PACIFIC SOUTHWEST
Forest and Range
Experiment Station

FOREST SERVICE
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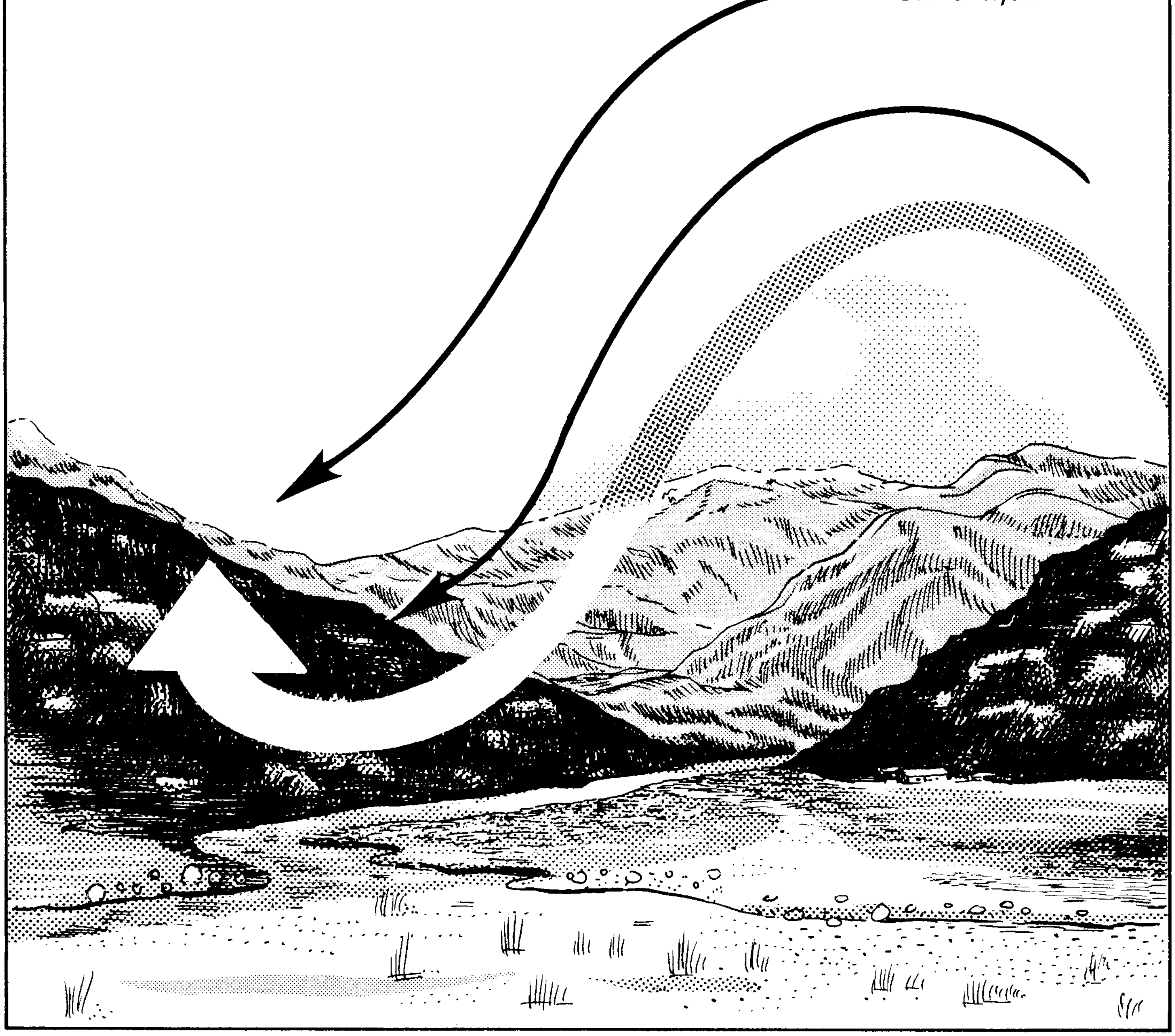
A VERTICAL PERSPECTIVE OF SANTA ANA WINDS IN A CANYON

Bill C. Ryan



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Contents

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ACKNOWLEDGMENTS

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Changes of windspeed and wind direction are of great importance to forest fire behavior. The ability to predict changes in winds can be of vital importance in fire fighting. One of the most significant wind phenomena affecting fire behavior is the foehn wind, which occurs in many parts of the world. Santa Ana winds of southern California are a good example of this warm, dry, downslope wind. Both strong and weak foehn conditions influence the ignitability of fuels and the rate of spread of fires. Strong winds are especially destructive because they induce a high rate of spread. The danger under weak foehn conditions however, is often underestimated. Under weak foehn conditions the wind direction at the zone of convergence (or more properly, confluence) with upslope airflow on the lee side of coastal ridges is extremely variable, making both fire behavior predictions and fire control more difficult. Under these weak foehn conditions on the lee side of coastal ranges very dangerous situations may occur.

The great influence of foehn winds, such as Santa Anus, on fire behavior makes it important to develop better techniques to forecast their occurrence, strength, and duration. Techniques to improve forecasts of a few minutes to several days are needed. A fundamental requirement is knowledge of the relations of location, time, and strength of wind to the synoptic situation. If such relations are established, the forecasting of foehn winds becomes a matter of forecasting synoptic patterns, for which techniques are more advanced and these forecasts are made routinely. But, the relation of the wind to the synoptic situation is complicated, primarily by the effects of topography on wind patterns, which are highly significant in southern California because of the size and variety of topographic features.

The basic large-scale patterns associated with foehn winds have been studied statistically and are quite well defined (Sergius 1952; Schroeder et al. 1964). Fosberg, O'Dell, and Schroeder (1966) studied the three-dimensional structure in two instances of Santa Ana winds on a scale involving the entire Los Angeles Basin. They also present a comprehensive account of earlier studies of both foehn and Santa Ana winds. However, little is known about local and short-time foehn effects, especially in the vertical dimension, although knowledge of these effects is particularly important in fire prevention and control. Few studies of the small-scale foehn effects have been made, primarily because of the cost of maintaining dense networks for small-scale analysis.

The purpose of this study was to develop techniques of small-scale analysis and obtain a more detailed vertical perspective of Santa Ana winds.

Field Study

San Antonio Canyon in the San Gabriel Mountains was chosen for this study of the effects of topography on the vertical variation and distribution of wind velocities. This canyon is highly suitable because of its location to the southwest of the ridge of the San Gabriels and its almost due north-south orientation *(figs. 1, 2)*. Some bends cause perturbations in the wind field and complicate analysis, but as a whole the canyon appears to be close to ideal.

Instrumentation was set up several weeks before Santa Ana conditions occurred and actual field operations could begin. At each weather station we mounted instruments on a 20-foot steel mast. A cup anemometer and wind vane were mounted at 20 feet and a psychrometer, aspirated by an electrically driven fan, was mounted at 4 feet. This system of wind and temperature measuring devices was connected electrically to a timer and a programming set of relays, which interrogated the instruments every half hour sequentially for windspeed, wind direction, temperature, and wet-bulb temperature. The instruments were also connected to a chart recorder.

Eight weather stations were placed along the canyon in locations 11-18 *(fig. 1)*. Several considerations made the selection of suitable sites difficult. It was most important that the site have winds and temperatures that were representative of the area. But almost as important, the site had to be protected as well as possible from vandalism. We were only partially successful in meeting either requirement. Observations taken near the recording surface stations suggested that at some of the sites the data were representative of only a small area, and three stations were either stolen or damaged before this part of the study was completed.

Two trailers for rawinsonde (RAWIN) observations were taken to the California Division of Forestry Phelan Station and prepared for quick activation for the field study. A suitable aircraft for carrying sensing and recording instruments was located and contracted to fly on short notification. The four-channel high-precision tape recorder, temperature probe, and pressure transducer were installed, and a test run was made.

Two sites for double-theodolite pilot balloon (PIBAL) observations were established. They were located at P1 and P2 *(figs. 1, 2)*. A third was established at Mt. San Antonio (Mt. Baldy) Notch, but was not used due to lack of personnel.

Field Operation

In January 1968, after the equipment and plans were readied, the 13 persons required for the operation, plus several alternates, were alerted to be ready to move to the field for a 12-hour operation upon a forecast of Santa Ana conditions. The first applicable Santa Ana occurred on February 29. It lasted only a few hours. Two other operations were run before the study was discontinued for the summer. The second operation took place on March 20, 1968, and the third on April 22, but in both cases the Santa Ana conditions dissipated within a few hours so that a prolonged study was not possible. However, sufficient data were gathered to construct streamline analyses and vertical cross-section isentropic analyses.

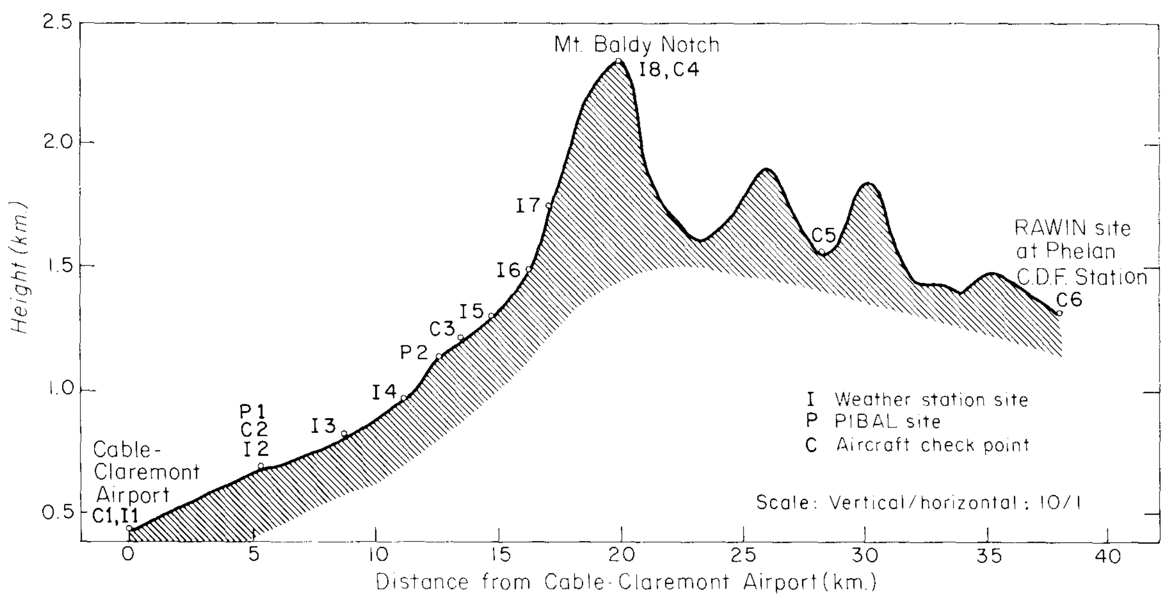

Figure 1.—*Location of weather stations, aircraft checkpoints, PIBAL sites, and RAWIN sites.*

Data Reduction and Analysis

The surface observations that had been recorded on chart paper were read, plotted, and analyzed.

The instrumented aircraft obtained temperatures through a cross section of the atmosphere from Cable-Claremont Airport to the Phelan Station. These cross sections extended from about 10,000 feet to as near the ground as possible. Temperatures and pressure altitudes were recorded continuously on magnetic tape as the aircraft flew along flight paths at 1,000-foot height intervals. At the same time, the observer in the aircraft dictated notes into another channel of the recorder. The recorded comments of the aircraft observer were used to verify the direction of vertical air motion, especially in areas where interpolation was used in the streamline analysis. The observer's reports of turbulence were also often useful to verify the existence of zones of vertical and horizontal shear indicated by the streamline analysis. After the operation, the tape record was transferred to chart paper. The temperature and pressure data were read from the chart paper and entered into the computer for computation of potential temperature and height above sea level. These data were then plotted on vertical cross sections and analyzed.

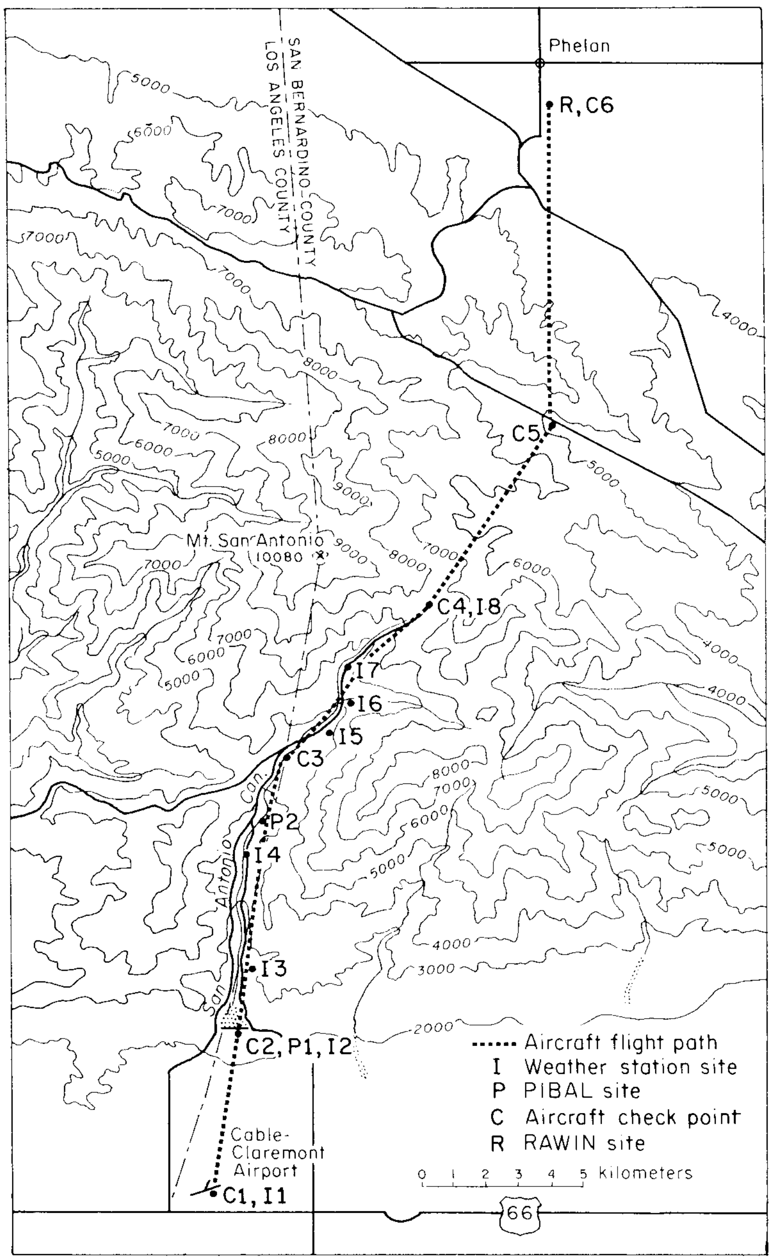

Figure 2.—*Locations of weather stations, aircraft check points, PIBAL and RAWIN sites.*

The rawinsonde data were also punched into cards, and computations of windspeed and wind direction, temperature, and dewpoint temperature were made and plotted against height above sea level by computer. The vertical wind component was determined by calculating the actual vertical velocity less a computed average velocity to the top of the sounding.

The double-theodolite observation recordings on paper tape were read, and the data from the paper tapes as well as the data recorded manually were punched into computer cards. Windspeeds, wind directions, vertical motion, north-south and east-west components of motion, and observational error were determined, by the technique given by Thyer (1962), and windspeed and wind direction were plotted against height by computer. The vertical wind component was determined from the double-theodolite soundings by calculating the actual vertical velocity less the standard vertical velocity used to make single pilot-balloon observations.

Vectors indicating wind velocity in the plane of the vertical cross section were determined from the vertical and north-south wind components obtained from the PIBAL and RAWIN observations. These vectors were plotted on the cross section with the plots of the surface wind observations, and analyzed. Many more PIBAL observations were taken than are reported here, but frequently one or more of the four observers at the two sites had to abort the observation before completion because he lost track of the balloon behind an obstacle. As a result, only a few observations were synoptic or close enough to be used. Fortunately, the similarity of the analyses for the same day indicates that fairly steady state conditions existed on these days. From this evidence, and evidence from the aircraft observer, the assumption can be made that the small differences in times of observations that were used did not cause excessive errors in the streamline and temperature analyses.

Facsimile synoptic charts from the U.S. Weather Bureau were used as the source of information for large-scale weather patterns.

Discussion

In the typical Santa Ana situation, a cold high-pressure system is found at the surface in the Great Basin, so that there are much higher pressures and lower temperatures in Nevada than along the coast of southern California; windflow aloft is relatively strong from the north or northeast. January 19, the day the aircraft instrument test was made, was a good example of Santa Ana conditions. There was a cold, well-developed high pressure center *(fig. 3)* in the Great Basin and a strong pressure and temperature gradient from Nevada to southern California. (Strong winds occurred in the San Gabriel Valley during the day, although they were not plotted on this chart.) The 500-mb. height contours *(fig. 3)* are indicative of the northerly winds that support strong Santa Ana winds. On January 19 there was also a well-defined isentropic pattern *(fig. 4)* parallel to the windflow. This is the typical pattern associated with Santa Ana and lee wave occurrence (Fosberg et al. 1966).

The typical synoptic situation for a Santa Ana seemed to be developing a few days before the date of our first field operation. By the evening of February 26, the movement of the isobaric pattern from the northwest to the southeast indicated that a Santa Ana was possible within the next 2 or 3 days. The high-pressure system centered in southwestern Canada was moving into the Great Basin. The upper-air ridge was increasing in amplitude along the coast of California. The trend continued, and the first field operation was scheduled to begin at 1200 P.s.t. on February 29. The surface high had moved into the Great Basin *(fig. 5, left)* and weak northerly flow developed over southern California. By 1600 P.s.t. the situation had deteriorated. The shift by 1600 P.s.t. of the windflow to southerly and westerly at 500 mb. is shown in figure 5 (right). By 2200 *(fig. 6)* the surface gradient had decreased so that only light winds were observed in the area. Figures 7 and 8 show the streamlines and potential temperature (isentropic) patterns for the afternoon of February 29. (The potential temperature is the same on both figures because only one flight was made on that day.)

The isentropic pattern of February 29 can be compared with the pattern on January 19 *(fig. 4)*, when the aircraft instrument test flight was made. The pattern on January 19 was the typical potential temperature pattern in Santa Ana conditions. The potential temperature pattern on February 29 does not show this characteristic pattern, in which the isentropes are parallel to the streamlines, except to some extent over the Notch. This lack of correspondence between the two patterns is evidently due to the lack of static stability and a nonlaminar temperature field, as shown by the almost adiabatic lapse rate and the nonlaminar isentropic pattern.

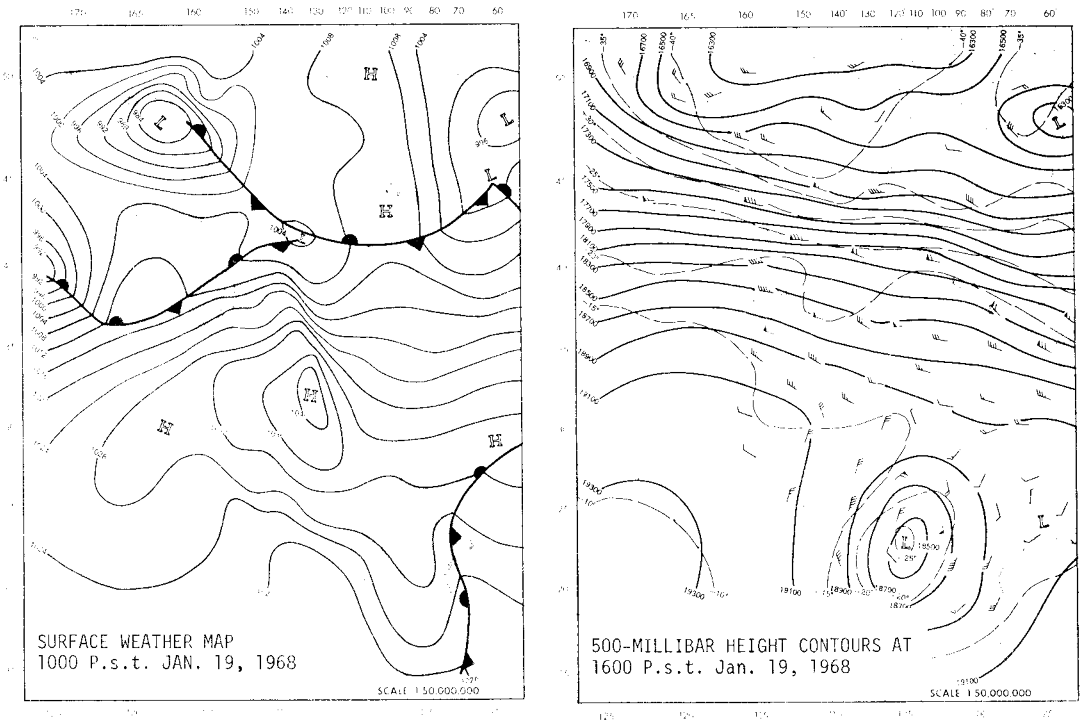

Figure 3.–*Surface weather and 500-mb. height contours on January 19, 1968.*

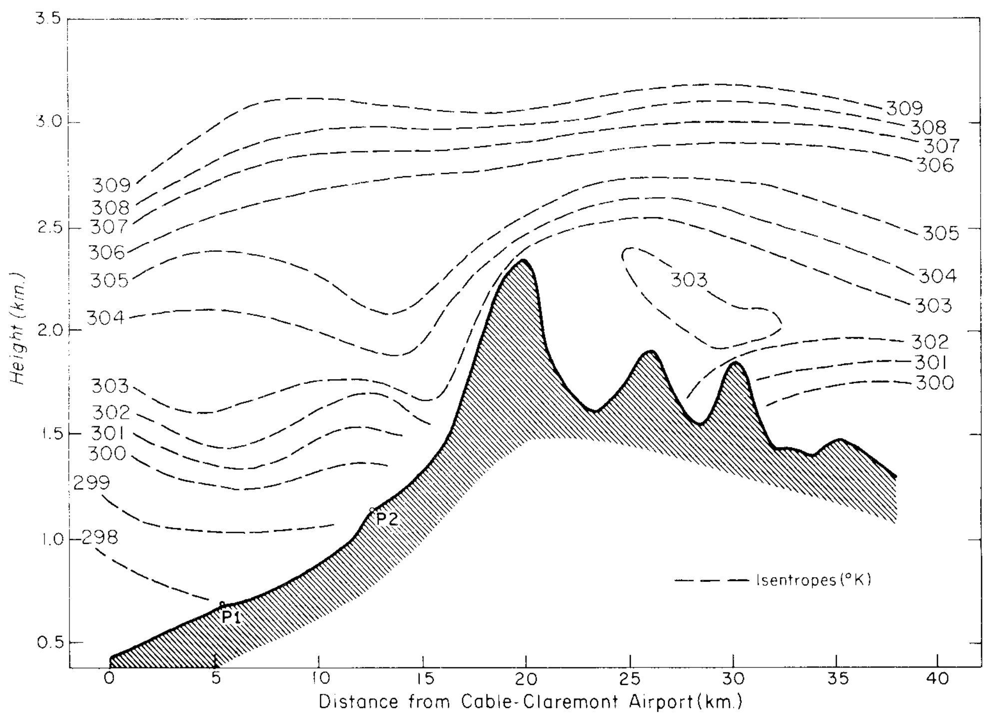

Figure 4.–*Potential temperature field obtained by aircraft from 1355 to 1555 P.s.t., January 19, 1968. Potential temperatures are in degrees Kelvin on this chart and on all other charts.*

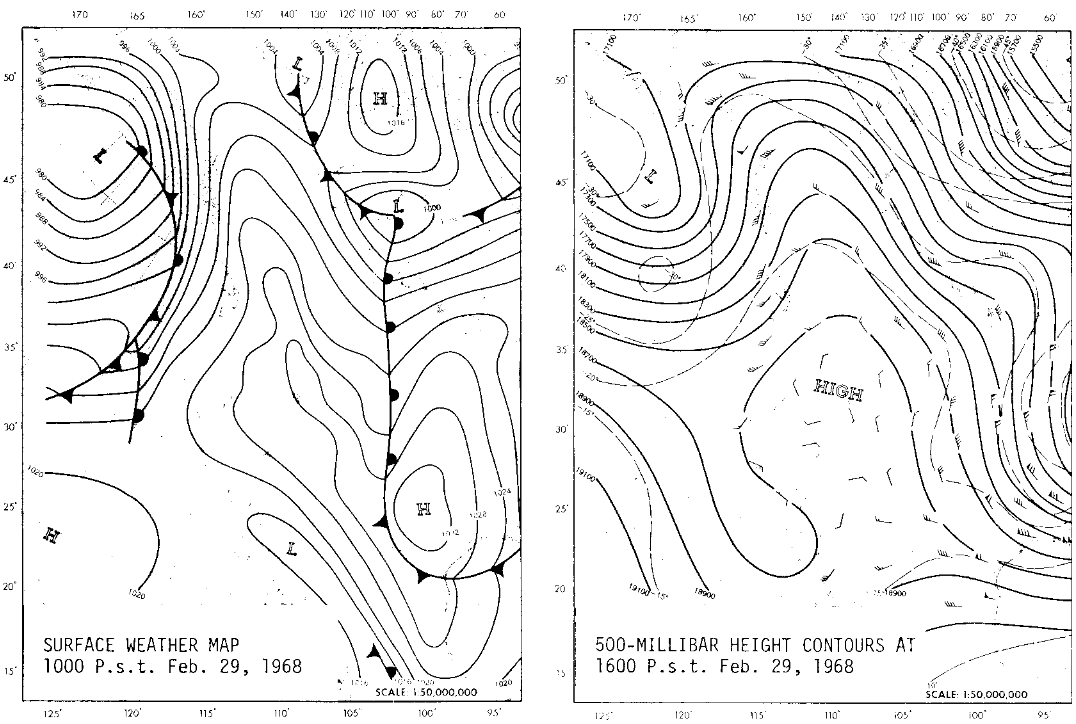

Figure 5.—*Surface weather and 500-mb. height contours on February 29, 1968.*

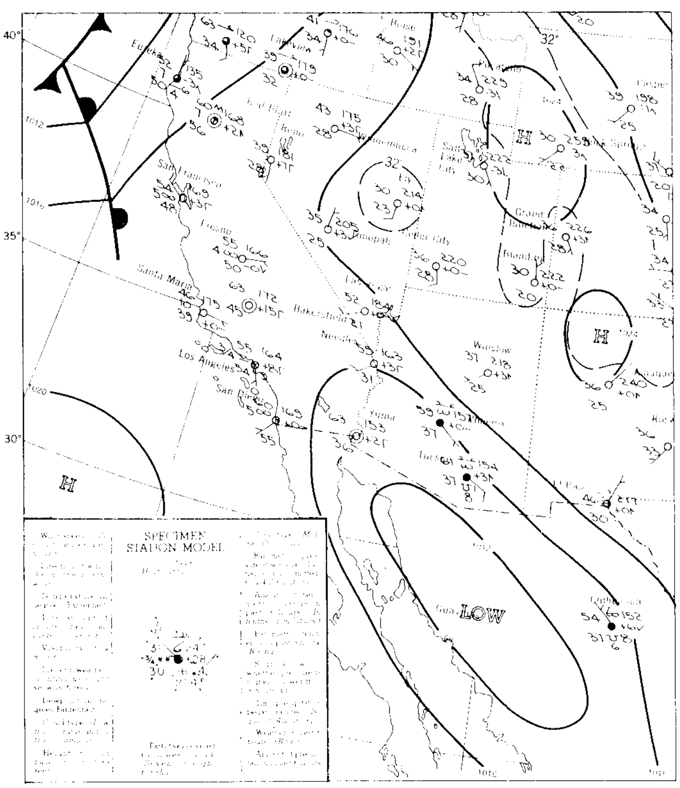

Figure 6.—*Surface weather map and station weather at 2200 P.s.t., February 29, 1968.*

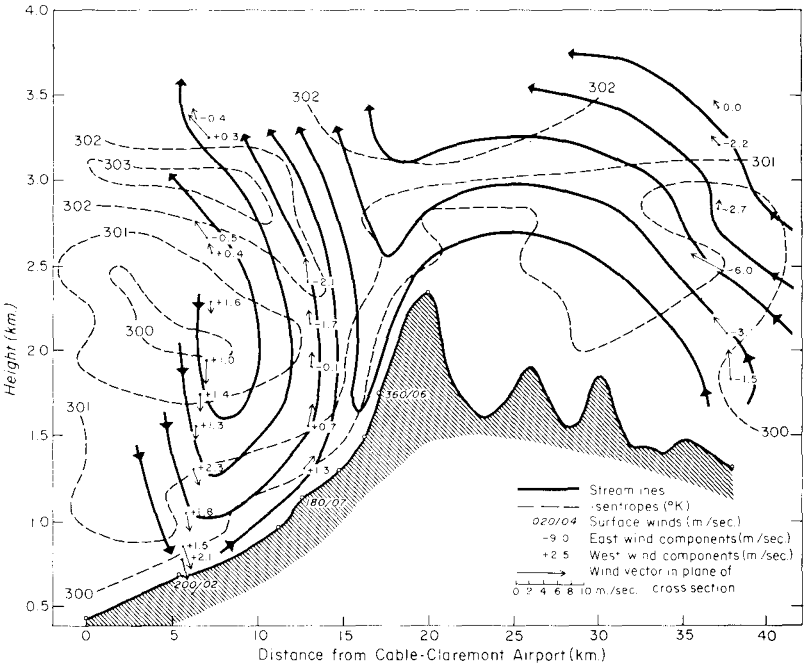

Figure 7.—*Streamline analysis from double-theodolite PIBAL observations at site P1 at 1300 and site P2 at 1255 P.s.t., surface wind observations near 1300 P.s.t. and RAWIN observations at 1200 P.s.t. Potential temperature field obtained by aircraft from 1154 to 1315 P.s.t. February 29, 1968.*

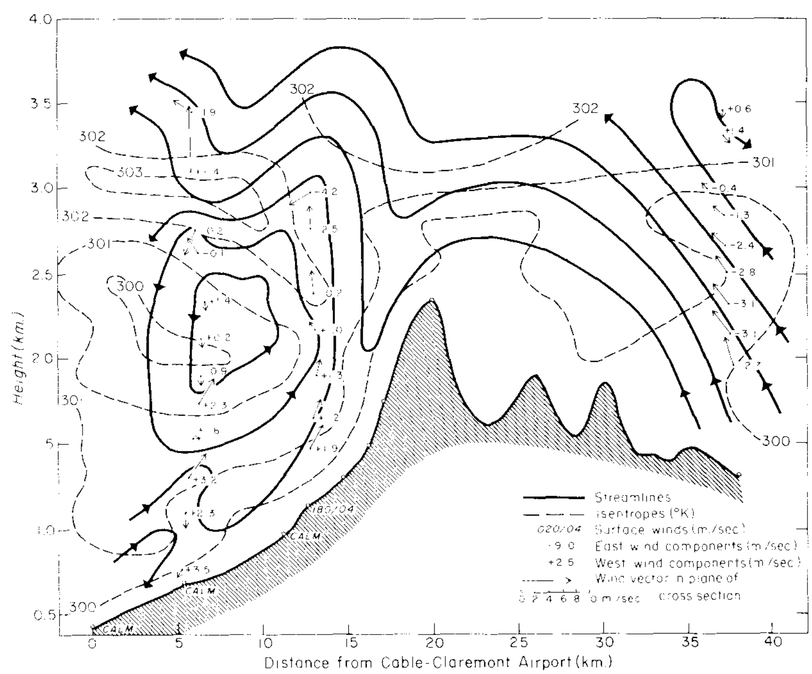

Figure 8.—*Streamline analysis from double-theodolite PIBAL observations at site P1 at 1502 and site P2 at 1504 P.s.t., surface wind observations near 1500 P.s.t. and RAWIN observations at 1400 P.s.t. Potential temperature field obtained by aircraft from 1154 to 1315 P.s.t., February 29, 1968.*

The potential temperature pattern on February 29 indicated that the atmosphere was not very stable. Potential temperatures showed little or no increase with height, much less than on January 19. The flow on the north side of the range over Phelan was northerly, but no strong Santa Ana winds occurred in the San Gabriel Valley as they did on January 19. This is understandable in that lee waves are associated with stable atmospheric conditions (Scorer 1949) such as occurred on January 19. The striking characteristics of the flow on February 29, as on the other two days of operation, are the penetration of the air into the canyon as it comes over the crest of the range, and the sharply defined zone of converging winds. The movement of the zone evident in a comparison of the 1300 P.s.t. analysis with the 1500 P.s.t. analysis is interesting. The weakening of the flow is reflected in the greater penetration of the south wind on the south side of the slope later in the afternoon. Under situations such as this, the light winds pouring over the crest of the range from the offshore direction react strongly with air moving up the valley from the onshore direction. It is evident that a slight rise or lowering of the airflow pattern can cause rapid change in windspeed and direction. One can also see how rapid change in temperature and dewpoint temperature may accompany these changes in windflow.

The three-dimensional flow in the area from the lower PIBAL site to the C.D.F. Phelan Station can be determined by considering the vertical and north-south flow, indicated by the vectors on the cross section, and the east-west flow, indicated beside the wind vectors. For instance, in the early afternoon of February 29, as shown in figure 7, the flow over the dam was descending from the southwest. This flow was evident from near the surface to near 2.4 km. Above 2.4 km. the flow ascended with little horizontal component. Over the upper site the flow was ascending from the southwest. This flow was evident up to about 1.8 km.; then the flow became easterly. Over Phelan the flow was ascending from the northeast.

The second field operation was on March 20. This Santa Ana situation set up in quite a different way from that of February 29. The strong winds aloft were established in southern California by March 18. These northeasterly winds were associated with a strong trough to the east of the area *(fig. 9)*. The surface pressure gradient was not established until March 20, and even then did not reach great enough strength to cause strong winds *(fig. 10)*. Winds on March 20 were stronger than on February 29 and a deeper lee trough formed *(figs. 11, 12)*. There was

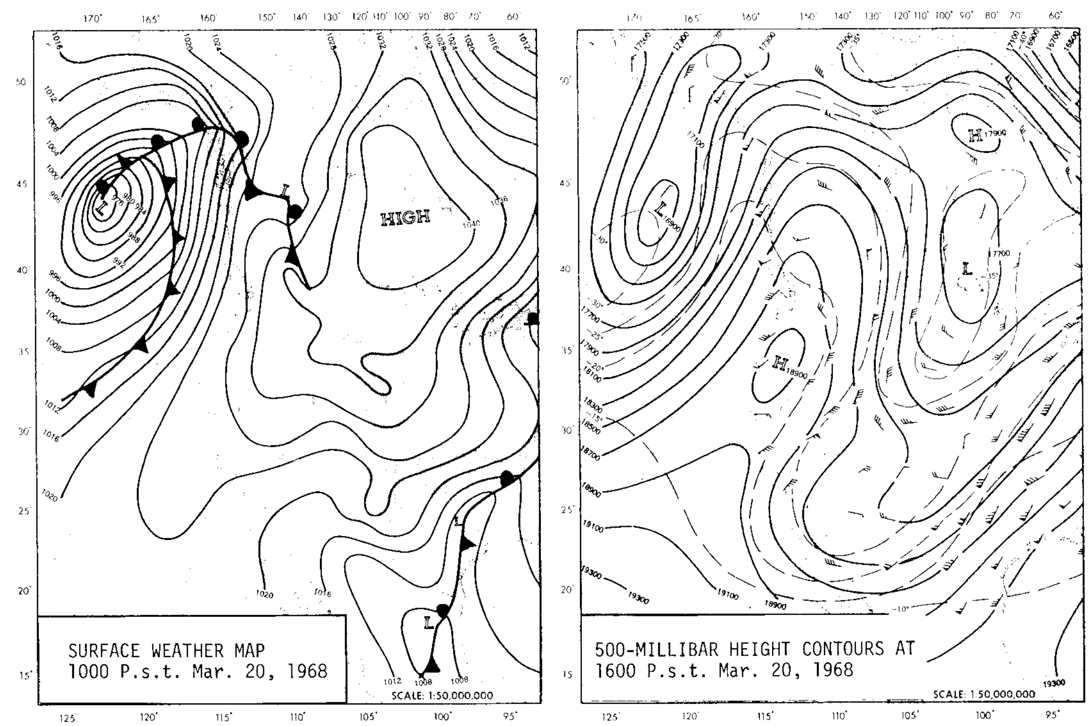

Figure 9.—*Surface weather and 500-mb. height contours on March 20, 1968.*

little movement of the trough between the time of the first observation at 1400 P.s.t. and the observation at 1700 P.s.t., but a great change occurred at San Antonio Dam, where the surface winds changed from 160° at 4 in./sec. to 340° at 9 m./sec. The cross-section analyses show how the vertical eddy changed to cause the reversal of flow. Examination of the isentropic pattern shows an almost unstable condition. There was little increase in potential temperature with height. Above the surface layer both at 1400 P.s.t. and 1700 P.s.t. there was a sudden change of horizontal wind direction between PIBAL site 2 and site 1. For instance, at 1400 P.s.t. at 2.2 km., winds were from 054º at 15.9 m./sec. at site 2, but 304° at I .8 m./sec. at site 1.

On April 20 it appeared that there was a good chance of Santa Ana conditions within the next two days. A cold front passed through the western part of the country in the morning, followed by a short wave trough. This is the fairly common sequence of development of Santa Ana winds. The trough aloft moved over southern California and established strong northerly winds aloft. The cold surface high-pressure system finally built up in the Great Basin on April 22, to be wiped out a few hours later by another cold front. Comparison of figures 13 and 14 shows how fast the high-pressure system built up. It broke down just as fast. By the following day, April 23, the front was lying across the Great Basin where the high center had been.

The winds reported by the rawinsonde unit at Phelan at 1200 P.s.t. *(fig. 15)* and 1450 P.s.t. *(fig. 16)* on April 22 were strong and northerly. At 1200 P.s.t. the wind at 3.3 km. was 350° at 11.8 m./sec.; at 1450 P.s.t. the wind at 3.4 km. was 348° at 12.7 m./sec. At both times there was a large vertical component to the wind. The lee trough was again noticeable over the upper double-theodolite site at the times of both analyses on this date. Little convergence was shown by these observations at the upper levels, but there was a large vertical shear of winds in the lower levels.

The wind was southerly at and just above the lower PIBAL site, but the 1.8 km. level above the site. the winds were northerly. At the upper site the wind became northerly below 1.4 km. Similar vortices were evident at the times of both analyses on April 22. It appears that this pattern moved from over the dam up the canyon to a position almost over site P2 between 1330 P.s.t. and 1500 P.s.t. With this movement, the lee trough also retreated up the canyon. At both times the lee wave penetrated only deep enough to influence the surface winds very slightly. No winds recorded on the surface along the canyon showed much northerly component.

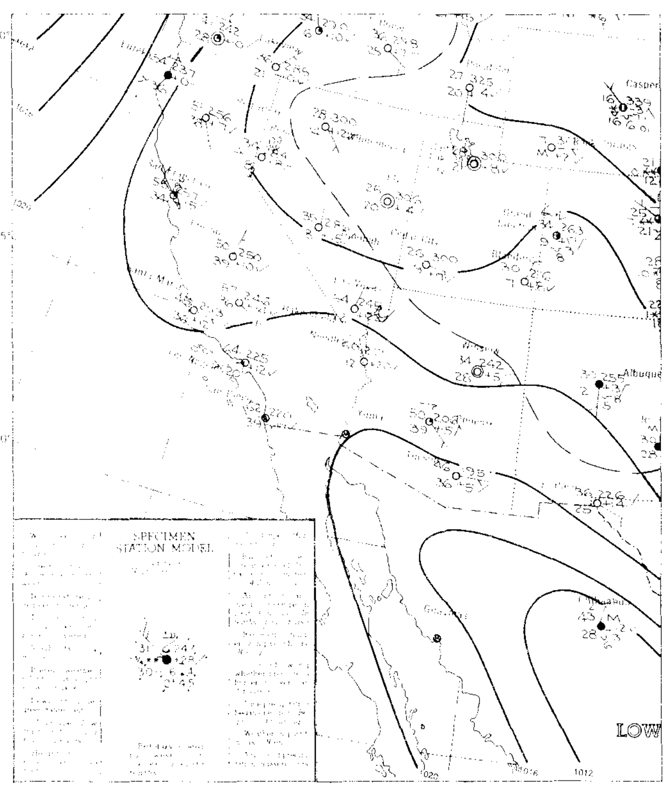

Figure 10.–*Surface weather map and station weather at 2200 P.s.t., March 20, 1968.*

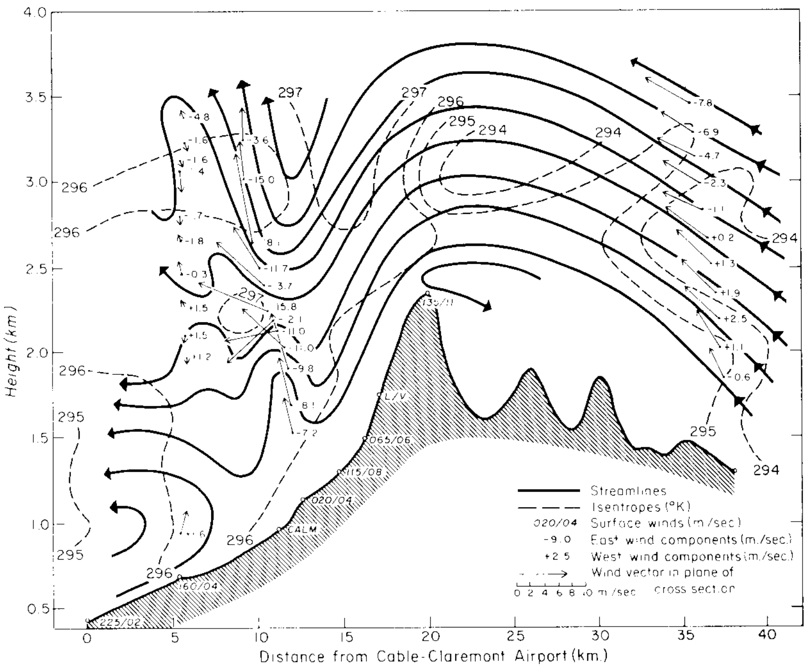

Figure 11.—*Streamline analysis from double-theodolite PIBAL observations at site P1 at 1359 and site P2 at 1400 P.s.t., surface wind observations near 1400 P.s.t. and RAWIN observations at 1450 P.s.t. Potential temperature field obtained* by *aircraft from 1211 to 1336 P.s.t., March 20, 1968.*

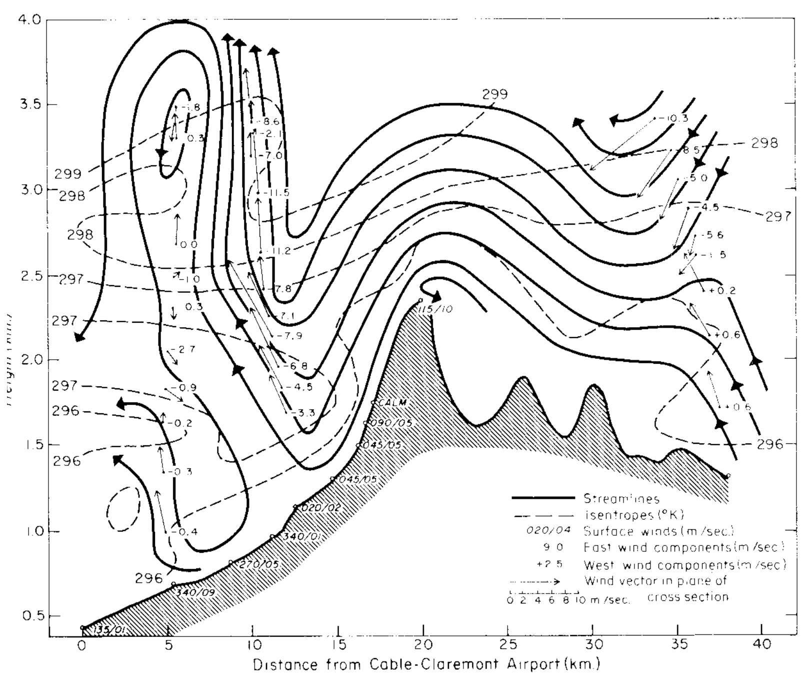

Figure 12.—*Streamline analysis from double-theodolite PIBAL observations at site P1 at 1659 and site P2 at 1700 P.s.t., surface wind observations near 1700 P.s.t. and RAWIN observations at 1800 P.s.t. Potential temperature field obtained by aircraft from 1615 to 1734 P.s.t., March 20, 1968.*

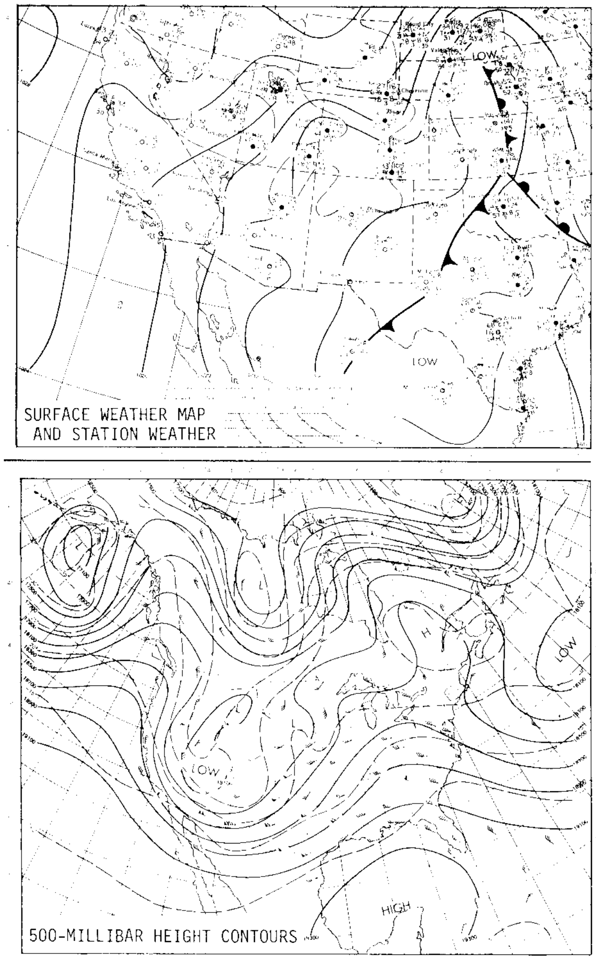

Figure 13.—*Surface weather map and 500-mb. height contours, 0400 P.s.t., April 22, 1968.*

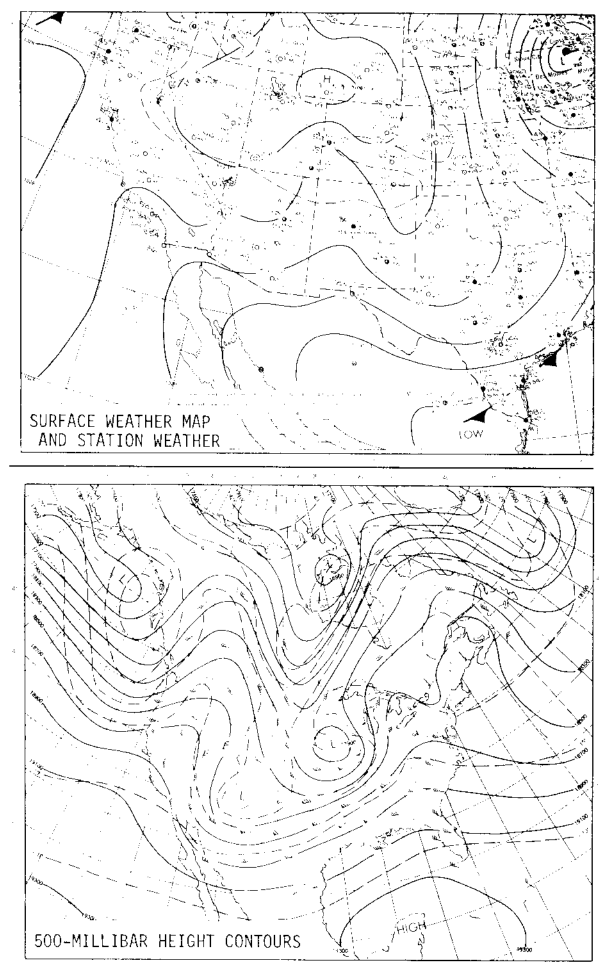

Figure 14.—*Surface weather map and 500-mb. height contours, 0400 P.s.t., April 23, 1968.*

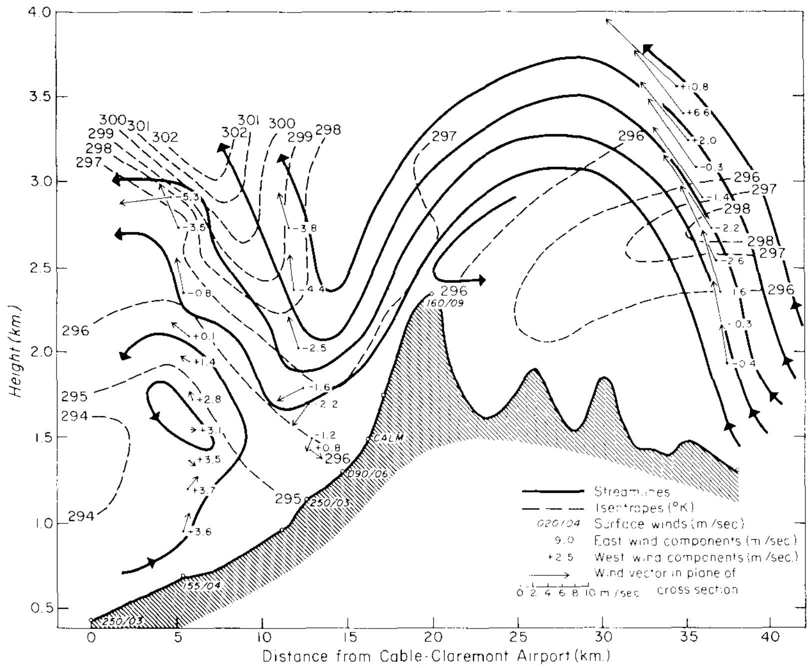

Figure 15.—*Streamline analysis from double-theodolite PIBAL observations at site P1 at 1325 and site P2 at 1330 P.s.t., surface wind observations near 1330 P.s.t. and RAWIN observations at 1200 P.s.t. Potential temperature field obtained by aircraft from 1200 to 1317 P.s.t., April 22, 1968.*

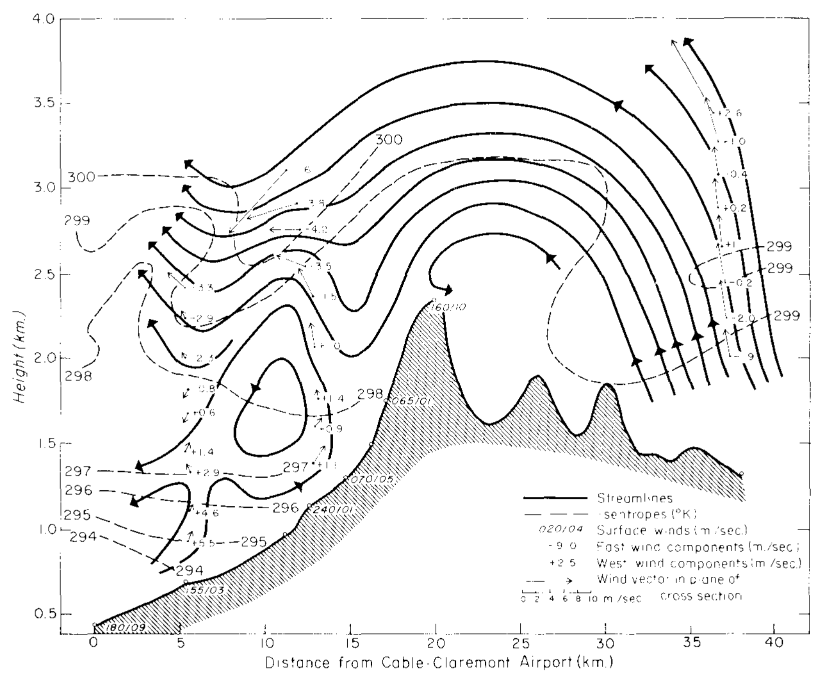

Figure 16.—*Streamline analysis from double-theodolite PIBAL observations at site P1 at 1500 and site P2 at 1500 P.s.t., surface wind observations near 1500 P.s.t. and RAWIN observations at 1450 P.s.t. Potential temperature field obtained by aircraft from 1615 to 1735 P.s.t., April 22, 1968.*

Conclusions

The cross-section analyses of the 3 days of weak Santa Ana conditions reveal how rapid changes in windspeed and direction may occur under these conditions. The analyses indicate the significant dip of the wind field down the lee side of the range even under relatively light wind conditions, and show how opposing wind systems interact on the lee side to allow rapidly changing surface winds. The well-defined convergence zone and the vertical wind field are obvious.

The perspective derived from these cross-section analyses can give fire weather and fire behavior forecasters a greater insight into wind field variations, and give them a better grasp of the reasons for the complexities of surface wind variations.

We plan to continue the study to investigate Santa Ana winds and foehn winds in other areas under varying strengths and conditions. With more data we can establish a closer relationship of synoptic parameters to Santa Ana winds and the surfacing of lee waves, and on this basis, make more accurate forecasts of wind and wind shifts as a function of topography. We can also determine the relationship of wind field to temperature field under varying atmospheric conditions, and thus better determine wind fields from temperature fields, which are more easily measured. These data and data collected in the future will also be used to develop mathematical models based on atmospheric stability, wind pressure, and temperature fields. With these models, fire weather and fire behavior forecasters will be able to predict fire behavior more objectively.

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