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

PART I – THE MARINE LAYER AND ITS EFFECT ON PRECIPITATION AND HEATING

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(BASED ON SHORT TERM CLIMATOLOGICAL APPROXIMATIONS)
PART I – THE MARINE LAYER AND ITS EFFECT ON PRECIPITATION AND HEATING

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ABSTRACT

The varied terrain of southern California and its proximity to the Pacific Ocean results in many unique forecast challenges in southern California, therefore unique approaches for diagnosing and forecasting in this area are necessary. The purpose of this Forecasters Handbook is to present a variety of approaches to not only understand the 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 some meteorological parameters. Forecaster hints are "quick and dirty" guidance for the forecaster to get an initial idea of what to expect for certain parameters (although, not guaranteed to work in all cases), and more information is embedded in the discussions. Also for more detailed information the references can be consulted. It is hoped that this information helps to increase the understanding of the phenomena that occur in the extreme southwestern corner of our nation and also help to improve the ability to forecast them.

1. INTRODUCTION

The coastal marine layer is one of the most persistent characteristics of southern California weather (fig. 1) and affects the entire Southern California Bight Region. [The Southern California Bight Region is essentially the area west of a 3000 foot contour on the higher mountains surrounding the coastal plain, and extends from Point Conception (just west of KSBA) south to the Mexican Border near KSAN. The coastal waters, out to about 60 miles, are also included]. The marine layer advects off the ocean to moderate the weather, with the amount of moderation based on the distance from the ocean and terrain height. It has the effect of cooling down the coastal areas during warm season afternoons, as well as keeping coastal areas warmer overnight during the cool season. The clouds do present a hazard, with dense fog becoming an issue. Dense fog develops any time of year, and is frequently associated with the cloudy air near/below the semi-permanent marine layer inversion. Southern California's terrain varies from lower than 100 feet below sea level to over 11,500 feet. (All heights are in reference to MSL, unless otherwise noted). If there are low clouds below the inversion, there is almost always at least some patchy dense fog somewhere in the forecast area where the marine layer clouds and terrain meet. Hot days with strong subsidence (sinking motion) or moist monsoonal flow typically results in low (shallow) inversions, and confines the low clouds to near the immediate coast. Days with weaker subsidence tend to be cooler, with deeper marine layers (higher inversions) that allow the marine layer to extend inland to the coastal slopes, and locally through the mountain passes to the desert's western edge. On nights with relatively high dewpoints (such as those after a rainstorm), and clear, moist nights with good radiational cooling, radiation fog develops as the cool air collects in the low spots such as river valleys, and possibly extend westward to near the coast. Even without rainfall, visibilities fall to 4 miles or lower from just before sunrise until 11 AM or so in the inland valleys (for example KCNO) almost every night when winds are light. During the summer, there is almost always a marine layer inversion and coastal low clouds, and most likely in the southern areas. During patterns with cooling aloft, the marine layer deepens as the inversion rises and weakens. The marine layer can become so deep that rain can develop, even without a perceptible cold front or with atmospheric dynamics. On the other hand, during periods when high pressure aloft is strong enough to "squash the marine layer", or push the coastal marine layer westward, and even totally out of the coastal areas, heat waves result (most effective when coupled with offshore flow). The burning question during these heat waves is how far

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west will the marine layer influence be pushed, and how high will temperatures rise as a result. The factors surrounding these phenomena, in addition to others, will be explored in upcoming sections.

Numerous figures and tables are used to help better visualize the different aspects and effects of the marine layer. One figure shows graphs of the June, August, and the June-September mean inversions (353 of a possible 366 soundings were available) for the period 1998-2000. Also included are temperature markers at 850 mb and at the inversion top values of 27 C and 30 C respectively. Those values are typically associated with very hot days during the warm season (June - September) when highly populated areas with east winds reach 110 F or higher. A comparison of warm season 500 mb heights, 1000-500 mb thickness, 650 mb relative humidity (approximate level of the monsoonal jet) , and KNKX to KDRA 850 mb height gradient for the 1998-2000 warm season periods follow. The data consists of 714 of a possible 732 soundings, and the data for each "half month" period for June through September is used for the graphic. The 650 mb relative humidity is also a good approximation of the 700 mb relative humidity, and warm season thunderstorms can erupt if the 50 % relative humidity in the mid levels falls as low as 650 mb. To look at the relationship between surface pressure gradients and high temperatures, a graph of the mean 2000-2003 surface pressure gradient (in mb) from Las Flores at the coast to the Rice Valley sensor in the lower Colorado River Valley area near the Arizona border (LSF-RIC) was made. There were 1071 4 am local standard time observations out of a total of 1461 possible values available for the time period. The marine layer inversion was analyzed using a graph of the 1200 UTC inversion strength and marine layer depth versus 850 mb temperature, inversion strength, and inversion strength running total. There were 460 of a possible 488 values for June through September 2000-2003 available. A graph of the marine layer depth based on 850 mb temperature gives some idea of how the two values compare. Events with onshore (offshore) flow at 850 mb are shown as shaded (clear) bubbles for June-September 1998-2000. There were 360 of a possible 366 values for June-September 1998-2000 included in that graph. A table showing a comparison between warm season inversion heights and 850 mb temperature (360 of a possible 366 values were available) is included. A “Storm Probability of Precipitation” (SPOP) is introduced. It was developed using the marine layer depths of 51 available storms for the 1998-2000 period, and 850-700 mb (lower mid-level) relative humidity from 52 available storms for the 1998-2002 period. Areal coverage of precipitation for 48 hour periods was used to determine the SPOP. Cool season storms (October-May) were used to develop SPOP, but the values are likely to be applicable for the entire year. (An upper level low is frequently necessary in order to squeeze rainfall out of lower mid level relative humidities below approximately 75 percent during the summer west of the mountains). Afternoon high temperatures were compared for 359 of a total of 366 days for the coast, valleys, mountains, and deserts for June-September 1998-2000. In order to look at heat waves, a graph of heat wave days was compiled for weak gradient days (a total of 46 days were included). As a preliminary look at the relationship between the maximum and minimum temperatures in the lower mountains, a table was compiled for the Santa Ana Radar Site (KSOX) at 3092 feet MSL (288 of a possible 365 days were available). Finally, tables showing various relationships among certain key parameters such as 850 and 700 mb winds, inversion height, inversion top temperature, 850 mb and 700 mb temperature, and 850 mb dewpoint (along with the number of days satisfying certain conditions) are included.

Mesoscale circulations make marine layer forecasting even more difficult, causing significant deviations from tables and charts developed to forecast atmospheric conditions. For example, a Catalina Eddy, a vortex that develops over the coastal waters, will sometimes strengthen rapidly. The strengthening is frequently during the late morning/early afternoon portion of the day when sea breeze augmentation occurs, and the strongest south to southwest eddy winds typically develop. This results in a rather rapid rise in the marine layer depth (inversion base height). On other occasions (however less frequently) the opposite occurs, when the eddy totally dissipates during the midday period, and the inversion base collapses to the surface, resulting in an unexpected warming. Even imbedded waves in the marine layer

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result in unexpected local clearing, along with some warming. It is my hope that this Technical Memorandum helps to explain some of the weather phenomena that occur in the extreme southwest corner of our nation as far as the marine layer and its effect on precipitation and heating are concerned. To assist this, sections with forecaster hints are included.

2. MARINE LAYER

2.1 GENERAL MARINE LAYER CHARACTERISTICS

Although it seems like clockwork at times, the marine layer and its effects are quite variable. The effects may be in the form of a cold gravity wave associated with the afternoon sea breeze (and a temperature drop with no clouds), or possibly filled with clouds. Strong onshore flow, strong onshore pressure gradient trends, downstream blocking terrain and PVA (positive vorticity advection from a low pressure area or trough aloft) all serve to locally deepen the marine layer, and even bring low clouds inland early (near or before sundown). Even the pressure gradient trend (the 24 hour change in the surface pressure gradient) is surprisingly significant in the overall forecast process. Strong high pressure aloft, weak onshore surface pressure gradients, weak onshore flow, offshore pressure gradient trends, as well as downslope flow all serve to lower the inversion. Mid level cloudiness (slows nighttime cooling), a California gulf surge of relatively cool, moist air into the deserts (reduces the onshore surface pressure gradient), a monsoonal thunderstorm outflow boundary (raises the pressure inland to reduce the onshore surface pressure gradient), as well as an offshore surface pressure gradient or surface pressure gradient trend tends to slow/disrupt the development or inland progression of the marine layer and associated low clouds. These are some of the challenges for the forecaster.

Sometimes the factors that frequently help make the marine layer become more shallow can set off mesoscale events that actually <u>deepen</u> the marine layer. Ridging to the north, rising geopotential heights, and offshore flow aloft from the north serves to bring warming via subsidence aloft, which helps to lower the inversion. At the same time the associated low level northwest flow over the outer waters (30-60 miles offshore) jumps to 15-20 knots. This frequently generates a Catalina Eddy, which tends to deepen the marine layer, counteract coastal warming, and make the clouds more persistent near the coast. Even while the clouds over land are burning off, the advection of low clouds due to the eddy will frequently keep the clouds from totally clearing near the coast. If upper level heights and thicknesses are increasing, inland areas and areas at higher elevations see 24 hour temperature <u>increases,</u> while at the same time coastal areas are seeing <u>lower</u> afternoon high temperatures because of a more persistent marine layer cloud deck. Although the marine layer depth typically slopes downward to the north, and slopes upward to the east toward the mountains, a rather strong eddy will sometimes make the depth nearly the same everywhere.

Seasonal changes such as the sea surface temperature increases and mid level (and possibly upper level) cloudiness make for a very erratic, confused deck of overnight low clouds during the mid summer through early fall. Perhaps the strongest fight that causes the inversion to oscillate is the fight between the Pacific high, its subsidence, its low level northwesterly jet just off the coast, and the Monsoonal high, with its moist east to southeast mid level jet and moist low level surges of monsoon moisture into the deserts from the southeast. Some surges, possibly in conjunction with thunderstorm outflow boundaries, can send damaging winds and low visibilities in blowing dust as they weaken the coast-to-desert pressure gradient. In addition, there are pockets of upward motion from disturbances in the mid level flow which tend to disrupt the subsidence and weaken the inversion at times.

During the spring through early summer, and again in the early fall the subsiding air of the Pacific high raises the temperature at the top of the inversion and strengthens the inversion, with strong heating of the deserts, and the higher valley, foothill and mountain areas near and above the inversion. Desert

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temperatures climbing to around 115-120 F are a signal of this pattern. This enhances the onshore flow at the coast as the deepening thermal low in the deserts increases the coast-to-desert pressure gradient. This results in relatively cool afternoon temperatures in the coastal areas and a more persistent low cloud layer as the strong onshore flow pulls the marine air in beneath the inversion (which strengthens the inversion even more). This is most prevalent from May through early July.

Further east, the development of the Monsoonal High over the "4 corners area" of the states of Colorado, New Mexico, Arizona, and Utah counteracts some of the effects of the Pacific high during the mid summer through early fall. This monsoonal high develops over the interior, and generates a southeasterly monsoonal jet that initially develops around 700-500 mb along with the highest relative humidity aloft outside of the winter rainy season. This cloudiness reduces overnight thermal radiation along the coast. It also reduces the heating in the desert resulting in a weaker east-west (onshore) pressure gradient, a weaker inversion, and better afternoon clearing of the marine layer. This pattern is easily seen with 700 mb dewpoints reaching 0 C and 850 - 800 mb dewpoints of around 10 C or more for the "lopsided inversion" type of pattern. [The huge dewpoint depression at the inversion level associated with the rapid fall in dewpoint (commonly found with subsidence from the Pacific high, and is apparent in figure 2) becomes nearly absent, resulting in a "lopsided inversion"]. Although this profile favors monsoonal convection, it is prone to supporting a very erratic low cloud pattern. Perhaps a stronger effect on the marine layer is the southerly surge of low level moisture into the deserts. This weakens the thermal low in the deserts via a surge of cooler, moist air from decaying large thunderstorm or Mesoscale Convective System (MCS) outflow boundaries that develop over Mexico or Arizona. Another source is a surge of cool, moist low level air generated by a huge north-south pressure gradient from the deserts to the southern tip of Baja. The combination of the surface flow and the moisture aloft, (and in particular with easterly flow) works to keep the low clouds out completely or only allow them to develop during the late night and morning hours.

Near the end of summer the first few fronts result in surface high pressure areas building over the Great Basin plateau and locally into the deserts, which weakens the onshore pressure gradient (thus weakens or delays the sea breeze). This allows heat waves at the coast that are commonly seen in September. At the peak of our "tropical storm remnants" season (late August into September), the south and southwesterly flow from transition season cut-off lows and troughs finally dip far enough south at a higher frequency, and pull in moisture aloft from tropical storms while the low level remnants (typically the low level circulations) pass by to the south. This moisture flowing into southern California further disrupts the coastal marine layer under the moisture of the wave (including mid and high level clouds). It is more likely for low clouds to develop in a more solid fashion around the edges of the mid and high cloud shield as opposed to under the shield. One fly in the ointment is if the mid level moisture is minimal when the trough or low moves over, the marine layer might actually deepen.

Fig. 2 shows the variation in the marine layer from June to August, along with the mean inversion. Figure 3 gives some of the reasons behind the inversion lowering from spring to summer. First, the upper level high over the Pacific (the dominant high during the spring and early summer) loses some of its influence as the upper level (monsoonal) high builds to the east. The 500 mb heights peak at 591 decameters and 1000-500 mb thickness peaks around 579 decameters during the second half of July. The 850 mb height gradient from the coast to southern Nevada remains an "onshore" gradient, but continues to weaken all summer. The reflection at the surface is seen via the weakening of the onshore surface pressure gradient. Along with increasing temperatures aloft through mid summer, the inversion is forced downward from 2000-2500 feet msl in June to 1000-1500 feet msl in August. Aloft, the 650 mb relative humidity rises, (a reasonable height of the monsoonal jet and an approximation of the 700 mb moisture) which has the effect of slowing low cloud development. This disrupts the marine layer low cloud pattern, resulting in breaks in the cloud deck, along with erratic arrival/departure times for the

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low clouds. This is in addition to the cool moist southerly surges into the deserts, which cools the deserts and weakens the coast-to-desert pressure gradient, as well as affects the sea breeze. These factors, in addition to higher sea surface temperatures, tend to result in decreased episodes of widespread, persistent low cloudiness during the mid summer period, and only patchy low clouds develop on some days.

Also due to the change in heights, thickness, and temperatures aloft, the onshore surface pressure gradient from the coast to the Lower Colorado River [for example, from Las Flores (LSF) near Camp Pendleton (KNFG) to Rice Valley (RIC) near Blythe (KBLH)] changes. The gradient falls from near 6.5 mb to around 4.5 mb between late spring (June) and mid summer (August), as seen in figure 4. This helps change the marine layer pattern from a deep persistent "all day overcast in some areas" pattern, to one where the land areas (including the beaches) routinely clear during the mid morning hours. (However, there are occasions when the clearing is as late as mid afternoon). During the spring and early summer desert heating far outpaces the coastal heating (desert afternoon high temperatures peak in July, with the coastal area high temperatures peaking as late as September). This strong inland heating creates the largest coast-to-desert temperature differentials of the year, approaching 60 degrees F at times (hence the annual maximum pressure gradient occurs during the late spring and early summer). This helps to pull in the low clouds. The low clouds, during deeper marine layer episodes, can push inland through the passes to the desert edge of the mountains, with strong cooling in the deserts to well below normal. Desert temperatures easily drop below 100 degrees with some episodes. The clouds, although visible from the desert, typically evaporate before they push into the deserts, which also results in higher relative humidity on the coastal side of the mountains than on the desert side at similar elevations. On average, higher, weaker inversions in the spring become lower, stronger inversions mid summer. However, inversion strength in the 1000-1500 foot msl range might actually be weaker during mid summer than spring. Part of the reason is the sea surface temperatures at the inner coastal waters buoys rise into the upper 60s by September, which could result in weaker inversions in the 1000-1500 foot range and better clearing. Aloft, the height gradient at 850 mb is weaker during the mid summer period than it is during the spring. Along with the relatively cool, moist surges into the deserts from the south during the mid and late summer period, the combination results in a weakening of the surface pressure gradient and weakening of the onshore flow. Above the marine layer there is around 2000 feet of warm inversion layer air. The mid to late summer weakening of the onshore flow partially explains the September peak in afternoon high temperatures at some coastal sites. (This is in contrast to the July maximum temperature peak in the deserts, where the marine influence is less of a factor than the atmospheric thickness between pressure levels and "heights" of the mandatory pressure levels aloft such as those at 500 mb and 850 mb).

Going into the mid summer period, day to day changes can be rather small.

When 24 hour changes in conditions (or expected changes) are subtle, for example:

1. Pressure gradients to local deserts (for example KLAX-KTRM) change less than 1.5 mb
2. The 850 mb temperature changes less than 1.5 degrees C
3. The inversion base height changes 300 feet or less

conditions are very similar to those of the previous day in most cases, and persistence just might be the best solution.

During mid summer the low clouds almost never remain in the valleys all day, and rarely stay in at the coastal airports all day (and it is generally best not to forecasts these events to occur). For the low clouds to remain at the beaches all day during the mid summer period, conditions should approximate the following (very strong inversion for the depth involved along with strong onshore gradients and trend),

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1. Inversion depth (in thousands of feet) + inversion strength (in degrees C) should exceed 11.
2. Approximately 6-8 mb or more of onshore gradient to the local deserts (coast to KDAG, KTRM, KPSP, or KIPL) where "coast" can be KLAX or KSAN.
3. Approximately a 2 mb onshore trend to the local deserts and about a 4 mb onshore trend coast to Tonopah (KTPH), Nevada.

An upper level trough or low moving over the area also helps.

On the other hand, a 2 mb offshore gradient coast to KDAG (or KTRM) with a 2 mb offshore 24 hour trend to these local desert sites accompanies a lowered inversion base, and the low clouds clear everywhere much of the time, including the coastal waters, with above normal temperatures. This is true all year, but is particularly reliable during the summer. A "Marine Layer Matrix" outlining approximated morning cloud/fog coverage as well as clearing times can be found in Appendix A.

Figure 5 shows the relationship between the 850 mb temperature, the inversion base height, and inversion strength for June-September 1998-2000. Highlighted are the June (deep marine layer period), August (summer marine layer depth minimum or "shallow marine layer period") and the June-September summer mean. Lower 850 mb temperatures (basically cooling aloft) correlate well with deeper marine layers and weaker inversions. Higher 850 mb temperatures correlate well with shallower marine layers and stronger inversions, so typically, the inversion weakens as the marine layer deepens. Conversely, in many cases the inversion strengthens as the inversion lowers.

2.2 EXAMPLE OF A BASIC MARINE LAYER EVENT

Typically, during the winter, the polar jet migrates far enough south to bring strong lows and troughs through southern California. Occasionally, it combines with the subtropical jet for an enhanced thermal gradient and very strong rainfall/thunderstorm activity. On the edges of the cool season (mid fall and mid spring), subtropical high development pushes the polar jet northward, nearly eliminating the threat of storms moving along a low latitude track. During these periods the biggest storms are cutoff lows (hence the phrase "cut off seasons"). Most troughs pass by to the north, and simply modulate the deepening and lowering of the marine layer during the late spring through early fall. Since the fronts stay further north during the mid summer period, the fluctuations in the marine layer depth are much smaller during mid summer.

Figures 6 and 7 show an "Enhanced Marine Layer Event" or possibly a "Hybrid Weak Frontal/Marine Layer Event". The basic marine layer cycle will typically begin with a "transition day" possibly with little or no marine layer clouds or fog. This is sometimes the case after a period of offshore flow and offshore trend. If the winds at the beaches are easterly and about 10 knots or more the marine layer and associated marine inversion is effectively wiped out. When the wind stops or temporarily turns west with the sea breeze, the marine layer air deepens to about 500 feet deep. Conditions often transition to onshore flow and trend with dense fog developing at the major coastal airports. The fog generally resides in a layer just under the inversion base (and within 800 to 1000 feet of the inversion base) with the inversion base itself at or below 1000 feet MSL for coastal dense fog events. The fog can distribute upward into the inversion to about 800-1000 feet AGL for surface based inversions. The change to a shallow marine layer regime results in a capping inversion near 800-1000 feet MSL, and dense fog over the highly populated coastal and mesa areas if the onshore trend in the pressure gradient is small. When the inversion base approaches 1000 feet, the visibilities at the lower airports can improve significantly since the typical low inversion stratus deck is about 700 feet thick (sun or moon dimly visible) to about

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1000 feet thick (opaque). If the winds aloft are rather strong [southwest at around 50-60 knots (30 knots) or more at 500 mb (700 mb)] with cyclonic flow aloft, the rapidly deepening marine layer, on occasion, will bypass this coastal dense fog stage (picking it up later in the valleys and/or mountains). These events are generally expected to result in a rather saturated airmass with bases down to below 1500 feet as the cloud tops rise and thicken into a deep marine layer. When the winds aloft are strong there is probably a weak front involved, [which helps keeps the cloud bases low (lower layers more saturated)] and the clouds thicken upward. Winds near 500 mb of 50-60 knots or more are notorious for squeezing measurable rain out. (A moderate acceleration of the onshore flow, such as that associated with a Catalina eddy, upper low/trough, or simply southerly flow) also help to make the coastal dense fog stage brief or non-existent, followed by a "stratus" stage as the cloud bases lift up). The passage of a strong trough to the north rapidly lowers pressures inland over the plateau region of Nevada/Utah, and rapidly deepens the marine layer cloud tops up to near 2500 feet. This could generate 2 cloud decks [possibly transition to a cumulus regime in the boundary layer, signified by a lower (convective) deck with or without solar heating]. Although convection does occur with only 1500 foot deep marine layers, some marine layers with cloud tops of around 2500 feet (along with clouds "convecting" beneath the inversion with cloud bases 1000-1500 feet or so) generate episodes with drizzle, and even have locally lower cloud bases to below 1000 feet. This drizzle scenario is common for rapidly deepening marine layers with cloud top heights of approximately 2500 feet deep or deeper, especially if the inversion is strong. Eventually, the cloud bases rise a bit as the inversion base rises. The marine layer dense fog region associated with the cloud deck then spreads inland and upward, generally at altitudes within 800 - 1000 feet of the cloud tops (where cloud tops are approximately the inversion base). If the clouds reach 1500 to 2000 feet thick, (which is actually rather thick for a marine layer cloud deck), drizzle might occur long enough to "measure" at non-ASOS sites, and even at standard NWS observing locations (ASOS) sites with clouds of over 2000 feet thick. Although measurable drizzle might occur with marine layers only 2500-3000 feet deep (cloud layer thicknesses approaching 2000 feet thick for a fairly saturated marine layer), these situations are quite rare as trace amounts are more common with marine layers depths of only 3000 feet or so. Drizzle from such thick marine layer clouds with cloud tops 2500-3000 feet deep are typically followed by an afternoon with little if any coastal clearing. Drizzle is a good sign that clearing, if any, will be slow, and if there was no drizzle the previous day, it is a good bet that it will clear later than it did the previous day since the marine layer is typically deepening during such a pattern.

Some light rain reports, with measurable amounts possible, occur with clouds tops reaching approximately 4000 feet with cloud thicknesses of 2000-2500 or more. At 5000-6000 feet deep, with cloud bases still down around 2000 feet or lower (lowest levels still relatively saturated, resulting in a thick cloud layer), scattered light rain develops. This is rather reliable if the inversion is fairly strong compared to the marine layer depth. A very strong inversion in comparison to cloud top height is when the approximate inversion height (or marine layer depth) in thousands of feet + inversion strength in degrees C is 11 or more. Locally moderate rain falls from the lower based convective clouds when their tops stretch upward to near the top of the marine layer, resulting in rather thick marine layer clouds. If the cloud distribution is mainly one of relatively thin stratiform layers, then much less rain occurs.

At a cloud top height of a little over 7000 feet, which is rare for mid summer, it rains almost everywhere from the mountains westward (with rainfall heavier and more likely along the coastal slopes). This is more of an "enhanced" marine layer, or moist layer, since a front with thick cloud layers is possibly associated with such a deep moist layer. Some of these are more of a "hybrid marine layer/weak frontal event".

Below 800 mb (around 6200 feet MSL), the cooling at and just below the <u>base</u> of the inversion is mainly a reflection of the rising inversion base (deepening marine layer). This creates a very unstable marine

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layer with a large temperature lapse rate from the surface to the inversion base in many cases. This easily results in boundary layer convection. On the other hand, while the deepening occurs, the inversion is weakening since the cooling flow aloft near the top of the inversion is probably going to exceed the cooling at the base of the inversion due to the lifting marine layer inversion base, (especially for deeper marine layers). In some cases, the inversion base will lift up to just higher than the mountain resorts near 6000 feet, and cool enough for snow to fall out of mainly marine layer moisture. This type of scenario has occurred as late as June.

The time of day is also significant when it comes to drizzle and light rain scenarios. If these deep moist layers or “weak fronts" arrive midday, then the probability of rainfall decreases since there is a midday minimum in the boundary layer relative humidity. Mid day periods are the most unfavorable conditions for weak fronts to produce rain. The lowlands west of the mountains (and away from upslope flow influences) are more prone to this drying. The higher night and morning relative humidity favors night and morning drizzle and/or light rain since the drying in the lowest portion of the sounding becomes a “low level inverted V” profile during the day. If a front approaches a well developed marine layer, it could enhance and deepen the marine layer by becoming entrained into it. The front is likely to hold together better with higher precipitation probabilities during the night and morning hours (with the peak late night through mid morning). The clearing of the dense fog at around 8 to 9 am or so signals the thinning of the low clouds, a reduction in the drizzle, and possible development of a mid day inverted “V” low level profile. One variation on the daytime weak frontal theme is if the marine layer deepens up to near 8000 feet and is conditionally unstable (nearly isothermal above the moist layer near mountain top), there could be some afternoon convective showers in the mountains. These light rain scenarios are in contrast to much of the rest of the country away from the coast. The diurnal cycle in the marine layer moisture is so strong that it skews the light rainfall events into a late night and morning maximum in coastal southern California (for example, measurable amounts of less than a tenth of an inch in one hour). This is in contrast to the fact that many locations in the nation’s interior have an afternoon and evening maximum for rain events. Such light rainfall events have a big impact on travel, such as traffic accidents on slick roads, and airport runway landing pattern changes caused by wet runways (in conjunction with wind speed thresholds).

Shallow, weaker fronts have trouble getting past Point Conception, and a break often develops in the front. Fronts with a northwest to southeast trajectory are most vulnerable. When the moist layer depth falls below 8000 feet deep or so, blocking by the mountains to the north (and some downslope flow to the lee of the mountains) shuts off the precipitation to many northern areas, and the northwest flow shifts to become more westerly south of Point Conception. This is also true for postfrontal airmasses in west to northwest flow), when the moist layer depth falls below 8000 feet deep. With the rain tapering off or ending in the north, the largely un-obstructed, shallow west to northwest flow into the southern areas (along with island effects) helps keep rain going well after the dynamics end there, producing more precipitation in the south than the north if the airmass is very moist and somewhat unstable. If the dynamics hold together past Point Conception, the residual weakening front results in a typical rainfall pattern (A typical weakening front has more rain in the north than in the south since northern areas are closer to the stronger dynamics and lifting of the front). This typical scenario occurs when the low level airmass is not terribly unstable. Very weak fronts in this flow might have only clouds that simply end up banked up against the mountains with little or no precipitation anywhere. A convergence zone often develops and parallels the coast during post frontal flow, locally enhancing any precipitation under the convergence zone. (This type of convergence zone is frequently seen in the visible satellite imagery during a Catalina Eddy). A Hybrid Coastal Convergence Zone/Land Breeze front develops when there is a weak land breeze that collides with westerly or southerly flow over the coastal waters.

At some point in the life cycle of a marine layer event (usually near the end of the cycle), a low level inverted V marine layer moisture profile can develop. In these cases, the clouds become quite thin as the cloud base heights rise faster than the marine layer deepens, and the drizzle and light rain ends. (Also the inversion weakens, so clouds become thin and/or break up, which helps end the rapid deepening/light rain period). Later, a second, lower inversion generally develops around the 1500-2500 foot level, and the marine layer re-establishes itself in the typical night and morning fashion. In these cases, clouds form under the strengthening, lowest inversion, and the clouds dissipate aloft at the old inversion. Eventually, the old, upper inversion dissipates. This is typically the "transition day" in the offshore trend direction, when the marine layer transitions from a day with clouds most of the day (if not all day) to a day that has better clearing most areas by afternoon. Before the marine layer becomes a solid, re-established deck, the cloud pattern becomes somewhat erratic, (partly because the inversion is so weak) and the pull on the low clouds (via an onshore trend) is absent. With such a weak inversion, the marine layer clouds are prone to "reverse clearing" (low clouds clear in the coastal areas before the inland areas clear, partly due to boundary layer convection inland and stabilizing marine air moving in off the Pacific). In some cases it is actually cloudier during the day than at night while the re-adjustment of the marine layer occurs due to the daytime boundary layer convection. West of the inland edge of the marine layer, holes in the marine layer tend to fill in during the transition to a more convective marine layer regime, especially when the marine layer is rather deep.

Near the end of the event, the trough moves further inland, and high pressure develops aloft and over the plateau areas of Nevada and Utah to the northeast. The surface pressure gradient decreases, and the heights and thicknesses rise. If the offshore flow event is strong enough, the inversion is wiped out and clear skies prevail until a new inversion strengthens enough to cap a significant marine layer cloud deck (5 C or more). If the inversion reaches 5 C, or stronger, there is almost always a morning low cloud deck in some areas during the summer. Conditions favor development in the south first, and if it only develops in one area, it is most likely in the south. (Typically, the inversion height is higher in the south, due partly to better exposure to the northwesterly flow over the coastal waters, so low clouds develop or advect in more frequently, and there is a good chance that the clouds will hang around longer in the south).

2.3 MORE VARIATIONS IN THE MARINE LAYER CLEARING PHASE

One of the big challenges is the clearing pattern. If the offshore gradient trend is very fast (for example, a 5 mb offshore trend from the coast to the local deserts), there are mostly clear skies since the inversion is lowered to the surface or is totally wiped out. The actual pressure gradients might become offshore. On some occasions the gradients become weak, but not offshore enough to push the marine layer offshore. In these cases, the marine layer inversion will lower and strengthen. With the cooler, transition season sea surface temperatures, after the low clouds burn back to near the coast during the day, the beaches may not clear since the stratus may linger at the beaches well into the afternoon. In the opposite flow direction, when a period of offshore flow ends, the result is basically the same. The onshore gradient trend results in an onshore flow of marine air, the re-establishment of a shallow marine layer and a low, strong marine layer inversion. This also results in the beaches remaining cloudy, or mostly cloudy skies lingering at the beaches well into the afternoon. During the evening, stratus that is still at the beaches tends to move inland faster than it does when it either has to form, or move in from a point further offshore. With strong surface and 850 mb onshore gradients in May and June and an even deeper marine layer than the later months, low clouds linger much of the day over the coastal plain. The low clouds remain much of the day in the valley and coastal slope regions on some days when the marine layer is very deep. If it is August or September, there is a good chance that all land areas will clear and the stratus will move offshore away from the beaches in the afternoon. "All day" low cloud patterns become rare by mid summer as the inland "pull on the low clouds" is reduced. This is possibly

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due to the weaker onshore gradients, cooling gulf surges into the deserts, monsoonal moisture aloft, and possibly somewhat higher sea surface temperatures. This reduction in onshore pull results in the beaches becoming clear almost every afternoon mid July through September. The low clouds that do happen to occasionally linger are very patchy. If the gradients are weak [or better, offshore (with pressure values higher inland than over the coastal waters] during the mid summer period, the marine layer will typically be reduced or wiped out, resulting in heat waves.

At times a trough in the flow aloft or an upper level low is marked by a band of high clouds while it moves though California. It is possible for the low or trough to provide enough lift to keep the marine layer in all day, or bring it in during the mid afternoon, earlier than the usual pattern of near or after sundown. (Basically, mid and high clouds associated with a trough stop the clearing of the low clouds, and enhance the low clouds enough for an early evening arrival. At other times it simply slows the daytime burn-off).

Low, strong inversions (typically 10 degrees C or stronger with a depth of around 1500 feet MSL or lower) precede a transition from morning fog to thick afternoon haze for locations at and below the inversion base. This haze causes a mid afternoon dip in visibilities as a "haze front" on the leading edge of the sea breeze as it sweeps past the inland valley airports. For instance, a 3 mile visibility around noon at KSNA will typically cause a haze front in the Inland Empire as the winds jump to 8 to 15 knots from the west at KONT or KCNO, temporarily reducing the visibility. An early stratus arrival is a good bet when the visibility at KCRQ is restricted to 5 miles or less in afternoon haze, or stratus clouds surround Catalina Island (KAVX) during the afternoon. This is a characteristic of a pattern with marine layer low clouds that are only a few miles offshore or locally onshore in spots, and the inversion is strong. In these situations, coastal cities, including major coastal airports get the low clouds around sundown as the advection of low clouds overpowers the dissipating effect of solar heating early. If the KCRQ midday visibility jumps up to 6 miles or more, the low clouds and fog tend to wait till after midnight or so to move in at KCRQ and the other coastal airports.

2.4 MORE ON LOW LEVEL (MARINE LAYER) INVERTED V SOUNDINGS

The deterrent to all deep marine layers producing widespread drizzle and/or light rain is the low level inverted V sounding. The question is will the marine layer be saturated from the surface to the inversion base, or will there be a low level inverted V sounding throughout the entire event (not just at the end of an event)? These "unsaturated" events are characterized by a rather thin cloud deck just below the inversion base, with very little drizzle or light rain. For very deep events with cloud tops reaching upward to 7000-8000 feet or higher, (better if associated with a weak front), at least for a while the airmass becomes rather saturated with a period of rain from a thick layer of clouds with no low level inverted V problem. Also in this type of case, 500 mb winds typically reach 60 knots or more, which seem to accompany rain events primarily consisting of boundary layer moisture. Heights around 500 mb approaching 564 decameters (best during cyclonic flow) accompany many of these weaker events. At around this 7-8 thousand foot depth are the "high POP low QPF" type events, where the probability of precipitation (POP) is high, but the quantitative precipitation forecast (QPF, or expected rainfall accumulation) is low. For example, the POP will sometimes be 60-80 percent, but less than 1/4 inch of accumulation is expected in most areas. Interestingly, with events consisting of mainly boundary layer moisture, if there is a light low level wind with an easterly component at or below 850 mb the moist layer just might stay rather saturated down to near the surface. This cooling, "drainage wind" type of effect lowers the surface temperature, reduces the dewpoint depression, and consequently keeps the lifting condensation level (LCL) low. However, if the winds are in excess of 10 knots or so, it helps to dry the boundary layer and delay the onset of any rain.

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2.5 MORE ON REVERSE CLEARING

Reverse clearing patterns occur during any season, and are a frequent occurrence behind winter storms. [Reverse clearing is when instead of the low clouds clearing inland areas first (before clearing westward back to the coast) the low clouds clear at the coast first, with the clearing typically following the stabilizing sea breeze air inland]. During the non-winter months it is most likely to occur during the transition seasons of spring and fall (most probable in the spring) and least likely to occur during mid summer. The pattern starts with low clouds already in place. As the cold advection settles in aloft (typically associated with a trough passage), the marine layer deepens while the inversion rises and weakens. This weakening inversion is seen in the low cloud pattern as clearing moving down the coast in the Point Conception area west of Santa Barbara (KSBA) over the offshore waters (where there is a tendency to clear first). Downslope flow into a weak inversion is a strong contributor to the clearing there. The deepening of the marine layer during these “boundary layer convection/reverse clearing episodes” can result in the clouds clearing all areas, except the low clouds that are still “slapped up against the mountains” during the afternoon since the convection continues there.

At the end of the deepening episode there is frequently a “transition day” as 850 mb temperatures fall into the low to mid teens (when the 24 hour pressure gradient trends become 0 or reverse to become offshore). If the reverse is slow, then the moist layer slowly erodes from the top, and the inversion lowers. The inversion eventually caps the shallower moist layer at a more “seasonable” level. This “seasonable” level is around 1500 to 2500 feet. Initially a disorganized marine layer cloud deck (if at all) is expected with cloud bases somewhere in the 1000 to 2000 foot range if the marine layer inversion is rather weak.

Occasionally, a more “wind enhanced” inversion aloft is created via a jet streak and associated jet dynamics [possibly in addition to or above any other inversions]. This is sometimes seen via strengthening of the winds aloft and possibly a wind shift, along with warming aloft (for example, at 850 or 700 mb) resulting in a sounding with a “double inversion”. The inversion aloft, created via a jet streak and associated jet dynamics lowers and/or swallows up the old (lower) inversion and establish itself as the “new inversion”. During some events this lowering brings the inversion to within 1000 feet of the surface, resulting in dense fog in the highly populated coastal areas. If the reverse in the pressure gradient trend is fairly rapid from onshore to offshore, then the moist layer significantly dries as the marine layer is “wiped out”. It is possible to have a period with little (if any) inversion or marine layer before the re-establishment of a low inversion and the “new marine layer” develops.

Marine layer inversions are occasionally very weak, (possibly even isothermal). In these cases solid low cloud development becomes very difficult since the inversion is too weak to “cap” the marine layer very well. The typical “night and morning low clouds and fog” cycle is reversed, with the best cloud cover during the midday period due to solar heating when the marine layer is deep, and if there are breaks in the clouds during the midmorning hours. (These marine layer “disruptions” are rather frequent in the spring and fall since troughs and fronts are stronger and more frequent, but they also occur during mid to late summer monsoonal moisture intrusions). During these events the best low cloud coverage during such a deep pattern might be in the inland areas for a day or so. The transition from a “standard clearing pattern” (clears inland first) to a reverse clearing pattern (clears at the coast first) generally occurs when cloud tops reach or exceed 3500 feet MSL and the inversion weakens enough to allow it. Embedded in the annual cycle is a diurnal cycle of the marine layer strength. A morning sounding typically contains the strongest inversion of the day, with the weakest inversion on the afternoon sounding. A quick estimate of the inversion strength for the following morning is obtained by lowering the temperature at the base of the inversion on the 0000 UTC sounding by about 1 or 2 degrees C. This adjustment is likely to be a smaller value for days with little clearing and a larger value for days with good clearing.

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This is because the better drying and larger temperature/dewpoint spread on days that clear well necessitate a larger temperature drop and dewpoint temperature increase to reach saturation at the inversion base.

Typically the inversion strength weakens in proportion to its depth, and is less than 7 C for deep marine layers. The 850 mb temperatures are also relatively low [low to mid teens (in degrees C)] for deep marine layers. Cloud decks are generally less solid with such weak inversions. These weak inversion scenarios, at times, are characterized by higher daytime than nighttime cloud coverage, with marine layer depths at or in excess of 3500 feet deep, with a significant impact on high temperatures.

Under more extreme offshore trends, such as Santa Ana Winds, a very dry, relatively hot airmass advects in. This might be enough to totally clear out the low clouds for a day or so. This allows a shallow, “dense fog producing” inversion to develop after a day or two near the coast as the cool, low level oceanic moist layer returns under the hot airmass (transition day). At times this is a rather frequent pattern, with the most vulnerable periods being the fall and early winter. At around the same time the 500 mb ridge axis moves inland to reduce some of the subsidence. The transition must be slow enough so that the layer deepens slowly, otherwise the coastal dense fog stage is bypassed completely. Interestingly, areas 15 miles or more inland are quite possibly as warm (or warmer) than the previous day while beach highs are actually lower than the previous day during such a transition.

While the 500 mb ridge is overhead, and the 700 mb closed high is to the north [possibly supplemented by northeast winds at Fremont Canyon (FMC)] record high temperatures frequently occur. In these cases 850 mb potential temperatures surface all the way to the coast. Highs in the “inland coastal areas”, approximately 10 miles or so inland, are expected to be around T850 + 26 to T850 + 30 F. Hot days with a big temperature gradient, (for example, those with over 40 degrees of temperature difference from the coast to the inland valleys) may generate a pressure gradient that boosts the sea breeze as much as 5 mph from 10 to over 15 mph (and gusty), which is very noticeable in the highly populated coastal areas. This is common during the later periods of a heat wave event. If an eddy develops, gust to 15-25 mph are even possible. A signal for eddy development is when the pressure gradients get into the favored eddy configuration (trending offshore to the north, and trending onshore to the south and east) as a trough moves inland. The isobars sometimes orient themselves parallel to the coast, which tends to be a signal for a significant increase in low clouds.

2.6 VARIATIONS IN THE TYPICAL MID SUMMER MARINE LAYER CYCLE

Enhanced marine layer events are rare during the mid summer period (much of July and August) and the cycle is somewhat different. It is very difficult to generate marine layers over 3500 feet deep during the mid summer period. Southerly surges of cool gulf of California air into the deserts weakens the coast to desert pressure gradient, and the mid level monsoonal moisture also helps to disrupt the low cloud pattern, making all day low cloud events in the inland areas very rare. This is in addition to high sea surface temperatures helping to weaken the inversion and assist with clearing. When the flow starts to trend onshore, (and during extreme cases, deepen up to 2500-3000 feet), it should still clear over all land areas, including the beaches, by mid afternoon during this mid summer period.

2.7 MARINE LAYER EFFECTS ON TEMPERATURES AND PRECIPITATION

As for the relationship between 850 mb temperatures and the marine layer depth changes, figure 8 and table 1 gives a better look at how the inversion height changes with 850 mb temperature. The top of most marine layers are below 4000 feet MSL, where the inversion base typically changes 200 feet for every degree C. (This rate roughly doubles in the 4000-6000 foot realm, and roughly doubles yet again at depths over 6000 feet). For a 2500 foot deep marine layer, a 4 degree C increase in the 850 mb

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temperature should lower the marine layer 800 feet. The marine layer inversion base is very resistant to lowering below 800 feet during the summer, and will do so only under extreme conditions. As for precipitation, figure 9 and table 2 hint at the marine layer depths of just over 3000/5000/6000/7000 feet MSL as 10 %, 20 %, 60 %, and 80 % respectively, which are the slight chance, slight chance again, likely, and "categorical" rainfall categories. The deepening can really help to keep temperatures down. For relatively shallow fronts moving in from the northwest, it is a good idea t o check the moisture depth on the Vandenberg (KVBG) sounding and its surrounding observations (including the offshore islands) to see how much rain has fallen in order to gage how much precipitation sweeps south into the Bight region (the region from near KSBA down to near KSAN). This is because many fronts cannot survive the trip past Point Conception intact. It is a good reality check on how well the inversion depth matches the probability of rainfall. Although some of the moisture is swept out during shallow events by the Santa Ynez Mountains near KVBG, enough moisture still sweeps past the area just offshore and hits mainly our southern areas. The precipitation for marine layer events with mainly shallow southwest to northwest flow develops from the coastal slopes of the mountains westward. When the winds aloft "go south" (switch to become southerly) tropical airmasses advect into the area, and rain chances increase dramatically in the deserts as well. If a summer storm moving into the area is strong enough to generate deep southerly flow, or even easterly flow, precipitation becomes rather heavy (since there are almost always thunderstorms with these summer rain events), and fall heaviest on the eastern slopes of the mountains. Heavy rains with flooding are possible. During the summer, it is most likely that a tropical storm or a rather strong upper low will accompany this scenario.

Pressure gradient <u>trends</u> (the 24 hour change in the pressure gradient) have more of an effect on heating and clouds than the <u>actual</u> pressure gradient at times. Pressure gradient trends result in their largest net change in local weather when the gradients are "weak onshore" (Table 3) as far as temperatures and clouds are concerned.

When <u>actual</u> pressure gradients are already "strongly onshore" it is difficult for significant 24 hour changes in maximum temperatures to occur over the coastal and valley areas for deep (3000 feet) marine layers and weak offshore pressure gradient <u>trends</u>. A couple of mb of offshore <u>trend</u> (or even weak onshore <u>trend</u> at times), results in much smaller 24 hour changes in high temperatures than if the <u>actual</u> gradients were already weak, (in particular, for regions well below a strong inversion). This is because the thermal transition zone (responsible for many of the large 24 hour temperature changes) is so far above the coastal and valley locations that small gradient changes have very little effect. (All of the mixing occurs inside the cool air of the marine layer). This assumes that the cloud cover pattern remains basically unchanged. Of course, mountain locations near the inversion see much bigger changes as the inversion moves.

The significant 24 hour changes in temperature and cloud cover typically occur if either;

1. The pressure gradient trends are strong enough to pull in cold air, which weakens the inversion enough to clear the clouds (in the onshore trend direction)
2. The clouds remain all day (in the onshore trend direction) when the previous day saw some clearing.
3. The "Thermal Transition Zone" sweeps by via changes in the flow direction or subsidence pattern (either the offshore or onshore trend direction).

For example, a pressure gradient change from 10 mb onshore to 8 mb onshore from the coast to the local deserts in 24 hours during a deep marine layer will most likely have almost no affect on temperature (since the clouds become persistent, and the flow cannot dislodge the marine layer cold air). In comparison, a change in the gradient from near 0.0 mb to -2.0 mb from the coast to the deserts is still a 2 mb offshore trend, but the difference is due to the marine layer inversion being so close to the surface with such a weak gradient. The 850 mb potential temperature easily lowers to the surface in the highly populated coastal areas for a higher impact, and the inversion correspondingly lowers and sweeps the thermal transition zone and associated clouds westward. In these cases large 24 hour temperature changes (which tend to follow the inversion) occur. This is frequently the case with 850 mb temperatures and inversions that are around the August average of 1300 feet and 23 C, which places the warmest inland valley high temperature around 100 F. During these times there is a huge temperature (and humidity) change with distance from the coast to inland areas as well as with elevation. Jumps of 10-20 degrees F with the "inversion base passage" can occur in some locations over the previous day. In the mountains and foothills, this zone is typically found near the 1500 to 4000 feet MSL region, seen as heating or cooling that follows the inversion when the inversion sweeps past. Lower mountain and foothill regions become very warm during a downward sweep, with high temperatures in the mid 90s resulting in low temperatures in the mid 70s. At times, highest mountain minimums match the 950 mb temperatures when they are in the 70s or higher. The inversion locally lowers to below passes and canyons when winds aloft lower to the surface there, resulting in huge one hour temperature changes, occasionally some 20 to 30 degrees F. Ramona (KRNM) in the inland valley area east of San Diego (KSAN) and the Devore (DEV)/Riverside (KRAL) in the inland valley area east of Santa Ana (KSNA) are notorious for rapid fluctuations. Large temperature variations of 20 to 30 degrees are common between cities, sometimes only 5 miles apart.

When the inversion base falls below 1000 feet, the transition zone pushes westward into the coastal plain, resulting in huge temperature differences across the area, with dense morning fog and very hazy afternoon skies. On very hot days, even small amounts of surface and atmospheric moisture results in some clouds developing over the mountains by afternoon. Good visibility during the morning (most prominent as one looks toward the mountains) most often precedes a very hot day during the summer. This is a sign that the marine layer inversion has been lowered to the surface and the marine air has largely been pushed offshore, possibly by warming, descending easterly flow below the canyons and passes with much less haze.

As for the onshore flow direction, a 2 mb onshore trend with weak gradients are prone to generating a sharp decrease, (sometimes 10-25 degree F 24 hour temperature falls) near the coast as the inversion rises and heat no longer mixes down easily to the levels of the previous day. When the inversion base rises, the transition zone pushes eastward across the coastal plain, resulting in these huge 24 hour temperature falls across the area. During the waning stages of a warm spell the sea breeze front (especially those that are accompanied by low clouds) can drop temperatures more in one hour than most synoptic scale cold fronts do. Large 24 hour temperature differentials easily occur with low, strong transition season inversions since the stratus might clear near the coast on day 1 and clear little if at all on day 2. This can result in lower afternoon high temperatures coastal areas (possibly to below normal). Temperatures have actually experienced 10 degree F falls in only 20 minutes as early in the day as late morning! At the same time increasing thickness values and 850 mb temperatures can simultaneously result in an increase in afternoon high temperatures to well above normal in the inland areas on some of those occasions. Temperature patterns with near to below normal values at the coast with record highs inland at the same time are not uncommon.

On a day during the spring and early summer when the clouds do not clear west of the mountains (deep marine layer) high temperatures west of the mountains are almost always in the 60s to lower 70s, even in the valleys. Because of the adiabatic profile and lifting/cooling in the upper portion of the marine layer, locations like Julian (JUL, in the foothills around 4000 feet MSL) are the coolest locations in the forecast area ("reverse heating pattern" foothills westward, with higher temperatures and better clearing closer to the coast). The higher mountains get rare marine layer snow during some transition season enhanced marine layer events. In these cases the lowest temperatures in the surface to 10,000 foot MSL region are found at the base of the inversion near mountain resort levels (approximately 6000-8000 feet MSL).

Inversion height and cloud top height are frequently different. Since marine layers are generally “conditionally unstable” below the inversion, the boundary layer easily “convects” with or without solar heating and frequently create a second cloud deck, especially for marine layer depths of around 2500 feet or more above ground level (AGL). If the inversion strength is less than 7 C, (even more likely for nearly isothermal inversions), cloud tops easily extend into the inversion, possibly to near the inversion top in inland areas and near mountains where stronger convection and upslope flow are present. For example, with little pressure gradient trend, clouds under a transition season 3500 foot deep inversion with an 8 degree C inversion will become scattered clouds in the Inland Empire in areas such as KONT and KRNM. However, the cloud deck remains solid over the coastal plain (best with a “typical cloud thickness” of 800 - 1000 feet thick or thicker). With a weaker inversion (for example, a 3 degree inversion capping the marine layer) it might clear early, or start out mostly clear in the morning. If there are clear spots at around 1600 UTC, then the moisture will often “convect” into a midday cloud ceiling in the clear areas west of the inland edge of the marine layer air (clouds “fill in” the gaps in the cloud cover). On these days dramatically slowed clearing of these midday decks is expected, with clouds that stay in most (if not all) day in most areas. (In the forecast models such as the time/height crossection, the marine layer is the portion below the 40 % contour on the GFS and the 50 % contour on the NAM/NGM models). Sometimes the models don’t “moisten up fast enough” after a dry period in the boundary layer, and shallow marine layers sneak into the coastal areas before the model contour thresholds listed above are reached. The marine layer is basically below the 60 % relative humidity level on the actual sounding. In the other direction, an offshore flow event with approximately 10 mb of offshore gradient from the coast to Nevada (for example, KLAX to KDRA) often results in 850 mb dewpoints and relative humidities dropping to the surface rather than the “wetter” surface values shown in the models.

2.8 LOW LEVEL REDEVELOPMENT OVER THE COASTAL WATERS

For very strong inversions (typically around 10 C or more), the cloud tops are confined to near the inversion base. With the “low strong inversions” of around 1500 feet or less with 10 degrees C or more, the transition season marine layer typically retreats temporarily off the coast mid morning. If it moves far enough offshore and the deck is less than around 800 – 1000 feet thick, it generally will not support much island effect stratus/blocking stratus, and little if any coastal re-development around noon. In contrast, the low clouds will re-develop near the coastline an hour or so after the initial clearing if the edge of the main low cloud deck is 10 miles or less from the coast during the afternoon. Sea breeze convergence or shoreline blocking helps the low clouds to re-develop. In some cases the low clouds are simply “advected back in” during the late morning hours, eliminating the complete late morning clearing.

2.9 ISLAND EFFECTS

With low inversions, sometimes the flow downwind of the islands creates alternating bands of enhanced stratus and reduced stratus in their wake, that move into the coastal areas. At other times the heating of the islands clears all of the stratus downwind (quite noticeable for very low inversions). To add more difficulty, some cloud patterns consist of just a single convergence band downwind of an island with clearing on either side of the band that moves into the coastal areas. Deciding whether the clear portion or the cloudy portion will be over a forecast site (and when) is very difficult.

2.10 EDDY FLOWS

Although smaller eddies occasionally form near Point Conception, or downwind of terrain features such as the islands, the most famous local eddy is the “Catalina Eddy”. It typically starts with a trough moving through to the north, followed by northwest flow of 15-20 knots out near San Nicolas Island

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(KNSI) and outer water buoys. A good indicator of a developing eddy is when KSAN winds pick up a southerly component (wind directions from 140 degrees to 240 degrees are a good indicator of an eddy). The Catalina Eddy has a habit of showing up or strengthening during the mid morning hours. Eddies often spin up during the mid morning with very little notice. They occasionally become strong. (“Strong” is 7 knots sustained on 3 hourly observations between 0700 and 2100 UTC and between 140 and 240 degrees, with at least one gust to 10 knots). This helps to keep the low clouds from clearing near the coast, typically from the KCRQ area south. A moderate eddy is essentially when the sustained winds between 140 degrees and 240 degrees reach 7 knots on at least 3 hourly reports at KSAN between 0700 UTC and 2100 UTC. The eddy winds typically peak late morning and become more southwesterly as the day progresses. A strong eddy is in place if during a moderate eddy at least one 10 knot report is received during that time period. Pressure gradients that “trend offshore to the north and onshore in the south” are a good precursor for eddy development. The result is a deepening marine layer with “road wetting” drizzle possible. The marine layer deepens rapidly (1000 feet or more in 24 hours) to nearly 2500 feet deep or more during such a pattern. The circulation pushes the stratus inland and northward, or just northward along the coast. During these southerly pushes, the low clouds reach KONT through the “back door” (from the southeast, hitting the southern inland valleys first) rather than the typical arrival from the west. Depending on the depth and position of the circulation, it even pulls the stratus westward out of the coastal and valley areas and speeds up the clearing at times. Another issue is the advection of deeper marine layer clouds toward the coast from the inland and southern areas, which results in higher cloud tops near the coast than is expected since tops are generally higher inland and in the south. This causes a later clearing time than previously thought. On some occasions an upper level low (large scale eddy) drifts over the area and mimics the flow and effect of a Catalina Eddy with an “eddy like flow”. An eddy like (southerly) flow along the coast, whether or not it is eddy related, just might keep the low clouds in all day under a low, strong inversion.

Mesoscale flow directions also have serious effects on afternoon temperature and wind direction at smaller scales. With the southerly eddy flow, winds in the KFUL/Anaheim area are southerly, with only 10 miles of trajectory over land. When eddy winds are weak or absent, the flow over the coastal areas is mainly west-northwesterly, and heated airflow from the northern coastal areas of the California Bight (from the KSBA area to the KLGB area) drifts south and southeast over the coastal waters north of the KCRQ area. This results in complete afternoon clearing in the coastal waters north of KCRQ. Also, without the overpowering southerly winds of an eddy, a west-northwest sea breeze flow develops around the northern side of the Palos Verdes peninsula (a hill approximately 1500 feet high just south of KLAX and north of KLGB). When this occurs, the overland trajectory of the sea breeze air into the KFUL/Anaheim area increases to 20 miles. Thus, afternoon high temperatures are expected to be higher at KFUL/Anaheim with west winds than south winds. Here, prediction of whether or not there is an eddy makes a big difference in the afternoon temperature and wind direction forecasts.

As for inland extent, the clouds typically reach the coastal valleys, Inland Empire (KONT/KRIV area), and coastal slopes with cloud tops near 1300 feet, 1800 feet, and 3000 feet respectively during the transition season, but might need to deepen to around 2500 ft deep to reach Ontario (KONT) during mid-summer. (A deeper layer is more necessary if there is no eddy present to help “prop up" the marine layer and push the low clouds inland). With weak easterly flow aloft and/or weak offshore surface pressure gradient trends, the low clouds may be delayed till morning. For weak inversions with deep marine layers, (and only patchy or areas of low clouds overnight) there can be a dramatic increase in cloud coverage into a ceiling to fill in the gaps in coverage during the morning, (mainly through boundary layer convection). On these occasions it is less cloudy overnight than during the day.

Mid level moisture moving in aloft from the south typically “disrupts” the marine layer, (making it very patchy), similar to what happens when the inversion weakens. These are hot humid summer days with

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monsoonal moisture moving in aloft, raising 700 mb dewpoints to near 0 C or higher. Also, near the coast maximum and minimum temperatures as well as low cloud cover basically follow the sea surface temperatures during the year. Sea surface temperatures may peak in September, explaining why some coastal sites have their annual high temperature peak in September. Cooling surges of gulf of California moisture into the deserts also weaken the "coast to desert" pressure gradient and disrupt the marine layer. Surface dewpoints rise as well, and could reach 70 F, even at the coast, during such hot humid days. This can easily result in a "heat index" rise to near warning levels, especially for temperatures around 105 F.

The low cloud deck also seems to react to dynamics such as those associated with waves in a subtropical jet from the southwest or monsoonal flow. Outflow boundaries from Mesoscale Convective System (MCS) development over Mexico are prone to generating waves of enhancement and dissipation in the low clouds, and are visible as waves traveling away from the coast through the cloud field. At times tropical cloud features locally clear the low clouds below as they pass by.

2.11 DENSE FOG EPISODES SURROUNDING SANTA ANA WIND EVENTS

Because of the way it hugs the bottom of the almost daily inversion, some dense fog is evident almost every day during the spring through fall period. For the typical 1000-3000 foot marine layer, at least patchy dense fog is found at an elevation halfway between sea level and the top of the marine layer [the "half-depth point", or approximately 800-1000 feet below the top of the marine layer (whichever is lowest)]. The days surrounding Santa Ana Winds are notorious for setting the stage for dense fog. A typical cycle begins when the atmosphere has exhibited offshore flow and hot days, but the surface pressure gradients have begun to trend onshore along with the actual gradients (transition day). The 500 mb upper level ridge axis moves inland as well, which reduces the subsidence and allows deepening of the marine layer. The upper level flow changes from anticyclonic to cyclonic, and the coastal marine layer low clouds return and deepen. The end of a Santa Ana wind event that slowly weakens results in dense fog in the highly populated coastal areas for 2 days or so as the marine layer depth re-adjusts to the normal height of around 1300-2400 feet deep. If the return to onshore flow progresses slowly, then a layer of dense fog follows the inversion from over the Pacific, into the coastal areas, into the valley areas, and possibly into the mountains over a period of several days. If the marine layer becomes very deep it extends through the passes and locally into the deserts. When the upper level high begins to build in again, and the flow becomes anticyclonic, subsidence lowers the inversion so even lower terrain is again within 800-1000 feet of the inversion base, and dense fog retreats back to the lower elevations such as the western portion of the valleys or into beaches and mesas of the coastal areas. Dense fog tends to lift somewhere between 8 and 9 am local time during the warm season (1500–1600 UTC is a good estimate). It is possible to have strong high pressure generating high winds below the passes on the inland side of the valley areas, while at the same time 20 miles away the western portions of the valleys remain covered with dense fog, resulting in both dense fog and high winds coexisting in opposite ends of the same valley forecast zone! (More commonly seen is clear skies, calm wind and cold pooling in one part of the valley, while strong winds and temperatures 15-25 degrees warmer occur in another part of the valley). In these cases, when strong winds and low clouds already exist, a Catalina Eddy is probably in progress. The Catalina Eddy and associated clouds can hang on tenaciously during the beginning of an offshore flow event until the offshore flow finally scours it out. After the offshore flow event has been around for a while, eddies sometimes develop midday near the end of the offshore flow event, and possibly drop temperatures 10 degrees near the coast in one hour or less, heralding the return of onshore flow. In some cases there is an upper level trough of low pressure moving into the west coast with a cold front sweeping through the plateau, rapidly lowering the surface pressures inland. If the onshore trend is strong (approximately a 24 hour increase of 2 mb to the local deserts and 4 mb to the plateau or more, respectively), the dense fog phase is by-passed completely in the coastal areas (possibly

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associated with an eddy or some sort of southerly flow to help lift the inversion) along with good coastal visibilities. However, near the inversion in the foothills and mountains, it is likely to be a dense, precipitating fog. A rapidly deepening marine layer during the warm season will typically deepen around 1000 feet per day or more during these patterns. These conditions should be watched as dense fog and drizzle rapidly moving into previously clear areas results in an instantaneous drop in visibility and slick wet roads.

Multi-car chain-reaction accidents occur every few years or so in the Cajon Pass along Interstate 15 east of San Bernardino. The usual pattern is an approaching trough with a marine layer rapidly deepening against a strong inversion. These types of scenarios produce drizzle or light rain that wets the roadway, along with near-zero visibilities in fog. The dense fog generally occurs at or just under the inversion. In these cases, it will at times go from clear with unlimited visibilities to zero visibility almost instantly. Even thin cloud layers result in hazardous dense fog episodes.

The 850 mb temperature is useful during the warm season for estimating the depth of the coastal marine inversion and approximating the day to day changes in the marine layer depth. Also it helps to determine where the fog will be, since if there is an inversion, there will be at least patchy dense fog somewhere in the forecast area under the inversion.

2.12 FORECASTER HINTS – MARINE LAYER:

a. There is a significant difference in the cloud patterns with the exact same inversion height and strength between the transition season and the mid summer season. This is largely because of lower sea surface temperatures, increased mid level moisture, and weaker onshore surface pressure gradients during the mid summer period. See the “Marine Layer Matrices” in Appendix A for the “expected” marine layer characteristics for the transition seasons and for the summer season. In order to help illustrate some of the characteristics of the marine layer, Appendix B contains several examples of marine layer variability. One case highlights how a stratiform pattern (with afternoon clearing inland areas only) transitions to a more convective pattern with multiple cloud layers, then finally to a pattern with clearing favored coastal waters and immediate coastal areas rather than inland. Another case shows a marine layer cycle (from a shallow marine layer to a deep marine layer, then back to a relatively shallow marine layer again). To round out the discussion a shallow convective event, and two dense fog cases are also included.

b. Marine layers with weak inversions (less than 7 C, and generally around 2500 feet deep MSL or deeper) allow convection to deepen up into the inversion, sometime reaching the inversion top. Cloud tops are closer to the inversion base height for lower, stronger inversions.

c. The deeper the marine layer, the weaker the inversion is in many cases, and the more convectively unstable it is, even “convecting” into 2 or more decks without sunlight due to boundary layer instability, especially for layers about 2500 feet deep or deeper.

d. The change in marine layer height with 850 mb temperature generally becomes more dramatic with lower 850 mb temperatures. Marine layer depth is inversely proportional to 850 mb temperature on most warm season days. Although on most days a 1 degree C increase (decrease) corresponds to a 200 foot decrease (increase) in height, eddy circulations might deepen the marine layer while 850 mb temperatures remain steady or increase.

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e. During the transition seasons (late spring and early fall), inversion strengths of 10 C or more, for low inversions [1500 feet deep or less, and a cloud thickness approaching 1000 feet thick or more)] will allow all beaches to clear for an hour or so around mid morning, then clouds move in at the "cloudy beaches of the day" [either the Orange County beaches (near KSLI- KSNA) in the north, or the San Diego County beaches (KNFG-KNZY) in the south. This is also dependent on eddy location or whether or not there is an eddy at all (simple west-northwest flow)]. The thickness of the morning cloudiness (or cloud brightness near one beach compared to that of another on the visible satellite imagery or pilot reports) can help determine the "cloudy beaches of the day" where cloudiness will not completely clear all day. (With little 24 hour change in marine layer depth, surface pressure gradient, surface pressure gradient trend, and inversion strength, persistence is often the best forecast). In many cases, the beaches in the south are the "cloudy beaches of the day" and the beaches in the north are the "sunny beaches of the day".

f. For the Inland Valleys (for example the Inland Empire area around KONT) low clouds reach Ontario (KONT) for KNKX sounding marine layer depths of 1800 feet or so during the transitions seasons, and as much as 2500 feet deep during the summer. This is possibly because of higher sea surface temperatures, better afternoon beach clearing, and later development time at the coast during the summer. Typically there is a rather large south-to-north sloping of the marine layer depth, with marine layers deeper in the south near KNKX than in the north in many cases. Other areas might also need deeper marine layers than the 1300, 1800, and around 3000 foot transition season depths to reach the coastal valleys, inland valleys, and lower coastal slopes respectively.

g. The number of hours after sunrise that a low cloud layer typically dissipates is approximately the cloud thickness at sunrise divided by 200 feet, since on average the "burn off " rate is around 200 feet of cloud thickness per hour, (assuming no clouds exist above the stratus). Although the "average" for the morning is 200 feet per hour, the instantaneous rate climbs to about 350 feet per hour after about 9 AM local time during the mid summer. Rates are slightly slower outside of the summer season. (See the "Marine Layer Matrix" in Appendix A for more information on clearing times since certain conditions can dramatically affect the results of such simple formulas).

h. The following conditions result in broken skies (mostly cloudy) till at least mid afternoon and possibly all day for the following cloud top heights and locations. (Conditions are mainly for days beginning with broken cloud decks and a cloud thickness of 800-1000 feet thick or thicker), and especially during the transition seasons;

(1) Coastal Slopes of the Mountains (locations 3000 feet MSL and higher)
- (a) Stratus deep into the passes in the morning
- (b) 3500 feet deep or deeper and inversion strength < 7 C (convects into weak inversion)
- (c) 3500 feet deep with +4.0 mb onshore trend to Plateau
- (d) Few (if any) clear spots over the coastal waters at sunrise

(2) Coastal Valleys
- (a) All of the above
- (b) 3500 feet deep with any inversion strength
- (c) 2500 feet deep with +4.0 mb onshore trend to Plateau

(3) Major Coastal Airports
- (a) All of the above

(4) Beaches

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(a) All of the above (with at least broken skies out to the islands, otherwise it may reverse clear).
(b) Inversion strength around 10 C or more with any depth during the transition season.

i. During the warmest 3 month period in the coastal areas (July through September), the clouds typically clear, but linger at the beaches if

1) There is an upper low over the area
2) An unusually strong onshore pressure gradient trend develops (2 mb onshore trends to the local deserts (for example KLAX-KTRM), and 4 mb onshore trends to the plateau (for example KLAX-KTPH).
3) There is around 6-8 mb of onshore pressure gradient to the local deserts during the morning and a Catalina eddy is present

j. Upper level lows can deepen the marine layer up to more of an "enhanced marine layer" of over 6000 feet deep, (or simply a surface based moist layer), without strong onshore gradients, since a weak front can push into the area, or the airmass is lifted. Approaching upper level lows may deepen the marine layer even with residual offshore pressure gradient trends still in force.

k. Stratus burns from the base upward during the day, and tends to advect in during the early evening at around 1/2 to 2/3 the height of the afternoon ceiling. This is partly because stratus that advects in from the ocean comes from an area of rather weak daytime heating, so the stratus bases have not been burned upward as much as the cloud bases over land.

l. Non-frontal stratus with a low inversion height moving in from the north along the coast, (if not associated with a cold front and in the absence of an eddy) tends to stay rather low when it moves inland, and result in dense fog in the coastal areas. Typically southerly flow is a "deepening flow" with the marine layer becoming deeper and the cloud bases typically become higher with time.

m. A weakening or slow moving cold front will occasionally transition into an eddy over the coastal waters in the Southern California Bight [the coastal areas and coastal waters between Point Conception (KSBA area) and the California/Mexico Border]. It is not unusual to have a low aloft that is reflected in the low cloud pattern and basically "acts" like an eddy, with low clouds held in at the coast all day in some areas (with a preference for southern areas).

n. An early stratus arrival is a good bet when the Carlsbad (KCRQ) visibility is restricted to 5 miles or less in afternoon haze (means the marine layer low clouds are at the shoreline or only a few miles offshore, and the inversion is strong). If a very strong onshore trend develops (such as that associated with a trough or low aloft), the low clouds easily move into the coastal airports mid afternoon rather than waiting until closer to sundown to move in.

o. For standard inversion base height (1000 to 3000 feet deep) the following occur around ½ the height of the marine layer inversion base (the "½ depth" point). This is assuming a strong inversion, so cloud tops are close to the inversion base.

1) Bases are ½ as high as the inversion
2) The low clouds will move inland to terrain that is close to ½ the depth of the inversion, for example,
    i. A 1300 foot deep marine layer will generally allow stratus inland to near the 650 foot contour [lower portion (or western portion) of the coastal valleys]

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ii. An 1800 foot deep marine layer will move inland to approximately the 900 foot contour (lower portions of the inland valleys).

3) There is almost always at least some patchy dense fog at the ½ depth point.
4) Although the clouds are typically around 800-1000 feet thick for the more typical summer depth range, dense fog will extend lower if the clouds become very thick.
5) For surface based inversions, the night and morning low clouds typically extend no further inland than the mesas (near the 500 foot terrain contour), with tops to around 800 feet common, resulting in dense fog at several major airports.
6) With a shallow marine layer and no inversion the coastal regions below 500 feet still have a strong "marine air influence" unless there is strong offshore flow (about 10 knots or more) at the beaches. In these cases the top of the marine layer is assumed to be around 500 feet MSL.
7) With 10 degree C temperature/dewpoint spreads in the lowest part of the evening sounding (for example, surface to 850 mb) the overnight period will most likely remain clear, and a rapid temperature rise is possible the following day. This is especially true if the pressure gradient trend is offshore or near neutral.

p. At 3000 feet deep and deeper, instead of the ½ depth point, the elevation level of the inland extent of the low clouds along the coastal mountain slopes typically exceeds the coastal inversion base height since the inversion near the mountains seems to slope upward into the mountains.

q. "Inversion base passages" (or "transition zone passages") associated with the return or retreat of the marine layer is similar to cold frontal passages. The warm, dry air above the inversion is replaced by the cool, moist marine air (and possibly drizzle or a wetting mist) beneath the inversion. It is sometimes accompanied by 10-25 degree 24 hour temperature changes. Rather dramatic changes occur in mountainous areas as the inversion rises and falls. With changes from day 1 with a clear afternoon to all day cloud cover on day 2, even larger 24 hour temperature changes are possible. Little if any drizzle is expected during the marine layer inversion lowering phase, (since the "drizzle" phase is generally associated with the deepening phase of the marine layer cycle, and usually there is a rather abrupt end to the precipitation when the deepening phase ends).

r. Most chain reaction accidents occur in the mountains (in particular, the Cajon Pass) with drizzle and/or light rain accompanying dense fog. The mountain portion of the pass is between 3000 and 4500 feet MSL, so inversions approaching around 3000 feet deep or deeper likely produce fog, possibly dense in the passes.

s. A common chain reaction accident pattern involves cyclonic flow, resulting in a marine layer rapidly deepening against a strong inversion that is producing drizzle or light rain (possibly enhanced when coupled with upslope flow in the mountains). Without ridging to break the pattern, cyclonic flow continues to push moisture into the area, resulting in an extended period (possibly many days) of dense fog and drizzle for poor visibilities and slick roads.

t. Another common chain reaction accident pattern is a warm rain event (for example warm frontal patterns) which also produces very light rain and again, persistent onshore flow. These patterns typically persist and warming is sometimes delayed until anti-cyclonic flow (ridging) re-develops.

u. Checking the marine layer depth on the Vandenberg sounding (KVBG) upstream as well as the observations around it (including the offshore islands) for rainfall gives a good estimate of the characteristics of an approaching front, such as moist layer depth and/or rainfall rates and amounts.

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v. In many cases the most widespread precipitation during a deep marine layer or shallow front is during the rapid deepening stage.

w. Much of the populated region near the coast experiences dense fog with marine layer depths (inversion bases) of around 1000 feet or lower (a common feature of post-offshore flow periods).

x. Dense fog (less of a problem mid-summer since it is frequently quite patchy then) is typically associated with cloud bases down to 800 - 1000 feet below the inversion base, and is quite hazardous with marine layers deepening 1000 feet per day to above 2500 feet or so for drizzle and wet roads. Conditions are even more critical at depths above 3000 feet deep in the coastal slopes and mountain passes.

y. Fog, locally dense, has a tendency to form in river valleys (or inland valleys) overnight, and is locally advected down the river valleys to near the coast. This commonly occurs during mostly clear nights after a rainstorm, with patchy marine layers, (for example, 1000-1500 feet deep), or simply with high surface relative humidity but slow development of overnight cloudiness.

z. Valley areas can have high winds below the mountain passes and at the same time have dense fog on the coastal side of the valley. Sometimes the dense fog will hang on at the coastline.

3. HEAT WAVES

Daily mean temperatures in the southern California coastal areas do indeed deviate from "room temperature" on occasion. Hot weather tends to develop when the 500 mb north-south ridge axis moves over southern California with the ridge axis overhead. Another potentially more volatile set-up is when in addition, the east-west ridge axis pushes north to a position over (or north) of southern California with strong offshore winds around the bottom of the high and around the bottom of the east-west ridge axis.

Figure 10 is a schematic showing the relationship between the subtropical moisture, flow direction, and the position in relation to the ridge axis. Shown is the 700 mb relative humidity, wind barbs and streamlines. The subtropical moisture tends to remain south of the axis in mainly easterly flow, with the deep easterlies occasionally impinging on the ridge axis. At the wind shift line (where the winds shift from easterly to southerly, then westerly), some of the moisture advects north of the ridge axis, but the airmass tends to dry out as the flow moves north of the axis and joins with the westerlies. The easterly flow beneath the 500 mb ridge axis is a key player for heating southern California. The easterly flow lowers the inversion, and may eliminate it altogether. The moisture aloft helps disrupt the low clouds, causes morning low temperatures to be higher, and raises the temperature-humidity index as well for muggy conditions.

Figure 11 shows heat wave map types 1 through 4. These are schematics of 500 mb patterns commonly found with heat waves in extreme southwestern California. All typically occur with easterly low level flow at least as far west as the inland valleys, and all the way to the coast during the more extreme, widespread events. Type 1 has the 500 mb high center to the north, so weaker synoptic scale subsidence occurs. At the same time stronger northeast winds (stronger than those that would occur if the high were overhead) can develop around the high as the flow aloft couples with the flow closer to the surface. The high to the north allows easterly flow south of the high into the area to lower or dissipate the marine layer and associated inversion. Mesoscale mountain wave subsidence is also rather strong with these events. Type 2 events have the high center close to if not directly over southern California. With the high nearly overhead the synoptic scale subsidence can be very strong. On the other hand the northeast flow is weaker since the winds around the high cannot help to supplement the low level flow since

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winds aloft are weak. These are mainly events driven by synoptic scale subsidence. Type 3 events occur when the north-south ridge axis is directly overhead. This easily results in strong subsidence. If the ridge is displaced slightly to the west, then very strong northeast winds can still develop over the area to couple with the subsidence aloft. Type 4 events are when a rather strong east-west ridge axis develops to the north. The pattern has little of any west coast “troughing”, so the pattern is dominated by subsidence from the surface high pressure areas.

The occasions when the 500 mb high reaches around 6000 meters can be expected to bring above normal temperatures with a few record highs. The mountains, foothills and Inland Empire begin to become very vulnerable during weak to offshore pressure gradient patterns (“weak flow patterns”) which accompany these scenarios. This generally brings hot northeasterly canyon/pass winds and lowers the inversion top to near the higher valleys and mountain/foothill elevations, and on extreme occasions, down to sea level. These warm inversion tops tend to raise minimum temperatures in their vicinity, possibly into the 70s, with correspondingly higher afternoon temperatures. (The mountains are particularly vulnerable).

Weak flow patterns (table 3) are generally gradients of approximately -3.0 mb from the coast to Tonopah (KTPH), near zero (neutral gradient) from the coast to Daggett (KDAG), and +2.0 mb from the coast to Thermal (KTRM) or Imperial (KIPL). (These are the gradients to the “plateau”, northern deserts, and southern deserts) respectively. These weak flow conditions help to keep the cool marine layer to the west, and result in strong warming in the valleys. Also the coast to KLAS gradient of less than +3.0 mb is in the “weak” category (another critical and very useful parameter). The pressure gradient trend (24 hour change in the pressure gradient) is also very important when coupled with the actual gradient. With inversion tops below 960 mb a rapid morning rise in temperatures to above seasonal normals is possible as the heat mixes down before the sea breeze becomes established. This is especially true if there are no morning low clouds, the inversion is surfaced based, windy offshore flow conditions occur, or the inversion becomes very weak or dissipates. Low level easterly flow just above the surface is almost always a big help, (as long as it is strong enough to lower the inversion base to the surface, begin drying the boundary layer, and weaken the inversion, rather than just strong enough to lower and strengthen the inversion). Huge morning temperature jumps occur, with a focus on areas just below mountain passes such as Ramona (KRNM), Devore (DEV), and Beaumont (BUO), and even further from the passes in the mid-valley regions at locations such as Riverside Arlington (KRAL).

The 850 mb temperature (as well as lower level temperature and wind structure), are valuable for marine layer depth and heating determination (table 1 and table 3). The marine layer changes some 200 feet per degree C below 4000 feet. With morning offshore flow in the favored areas, 26-30 degrees F can be added to the 850 mb temperature (for example, using the KNKX sounding) to approximate the highest temperatures (just west of the passes during mid summer, and closer to the coast when some Great Basin cold advection occurs below the passes). Temperatures are likely to be rather uniform across the coastal plain and valleys at times during these events, as opposed to the usual pattern when coastal temperatures are much cooler than valley temperatures. High temperatures in the mountain and desert areas respond well to changes in thickness (for example, the temperature changes 1 degree F per every decameter of 1000-500 mb thickness change).

Most of the time the offshore flow is seen following the inversion down as the pressure gradients trend offshore (an offshore trend from the coast to the local deserts of 2 mb is significant, especially for actual surface pressure gradients that are “less onshore” than +3 mb from the coast to the local deserts). This is reflected in the marine layer and associated heating. About a 12-15 degree F or more increase in the boundary layer temperature (950 mb is a good estimate for boundary layer temperature) allows the flow to warm adiabatically at 5.5 degrees F per 1000 feet and “surface the flow”. The “850 mb temperature

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plus a constant" (with the constant somewhere between 26 and 30) develops at the surface. A T850 + 26 to 30 F temperature is prone to extending westward to at least the inland coastal plain (5-25 miles from the ocean), and on occasion to the beaches. Low level winds should also be factored in to help make a determination (table 3).

Although the mountains (fig 12) are the coldest zones for lower 850 mb temperatures (lapse rate related), mountain highs generally exceed those of the coastal zone for higher 850 mb temperatures. The marine influence strongly modulates heating below the inversion (Fig 13 and 14), but only at the immediate coast on such very warm days.

Weak-moderate offshore flow is a very consistent pattern that produces hot days during the summer. KLAX-KTPH exceeds 5 mb offshore and surface pressure gradients to the northern deserts and southern Nevada become offshore at a mb or two. The gradients to the southern deserts are expected to be near neutral. (These "weak offshore flow" gradients are 2 mb more "offshore" than the "weak flow" gradient values discussed earlier). With monsoonal thunderstorm episodes that reach the coastal areas, morning low temperatures in the upper 60s and lower 70s occasionally occur, possibly with high and mid level clouds west of the mountains and a surge of high dewpoints in gulf surge air that moves into the coastal areas. On rare occasions, heat indices rise over 105 west of the mountains, and 120 in the deserts during these surge patterns. Although southerly flow off the Pacific is typically dry during June and July, tropical features moving by to the south (August and September are the key months) makes even southerly flow a producer of moisture (including various degrees of cloudiness). The marine layer is prone to becoming very sporadic during these patterns.

The rather strong onshore flow during the spring weakens gradually into September as the strong Pacific high and its strong onshore flow continues to be replaced by the monsoon-generated upper level high and the associated surface reflection which develops near the 4 corners. This makes it easier for offshore flow and possible heat waves to develop late August and into fall. Although heat waves occur during any summer month (table 4 – 7), the combination of very strong upper level highs and weak low level flow makes late August and September prime months for the hottest heat waves of the year. A graphic of heat waves strung end to end along with 950 mb , 850 mb, and inversion top temperatures are compared to high temperatures at UCR (in the inland valley area near KONT) and KSAN in Figure 15. Minimum temperatures near the inversion base (lower mountain areas) climb, with an associated rise in afternoon high temperatures (fig. 16) during these heat waves. Combined with surges of moisture from the southeast, or high sea surface temperatures, the resulting high dewpoints cause heat index values to skyrocket (however, this is more of a problem in the deserts as dewpoints reach 80 deg F at times). Warm season severe weather potential also peaks with all of this heating and moisture in late August through early September. Strong offshore flow is sometimes successful in clearing the low clouds completely (with no overnight low clouds), and generates a heat wave. One problem that has to be watched is if the offshore flow does not become very strong, it has the opposite effect near the coast. As the warm, easterly flow moves west over the inversion, this very weak offshore flow causes warming aloft, but strengthen the inversion, and makes the low clouds more persistent and the low cloud deck more solid. Trying to determine whether the offshore flow will cause warming or cooling near the coast is often very tricky. In the spring through early fall period, lowering and strengthening of the inversion associated with a quick burst of offshore flow is frequently the case, with cooling at the immediate coast. There is a better chance that a stronger offshore flow will clear out the low clouds from the coastal areas before May and after September.

Subsidence around the edge of an approaching tropical storm can bring strong heating all the way to the coast. Also the pressure gradient associated with approaching tropical storms might weaken the typical onshore surface pressure gradient, or even generate strong heating through offshore flow, and should be

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watched. Small features in the subtropical jet have been known to produce sprinkles, followed by strong heating and a strong burst of <u>onshore</u> wind. During these unusual events temperatures correspond with a spike up to or above the mid 80s at KSAN, however these summer rapid-heating type onshore flow events are rather rare.

Many times after a heat wave the coastal marine layer returns in a rather solid fashion. If the transition is slow, the marine layer low cloud deck results in dense fog in the heavily populated coastal areas. If the transition is rapid, it lifts up into a stratus deck there. A typical pattern at the end of a heat wave is the interior keeps warming up, possibly with a higher afternoon temperature than the previous day, but at the same time the cooling marine air results in lower afternoon highs affecting only the areas near the coast. An enhanced sea breeze locally develops with heat waves, as the descending easterly flow gets entrained into the sea breeze. This increases the onshore flow already induced by the strong ocean to desert thermal gradient. During the phase of the marine layer cycle when the surface pressure gradients are in the “weak” category (or offshore) strong heating frequently develops (best with a strong offshore trend in the pressure gradient).

There is a transition period spanning the season with the strongest high pressure aloft and the warmest sea surface temperatures (late summer/early fall) and the season with the most offshore flow events (fall). This helps to explain why the highest temperature ever recorded in San Diego occurred in what is technically “fall” (26 September 1963). This makes the late August and though early October period prone to heat waves. Some heat wave events are “offshore flow dominated” with strong winds while others have weak winds and are “subsidence high dominated”. Many events are a combination of the two (combined subsidence high/offshore flow events). The strong “offshore flow dominated heat wave events” typically contain wind gusts at or above advisory levels (gusts to around 35 mph) in populated areas. Offshore winds are much weaker during the summer than they are during the late fall through early spring period, so “subsidence high dominated heat wave events” are by far more common during the summer, while “combined subsidence high/offshore flow events” and “offshore flow dominated events” are very common during the cool season. Figure 17 is a schematic that combines many aspects of the marine layer and the flow into effects on temperature and clouds at both a coastal and inland valley site. The schematic is geared toward the transition seasons (spring and fall) and the cloud layer is assumed to be approximately 800-1000 feet thick. Other factors like pressure gradients, pressure gradient trend, lows aloft, Catalina Eddies, moisture (with or without clouds) aloft, and monsoonal moisture in the deserts can all have an effect on the conditions in the schematic and cause conditions to deviate significantly from the schematic. Still, the schematic should give a good overview of the different scenarios.

3.1 FORECASTER HINTS – HEAT WAVES;

3.1.1 High afternoon temperatures reaching west into the mid-coastal plain (around KFUL)

The parameters below help allow warming adiabatic flow to reach the surface. Adiabatic high temperatures are 26 to 30 deg F higher than the 850 mb temperatures. It is probably best to use the 0000 UTC 850 mb temperature forecast (which are a few degrees F, or a couple of degrees C higher than at 1200 UTC). Any 3 of the 11 parameters below can be enough to generate well above normal afternoon high temperatures that can reach the mid-coastal plain near the Fullerton/Anaheim area (5-25 miles inland near KFUL). This is especially true July-September when the beaches generally clear by mid afternoon (since persistent beach cloudiness can cool the mid coastal plain more than expected). There are 4 distinct map types associated with heat waves in southern California. Brief case studies involving examples of each of the 4 map types commonly associated with heat waves are shown in Appendix C.

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a) Weak (near neutral) to offshore gradients, at or more "offshore" than the following values;

    1) KLAX-KTPH value of -3.0
    2) KLAX-KLAS value of +3.0 (a key parameter)
    3) KLAX-KDAG value of 0.0 (near neutral values are sufficient)
    4) KLAX-KTRM (OR KSAN-KIPL) value of +2.0

b) Strong highs

    1) East-west upper level ridge axis to the north (preferably with easterly afternoon 700 or 850 flow at KNKX).
    2) Strong high directly over the region (preferably 590 decameters or more).
    3) Very strong (approaching 6000 meters) 4 - corners high, preferably with easterly afternoon 700 or 850 mb flow at KNKX.

c) Large 24 hour changes in the boundary layer temperature (easily approximated using 950 mb temperatures);

    1) Large 24 hour increases in the boundary layer temperature (approximately the 950 mb temperature) of 12-15 degrees F (or half as much increase in the 850 mb temperature). This is a classic example of a "transition day" because there is usually strong warming.

d) Large offshore trends in the pressure gradients

    1) A large (2 mb or more in 24 hours) offshore trend to the local deserts when gradients are already in the weak category is significant. This is also an example of a "transition day".

e) Rather high morning boundary layer (950 mb) and 850 mb temperature

    1) Morning temperatures at 950 mb and 850 mb in the mid 20s in degrees C (mid 70s in degrees F) often result in rather hot days, and upper 20s and 30s in degrees C (80s in degrees F) are likely to accompany very hot days.

f) Morning offshore winds at Devore (DEV), Fremont Canyon (FMC), or Campo (CZZ)

    1) Wind gusts in and below canyons and passes of 15-25 mph adiabatically warms areas in and below the passes, possibly reaching the inland coastal sites of KFUL/Anaheim and KSNA. If the subsidence and easterly flow is not strong enough, (for example during a Catalina Eddy), the easterly wind may be delayed at the coast, or remain above the inversion at the coast with little or no coastal warming. Coastal conditions may even be cloudier and cooler than expected rather than warmer if an eddy continues or develops.

g) Low Inversion Tops With High Inversion Top Temperatures

    1) Morning inversion tops near to below 950 mb with inversion top temperatures approaching 30 degrees C typically result in rapid morning warming before the sea breeze has much affect on slowing down the rapid temperature rise. (Due to the diurnal trend, the afternoon inversion top values are typically 2 C higher than morning values).

h) 1200 UTC coastal area (eg KNKX) surface dewpoint depressions in excess of 10 degrees C

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(which is a common "heat wave" sounding profile, especially with neutral to offshore pressure gradient trends).

1) No cool marine layer air to slow the heating

i). Surface based inversion with a top below 950 mb

1) Less marine layer to burn away so heating develops rapidly. On such days, if the inversion is surface based, the KFUL/Anaheim high temperature is at least 12 degrees F higher than the 950 mb temperature if the pressure gradient trend is no more than slightly onshore (somewhat erratic in the fall).

j) East winds all the way to the coast gusting to 10 mph or more

1) Air mass replacement (advection) to warm even the beaches. This could result in reverse heating and/or maximum temperatures based on elevation, especially during the cool season due to cold advection affecting the inland areas.

k) Generally, the stronger the offshore flow, the later in the afternoon the temperature peaks (delays the sea breeze).

3.1.2 Other areas.

a). High temperatures just over the 850 mb potential temperature (26 to 30 degrees F above the 850 mb temperature) occurs below the favored canyons and passes in the Inland Empire with northerly winds at Devore (DEV). Devore is usually the first site that northerly winds surface below mountain passes and canyons, since many of the passes and canyons in the forecast area are more vulnerable to easterly flow. In the easterly flow cases, strongest Inland Empire winds are often in the Beaumont (KBUO) area.

b). High temperatures just above the 850 mb potential temperature (26 to 30 degrees F above the 850 mb temperature) occur below the favored canyons and passes of the coastal plain with northeasterly winds at Fremont Canyon (FMC), especially if gusts at FMC are around 25 mph or more. San Juan Canyon, on the coastal side of the Santa Ana Mountains east of KSNA can be as warm or warmer than some inland valleys sites (at the mouth of the valleys) such as Chino (KCNO).

c). High temperatures just over the 850 mb potential temperature (26 to 30 degrees F above the 850 mb temperature) occur below the favored canyons and passes in the southern valleys with northeasterly winds at Campo (KCZZ), especially if gusts at KCZZ are around 25 mph or more.

d) A quick approximation for heat index follows;

1) The heat index is approximately equal to the temperature (in degrees F) when dewpoints reach 59 degrees F.

2) The heat index is approximately equal to the temperature + dewpoint – 60 (where the temperature and dewpoint are in degrees F). For example a temperature of 120 with a dewpoint of 60 minus 60 is approximately a heat index of 120.

3.1.3 Ingredients for high minimum temperatures

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a. On days with low 850 mb temperatures, warmest coastal minimum temperatures are actually higher than the warmest desert minimum temperatures, since warm coastal waters warming the boundary layer keeps the coast warm (cool season).

b. As boundary layer and low level temperatures increase, the highest mountain minimums reach 70 degrees F for 850 mb temperatures in the upper 70s (25 degrees C or more). This reflects the warming, and likely the lowering of the inversion and inversion top to (and below) the thermal belt level (the 1000-4000 foot MSL region).

c. Minimum temperatures in the higher portions of the valley areas are close to the mountain values, and basically match them for the stronger summer offshore flow events (possibly in the 70s or higher).

d. For the hottest nights mountains westward, warmest minimum temperatures are highest in the mountains, and lowest at the coast (inversion height and possibly east wind and mixing related).

e. For 850 mb temperatures in the upper 20s (degrees C) or higher, highest mountain minimum temperatures easily exceed 70 (degrees F) with high temperatures in the Santa Ana Mountains generally 15-20 degrees above the minimums in the Santa Ana Mountains.

f. High temperatures in the mountain areas are prone to occur before noon, especially the higher mountains around resort level (6000 feet MSL or so).

3.1.4 Characteristics for ending a warm spell (Large 24 hour changes in high temperatures)

a. Upper level ridge axis moves inland (reducing coastal subsidence, allowing coastal low clouds to develop, the marine layer to deepen, and transition zone to move inland).

b. Eddy develops (cool marine layer air deepening against the subsidence aloft results in a strong inversion, and persistent coastal stratus) This might be signaled by increasing northwest flow over the coastal waters, with offshore pressure gradient trends to the north, and onshore pressure gradient trends to the east (to the local deserts), which is the classic pressure gradient pattern for coastal eddies.

c. Onshore surface pressure gradient trend around +2 mb to local deserts and +4 mb onshore trend to plateau (even if there is a classic heat wave sounding with a 10 degree C dewpoint depression at and below 850 mb). This is because such strong onshore trends will usually overpower the initial lack of a marine layer).

d. Strengthening northerly flow has a tendency to cool sea surface temperatures via upwelling, which combined with warming flow aloft, tend to strengthen the inversion, and possibly generate more stratus.

e. In easterly flow aloft, as onshore flow develops at the surface, there is cooling at the base of the rising inversion. This strengthens the inversion, and makes the low clouds more persistent and the low cloud deck more solid.

f. Surface pressure gradient contours that become parallel to the coastline often accompany an increase in stratus.

4. SUMMARY AND CONCLUSION

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Many events that occur in southern California are "high impact" because of the number of people affected. The coastal marine layer wind, temperature, and moisture profile is responsible for many of the high impact events, such as travel on the freeways through passes and air travel as well. For much of the year the coastal marine layer cloud deck plays a strong role in southern California weather. The cloud deck is typically 800-1000 feet thick. The top of the cloud deck is near the base of the temperature inversion when the inversion is strong (especially when the height of the inversion base is near "average" for the season). The average inversion base (approximately the marine layer depth) falls in height from around 2400 feet MSL in early spring to approximately 1300 feet MSL mid summer. The marine layer inversion base is typically higher in the south and toward the mountains to the east. When the inversion is weak, the cloud tops can actually be significantly higher than the inversion bases as the clouds convect into the area between the inversion base and the inversion top. This is especially true near the mountains and with "weaker" inversions. During mid summer the coastal airports clear at approximately 1700 UTC (around 10 am local standard time), and the low clouds move back in again around 0400 - 0800 UTC (around 8 pm to midnight local standard time). It tends to arrive earlier and depart later during the transition season. When the marine layer is deep, its cooling effects reach all the way into the deserts. A chance of showers develops for depths up to 6000 feet deep, and showers are likely if the layer deepens up to around 6250 feet MSL (800 mb) or more and the marine layer remains relatively saturated.

Many factors affect stratus. Ridging to the north, rising heights, and offshore flow aloft bring warming via subsidence aloft, which helps lower the inversion. At the same time the associated low level northwest flow over the outer waters (30-60 miles offshore) often generates a coastal eddy, which tends to deepen the marine layer, counteract coastal warming, and make the clouds more persistent near the coast. If upper level heights and thicknesses are increasing, inland areas and areas at higher elevations are likely to see higher temperatures than those 24 hours prior at the same time that coastal areas experience lower afternoon high temperatures than those 24 hours prior (because of more persistent marine layer cloud cover at the coast). As for the beaches, the "preferred beaches for clearing" are the only beaches that see any sun at all. The beaches in the northern areas are typically the preferred beaches for clearing (or "beaches of the day for clearing"), while the southern beaches are the "preferred beaches for cloudiness". Even weak upper level low pressure systems can move over and deepen the marine layer for more low clouds, in spite of the pressure gradient trends. (This assumes, of course, the inversion does not weaken so much that the clouds actually decrease). On the other side of the coin, if the mean mid level relative humidity in the 700-500 mb layer reaches the mid 40s (percent) as the upper level low passes over, thunderstorm development is possible, and the marine layer low clouds become very disorganized, patchy, or dissipate. What seems to be a pattern at times is after an episode of coastal thunderstorms, the marine layer low cloud pattern becomes more organized and comes roaring onshore by the following morning (especially during the late spring through early fall period).

The height of the marine inversion oscillates quite a bit. Perhaps the strongest feature that causes the inversion to oscillate is the fight between the Pacific high and the Monsoonal high. The Pacific high and its subsidence will tend to dominate the equation during the spring and early summer, with its large scale subsidence over the entire area, and a low level northwesterly jet over the coastal waters. As a result, desert heating during the spring and early summer enhances the onshore flow at the coast by deepening the thermal low in the deserts and increasing the coast-to-desert pressure gradient. This results in relatively cool afternoon temperatures in the coastal areas and a more persistent low cloud layer as the strong onshore flow pulls the marine air in beneath the inversion, which also strengthens the inversion (mainly May through early July).

By mid July and continuing into September, the Monsoonal high (along with its moist mid level jet, low level surges of moisture into the deserts from the southeast, weaker surface pressure gradient, and occasional upward motion from disturbances in the flow) tends to weaken the inversion. This helps the

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marine layer pattern to become very erratic. This monsoonal high develops over the interior and overshadows the Pacific high at times. Clouds aloft reduce the overnight thermal radiation along the coast and reduce the heating in the desert. This results in a weaker east-west (onshore) pressure gradient, a weaker inversion, and better afternoon clearing of the marine layer. This pattern is easily seen in 700 mb dewpoints reaching 0 C and 850-800 mb dewpoints of around 10 C or more for the "lopsided inversion" type of pattern. The rapid fall in dewpoint (commonly found with subsidence from the Pacific high at the inversion level) is nearly absent during a strong monsoonal event. Although this profile favors monsoonal convection, it results in a very erratic low cloud pattern. Also it is common for the marine layer inversion to weaken during surges of monsoonal moisture aloft, making it difficult for the marine layer to form (disrupting the formation of the marine layer cloudiness). Closer to the surface, another strong effect on the marine layer is the surge of low level gulf moisture into the deserts. This weakens the thermal low in the deserts via a surge of cooler, moist air from decaying MCS outflow boundaries that develop over Mexico or Arizona, or simply a surge of cool, moist low level air generated by a huge north-south pressure gradient from the deserts to the southern tip of Baja. The combination of the two, especially with easterly flow might keep the low clouds out completely or only allow them to develop during the late night hours. These surges typically show up sometime during the late night through mid morning hours. The leading edge can have a blast of southerly winds 15-20 mph, and typically drop off a bit thereafter. The surface pressure in the deserts can rise 5 mb and the relative humidity and dewpoint jump up 30 percent and 30 degrees F respectively in a matter of hours. Dewpoints might even surpass 80 degrees F. These surges bring higher temperatures than expected to the coastal and valley areas due to a decrease in onshore gradients, and lower temperatures than expected to the deserts. The pressure gradient change will sometimes occur during the day, making the morning airmass different than that of the afternoon period. Temperature forecasting becomes very tricky when the onshore pressure gradient across the extreme southern part of the state from the coast to the local deserts falls to only 4 mb during such an episode.

Outflow boundaries and easterly waves (as well as waves in the subtropical jet from the southwest) are frequently seen rippling along the top of the marine layer. Most of the time the waves at the top of the marine layer propagate to the west, and systematically dissipate parts of the low cloud deck (especially in areas where the clouds are thin) and may disrupt the night and morning low cloud pattern. In addition, if high pressure inland becomes strong enough to lower the marine layer down to 500 feet MSL or so, the marine layer will most likely clear each afternoon all land areas, and have trouble moving back in overnight (if it comes back in at all). The change in marine layer height generally increases with lower 850 mb temperatures. Although most changes are 200 feet per degree C, eddy circulations, on occasion, actually deepen the marine layer while 850 mb temperatures remain steady or increase.

Flow direction also has serious effects on the marine layer. An eddy-like flow (southerly flow) along the coast has a tendency to keep the low clouds in all day, capped by a rather strong inversion. Eddies typically spin up during the mid morning with very little notice, become strong (10 knots sustained) within a few hours, and help keep the low clouds from clearing near the coast, especially from the KCRQ area south. Predictions of whether or not there is an eddy results in substantial differences in the afternoon temperature and wind direction forecasts (for example, southerly eddy winds verses the typical westerly winds).

Re-development of the low clouds can be a challenge as well. Moisture aloft, offshore surface pressure gradients, a weak inversion, offshore surface pressure gradient trends, and moderate to strong offshore flow delay the low cloud development till the late night hours. Sometimes the inland edge of the marine air stays offshore and little if any low clouds develop. On the other hand, a low, strong inversion, a strong surface onshore pressure gradient, a strong onshore surface pressure gradient trend, or an approaching upper level trough or low often results in early re-development or re-introduction of the low

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clouds into the coastal areas, especially if there is still a rather solid bank of low clouds just offshore during the afternoon. A tricky scenario occurs during occasions when the patchy low clouds come in during the afternoon and evening, only to drain out during the late night after the sea breeze weakens (especially true during the transition seasons when longer, cooler nights produce better drainage winds). This affects air traffic in and out of the area during the evening aviation rush hour. Isolated bands of low clouds frequently form via confluence due to flow around the islands or by opposing flows over the coastal waters (coastal convergence zone).

At times the marine layer cloud deck is thin and exists only in a thin, elevated layer at to just below the inversion. This is a characteristic of a "low level inverted V" sounding, and skies may clear rapidly during the morning with such thin layers, even though the marine layer might be rather deep (for example, 4000 feet deep). This type of thin layer typically happens near the end of a deepening event, when the marine layer becomes quite deep, and the inversion weakens. If there are numerous holes in the deck during the morning, then a reverse clearing event is a good bet. (Reverse clearing is when the low clouds clear at the coast, but convection in the inland areas delays the inland area clearing until later). These events often have very patchy cloudiness before sunrise, followed by an explosion of near-sunrise through mid-morning development.

Because of the way it hugs the bottom of the almost daily inversion, dense fog is evident almost every day during the spring-fall period, with coastal dense fog and very shallow inversions rather prevalent in the fall. For the typical 1000-3000 foot deep marine layer, at least patchy dense fog is often found at an elevation halfway between sea level and the top of the marine layer, or 800-1000 feet below the top of the marine layer (whichever is lowest). Toward the end of a slowly weakening Santa Ana wind event, dense fog typically occurs in the highly populated coastal areas for about 2 days as the marine layer depth re-adjusts to the normal height range of somewhere between 1000 and 3000 feet deep. If the marine layer continues to deepen, the low clouds and dense fog eventually reach the mountains. On the other hand, the marine layer can become very shallow and be pushed offshore when the surface pressure gradients become rather weak (near neutral), then offshore (negative), with strong heating aloft and inland. These are the types of scenarios that evolve into heat waves. When the marine layer returns, it is typically rather shallow and results in dense fog in the coastal areas, advects inland as the coastal marine layer deepens, and finally reaches the mountains at 3000 feet deep or so. The fog is likely to have a big impact on air, marine, and highway traffic. Add a little drizzle to make the roads slick, and the effect is even stronger. Power consumption is strongly driven by these events. Knowing what causes the variations in these phenomena helps to give a "heads up" on what to expect when such things occur.

When the surface pressure gradients are in the "weak" category (or offshore) strong heating usually develops (especially with a strong offshore trend in the pressure gradient). There is a transition period between the period with the strongest high pressure aloft and warmest sea surface temperatures (late summer/early fall) and the period with the most strong offshore flow events (fall). This helps to explain why the highest temperature ever recorded in San Diego occurred in what is technically "fall" (26 September 1963). This makes the late August and though early October period prone to heat waves. Some heat wave events are "offshore flow dominated" with strong winds while others have weak winds and are "subsidence high dominated". Many events are a combination of the two (combined subsidence high/offshore flow events). The strong offshore flow dominated heat wave events typically contain wind gusts at or above advisory levels (gusts to around 35 mph) in populated areas. Offshore winds are much weaker during the summer than they are during the late fall through early spring period, so "subsidence high dominated heat wave events" are by far more common during the summer, while "combined subsidence high/offshore flow events" and "offshore flow dominated events" are very common during the cool season. Near the end of summer the first few fronts result in surface high pressure building over the plateau and locally into the deserts, which serve to weaken the onshore pressure gradient (and sea breeze), and even result in heat waves at the coast that are commonly seen in

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September and October. Other factors like pressure gradients, pressure gradient trend, lows aloft, Catalina Eddies, moisture (with or without clouds) aloft, and monsoonal moisture in the deserts can all have an effect on the conditions in the schematic (Fig. 17) and cause conditions to deviate significantly from the schematic. Still, this schematic should give a good overview on the interactions.

It can easily be seen that there are many different features that affect boundary layer conditions in southern California, with some of the features having opposite effects from one pattern to another. For example, during the summer, moderate subsidence can actually cool the coastal areas by strengthening the inversion and making the low clouds more persistent (Fig. 17). During the winter the same amount of subsidence serves to clear the skies and warm the coastal areas. Other factors like pressure gradients, pressure gradient trend, lows aloft, Catalina Eddies, moisture aloft, and monsoonal moisture in the deserts can all have an effect on the conditions in the schematic. One final point to be made is sometimes the marine layer almost seems to be de-coupled from the low level flow. Stratus has been known to tenaciously hold on at the coast, even with 5 mb of offshore surface pressure gradient from the coast to KDAG, and 2 mb of offshore pressure gradient from the coast to KTRM, during a period of offshore pressure gradient trends! This shows that even though offshore gradients of these magnitudes frequently result in the clearing of the low clouds, it is not guaranteed to do so. Although more interrogation into these issues in needed, it is hoped that at least some light has been shed on the more important details associated with low clouds, dense fog, and heat waves in southern California.

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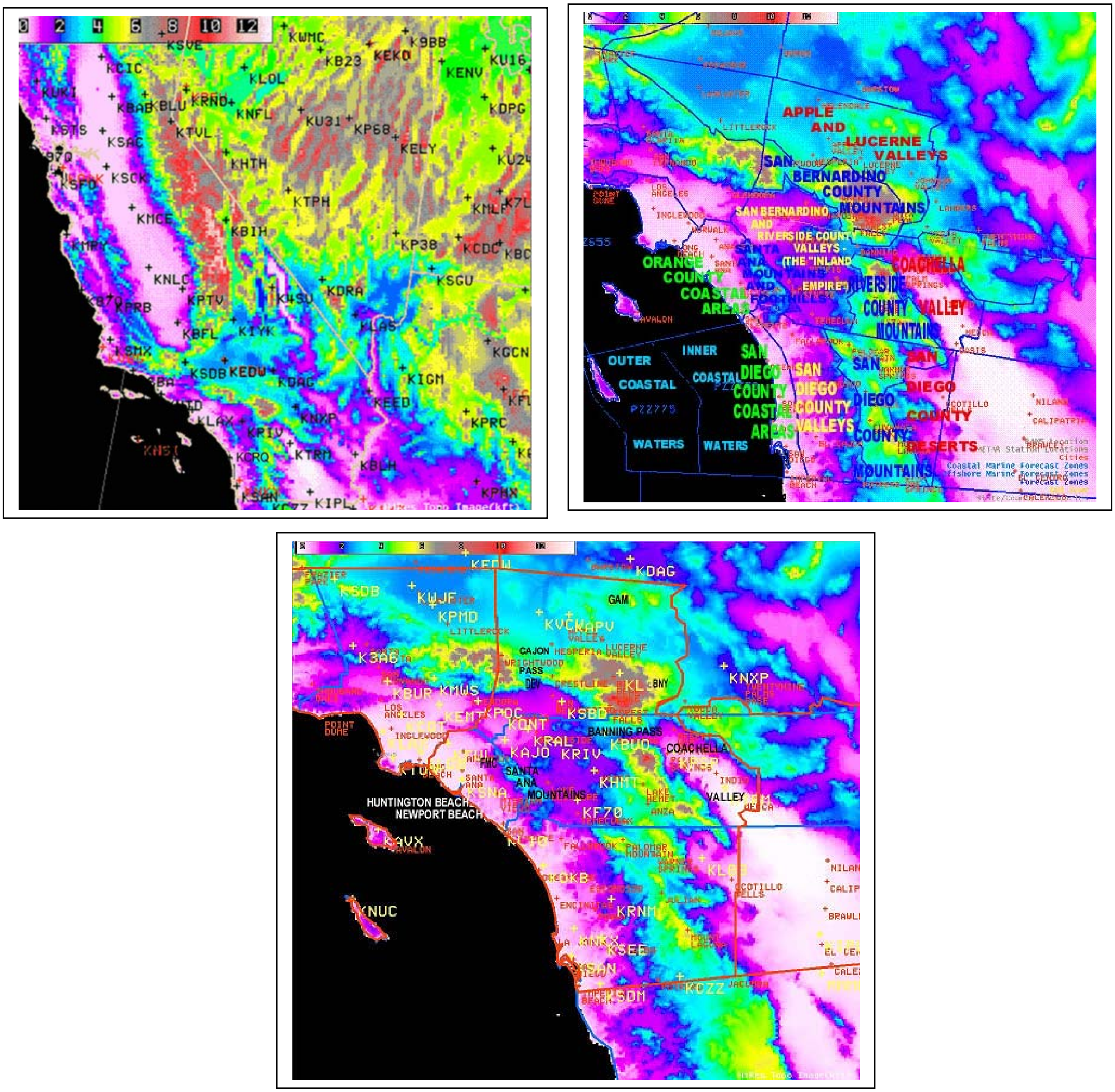
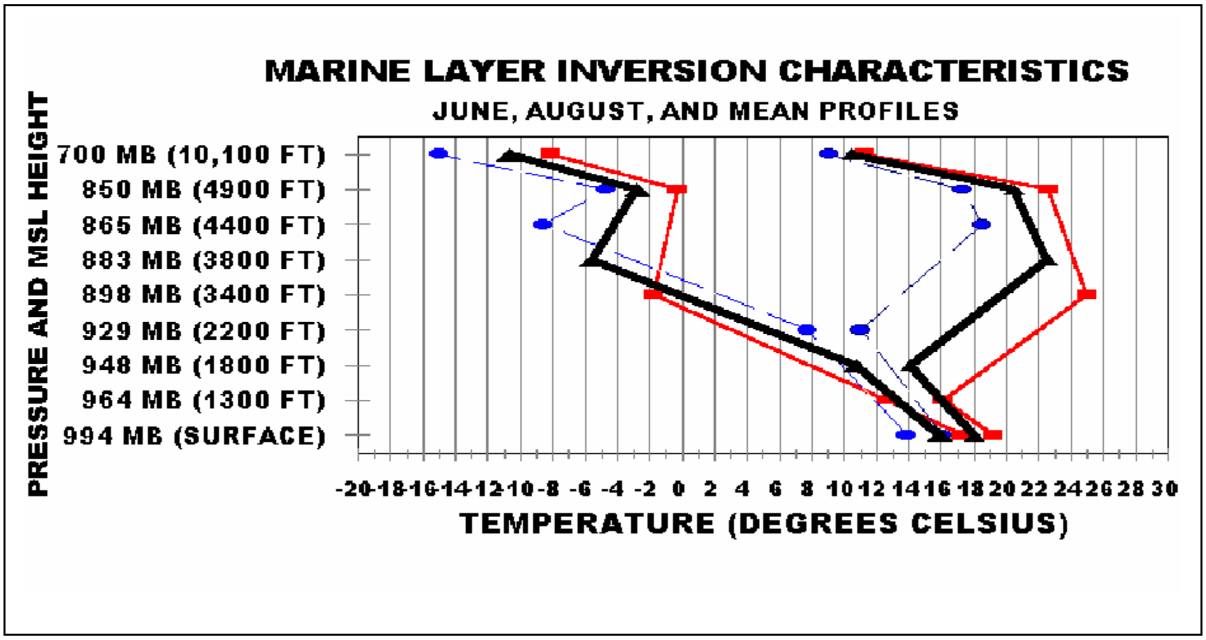


Fig. 1. Terrain map of the WFO SGX CWFA. Color coding in the legend is in thousands of feet MSL.



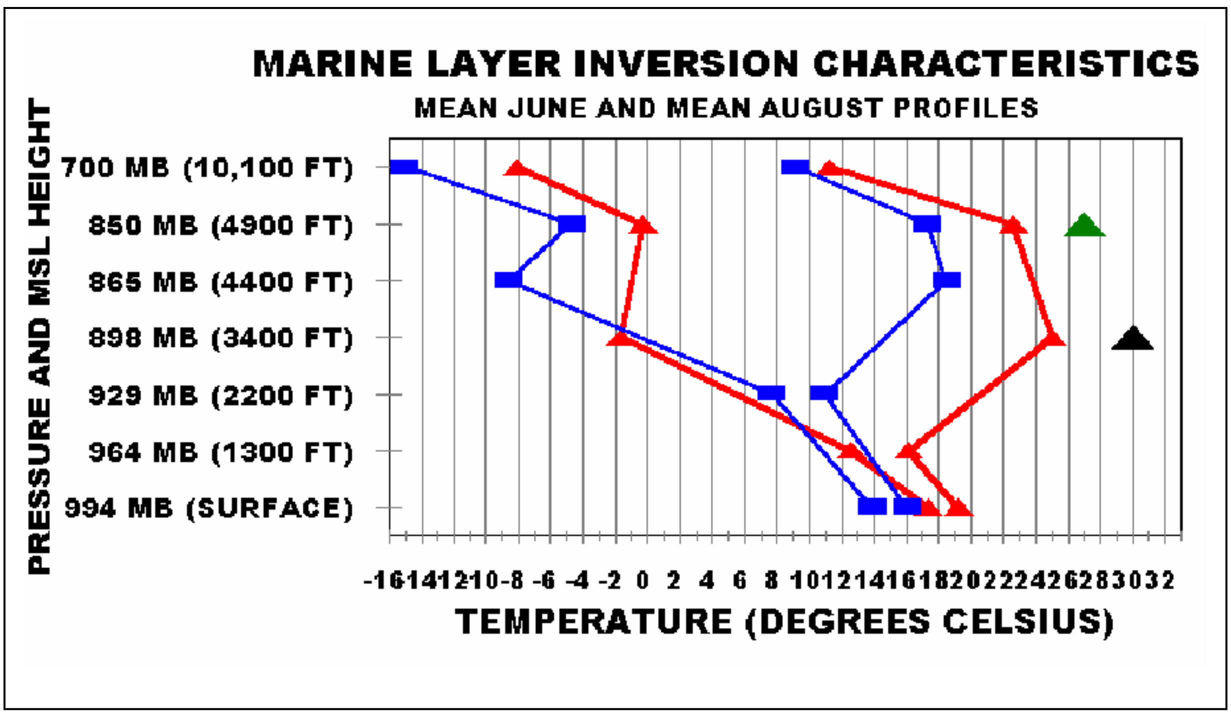


Fig. 2. 1200 UTC KNKX mean sounding values for 1998-2000. For the upper figure, the thick black sounding with triangles is the mean summer sounding, the dashed blue sounding with ovals is the June mean, and the thin red sounding with rectangles is the August mean. For the lower figure, the blue sounding with rectangles is the June mean and the red sounding with triangles is the August mean. The green triangle (850 mb temperature around 27 C) and the black triangle (inversion top temperature around 30 C) are usually associated with at least 105 F in the warmest inland valley areas (and 110 F or more with 10 - 20 knot gusts below canyons and passes during the mid summer period, or afternoon east winds at 850 and 700 mb during the mid summer period).

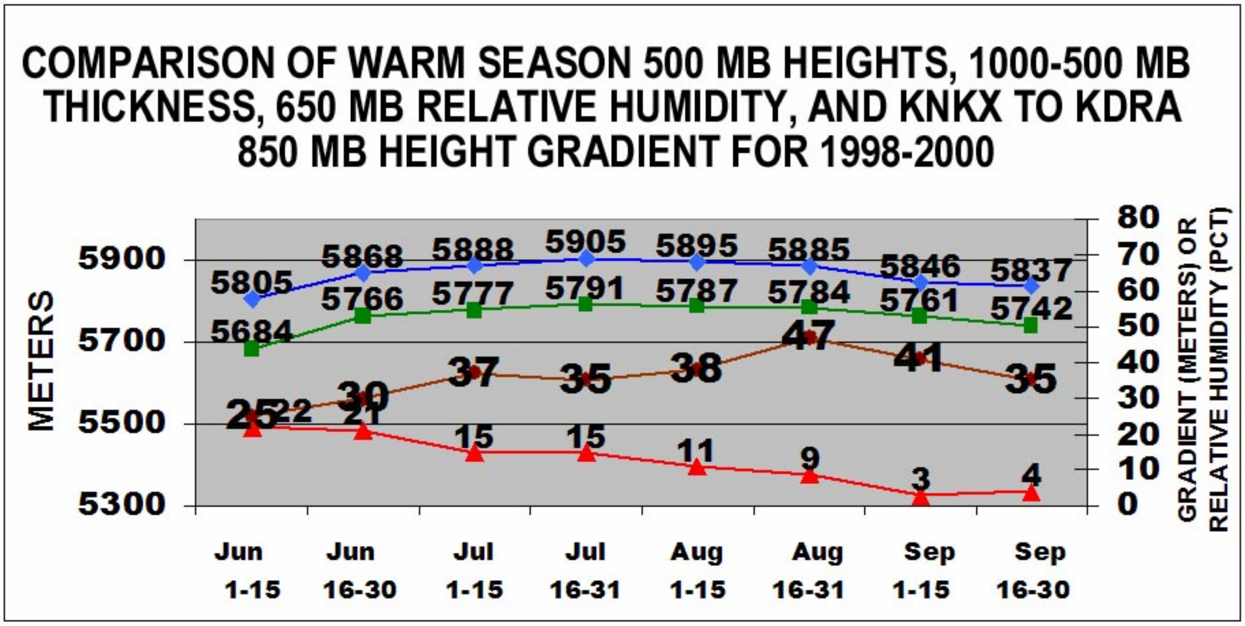


Fig. 3. The chart shows the summer trends for the selected parameters for each half-month period based on the 1200 UTC KNKX sounding values for 1998-2000. The 850 mb height gradient from KNKX to KDRA is also shown. Since heights are higher at KNKX during the entire period, all 850 mb height gradient values are onshore (positive). The 500 mb heights (blue, diamonds) and 1000-500 mb thickness (green, squares) have peaks during the second half of July. The 650 mb relative humidity (brown, circles, and is basically mid level monsoonal jet moisture) continues to increase, and peaks at the end of August, spilling into early September. The 850 mb height gradient (red, triangles) decreases into at least September. (This makes for the most volatile time period for strong to severe convection from mid August to mid September with a peak around September 1st, corresponding closely with the moisture maximum consisting of values over 40 %). This moisture maximum results in a peak in the probability of thunderstorm outflows from the south and southeast that affect the marine layer. Summer peaks in 500 mb heights 1000-500 mb thickness, and 650 mb moisture (close to the 700 mb value) are 591 decameters, 579 decameters, and 47 percent respectively.

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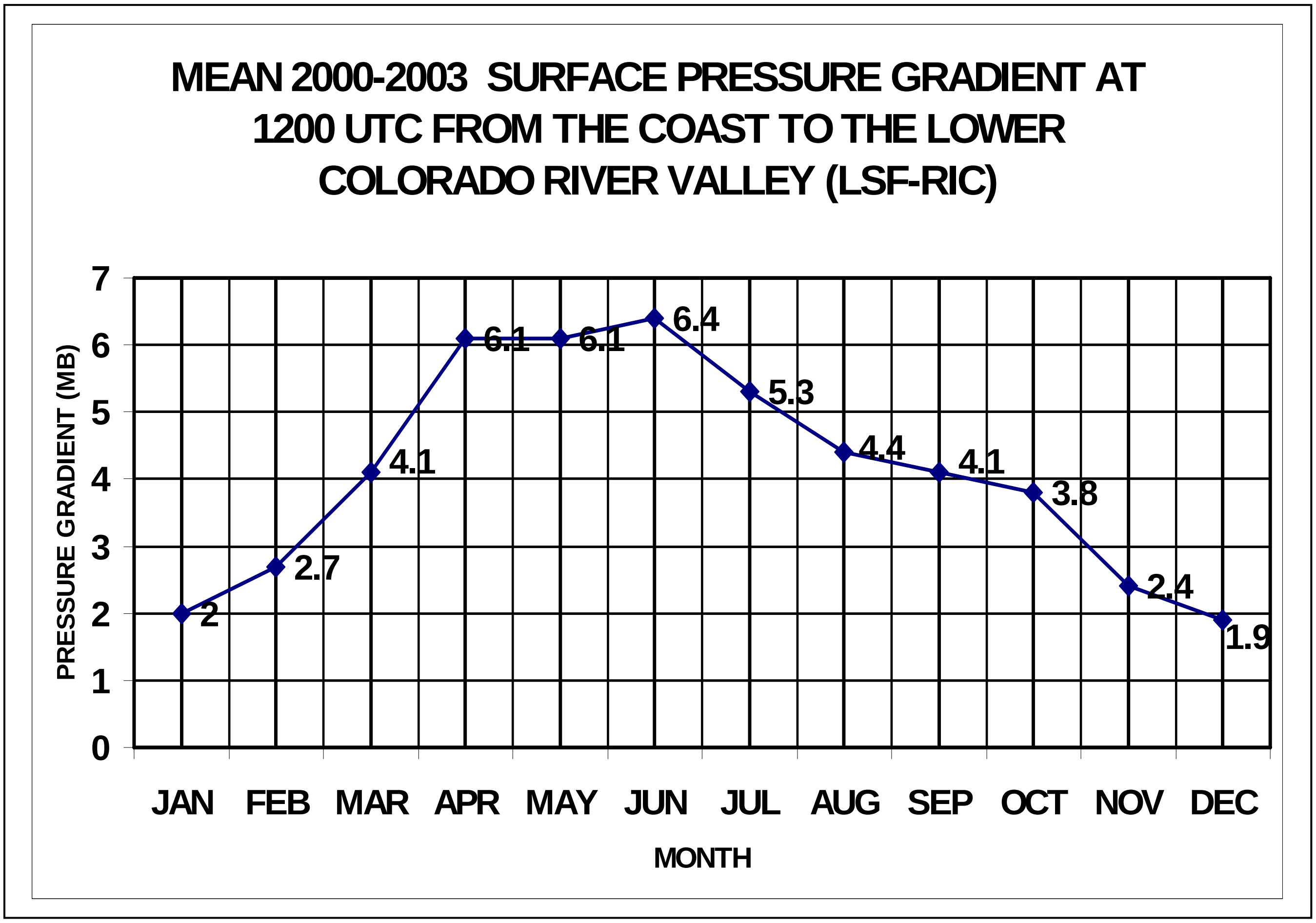

Fig. 4. The above chart shows the character of the annual surface pressure gradient at 1200 UTC for each month between Las Flores (LSF) [near Camp Pendleton (KNFG) at the coast] to Rice Valley (RIC) [near Blythe (KBLH) in the lower Colorado River Valley area]. During the spring and early summer strong heating inland areas and the building Pacific high result in increasing onshore flow and onshore gradients. This strengthens the inversion below the subsiding air at the same time that the marine layer deepens. The pressure gradient rises above 6.0 mb between April and June, with an annual maximum in June, which helps to explain why the marine layer is most persistent during the period April - June. The stronger onshore gradients may also help the strong northwest winds of spring to "surface" in the mountains and deserts. There is a rapid decrease in the gradient thereafter (33 % from June to August), partly due to cooler conditions inland under falling heights/thicknesses with the change in sun angle. There are also moisture surges into the deserts from the southeast to help cool the deserts and weaken the pressure gradient at times. Another factor is the sea surface temperature increase to an annual maximum in August and September. This combination results in the "shallowest" inversion and marine layer of the summer season for better clearing along the coast in August and September. Some locations reach their annual temperature maxima in September due to the combination of these conditions. There is a continued decrease in the pressure gradient to an annual minimum in December as high pressure areas develop to the north and drop into the plateau, which is reflected in the December peak in offshore flow. The mean gradient for every month is onshore.

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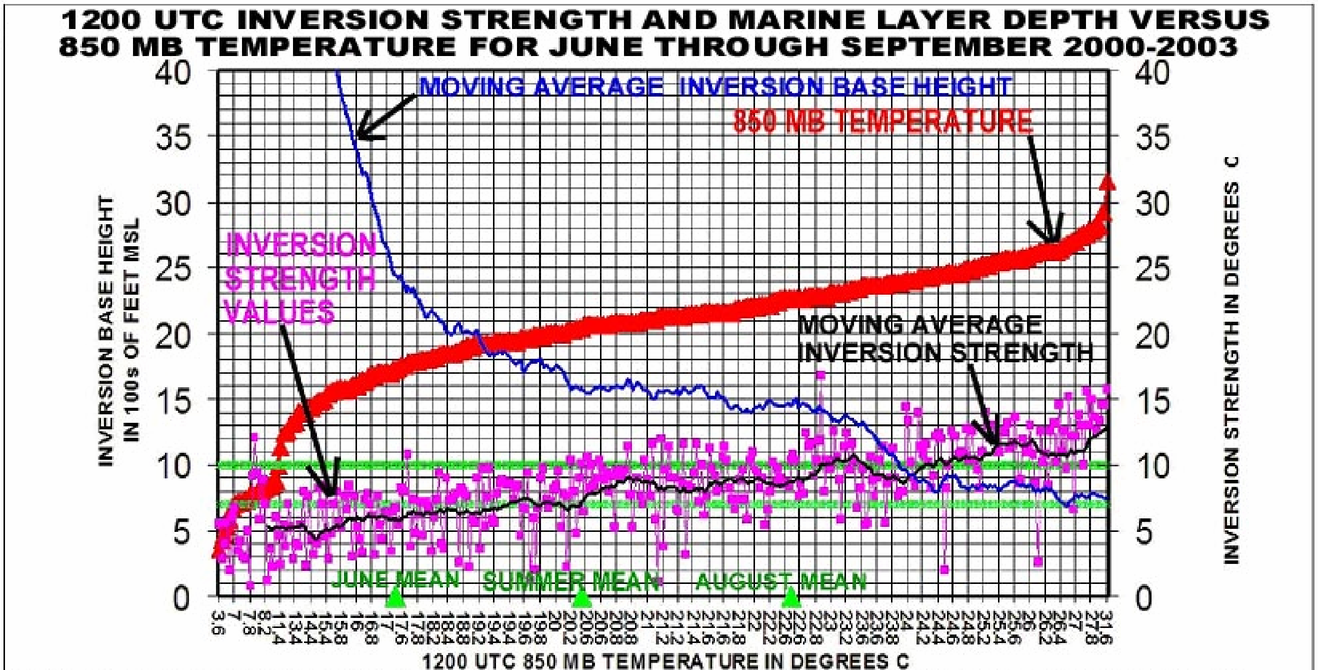

Graph of inversion base (blue), 850 mb temperature (red), inversion strength (purple) and inversion strength running mean (black). Green triangles are the mean 850 mb temperatures for June (17.3), June - September (20.5) and August (22.6) respectively with inversion bases around 2000-2500 feet, 1500-2000 feet, and 1000-1500 feet respectively. Horizontal green lines are transitions between weak (< 7 C), moderately strong (7 to nearly 10 C), and very strong inversions (10 C and stronger).

Fig. 5. Basically, the above graph shows how changes in the 850 mb temperature affects the inversion base height, inversion strength, and their relative values for June (deep marine layer), August (summer marine layer depth minimum) and the summer mean based on the 1200 UTC Miramar (KNKX) sounding. Lower 850 mb temperatures correlate well with deeper marine layers and weaker inversions. Higher 850 mb temperatures correlate well with shallower marine layers and stronger inversions. (The inversion usually weakens as the marine layer deepens, and strengthens as the marine layer becomes "more shallow").

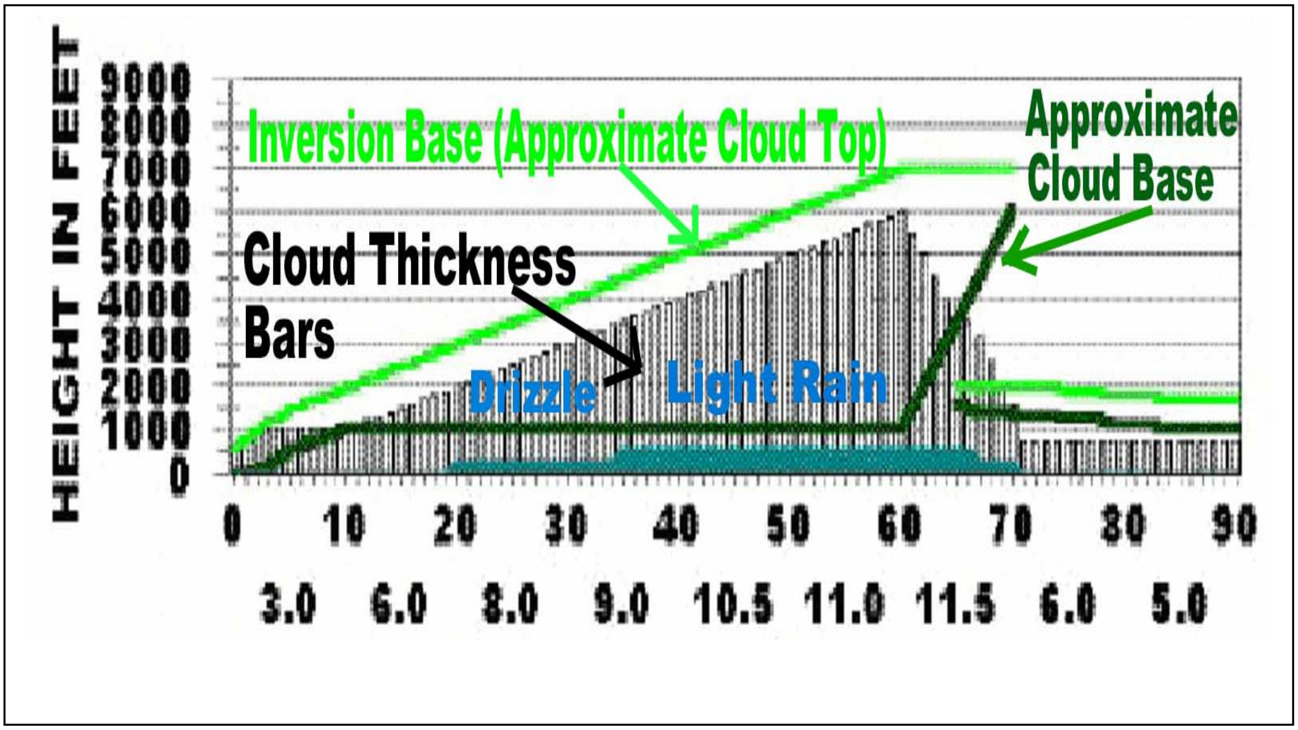

Fig. 6. The figure is a schematic of an "Enhanced Marine Layer Event" (or a "Hybrid Weak Front/Marine Layer" Event). The airmass under the inversion is assumed to be relatively saturated (approaching or exceeding 90 % relative humidity from just above the surface to the base of the inversion for thick cloud development) until the event begins to wind down, on average, toward the end of day 3. (If the airmass is not relatively saturated, less precipitation occurs). The event progresses from the coastal dense fog stage, through the rapid deepening stages with drizzle and/or light rain, and ends with the lowering/re-establishment of the marine layer low inversion. The upper, light green contour is the height of the inversion base (or roughly the cloud top). The lower, dark green line is the base of the clouds. The vertical bars are the thickness of the clouds. The thin blue shaded region along the bottom is the drizzle period. The thick blue shaded region along the bottom is the light rain period. The upper x- axis is the time in hours from the beginning of the event. The lower x- axis is the estimated surface pressure gradient from the coast to the local deserts (for example, KLAX-KDAG). The schematic assumes a "Nevada Low" type of synoptic pattern (with a strong trough development or passage to the north and east, and a surface low in the interior).

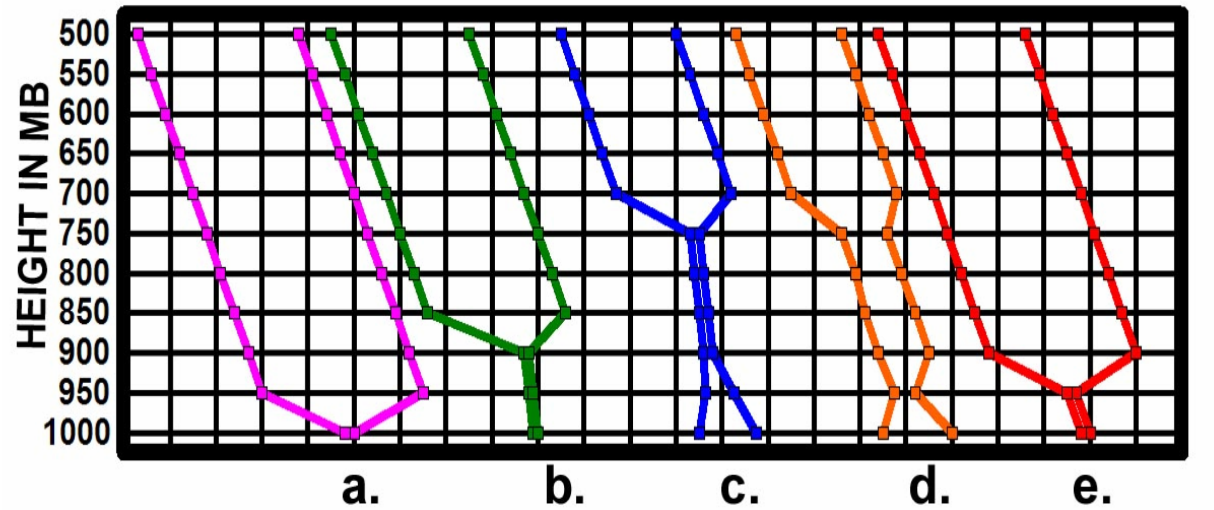

Fig. 7. These are examples of soundings that may be associated with a typical marine layer cycle. (a) The low, strong inversion marks the beginning of a transition stage from offshore to strengthening onshore flow. (b) The middle of the rapid deepening stage (which typically coincides with the onset of widespread drizzle or light rain). (c) The end of the rapid deepening stage and development of the low level inverted V, (with precipitation, but a general decrease in precipitation ensues due to the following "thinning" of the cloud deck). (d) The transition stage from onshore to offshore trend. [Schematic shows the weakening of the upper (old) inversion and re-establishment of the lower (new) inversion and re-developing marine layer. A jet aloft may also result in an elevated inversion]. (e) The marine layer has become re-established and the old inversion has been wiped out. Sounding d can be a period marked by a disorganized marine layer clouds. There can be a combination of mostly residual stratus, stratocumulus, and a few cumulus, followed by daytime boundary layer convection (with the low deck of cumulus beginning to "fill in" any clear spots as the regime transforms to a more convective marine layer pattern). Some events skip past sounding d and go directly from sounding c to sounding e, resulting in a simple lowering of the high inversion with a sharp increase in wind speed and/or a wind shift just above the inversion.

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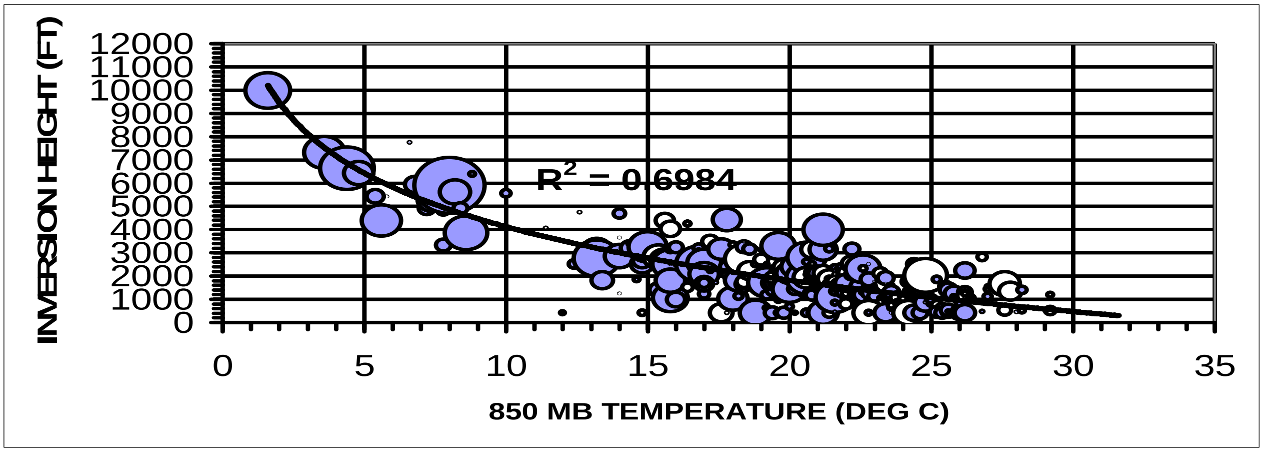

Fig. 8. The above graph depicts marine layer depth (curve and bubbles) for onshore 850 mb height gradients (blue bubbles) and offshore 850 mb height gradients (clear bubbles) for June-September 1998-2000.

WARM SEASON MEAN INVERSION BASE HEIGHT BASED ON 850 MB TEMPERATURE							
850 MB TEMPERATURE (DEGREES C)	30	25	20	15	10	5	2
APPROXIMATE INVERSION BASE HEIGHT (FEET MSL)	Most often around 1000 ft	Most often around 1000 ft	2,000	3,000	4,000	6,500	10,000
	Starting with 20 C approximately = 2000 ft, the inversion base changes at nearly 200 ft per degree either side of 2000 ft up to around 4,000 feet MSL, and down to 1000 ft MSL. (The inversion tends to fall no lower than 800-1000 feet MSL during the midsummer period unless it is very warm aloft or there is east wind below coastal canyons and passes, which is typically a transition season or cool season phenomena).					Inversion base changes 500 feet per degree 4,000 - 6,500 feet MSL	Inversion base changes at 1,000 feet per degree C 6,500 - 10,000 feet MSL

Table. 1. Basically, warm season inversions heights average 1300 feet and 850 mb temperatures around 23 C mid-summer, with a 200 ft per degree C change to either side. One exception is the inversion height tends to fall to no lower than around 800-1000 feet MSL unless it is very warm aloft or east wind develops below the passes and canyons. Gusts approaching 30 mph often wipe out the marine layer, as can very strong subsidence aloft. For higher inversions the changes are larger per degree C (500 feet per degree C 4000-6500 feet MSL, and 1,000 feet per degree C 6500-10000 feet MSL). Events such as eddy circulations, onshore trends, and stronger onshore gradients than what is expected for a particular 850 mb temperature may tend to raise the inversion above these values. A "non-eddy" pattern of northwest flow, offshore trends, or weaker gradients than what is typical may tend to result in inversion heights lower than the above values for a given 850 mb temperature. Locally significant boundary layer rains are possible with 850 mb temperatures in the lower single digits since depths are generally around 7,000-10,000 feet. However such events are usually absent in the middle of the warm season, when very deep marine layers are very rare.

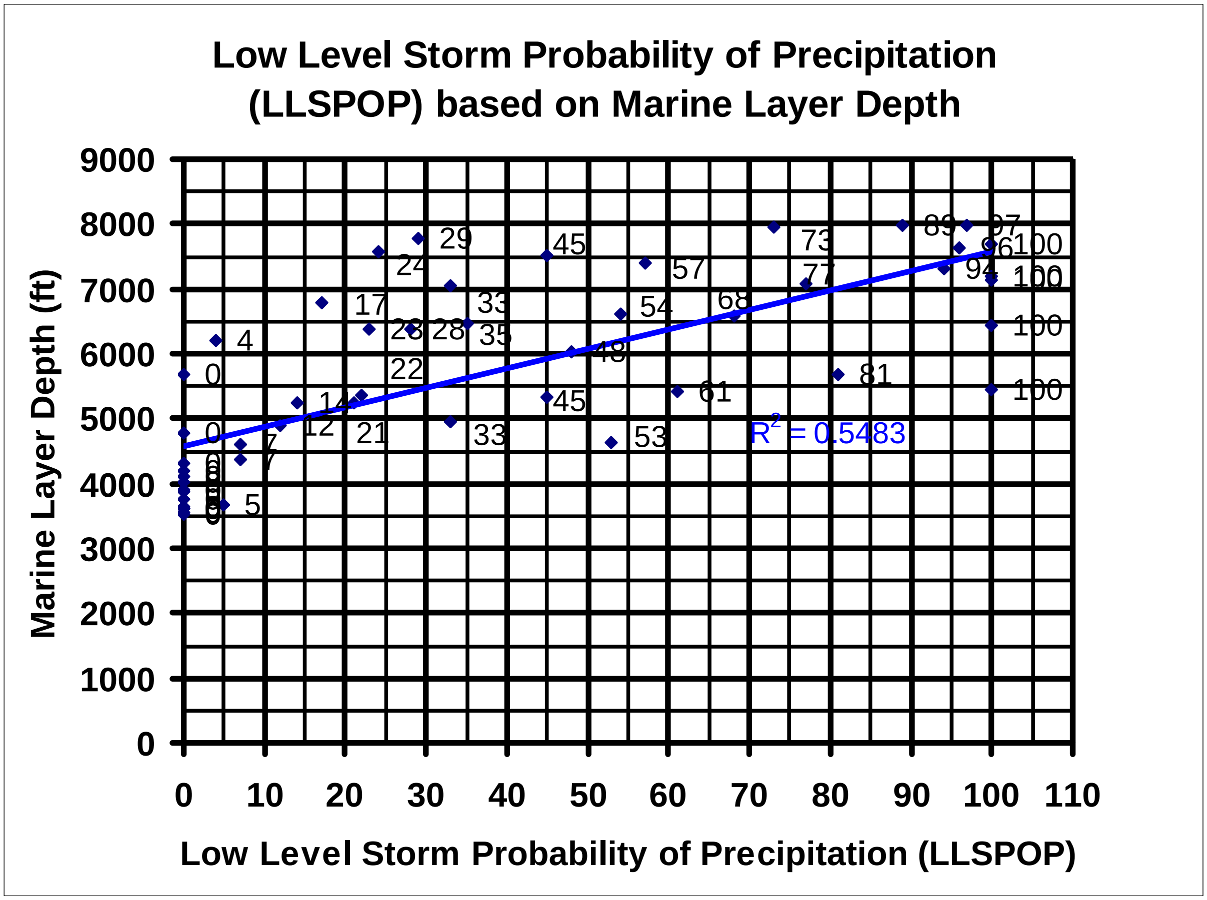

Fig. 9. The above figure shows the Low Level Storm Probability of Precipitation (LLSPOP) in the coastal and valley areas based only on marine layer depths 4000-7900 feet deep for the cool seasons (defined as October – May) of 1998-2000. The LLSPOP is the percentage of stations with measurable rainfall for a 48 hour period ending a 4 pm local standard time of day 2. Basically, the LLSPOP assumes that much of the rainfall from a storm occurs within a 48 hour period, so it is basically a 48 hour areal coverage. For example, over the 48 hour period, if 90 of 100 stations report measurable precipitation, the LLSPOP is 90 %. The marine layer depth was defined as the top of the surface based 60 % relative humidity layer during a storm at the KNKX sounding site. The correlation is better if there is a nearly saturated (at least 90 % relative humidity) air mass or an 80 % relative humidity layer somewhere between 850 and 700 mb. Although there is a rather large amount of variation (since the amount of saturation of the marine layer is a big component, not included in the curve), depths around 6000 feet are considered to be in the “chance “ category, with a changeover to “likely” at around 6250 feet (about 800 mb or so). The two-day time period for LLSPOP is designed to catch most marine layer or weak frontal events, so LLSPOP can be larger than the 6 hour POP or 12 hour POP. Basically, just over 3000 ft deep is a slight chance of rain (10 percent), just over 5000 ft is a slight chance (20 percent), a chance is around 6000 feet (30-50 percent), just over 6000 ft (near 800 mb) is likely (60 percent), and just over 7000 feet is categorical (80 percent), The likely and low end categorical regions mark the changeover to “high POP, Low QPF events (with a high probability of precipitation, but a low quantitative precipitation forecast).

QUICK STORM PROBABILITY OF PRECIPITATION ESTIMATES (SPOP) BASED ON MARINE LAYER AND "LOWER MID-LEVEL" MOISTURE COMBINED

LOW LEVEL SPOP (LLSPOP)

Marine layer depth just over 3000 ft = Slight Chance (10 percent)
Marine layer depth just over 5000 ft = Slight Chance (20 percent)
Marine layer depth just over 6000 ft = Likely (60 percent)
Marine layer depth just over 7000 ft = Categorical (80 percent)

LOWER MID-LEVEL SPOP (LMLSPOP)

Lower Mid-Level SPOP is based on the 850-700 mb relative humidity. Approximate lower bounds for the 850-700 mb relative humidity are;

65 % = slight chance
70 % = chance
75 % = likely
80 % = categorical

This is based on 52 available storms from 1998-2002 cool season (October – May) data, and should still be applicable for the warm season. The average areal coverage of the precipitation (the average SPOPs) for 850-700 mb relative humidity values of 80%-84%, 85%-89%, 90%-95%, and 95%-100% were 73%, 86%, 95%, and 97% respectively. Basically, for 850-700 mb relative humidity of 75% or more, the SPOP at least matches the relative humidity, and an 80 percent spike in the relative humidity in the 850-700 mb layer is essentially a "rain layer" since this elevated wet layer will result in measurable rain in many cases.

Values may be appropriate for use during the summer monsoon over the mountains and adjacent deserts, (and possibly representative for all areas).

For example, for the Lower Mid-Level SPOP:
With an 850-700 mb relative humidity of 80 % the best estimate is "a categorical rain probability of 80 % or more". It must be remembered that although there is a high probability of measurable rain, if the dynamics are well to the north, actual rainfall totals can be minimal.

COMBINED (OR FINAL) SPOP

DEFINED AS THE LOWER MID LEVEL SPOP IF THE LOWER MID-LEVEL SPOP IS 80% OR HIGHER, OTHERWISE IT IS THE LOW LEVEL SPOP

For example,
1. The SPOP for a 7 or 8 thousand foot deep moist layer is likely to be a high SPOP (greater than 80 %) low QPF (less than 1/4 inch) event.
2. The SPOP for a 10000 ft deep moist layer with a 90 % 850 -700 mb relative humidity is categorical, with urban flooding possible.
3. The SPOP for a 20000 ft deep moist layer with a 90 % 850-700 mb relative humidity is also categorical, with widespread urban flooding likely, and flash flood possible. This is especially true for strong low level winds (for example at 850 mb), reaching 25 knots.

For elevated precipitation events, for example high based convection or overrunning (anywhere and any season) 50 % relative humidity down to 650 mb with a 70 % or higher maximum usually provides at least sprinkles at the surface (with a better chance of reaching the ground at the higher elevations such as the mountains). An upper level low may be needed to squeeze rainfall out of lower mid level relative humidities of around 75 percent or less during the summer west of the mountains.

EXAMPLES OF QUICK SPOP ESTIMATES

SPOP FORMULA =

A MARINE LAYER JUST ABOVE 3000 FEET DEEP IS APPROXIMATELY A 10 PERCENT SPOP
A MARINE LAYER JUST ABOVE 5000 FEET DEEP IS APPROXIMATELY A 20 PERCENT SPOP
A MARINE LAYER JUST ABOVE 6000 FEET DEEP IS APPROXIMATELY A 60 PERCENT SPOP
A MARINE LAYER JUST ABOVE 7000 FEET DEEP IS APPROXIMATELY AN 80 PERCENT SPOP

OR

THE MEAN RELATIVE HUMIDITY OF THE 850-700 MB LAYER IFTHE 850-700 MB LAYER RELATIVE HUMIDITY IS 80 % OR MORE

Marine Layer Depth [Depth of the 60 % layer (in ft MSL)]	**Relative humidity of the 850-700 mb layer**	**Rain Chance Calculations**
Just over 4000 feet deep	Below 60 % (fairly dry mid levels)	**10 %** (Slight Chance)
Just over 5000 feet deep	Below 60 % (fairly dry mid levels)	**20 %** (Slight chance)
Just over 6000 feet deep	Below 60 % (fairly dry mid levels)	**60 %** (Likely)
Just over 6000 feet deep	**80 %** (wet mid levels)	**80 %** mid level layer is the final SPOP since it is above 80 % (Categorical SPOPs)
Just over 7000 feet deep (High SPOP/Low QPF)	Below 60 % (fairly dry mid levels)	**80 %** (Categorical)
Just over 8000 feet deep (High SPOP/Low QPF)	Below 60 % (fairly dry mid levels)	Near **100 %** (Categorical SPOPs)

TABLE 2. Estimated Storm Probability of Precipitation (SPOP) based on the boundary layer [marine layer (or moist layer) depth] and the 850-700 mb relative humidity (Lower mid-level moisture). There is a big gradient between 20 % (just over 5000 feet) and 60 % (just over 6000 feet) SPOP, with much variability involved. These values work best when 500 mb southerly winds exceed about 60 knots, and such excessive wind speed may result in increased SPOPs. Southwesterly flow along with a 564 decameter heights or lower also favors precipitation. Depths around 7-8 thousand feet are more “High SPOP, Low QPF” type events (high storm probability of precipitation, low quantitative precipitation forecast) since durations are generally short which corresponds to a “high POP, low QPF” situation as well. Values are especially true during the rapid deepening period and during night and morning hours when measurable precipitation seems more probable. If the trajectory is west to northwest and the moisture depth is 8000 feet or less, the low level moisture is swept out by the Santa Ynez mountains, virtually “shutting off the precip” northern areas, but moisture just west of Point Conception is generally unaffected, and can still sweep in for heavier precipitation southern areas.

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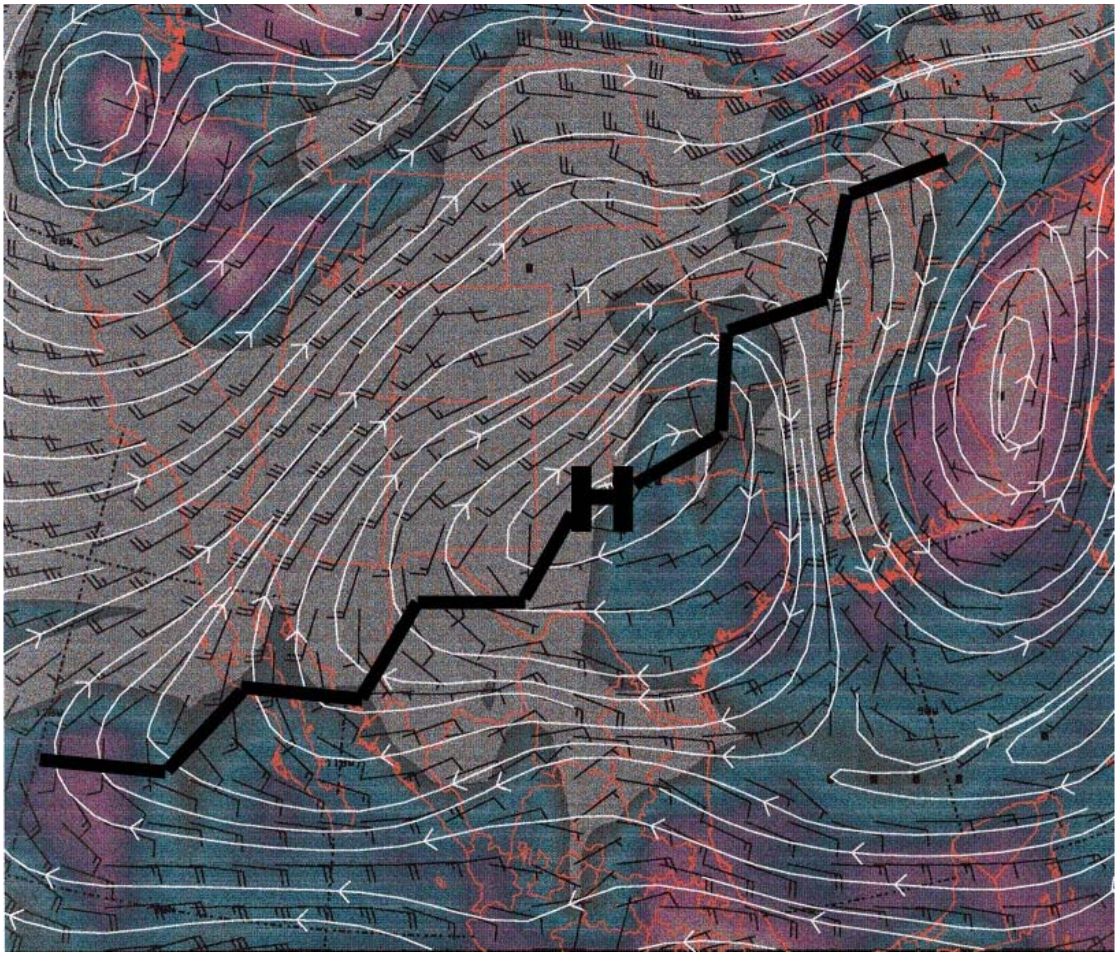

Fig. 10 is a schematic showing the relationship between the subtropical moisture, flow direction, and the position in relation to the ridge axis. Shown is the 700 mb relative humidity (in percent) shaded above 50 percent, wind barbs (in knots), and streamlines (solid white contours). The subtropical moisture tends to remain south of the axis in mainly easterly flow, with the deep easterlies occasionally impinging on the ridge axis. At the wind shift line (where the winds shift from easterly to southerly, then westerly), some of the moisture advects north of the ridge axis, but the airmass tends to dry out as the flow moves north of the axis and joins with the westerlies. The easterly flow beneath the ridge axis is a key player for heating southern California. The easterly flow lowers the inversion height. This moisture aloft helps disrupt the low clouds, causing morning low temperatures to be higher, and raising the temperature humidity index for muggy conditions.

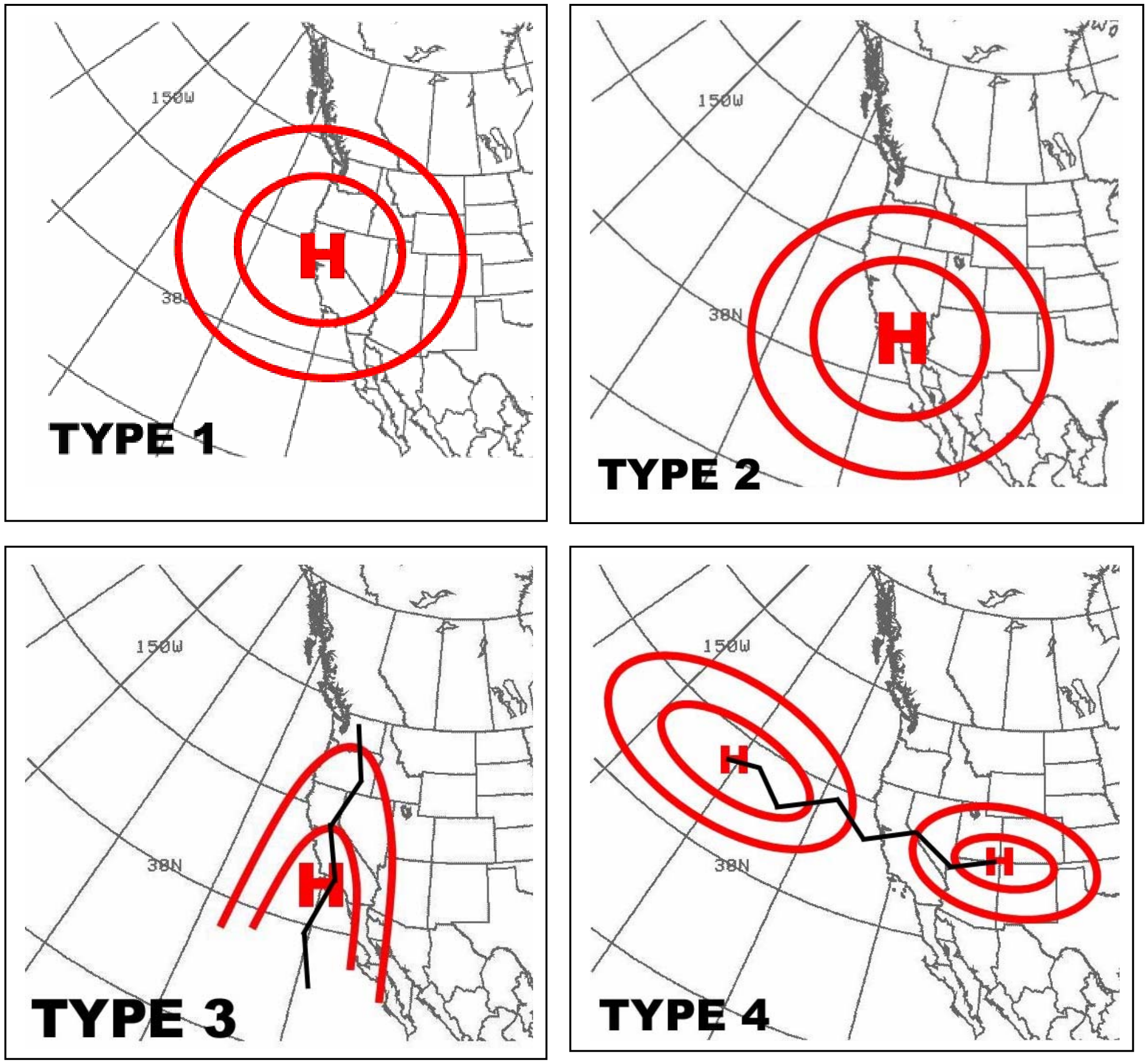

Figure 11. Heat Wave Map Types 1 through 4 shown above are schematics of 500 mb patterns commonly found with heat waves in extreme southwestern California. All typically occur with easterly low level flow at least as far west as the Inland Valleys, and all the way to the coast for the more extreme widespread events. Type 1 (upper left) has the high center to the north, so weaker synoptic scale subsidence occurs, but stronger northeast winds can occur around the high as the flow aloft couples with the flow closer to the surface. The high to the north allows easterly flow south of the high into the area to lower or dissipate the marine layer and associated inversion. Mesoscale mountain wave subsidence is also rather strong with these events. Type 2 events (upper right) have the high center close to, if not directly, over southern California. With the high nearly overhead the synoptic scale subsidence can be very strong. On the other hand the northeast flow is weaker since the winds around the high cannot help to supplement any low level flow since winds aloft are weak. These are mainly events driven by synoptic scale subsidence. Type 3 events (lower left) occur when the north-south ridge axis is directly overhead. This easily results in strong subsidence. If the ridge is displaced slightly to the west, then very strong northeast winds can develop over the area to couple with the subsidence aloft. Type 4 events (lower right) are when a rather strong east-west ridge axis develops to the north. The pattern has little of any west coast “troughing”, so the pattern is dominated by subsidence from the surface high pressure areas.

LOCATION	"WEAK FLOW" [APPROXIMATE WARM SEASON PRESSURE GRADIENT UPPER BOUNDS FOR STRONG VALLEY WARMING] (Strong coastal warming is possible with easterly canyon winds)]	"WEAK-MODERATE OFFSHORE FLOW" [TYPICAL WARM SEASON PRESSURE GRADIENT VALUES FOR STRONG COASTAL WARMING] (Values are about 2 mb more offshore than the weak flow values)]
COAST - KLAS	**+3.0 (Weak Onshore)**	**0.0 (Neutral)**
COAST - TRM	+2.0 (Weak Onshore)	0.0 (Neutral)
COAST - KIPL	+2.0 (Weak Onshore)	0.0 (Neutral)
COAST - KDAG	**0.0 (Neutral)**	**-2.0 (Weak Offshore)**
KLAS - KCDC	-3.5 (Weak Offshore)	-5.0 (Moderate Offshore)
COAST - KTPH	**-3.5 (Weak Offshore)**	**-5.0 (Moderate Offshore)**
COAST - KWMC	-7.0 (Weak Offshore)	-9.0 (Moderate Offshore)
EFFECTS	Strong valley warming to 850 mb potential temperature expected. Strong warming possible coastal areas under an upper ridge or easterly flow below 700 mb. Generally at least 100 warmest inland valley locations. Basically near record warmth.	High likelihood of strong valley warming and inland coastal area warming to the 850 mb potential temperature. Generally at least low 80s at KSAN and at least 90 mid coastal plain sites such as KFUL. Especially true under an upper ridge aloft, easterly flow below 700 mb, or with an inversion top temperature maximum below 960 mb. Basically at or above record levels is a good bet.

Table. 3. Optimal upper bounds of selected surface pressure gradient categories for above normal temperatures during the warm season (June – September). "COAST" is either KLAX or KSAN. Key gradient values are shown in bold.

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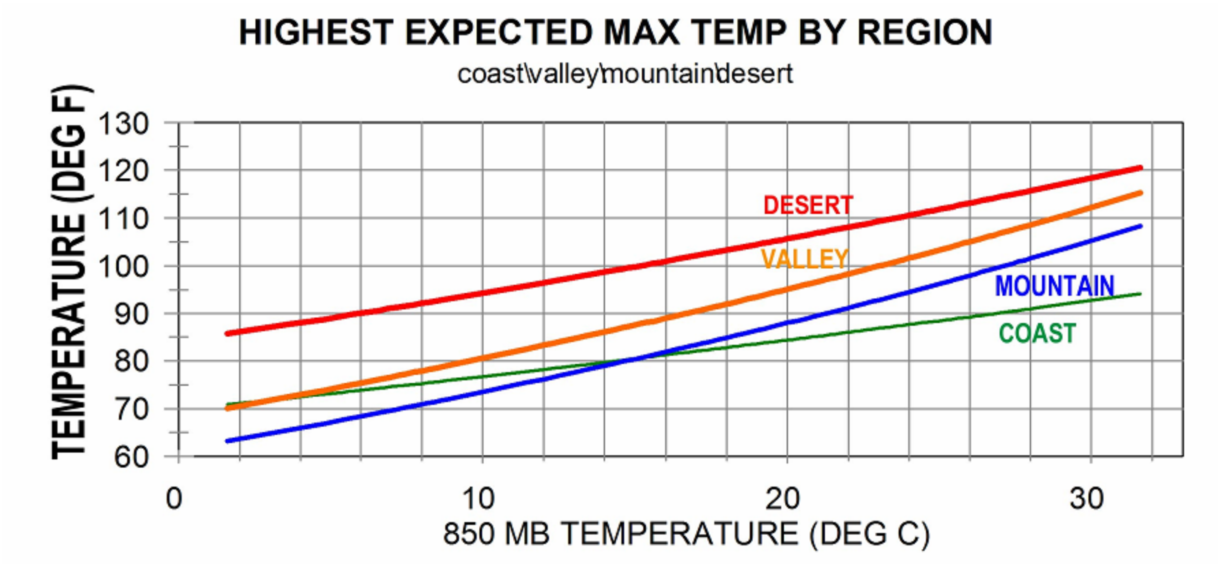

Fig. 12. Chart shows the **highest expected maximum temperature** in each region for the coastal (green), mountain (blue), valley (orange), and desert (red) regions respectively based on 850 mb temperature for June-September 1998-2000. Note that for the warmest days, the warmest values are in the deserts, valleys, mountains, and coasts respectively. For the coolest days, the coolest values are not at the coast, but in the mountains, with the valleys slightly cooler than coastal areas. During the cooler days of the warm season, mountain highs (blue curve) are the coldest areas on the cool end of the chart with lower 850 mb temperatures invading the mountains (possibly since this scenario can have a deep marine layer with an unstable lapse rate that cools rapidly with height. Also, reverse clearing results in reverse heating, so coastal areas can get more sunshine and become a bit warmer than the valleys and lower mountain slopes). Higher 850 mb temperatures result in mountain highs that are actually warmer than coastal areas (at the warm end of the chart the warm inversion air invades the mountains). On most summer days, maximum temperatures are coolest at the coast (due to the proximity to the cool ocean), and are higher in the mountains, valleys and deserts respectively. This graph is meant to give a simple comparison. During certain conditions, such as the occasional day with cold advection into the mountain and valley areas, the temperature comparison between the coast, valleys, and mountains can reverse, with the highest temperatures at the coast, the lowest temperatures in the mountains, and the valleys somewhere in-between due to the adiabatic temperature profile (steady cooling with height) during such events. Discrepencies would more likely be seen at the coast on the warm end since the marine layer is perhaps the largest variable to affect the temperature during the warm season. For example, with 850 and 700 mb winds from the east during the afternoon and 850 mb temperatures around 30 C the highest coastal temperature is more likely to exceed 100. With the same conditions, except adding a strong onshore pressure gradient trend, the regional maximum temperature for the coastal areas is probably around 90. Much less effect is seen further away from the marine layer influence in the valleys, mountains, and deserts respectively.

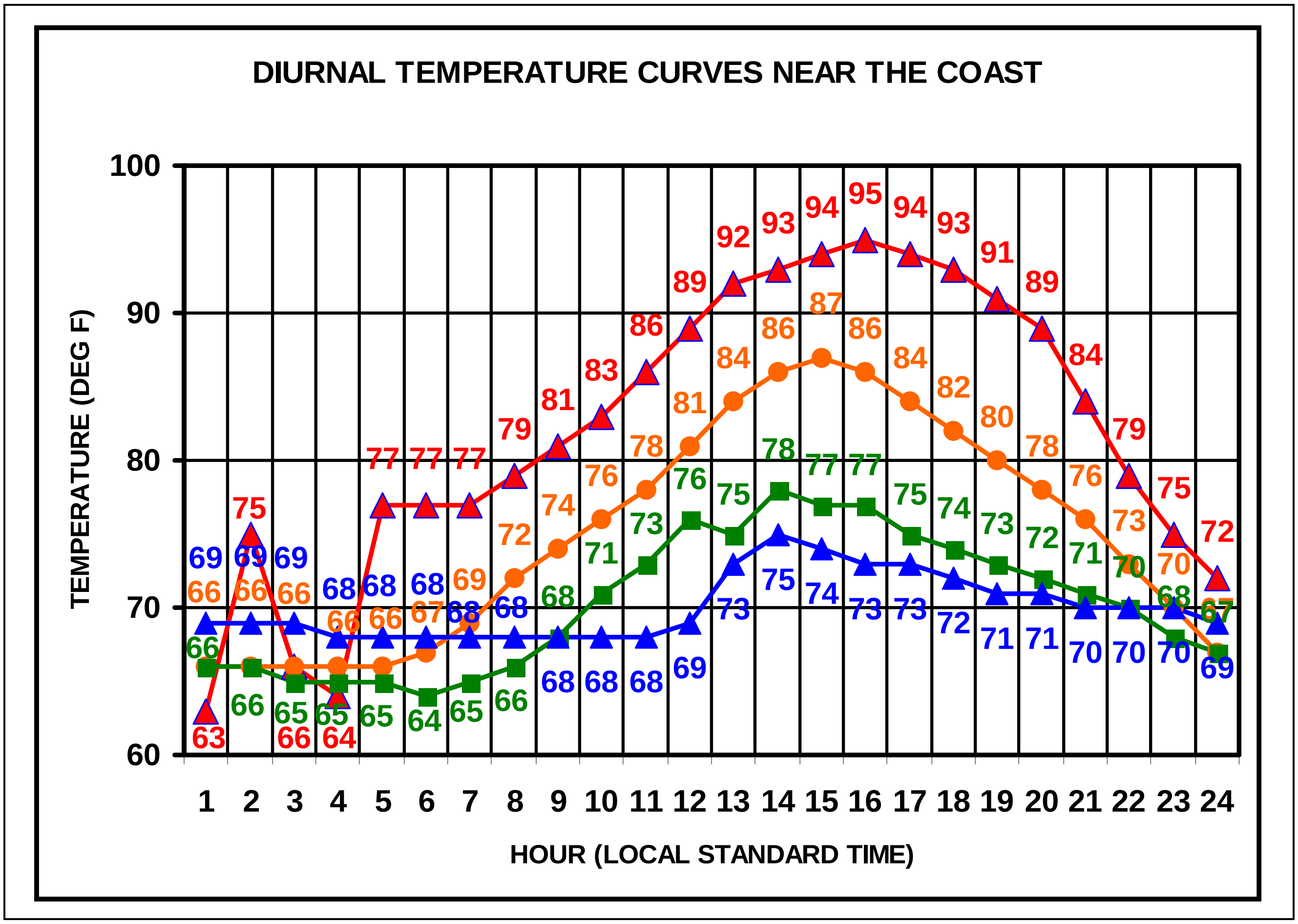

Fig. 13. The graphic shows examples of diurnal temperature curves near the coast. The green curve with squares shows a rather typical profile. This typical curve begins with a cloudy morning with temperatures near the sea surface temperature, then temperatures steadily climb when the clouds clear mid morning or so. The sea breeze can be seen to temporarily "knock down" or stall the temperature rise somewhat at around noon, but temperatures can climb a bit more til about 2 or 3 pm, when the downward trend generally begins. The blue curve with triangles is an example of an exceptionally cloudy day when the marine layer clears rather late (around noon or later). Overnight low temperatures are a bit warmer due to the earlier cloud cover during the evening prior to these "persistent marine layer" days. When the low clouds finally clear at around noon, the temperature jumps up rapidly, but still peaks lower than what is expected for a clear day due to the delayed heating. The orange curve with circles is an example of a day when offshore flow dominates. The temperature might start out lower, mainly due to the drier air and lack of insulating cloud cover, but can rise rather steadily after sunrise. The temperature continues to rise, and peaks later in the afternoon, showing that either the sea breeze is delayed, or the sea breeze simply brings relatively warm, dry continental air previously deposited offshore (by northeast flow aloft) back to the coastal areas well into the afternoon. The red curve with triangles (the curve with the warmest values) is an example of a mountain wave that surfaces at night briefly, the cold pooling and drainage wind returns after the wave temporarily lifts off the surface, then the wave surfaces again and remains on the surface. There is a rapid rise, possibly well before sunrise when the wave finally remains at the surface. There is a much higher afternoon temperature, and a later temperature peak than the norm. If the wave cannot surface during the overnight hours, the rapid rise can occur mid morning when mixing can "surface" the hot air from above a very low inversion, since the hot air in a shallow inversion is very close to the surface. During very strong events, temperatures can stay rather warm (upper 60s and even 70s) overnight. Sometimes the surfacing of the winds can make temperatures oscillate wildly as the cold pooling at night battles the mixing effect of the winds. Oscillations occasionally exceed 20 degrees F in one hour, especially in and below canyons (which includes some valley areas such as KRNM and KRAL).

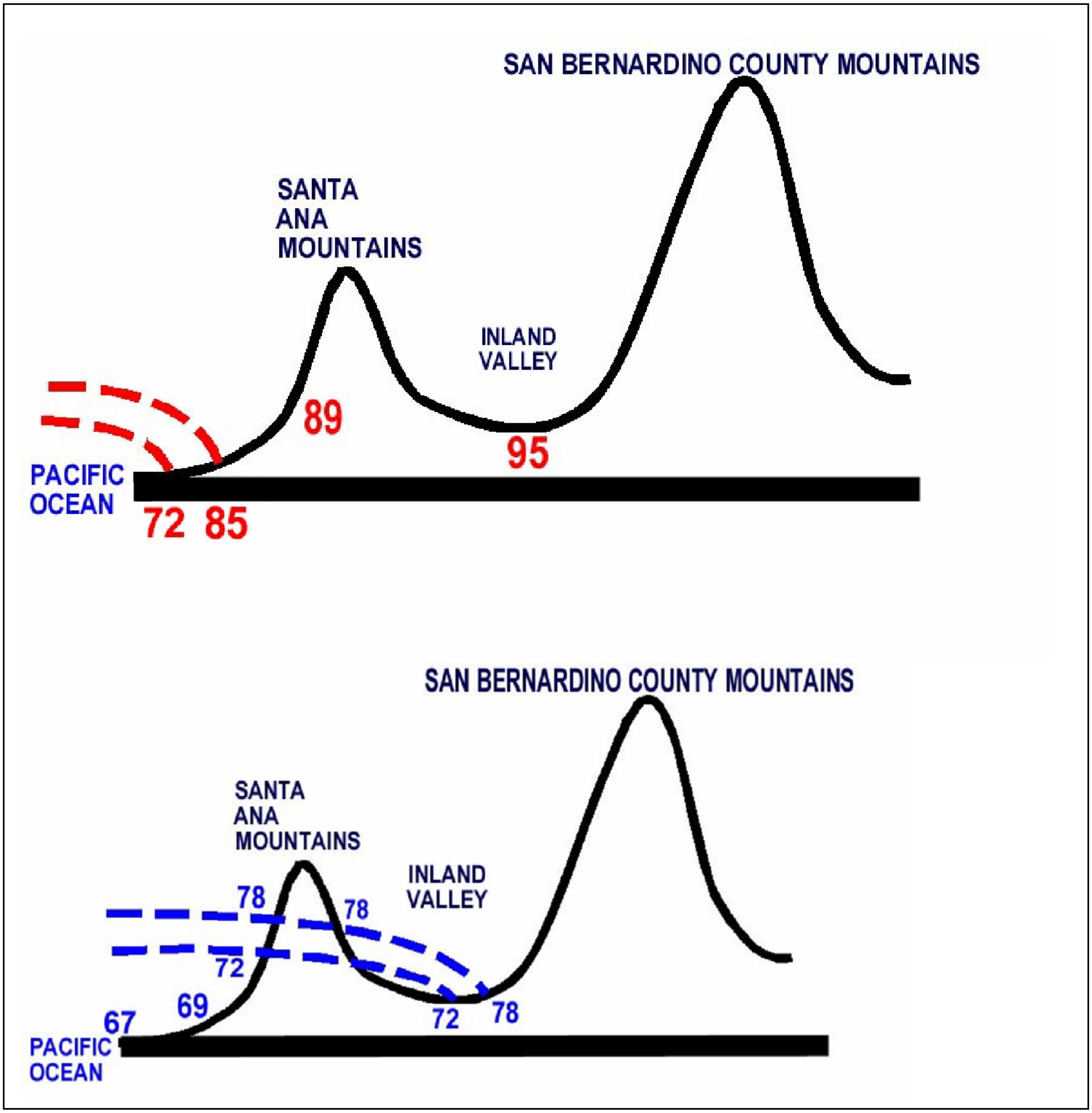

Fig 14. Example of the movement of the transition zone associated with the marine layer air and inversion layer. Temperatures are shown in degrees F. The transition zone acts like a "mini frontal passage", with 20 degree 24 hour temperature falls possible after the transition zone sweeps by (and on occasion, in only an hour or two). Drizzle often occurs with rapidly deepening marine layers, especially during the transition seasons. Afternoon temperatures on the coastal side of the Santa Ana Mountains above the inversion can be higher than the western portion of the inland valleys beneath the inversion as the marine layer air flows through canyons and passes into the inland valleys. After a "lowering trend", (resulting from a marine layer inversion that lowered and pushed toward the coast as a transition zone), a deepening trend can push the transition zone inland from the coast, then into the valleys. It is basically the "rapid change zone" not only for the current temperature gradient across the transition zone, but also for day to day changes. Moisture also changes rapidly across the zone. This is important at the end of a hot, dry episode (since before the transition zone arrives, very low dewpoints and high temperatures can continue above the inversion as the winds increase aloft).

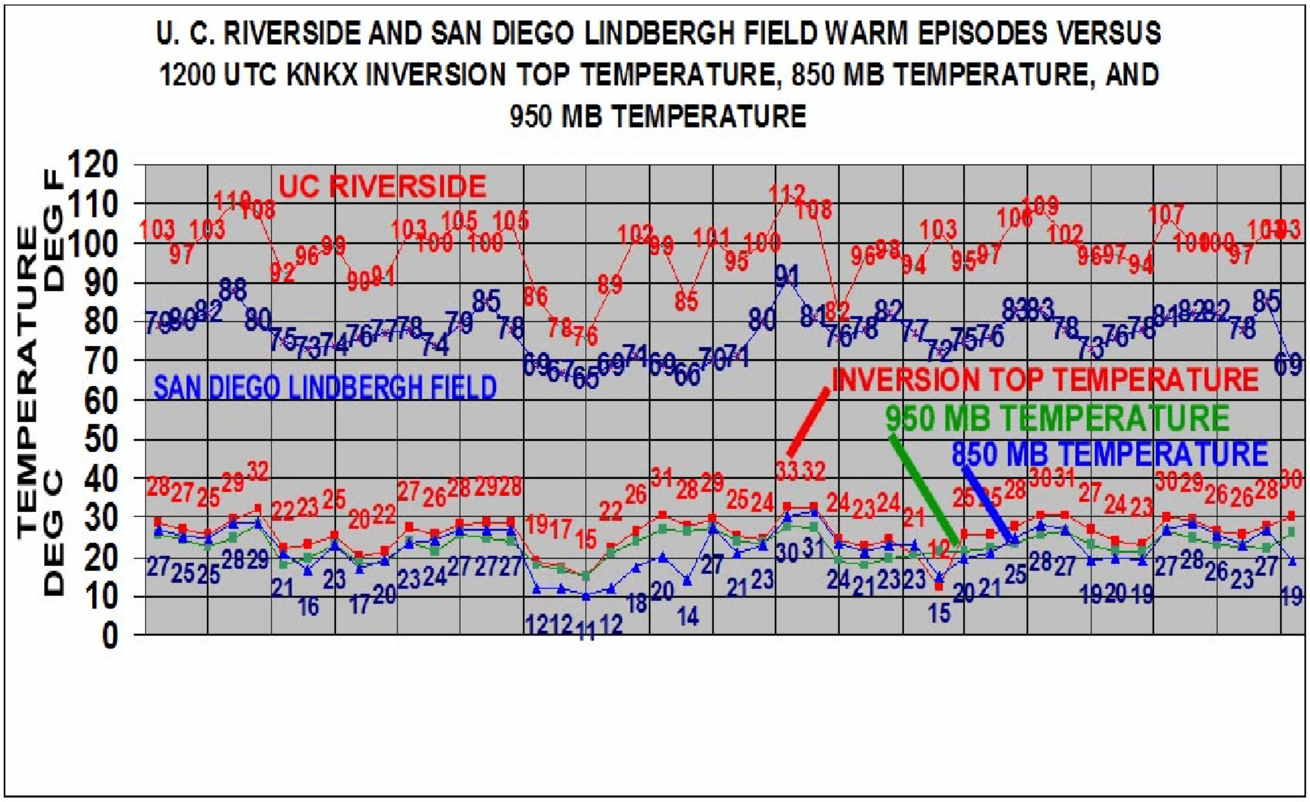

Fig. 15. Summer days with weak gradients only (less than 3 mb onshore from the coast to the lower Colorado River Valley) end to end, for the period June-September 2000-2003. The pressure gradient is from LSF (near KNFG in the coastal areas) to RIC (near KBLH near the Arizona border). The graph shows how the U. C. Riverside high temperature (highest, red curve) and the San Diego Lindbergh Field high temperature (KSAN, which is the second highest curve, in blue) relate to selected KNKX sounding temperatures. The lowest, second lowest, and third lowest curves in the graphic are the 850 mb temperature (blue curve, with triangles), the 950 mb temperature (green curve with squares) and the inversion top temperature (red curve with squares) respectively. The graphic basically strings together all of the weak gradient days for 3 consecutive summers for comparison. The 950 mb temperature (the second lowest from the bottom, in green) is a good approximation of the boundary layer temperature. The Lindbergh Field high temperature is approximately the 850 mb temperature or slightly higher if the 850 mb temperature reaches the upper 20s in degrees C (about 80 F), especially with east winds in the passes (for example, KCZZ). With east to northeast wind gusts to about 30 mph in the mountains during the warm season the adiabatic temperature (about 26-30 degrees F higher than the 850 mb temperature) can surface all the way to the coastal areas to around 5 miles from the coastline. With clear skies and east winds at coastal sites such warming can reach the coastline (with a better chance if there is a high overhead and strong subsidence aloft.

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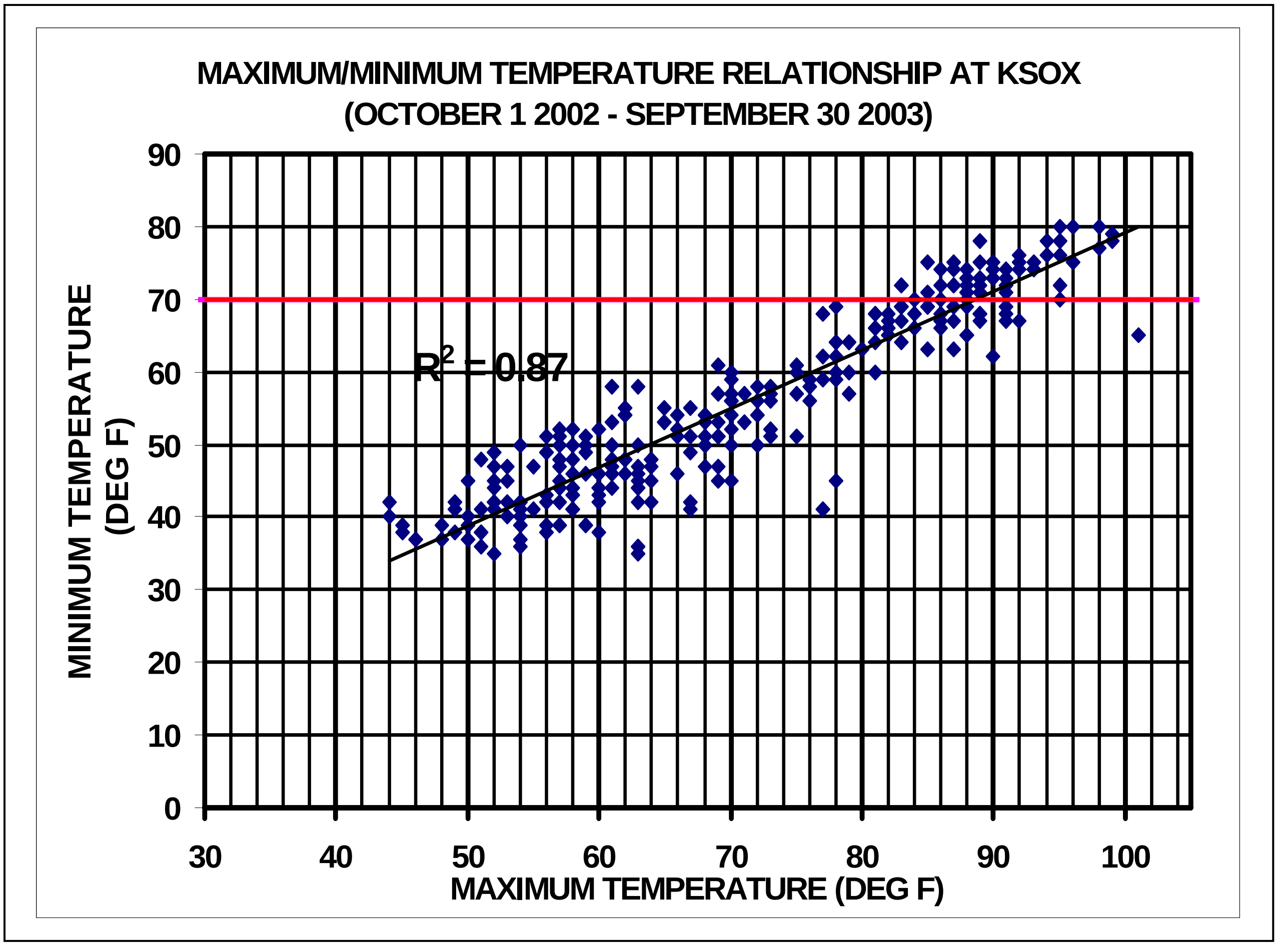

Fig. 16. The preliminary data in the above graphic shows how KSOX (Santa Ana Radar, near 3092 feet MSL) minimum and maximum temperatures relate during a 12 month period. Maximum and minimum temperatures are somewhat correlated. The difference between minimum and maximum temperatures averaged approximately 15 degrees F during the warm season (afternoon maximum temperatures in the upper 80s are often associated with minimum temperatures in the lower 70s in areas such as the foothills). The difference is smaller for lower temperatures, and larger for higher temperatures (closer to a 10 degree difference at high temperatures around 50 deg F, and about a 20 degree difference for high temperatures around 100 F). This relationship is relatively common for lower mountain locations. Basically, there is somewhere in the neighborhood of a 25 percent difference between maximum and minimum temperatures, and one is easily estimated from the other by adding (or subtracting) 25 percent.

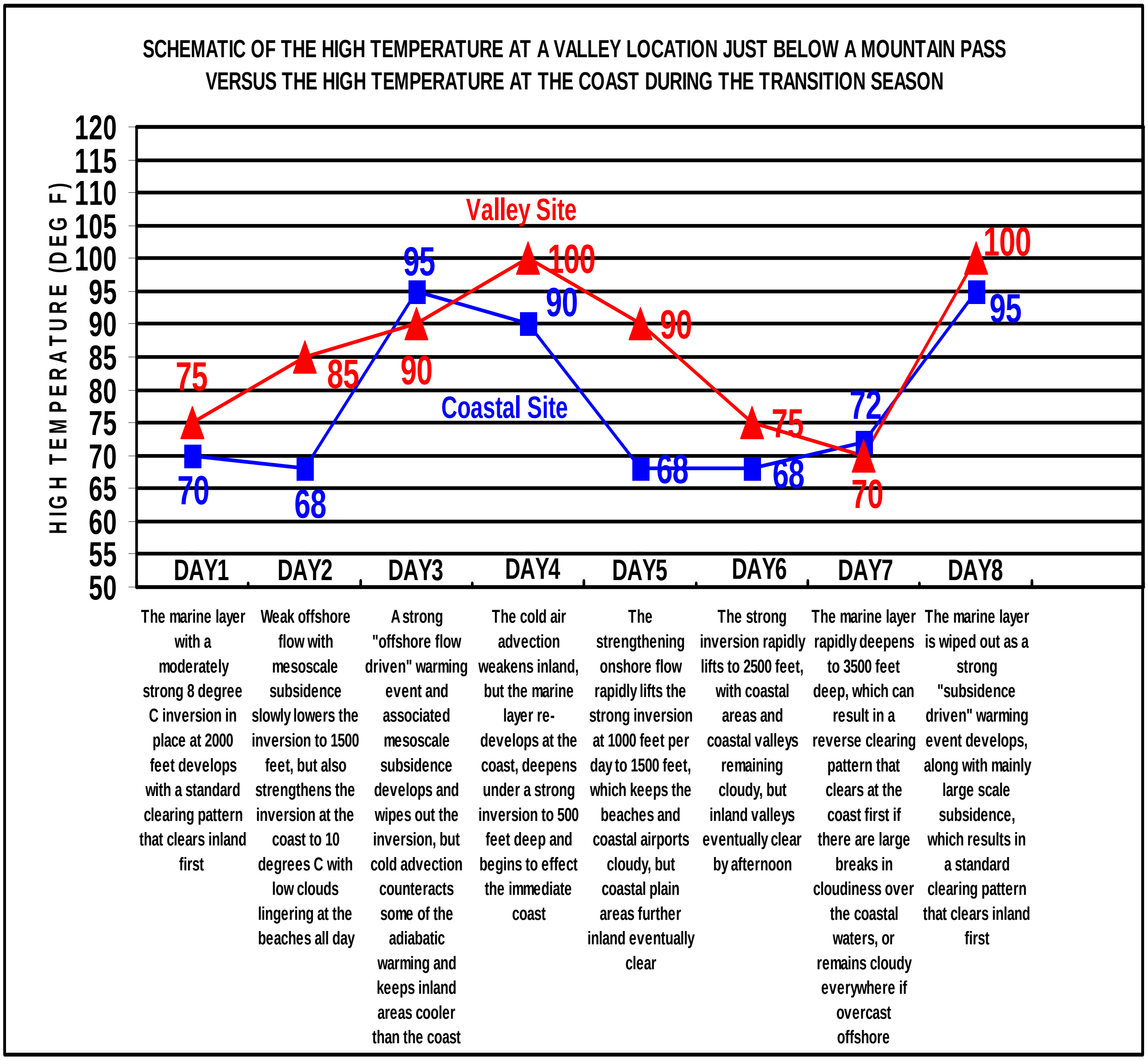

Fig. 17. The above schematic shows how the temperature for a coastal site (blue curve with squares) and a valley site near the foothills (red curve with triangles) respond to changes in the marine layer depth and the character of the flow. The schematic is geared toward the transition seasons (spring and fall). The cloud layer is assumed to be approximately 800-1000 feet thick. Other factors like pressure gradients, pressure gradient trend, lows aloft, Catalina Eddies, moisture (with or without clouds) aloft, and monsoonal moisture in the deserts can all have an effect on the conditions in the schematic and cause conditions to deviate significantly from the schematic.

WARM SEASON TEMPERATURE CORRELATION TABLES
(from June-September 1998-2000 data)

Table 4. AFTERNOON HIGH TEMPERATURES

Morning (1200 UTC) 850 MB temperature At or above 27 degrees C	**Highest Inland Empire temperature of at least 105 for any inversion depth. (14 of 15 days)** **AND** **Highest Inland Empire temperature of at least 107 for low inversions (near or below the August average of 1300 feet MSL). (9 of 9 days)**

Table 5. AFTERNOON HIGH TEMPERATURES

Morning (1200 UTC) inversion top temperature 30 degrees C or higher	**Inland coastal plain hot spot of at least 90 (15 of 17 days)** **AND** **Inland Empire hot spot of at least 105 degrees F (17 of 17 days).**

Table 6. AFTERNOON HIGH TEMPERATURES

Afternoon (0000 UTC) wind east at 850 or 700 mb at any speed **AND** **Afternoon (0000 UTC) 850 mb/inversion top temperatures at least 27/30 C**	**Highest Inland Empire temperature at least 110 degrees F (7 of 8 days)**

Table 7. OVERNIGHT LOW TEMPERATURES

Morning (1200 UTC) 850 mb wind easterly at any speed **AND** **Morning (1200 UTC) 850 mb dewpoint temperature greater than 13 degrees C**	**Highest overnight minimum temperatures coastal and valley areas at or above 70 degrees F (4 of 4 days).**

APPENDIX A. MARINE LAYER MATRICES

,

TRANSITION SEASON MARINE LAYER MATRIX (LATE SPRING/EARLY FALL)

INVERSION STRENGTH	INVERSION BASE	CHARACTER
WEAK (< 7.0 C)	around 1300 ft or less	Patchy dense fog with beaches affected shallow end, and mesas and western edge of coastal valleys deep end of height range. Clear everywhere by late morning
	1300 - 1999 ft	Patchy dense fog affecting mesas and coastal valleys shallow end, and coastal valleys and western inland valleys deep end of height range. Clear all areas by noon
	2000 - 2499 ft	Patchy dense fog into all valleys. Clear all areas by noon
	2500 - 3000 ft	Patchy dense fog into all valleys. 2nd convective deck forms, likely to reverse clear, and is slow to clear, with all areas clear mid afternoon. Cloud tops near mountains reach height of approximately the top of the KNKX inversion with foothills clearing last.
	3000 - 4000 ft	Patchy dense fog to coastal slopes. 2nd convective deck forms, likely to reverse clear, but slow to clear, and takes til late afternoon for all areas to clear. Cloud tops near mountains reach height of approximately the top of the KNKX inversion with mountain slopes clearing last.
	4000 ft deep and up	Patchy dense fog to coastal slopes. At least a couple of convective decks typically form, likely to reverse clear, but inland valleys and lower mountain slopes may not clear. Cloud tops near mountains reach height of approximately the top of the KNKX inversion with best cloud coverage on slopes.
MODERATELY STRONG "Typical Inversion" (7.0 - 9.9 C)	around 1300 ft or less	Areas of dense fog with beaches affected shallow end and mesas and western edge of coastal valleys affected deep end of height range. Clears everywhere by late morning
	1300 - 1999 ft	Areas of dense fog affecting mesas and coastal valleys shallow end, and coastal valleys and western inland valleys deep end of height range. Clear by noon (except near 9 C, after temporary morning clearing, areas of clouds reform or advect in at the beaches of the preferred "beaches of the day for clouds" around noon).
	2000 - 2499 ft	Areas of dense fog affecting coastal and inland valleys. Clears by noon all areas (except near 9 C, after temporary morning clearing, areas of clouds reform or advect back in at most beaches around noon).
	2500 - 3000 ft	Areas of dense fog, mainly in the inland valleys. A 2nd convective deck forms, but still clears by mid afternoon all areas (except cloudy at most beaches near 9 C).
	3000 - 4000 ft	Areas of dense fog higher inland valleys and lower coastal slopes of the mountains. A 2nd convective deck forms. Clouds become scattered inland valleys in the afternoon but stays overcast remaining coastal areas and coastal valley areas.
	4000 ft deep and up	Areas of dense fog lower slopes. Multiple convective decks are expected. Skies become scattered inland valleys in the afternoon but stays overcast remaining coastal areas and coastal valley areas. (Assumes overcast offshore, or it may reverse clear).
STRONG (10.0 C OR MORE)	around 1300 ft or less	Areas of dense fog with beaches affected shallow end, and mesas and western edge of coastal valleys deep end of height range. May clear approximately an hour or so at the beaches late morning, but returns to the beaches in the "county of the day for clouds" just before noon (If no eddy, then the "favored beaches of the day for cloudiness" will likely be in San Diego County, and via coastal blocking and island effect stratus bands. The Orange County Beaches from KSNA to KSLI are the favored "beaches of the day for clearing"). Erratic in Fall.
	1300 - 1999 ft	Areas of dense fog affecting mesas and coastal valleys shallow end, and coastal valleys and western inland valleys deep end of height range. Clears for approximately an hour or so all beaches late morning, but returns to the beaches in the "county of the day" just before noon. (If no eddy, then stratus affects mainly the favored San Diego County beaches, via coastal blocking and island effect stratus bands). Erratic in Fall.
	2000 - 2499 ft	Areas of dense fog affecting coastal valleys and inland valleys, but only inland valleys clear by early afternoon. Coastal airports remain cloudy.
	2500 - 3000 ft	Areas of dense fog higher portions of inland valleys, but only inland valleys clear by early afternoon while coastal areas and coastal valleys remain cloudy. 2nd convective deck forms.
	3000 - 4000 ft	Areas of dense fog inland valleys and lower coastal slopes. Only inland valleys clear by early afternoon while coastal areas and coastal valleys remain cloudy. 2nd convective deck forms.
	4000 ft deep and up	Areas of dense fog coastal slopes, becoming scattered inland valleys in the afternoon, and remains overcast coastal areas and coastal valleys. Multiple convective decks are expected. Above 5000 feet expect cloudy conditions to the coastal slopes all day, although reverse clearing may occur along the immediate coastal strip if it is clear offshore during the morning.

Table A1. Approximate marine layer characteristics (for a cloud thickness of around 800-1000 feet thick or thicker). Lower sea surface temperatures (generally lower 60s or lower at the local buoys and mid 60s or lower at the beaches) may result in stronger inversions than mid summer for the 1000-2000 ft deep region, and along with cooler conditions and overall deeper inversions. This may serve to make low clouds more persistent than mid summer. For the more typical marine layer depths (up to 3000 feet deep, the clouds can normally be expected to extend inland to the terrain height corresponding to ½ the depth of the marine layer ("the half-depth point"). For example, a marine layer inversion base at 1300 feet MSL supports low clouds moving inland to near the 650 foot MSL terrain contour.

Clearing time assumes approximately 80 % or more coverage west of the inland edge of the marine layer around sunrise and sufficiently thick (800-1000 feet thick or thicker) or the clouds are likely to clear sooner than usual. Works best for neutral to slightly onshore trends to the local deserts. If cloud bases are high, and the airmass below 3000 feet is so dry that the LCL approaches 3000 feet, the cloud deck is probably thin, and will generally clear everywhere). For moderately strong onshore trends (around 2 mb or more to the local deserts and around 4 mb or more to the plateau, add 1000 feet to the depth to obtain slower clearing). For moderately strong offshore trends (2 mb or more to the local deserts, and 4 mb or more to the plateau, subtract 1000 feet from the depth to show better improvement). Offshore trends during "weak gradients" (+3.0 mb or less KLAX-KLAS) are often very tricky to deal with and significantly lower tops/inversion heights. Pilot reports and ACARS data give additional clues on trend. Results might be offset by strong Catalina Eddy formation, which can supply clouds to advect in, and change the "favored beaches for cloudiness", but based on the position and depth of the Eddy, the low clouds can be pulled out of some coastal areas. In general, if there is weak easterly flow aloft and/or weak offshore surface pressure gradient trends, low cloud development may be delayed till the following morning. For fairly weak inversions with deep marine layers, (typically around 2500 feet deep MSL or deeper with patchy/ or just areas of low clouds overnight) there can be a dramatic increase in cloud coverage to form a ceiling during the morning (low clouds fill in the gaps in coverage mainly through boundary layer convection). For the lower, stronger inversions cloud tops are generally around a few hundred feet above the base of the inversion, but with deep marine layers (typically with weaker inversions that slope more gently in the vertical), cloud tops will attempt to convect upward to near the top of the inversion, especially inland valleys and near the mountains. Patchy dense fog extends down to 800-1000 feet or so below base of inversion for the more "average" marine layer depths of 1000-3000 feet deep (MSL). Marine layer clouds are prone to "reverse clearing" with weakening inversions, often seen as a "patch of clearing" developing over the northern portion of the California Bight Region downwind of the Santa Ynez Mountains that spreads south and east. Persistent stratus about 10 miles or so offshore may re-develop at the coastline mid afternoon, or may advect in just before sundown. On a few occasions, afternoon and evening low clouds may "drain out" if significant draining winds develop. Transition season marine layers seem to deliver a thicker cloud deck than mid summer marine layers, (even when the depth is the same), and could produce more drizzle at lower marine layer depths (such as 2500 feet or so). Conditions will at times deviate significantly from those indicated in this table.

SUMMER MARINE LAYER MATRIX (JULY – SEPTEMBER)		
INVERSION STRENGTH	**INVERSION BASE**	**CHARACTER**
WEAK (< 7.0 C)	around 1300 ft or less	Patchy dense fog with the beaches affected shallow end, and mesas and western edge of coastal valleys deep end of the height range. Clear everywhere by late morning
	1300 - 1999 ft	Patchy dense fog affecting mesas and coastal valleys shallow end, and coastal valleys and western edge of the inland valleys deep end of height range. Clear all areas by noon
	2000 - 2499 ft	Patchy dense fog into all valleys. Clear all areas by noon
	2500 - 3000 ft	Patchy dense fog into all valleys. 2nd convective deck forms, convects (or re-convects) in some areas, and is slower to clear, with all areas clear by early afternoon.
	3000 - 4000 ft	Patchy dense fog to coastal slopes. 2nd convective deck forms, likely to reverse clear, but slow to clear, and takes til late afternoon for all areas to clear. Cloud tops near mountains reach height of approximately the top of the KNKX inversion with mountain slopes clearing last.
	4000 ft deep and up	Patchy dense fog to coastal slopes. A couple of convective decks can form, likely to reverse clear. Cloud tops near mountains reach height of approximately the top of the KNKX inversion with best cloud coverage on slopes.
MODERATELY STRONG "Typical Inversion" (7.0 - 9.9 C)	around 1300 ft or less	Patchy dense fog with beaches affected shallow end and mesas and western edge of coastal valleys affected deep end of height range. Clears everywhere by late morning
	1300 - 1999 ft	Patchy dense fog affecting mesas and coastal valleys shallow end, and coastal valleys and western inland valleys deep end of height range. Clear by noon (except near 9 C, some patchy low clouds may persist into early afternoon in the preferred "county of the day for clouds" where the thickest clouds are).
	2000 - 2499 ft	Patchy dense fog affecting coastal and inland valleys. Clears by noon all areas (except near 9 C, some patchy low clouds may persist into early afternoon in the preferred "county of the day for clouds" under thickest clouds).
	2500 - 3000 ft	Patchy dense fog, mainly in the inland valleys. A 2nd convective deck may form, but still clears by mid afternoon all areas (except patchy clouds at some beaches well into the afternoon near 9 C).
	3000 - 4000 ft	Patchy dense fog to coastal slopes. A 2nd convective deck may form, but still clears by mid afternoon all areas (except patchy clouds at some beaches near 9 C where the thickest clouds are).
	4000 ft deep and up	Patchy dense fog lower slopes. Multiple convective decks typically form, but still clears by mid afternoon all areas (except patchy clouds at preferred "beaches of the day" near 9 C under the thickest clouds).
STRONG (10.0 C OR MORE)	around 1300 ft or less	Patchy dense fog with beaches affected shallow end, and mesas and western edge of coastal valleys deep end of height range, with beach clearing before noon. (If no eddy, then the thicker clouds and "favored beaches of the day for clouds" are in San Diego County from approximately KCRQ to KSDM, and possibly via coastal blocking and island effect stratus bands). Those areas clear last.
	1300 - 1999 ft	Patchy dense fog affecting mesas and coastal valleys. Clears at the beaches just before noon. [If no eddy, then the thicker clouds and "favored beaches of the day for clouds" are in San Diego County (approximately KCRQ to KSDM), and possibly via coastal blocking and island effect stratus bands, which clear last around noon].
	2000 - 2499 ft	Patchy dense fog affecting coastal valleys, but inland valleys generally remain clear. Clears at the "beaches of the day for clearing" mid afternoon.
	2500 - 3000 ft	Patchy dense fog inland valleys. Generally clears all areas by mid afternoon.
	3000 - 4000 ft	(Rare mid summer) Patchy dense fog inland valleys and lower coastal slopes. Generally clears all areas by mid afternoon.
	4000 ft deep and up	(Very Rare mid summer). Patchy dense fog coastal slopes. Generally clears all areas by mid afternoon

Table. A2. Approximate marine layer characteristics (for cloud thickness of around 800-1000 feet or thicker). Summer days are warmer with weaker onshore gradients, along with more mid level moisture, hence clear better than transition season days (valleys almost always clear). Also warmer water temperatures (generally upper 60s or higher local buoys and around 70 or higher coastal waters observing sites) results in weaker inversions and poorer/slower nighttime re-development, especially in the 1000-2000 foot deep range. In general, temperature increases in the inversion are more dramatic for a "flatter" inversion, which improves mixing and clearing for the deeper marine layers. Deeper marine layers (typically around 2500 feet or more AGL) allows boundary layer convection into areas that are clear at around 1500-1600 UTC or so west of the inland edge of the marine layer air. For the more typical marine layer depths (up to 3000 feet deep), the clouds can normally be expected to extend inland to the terrain height corresponding to ½ the depth of the marine layer ("the half-depth point"). For example, a marine layer inversion base at 1300 feet MSL supports low clouds moving inland to near the 650 foot MSL terrain contour. A deeper marine layer might be needed to reach Ontario during the mid summer period in comparison to the transition season (possibly 2500 ft deep compared to 1800 ft deep). This is likely due to more strong eddy development in transition season, possibly a thicker cloud layer during the transition season in comparison to mid summer, and the later re-development of the low clouds during the mid summer overnight periods. With very rapid deepening (4 mb onshore trend) to the local deserts, and especially with 6-8 mb onshore gradients, conditions resemble transition season conditions, except the valleys will almost never remain cloudy all day.

<u>Clearing time assumes approximately 80 % or more coverage west of the inland edge of the marine layer around sunrise and sufficiently thick (at least 800-1000 feet thick) or the clouds are likely to clear sooner than usual.</u> Matrix works best for neutral to slightly onshore trends to the local deserts. If cloud bases are high, and the airmass below 3000 feet is so dry that the LCL approaches 3000 feet MSL, the cloud deck is probably thin, and will generally clear everywhere. For moderately strong <u>onshore</u> trends [2 mb or more to the local deserts (for example KSAN to KTRM) and 4 mb or more to the plateau (for example, KLAX to KTPH), add 1000 feet to the depth)] For moderately strong <u>offshore</u> trends (2 mb or more to the local deserts and 4 mb or more to the plateau, subtract 1000 feet from the depth). Offshore trends during "weak gradients" (for example, +3.0 mb or less KLAX-KLAS) tend to be very tricky to deal with and can significantly lower the inversion top and inversion height. Pilot reports and ACARS data help to give clues on trend. Results might be offset by strong Catalina Eddy formation, which rather frequently supplies clouds to advect in, but based on the position and depth, eddies can pull low clouds out of some coastal areas. In general, if there is weak easterly flow aloft and/or a weak offshore surface pressure gradient trend, low cloud development may be delayed till the following morning. For fairly weak inversions with deep marine layers, (typically around 2500 feet deep MSL or deeper with patchy/ or just areas of low clouds overnight) there can be a dramatic increase in cloud coverage to form a ceiling during the morning (low clouds fill in the gaps in coverage mainly through boundary layer convection). For the lower, strong inversions cloud tops are generally around a few hundred feet above the base of the inversion, but with deep marine layers (with weak inversions) cloud tops tend to convect upward to near the top of the inversion, especially inland valleys and near the mountains. Patchy dense fog extends down to around 800-1000 feet below base of the inversion for the standard 1000-3000 foot inversion. Marine layer clouds are prone to "reverse clearing" with weakening inversions, often seen as a "patch of clearing" developing over the northern bight (downwind of the Santa Ynez Mountains north of KSBA) that spreads south and east. Persistent stratus up to 5-10 miles off the coast may re-develop at the coastline mid or late afternoon, or advect in just before sundown as the heating slows. Conditions will at times deviate significantly from those indicated in this table.

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APPENDIX B. MARINE LAYER CASE STUDIES

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MARINE LAYER DEEPENING EVENT

(Transition season, deepening around 1000 feet per day)

During the period 15-22 June 2003 the marine cloud tops deepen from 2000 to 5000 feet deep with pilot reports of 6000 feet near the mountains by the end of the period.
On the 18th at the beginning of the event the morning cloud bases were 1200 feet with afternoon tops of 2200 feet. Normally, 2200 foot deep marine layers clear at the coastal airports, but with the 10 degree C inversion and 1000 ft/day deepening, ceilings continue past noon coastal airports, with partly cloudy skies at best coastal plain and southern valleys in the afternoon.
On the 19th, a convective cloud deck (1800 feet) was visible beneath a higher stratiform deck (about 2500 feet) during the morning, with a top around 3000 feet. Since the 1000 ft/day deepening makes the clearing pattern resemble that of a 4000 foot deep marine layer, there was no clearing coastal valleys, and little clearing inland valleys.

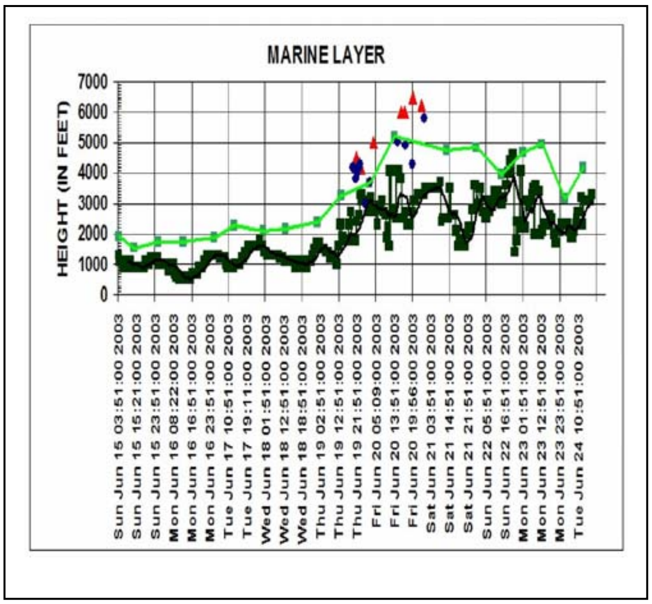
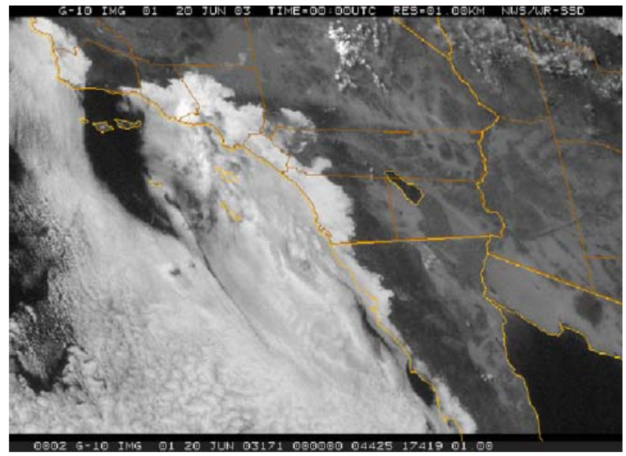
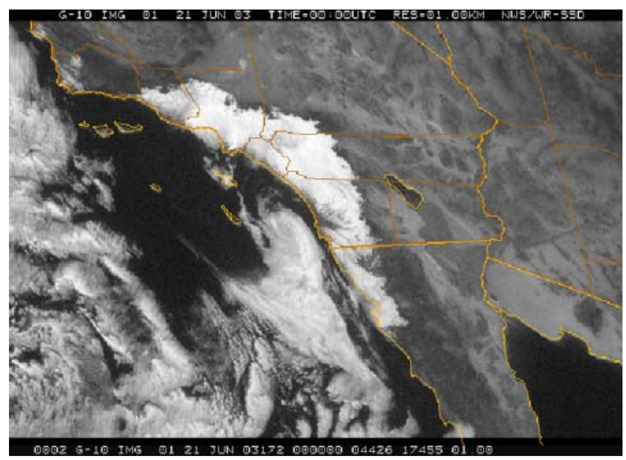


Fig. B1. Graphic shows the marine layer cloud tops deepening from 2000 feet deep to about 6500 feet deep, than back down to 4000 feet deep. The upper line (light green) is the inversion base at KNKX. The lower line (thick green) is the cloud base at KSAN. The blue circles are pilot reports near the coast. The red triangles are pilot reported cloud tops near the mountains, which appear to be higher than those near the coast, showing an upward slope in the marine layer cloud top height and marine layer inversion base height. The diurnal rising/falling of the LCL is easily seen early in the event, and the multiple cloud decks develop during the middle and latter portions of the event. Essentially, the bases burn away from the "bottom up" during the day, then advect in again at around ½ the afternoon base height in many cases (since the essentially "unburned" bases advecting in from the ocean are still low). The clouds also re-develop and thicken while the bases lower at night as the typical nighttime strengthening of the inversion occurs (and LCL lowers). Clouds also re-develop during the daytime via convection during deep marine layer episodes. The inversion typically weakens during the day up until late afternoon.

0000 UTC 19 June 2003



0000 UTC 20 June 2003



0000 UTC 21 June 2003

Fig. B2. Visible Satellite Imagery

On the 20th, the main morning cloud base was around 2500 feet and top around 5000 feet. The airmass became a very unstable layer. The saturated airmass with a strong lapse rate was so unstable it began to convect into 2 lower decks overnight, without solar heating. It produced 3 clouds decks (at 1800, 2500, and 4200 hundred feet as seen on 1200 UTC sounding and graphic). Enough cold advection to lower the 850 mb temperature to the mid teens (eventually around 10, then into the single digits), along with subsidence downwind of the Santa Ynez mountains cleared the coastal waters, and resulted in reverse clearing. The difference between the bases and inversion (tops) results in clouds thickening from nearly1000 to approximately 3500 feet thick.
Rainfall amounts were heaviest in the southern coastal and valley areas. (Convection in the south develops on spiral bands around the eddy, which are intensified in regions of blocked flow parallel to the coast). The heaviest amounts were Spring Valley (0.13), Escondido (0.10), La Mesa (0.09), Montgomery Field (0.06), Rancho Bernardo (0.05), and National City (0.05). Without a thick isothermal layer to aide convection higher mountain slopes,

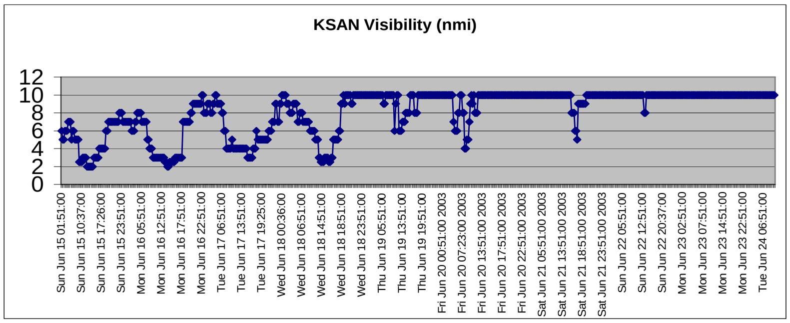


Fig. B3. San Diego (KSAN) visibility in miles.

mountain amounts were meager at best. Only KSOX in the Santa Ana Mountains reported rain (0.04). With bases just below 1000 feet for the first few days, visibilites dipped to or below 3 miles in the morning, otherwise visibilities were good.

GRADIENT/ TRENDS (June 2003)	6/15 12Z	6/16 12Z	6/17 12Z	6/18 12Z	6/19 12Z	6/20 12Z	6/21 12Z	6/22 12Z	6/23 12Z
LAX-SFO	-5.2	-2.1 (3.1)	-1.5 (0.6)	-1.9 (0.4)	0.0 (1.9)	0.3 (0.3)	-0.4 (-0.7)	-0.7 (-0.3)	0.7 (1.4)
LAX-WMC	-1.6	-2.7 (-1.1)	-2.0 (0.7)	3.1 (5.1)	4.2 (1.1)	5.5 (1.3)	3.1 (-2.4)	-0.1 (-3.2)	3.7 (3.8)
LAX-TPH	-0.1	0.6 (0.7)	0.0 (-0.6)	1.8 (1.8)	6.8 (5.0)	8.1 (1.3)	6.4 (-1.7)	4.8 (-1.6)	6.8 (2.0)
LAX-LAS	3.4	3.4 (0.0)	4.0 (0.6)	3.9 (-0.1)	7.4 (3.5)	9.6 (2.2)	7.6 (-2.0)	6.7 (-0.9)	10.0 (3.3)
SAN-IPL	5.7	6.3 (0.6)	6.3 (0.0)	6.7 (0.4)	8.0 (1.3)	8.0 (0.0)	6.7 (-1.3)	6.7 (-0.0)	7.7 (1.0)
SAN-YUM	5.6	6.1 (0.5)	mm	6.1	7.6 (1.5)	7.3 (-0.3)	6.7 (-0.6)	5.2 (-0.5)	7.9 (2.7)

Table B1. Pressure gradients (black) onshore trends (blue), and offshore trends (red negative values) beneath.

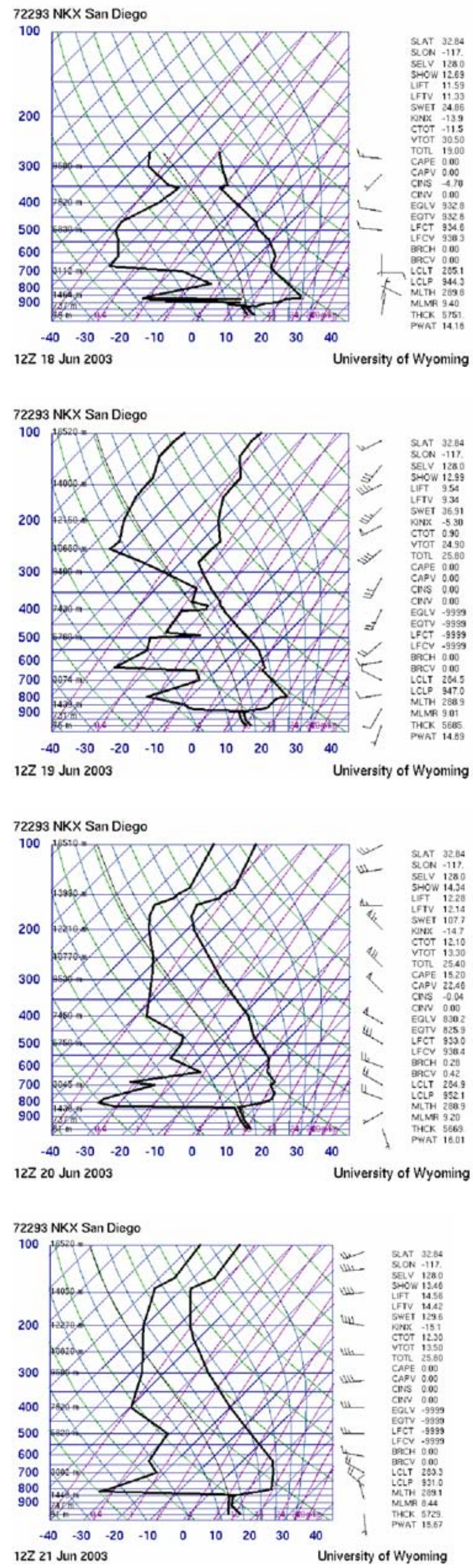


Fig. B4. KNKX Sounding data

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:SOUTHWESTERN CALIFORNIA TEMPERATURE AND PRECIPITATION SUMMARY
:NATIONAL WEATHER SERVICE SAN DIEGO CA
:810 PM PDT FRI JUN 20 2003
:
:***** AMENDED FOR IMPERIAL BEACH AND CUYAMACA PARK *****
:
:TODAYS HIGH AND OVERNIGHT LOW TEMPERATURES AS OF 5 PM TODAY.
:   * DENOTES 24 HOUR HIGH TEMPERATURES BETWEEN 4 PM YESTERDAY
:     AND 4 PM TODAY. OCCASIONALLY THE HIGH TEMPERATURE MAY HAVE
:     OCCURRED AFTER 4 PM YESTERDAY.
:
:PRECIPITATION FOR THE PAST 24 HOURS.   M DENOTES MISSING.
:   T DENOTES TRACE OF PRECIPITATION
:
.B SAN  0620 P DH16/TX/TN/PPD/SD
:
: ID :       STATION          ELEV : HIGH / LOW /  PCPN / SNODEP
:                             FEET                        INCHES
:
:        ...COASTAL AREAS...
:
YBLC1:    * YORBA LINDA         350 :   65 /   M /  0.00 /
FUL  :      FULLERTON AIRPORT    96 :   68 /  60 /  0.00 /
ANAC1:    * ANAHEIM             335 :   67 /  61 /  0.00 /
STAC1:    * SANTA ANA           135 :   70 /  60 /  0.00 /
SNA  :      JOHN WAYNE AIRPORT   55 :   70 /  61 /     T /
3L3  :    * NEWPORT BEACH        10 :   66 /  62 /  0.00 /
LAGC1:    * LAGUNA BEACH         35 :   74 /  59 /  0.00 /
SJYC1:    * SAN JUAN CANYON     375 :   65 /  58 /     T /
L34  :    * OCEANSIDE HARBOR     10 :   65 /  59 /  0.00 /
OKB  :      OCEANSIDE AIRPORT    28 :   68 /  59 /  0.03 /
VSTC1:    * VISTA               330 :   65 /  57 /  0.00 /
CRQ  :      CARLSBAD AIRPORT    328 :   66 /  58 /     T /
SOL  :      SOLANA BEACH         75 :    M /   M /  0.00 /
DMRC1:    * DEL MAR             100 :   67 /  58 /  0.00 /
NKX  :      MIRAMAR             477 :   68 /  58 /     T /
MYF  :      MONTGOMERY FIELD    420 :   64 /  57 /  0.06 /
SWDC1:      SEA WORLD SAN DIEGO  10 :   67 /  58 /  0.03 /
SAN  :      SAN DIEGO            15 :   65 /  60 /     T /
CDOC1:    * CORONADO             25 :   65 /  58 /  0.04 /
L13  :    * CABRILLO NATL MNMT  364 :   67 /  57 /  0.06 /
NATC1:    * NATIONAL CITY        30 :   71 /  56 /  0.05 /
CVAC1:    * CHULA VISTA          56 :    M /   M /     M /
IPLC1:    * IMPERIAL BEACH       22 :   72 /  60 /  0.00 /
SDM  :      BROWN FIELD         525 :   66 /  56 /  0.06 /
:
:        ...INLAND AREAS...
:
ONT  :      ONTARIO             943 :   63 /  58 /     T /
L67  :      RIALTO             1420 :   66 /  57 /  0.00 /
SBOC1:    * SAN BERNARDINO     1125 :    M /   M /     M /
UCR  :      RIVERSIDE           986 :   70 /  57 /  0.02 /
EORC1:    * ELSINORE           1285 :   74 /  46 /  0.00 /
HEMC1:    * HEMET              1655 :   66 /  51 /  0.00 /
TEMC1:    * TEMECULA           1020 :   67 /  56 /  0.00 /
FALC1:    * FALLBROOK           698 :   63 /  57 /  0.02 /
ESCC1:    * ESCONDIDO           600 :   67 /  46 /  0.10 /
ASCC1:    * WILD ANIMAL PARK    420 :   70 /  58 /  0.00 /
RAMC1:      RAMONA             1393 :   60 /  54 /  0.01 /
SGX  :      RANCHO BERNARDO     690 :   66 /  56 /  0.05 /
POWC1:    * POWAY               648 :   68 /  57 /  0.00 /
ALPC1:    * ALPINE             1735 :    M /   M /     M /
SNTC1:    * SANTEE              340 :    M /   M /     M /
ELJC1:    * EL CAJON            405 :   65 /  57 /  0.00 /
LMAC1:    * LA MESA             530 :   77 /  56 /  0.09 /
SPVC1:    * SPRING VALLEY       270 :   72 /  58 /  0.13 /
LMGC1:    * LEMON GROVE         427 :   64 /  57 /  0.00 /
:
:        ...MOUNTAIN AREAS...
:
SOX  :      SANTA ANA RADAR    3092 :   52 /  49 /  0.04 /
WRIC1:    * WRIGHTWOOD         5980 :   72 /  39 /  0.00 /
ARWC1:    * LAKE ARROWHEAD     5205 :   68 /  54 /  0.00 /
BBLC1:    * BIG BEAR LAKE      6760 :   75 /  42 /  0.00 /
IDYC1:    * IDYLLWILD          5380 :   69 /  41 /  0.00 /
PLRC1:    * PALOMAR MOUNTAIN   5550 :   71 /  41 /  0.00 /
JUL  :      JULIAN             4240 :   52 /  45 /  0.01 /
CUYC1:    * CUYAMACA PARK      4870 :   75 /  51 /  0.00 /
MTLC1:    * MT. LAGUNA         5760 :    M /   M /     M /
CZZ  :      CAMPO              2615 :   60 /  51 /  0.00 /
:
:        ...DESERT AREAS...
:
HESC1:    * HESPERIA           3055 :    M /   M /     M /
APLC1:      APPLE VALLEY       2780 :   75 /  54 /  0.00 /
PSP  :      PALM SPRINGS        425 :   85 /  67 /  0.00 /
IDOC1:    * INDIO               -21 :  103 /  69 /  0.00 /
TRM  :      THERMAL            -117 :   90 /  70 /  0.00 /
BROC1:      BORREGO             805 :   85 /  61 /  0.00 /
OCTC1:    * OCOTILLO WELLS      390 :  102 /  65 /  0.00 /
TYEC1:    * TWENTYNINE PALMS   1975 :   98 /  62 /  0.00 /
```

Near the end of the event the boundary layer near surface begins to dry out, and the low level inverted V sounding accompanies decreasing rainfall.

With the shallower marine layers the drizzle is more of a night and morning phenomena, but when it begins to convect around the mountains in an isothermal inversion and around 6000 feet deep or deeper, the precipitation can become as prevalent (if not more) during the afternoon, with sprinkles/light rain becoming the dominant type.

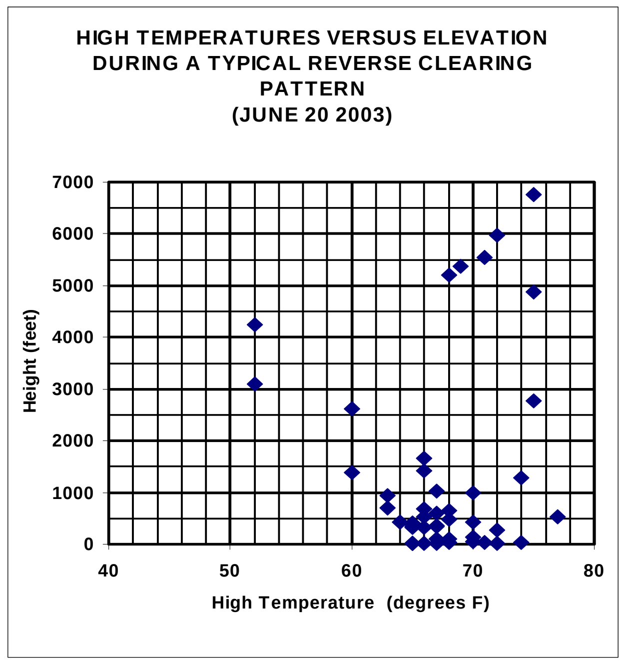


Fig. B5. The above figure shows a temperature profile typical of a reverse clearing pattern. The region at approximately 3-4 thousand feet around the mountains stays coolest (lowest temperatures on the sounding, and may remain cloudy all day). The lowest high temperatures are in the lower mountains just below the inversion base. Above and below the inversion base there are clear skies and better heating. It is over 20 degrees warmer near 7000 feet MSL than it is near the inversion base near 3500 feet MSL.

MARINE LAYER CYCLE

(Lowering event, then deepening event)

During this May 2000 case the marine layer clears all land areas day 1 (19 May 2000), but does not clear at most beaches day 2 (20 May 2000). Also a huge increase in inland temperatures occurred. Anticipating the possibility of this scenario during the evening shift on 19 May 2000, the author mentioned in the Area Forecast Discussion (AFD) that the latest runs have “the valleys down right hot...especially by Sunday”. A lowering/strengthening inversion was expected to result in this warming. Basically, the increasing heights, thicknesses, 850 mb and 950 mb temperatures, along with easterly flow aloft would bringing the warmer air in/above the inversion closer to sea level (and further west), forcing the inversion down. The figures indicate this fact over the 24 hour period. Also stated in the AFD was “the tricky part of this whole scenario is the coastal low clouds and fog. It may hang tough in some location through a good portion of the day. For now....I will think along the lines of at least a few hours of sunshine for the beaches during the afternoon”. As expected, the lowering and strengthening of the inversion made the low clouds so persistent that clearing was limited to only the far northwest corner of the forecast area (not an unusual occurrence for the more “concave” coastline in that area). Since strong heating is generally limited to the land areas, the warming over the ocean was insufficient to clear the low clouds or even get close to breaking the inversion. A dewpoint inversion has also developed. Afternoon high temperatures are higher everywhere, except over the coastal plain, where increased cloud cover and a strengthened sea breeze (due to strong inland heating) actually results in lower high temperatures than on day 1. Temperatures to over 105 in the valleys result in some weak convection over the mountains, even with little moisture in the sounding. Significant temperature increases in the 950 mb region (around 1500-1800 feet) to around 73 degrees F (approximately 23 C) or higher are usually needed for significant warm-ups in the coastal plain areas (in which the high temperature at KSAN is approximately a few degrees lower than the 950 mb temperature as a first guess). The 950 mb temperature was around 68 F in this case. As the deepening trend progresses on the 22nd, the cooling is largest over the inland coastal plain area (KFUL), and in the valleys eastward on the 23rd, with the cooling maximum associated with the “thermal transition zone” progressing inland, essentially following the inversion base. In the far inland areas in places such as the higher mountains and deserts, lowering 850 mb temperatures and thickness falls play a strong part in the cooling process. As usual some dense fog was found just under the inversion base.

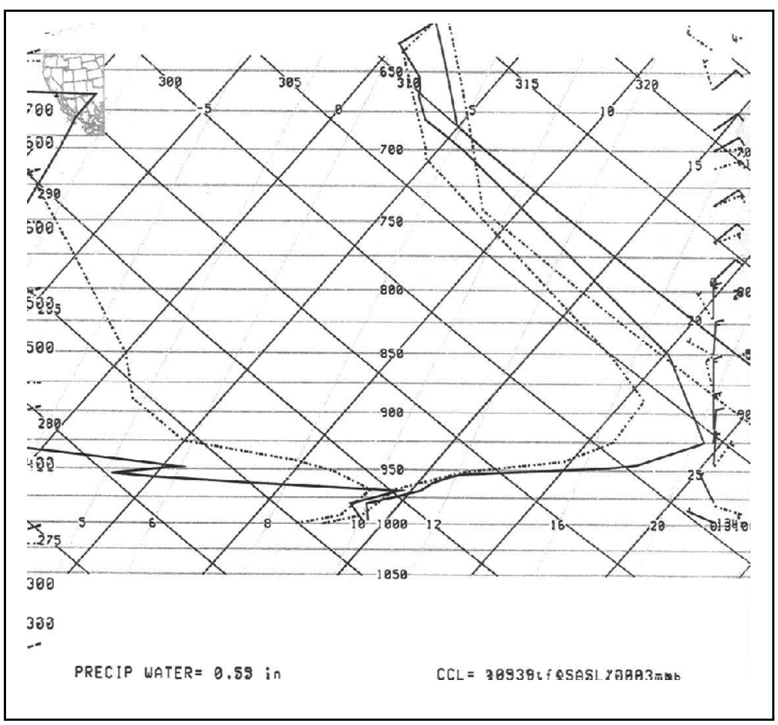


Fig. B6. 1200 UTC 19 May 2000 KNKX sounding (dashed) overlayed with 1200 UTC 20 May 2000 sounding (solid) showing lowering and strengthening of the inversion.

GRADIENTS AND TRENDS (May 2000)	5/18 12Z	5/19 12Z	5/20 12Z	5/21 12Z	5/22 12Z	5/23 12Z	5/24 12Z
KLAX-KSFO	-4.1	-3.4 (0.6)	-3.2 (0.2)	-1.4 (1.8)	-3.9 (-2.5)	0.3 (4.2)	1.1 (0.9)
KLAX-KWMC	-8.2	-5.7 (2.5)	-8.0 (-2.3)	-8.2 (-0.2)	-4.8 (3.4)	3.2 (8.0)	0.4 (2.8)
KLAX-KTPH	-3.7	-4.0 (-0.3)	-5.0 (-1.0)	-4.3 (0.7)	-2.9 (1.4)	-0.2 (2.7)	1.6 (1.8)
KLAX-KLAS	0.9	0.4 (-0.5)	0.1 (-0.3)	-0.5 (-0.6)	1.0 (1.5)	4.7 (3.7)	7.5 (2.8)
KSAN-KIPL	M	3.7	3.7 (0.0)	4.7 (1.0)	4.7 (0.0)	5.0 (0.3)	7.0 (2.0)
KSAN-KYUM	4.8	3.1 (-1.7)	5.0 (1.9)	5.1 (0.1)	5.3 (0.2)	6.0 (0.7)	7.6 (1.6)

Fig. B2. Pressure gradients (top) and 24 hour pressure gradient trends (bottom) in parentheses (offshore in red, underlined, and onshore in blue).

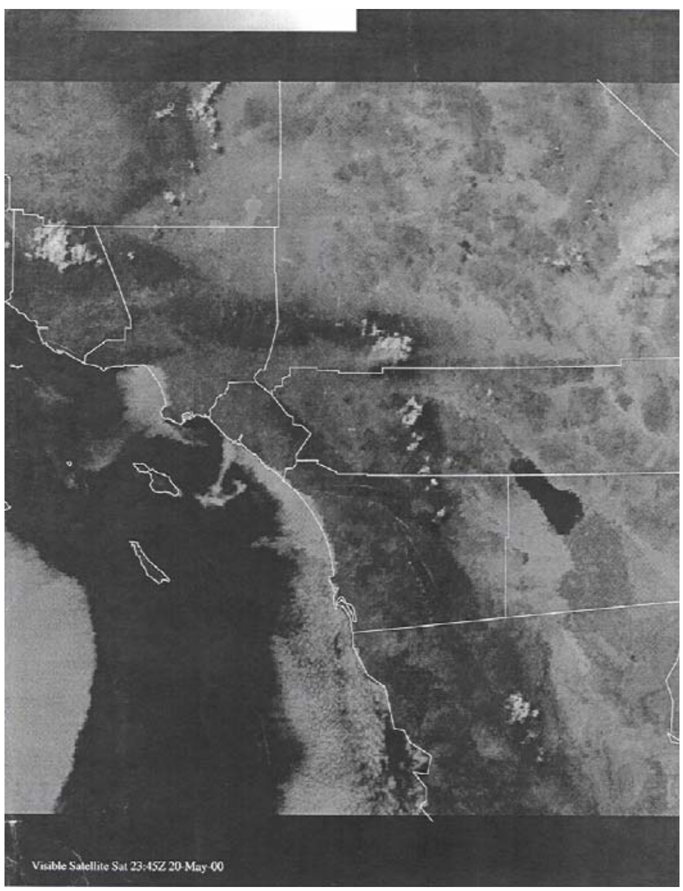


Fig. B7. 2345 UTC 20 May 2000 visible satellite imagery.

Parameter	5/18 12Z	5/19 00Z	5/19 12Z	5/20 00Z	5/20 12Z	5/21 00Z	5/21 12Z	5/22 00Z	5/22 12Z	5/23 00Z	5/23 12Z	5/24 00Z
inversion base height in mb	942	953	968	950	981	963	981	956	966	953	934	933
inversion base height in meters	614	537	407	560	270	416	261	483	381	517	672	699
inversion base height in feet	2015	1761	1335	1837	886	1365	856	1585	1251	1696	2204	2293
inversion base temperature in degrees C	10.2	16.6	12.8	21.4	13.8	20.2	13.0	17.0	13.2	15.8	11.8	12.4
inversion top height in mb	850	925	925	925	925	902	814	911	896	879	837	850
inversion top height in meters	1486	793	794	791	776	990	872	906	1039	1221	1621	1504
inversion top height in feet	4876	2602	2605	2595	2546	3248	2861	2973	3409	4006	5319	4630
inversion top temperature in degrees C	16.4	21.4	21.0	24.8	24.4	26.0	26.8	29.0	29.6	27.6	24.8	23.6
inversion strength in degrees C	6.2	4.8	7.2	3.4	10.6	5.8	13.8	12.0	16.4	11.8	13.0	11.2
Temperature at 850 mb in degrees C	16.4	17.6	18.0	19.4	20.2	22.0	23.2	24.6	26.0	25.8	22.0	23.6
1000-500 mb thickness in decameters	563	569	569	572	570	574	573	575	576	576	573	573

Site (elev)	THU 18th	FRI 19th	SAT 20th	SUN 21st	MON 22nd	TUE 23rd
KSAN (15)	70	72	70	68	65	65 (trace)
KFUL (96)	81	85	83	81	74	70
BUO (2600)	90	94	101	106	105	88
BBL (6760)	66	70	74	missing	82	missing
KTRM (-117)	101	104	111	114	110	105

Table. B3. Example of a cycle in the marine layer depth (inversion lowering from near 2000 feet to below 1000 feet then back up above 2000 feet) and the effect on selected locations. All heights are in feet MSL. Temperatures in upper portion of table in degrees C. Corresponding maximum temperatures for 18 May 2000 through 23 May 2000 are shown in the lower portion of the table in degrees F. Sites are coastal, inland coastal, valley, mountain, and desert respectively. Station elevations are in feet MSL. Deepening of the marine layer to near 2500 feet deep resulted in widespread cooling, with even a trace of drizzle. As the inversion lowered and strengthened on the 21st, afternoon highs were lower near the coast in response to the persistent cloud cover, but actually went up valleys, mountains, and deserts. The rise was in response to rising temperatures aloft, increasing thicknesses, and very high inversion top temperatures lowering enough to effect the inland areas, but not warm the coastal areas. On 22 June 2000 as the cooling spread inland, SAN fell only 3 deg F, since it was already rather cool. The thickness remained high, so Beaumont (BUO) only fell 1 deg F. At the same time, KFUL dropped 7 deg F on the inland coastal plain area, reflecting the maximum cooling band spreading inland. As this thermal transition zone passes Beaumont on the 23rd the 24 hour change was whopping 17 degrees F.

SHALLOW CONVECTION EVENT

(deep moist layer with isothermal layer aloft).

At 1200 UTC 30 April 2003 the sounding shows a nearly saturated layer below 3200 feet, but the inversion is much weaker than the approximately 7 degrees C usually needed to cap a solid overnight deck (in this case, it is nearly isothermal above the moist layer).

At 1430 UTC there is a very weak eddy shown by the southerly wind at the surface on the raob and the outer coastal convergence zone just off the Orange County coast, stretching south to northern Baja. Skies are clear over the coastal plain.

Since the marine layer moisture extends inland under the 3000 foot inversion, and it was clear at 1600 UTC west of the moisture boundary, some boundary layer convection was possible.

At 1900 UTC the clear skies in the coastal plain begins to convect, with the more stable sea breeze air moving inland behind the sea breeze front.

By 2300 UTC the coastal plain has stabilized, but now the afternoon convection along the mountain slopes has developed, since the cloudiness can distribute into an isothermal layer or weak inversion layer above the moist low levels. (Moist layers capped by an isothermal layer can produce locally heavy afternoon showers, especially around the mountains, for moist layers around 6000 feet deep or deeper). This differs from strong, low inversion patterns (which cap cloud tops to only a few hundred feet into the inversion layer).

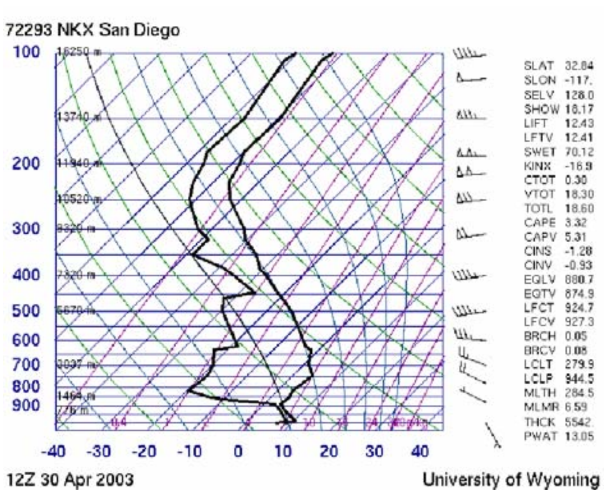


Fig. B8. KNKX Sounding data.

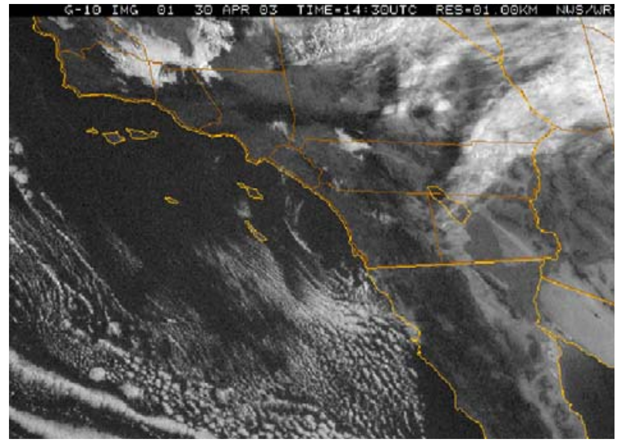


Fig. B9. 1430 UTC 30 April 2003 visible satellite imagery

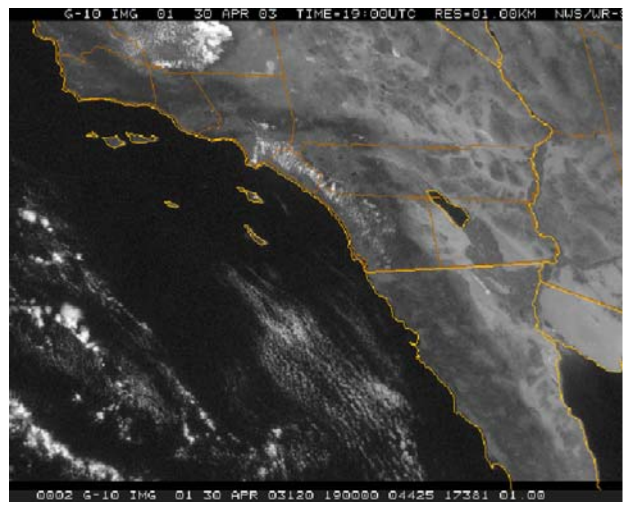


Fig. B10. 1900 UTC 30 April 2003 visible satellite imagery

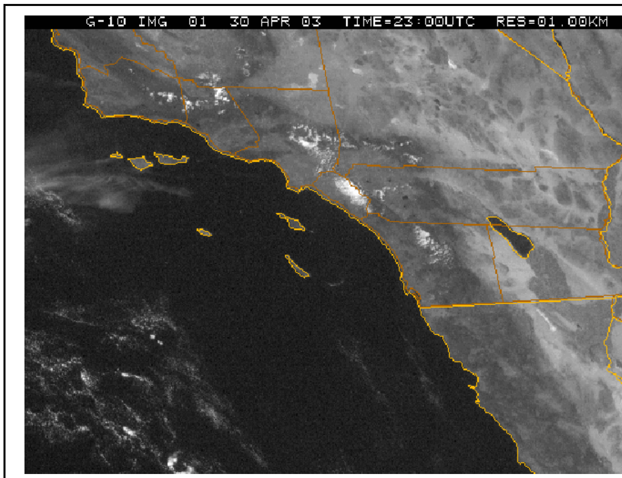


Fig. B11. 2300 UTC 30 April 2003 visible satellite imagery

DENSE FOG (Chain reaction accident in the Cajon Pass on 26 January 2001)

Although they do not always occur under these conditions, this scenario is a common one. Surface pressures were falling to the north and to the interior as a surface low approached the Pacific Northwest. Aloft, an upper level low pressure system was bearing down on the state with increasing cyclonic flow, hence a rapidly deepening surface based moist layer which moves into the coastal slopes. The moist layer deepened well into the Cajon Pass, possibly also wetting the road. This dense fog layer could have been rather deep.

Dense fog in the Cajon Pass along Interstate 15 near Devore (DEV) led to 78 vehicle accidents, one of which included a 26 car pileup that sent 9 people to hospitals with minor to moderate injuries. (KNKX soundings on next page).

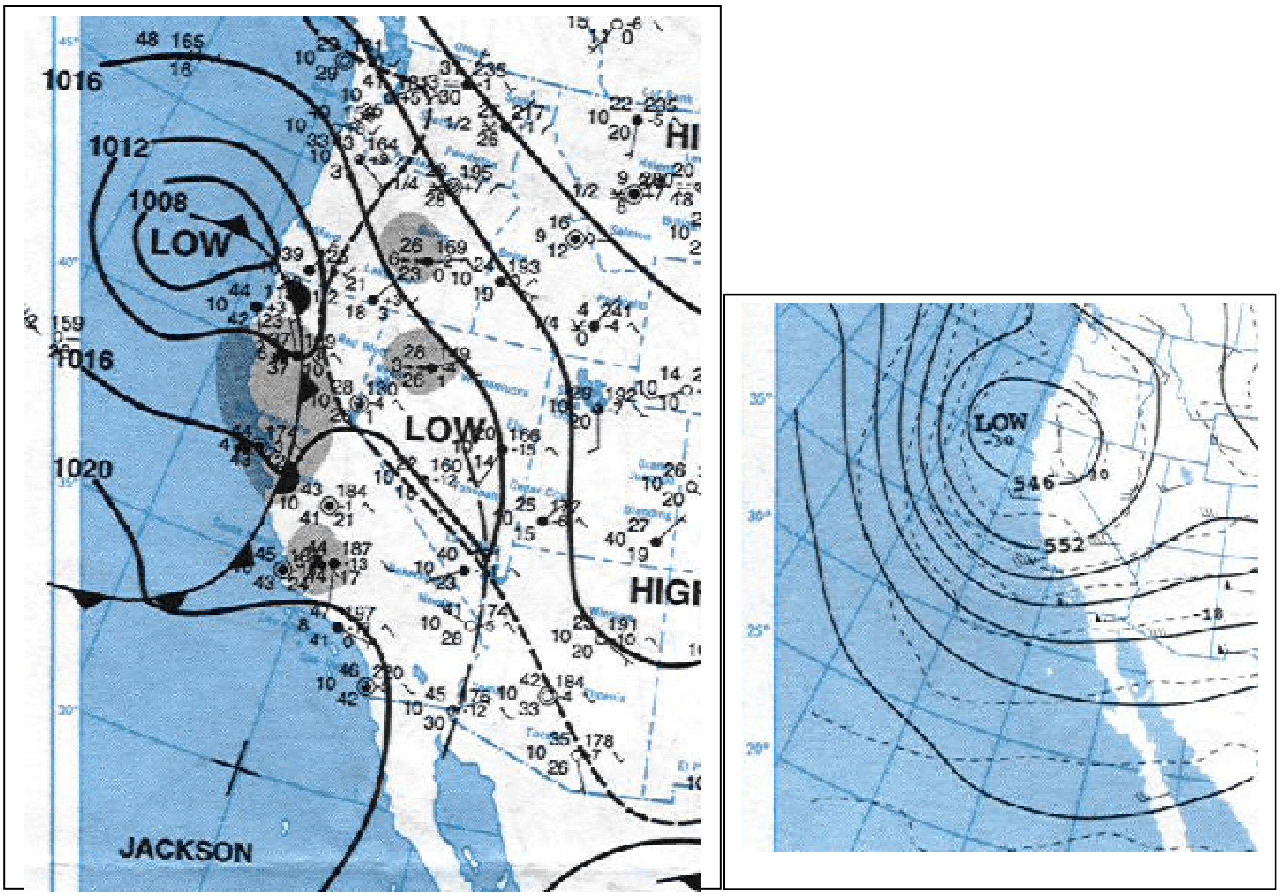
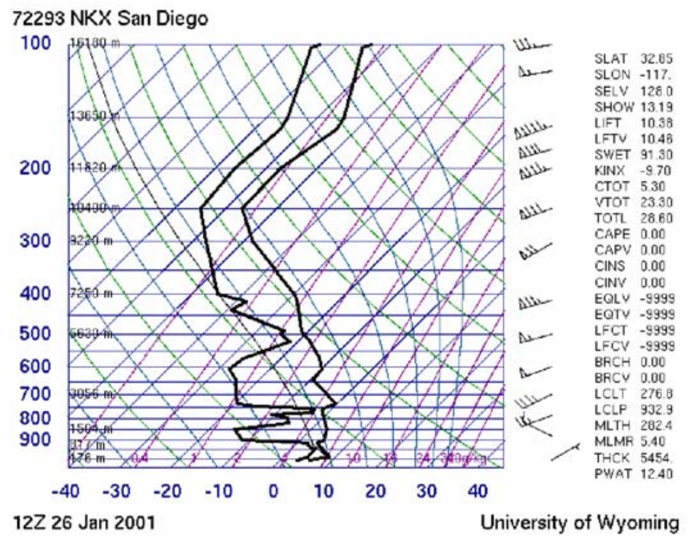


Fig. B12. 1200 UTC 26 January 2001 surface analysis (mb) and 500 mb heights (decameters), temperatures (deg C), and winds (knots).



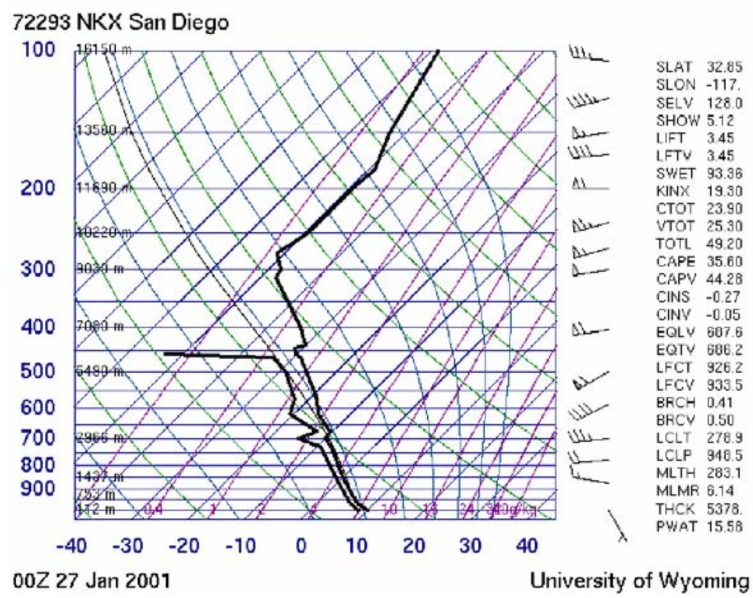


Fig. B13. KNKX sounding data.

DENSE FOG (Chain reaction accident in the Cajon Pass on 1 April 2004)

The scenario was a fairly common one. Surface pressures were falling to the north and to the interior as a surface low approached the Pacific Northwest. Aloft, an upper level low pressure system was bearing down on the state with increasingly cyclonic flow, hence a rapidly deepening marine layer. There was light rain reported. The marine layer deepened well into the Cajon Pass with dense fog (with precipitation wetting the road to make the problem even worse). Notice the low level inverted "V" sounding, with the actual fog layer rather thin (in this case) and just beneath the inversion. (KNKX soundings on next page).

Dense fog in the Cajon Pass along Interstate 15 led to 66 vehicles in a chain reaction accident.

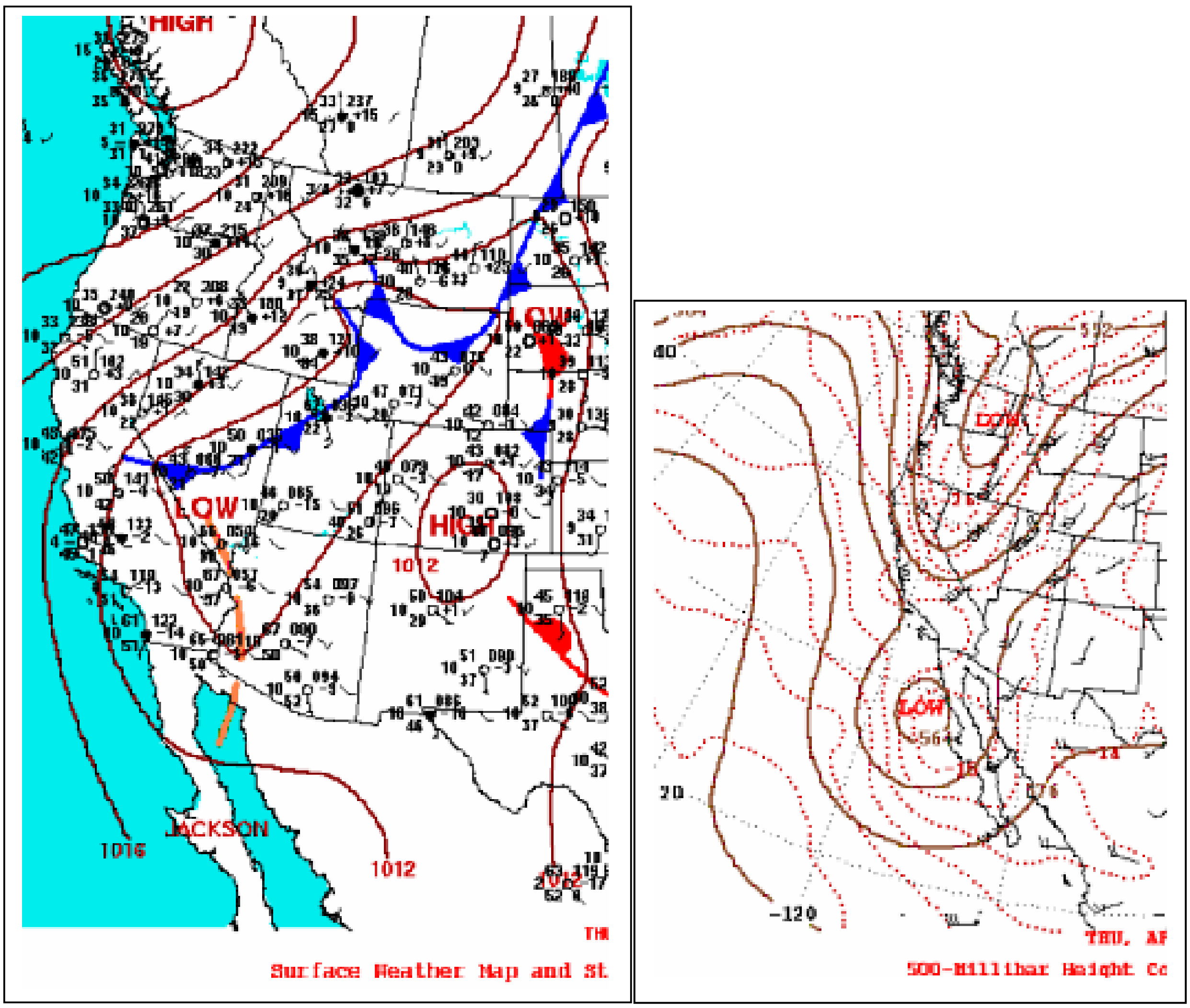


Fig. B14. 1200 UTC 1 April 2004 surface analysis (mb) and 500 mb heights (decameters), temperatures (degrees), and winds (knots).

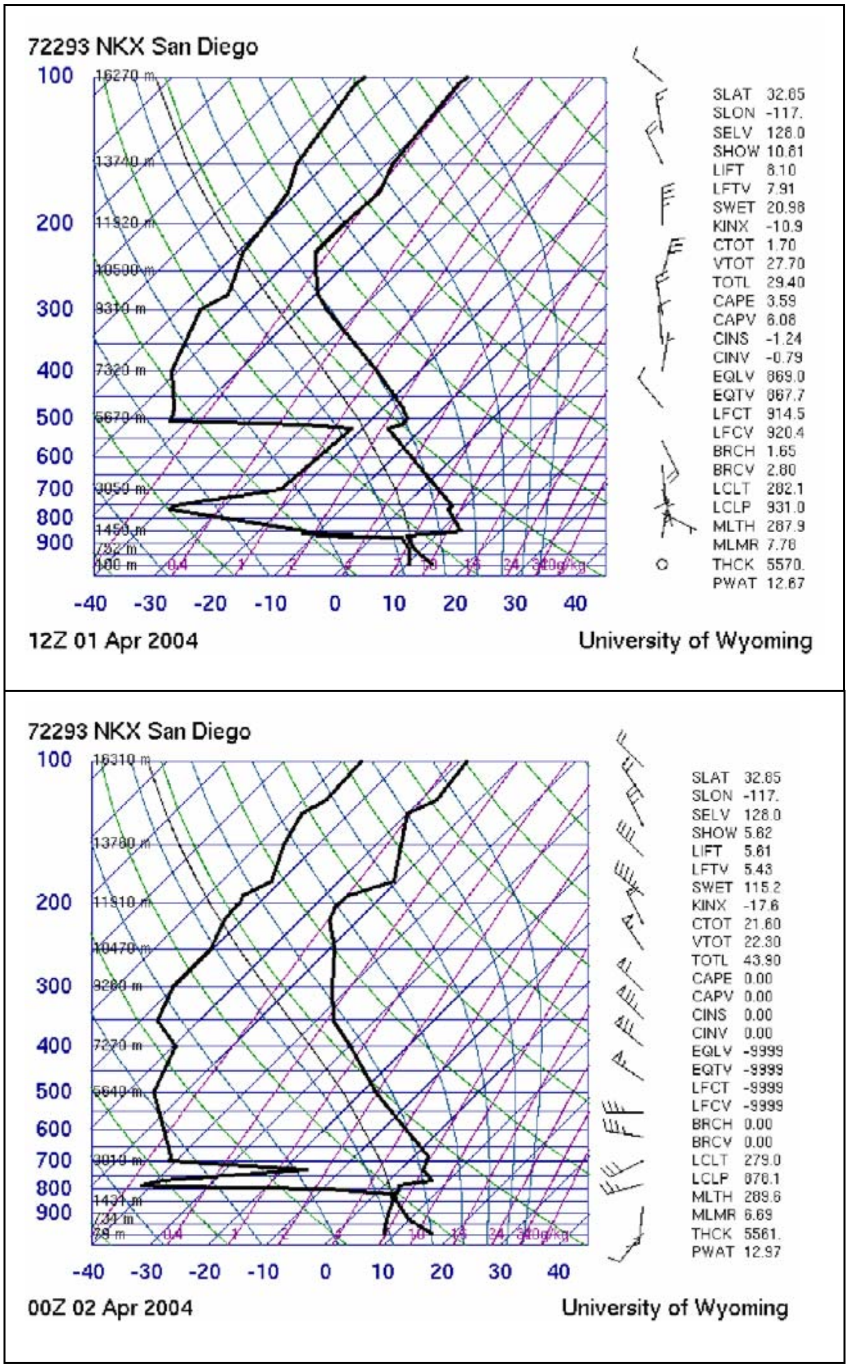


Fig. B15. KNKX Sounding data

APPENDIX C. HEAT WAVE CASES

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Type 1. High to The North Event (mesoscale subsidence via strong offshore/downslope winds) (All time record 111 F at San Diego)

On 26 September 1963 relatively strong high pressure developed aloft, and combined with very strong surface high pressure at the lower levels, they produced very high temperatures. The 500 mb high initially developed over San Diego due to a building ridge in response to a developing low further offshore. At the peak of the heat wave on the 26th, a "high pressure to the north" pattern (rather than a high directly overhead) with offshore flow combined with 850 mb temperatures to near 26 C in the basin. The conditions resulted in the highest temperature in history at the official San Diego observing site (111 degrees F). Gusty winds that reach all the way to the coast basically guarantees record breaking heat during the warm season. Winds gusted to 18 miles per hour all the way to the coast in this case. The downward motion was mainly due to mesoscale subsidence associated with mountain wave activity. Note that the record was set in what is technically considered to be the "fall" season rather than summer.

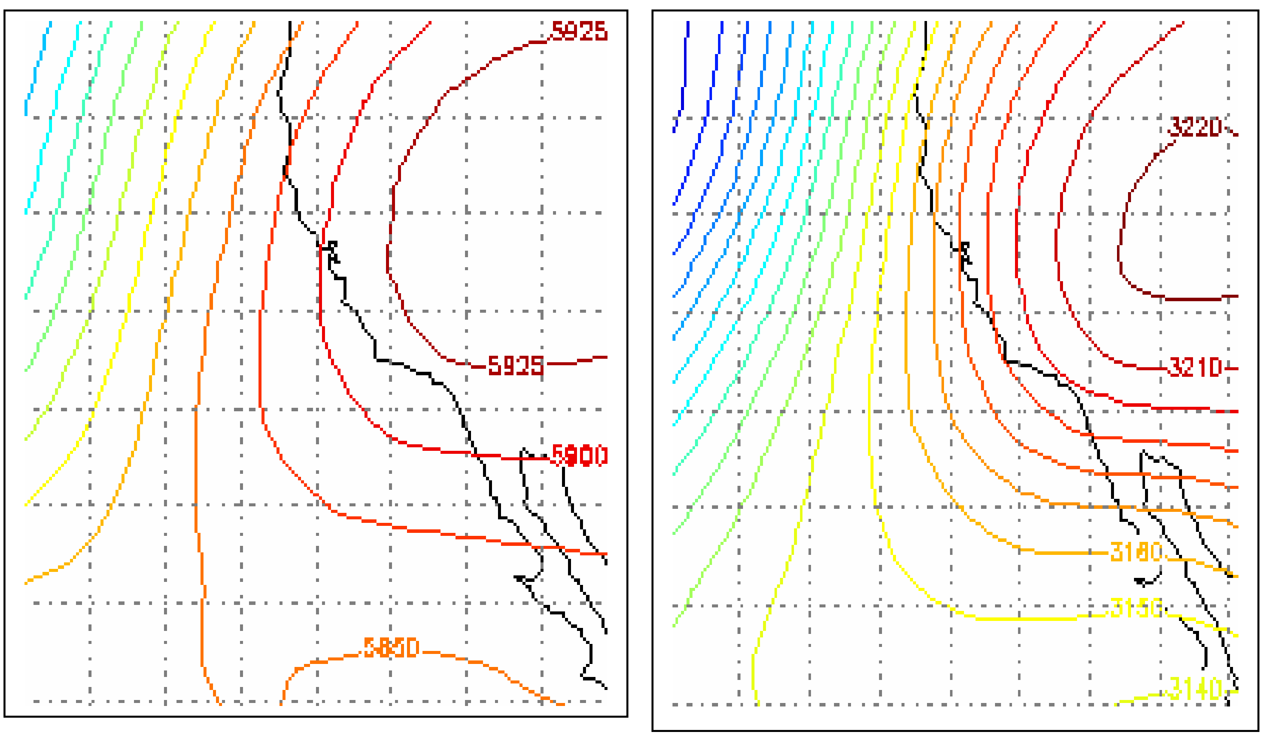


Fig. C1. 26 September 1963 reanalysis 500 mb heights (decameters) and 700 mb heights (decameters).

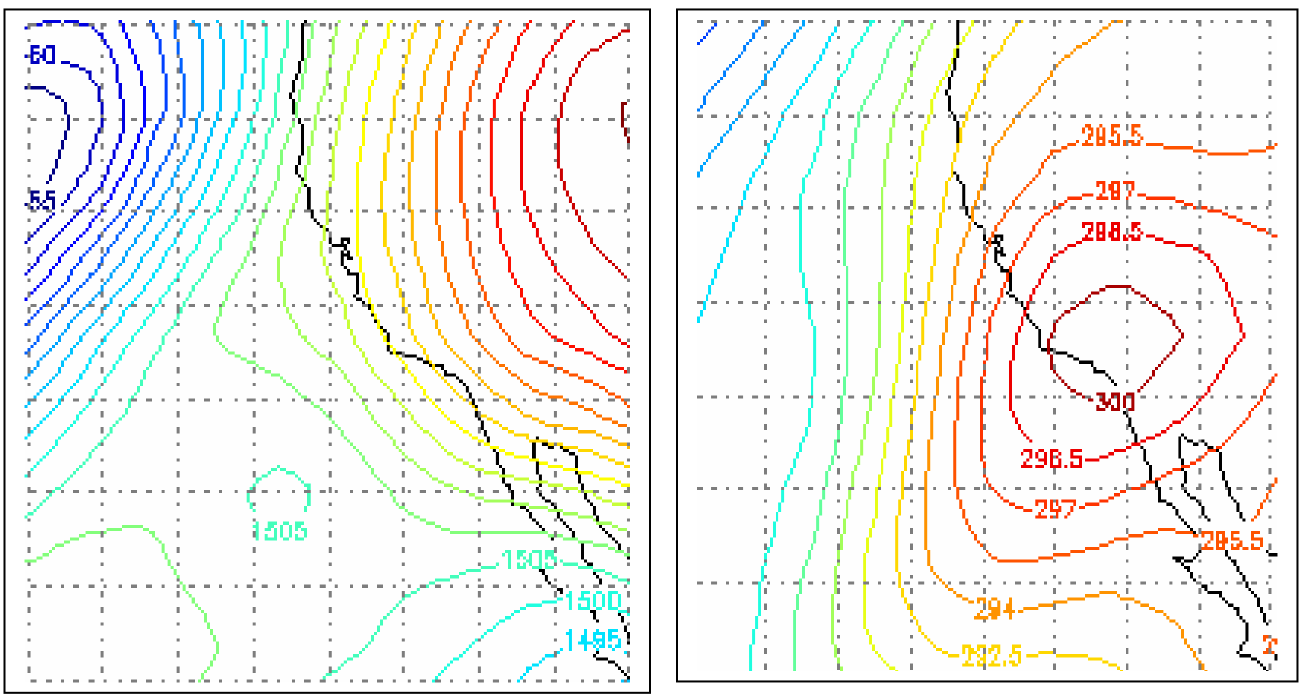


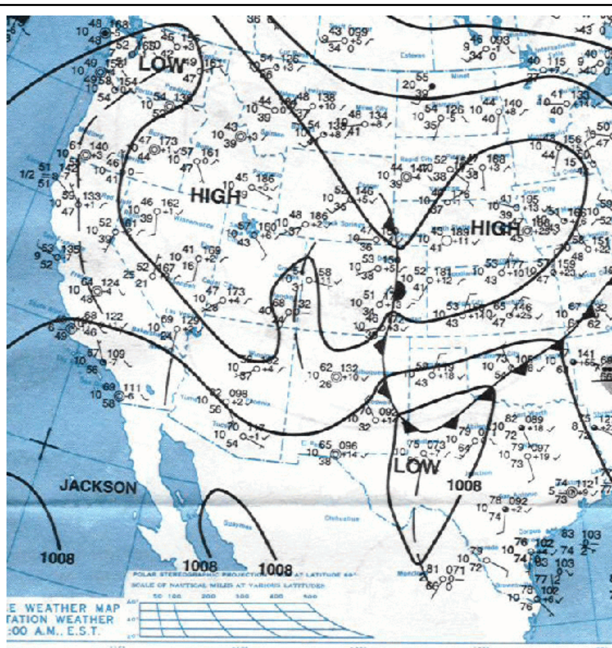
Fig. C2. 26 September 1963 reanalysis 850 mb heights (decameters) and 850 mb temperatures (degrees K). The 850 mb temperature at KNKX is 26 deg C (79 deg F).

Type 2. High Overhead Event (Subsidence Driven Heating) on 12 September 2000

On 12 September 2000 very hot conditions developed as far west as the coastal plain. Lindbergh Field hit 88, and some coastal temperatures were over 100. There was a large high centered over southern California. The KLAX-KLAS surface pressure gradient was offshore (-2.0), well under the "weak category optimal" upper bound of +3.0 mb onshore, and KLAX-KTPH was nearly -6.0 mb offshore, allowing the warmup to occur all the way to the coast. The 850 mb/Top of the inversion temperature couplet was well above normal at 25 C/29 C. The winds aloft during the morning in the 850 to 700 mb layer were east at about 10 knots. Combined with the low inversion, this scenario usually (and did) result in a rapid warmup coastal and valley areas. The strong offshore gradients brought the 850 mb potential temperature of near 103 into the valleys and nearly so into the inland coastal plain. West of the mountains, minimum temperatures were generally in the 60s, even thought there was a rather high temperature at the top of the inversion. This may be because the early morning east winds were generally confined to the foothills (which saw some 70s) in the morning, and the since the 850 mb dew points were only about 5 C. Surface dew points were only in the lower 50s. Some high temperatures were Newport Beach 74, Oceanside Harbor 75, Lindbergh Field 88, Anaheim 98, Ontario 105, Riverside 110, Big Bear Lake 82, Hesperia 107, and Thermal 111. (KNKX sounding data on the next page).

SURFACE PRESSURE GRADIENT (1200 UTC)	DATE: 11 SEP 2000	DATE: 12 SEP 2000
LAX-SFO	-1.6	-2.6
LAX-WMC	-3.3	-5.3
LAX-TPH	-2.6	-5.9
LAX-LAS	1.0	-2.0
SAN-YUM	M	M

Table C1. Surface pressure gradient data



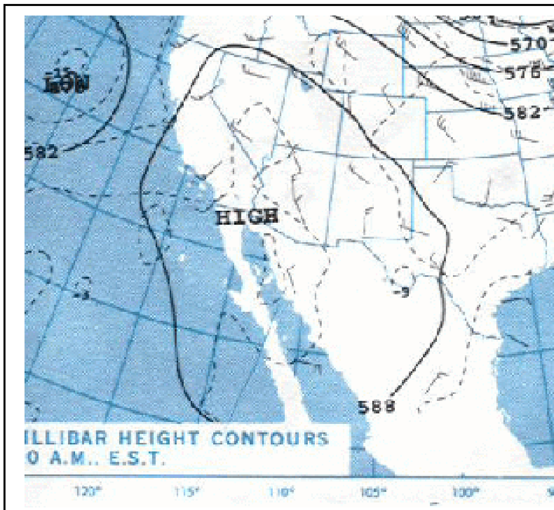
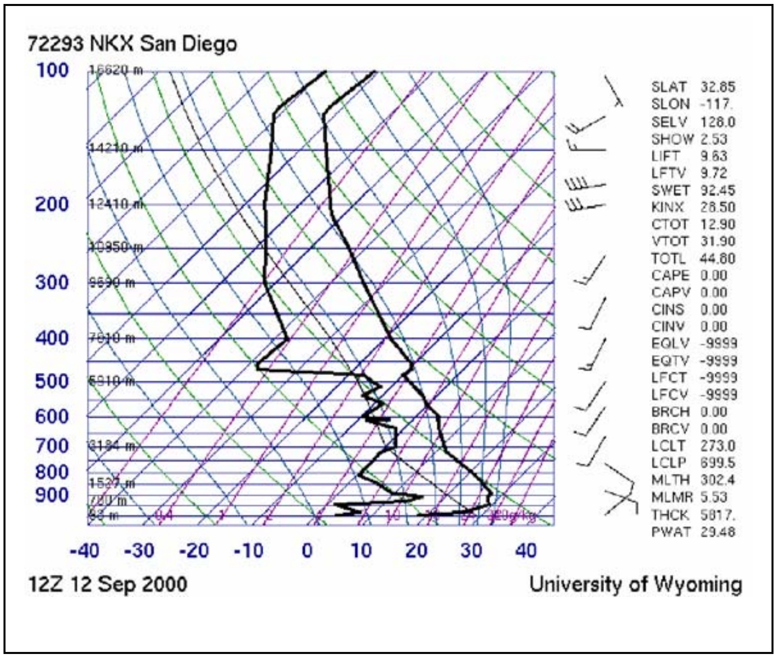


Figure C3. 1200 UTC 12 September 2000 500 mb heights in decameters, temperatures in degrees C, and winds in knots (left), along with station plots and mean sea level pressure in mb (right).



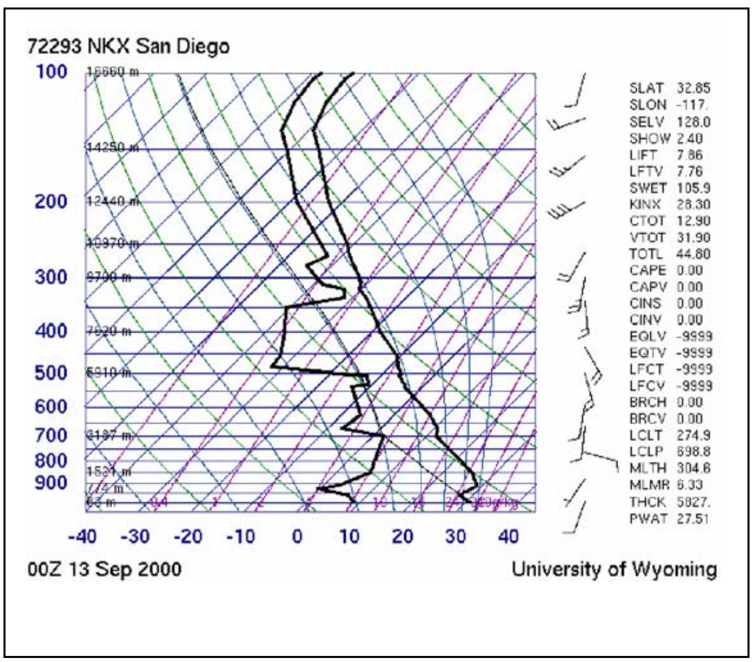


Fig. C2. KNKX sounding data.

SURFACE PRESSURE GRADIENT (1200 UTC)	DATE: 11 SEP 2000	DATE: 12 SEP 2000
LAX-SFO	-1.6	-2.6
LAX-WMC	-3.3	-5.3
LAX-TPH	-2.6	-5.9
LAX-LAS	1.0	-2.0
SAN-YUM	M	M

Table C1. Surface pressure gradient data

```
ASUS66 KSGX 130028 AMD
RTPSGX
:SOUTHWESTERN CALIFORNIA TEMPERATURE AND PRECIPITATION
SUMMARY
:NATIONAL WEATHER SERVICE SAN DIEGO CA
:530 PM PDT TUE SEP 12 2000
:
:***** UPDATED *****
:
:TODAYS HIGH AND OVERNIGHT LOW TEMPERATURES AS OF 5 PM
TODAY.
:   * DENOTES 24 HOUR HIGH TEMPERATURES AS OF 4 PM
YESTERDAY.
:     OCCASIONALLY THE HIGH TEMPERATURE MAY HAVE OCCURRED
AFTER
:     4 PM THE PREVIOUS DAY.
:
:PRECIPITATION FOR THE PAST 24 HOURS.   M DENOTES MISSING.
:   T DENOTES TRACE OF PRECIPITATION
:
.B SAN  0912 P DH16/TX/TN/PPD/SD
:
: ID :      STATION           ELEV : HIGH / LOW /  PCPN /
SNODEP
:                           FEET
INCHES
:
:        ...COASTAL AREAS...
:
FUL  :      FULLERTON AIRPORT   96 :   96 /  63 /  0.00 /
ANAC1:    * ANAHEIM            335 :   98 /  64 /  0.00 /
STAC1:    * SANTA ANA          135 :   94 /  67 /  0.00 /
SNA  :      JOHN WAYNE AIRPORT  55 :   89 /  65 /  0.00 /
3L3  :    * NEWPORT BEACH       10 :   74 /  62 /  0.00 /
:XX1 :    * S JUAN CAPISTRANO  730 :   89 /  58 /  0.00 /
L34  :    * OCEANSIDE HARBOR    10 :   75 /  60 /  0.00 /
OKB  :      OCEANSIDE AIRPORT   28 :   87 /  55 /  0.00 /
VSTC1:    * VISTA              330 :  101 /  66 /  0.00 /
CRQ  :      CARLSBAD AIRPORT   328 :   87 /  64 /  0.00 /
DMRC1:    * DEL MAR            100 :   92 /  74 /  0.00 /
NKX  :      MIRAMAR            477 :   94 /  64 /  0.00 /
MYF  :      MONTGOMERY FIELD   420 :   93 /  67 /  0.00 /
SWDC1:      SEA WORLD SAN DIEGO 10 :   79 /  64 /  0.00 /
SAN  :      SAN DIEGO           15 :   88 /  69 /  0.00 /
CDOC1:    * CORONADO            25 :   85 /  67 /  0.00 /
L13  :    * CABRILLO NATL MNMT 364 :   83 /  64 /  0.00 /
NATC1:    * NATIONAL CITY       30 :    M /   M /     M /
CVAC1:    * CHULA VISTA         56 :   89 /  65 /  0.00 /
IPLC1:    * IMPERIAL BEACH      22 :   81 /  62 /  0.00 /
SDM  :      BROWN FIELD        525 :   96 /  67 /  0.00 /
:
:        ...INLAND AREAS...
:
ONT  :      ONTARIO            943 :  105 /  66 /  0.00 /
SBOC1:    * SAN BERNARDINO    1125 :  105 /  64 /  0.00 /
UCR  :      RIVERSIDE          986 :  110 /  62 /  0.00 /
BUO  :      BEAUMONT          2600 :  105 /  59 /  0.00 /
EORC1:    * ELSINORE          1285 :  105 /  61 /  0.00 /
HEMC1:    * HEMET             1655 :    M /   M /     M /
TEMC1:    * TEMECULA          1020 :    M /   M /     M /
FALC1:    * FALLBROOK          698 :   99 /  68 /  0.00 /
ESCC1:    * ESCONDIDO          600 :    M /   M /     M /
ASCC1:    * WILD ANIMAL PARK   420 :  104 /   M /  0.00 /
RNM  :      RAMONA            1393 :  102 /  61 /  0.00 /
SGX  :      RANCHO BERNARDO    690 :   95 /  64 /  0.00 /
POWC1:    * POWAY              648 :    M /   M /     M /
ALPC1:    * ALPINE            1735 :   96 /  73 /  0.00 /
SNTC1:    * SANTEE             340 :    M /   M /     M /
ELJC1:    * EL CAJON           405 :  102 /  56 /  0.00 /
LMAC1:    * LA MESA            530 :   94 /  70 /  0.00 /
SPVC1:    * SPRING VALLEY      270 :    M /   M /     M /
LMGC1:    * LEMON GROVE        427 :   94 /  64 /  0.00 /
```

```
:
:        ...MOUNTAIN AREAS...
:
WRIC1:    * WRIGHTWOOD        5980 :   83 /  47 /  0.00 /
:RUN :      RUNNING SPRINGS   6080 :   92 /  63 /  0.00 /
BBLC1:    * BIG BEAR LAKE     6790 :   82 /  42 /  0.00 /
IDYC1:    * IDYLLWILD         5380 :   91 /  49 /  0.00 /
PLRC1:    * PALOMAR MOUNTAIN  5550 :    M /   M /     M /
JUL  :      JULIAN            4240 :   93 /  64 /  0.00 /
CUYC1:    * CUYAMACA PARK     4870 :   89 /  58 /  0.00 /
MTLC1:    * MT. LAGUNA        5760 :   85 /  57 /  0.00 /
CZZ  :      CAMPO             2615 :   98 /  56 /  0.00 /
:
:        ...DESERT AREAS...
:
HESC1:    * HESPERIA          3055 :  107 /  72 /  0.00 /
PSP  :      PALM SPRINGS       425 :  108 /  79 /  0.00 /
IDOC1:    * INDIO              -21 :  108 /  76 /  0.00 /
TRM  :      THERMAL           -117 :  111 /  65 /  0.00 /
BROC1:      BORREGO            805 :  106 /  76 /  0.00 /
TYEC1:    * TWENTYNINE PALMS  1975 :  101 /  62 /  0.00 /
:
.END
```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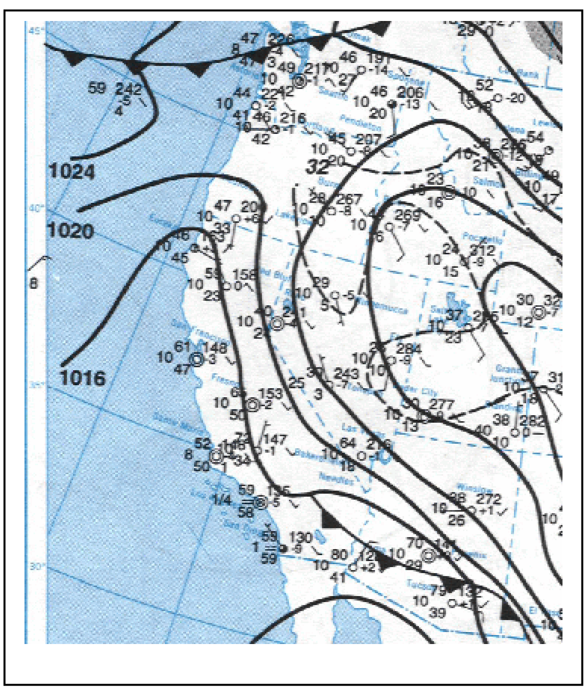
Type 3. North-South Oriented Ridge Event (Subsidence and Wind Driven)

The 29 September 1998 event is an example of an offshore flow event during a warm season month. It is characterized by the 500 mb ridge axis and upper level high center analyzed very close to the California coast. There is a gradient to the Great Basin plateau (COAST to KTPH) in excess of 10 mb offshore. The 1200 UTC 29 September 1999 KNKX sounding shows very little upper level support (only a weak east wind at 850 mb). However, there is significant low level flow to help clear the extremely shallow surface based inversion via mixing and airmass replacement associated with the easterly flow by midday. The cold air advection from the Great Basin into the deserts results in a “reverse heating” pattern, where the high temperatures are higher west of the mountains (up to 108) than they are in the deserts (up to 102). This anomalous situation produces higher minimum temperatures west of the mountains than east of the mountains (78 verses 77). The cold advection in the mountains results in highest maximum and highest minimum temperatures much lower than their valley counterparts (more typical of a cool season pattern). A placement of the upper level high further westward may have resulted in stronger winds since more upper level northeast flow can develop. (KNKX sounding data on the next page).

SURFACE PRESSURE GRADIENT (1200 UTC)	DATE: 29 Sep 1999
LAX-SFO	-1.3
LAX-WMC	Missing
LAX-TPH	-10.8
LAX-LAS	-8.1
SAN-YUM	0.8

Table C2. Surface pressure gradient data



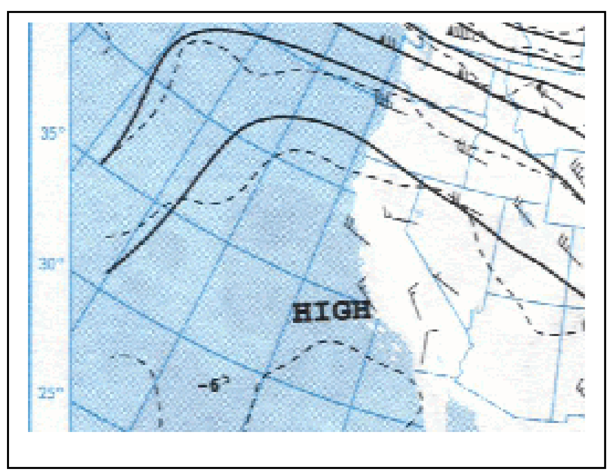
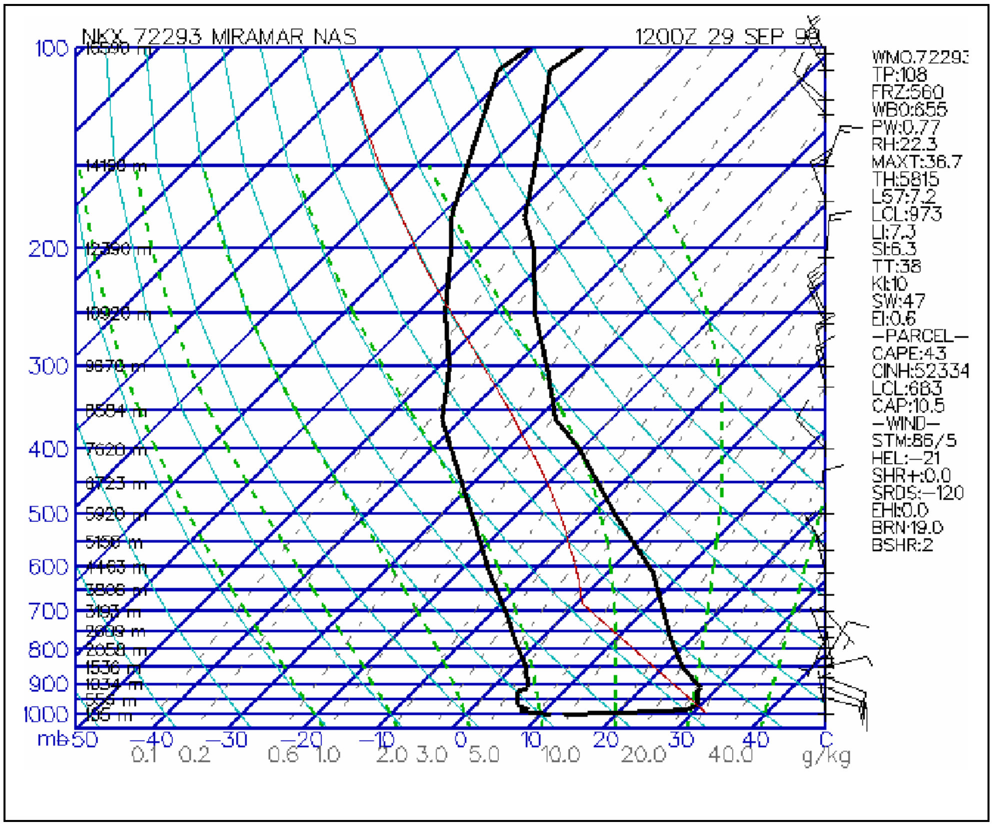


Figure C5. 1200 UTC 29 September 1999 500 mb heights in decameters, temperatures in degrees C, and winds in knots (left), along with station plots and mean sea level pressure in mb (right).



0000 UTC 30 September 1999 KNKX sounding not available

Fig. C6. KNKX sounding data.

SURFACE PRESSURE GRADIENT (1200 UTC)	DATE: 29 Sep 1999
LAX-SFO	-1.3
LAX-WMC	Missing
LAX-TPH	-10.8
LAX-LAS	-8.1
SAN-YUM	0.8

Table C2. Surface pressure gradient data

```
National Weather Service - San Diego, California
ZCZC LAXRTPSGX
TTAA00 KSGX 300022 AMD
:SOUTHWESTERN CALIFORNIA TEMPERATURE AND PRECIPITATION
SUMMARY
:NATIONAL WEATHER SERVICE SAN DIEGO CA
:530 PM PDT WED SEP 29 1999
:
:***** UPDATED *****
:
: TODAYS HIGH AND OVERNIGHT LOW TEMPERATURES AS OF 0.00
TODAY.
:   * DENOTES 24 HOUR HIGH TEMPERATURES AS OF 4 PM
YESTERDAY.
:     OCCASIONALLY THE HIGH TEMPERATURE MAY HAVE OCCURRED
AFTER
:     4 PM THE PREVIOUS DAY.
:
:PRECIPITATION FOR THE PAST 24 HOURS.   M DENOTES MISSING.
:   T DENOTES TRACE OF PRECIPITATION
:
.B SAN  0929 P DH16/TX/TN/PPD/SD
:
: ID :      STATION           ELEV : HIGH / LOW /  PCPN /
SNODEP
:                             FEET
INCHES
:
:        ...COASTAL AREAS...
:
FUL  :      FULLERTON AIRPORT   96 :  104 /  59 /  0.00 /
ANAC1:    * ANAHEIM            335 :  105 /  59 /  0.00 /
STAC1:    * SANTA ANA          135 :   99 /  56 /  0.00 /
SNA  :      JOHN WAYNE AIRPORT  55 :   97 /  57 /  0.00 /
3L3  :    * NEWPORT BEACH       10 :   83 /  58 /  0.00 /
:    :    * S JUAN CAPISTRANO  730     89 /  55 /  0.00 /
L34  :    * OCEANSIDE HARBOR    10 :   73 /  54 /  0.00 /
OKB  :      OCEANSIDE AIRPORT   28 :   92 /  50 /  0.00 /
VSTC1:    * VISTA              330 :  105 /  56 /  0.00 /
CRQ  :      CARLSBAD AIRPORT   328 :   92 /  60 /  0.00 /
DMRC1:    * DEL MAR            100 :   85 /  52 /  0.00 /
NKX  :      MIRAMAR            477 :   97 /  54 /  0.00 /
MYF  :      MONTGOMERY FIELD   420 :   99 /  56 /  0.00 /
SWDC1:      SEA WORLD SAN DIEGO 10 :   81 /  50 /  0.00 /
SAN  :      SAN DIEGO           15 :   90 /  59 /  0.00 /
CDOC1:    * CORONADO            25 :   85 /  56 /  0.00 /
L13  :    * CABRILLO NATL MNMT 364 :   94 /  57 /  0.00 /
NATC1:    * NATIONAL CITY       30 :   95 /  53 /  0.00 /
CVAC1:    * CHULA VISTA         56 :   96 /  55 /  0.00 /
IPLC1:    * IMPERIAL BEACH      22 :    M /   M /     M /
SDM  :      BROWN FIELD        525 :   99 /  55 /  0.00 /

:        ...INLAND AREAS...
:
ONT  :      ONTARIO            943 :  102 /  62 /  0.00 /
SBOC1:    * SAN BERNARDINO    1125 :    M /   M /     M /
UCR  :      RIVERSIDE          986 :  103 /  61 /  0.00 /
BUO  :      BEAUMONT          2600 :   96 /  71 /  0.00 /
EORC1:    * ELSINORE          1285 :  102 /  63 /  0.00 /
HEMC1:    * HEMET             1655 :  105 /  57 /  0.00 /
TEMC1:    * TEMECULA          1020 :    M /   M /     M /
FALC1:    * FALLBROOK          698 :  103 /  78 /  0.00 /
ESCC1:    * ESCONDIDO          600 :  104 /  57 /  0.00 /
ASCC1:    * WILD ANIMAL PARK   420 :  108 /  56 /  0.00 /
RNM  :      RAMONA            1393 :  102 /  59 /  0.00 /
SGX  :      RANCHO BERNARDO    690 :   97 /  58 /  0.00 /
POWC1:    * POWAY              648 :  102 /  55 /  0.00 /
ALPC1:    * ALPINE            1735 :  101 /   M /  0.00 /
SNTC1:    * SANTEE             340 :  104 /  53 /  0.00 /
ELJC1:    * EL CAJON           405 :  105 /  55 /  0.00 /
LMAC1:    * LA MESA            530 :  101 /  62 /  0.00 /
SPVC1:    * SPRING VALLEY      270 :  104 /  54 /  0.00 /
LMGC1:    * LEMON GROVE        427 :   77 /  55 /  0.00 /
```

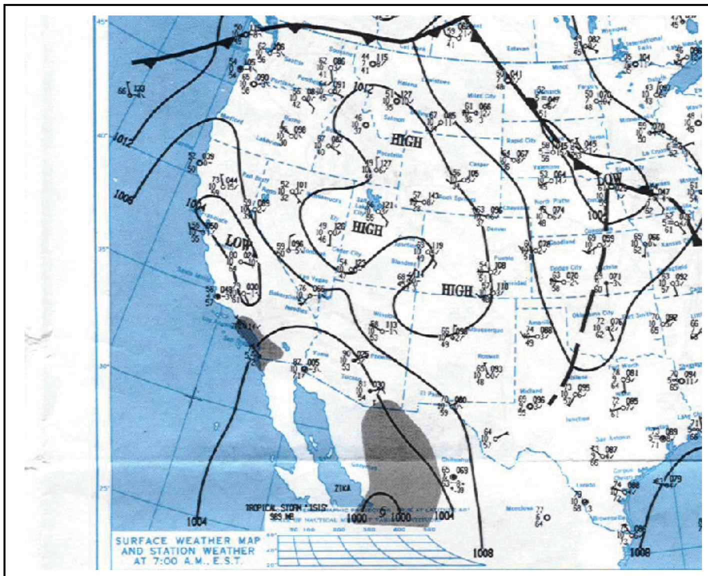
```
:        ...MOUNTAIN AREAS...
:
WRIC1:    * WRIGHTWOOD        5980 :   73 /  37 /  0.00 /
CTL  :      CRESTLINE         4650 :    M /   M /     M /
BBLC1:    * BIG BEAR LAKE     6790 :   74 /  37 /  0.00 /
IDYC1:    * IDYLLWILD         5380 :   86 /  48 /  0.00 /
PLRC1:    * PALOMAR MOUNTAIN  5550 :   83 /  63 /  0.00 /
JUL  :      JULIAN            4240 :   84 /  65 /  0.00 /
CUYC1:    * CUYAMACA PARK     4870 :   84 /  61 /  0.00 /
MTLC1:    * MT. LAGUNA        5760 :   76 /  60 /  0.00 /
CZZ  :      CAMPO             2615 :   88 /  61 /  0.00 /
:
:        ...DESERT AREAS...
:
:    :    * HESPERIA          3290     88 /  51 /  0.00 /
PSP  :      PALM SPRINGS       425 :  100 /  77 /  0.00 /
IDOC1:    * INDIO              -21 :  100 /   M /  0.00 /
TRM  :      THERMAL           -117 :   98 /  55 /  0.00 /
BROC1:      BORREGO            805 :  102 /  67 /  0.00 /
TYEC1:    * TWENTYNINE PALMS  1975 :   93 /  54 /  0.00 /
:
```

Type 4. “East-West Ridge Axis to The North” Event (Subsidence Driven)

On 3 September 1998 very hot conditions developed as far west as the coastal plain. Lindbergh Field (KSAN) hit 92, and some coastal temperatures were over 100. There was an east-west ridge axis to the north, common for very warm days. The KLAX-KLAS surface pressure gradient was well under the “weak category” upper bound of 3.0 mb onshore, reporting in at -2.2, and KLAX-KTPH was around -5.0 mb offshore, allowing the warmup to occur all the way to the coast. The 850 mb/Top of the inversion temperature couplet was about 24 C/30 C. The winds aloft during the morning at 850 and 700 mb were east at about 10 knots, good for warming the coastal and valley areas. Combined with the strong offshore gradients it brought the 850 mb potential temperature of near 101 into the valleys and inland coastal plain. Minimum temperature most areas were in the 70s, due to the very high temperatures at the top of the inversion, 850 mb dew points of around 10 C, and easterly winds below 700 mb. Some high temperatures were Newport Beach 92, Oceanside Harbor 92, Lindbergh Field 92, Santa Ana 101, Ontario 100, Wild Animal Park 102, Big Bear Lake 71, Hesperia 96, and Thermal 110. Large scale subsidence was the main factor driving the strong heating since winds were light. (KNKX soundings on next page).

SURFACE PRESSURE GRADIENT (1200 UTC)	DATE: 2 SEP 1998	DATE: 3 SEP 1998
LAX-SFO	-1.9	-0.6
LAX-WMC	-7.3	-5.6
LAX-TPH	-6.7	-5.2
LAX-LAS	-3.8	-2.2
SAN-YUM	3.4	3.5

Table C3. Surface pressure gradient data



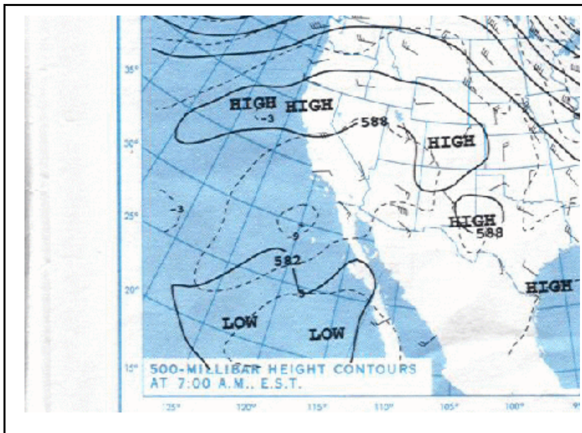
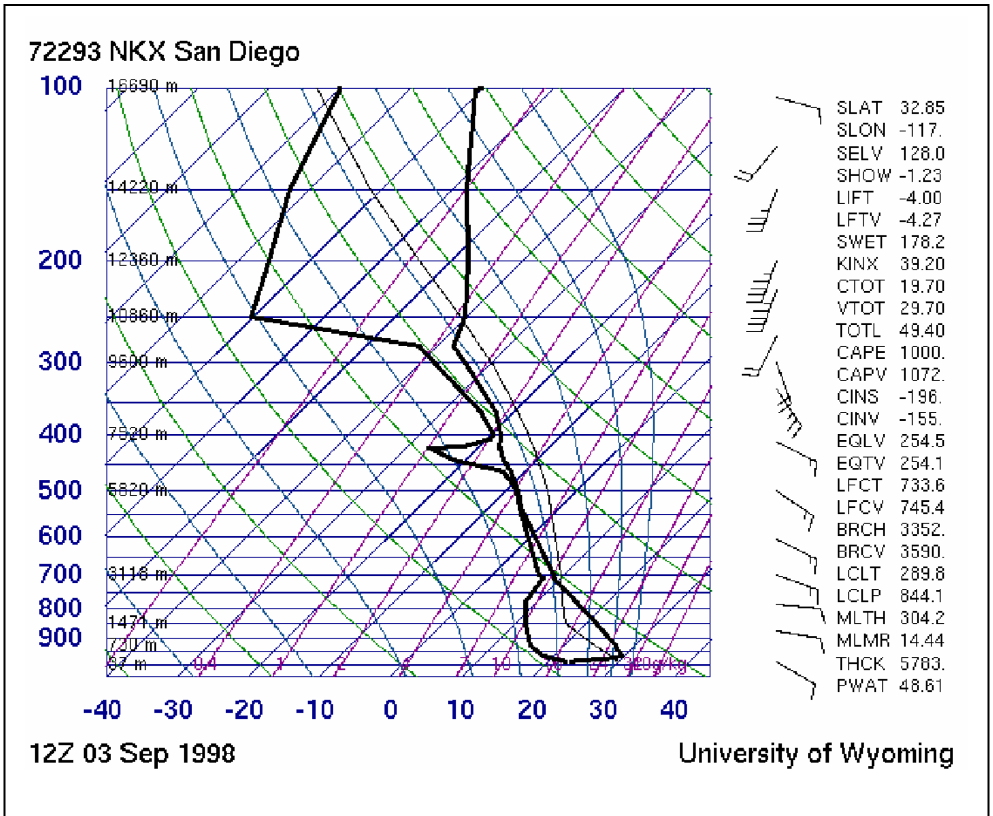


Figure C7. 1200 UTC 3 September 1998 500 mb heights in decameters, temperatures in degrees C, and winds in knots (left), along with station plots and mean sea level pressure in mb (right).



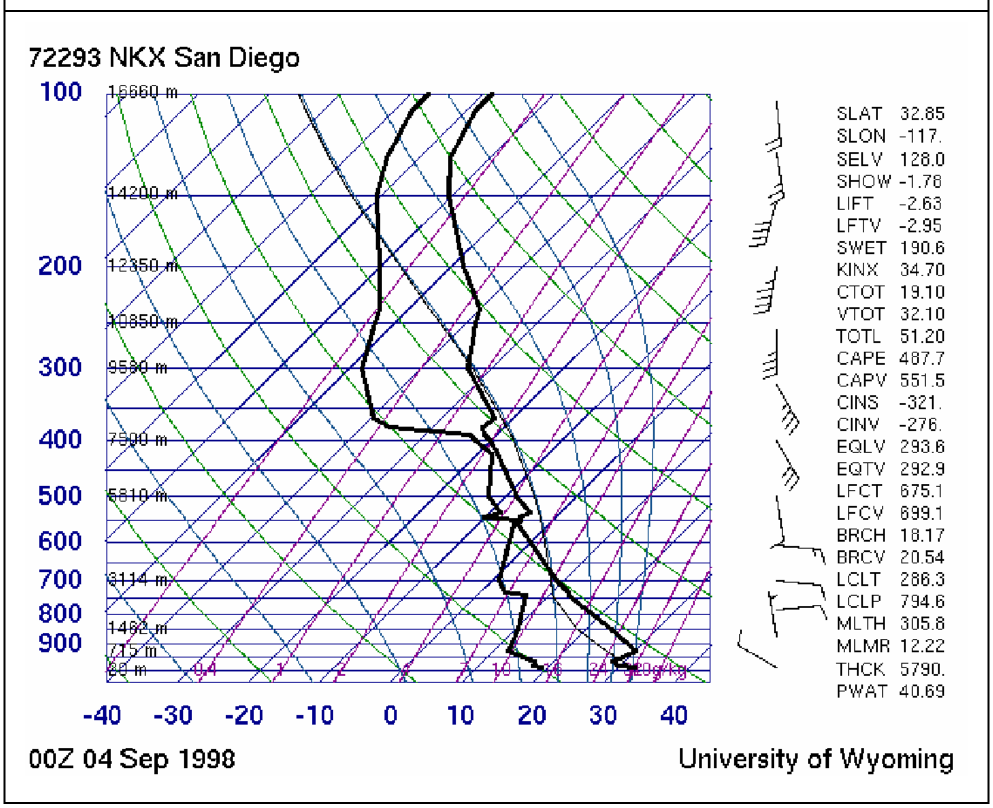


Fig. C8. KNKX sounding data. (Note that strong downslope warming can occur with clouds and limited sunshine).

SURFACE PRESSURE GRADIENT (1200 UTC)	DATE: 2 SEP 1998	DATE: 3 SEP 1998
LAX-SFO	-1.9	-0.6
LAX-WMC	-7.3	-5.6
LAX-TPH	-6.7	-5.2
LAX-LAS	-3.8	-2.2
SAN-YUM	3.4	3.5

Table C3. Surface pressure gradient data

```
ZCZC LAXSTPSAN
TTAA00 KSGX 040023 AMD
:SOUTHWESTERN CALIFORNIA TEMPERATURE AND PRECIPITATION SUMMARY
:NATIONAL WEATHER SERVICE SAN DIEGO CA
:530 PM PDT THU SEP 03 1998
:
:***** UPDATED *****
:
: TODAYS HIGH AND OVERNIGHT LOW TEMPERATURES AS OF 5 PM TODAY.
:   * DENOTES 24 HOUR HIGH AND LOW TEMPERATURES AS OF 4 PM TODAY.
:     OCCASIONALLY THE HIGH TEMPERATURE MAY HAVE OCCURRED AFTER
:     4 PM THE PREVIOUS DAY.
:
:PRECIPITATION FOR THE PAST 24 HOURS.   M DENOTES MISSING.
:   T DENOTES TRACE OF PRECIPITATION    + DENOTES NOT AVAILABLE
:
.B SAN  0903 P DH16/TX/TN/PPD/SD
:
: ID     STATION              ELEV    HIGH    LOW    PCPN /
SNODEP
:                             FEET
INCHES
:
:     ...COASTAL AREAS...
:
ANAC1: * ANAHEIM               335   :  99 /   75 /     0
STAC1: * SANTA ANA             135   : 101 /   72 /     0
NZJ  :   EL TORO               383   :  99 /   71 /  0.03
3L3  : * NEWPORT BEACH          10   :  92 /   78 /     0
:      * SAN JUAN CAPISTRANO   730      95 /   71 /  0.03
L34  : * OCEANSIDE HARBOR       10   :  92 /   70 /     0
VSTC1: * VISTA                 330   : 100 /   71 /  0.18
CRQ  :   CARLSBAD AIRPORT      328   :  95 /   73 /  0.01
DMRC1: * DEL MAR               100   :  90 /   72 /  0.21
NKX  :   MIRAMAR               477   :  95 /   73 /  0.09
MYF  :   MONTGOMERY FIELD      420   :  95 /   75 /  0.07
SAN  :   SAN DIEGO              15   :  92 /   72 /  0.03
CDOC1: * CORONADO               25   :  92 /   71 /  0.04
L13  : * CABRILLO NATL MNMT    364   :  92 /   70 /  0.03
NATC1: * NATIONAL CITY          50   :  96 /   71 /  0.05
CVAC1: * CHULA VISTA            75   :  93 /   72 /     0
IPLC1: * IMPERIAL BEACH         15   :  89 /   66 /  0.07
SDM  :   BROWN FIELD           525   :  96 /   69 /  0.07
:
:     ...INLAND AREAS...
:
ONT  :   ONTARIO               943   : 100 /   73 /     T
SBD  :   SAN BERNARDINO       1125   : 102 /   74 /     +
UCR  :   RIVERSIDE             986   : 101 /   74 /     0
BUO  :   BEAUMONT             2600   :  95 /   71 /     0
EORC1: * ELSINORE             1285   : 100 /   72 /     0
HEMC1: * HEMET                1655   :  92 /   70 /     0
TEMC1: * TEMECULA             1020   : 102 /   74 /  0.02
FALC1: * FALLBROOK             730   : 102 /   70 /  0.01
ESCC1: * ESCONDIDO             650   : 101 /   74 /  0.10
ASCC1: * WILD ANIMAL PARK      750   : 102 /   71 /     0
RNM  :   RAMONA               1140   :  98 /   73 /  0.01
SGX  :   RANCHO BERNARDO       690   :  94 /   71 /  0.05
POWC1: * POWAY                 525   :   M /    M /     M
ALPC1: * ALPINE               1860   :  95 /   71 /     0
SNTC1: * SANTEE                370   :   M /    M /     M
ELJC1: * EL CAJON              450   :  98 /   75 /  0.10
LMAC1: * LA MESA               540   :  97 /   74 /  0.50
SPVC1: * SPRING VALLEY         425   :  97 /   74 /  0.11
LMGC1: * LEMON GROVE           460   :  97 /   71 /     0
```

```
:
:     ...MOUNTAIN AREAS...
:
WRIC1: * WRIGHTWOOD           6200   :  76 /   53 /     0
CTL  :   CRESTLINE            4650   :  85 /   67 /     0
BBLC1: * BIG BEAR LAKE        6790   :  71 /   51 /  0.04
IDYC1: * IDYLLWILD            5380   :  85 /   62 /  0.03
FMNC1:   FREMONT CANYON       1781   : 102 /   70 /     0
PLRC1: * PALOMAR MOUNTAIN     5650   :  77 /   58 /  0.26
JUL  :   JULIAN               4130   :  87 /   66 /     0
CUYC1: * CUYAMACA PARK        4600   :  85 /   66 /  0.10
MTLC1: * MT. LAGUNA           6220   :  73 /   60 /  0.05
CZZ  :   CAMPO                2615   :  89 /   66 /  0.19
:
:     ...DESERT AREAS...
:
:      * HESPERIA             3290      96 /   66 /     0
:        YUCCA VALLEY         3260      93 /   69 /     0
PSP  :   PALM SPRINGS          425   : 105 /   87 /     T
IDOC1: * INDIO                 -21   : 107 /   87 /     0
TRM  :   THERMAL              -117   : 110 /   85 /     T
BROC1:   BORREGO               500   : 104 /   82 /  0.04
TYEC1: * TWENTYNINE PALMS     1975   : 100 /   77 /     0
:
.END
```