The Palmdale Wave: An Example of Mountain Wave Activity on the Lee Side of the San Gabriel Mountains

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Introduction

In areas of mountainous terrain, weather forecasters are presented with significant challenges due to the complex interaction between the atmosphere and the underlying hills, mountains, and valleys. One challenge, in particular, is the formation of orographic waves. In an orographic wave event, very strong, terrain-induced winds occur either where the winds are flowing perpendicular to the mountain ridgelines or they can occur on the downwind side, or lee of the mountains. In either case, the phenomena are classified as mountain wave winds. (Whiteman 2000). In the most significant mountain wave wind events, winds in excess of 75 mph—and sometimes more than 100 mph—have been observed. These winds can produce significant property damage and their associated severe turbulence and wind shear pose a significant hazard to aviation.

On December 6th and 7th of 2007, a winter storm moved across southern California that generated a significant mountain wave event over portions of Los Angeles County (**Fig. 1**). Specifically, the event was centered on the San Gabriel Mountains [elevation 10,000 ft] and the southern foothills of the Antelope Valley—the portion of the Mojave Desert that lies within Los Angeles County just to the north of the San Gabriels. Automated observations and weather spotter reports indicated wind gusts in excess of 75 mph across the foothill communities including Little Rock, Pearblossom, and Lake Palmdale. Due to its favored location, forecasters at the National Weather Service office in Los Angeles/Oxnard have nicknamed the event the “Palmdale Wave.” The purpose of this paper is to examine this particular event in order to provide forecasters more specific conditions that can produce “Palmdale Wave” events.

Overview of Mountain Wave Development

Due to the number of significant mountain ranges across the world and the impact these ranges have on our weather, mountain wave activity is a well researched phenomenon. From this research, it has been shown that there are three main ingredients necessary for significant mountain wave development. These are: wind flow perpendicular to the mountain range, a stable layer of air aloft, and increasing wind velocity with altitude (Whiteman, C. D. 2000).

The orientation of the wind flow with respect to the mountain barrier plays a significant role in determining both the frequency and strength of mountain wave formation. Air flow perpendicular or nearly-perpendicular to the barrier produces far more numerous waves and much more significant wave activity than flow parallel to the mountain barrier. Thus, cross-barrier flow is probably the most important ingredient for mountain wave development.

Whiteman further found that a stable air mass aloft is an essential part of mountain wave development. By definition, a stable air mass is not conducive to any vertical motion and will try to return to its previous altitude whenever it is forced either up or down from its equilibrium level. So, when strong winds of a stable air mass encounter a barrier, they are first lifted from their equilibrium level. Once past the barrier, the air sharply descends trying to attain equilibrium, but will "undershoot" and be carried below the equilibrium level by its own momentum. Responding to this over-buoyant condition, the air again accelerates upward, this time the momentum causes the air to "overshoot" the equilibrium level. As this undershooting/overshooting process continues, the stable air oscillates about its equilibrium level producing waves. Note that the amount of "under-" or "over-" shooting depends, in part, on the initial velocity of the wind component at right angles to the mountain barrier.

The third "ingredient" for the formation of mountain waves is strong, positive vertical speed shear of the wind profile. That is, the winds increase in velocity with altitude—and the stronger the increase the better for surfacing mountain waves. Higher wind speeds not only help to enhance the strength of mountain wave activity, but they also produce more under/over buoyancy to the point where very strong winds from aloft can actually surface on the lee side of the mountains.

If the atmosphere contains enough moisture, distinctive cloud formations can be observed with mountain wave activity. The two most noticeable cloud types are lenticular and rotor clouds. Lenticular clouds are lens-shaped clouds that form on the lee side around the ridge-top level as the wind undulates up and down in a wave pattern (**Fig. 2**). Rotor clouds are roll-shaped clouds that form at lower elevations due to turbulent eddies developing near the ground (**Fig. 3**).

December 6th and 7th Overview

Topography

Figure 4 shows the topography of central and northern Los Angeles County. The San Gabriel Mountains extend northwest to southeast across northern portions of the county and merge with the San Bernardino Mountain range to the east. The highest peaks of the San Gabriel Range are just over 10,000 feet at Mt San Antonio near the border of Los Angeles and San Bernardino Counties. As you move northwestward across the mountain range, the elevation drops sharply to between 4000 and 6000 feet. On the coastal side of the San Gabriel Range, both the San Fernando and San Gabriel Valleys are immediately adjacent to the mountain range. Across these valley areas, the elevations range from 500 to 900 feet. The high desert of the Antelope Valley lies on the leeward (north) side of the San Gabriel Mountains with elevations ranging between 2,500 and 3000 feet.

Atmospheric Stability

Ideally, to evaluate stability you would like to have an upper air sounding that is in close proximity to the location of interest. However, from the Antelope Valley, the nearest balloon soundings are taken at Vandenberg Air Force Base, over 140 nm to the west, or at Miramar Naval Air Station, about 130 nm to the south-southeast. Fortunately, there is a much closer and more timely source of sounding data. Aircraft Meteorological Data Relay (AMDAR) is a WMO sponsored program that is used to collect meteorological data from commercial aircraft. Useful sounding data can be provided from AMDAR equipped aircraft landing and departing from the Bob Hope Airport at Burbank, CA many times a day—not just once or twice. This airport is located less than 10 nm from the coastal foothills of the San Gabriel Mountains.

Figure 5 and **Figure 6** show two different AMDAR soundings from the Bob Hope Airport. The sounding shown in **Figure 5** is from an aircraft landing at Bob Hope Airport at 0039 UTC on 7 December. On this sounding, a stable inversion layer exists between 4000 and 8000 feet MSL with west southwest winds of 15 to 30 mph. **Figure 6** shows the sounding taken from an aircraft landing around 1254 UTC on 7 December—over twelve hours later. On this sounding, the inversion layer has lifted to between 8000 and 10000 feet MSL with southwest winds of 35 to 60 mph. The trend in these two soundings shows that the stable layer rose to an altitude above the mean ridge-top level; thereby trapping the strong southwest winds beneath it. This forced the strong southwest winds downward to the surface and helped generate the damaging surface winds across the foothill areas of the Antelope Valley.

Synoptic Conditions

Overall, the synoptic pattern during this Palmdale Wave event was typical of many winter storms across Southern California. **Figure 7** shows the observed 500 mb flow pattern across the area at 1200 UTC on 7 December. Notice the trough axis was northwest of Southern California with strong westerly winds around the base of the trough. **Figure 8** is the 6 hour forecast from the 0000 UTC 7 December run of the NAM, valid at 0600 UTC on 7 December, and shows the 700 mb wind speed and direction as southwest at 60 knots. Similarly, **Figure 9** shows the 0600 UTC 850 mb wind speed and direction as southwest at 40 to 45 knots. These NAM forecast winds agreed well with the AMDAR soundings shown in **Figures 5** and **6.**

Figures 7 through **9** clearly show that the first and third parameters necessary for mountain wave development were in place. The wind direction was west southwesterly, and at the same time, the wind speeds increased dramatically with altitude through 700 mb. This southwesterly direction provided a near perfect cross-barrier flow of the air across the northwest-southeast oriented ridgelines of the San Gabriel Mountains. **Figure 10** shows this relationship schematically with the air from the coastal side of the San Gabriel Mountains flowing to the leeward side.

Observed Weather

The Palmdale Wave event that occurred during the storm of December 6th and 7th, 2007 produced some very impressive, localized winds across the foothills of the Antelope Valley. **Table 11** shows the hourly wind data from two Remote Automated Weather Station (RAWS) sensors located in the foothills of the Antelope Valley (Lake Palmdale and Poppy Park). The strongest observed winds occurred at the Lake Palmdale sensor between 6:00 pm and 9:00 pm PST on the 6th of December (0200 and 0500 UTC 7 December) with sustained winds between 34 to 55 mph and the highest peak gust of 74 mph. The Poppy Park sensor recorded a wind gust of 58 mph at 9:30 pm PST. These automated observations agreed with reports received from trained weather spotters at Pearblossom where a maximum wind gust to 80 mph was recorded at 7:43 pm PST (0343 UTC). A high wind warning for this portion of the Antelope Valley had been issued at 6:24 pm PST with the mention of possible gusts to 70 mph.

Conclusions

On the evening December 6th and the morning of December 7th, the “Palmdale Wave” produced very strong and damaging winds across the foothills of the Antelope Valley. Wind gusts in excess of 75 mph were reported across the area.

This particular “Palmdale Wave” event exhibited all of the ingredients found during significant mountain wave events: 1.) A stable inversion layer was observed between 4000 and 10,000 feet MSL—which is at or just above the mean ridge-top level of the San Gabriel Mountains, 2.) Both vertical wind profiles and computer model forecasts indicated increasing southwesterly winds from the surface through 700 mb. This southwest orientation of the strong winds provided the prefect cross-barrier direction for the San Gabriel Mountains, 3.) The 850 mb wind speeds were at least 40 to 45 knots strong—with stronger winds to 60 knots at 700 mb.

Given the available model and observational data, forecasters should be able to better anticipate and forecast the development of significant “Palmdale Wave” events across the Antelope Valley. Computer models can provide the forecaster with good vertical wind profile forecasts of wind speed and direction across any mountain barrier. In addition, atmospheric soundings—including AMDAR data—can provide the forecaster with stability information as well as verification of computer model forecasts of wind speed and direction.

Acknowledgements

We would like to thank Mark Jackson and of WFO Los Angeles/Oxnard for his review of this paper.

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References

Whiteman, David, C., 2000: *Mountain Meteorology: Fundamentals and Applications.* Oxford University Press, 355 pp.

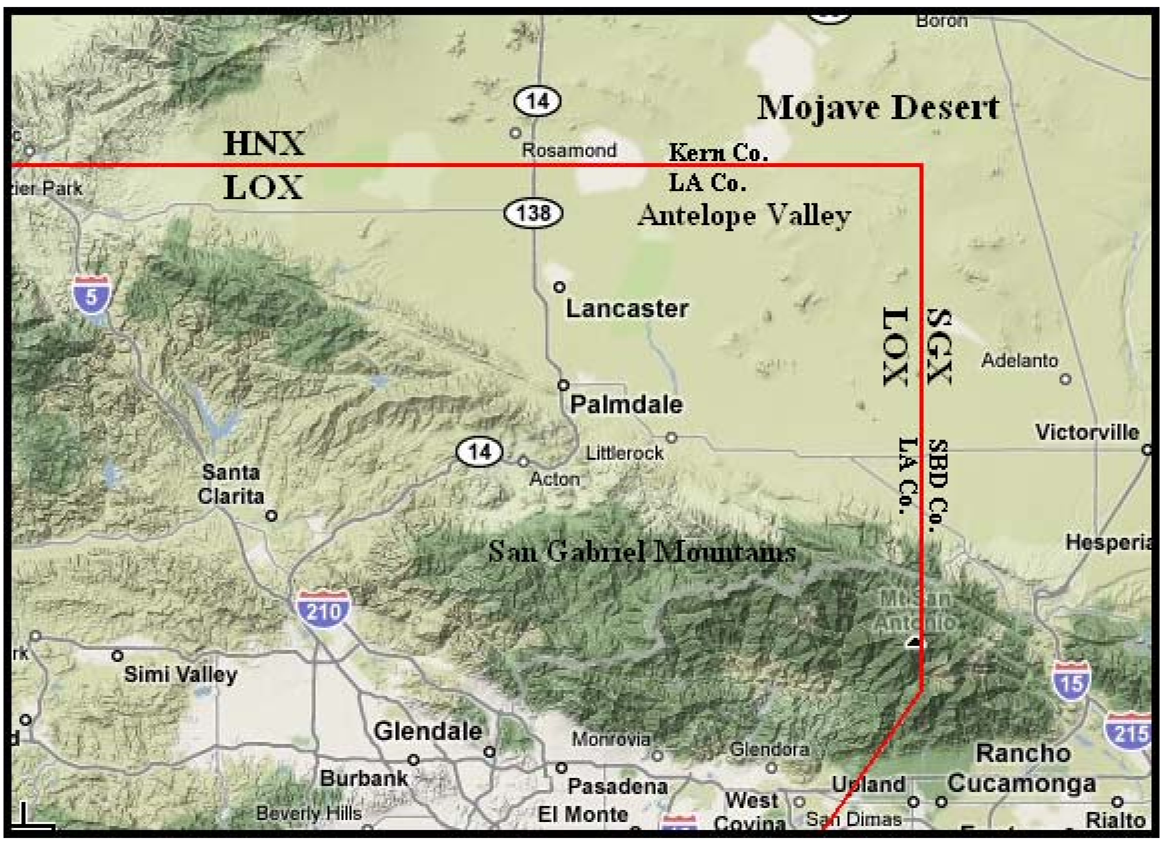

Figure 1. Antelope Valley, CA

Figure 2. This photo of lenticular clouds was taken by Issy Isgrigg near Pearblossom, CA on 2 February 2007. Pearblossom is located on the southern slopes of the Antelope Valley just north of the San Gabriel Mountains.

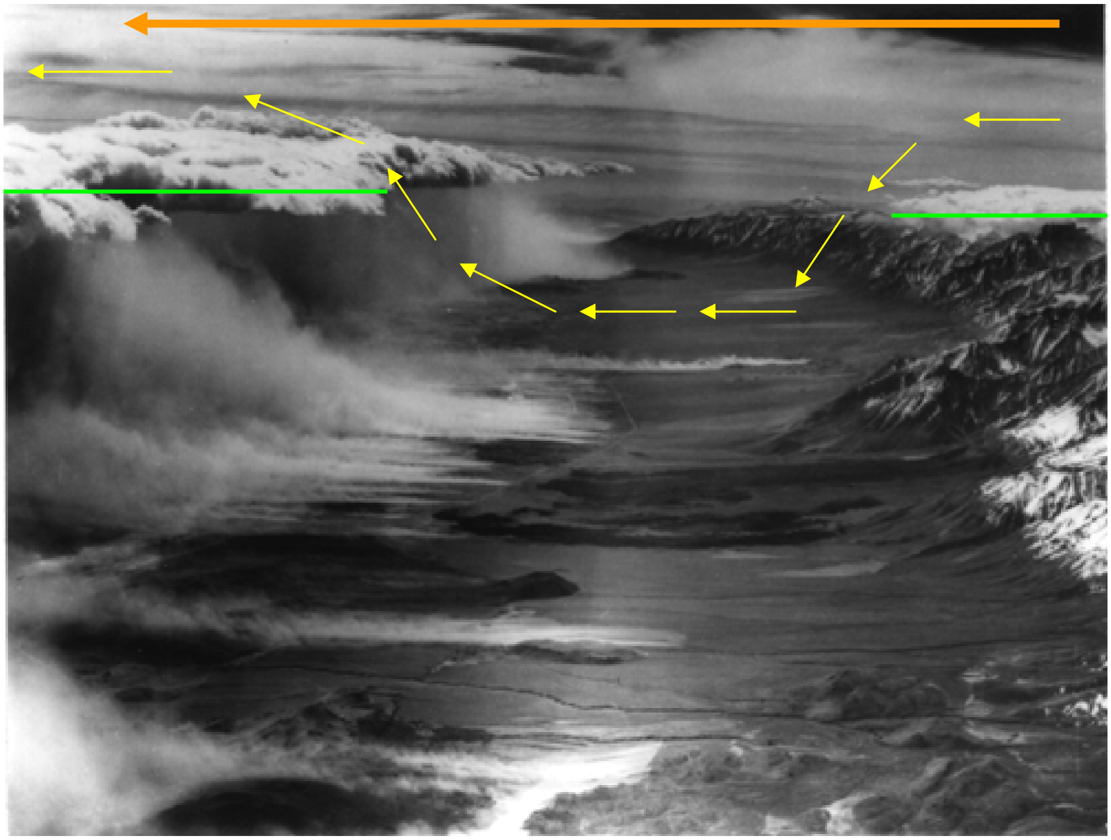

Figure 3. This is a photo of a turbulent rotor cloud (on left) occurring downwind of the Sierra Nevada Mountains. This view is of the Owens Valley looking south from near Bishop, CA. Very strong downslope winds gather dust on the valley floor, and then serve as a tracer showing the air rising suddenly into the clouds. The green lines represent the condensation level. This photograph was from:

http://www.atmos.washington.edu/gcg/Atlas/oro.html

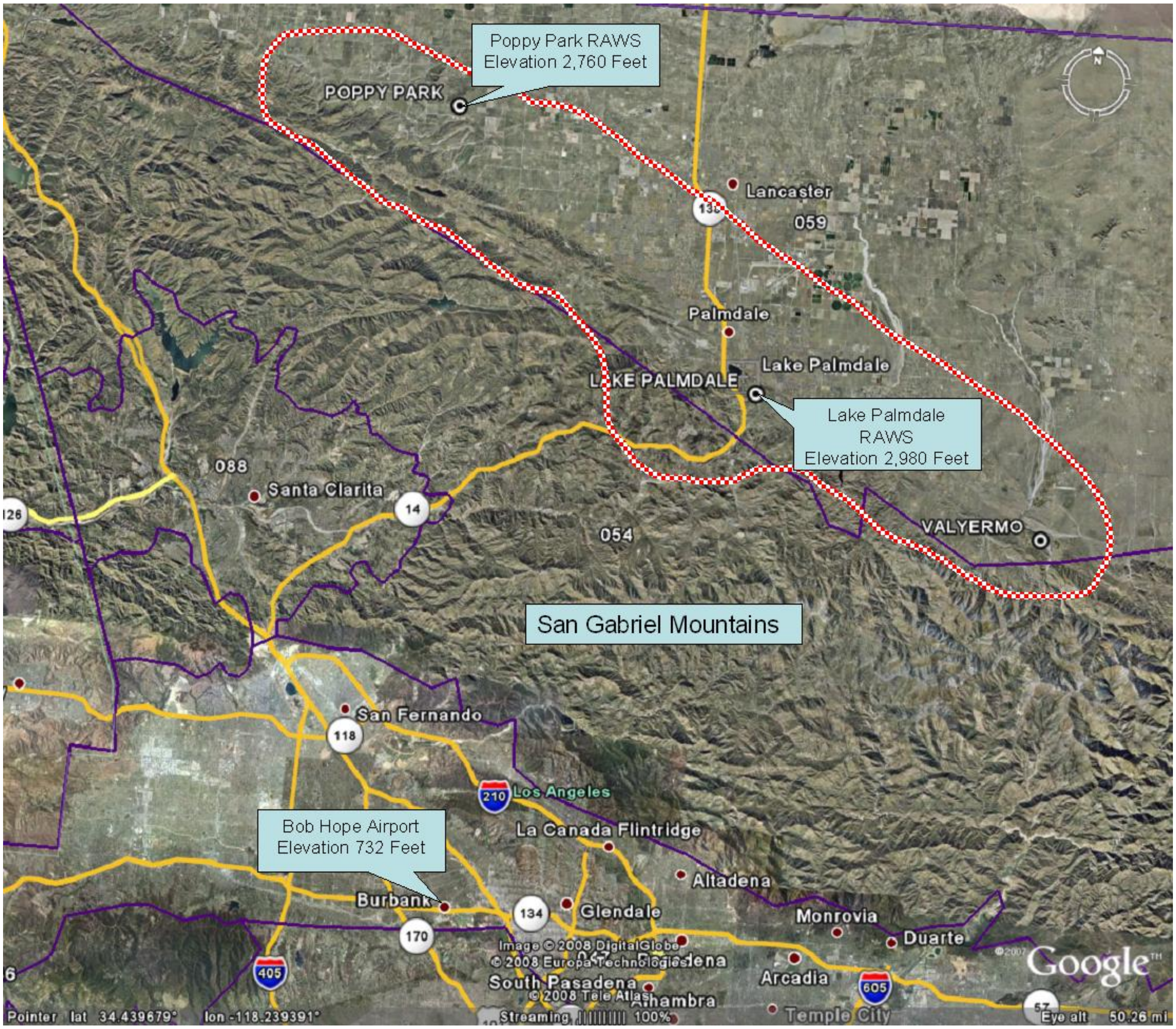

Figure 4. This is an areal view of central and northern portions of Los Angeles County. The area outlined by the red and white line is the where the "Palmdale Wave" usually occurs.

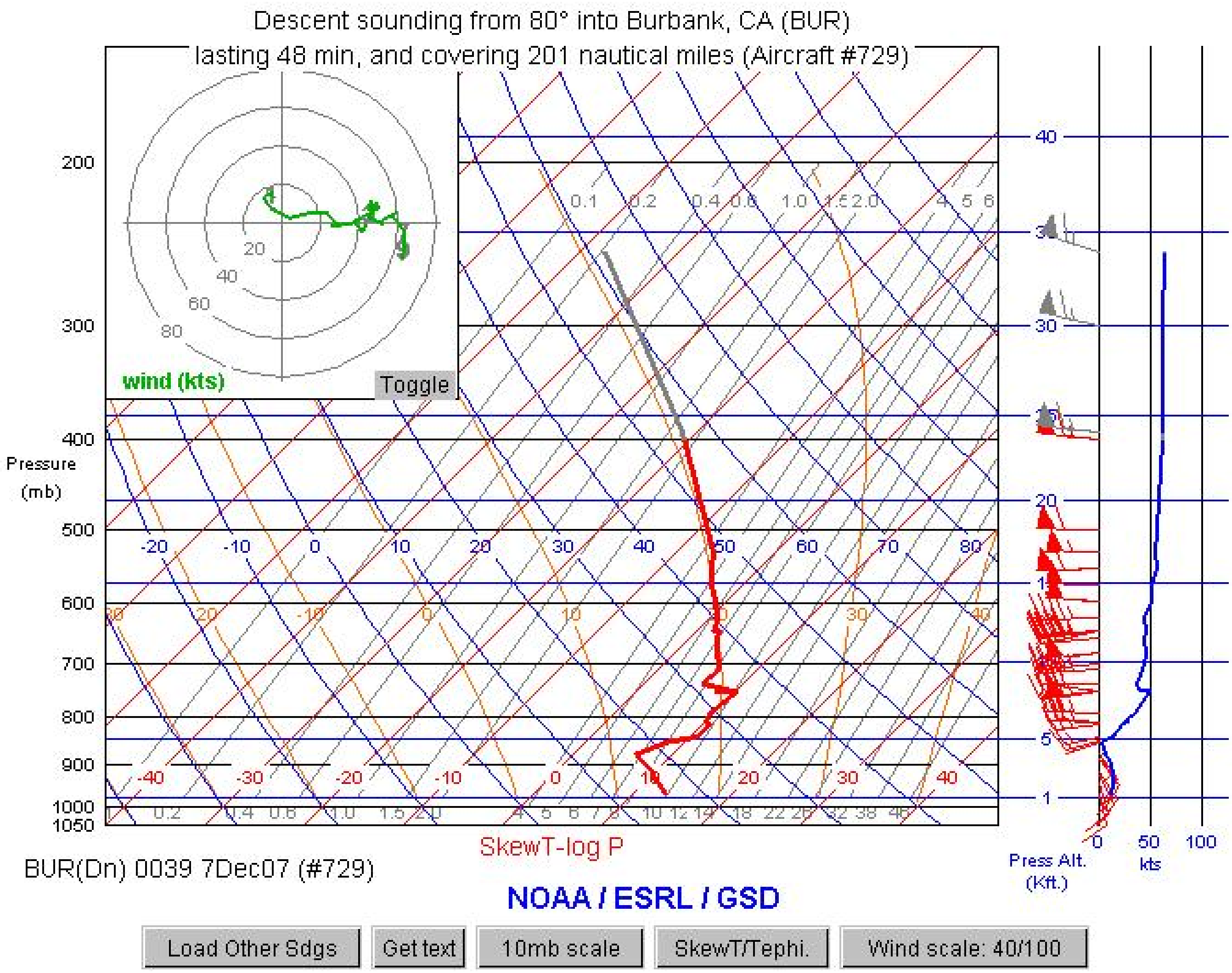

Figure 5. This AMDAR sounding is from an aircraft descending for a landing at Bob Hope International Airport at 0039 UTC on 7 December 2007.

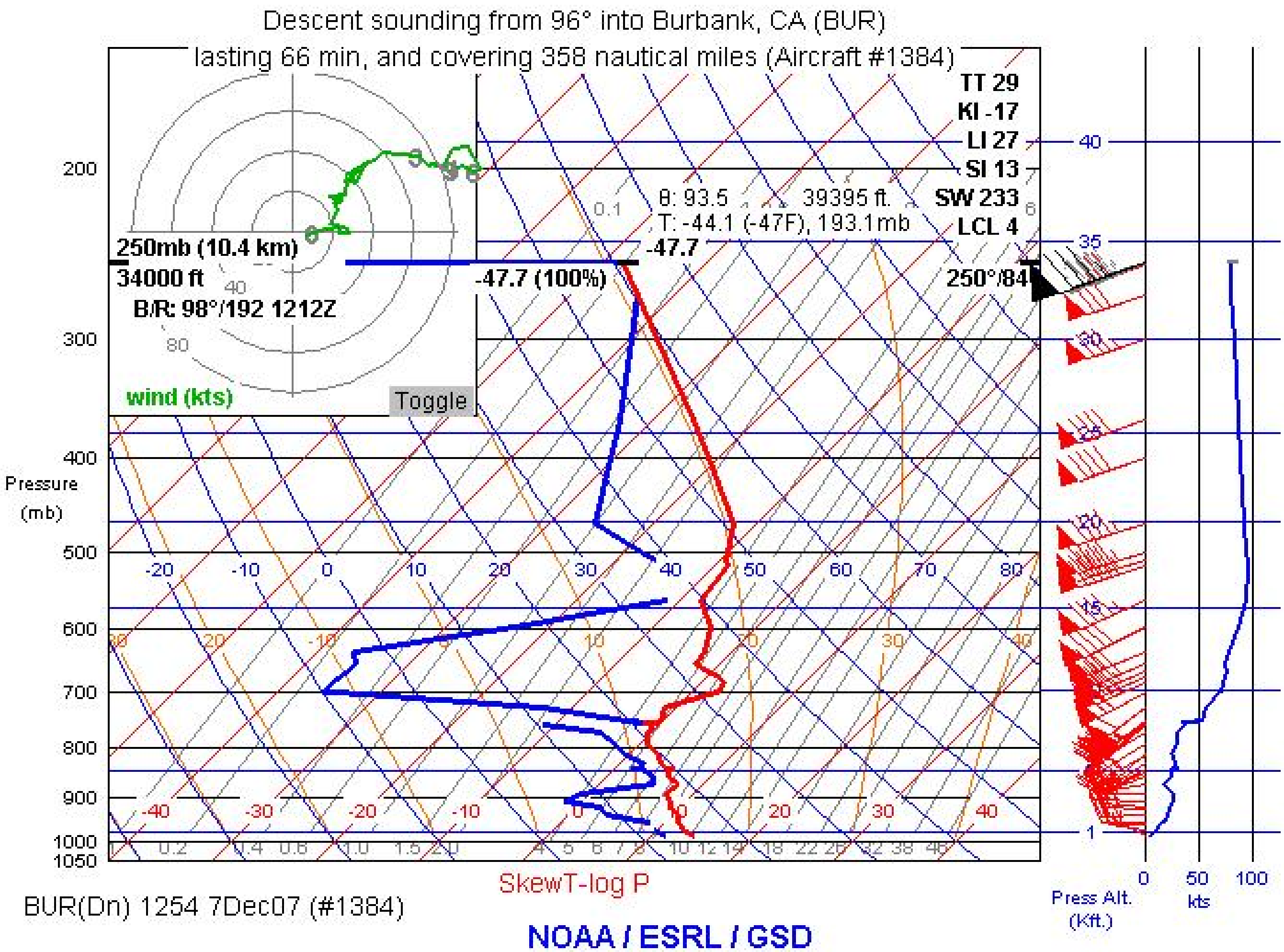

Figure 6. This AMDAR sounding is from an aircraft descending for a landing at Bob Hope International Airport at 1254 UTC on 7 December 2007.

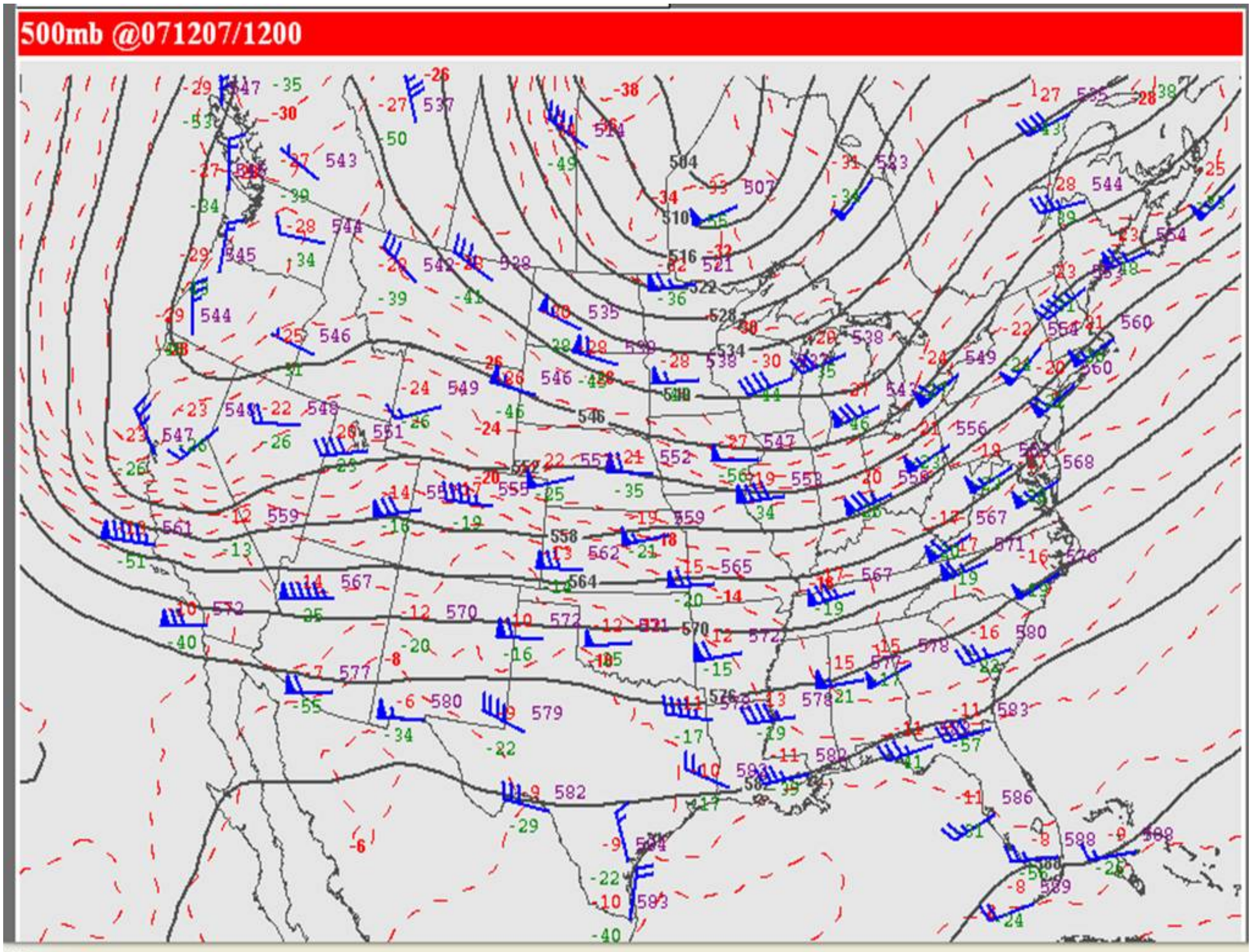

Figure 7. This is a map of observed 500 MB heights and winds from 1200 UTC 7 December 2007.

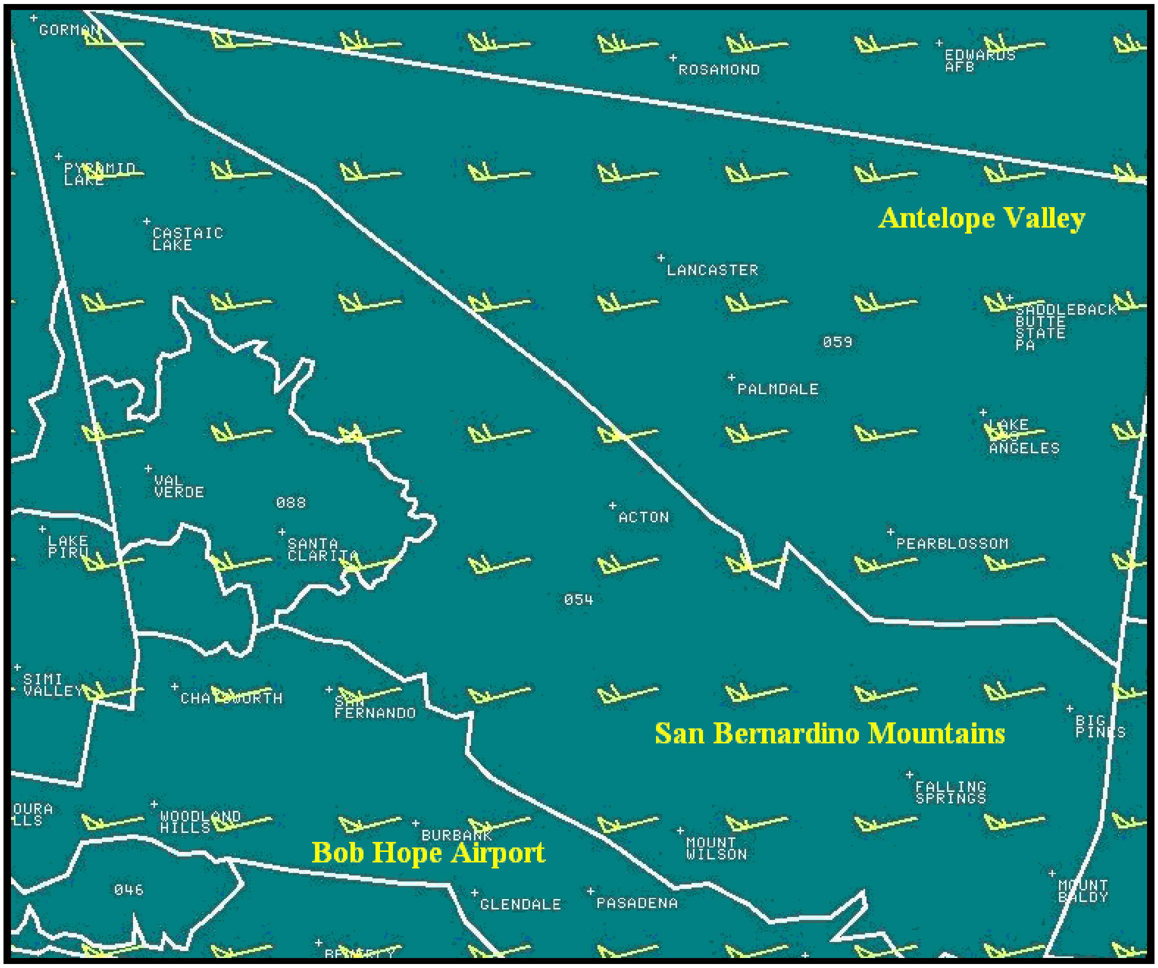

Figure 8. This figure shows the 0600 UTC forecast of the 700 MB wind pattern from the 0000 UTC NAM model run on 7 December 2007.

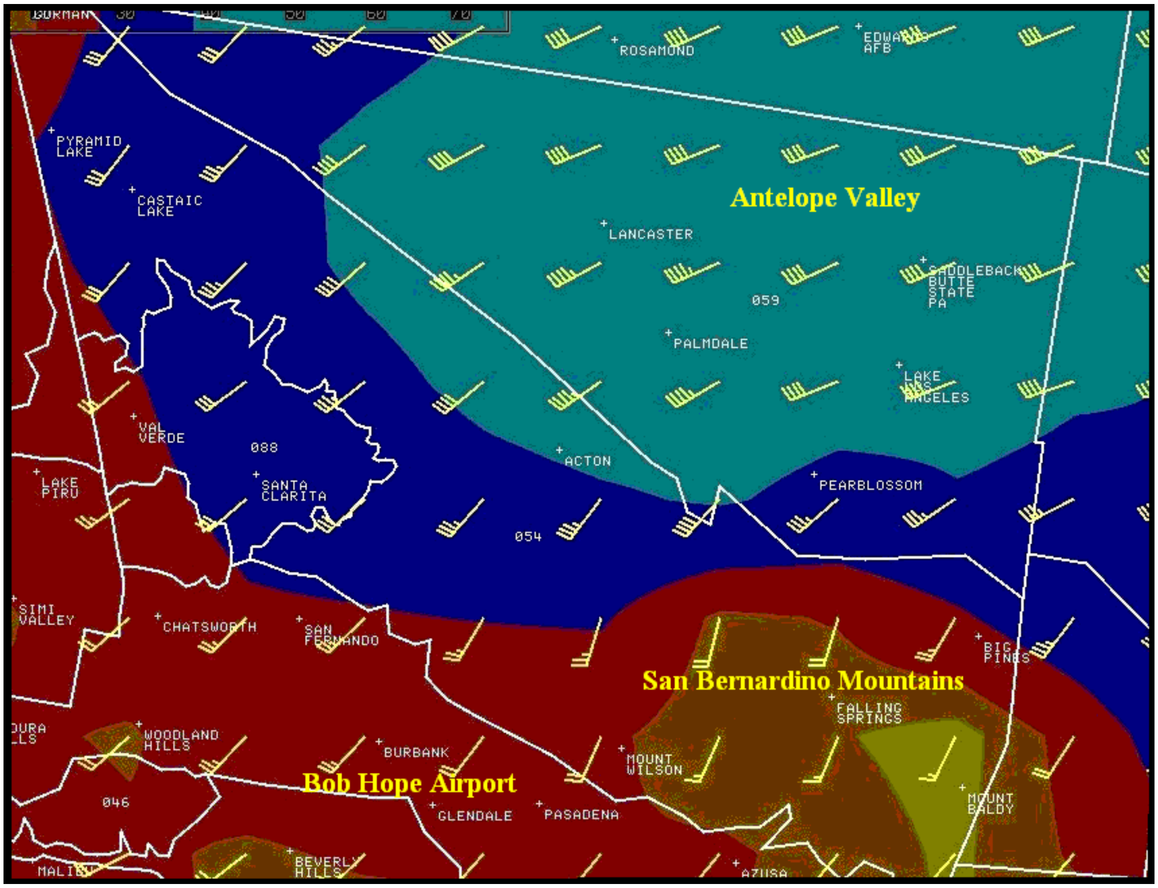

Figure 9. This figure shows the 0600 UTC forecast of the 850 MB wind pattern from the 0000 UTC NAM model run on 7 December 2007.

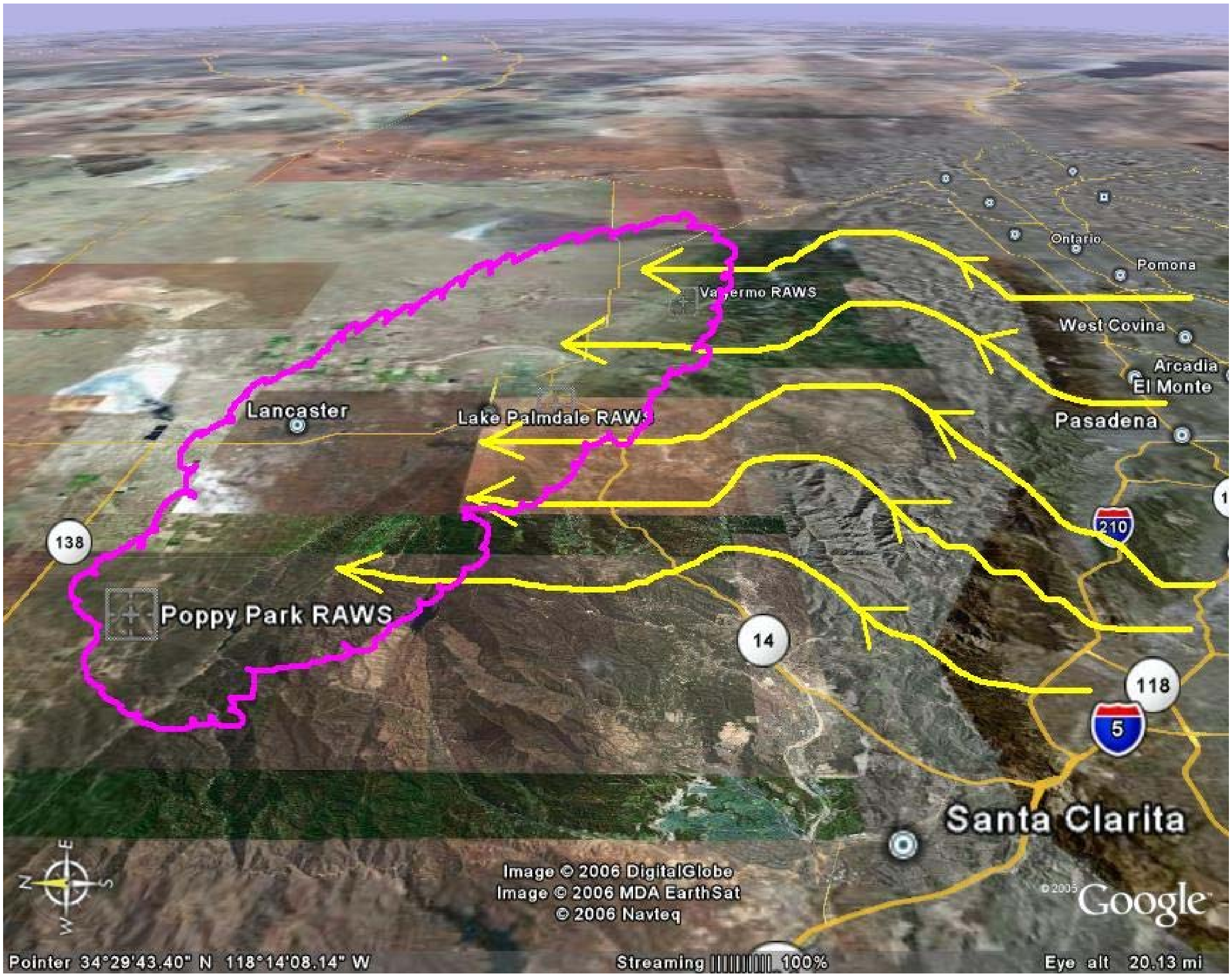

Figure 10. This image is a computer depiction of the San Gabriel Mountains looking almost due east from near Santa Clarita, CA. The yellow streamlines depict the south-westerly winds flowing across the mountains. The area outlined in fuchsia shows the approximate location where the strongest wind gusts occur during a typical "Palmdale Wave".

	Lake Palmdale	Poppy Park
01Z/07	SW 37G53	SW 25G40
02Z/07	**SW46G54**	SW 29G46
03Z/07	**SW 55G63**	SW 33G48
04Z/07	**SW39G74**	SSW 29G54
05Z/07	**SW 34G60**	SW 30G47
06Z/07	SW 27G54	**SSW 38G58**
07Z/07	SW 20G42	SSW 30G57
08Z/07	SW 15G39	SSW 18G45
09Z/07	SW 16G34	SW 9G29
10Z/07	SW 20G32	SW 13G33
11Z/07	SW 27G36	SW 15G25
12Z/07	SW 30G44	WSW10G28
13Z/07	SW 26G52	WSW 9G23
14Z/07	SW 42G46	SW 17G29
15Z/07	SW 39G59	SSW 22G40

Table 11

This table shows the hourly wind data (in MPH) for RAWS sites located across the foothills of the Antelope Valley. Individual weather elements highlighted in red denote observations that exceeded NWS Los Angeles/Oxnard High Wind Warning criteria. A high wind warning was in effect at the time of the strongest winds.