Weather Elements and Climatology for Prolonged Dense Fog Events at San Diego Lindbergh Field (KSAN)

Brandt Maxwell
NOAA/NWS, San Diego CA

Introduction

Dense fog occurs periodically along the southern California coast, especially at night. At near sea-level locations, such as San Diego Lindbergh Field (KSAN), dense fog is most frequent between October and February with visibilities of ¼ mile or less occurring approximately 2 nights per month for at least a portion of the night during that period, though dense fog can occur during any month of the year (Table 1). Low visibilities and ceilings associated with dense fog or very low stratus decks are the number one weather-related reason for delays, diversions and cancellations of flights at Lindbergh Field. Due to factors such as a short runway and the surrounding obstacles, such as buildings and terrain, KSAN has relatively high landing minimums for visibility and ceilings, 1 mile and 400 feet, respectively. The impacts on flights are greatest when low visibilities or ceilings persist at the airport for many hours.

Dense fog at Lindbergh Field (and other immediate coastal sites) occurs when the base of a temperature inversion (referred to here as the marine inversion) is near the surface, usually less than 800 feet above sea level, and normally the result of subsidence under high pressure aloft. The dense fog forms because very little mixing and very high relative humidity occur in the shallow marine layer, versus with a deeper marine layer (for example, the marine inversion would be 2000 feet above sea level), where there is enough mixing below the stratus layer to keep visibilities higher at KSAN, normally 4 miles or more. Dense fog usually occurs after a period of offshore flow, when the winds blow from land to sea (from northeast to southwest) due to surface pressures which are higher over land than over the sea. However, in this paper, specific (and relatively rare) cases of long-duration fog were analyzed, versus fog which lasts only a few hours. Emphasis is on elements which can be viewed or analyzed the day before an event, allowing forecasters to better predict long-lasting episodes of dense fog.

24 cases were analyzed for Lindbergh Field. 15 were cases where observed visibilities of ¼ mile or less persisted for 8 hours or more, with no reported break in the dense fog. 9 other cases had observed visibilities below one mile (the landing minimum) for 10.5 consecutive hours or more, even though the dense fog (¼ mile or less) lasted for less than 8 hours. All events had a majority of their hours of low visibility at night, and most events shared similar weather patterns and features which could be identified the day before. Dense fog can be very difficult to predict accurately. In two recent dense fog cases, 30-31 Dec 2008 where visibilities were below one mile for 10.7 hours (and ¼ mile or less for 6

hours) and 19-20 Nov 2006 where visibilities were below ¼ mile for 9.2 hours, no TAF for KSAN was issued that had visibilities below the critical minimum of one mile until the dense fog had arrived. In contrast, one TAF, in February 2009, predicted over 12 hours of dense fog for KSAN when only one of the seven conditions identified as favorable for long periods of dense fog at KSAN in this paper occurred.

Month	Average Number of Nights per Month with Minimum Visibility of ¼ Mile or Less	Average Number of Nights per Month with Minimum Visibility Less Than One Mile
January	1.6	2.2
February	1.6	2.4
March	0.8	1.4
April	0.5	0.9
May	0.3	0.7
June	0.4	0.9
July	0.3	0.9
August	0.3	0.8
September	1.3	2.0
October	2.5	3.6
November	2.1	2.8
December	2.4	3.1

Table 1: Average Number of Nights (Defined as a 24-Hour Period from Noon to Noon) Per Month with Low Visibilities (1973-2008)

Analysis

Surface METAR data, containing hourly and special observations, were analyzed for Lindbergh Field for a 36-year period from 1 Jan 1973 to 1 Apr 2009. During this period, there were 15 instances where visibilities were ¼ mile of less for 8 consecutive hours or more. There were 9 other instances where visibilities were less than one mile for 10.5 consecutive hours or more, but the duration of ¼ mile visibilities was less than 8 hours. In all of these 24 cases, upper air and surface data for various locations were analyzed, primarily for the day immediately preceding the dense fog. Tables 2 and 3 show each of the 24 events. The 24 cases had many factors (synoptic and mesoscale) in common with each other: upper-level ridging, above normal (and in most cases unseasonably high) surface temperatures in the inland valleys of Southern California (as well as between 850 and 925 mb), light low-level winds, a low-level (and usually strong) temperature inversion near the coast and higher surface pressures over southern Nevada than along the southern California coast, known locally as “offshore pressure gradients”, among others. In most cases, marine layer fog and stratus had occurred at KSAN the previous night. However, to study some of the differences in the flow aloft between the cases, all but one of the 24 cases were grouped into 3 subcategories, designated as Subcategories A, B and C (Table 4), in which composites for each were used to study the weather patterns. The other case (10-11 Oct 1988) had anomalies in its weather pattern (most notably an omega block at 500 mb) which prevented it from being included in any of the subcategories, yet it shared the most important factors (high pressure aloft, hot weather in the inland valleys and offshore pressure gradients).

Date	Number of Consecutive Hours of Visibilities of ¼ Mile or Less
20-21 Dec 1980	14.3
18-19 Jan 1986	10.7
09-10 Dec 1975	10.6
17-18 Feb 1977	9.9
16-17 Jan 1982	9.6
29-30 Sep 1980	9.4
06-07 Dec 1981	9.2
19-20 Nov 2006	9.1
18-19 Oct 1989	8.7
04-05 Feb 1995	8.5
13-14 Apr 1985	8.4
25-26 Nov 2000	8.4
09-10 Dec 1995	8.0
09-10 Oct 1996	8.0
12-13 Nov 1996	8.0

Table 2: Cases Where Visibilities Were ¼ Mile or Less for 8 or More Consecutive Hours

Date	Number of Consecutive Hours of Visibilities of Less Than One Mile
20-21 Dec 1980*	16.5
05-06 Feb 1980	14.0
04-05 Feb 1995*	13.0
18-19 Nov 1995	12.4
18-19 Oct 1989*	12.2
16-17 Jan 1982*	12.1
06-07 Nov 1991	11.3
27-28 Feb 1975	11.0
17-18 Feb 1977*	11.0
06-07 Dec 1981*	11.0
09-10 Oct 1996*	11.0
05-06 Dec 1981	10.9
18-19 Jan 1986*	10.7
30-31 Dec 2008	10.7
09-10 Dec 1975*	10.6
25-26 Dec 1978	10.6
10-11 Oct 1988	10.6
01-02 Oct 1980	10.5

* Cases (from Table 1) where visibilities were also ¼ mile or less for 8 or more consecutive hours.

Table 3: Cases Where Visibilities Were Less Than One Mile for 10.5 or More Consecutive Hours

Subcategory A:	Subcategory B:	Subcategory C:
9 Dec 1975	27 Feb 1975	5 Dec 1981
17 Feb 1977	25 Dec 1978	6 Dec 1981
29 Sep 1980	5 Feb 1980	18 Nov 1995
20 Dec 1980	1 Oct 1980	9 Oct 1996
13 Apr 1985	16 Jan 1982	30 Dec 2008
18 Jan 1986	6 Nov 1991	
18 Oct 1989	4 Feb 1995	
12 Nov 1996	9 Dec 1995	
25 Nov 2000		
19 Nov 2006		

Table 4: Cases Listed for Each Subcategory

500-mb Heights

Strong high pressure aloft occurred in each of the 24 cases. Figure 1 shows the 500-mb composite images of each of the dates within each subcategory plus the composite of all 24 cases for the dates preceding the event (so if the event occurred the night of 9-10 Dec 1975, the composite images were for 9 Dec 1975). There were 3 general patterns. The 10 cases within Subcategory A had a strong ridge extending from southern California through Nevada to interior portions of the northwestern United States (eastern Oregon, Idaho and/or western Montana). This was most common with prolonged dense fog (1/4 mile visibility or less) at KSAN. The 8 cases within Subcategory B had a more westerly position of a strong ridge, extending from off the coast of southern California north through the Pacific Northwest coastal areas. A corresponding trough over the Great Lakes was particularly strong in Subcategory B. Subcategory B was most commonly associated with long periods of below one mile visibility at KSAN, but not necessarily ¼ mile visibility. The 5 cases within Subcategory C had a somewhat less amplified ridge over the southwestern United States but yet with 500-mb heights over southern California higher than almost all other locations in the continental United States. The cases in Subcategory C were also more likely to be associated with the cases of prolonged visibilities less than one mile (versus ¼ mile) than with Subcategory A. The composite of all 24 cases shows the mean position of the 500-mb ridge just inland from the West Coast. Figure 2 shows the 500-mb high anomalies (adjusted for the respective times of year) for all 24 cases, and the anomalies were quite strong over the Great Basin, with a mean anomaly of around +120 meters over Nevada and anomalies greater than +80 meters covering most of the Western United States. In percentile terms (at Reno), anomalies of +120 meters corresponded to heights that ranged (within the normal dense fog season at KSAN) from 83rd percentile in January to 94th percentile in October.

Figure 3 shows the 500-mb heights the following day (the day after the night of dense fog at KSAN). The changes were minor, with the ridge being a little weaker and slightly to the east, suggesting a stable pattern is beneficial for prolonged dense fog at KSAN.

850-mb and 925-mb Temperatures

850-mb temperature ridging occurred in all of the prolonged fog cases, and in most cases, strongly. Figure 4 shows a composite of the 850-mb temperatures for all 24 cases (regardless of season), with the temperature difference between San Diego and an equivalent latitude in western Texas averaging around 8°C. Similar to the way that prolonged dense fog cases occurred during higher-than-normal heights over the region at 500 mb, they also were associated with higher-than-normal temperatures at 850 mb. Figure 5 shows 850-mb temperature anomalies (adjusted for the date) for the 24 cases which averaged +6°C over southern California and +3°C or greater along the West Coast from Washington south through about half of the Baja California peninsula. 925-mb temperature anomalies were similar to the 850-mb anomalies. In percentile terms (at San Diego/Miramar), anomalies of +6°C at 850 mb corresponded to temperatures that ranged (within the normal dense fog season at KSAN) from 85th percentile in February to 93rd percentile in October. When 850-mb temperature maps for the following day were analyzed, very little change occurred to the pattern (Figure 6).

Daily Maximum Temperatures in the Southern California Valleys

Daily maximum surface temperatures in all cases were above normal for the date (between +1°F and +23°F) at Ontario Airport, approximately 100 miles north of San Diego Lindbergh Field. The average departure from normal was +12°F. Other Southern California valley locations (defined in Figure 7) were almost always warmer than normal (and in some cases, much above normal) during prolonged dense fog events at Lindbergh Field.

This corresponds to anomalously high 850-mb temperatures. During periods when the surface pressures are higher over land than at sea (offshore flow), daily maximum temperatures in the Southern California valleys correlate closely with lowering 850-mb temperatures to the surface dry-adiabatically (with the absence of an inversion between the surface and 850 mb when the daily maximum temperatures occur). This is because the marine inversion is very low, below the elevations of most of the Southern California valleys, during offshore flow. As described in the next section, offshore flow prevailed during the prolonged dense fog episodes.

Mean Sea Level Pressure (MSLP) Gradients

In 23 of the 24 cases, MSLP was higher in Las Vegas than San Diego, which would indicate an offshore pressure gradient where winds would flow primarily from land towards the sea. In most cases, the surface high over land was centered somewhere over the interior western United States (usually over Utah, Wyoming or Idaho). At noon (PST) on days before prolonged dense fog at KSAN, the pressure averaged 3.5 MB higher at Las Vegas (KLAS) than at San Diego (KSAN). The range of KSAN-KLAS pressure gradients was from +0.9 MB (the only "onshore flow" case) to -8.5 MB. In the case where there was weak onshore flow, the previous two days experienced offshore flow, which could have contributed to conditions favorable for coastal dense fog. Offshore flow is typically associated with subsidence warming on the west and southwest slopes of the mountains, and this tends to strengthen and lower the marine inversion height. Figure 8 is a composite image for all 24 cases showing the pattern of offshore surface pressure gradients, where high pressure was centered, on average over Utah (though in the 24 cases, the high was centered as far west as western Washington, as far east as the Northern Plains and as far south as the Four Corners of Utah/Colorado/Arizona/New Mexico), and a low pressure trough lay near the Southern California coast.

Low-Level Winds

In most cases, the 12Z sounding from Miramar the day before the prolonged fog episode had light winds between the surface and 900 mb. 22 of the 23 cases (one case had missing low-level wind data in the sounding) had a maximum wind velocity of 8 knots or less between the surface and 900 mb. When all 12Z soundings were compared between 1973 and 2008 for months between October and March, 36 percent of the soundings had a maximum wind speed of 8 knots or less; thus, nearly all soundings the morning before the night of a dense fog episode had lighter than the median wind of 9 knots (the only value above this was one case with 10 knots). While light winds typically inhibit dispersion of the fog, another possible contribution of the light winds which occurred during most prolonged dense fog cases would be to minimize changes in the height of the marine inversion, and the temperature inversion would need to be consistently near the ground for development and maintenance of dense fog at Lindbergh Field (see next section). The other case had a maximum wind velocity of 10 knots between the surface and 900 mb, which was 60th percentile among all Oct-Mar 12Z soundings.

Low-Level Temperature Inversion

In all cases, the 12Z sounding from Miramar the day before the prolonged fog episode had a low-level temperature inversion. In 18 of the 24 cases, the inversion was surface-based (example in Figure 9), which given the elevation of 124 meters above sea level (about 400 feet) at the RAOB site, the marine inversion would either be absent or it would have a base at or below 400 feet above sea level. In the remaining 6 cases, the inversion bases were between 500 and 1200 feet above sea level (example of an inversion base 900 feet above sea level in Figure 10), all of which were below the average (and mode) for autumn and winter, around 1500 feet. Surface-based inversions occurred regardless if a marine layer had resulted in fog at Lindbergh Field the morning before the event or not.

The inversion was typically strong the morning (12Z) of the day before the event, with the average temperature difference between the top and bottom of the inversion being 10.6 °C among the 24 cases. The range was from 4.9 °C on 25 Dec 1978 to 17.6 °C on 1 Oct 1980 (which happened to be the strongest low-level inversion recorded for any Miramar sounding between 1973 and 2008). The average strength (12Z) of the low-level inversions in all soundings (1973-2008) which had one during the months from October through March was 5.2 °C. 23 of the 24 case studies had the strength of the inversion greater than this average value.

Dense fog, whether it be prolonged (like in these cases) or short-lived, at Lindbergh Field, normally occurs with a very low marine inversion, usually less than 800 feet above sea level. As stated before, this is because shallow marine layers typically have very little mixing and high relative humidity, especially at night. Deeper marine layers have an elevated stratus layer (often 1500 to 2000 feet above sea level) with enough mixing below this layer to keep visibilities well above critical minimums at KSAN.

Presence of Fog the Morning Before

In 21 of the 24 cases, either fog (with visibilities of one mile or less) or stratus had occurred at KSAN at some point the morning before. This ranged from a case with nearly 11 consecutive hours of visibilities less than one mile (the morning of 05 Dec 1981) to just brief episodes (one to two hours) of stratus and moderately reduced visibilities (such as 2 miles).

The three cases with no fog or stratus the previous morning (10 Oct 1988, 6 Nov 1991 and 12 Nov 1996) at KSAN were all autumnal situations with hot weather inland, surface-based inversions (with strengths between 8 and 12 °C) and weak offshore flow between 1000 and 700 mb. However, the upper-air patterns were different; the 10 Oct 1988 case had an omega block over the Western United States, the 6 Nov 1991 case had the upper-level ridge near the West Coast of the US, and the 12 Nov 1996 case had the upper-level ridge over the Interior West.

Summary

There were seven elements (Table 5), each of which were found in all or nearly all cases containing prolonged fog at KSAN (defined as observed visibilities of ¼ mile or less for 8 consecutive hours or visibilities of one mile or less for 10 ½ consecutive hours).

1. 500-mb ridge over the western United States
2. Anomalously high daytime temperatures at 850 mb and 925 mb over San Diego
3. Anomalously warm surface temperatures in the valleys of Southern California
4. Offshore MSLP gradients between Las Vegas and San Diego
5. Light winds between the surface and 900 mb
6. Moderate to strong low-level inversion near the surface
7. Stratus or fog the previous night at KSAN

Table 5: Elements Frequently Found with Long-Duration Low Visibilities at KSAN.

Of the above 7 elements, all were found in 16 of the 23 cases (one of the 24 cases had low-level winds which could not be determined), 6 of the 7 elements were found in 5 of the 23 cases, and 5 of the 7 elements were found in the other 2 cases. In most cases, the following could be found. A 500-mb ridge was over the western United States with a mean seasonally-adjusted anomaly of 500-mb heights of about 80 meters. Temperatures at 850 mb and 925 mb at Miramar were well above normal with a seasonally-adjusted anomaly of 6 °C. Above normal daytime temperatures were found at the surface in the southern California valleys, with a seasonally-adjusted anomaly of 12 °F (7 °C) at Ontario Airport (KONT). Offshore (land-to-sea) MSLP gradients prevailed, with the average MSLP being 3.5 MB higher at Las Vegas (KLAS) than at KSAN. Low-level winds at Miramar were light, 8 knots or less at all heights between the surface and 900 mb in all but one case. A low-level temperature inversion at Miramar was very near the surface (in fact, surface-based 75% of the time) and usually stronger than normal (in one case, the strongest 12Z Miramar sounding ever recorded in the 36-year period analyzed). Lastly, a marine layer usually was already established, despite the presence of an offshore-flow pattern.

All of these elements/variables occurred the day before the fog, so that forecasters could identify them while creating a terminal airport forecast (TAF) for KSAN. However, when compared with the following day (after the fog event), there were typically only minor changes (with the 500-mb height and 850-mb temperature ridges only slightly displaced to the east). Thus, the fog occurred most in these persistent fair-weather regimes. All except 2 of these cases occurred between October and February.

Reference

Kalnay, E. and Coauthors, 1996: The NCEP/NCAR Reanalysis 40-year Project. Bull. Amer. Meteor. Soc., 77, 437-471. http://www.esrl.noaa.gov/psd/

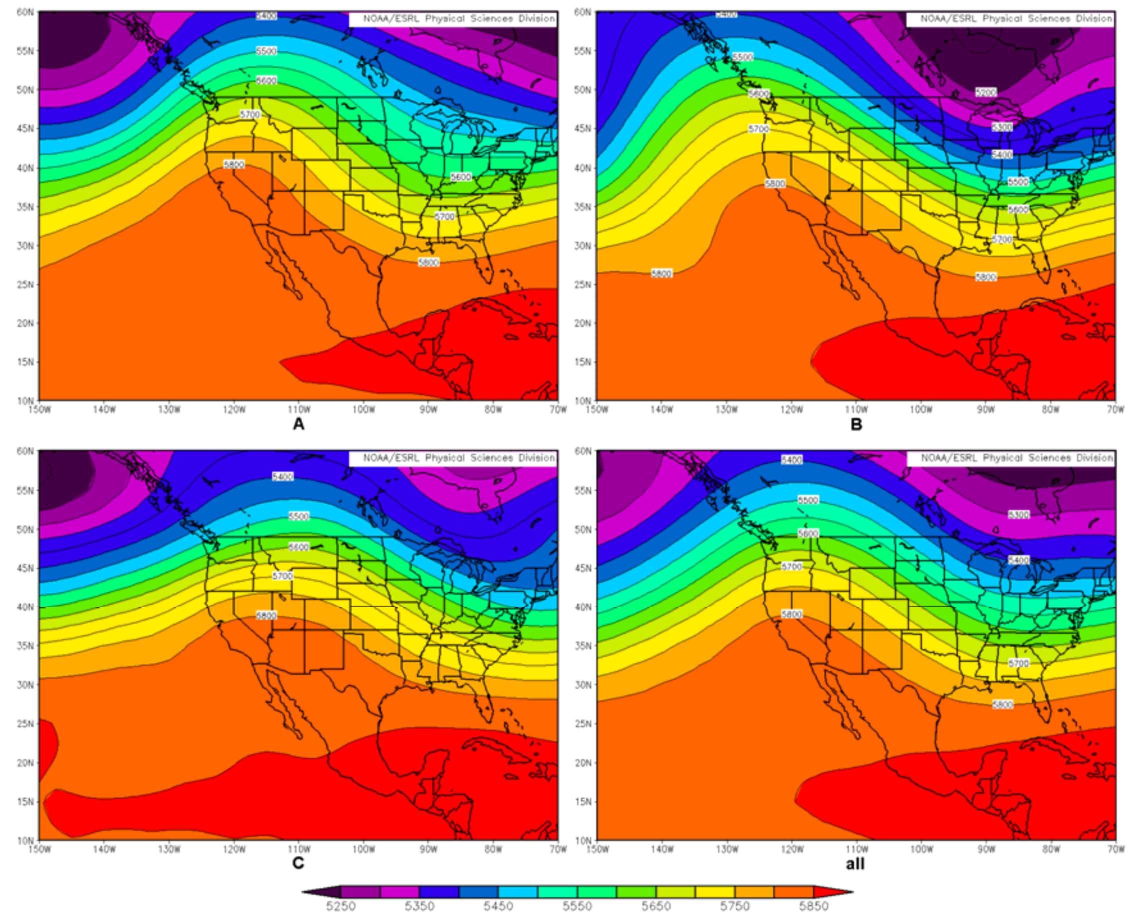

Figure 1: 500-mb Height (m) Composite Maps for the Day Before Fog Events at San Diego Lindbergh Field (KSAN) for the 3 Subcategories (A, B and C) and for All 24 Cases.

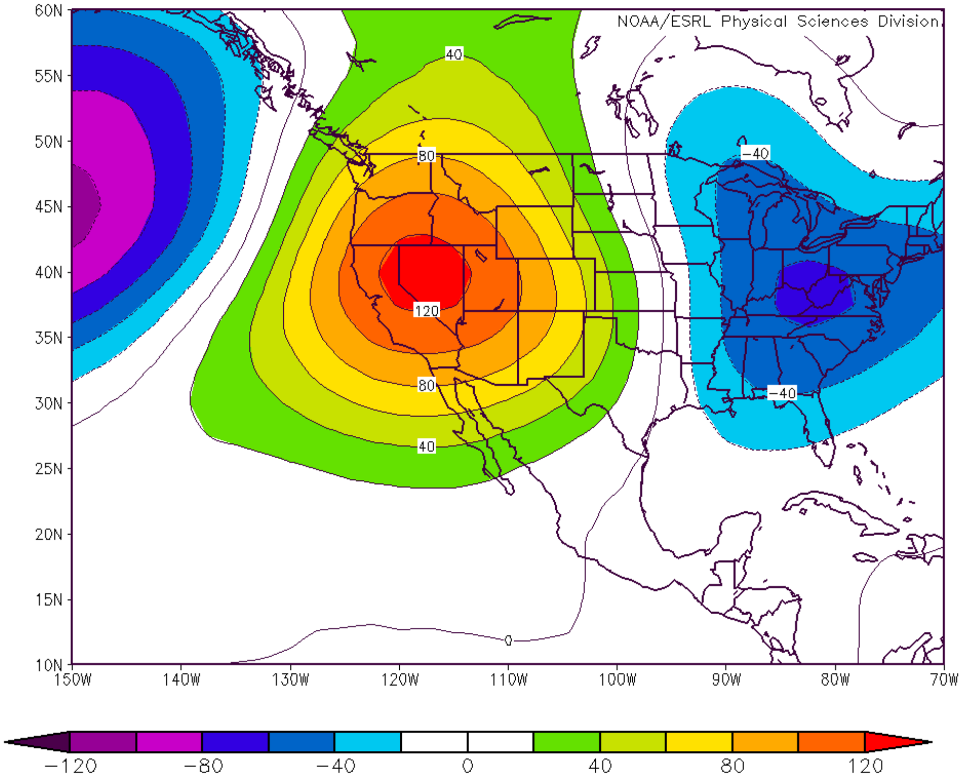

Figure 2: 500-mb Height (m) Anomaly Composite Map for the Day Before Fog Events at San Diego Lindbergh Field (KSAN) for All 24 Cases. These anomalies were the average of the difference of the analyzed 500-mb height compared to the mean for the day of the year for each case.

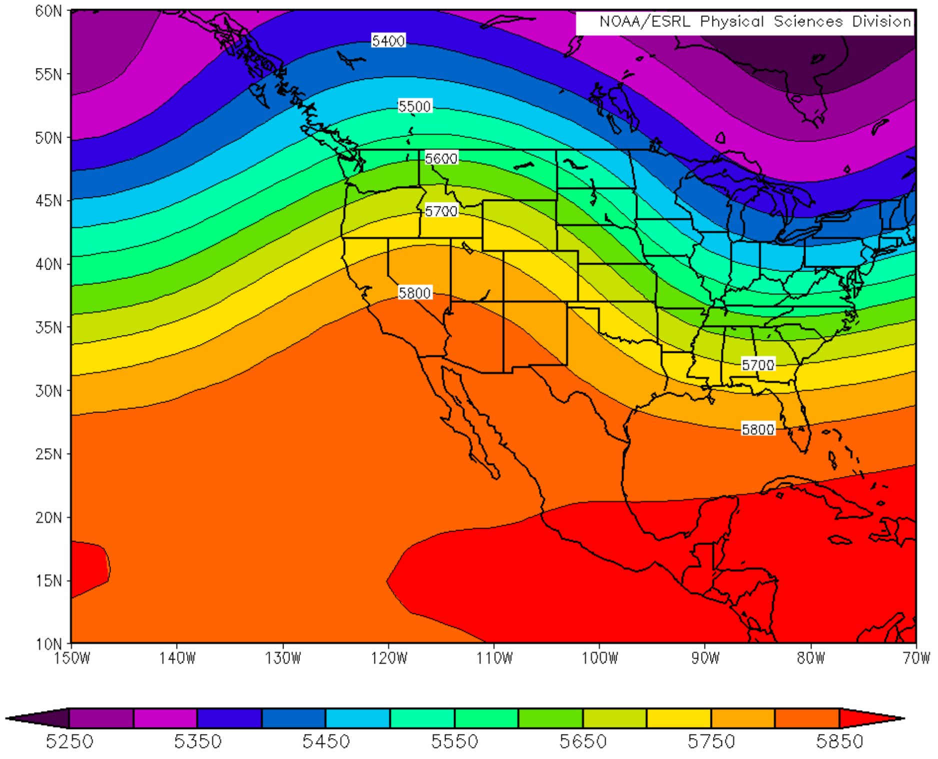

Figure 3: 500-mb Height (m) Composite Map for the Day After Fog Events at San Diego Lindbergh Field (KSAN) for All 24 Cases.

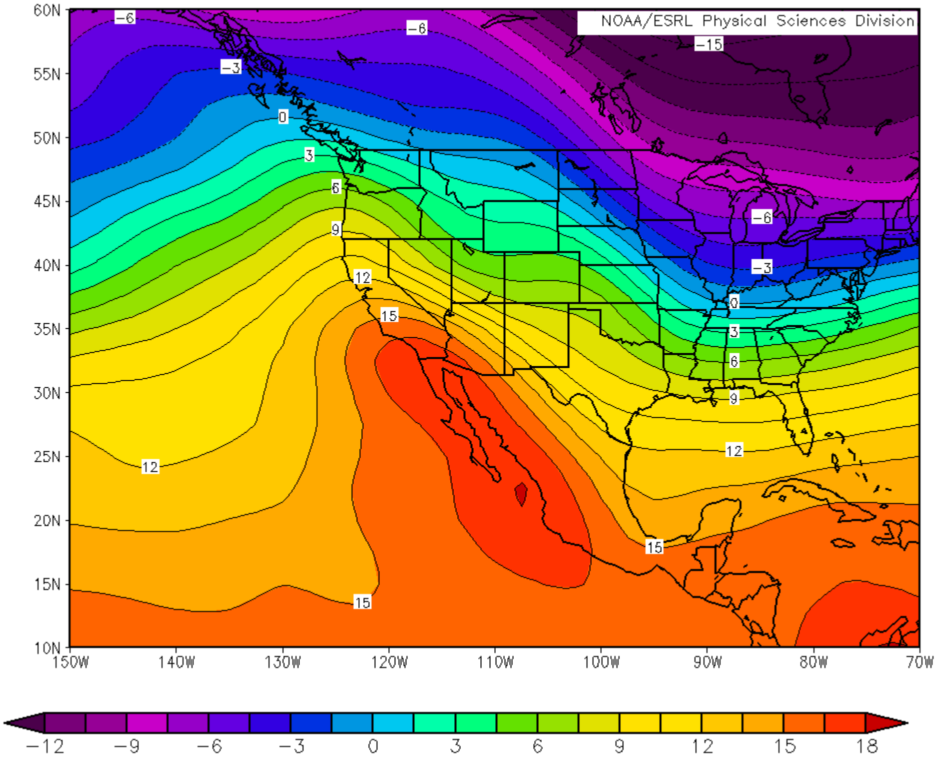

Figure 4: 850-mb Temperature (°C) Composite Map for the Day Before Fog Events at San Diego Lindbergh Field (KSAN) for All 24 Cases.

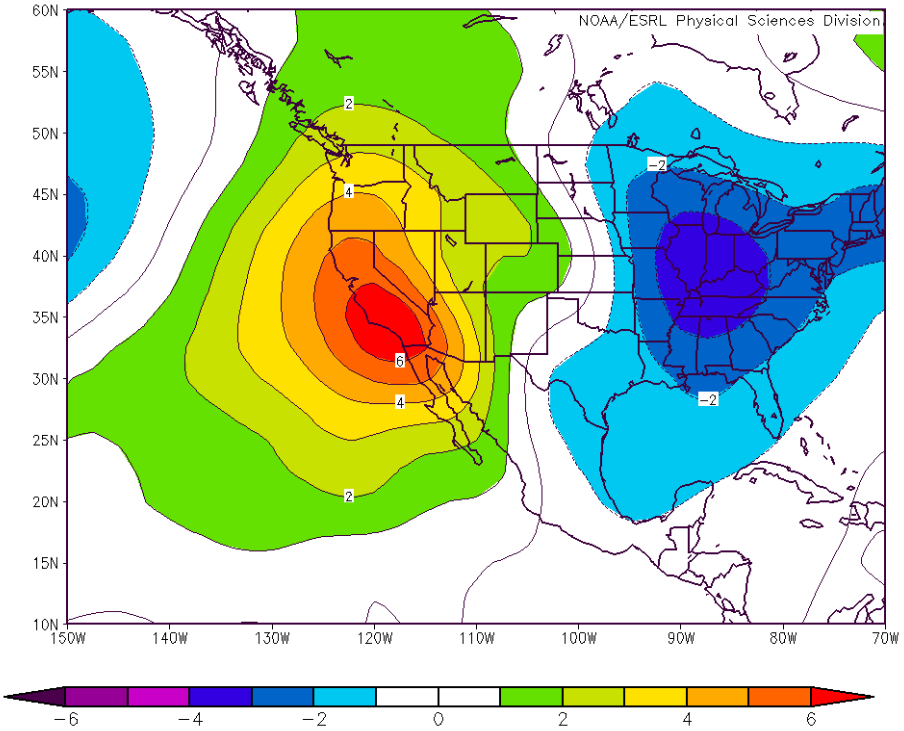

Figure 5: 850-mb Temperature (°C) Anomaly Composite Maps for the Day Before Fog Events at San Diego Lindbergh Field (KSAN) for All 24 Cases. These anomalies were the average of the difference of the analyzed temperature at the respective pressure level compared to the mean for the day of the year for each case.

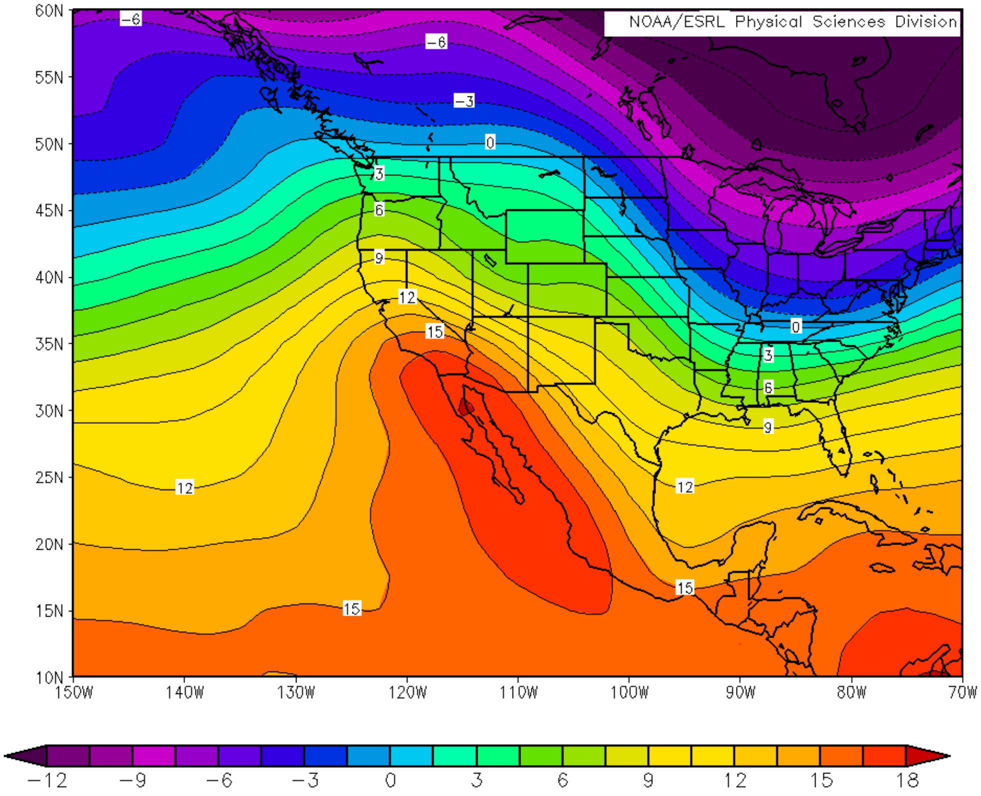

Figure 6: 850-mb Temperature (°C) Composite Map for the Day after Fog Events at San Diego Lindbergh Field (KSAN) for All 24 Cases.

Figure 7: Southern California Valleys As Defined for This Study (Outlined in Red). Map background is from Google Maps; see http://products.weather.gov/detaile.php?selrow=365 for more information.

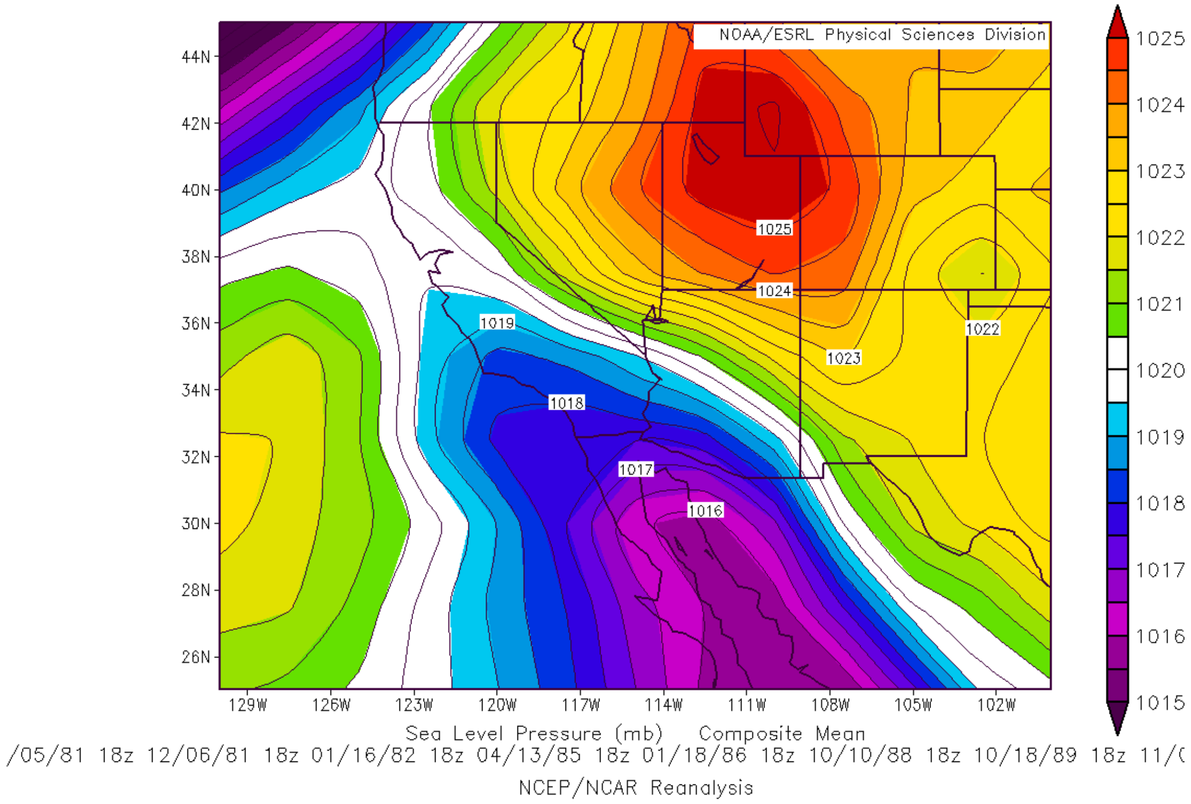

Figure 8: Mean Sea Level Pressure (mb) Composite Maps for 18Z (10 AM PST) the Day Before Fog Events at San Diego Lindbergh Field (KSAN) for All 24 Cases

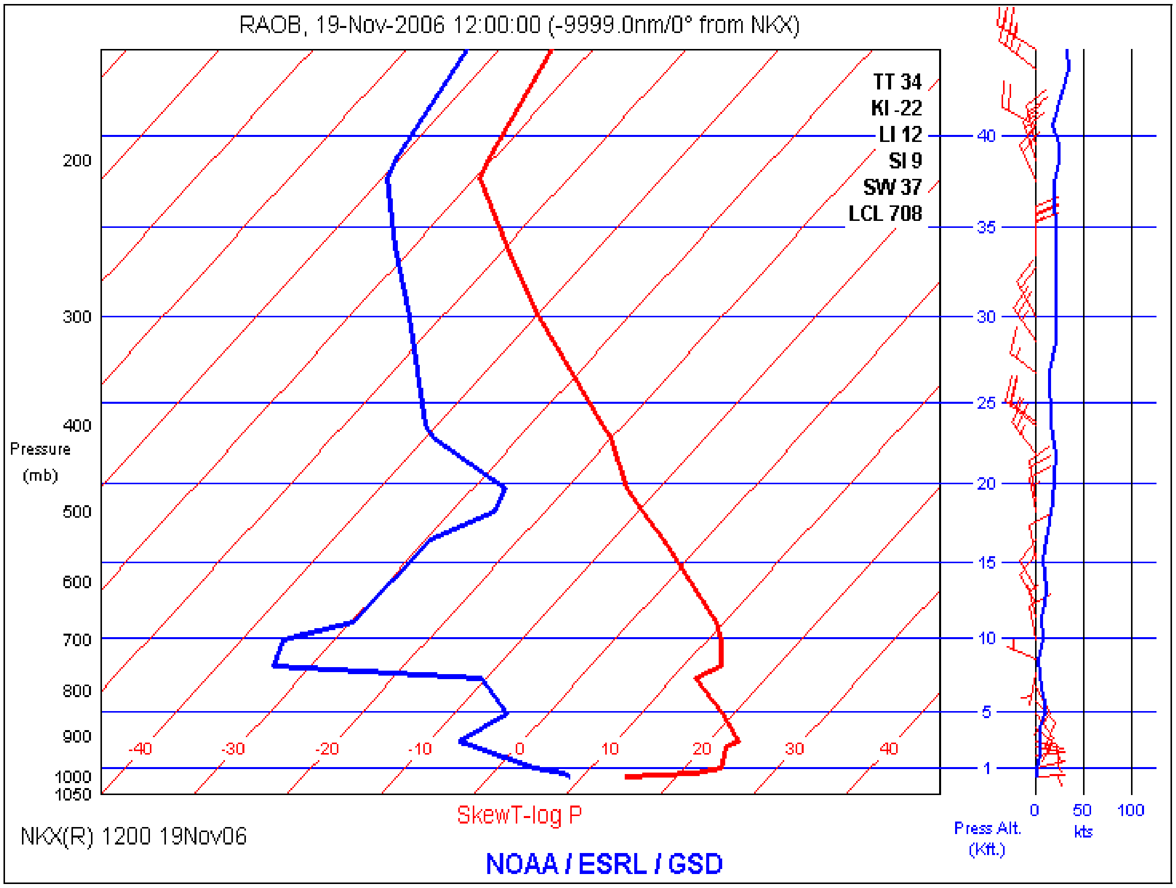

Figure 9: Example of a sounding for NKX where a surface-based inversion was present (1200 UTC 19 Nov 2006). The red line indicates temperature.

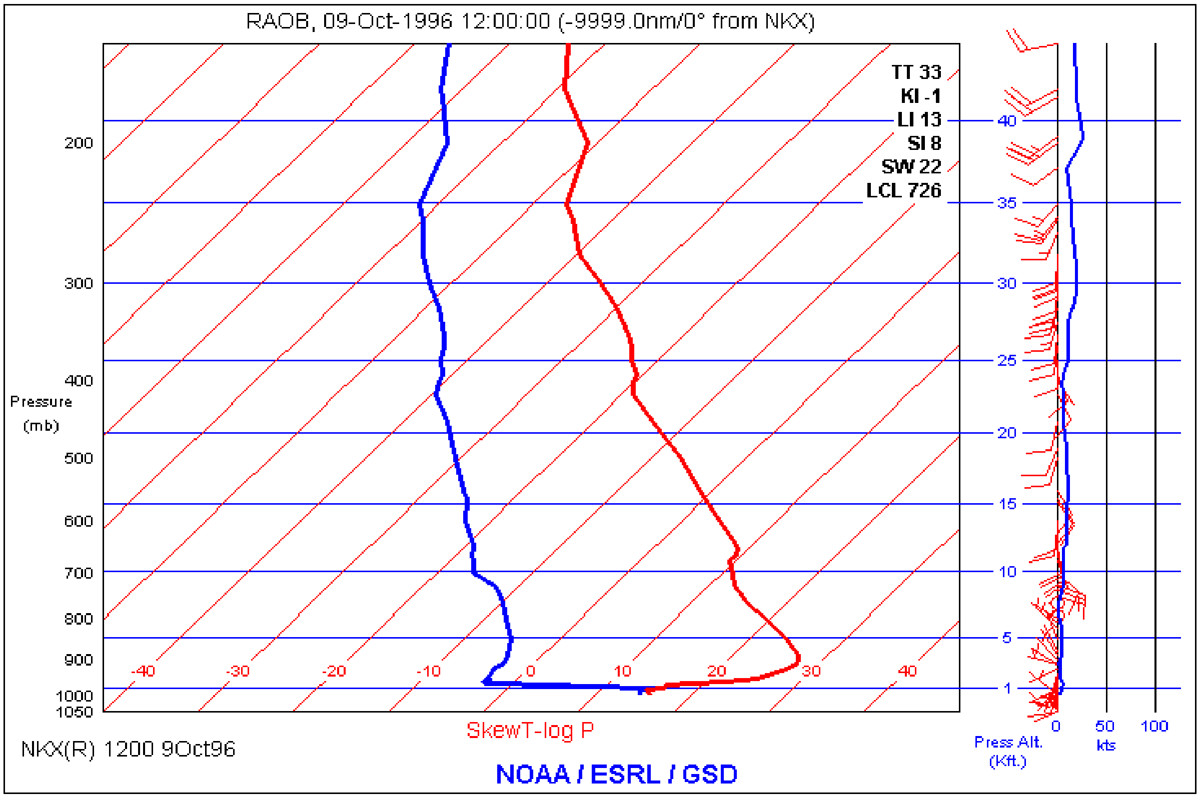

Figure 10: Example of a sounding for NKX where an inversion was present just above the surface (1200 UTC 9 Oct 2006), in this case, 900 feet above sea level (or 500 feet above ground level). The red line indicates temperature.