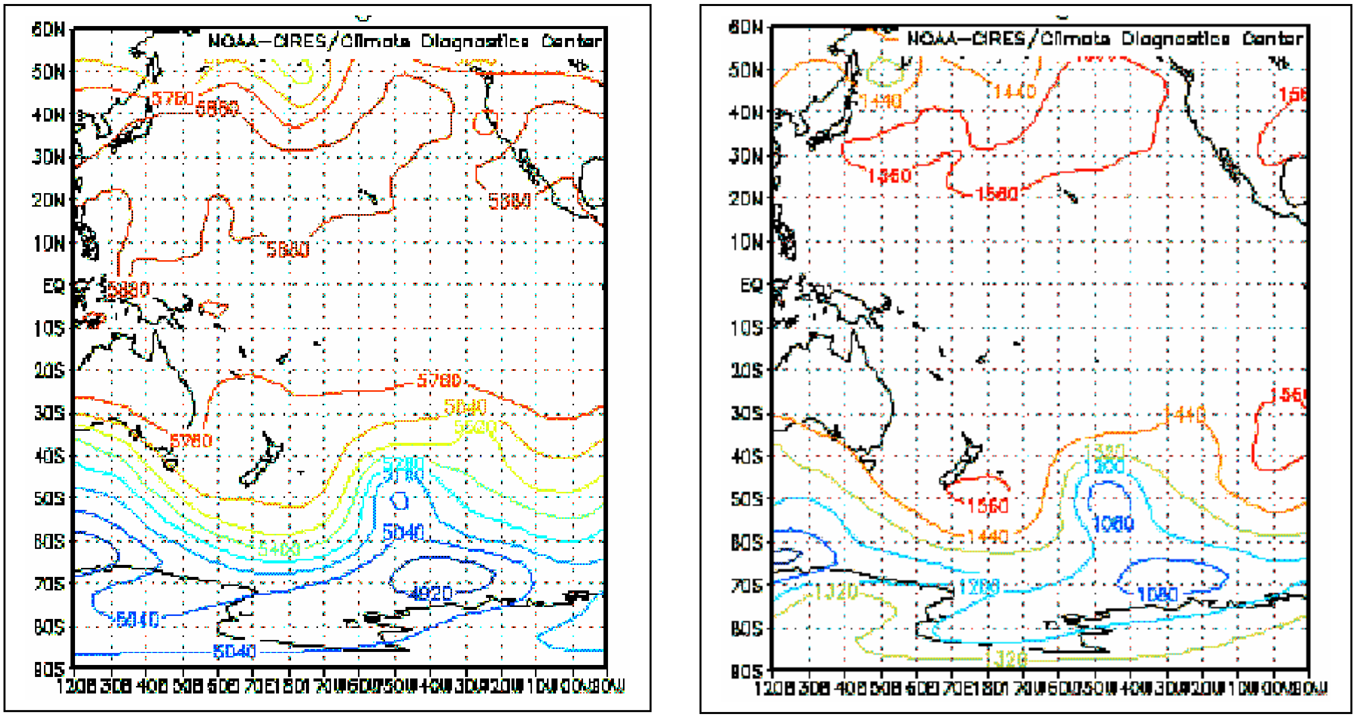


Figure C22. 1200 UTC 8 September 2005 500 mb heights in decameters (left), along with 1200 UTC 8 September 2005 850 mb heights in decameters (right).

No sounding data for this case.

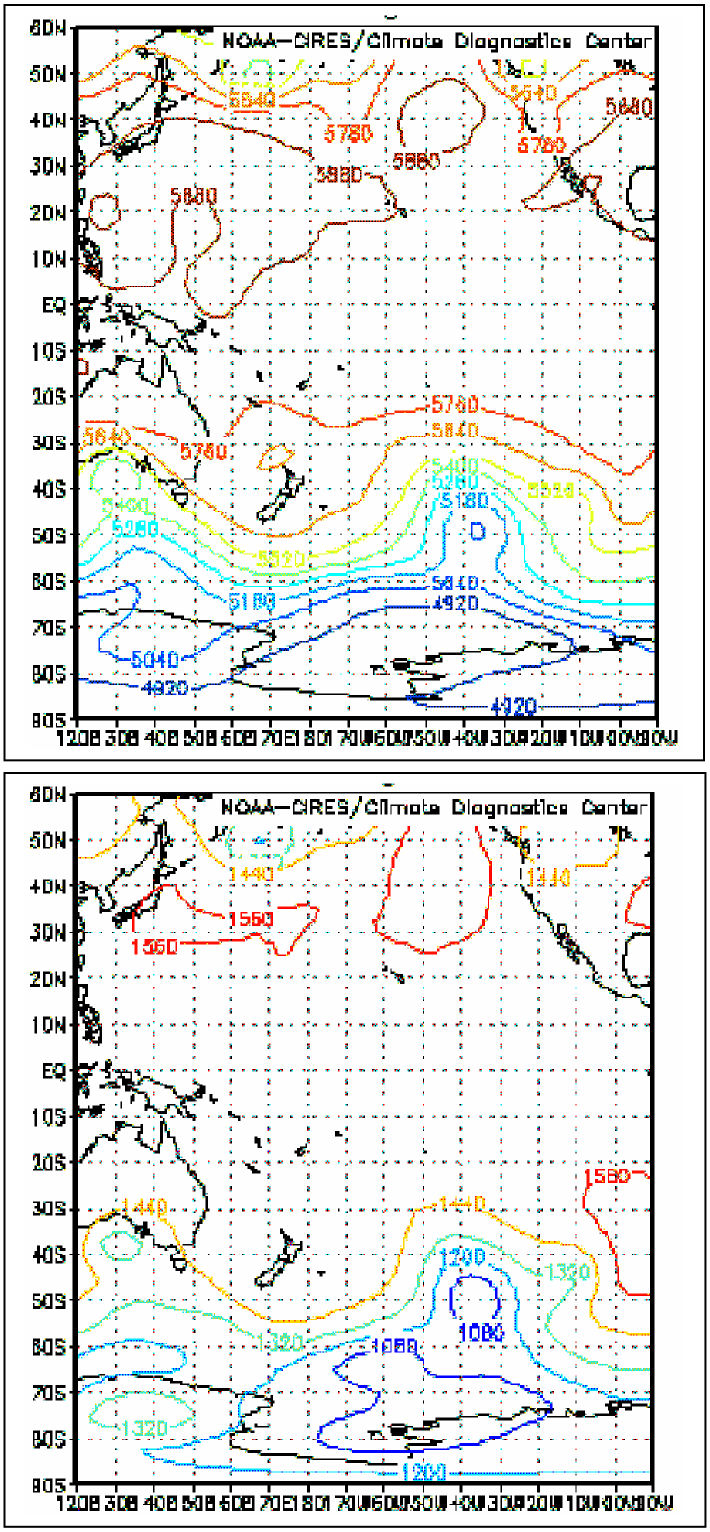


Figure C23. 1200 UTC 9 September 2005 500 mb heights in decameters (top), along with 1200 UTC 9 September 2005 850 mb heights in decameters (bottom).