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A Study of the Low Level Jet Stream of the San Joaquin Valley (Project Lo-Jet)

RONALD A. WILLIS AND PHILIP WILLIAMS, JR.

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U. S. DEPARTMENT OF COMMERCE
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A STUDY OF THE LOW LEVEL JET STREAM OF THE SAN JOAQUIN VALLEY (PROJECT LO-JET)

Ronald A. Willis
Weather Service Office
Fresno, California

Philip Williams, Jr.
Western Region Headquarters
Salt Lake City, Utah

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A STUDY OF THE LOW LEVEL JET STREAM OF THE SAN JOAQUIN VALLEY
(PROJECT LO-JET)

ABSTRACT

A network of eight pibal observation points was set up in the San Joaquin and southern Sacramento valleys of California to study the low-level evening jet stream that has been found to exist almost daily during summer. Data was also available from special radiosonde observations, an aircraft temperature sounding, wind tower measurements and hourly and special surface observations. Pibal observations were taken hourly from 1715 PST to 0015 PST on two consecutive evenings in early August 1971. Vertical sections, both along and across the valley, streamline analyses and time sections were prepared from observed upper-air data and supplemented with analyses of various surface parameters.

On both evenings of Project Lo-Jet, a relatively strong up-valley jet stream was found to exist at an average height of about 300 meters above ground level with highest wind speeds of about 20 mps from the northwest. The jet was found to be strongest in the north and central sections of the valley where cool marine air has an unobstructed path into the valley, and weakest in southern sections where the valley is ringed on three sides by high mountains.

Analysis of the data suggests that the low-level jet stream is caused by a number of contributing factors. Existence of the strong thermal low in the desert southwest, the source of cool marine air to the northwest, downslope winds from mountains on both sides of the valley and reduction of surface frictional drag at the top of the boundary layer after sunset are all thought to contribute to formation of the jet wind.

This summertime low-level jet stream is not unique to the San Joaquin Valley. Similar winds have been shown to exist in the Sacramento valley and should be suspected to exist in other valleys in the western states with similar geographical features. Once the existence of such a wind pattern in an area is determined, accurate forecasting of this wind would be very valuable to aviation interests, forest fire fighting officials, air pollution control agencies and others.

I. INTRODUCTION

Low-level jet winds are known to exist in many areas and have been described extensively in the literature. Means (1954) was one of the first to point out existence of a low-level southerly jet in the midwest.

Wexler (1961) and Gerhardt (1962) explained the nocturnal jet of the western Great Plains as a boundary-layer phenomenon, related to stability in the lowest layer. Blackadar (1957) stated that "examples of low-level wind maxima may be found almost anywhere in the United States during any season of the year...the phenomena is best developed over the Great Plains during nighttime hours". He further stated that wind speeds at the level of the jet maximum are considerably supergeostrophic, with the wind-speed maximum located at the top of the inversion. He postulates that after the nocturnal inversion first begins to be established, near sunset, turbulent mixing very rapidly dies away above the inversion and ceases to have any important effect on the motions at these levels. Miller (1968) studied the relationship of wind profiles to the temperature inversion of the San Francisco Bay area. He found a wind-speed minimum near the base of the inversion and a maximum near the top that frequently takes on the appearance of a jet. Rider and Armendariz (1971) have found a high frequency of occurrence of nighttime low-level wind maxima at White Sands Missile Range, New Mexico. They identified three types of low-level jet-like winds and classified them by existing synoptic weather patterns and the height at which the maximum wind speed was observed.

The San Joaquin Valley low-level nocturnal jet most certainly has some of the properties ascribed to jet phenomena in other localities by authors cited above; however, because of the topography of the valley and surrounding mountains, nearness to the ocean and marine layer, and presence of the Pacific high with its subsidence inversion, the San Joaquin jet must differ in certain important aspects.

The existence of a strong northwesterly nocturnal jet wind over Fresno, California, has been known for several years. This was shown by evening 30-gram pibals formerly taken at the National Weather Service Office (NWSO) Fresno. The jet wind appeared to be an almost daily occurrence in the hot summer months. In a summary of data from forty-two 2130 PST pibals taken during July 1964 and July 1965, the average surface wind speed at Fresno (elevation 100 meters) was about 7 mps. Wind speeds increased to a maximum of 13 mps at about 600 meters msl, then decreased to about half that speed at a height of 1200 meters msl (Figure 2). If the strong low-level winds observed at Fresno could also be found over much of the rest of the 100-mile wide 250-mile long San Joaquin Valley, it would be of considerable importance to a variety of weather-oriented operations. Project Lo-Jet was therefore initiated to determine the horizontal and vertical extent of this nocturnal low-level jet, the wind speeds involved, its thermal characteristics and its relation to the overall large-scale wind, temperature and pressure patterns. Due to limited resources, the study had to be confined to two evenings, August 2 and 3, 1971. These dates were chosen assuming the jet wind would be at or near its maximum intensity during the hottest time of the year.

The San Joaquin jet winds are related to afternoon marine air invasions into the San Francisco Bay and San Joaquin delta region, the flow later being up the San Joaquin Valley toward the southeast. Schultz and Fitzwater (1968) and Schultz (1971) have shown that in summer, penetration of marine air through the Bay area into the delta region begins in midafternoon taking the shape of a low-level jet after sunset. According to Schultz, an important feature of the inflowing air is the fact that jet winds are maintained until dawn, which is not in agreement with the usual land-sea breeze regime. He notes this phenomenon occurs on about 90 percent of all days in summer but declines to 25 percent in fall months. Since summer jet winds appear to be present over Fresno almost daily, the Bay area inflow can be presumed to be related to the jet winds over Fresno. Formation of a radiation inversion with consequent decoupling of the low-level flow from surface frictional influences, and down canyon winds from the Sierra Nevada to the east also appear to play major roles in formation, maintenance, and location of the nocturnal jet.

II. DATA ACQUISITION

In order to study the San Joaquin Valley summer nocturnal jet within limits of available resources, a network of seven pibal observation points within the San Joaquin Valley and one in the Sacramento Valley was established (Figure 1). Pibal observations were taken at Tracy and Stockton at the north end of the valley, Five Points, Caruthers, and Fresno in the central part and Taft and Bakersfield at the south end. Pibals were also taken at Sacramento at the south end of the Sacramento Valley.

Ten-gram pibals were used with single theodolite tracking. Pibals were tracked to a height of about 1600 meters above ground level (AGL). which was considered ample for the Lo-Jet study. The low termination height of observations eliminated necessity for a larger balloon. The slower ascension rate of the ten-gram balloon was deemed more desirable since the jet wind was known to have a very limited vertical extent. The ascension rate of the ten-gram balloons averaged about 128 meters per minute as compared to about 180 meters per minute for a 30-gram balloon. Azimuth and elevation angle readings were taken each minute. Readings every half minute would have been more desirable, but due to relatively high wind speeds in lower layers, tracking would have been difficult. Pibal observations were taken for eight consecutive hours from 1715 PST to 0015 PST on each of the two nights, August 2 and 3, 1971. The time was chosen so as to observe the jet during its onset, time of maximum intensity, and hopefully during its dissipation. (Note: all times mentioned in the discussion are PST.)

Two radiosonde observations (raobs) at Atmospheric Water Resources Research (AWRR), Fresno, (taken at 2129 and 2215 August 2 and 3 respectively), reached to about 3000 meters. One raob was taken at Lemoore Naval Air Station (NLC) at 2250 August 2 to above the 300-mb level. Aircraft soundings were taken at Stockton at 2000 both nights. These reached a height of 1830 meters, and recorded temperature only. Observations were taken every 150 meters above ground with the rate of climb of the aircraft about 150 meters per minute.

The regular 1600 and 0400 radiosondes for Oakland were also available plus a few wind speeds at Walnut Grove tower, between Sacramento and Stockton, at Mt. Tamalpais just north of San Francisco Bay and Pacheco Pass in the mountains west of San Louis Reservoir. Routine surface observations from NWS, military, and FAA weather observing stations throughout the area were used to plot and analyze 3-hourly surface isobaric charts for a 48-hour period from 0700 August 2 to 0700 August 4. Surface and 500-mb charts received from the NWS National Meteorological Center at Suitland, Maryland, were used to give a picture of the larger-scale synoptic patterns. The low-level jet normally forms under conditions of clear skies and warm temperatures.

Two ten-gram pibals were taken at Fresno within 24 hours prior to the study, at 2030 August 1 and 1315 August 2, 1971. These runs were taken to make certain Project Lo-Jet was being undertaken when the jet wind was well developed, as well as to confirm its diurnal nature (Figure 3). The jet showed up well at 2030 August 1 (solid line) with the normal diurnal slacking at 1315 the next day (dashed line).

NWS personnel encountered some difficulties with pibal observations at Tracy on August 2 due to inflation problems. No pibals were taken at 1815 and 2315 August 2, 0015 August 3, and data from the 2215 pibal was not deemed usable. Pibals for 2015 and 2115 August 2 were taken with a lighting unit, but additional gas was not added to the balloons to compensate for weight of the unit. Test runs at a later date indicated the ascension rate of a balloon thus inflated would be approximately 80 percent of the normal rate. Data for the two hours in question were then recalculated using the corrected ascension rate and should be reasonably accurate. Other missing observations, for various reasons, were the last 8 minutes of the 1715 August 2 observation at Stockton, and the observations at Bakersfield for 2315 August 3 and 0015 August 4.

The very slight downward slope of the San Joaquin Valley from south to north, approximately 260 meters in 250 miles, indicates the valley floor could be treated as a level surface. It is assumed frictional influences, as measured by distance above ground level, are far more important in this study then gravitational influences. For this reason, quasi-horizontal charts have been used to depict the flow at various levels above ground. However, longitudinal sections along the valley have been presented with data plotted above msl to validate this assumption.

III. THE SYNOPTIC SITUATION OF AUGUST 2 - 3, 1971

Typically during summer, a large surface high-pressure system lies off the west coast of California with a thermal low dominating the desert areas northwestward through the interior valleys of California. At 500 mbs a large high-pressure area is usually found centered over southwestern United States, with a weak trough off the West Coast. Surface and 500-mb charts for 1600 August 2 and August 3, 1971, are shown in Figure 4 and indicate Project Lo-Jet was undertaken during a time when overall synoptic conditions were nearly normal. The influx of marine air each afternoon from the Bay area appears to be related to the time of maximum onshore surface pressure gradient (see detailed surface charts, Figures 5a to 5e). On both days of the study, the minimum onshore gradient occurred at 0700 (Figures 5a, 5d) and the maximum at 1600 (Figures 5b and 5e). The gradient increase was caused by the greater intensity of the thermal low-pressure system in the interior valleys in the afternoon. Note that even in the evening hours when the jet was at its maximum intensity, there is very little pressure gradient along the axis of the valley (Figure 5c) and that the principal driving force appears to be the pressure gradient from the Bay area inland to about Merced (MER), which forces air into the valley and maintains its push through much of the night.

There were, however, some minor changes in the pattern the second day of the study which significantly affected the intensity of the low-level jet. Under normal summer conditions, the principal route for marine air to enter the San Joaquin Valley is through the San Francisco Bay area thence northeastward into the Delta Region at the northwest end of the valley (Figure 6). Some marine air can also flow through low passes in the coastal hills east of San Francisco Bay, as at Altamont Pass (300 M) west of Tracy (Figure 1). However, when the base of the marine inversion reaches a height of approximately 500 meters or greater, cool marine air can spill into the San Joaquin Valley over lower portions of the coast range from the west, especially through Pacheco Pass (420 meters) just west of San Louis Reservoir and Cholame Pass (520 M) northwest of Bakersfield. Depth of the marine air increased to this critical value from the first to the second day of the study as shown by the Oakland soundings. At 0400 August 2 (Figure 7a, dotted line), the base of the inversion was about 200 meters msl; at 0400 August 3 (solid line), it had increased to a little over 500 meters. The base of the inversion lowered to about 400 meters at 0400 August 4 (dashed line). The 1600 OAK soundings are shown in Figure 7b. Although there was no change in height of the inversion, slight cooling took place above the inversion from August 2 to August 3.

On both August 2 and 3, the influx of modified marine air during the afternoon at Paso Robles was very marked, with winds shifting from westerly about 4 mps at 1400 to southwesterly 8 mps at 1500. The temperature dropped 9°F. during this hour on August 2, but only a smaller drop was observed on August 3, as some modified marine air was already present.

Maximum temperatures on August 2 were well-above normal in the interior valley; 108 at Fresno and 109 at Bakersfield, for example. Temperatures were above normal in coastal valleys also; 105 at Paso Robles, for example. Presence of modified marine air in the San Joaquin Valley on August 3 is reflected by lower maximum temperatures, which were an average of 8 degrees cooler than on August 2. The 1500 August 2 observation at Pacheco Pass showed the surface wind to be northwest at 3 mps, while at the same time on August 3 the wind was southwest at 12 mps. The increase in depth of marine air and associated cooling in lower layers was also shown by hourly observations of wind speed, temperature and relative humidity at Mt. Tamalpais (elevation 829 M) 10 miles north of San Francisco (Table 1), by comparison of temperatures from aircraft soundings at Stockton (Figure 8), and by raobs at Fresno AWRR (Figure 9). The Naval Air Station sounding at Lemoore for 2250 is also shown in Figure 9. The sounding is similar to the one at AWRR. Note the extreme dryness of the air mass. This is typical of midsummer conditions in the valley.

For this study, August 2 was considered to be a typical summer day, and August 3 slightly less typical due to the marine air influence in the valley. Therefore, data from August 2 will be considered primarily, with reference to August 3 data when deemed significant. The jet was observed at all stations on both days of Project Lo-Jet, but was weaker on August 3, especially in the central part of the valley.

IV. RESULTS

Time section and longitudinal analysis of Lo-Jet data (Figures 10 and 11) indicate the onset of the jet wind is generally earlier at the northern end of the valley than at the southern end. The sharp increase at Stockton from 2215 to 2315 August 2 (Figure 10b) is questionable because of the short duration (essentially one hour). Tracy data was missing at this time and the increase was much less pronounced at Sacramento. Such a sharp increase would be difficult to explain, although it could be due to a brief surge of marine air.

Low-level winds in the north end of the valley at 1715 were stronger than in the central sections (Figures 11a and 12a) and showed some increase near the time of sunset (about 1900). Since this was the case both days of the study, it was assumed that the marine influx associated with formation of the daily jet had already begun prior to the first observation at 1715, and that the increase about sunset was due to the decrease in surface frictional drag.

In studies by Schultz and Fitzwater (1968) and Schultz (1970), the average time of onset of the marine influx into the Delta area was between 1500 and 1700. In the central sections of the valley, as shown by Lo-Jet data, the jet begins near the time of sunset, and at the south end, about two hours later. The later onset to the south results in hot afternoon temperatures being maintained there for a longer period of time. Maximum temperatures at Stockton and Fresno on August 2 occurred around 1500 and at Bakersfield between 1600 and 1700.

The jet reached its greatest strength over the central portion of the valley (Figure 11d) with peak wind speed of 20.1 mps over Fresno (FAT) at 2015, at an elevation of 433 meters AGL.

Figures 12a and 12b show an eddy in the circulation over the south end of the valley in the late afternoon. The later beginning of jet winds to the south gives the impression of a fast-moving mass of air flowing up the valley. From the quasi-horizontal flow patterns, Figure 12, however, it is apparent that no parcel of air moves up the valley at speeds of about 25 mps, which would be necessary to correspond with onset of the jet in the central and southern parts of the valley. Figures 12a - 12h indicate that the marine flow splits as it enters the interior valleys; with Sacramento (SAC) showing southwesterly winds, Stockton (SCK) and Tracy nearly westerly flow, whereas stations in the central and southern San Joaquin Valley show a northwesterly flow. With the low-level jet showing peak wind speeds in the central portion of the valley (Figures 11c - 11f), there would have to be considerable inflow from the sides of the valley north of Fresno to account for continuity of mass flow. There is undoubtedly some downflow in canyons of the Sierra Nevada after sunset; however, this downflow would occur along the entire length of the valley and not contribute essentially to peak winds in the central portion. Much of the inflow contributing to the central valley jet maximum is probably due to marine air flowing through low gaps in the coastal hills, especially east of San Francisco Bay, as mentioned earlier. Pibal observers at Tracy reported westerly surface winds of close to 10 mps during late afternoon and early eve on both days of the study.

Wind speed and temperature profiles at Fresno are shown in Figure 13. Wind speed plots at three hourly intervals from 1715 through 2315 further emphasize the variation of the jet wind speeds with time and height. Note the dramatic increase in speed from 1715 to 2015 near 500 M AGL. Also note that the wind maximum is well above the temperature inversion. These wind speed profiles can be compared with the average profiles of Figure 2.

Because of missing observations at Tracy, it was not possible to prepare longitudinal sections along the west side of the valley throughout the evening. However, a section along Tracy--Five Points--Taft is shown for 2115 (Figure 14) near the time of maximum jet winds. A comparison with Figure 11e shows that the jet is similar in strength on both sides of the valley, but the jet maximum is located further to the north on the west side of the valley, although lack of pibal observations does not permit a precise location of the jet maximum.

Since time sections (Figure 10) show that at nearly all stations the jet was still maintained at the last observation at 0015, it appears the jet in the valley is present throughout much of the night, as was found by Schultz (1971) to be the case for winds in the Delta Region. Several special pibals taken at 2100 and 0330 in August 1961 at Fresno, showed a well-developed low-level jet at 2130, with about half the cases showing the jet (although much weaker) still present at the 0330 observation.

Fosberg and Schroeder (1963) referred to the leading edge of the daily influx of marine air into the Delta Region as a sea breeze front. This front, according to their theory, loses its marine air temperature and humidity characteristics by the time it moves into the interior valley, but at the surface can be traced inland nearly 100 miles as a discontinuity in surface wind speed and direction. In the Lo-Jet study, evidence of the sea breeze influx appears to be present at Stockton as shown by the similarity of soundings there and at Oakland (Figures 7 and 8). Potential temperatures at the top of the inversion are similar both places. Potential temperatures are also much the same at Lemoore NAS and AWRR, Fresno (Figure 9), but to prove or disprove all are related to the sea-breeze front is not within the scope of this study. Note that near the time of maximum jet development, 2115 August 2, Figure 15, the height of the top of the inversion lowers from north to south in the valley, but that the jet level becomes higher in this direction as far south as Fresno. The jet wind is well below the main inversion in the north end of the valley, and a little above the main inversion in the central section of the valley. This seems reasonable, since the original marine push would be cool and shallow with greatest wind speeds in the marine layer, as at Stockton. As the air modifies and pushes up the valley, the jet seeks a more normal position near or just above the top of the inversion, where frictional inlfuences are less.

Cross sections through the central part of the valley (Figure 16) show relatively light winds at 1715 and 1815, with the jet much stronger and with greater vertical extent on the east side (over FAT) at 1915 (Figure 16c), but spreading westward after 2015. This westward spread of the jet maximum from Fresno to Five Points also took place on August 3 from 1915 to 2115. A deflecting effect due to downslope winds from the high Sierra to the east may be a partial explanation for this westward movement, but a complete explanation is not attempted here.

The general wind flow up the valley at various levels at the approximate time the jet was best established (2115) is shown in Figure 17. The jet is strongest at the 152-, 293-, and 433-meter levels, Figures 17b, c, and d. The generally lower wind speeds in the southern end of the valley are thought to be due to the blocking effect of the Tehachapi range that forms the southern boundary of the valley. This range is fairly high with passes southeastward to the desert and southward to the Los Angeles basin about 1200 meters in elevation. Time sections at Taft and Bakersfield (Figure 10) show that the jet moves upward after its onset. This may be an indication of air piling up in the south end of the valley and flowing over the mountains or through the passes later at night. The direction of the winds (300-340 degrees) at the time of the jet maximum indicates that if the jet does continue over the mountains, it most likely is directed southeastward toward the thermal low in the desert regions of southeast California and western Arizona. If this is true, winds either over ridges or through passes should be strong northerly or northwesterly. Winds at Sandberg (1350 meters) located on a ridge south of the valley, were northerly 2-4 mps most of the night of August 2 - 3, and southwesterly 4 - 7 mps the next night. This indicates little or no movement of air from the valley over this particular ridge; however, observations are needed to check air movement through the passes.

As mentioned earlier, the nocturnal jet was weaker at most stations on the second night (August 3 - 4) than on the eve of August 2 - 3. This was particularly true of stations in the central portion of the valley (i.e., those near Fresno). There was very little change in the large-scale synoptic situation (Figures 4c and 4d). However, a comparison of the detailed surface maps for 1600 August 2 and 3 (Figures 5b and 5e) indicates that the pressure gradient from the coast to the center of the San Joaquin Valley thermal low was greater on the 2nd--note the Monterey-Fresno pressure difference of 7 mbs as compared to 5.9 mbs on the 3rd. Also, there was more of a tendency for the nose of the High to move into the Delta Region on the 2nd. Thus the up-valley pressure gradient, Stockton-Fresno, is 1.7 mbs on the 2nd, but only 0.1 mb on the 3rd. There was therefore, reason for a stronger low-level flow on the 2nd. The higher pressure east of the Sierra on August 2 is due principally to thunderstorm activity.

Charts similar to those depicted for August 2 were also prepared for August 3; only a few of these will be shown here, however. The time section for Fresno, August 3 (Figure 18a), is similar to the one for August 2 (Figure 10d), except that the primary jet, at 2015, is about 6 mps slower, and is also located about 2 - 3 hundred meters lower. The latter-occurring jet maximum, at 2300, is essentially unchanged. August 3 time sections for Bakersfield and Stockton (Figures 18b and 18c) show similar reductions in maximum wind speeds.

A section along the west side of the valley, through Tracy, Five Points, and Taft, for 2115 August 3 (Figure 19), indicates the jet to be weaker than on August 2 (Figure 14). Also note that the maximum is further south and at a higher elevation than on August 2. The axis of the jet slopes upward to the south over the southern end of the valley on both nights.

The longitudinal section, Sacramento-Bakersfield, taken near the time of strongest jet maximum, 2115, for August 3 (Figure 20), can be compared with the similar section for August 2 (Figure 15). The jet maximum was a little weaker on August 3, but the principal difference is the greater height of the jet over Stockton on the 3rd (600 meters vs. 200 meters). Also note that the temperature at the top of the inversion on August 3 in the vicinity of Fresno is 6 degrees lower than on the 2nd.

The horizontal flow at 293 meters near the time of maximum jet strength (Figure 21) may be compared with the same chart for August 2 (Figure 17c). It can be seen that the flow patterns are similar, but wind speeds are slightly slower on August 3. Other features of the low-level jet on August 3 were similar to those on August 2, except for generally lower wind speeds, especially near the jet maximum and will not be discussed here.

V. CONCLUSIONS

The low-level jet is almost a nightly occurrence in the San Joaquin Valley during summer. It forms near sunset, reaching maximum strength during the evening and continues to exist for much of the night, although with gradually diminishing intensity. Speeds of 15 to 20 meters per second are not uncommon at heights of 200 to 400 meters above ground. The jet is strongest in the central sections of the valley. At the south end of the valley there is the possibility that it may rise and pass over the Tehachapi mountains toward the southeast.

The timing of the jet indicates it is not related to the normal valley-mountain regime, as the jet flows upvalley at night. Also the jet is not entirely dependent on the land-sea breeze regime as it continues to feed into the valley much of the night. Rather, it is primarily related to larger-scale thermal and pressure patterns, depending on the intensity of the eastern Pacific high-pressure cell and the southwest desert thermal Low. The jet is less developed when the marine inversion along the West Coast becomes sufficiently deep to allow cool air to spill over portions of the coast range into the valley and weaken the thermal low in the interior, as was the case on the second day of Project Lo-Jet. This provides the marine air with a shorter, broader path from ocean to mid-valley thermal Low. Forecasting location and strength of the jet should not be too difficult, due to its persistence, known vertical extent, constant wind direction, and known distribution of wind speed through the valley.

VI. SUGGESTIONS FOR FURTHER STUDY

Although the jet has been shown to be present over the entire San Joaquin Valley, its horizontal extent into adjoining foothills has not been studied. A study of wind flow from the edge of the valley into foothill and mountain areas is needed, especially to the east in the Sierra Nevada, where range and forest fires could be affected by low-level jet winds. Blow-up conditions of forest fires are suspected to be related to onset of the jet.

No definite proof has been given that the jet winds blow out of the San Joaquin Valley over the mountains toward the south or southeast. This could be of importance to accumulation of air pollutants, indicating whether the valley is partially flushed out each evening in summer, or if the south end of the valley becomes a giant reservoir for pollution until some larger-scale weather phenomenon cleans it out. Evening pibals at two or three points in passes of the Tehachapis would assist in determining flow out of the south end of the valley. Also, one or two evening pibals a week during spring and fall months could better define the seasonal onset and ending of the low-level jet. This would be of value for forecasting purposes. The above proposals are all inexpensive and could be accomplished using 10-gram pilot balloons and portable theodolites.

VII. ACKNOWLEDGMENTS

The authors are indebted to H. B. Schultz, University of California at Davis, for information on studies in the Delta Region and wind data from Walnut Grove Tower; also to EMSU units from San Francisco and Los Angeles that took pibals at Tracy and Taft; AWRR personnel at Fresno, and Naval Air Station, Lemoore; WSO personnel at Sacramento, Stockton, Bakersfield, and Fresno who took pibals at their respective stations; Dale Bryan, Bruce Renneke, and summer trainee Ralph Johnson who helped work up the wind data; and Mrs. Lucianne Miller who prepared most of the figures.

VIII. REFERENCES

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STATION MT. TAMALPAIS (829 meters)

DATA Windspeed (mps), Temperature (°F.), Relative Humidity (%), August 2, 3, and 4, 1971

	DATE	A. M. (PST)												P. M.											
		1	2	3	4	5	6	7	8	9	10	11	Noon	1	2	3	4	5	6	7	8	9	10	11	Mid't
Wind-speed	2	4.6	0.2	1.5	1.4	0.1	2.3	2.3	1.9	2.3	2.3	2.3	2.0	2.8	3.5	3.4	4.6	7.3	9.7	8.1	6.9	5.5	8.6	6.8	8.0
	3	8.2	9.4	9.0	8.2	8.0	7.7	7.3	8.7	7.7	6.4	5.7	6.1	7.4	5.9	7.7	10.9	10.9	10.7	12.0	10.9	9.2	8.6	8.6	7.7
	4	8.5	7.4	7.0	6.9																				
Temper-ature	2	76	76	76	78	79	82	83	83	80	80	79	80	78	78	79	79	78	75	74	74	72	68	69	66
	3	65	64	63	63	62	62	63	63	62	66	67	69	71	71	70	67	66	64	64	65	66	64	63	63
	4	63	64	63	62	60	60																		
Rela-tive Humidi-ty	2	27	25	27	12	15	11	09	12	23	26	30	35	41	42	34	25	24	28	32	32	39	48	52	47
	3	43	41	39	38	40	40	39	40	44	42	44	41	42	44	43	45	50	57	56	55	52	53	58	57
	4	58	53	54	57	61	65																		

TABLE I. WIND SPEED, TEMPERATURE, AND RELATIVE HUMIDITY AT MT. TAMALPAIS, AUGUST 2, 3, 4, 1971.

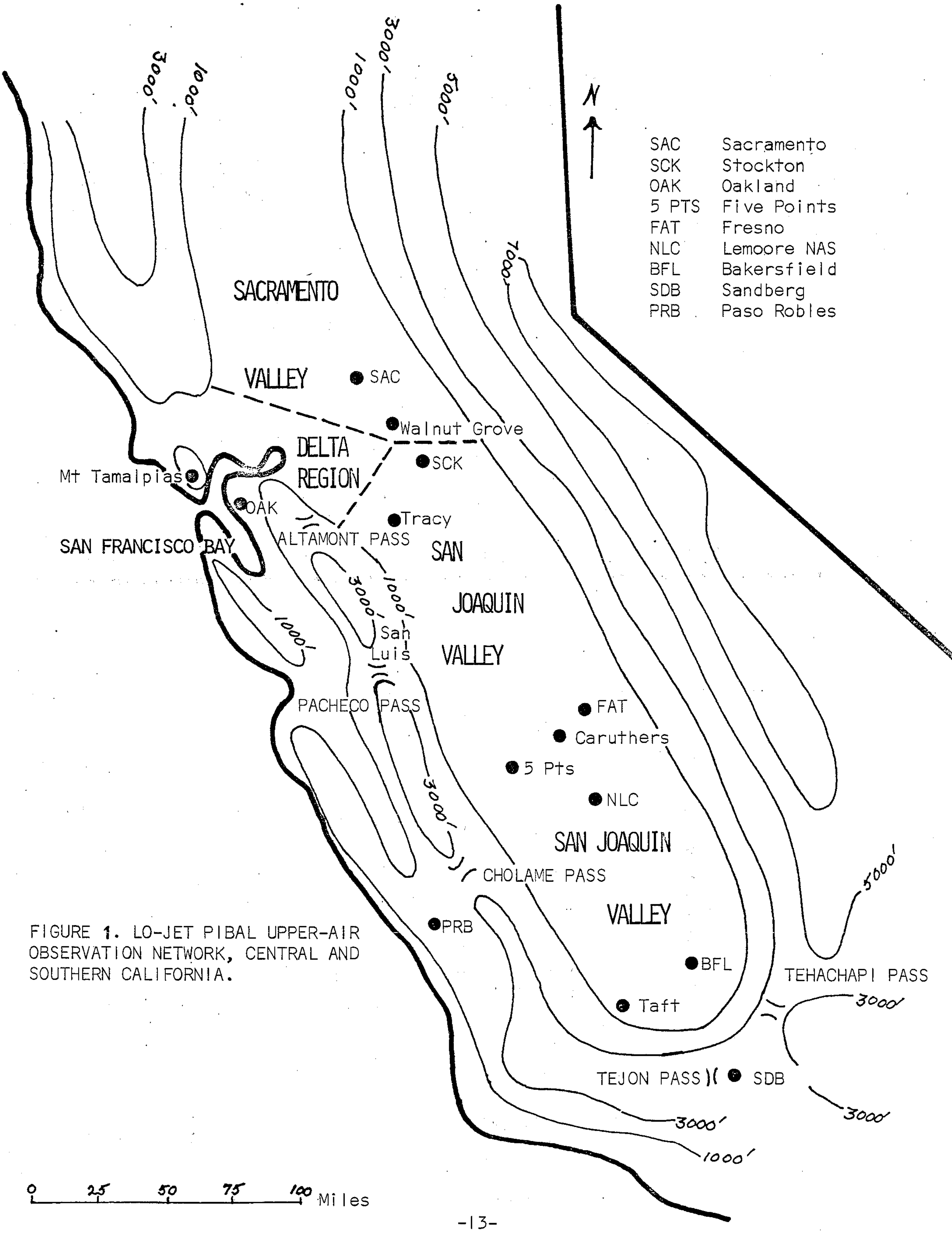

FIGURE 1. LO-JET PIBAL UPPER-AIR OBSERVATION NETWORK, CENTRAL AND SOUTHERN CALIFORNIA.

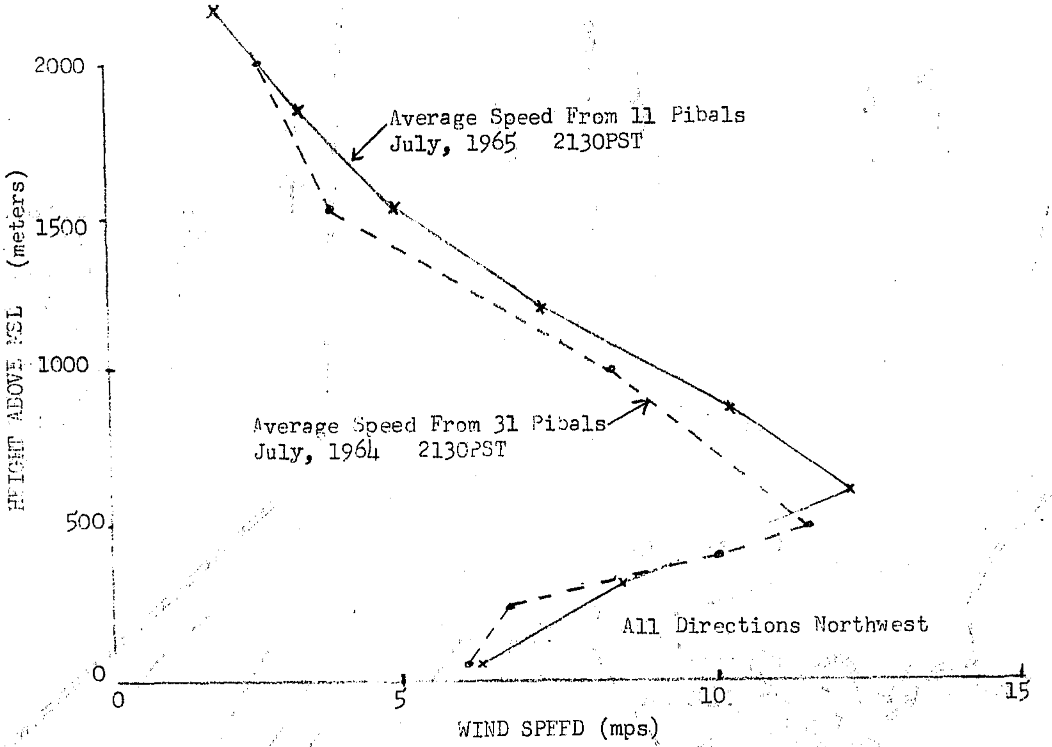

FIGURE 2. AVERAGE WIND SPEEDS AT FRESNO AIR TERMINAL, JULY 1964 AND 1965 (MPS).

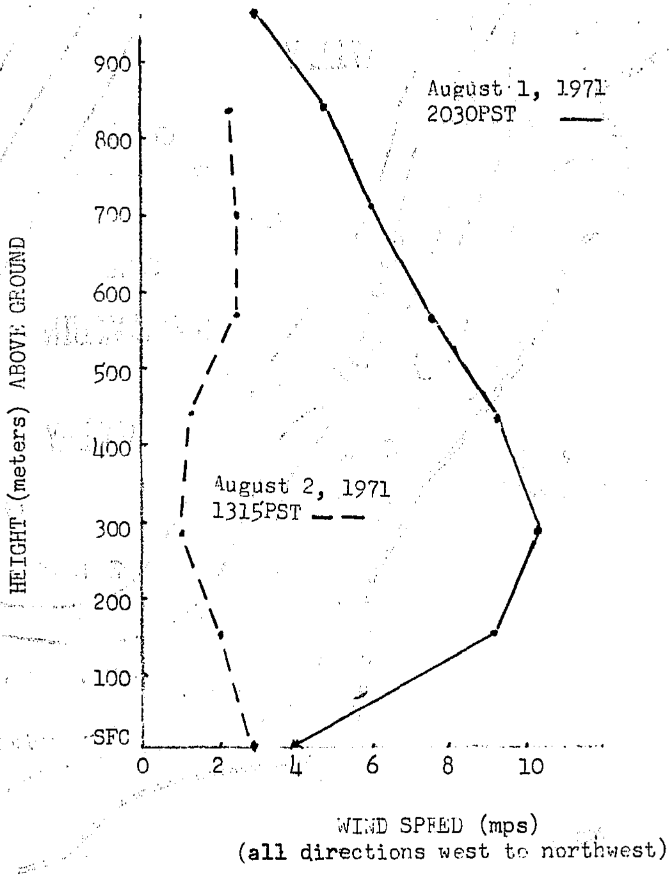

FIGURE 3. FRESNO AIR TERMINAL PIBALS, 2030 PST AUGUST 1 AND 1315 PST AUGUST 2, 1971.

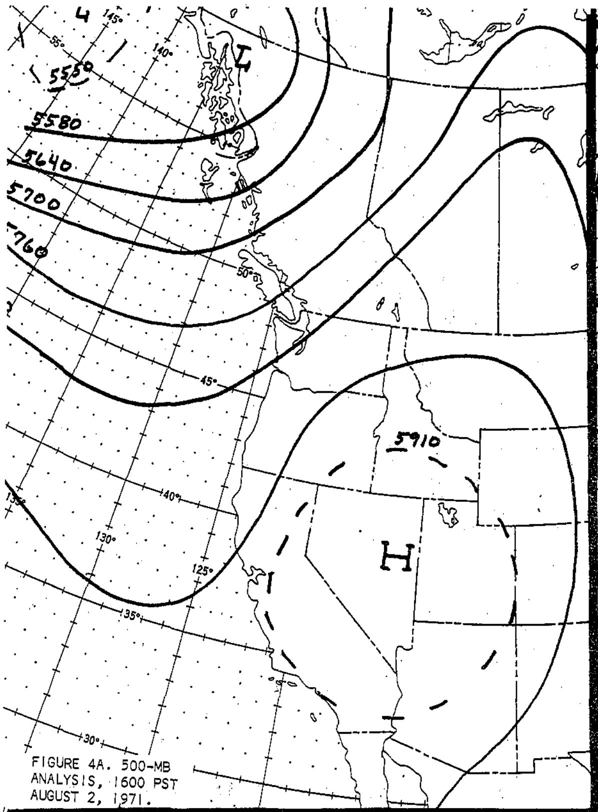

FIGURE 4A. 500-MB ANALYSIS, 1600 PST AUGUST 2, 1971.

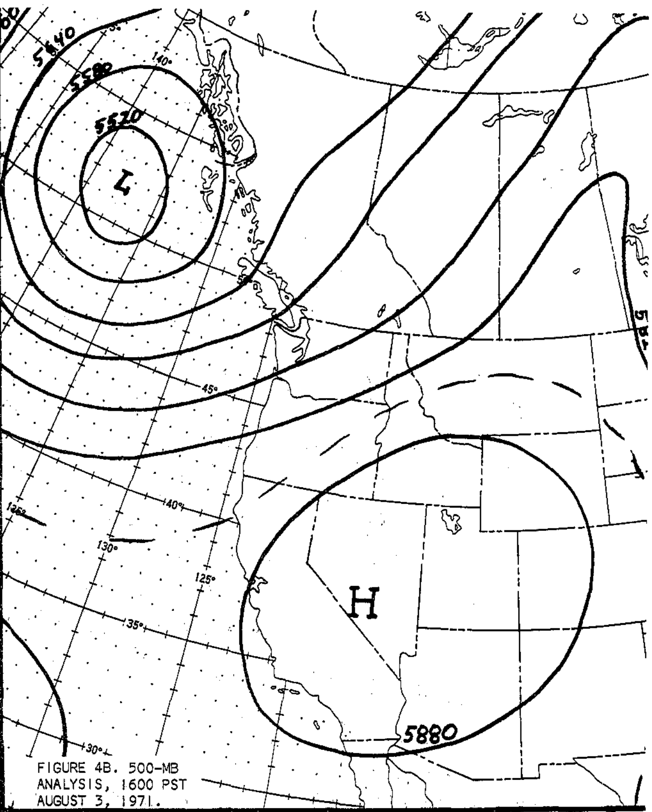

FIGURE 4B. 500-MB ANALYSIS, 1600 PST AUGUST 3, 1971.

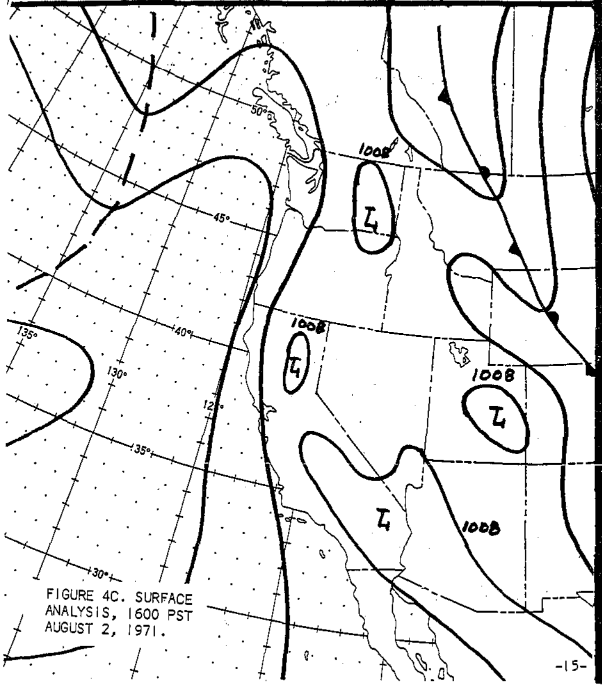

FIGURE 4C. SURFACE ANALYSIS, 1600 PST AUGUST 2, 1971.

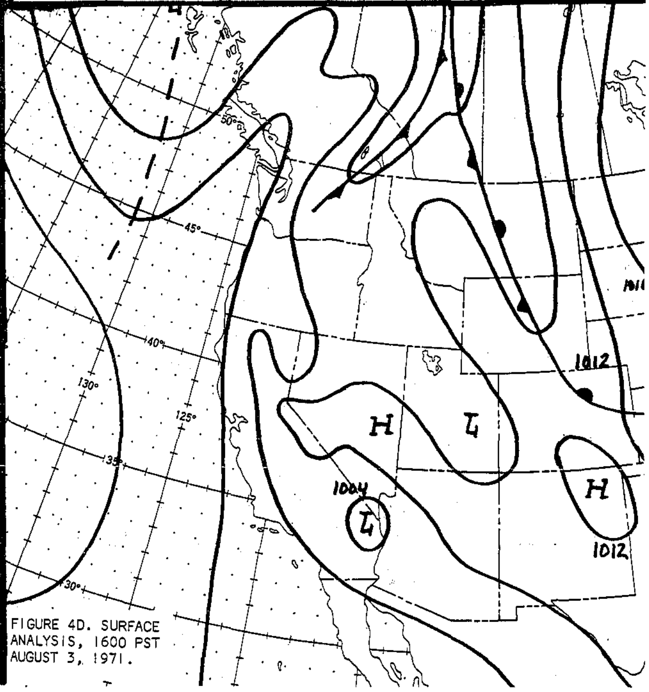

FIGURE 4D. SURFACE ANALYSIS, 1600 PST AUGUST 3, 1971.

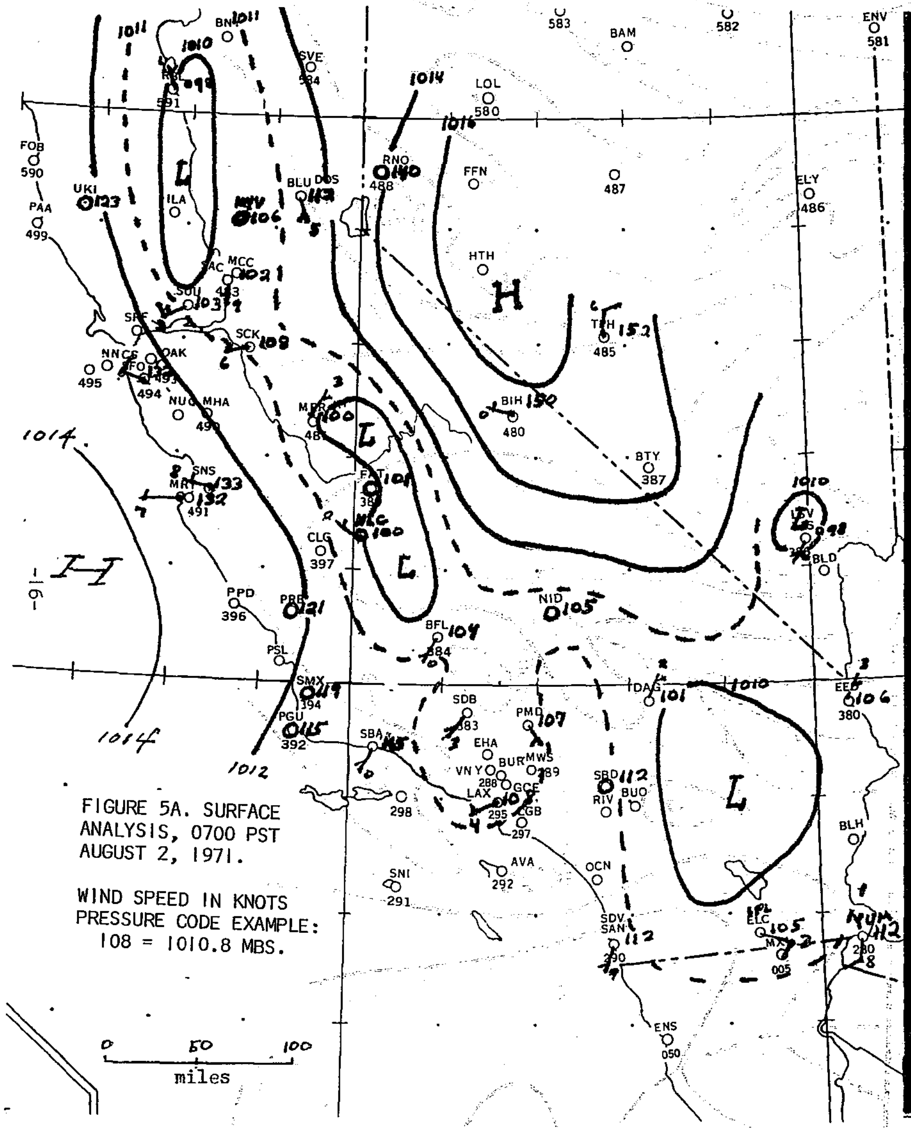

FIGURE 5A. SURFACE ANALYSIS, 0700 PST AUGUST 2, 1971.

WIND SPEED IN KNOTS
PRESSURE CODE EXAMPLE:
108 = 1010.8 MBS.

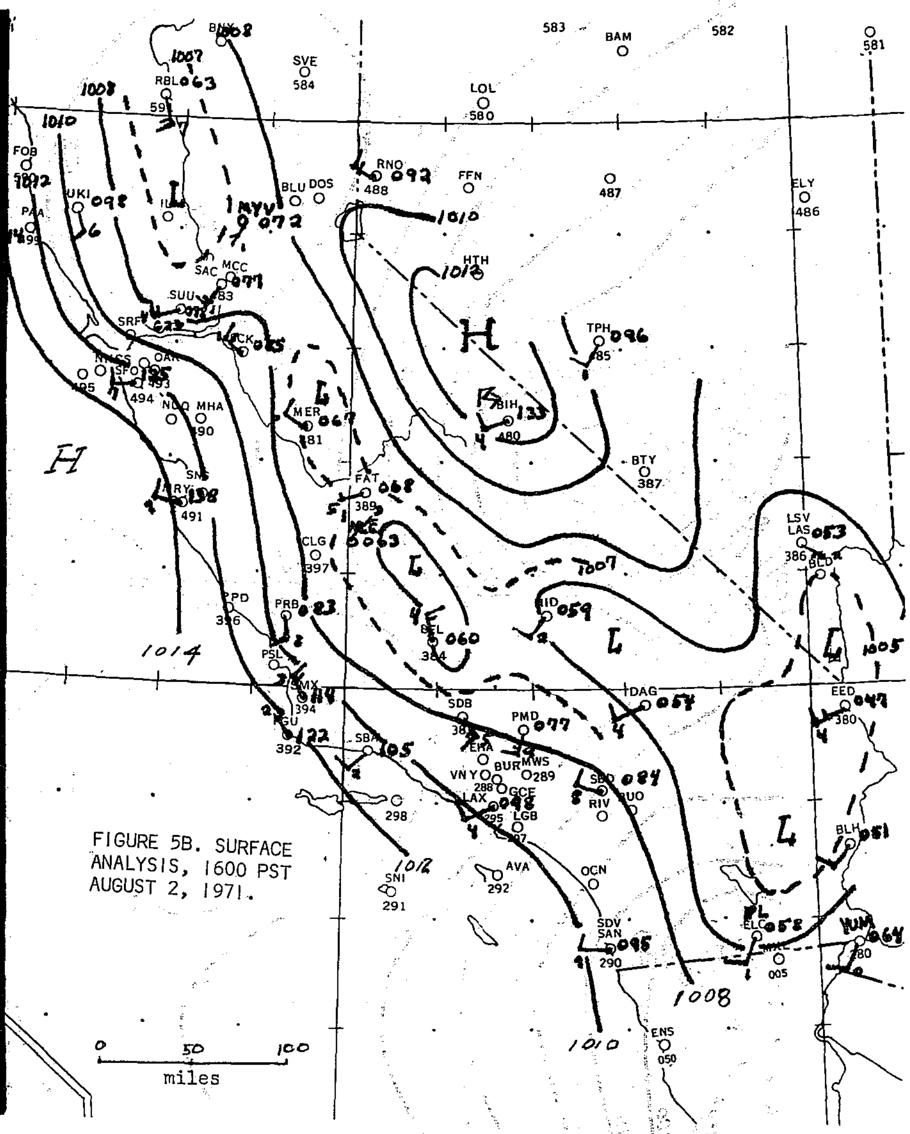

FIGURE 5B. SURFACE ANALYSIS, 1600 PST AUGUST 2, 1971.

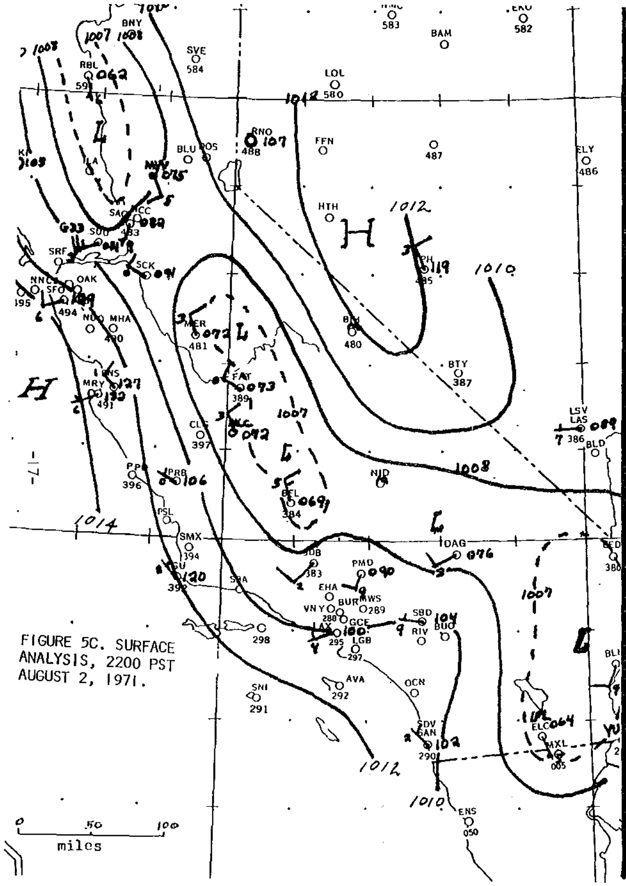

FIGURE 5C. SURFACE ANALYSIS, 2200 PST AUGUST 2, 1971.

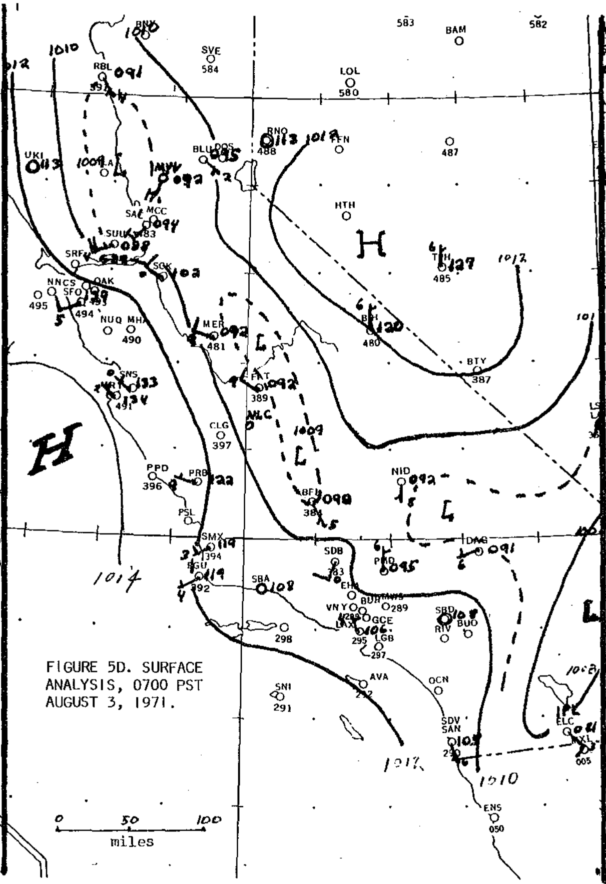

FIGURE 5D. SURFACE ANALYSIS, 0700 PST AUGUST 3, 1971.

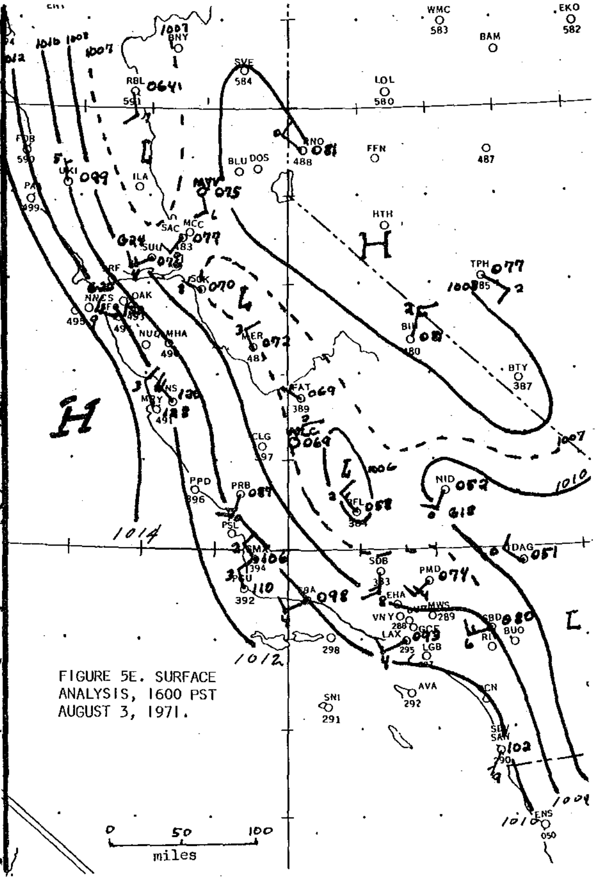

FIGURE 5E. SURFACE ANALYSIS, 1600 PST AUGUST 3, 1971.

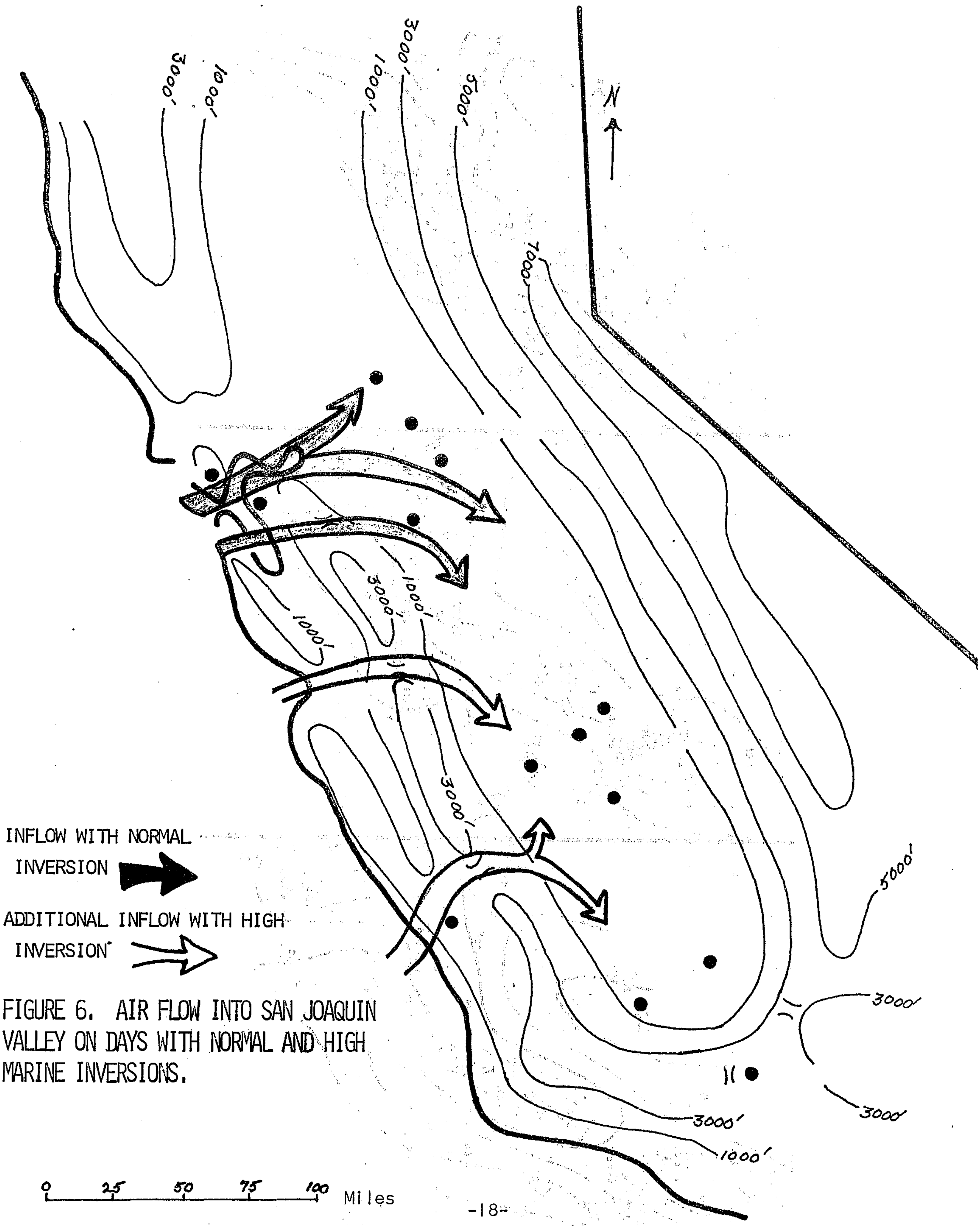

FIGURE 6. AIR FLOW INTO SAN JOAQUIN VALLEY ON DAYS WITH NORMAL AND HIGH MARINE INVERSIONS.

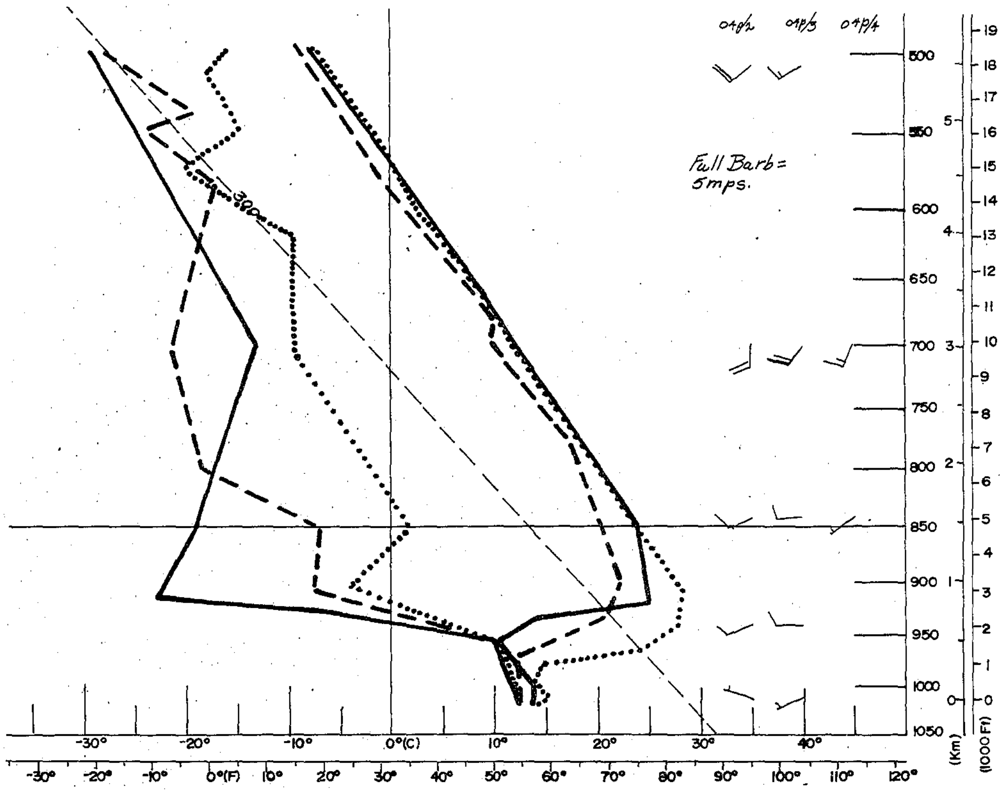

FIGURE 7A. OAKLAND, CALIFORNIA, SOUNDINGS FOR 0400 AUGUST 2 (DOTTED LINES), AUGUST 3 (SOLID LINES), AUGUST 4 (DASHED LINES), 1971.

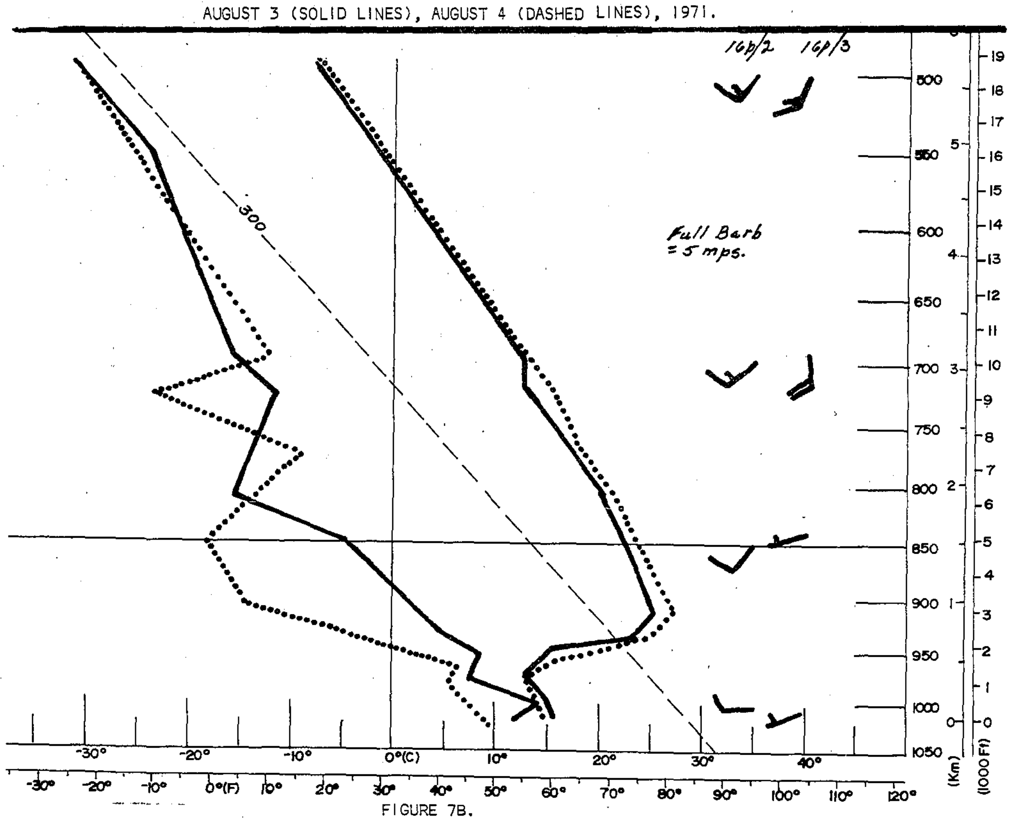

FIGURE 7B.

OAKLAND, CALIFORNIA, SOUNDINGS FOR 1600 AUGUST 2 (DOTTED LINES), AUGUST 3 (SOLID LINES), 1971.

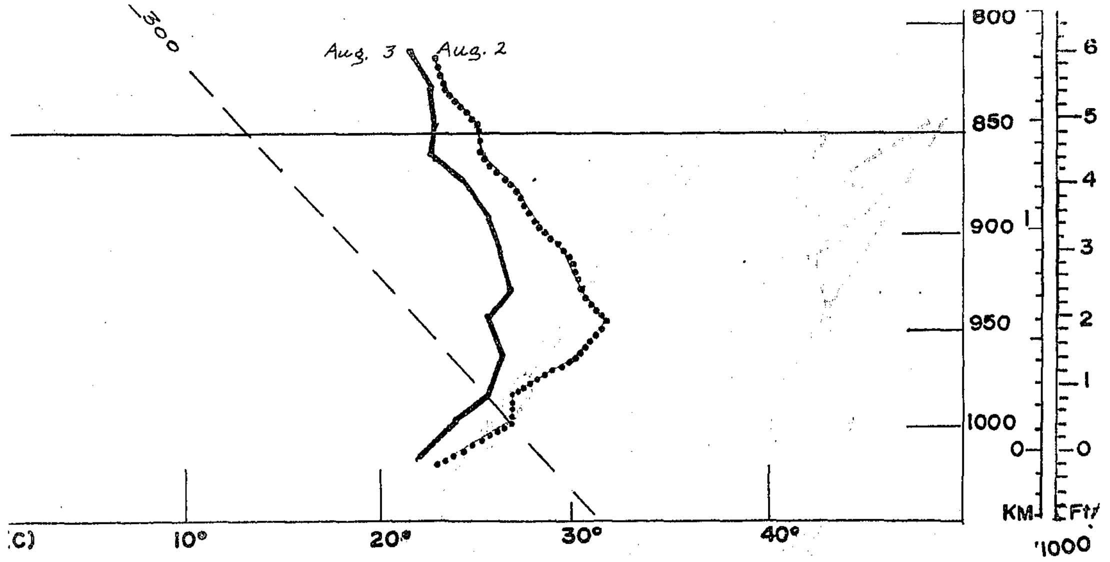

FIGURE 8. STOCKTON, CALIFORNIA, AIRCRAFT SOUNDINGS, 2030 AUGUST 2, 3, 1971.

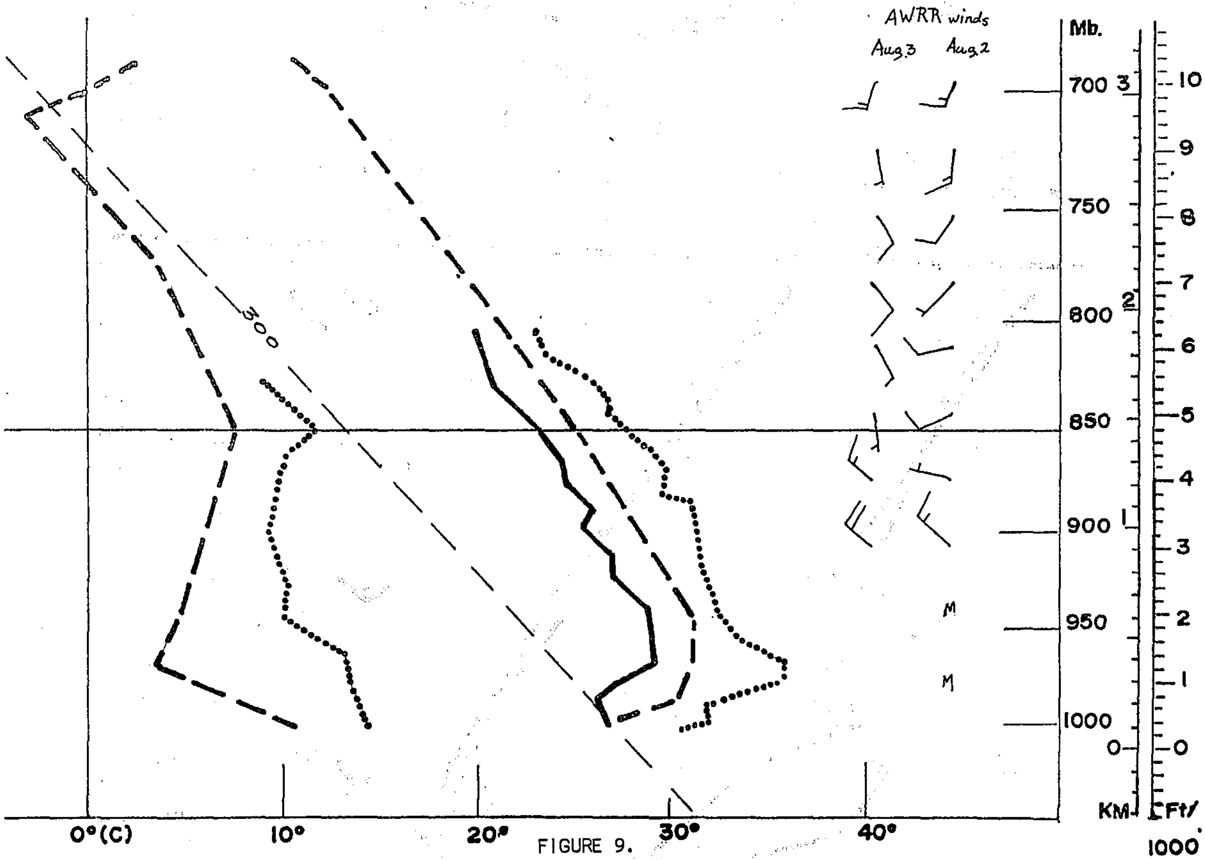

FIGURE 9.

RAOB SOUNDINGS FROM AWRR FRESNO, 2155 AUGUST 2 (DOTTED LINES); 2115 AUGUST 3 (SOLID LINE) AND SOUNDING AT LEMOORE NAS, 2250 AUGUST 2 (DASHED LINES), 1971.

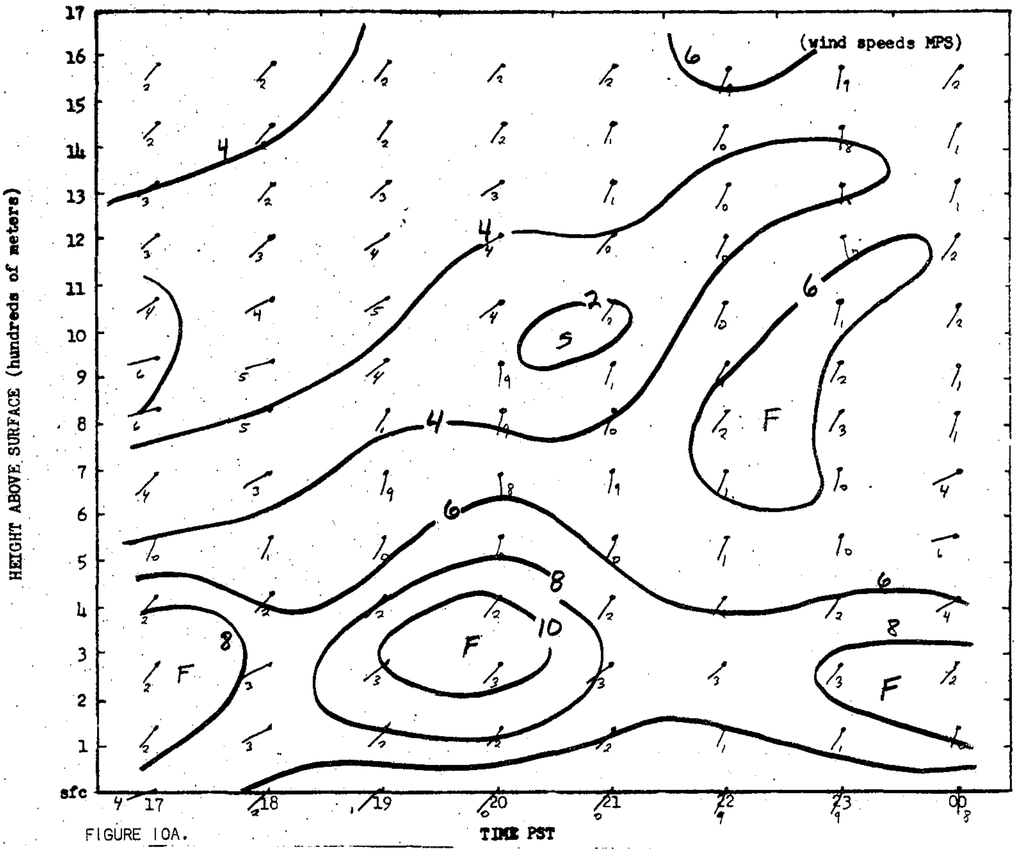

FIGURE 10A. TIME SECTION FOR SACRAMENTO, AUGUST 2, 1971. LINES ARE ISOPLETHS OF WIND SPEED (MPS). WINDS BLOW TOWARD DOT, DIRECTION IN TENS OF DEGREES. (EXAMPLE: 9 REPRESENTS 090, 190 OR 290 DEGREES; F IS FAST; S IS SLOW.)

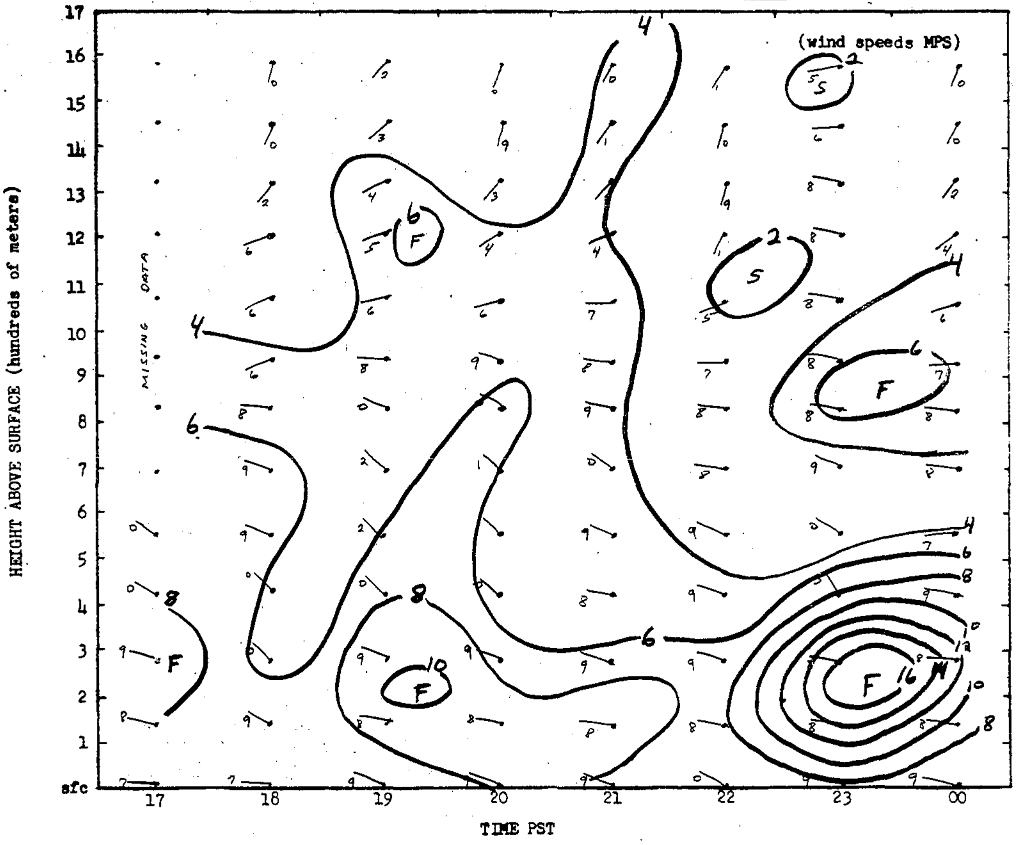

FIGURE 10B. TIME SECTION FOR STOCKTON, AUGUST 2, 1971.

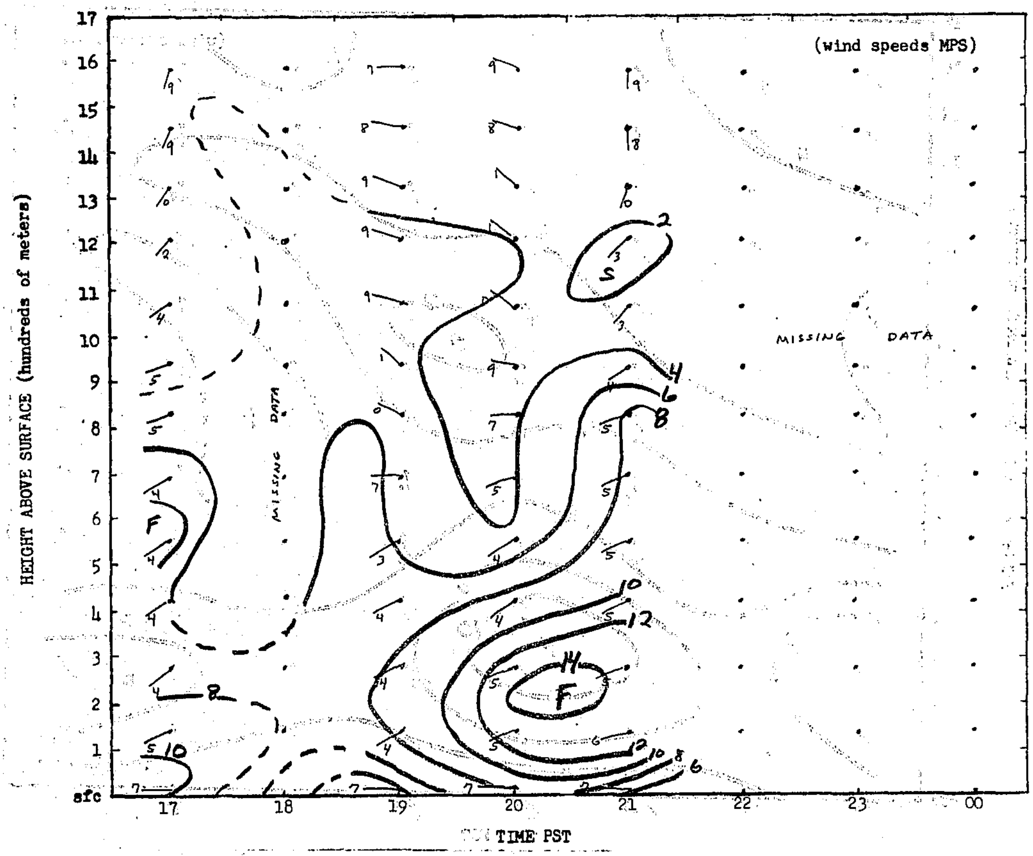

FIGURE 10C. TIME SECTION FOR TRACY, AUGUST 2, 1971.

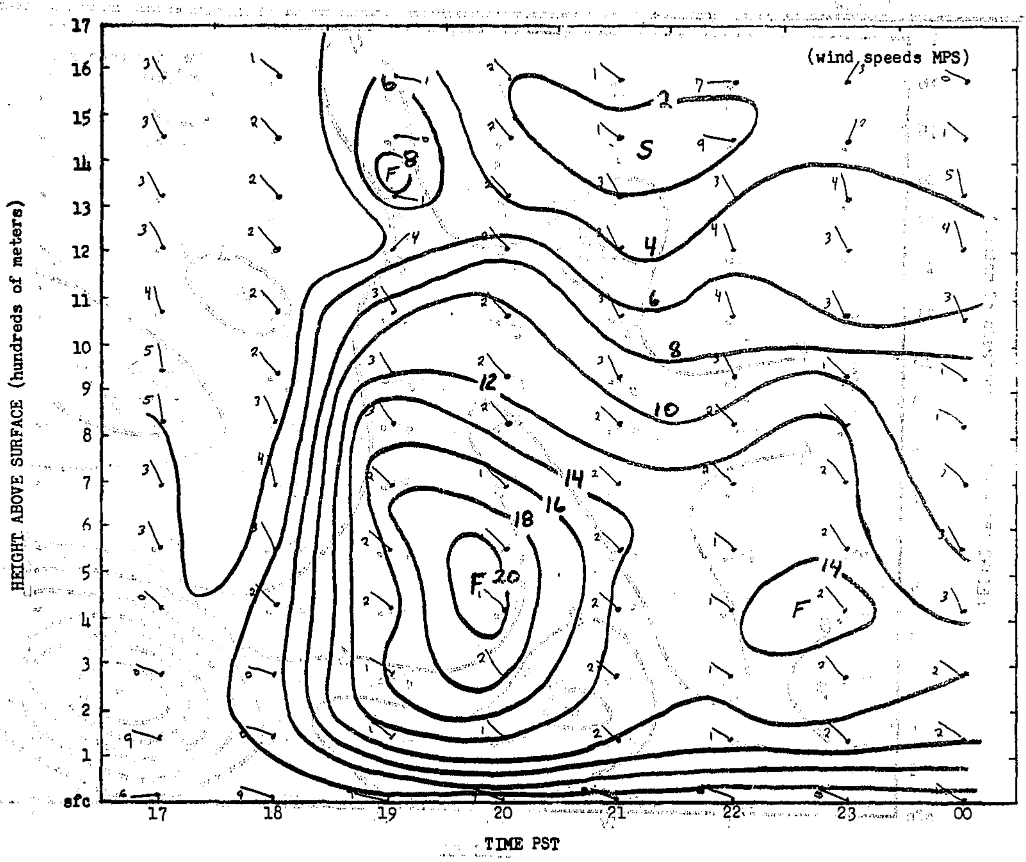

FIGURE 10D. TIME SECTION FOR FRESNO, AUGUST 2, 1971.

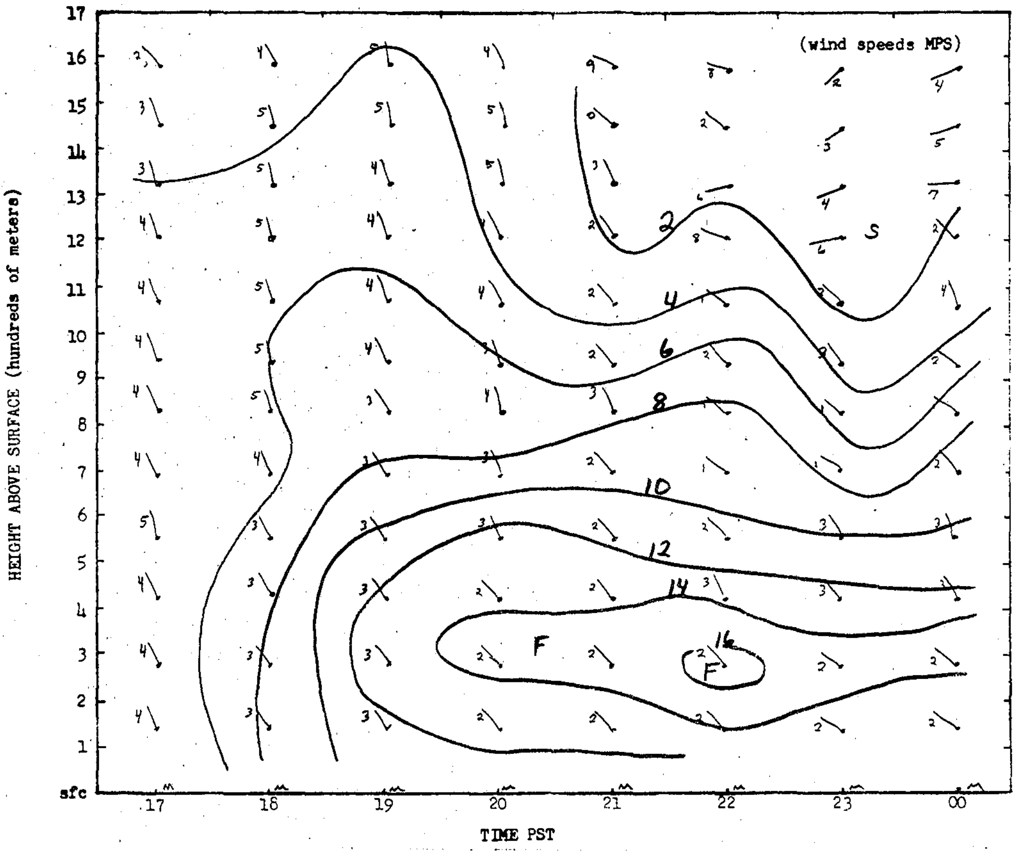

FIGURE 10E. TIME SECTION FOR CARRUTHERS, AUGUST 2, 1971.

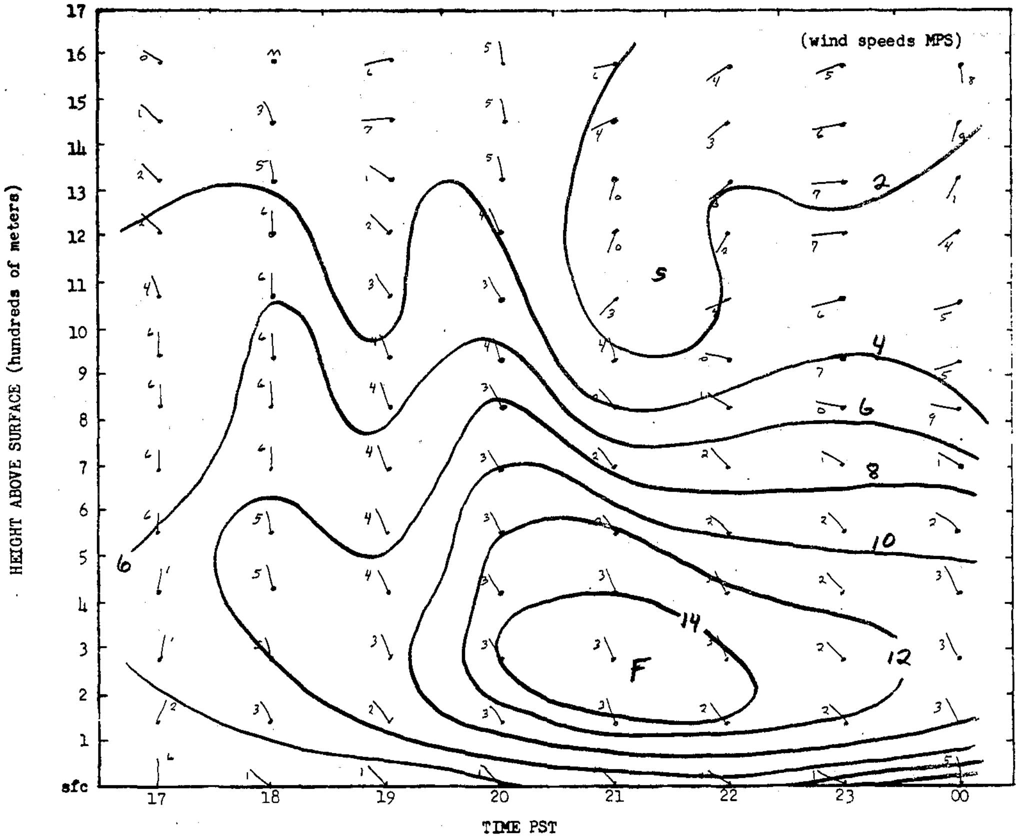

FIGURE 10F. TIME SECTION FOR FIVE POINTS, AUGUST 2, 1971.

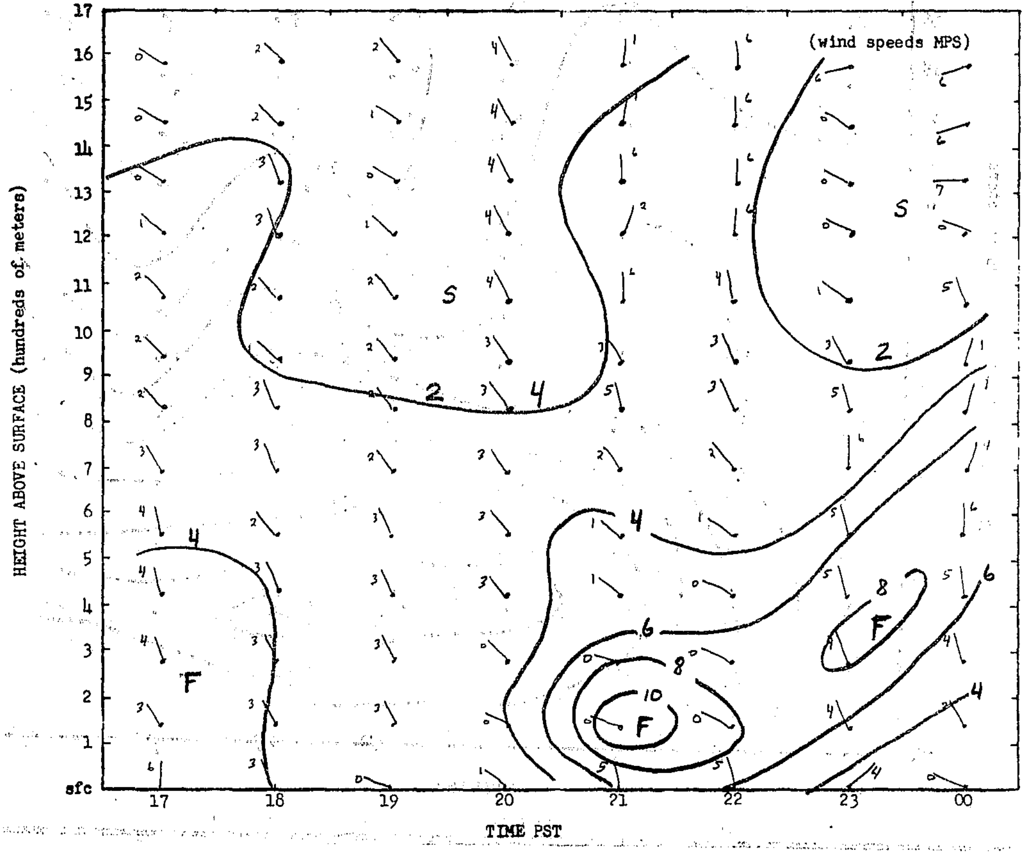

FIGURE 10G. TIME SECTION FOR BAKERSFIELD, AUGUST 2, 1971.

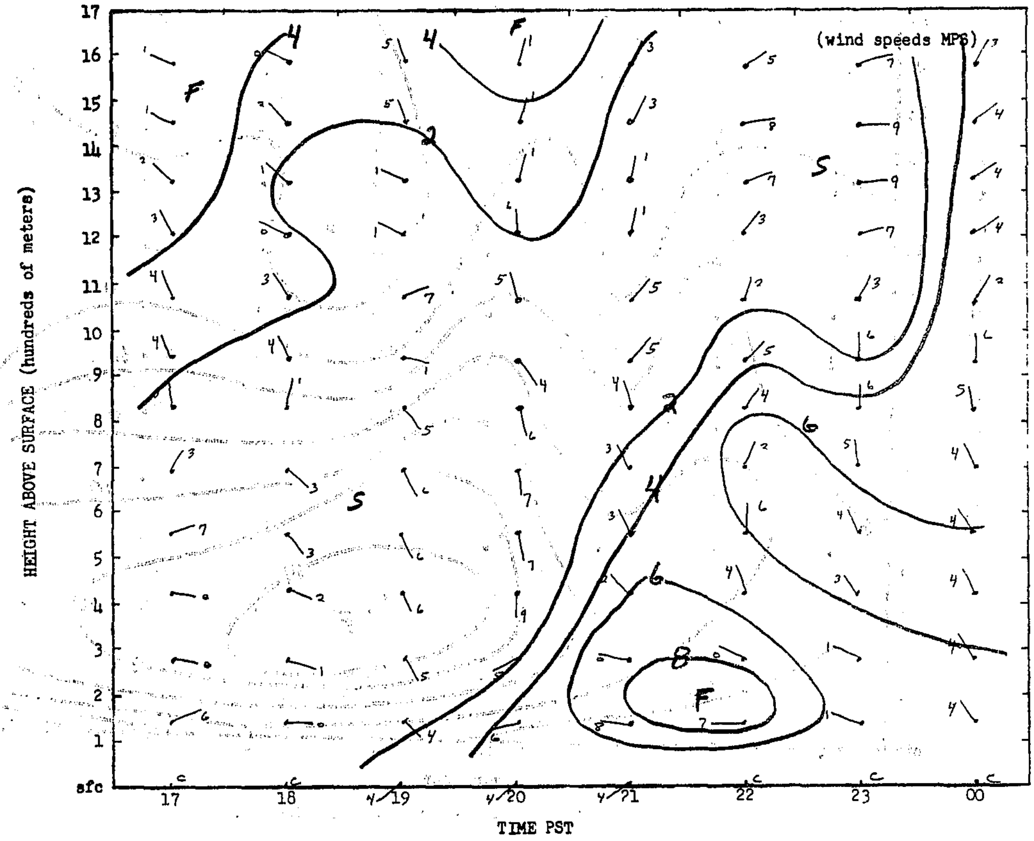

FIGURE 10H. TIME SECTION FOR TAFT, AUGUST 2, 1971.

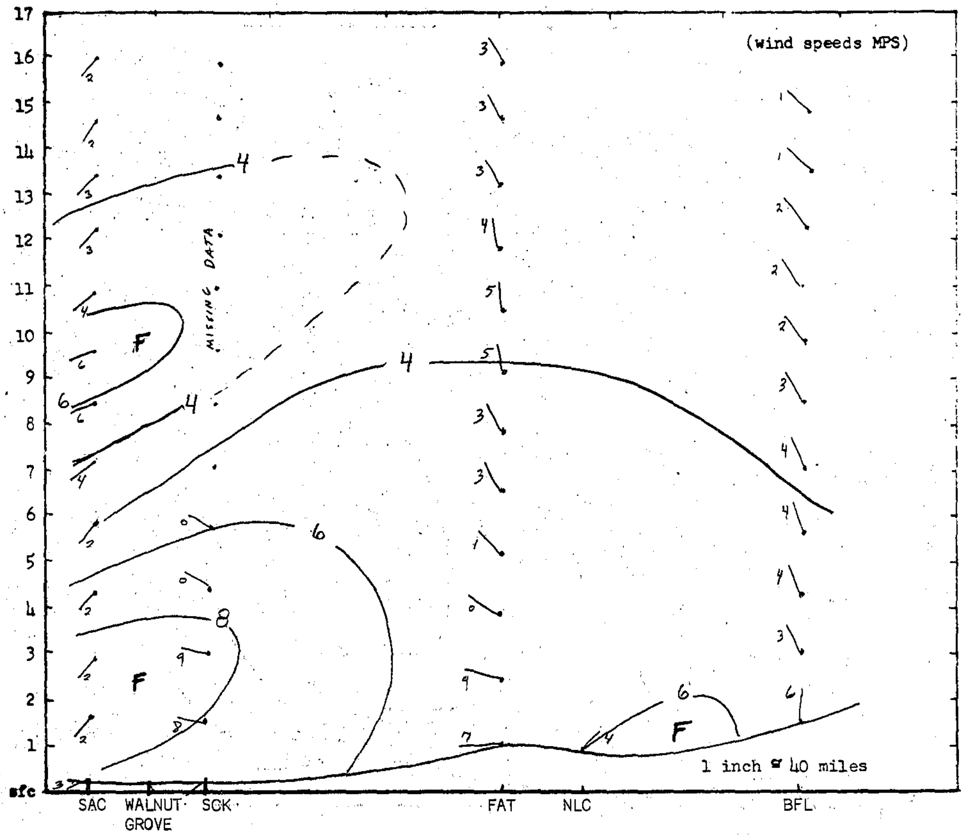

FIGURE 11A. LONGITUDINAL SECTION, SACRAMENTO-BAKERSFIELD, FOR 1715 PST AUGUST 2, 1971. LINES ARE ISOPLETHS OF WIND SPEED (MPS). WINDS BLOW TOWARD DOT, DIRECTION IN TENS OF DEGREES.

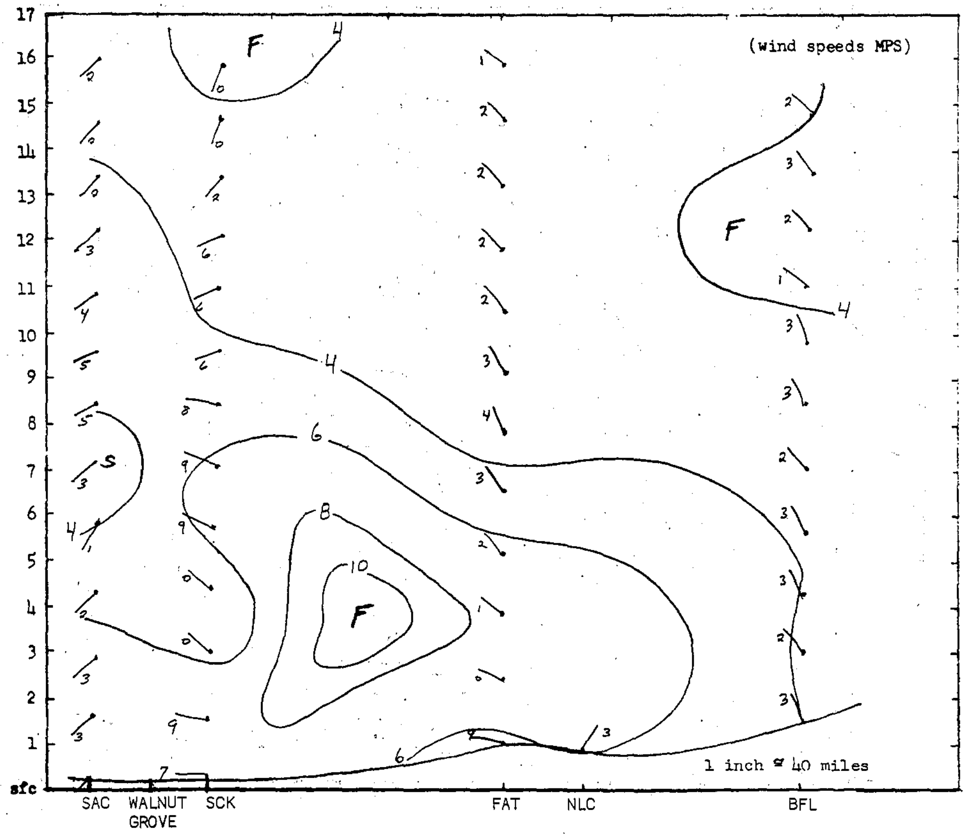

FIGURE 11B. LONGITUDINAL SECTION, SACRAMENTO-BAKERSFIELD, FOR 1815 PST AUGUST 2, 1971.

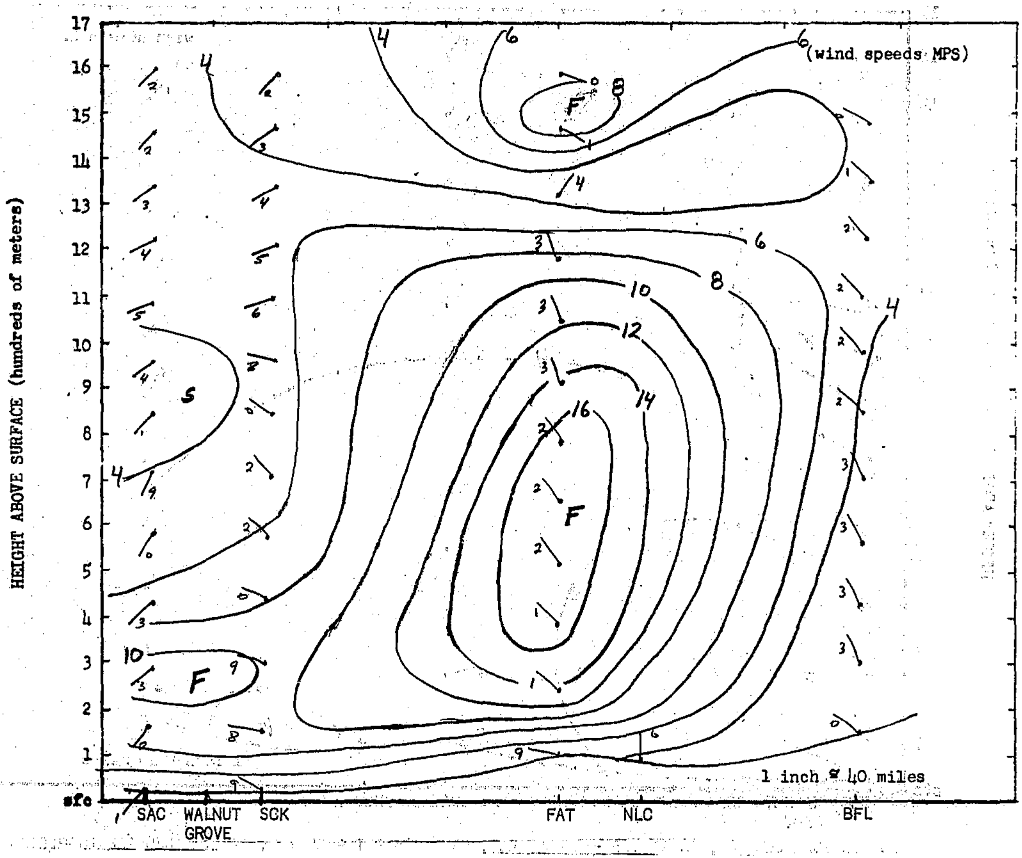

FIGURE IIC. LONGITUDINAL SECTION, SACRAMENTO-BAKERSFIELD, FOR 1915 PST AUGUST 2, 1971.

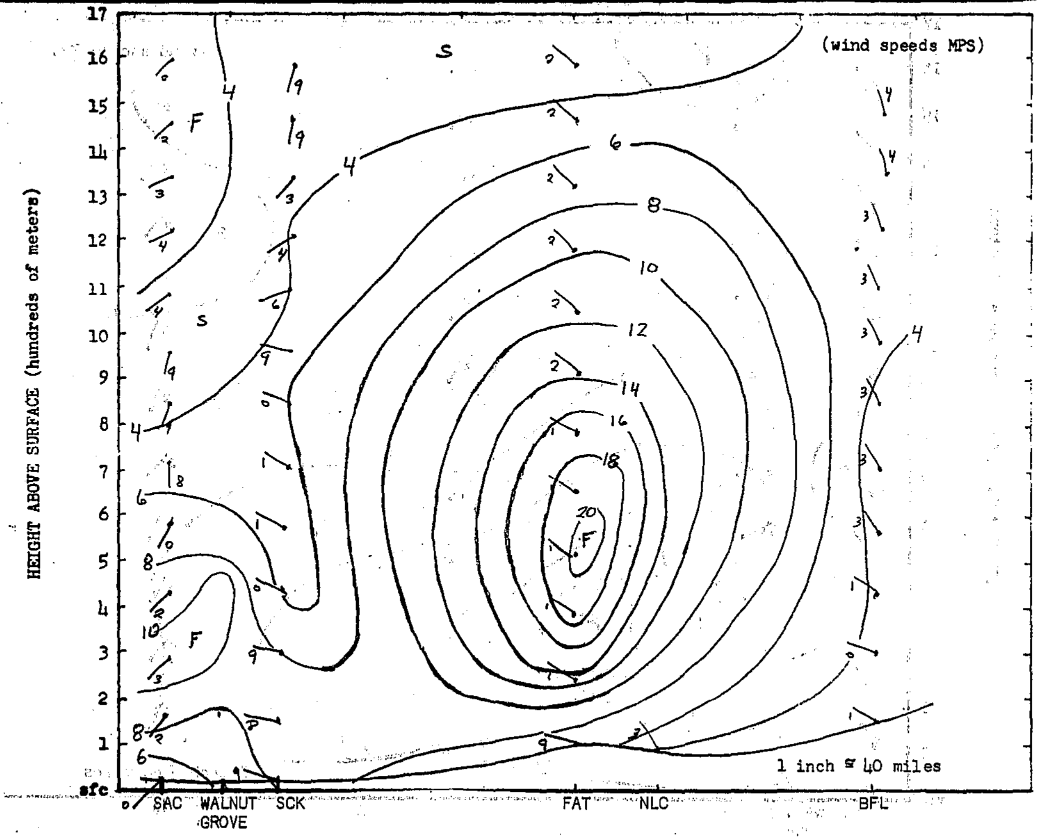

FIGURE IID. LONGITUDINAL SECTION, SACRAMENTO-BAKERSFIELD, FOR 2015 PST AUGUST 2, 1971.

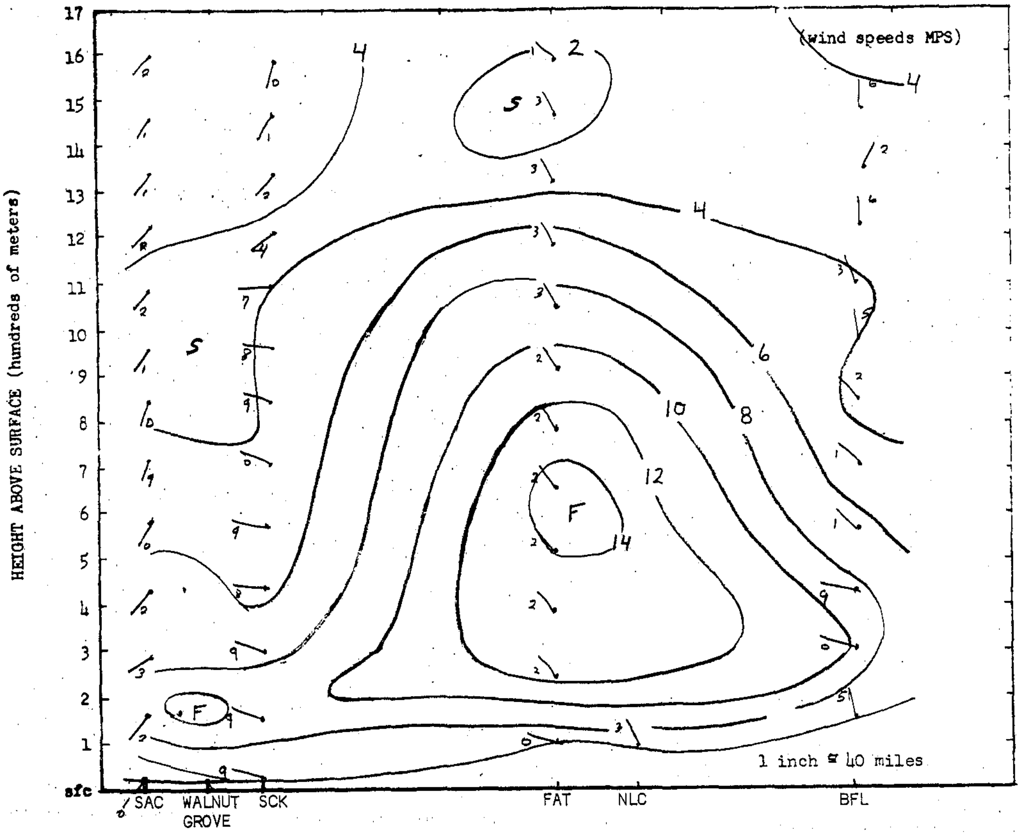

FIGURE 11E. LONGITUDINAL SECTION, SACRAMENTO-BAKERSFIELD, FOR 2115 PST AUGUST 2, 1971.

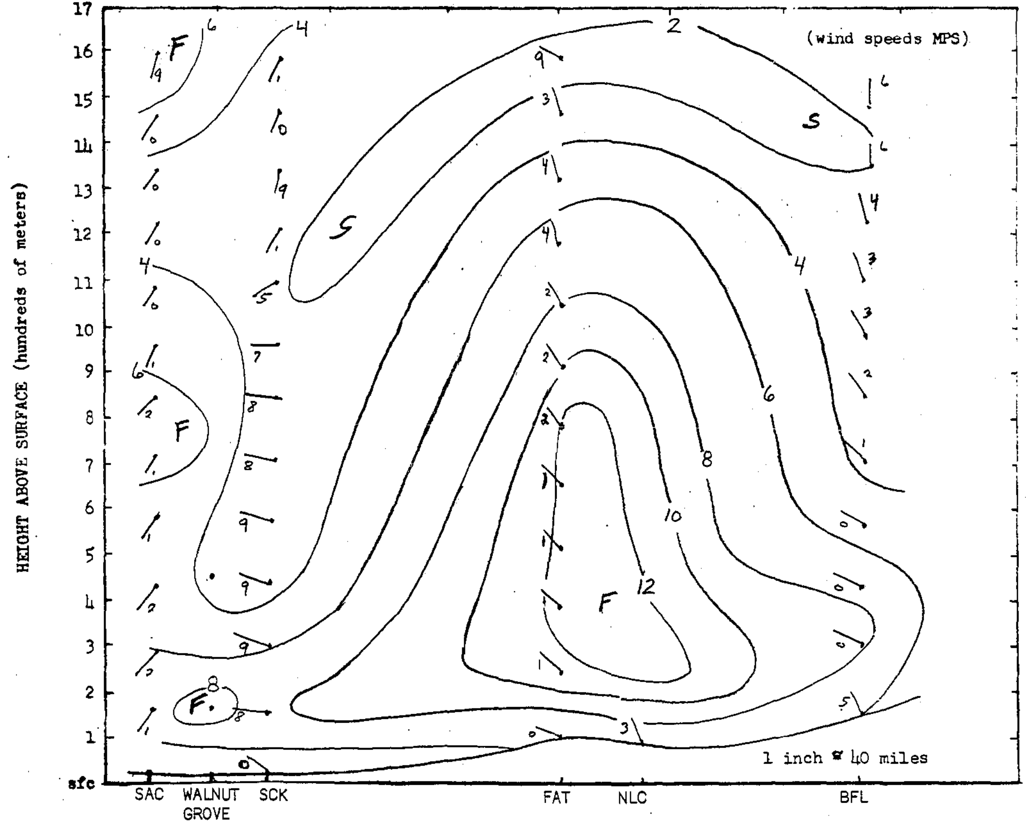

FIGURE 11F. LONGITUDINAL SECTION, SACRAMENTO-BAKERSFIELD, FOR 2215 PST AUGUST 2, 1971.

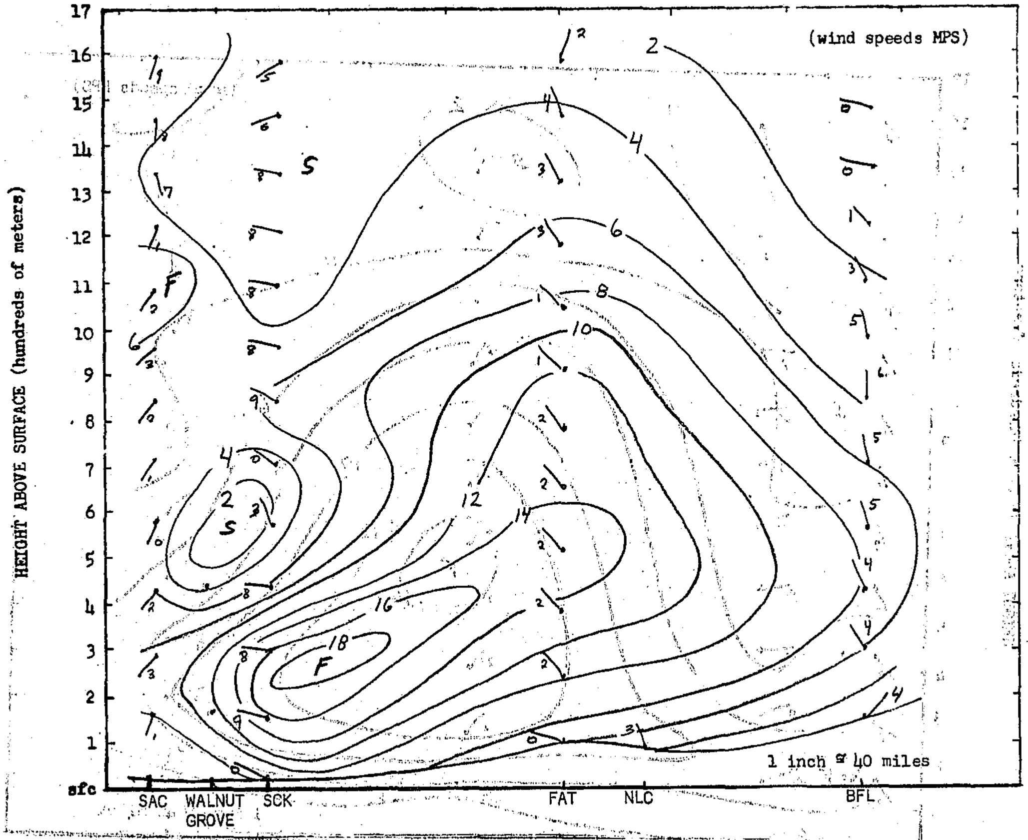

FIGURE 11G. LONGITUDINAL SECTION, SACRAMENTO-BAKERSFIELD, FOR 2315 PST AUGUST 2, 1971.

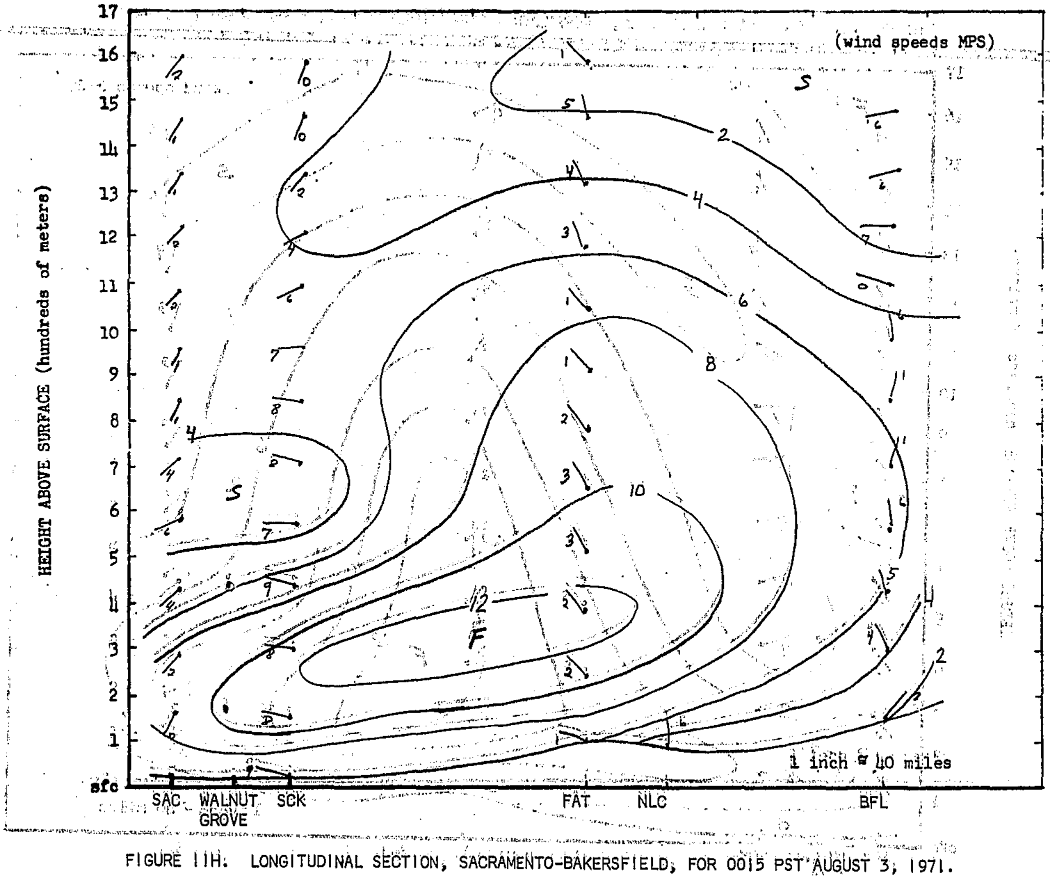

FIGURE 11H. LONGITUDINAL SECTION, SACRAMENTO-BAKERSFIELD, FOR 0015 PST AUGUST 3, 1971.

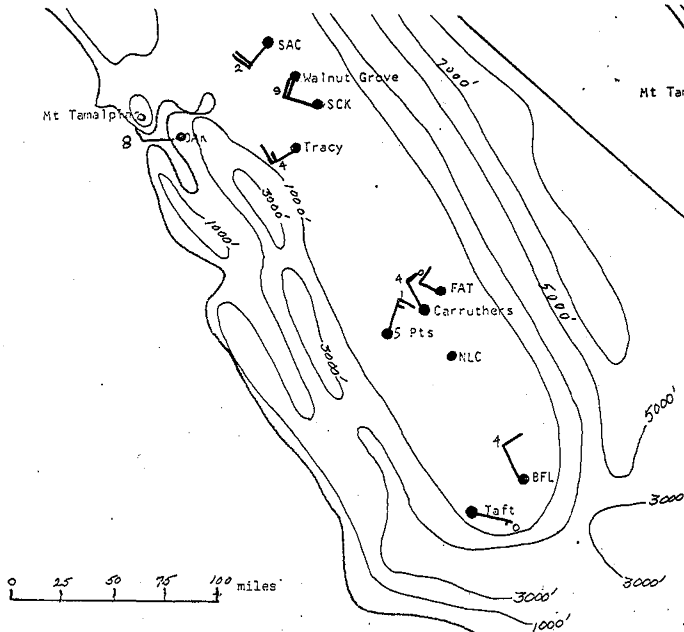

FIGURE 12A. WINDS AT 293 M. ABOVE GROUND FOR 1715 PST AUGUST 2, 1971. FULL BARB REPRESENTS 5 MPS. NUMBERS INDICATE DIRECTION TO TENS OF DEGREES.

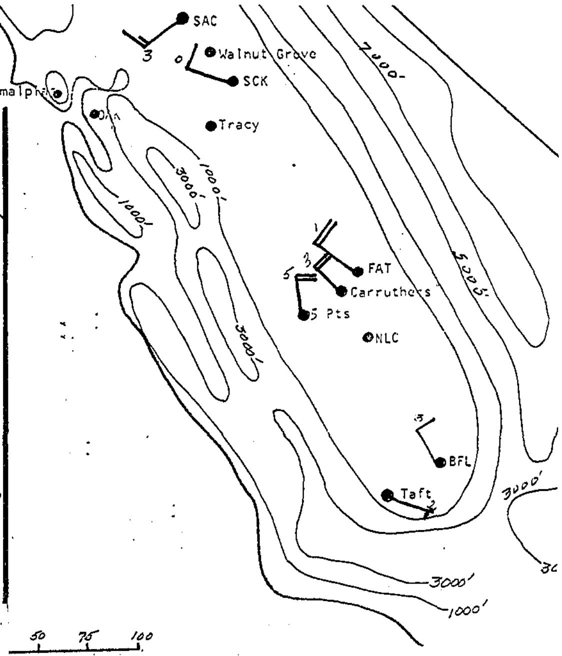

FIGURE 12B. WINDS AT 293 M. ABOVE GROUND FOR 1815 PST AUGUST 2, 197

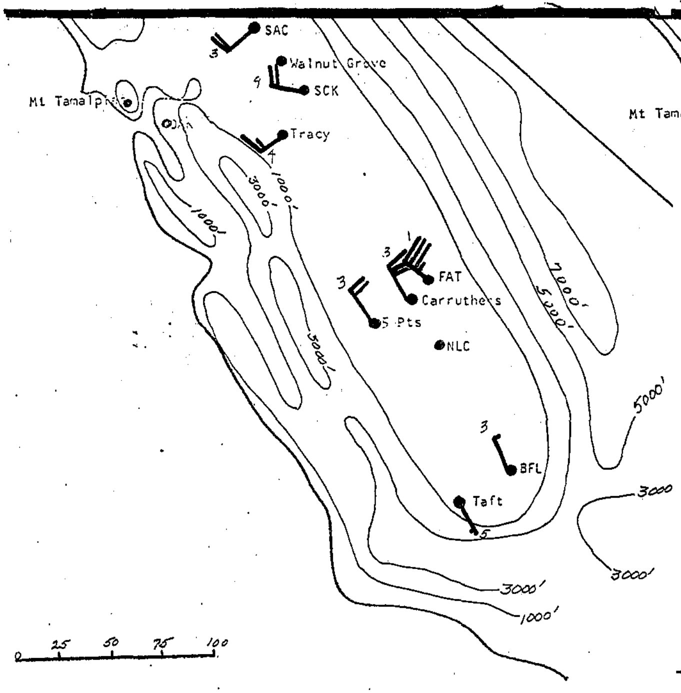

FIGURE 12C. WINDS AT 293 M. ABOVE GROUND FOR 1915 PST AUGUST 2, 1971

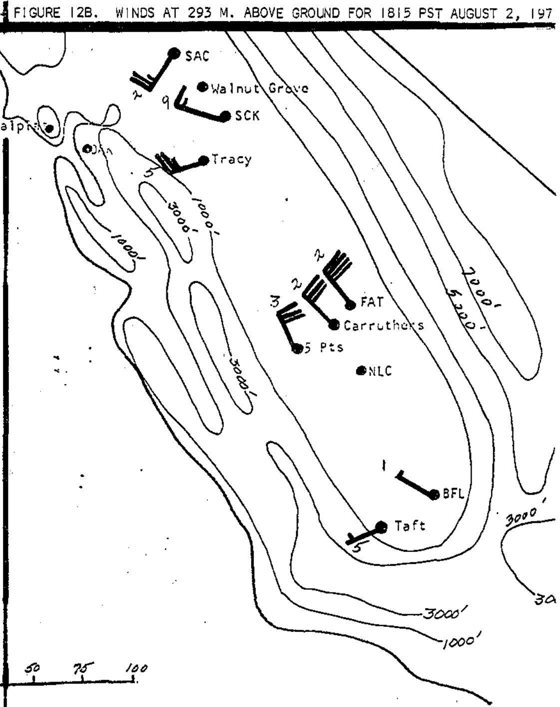

FIGURE 12D. WINDS AT 293 M. ABOVE GROUND FOR 2015 PST AUGUST 2,

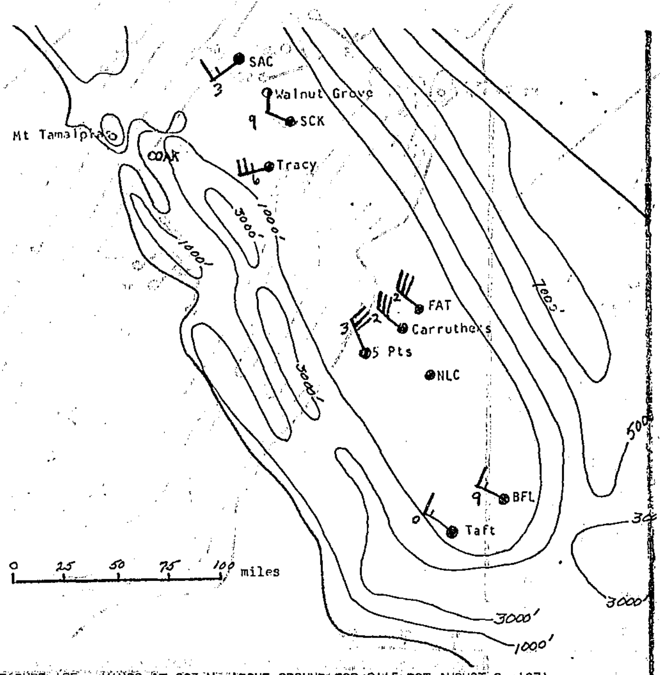

FIGURE 12E. WINDS AT 293 M. ABOVE GROUND FOR 2115 PST AUGUST 2, 1971.

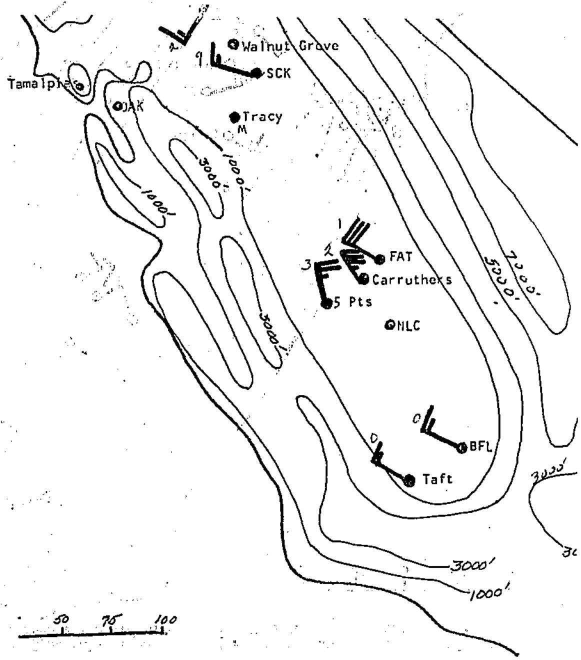

FIGURE 12F. WINDS AT 293 M. ABOVE GROUND FOR 2215 PST AUGUST 2, 1971

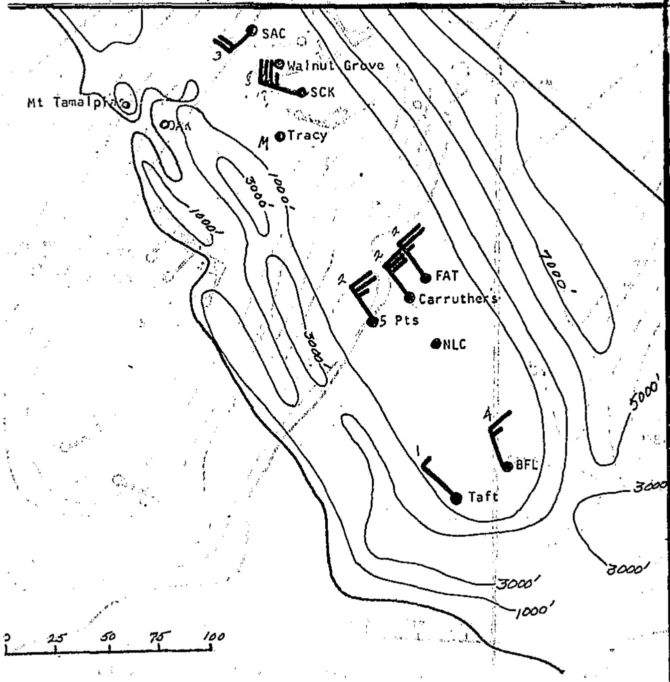

FIGURE 12G. WINDS AT 293 M. ABOVE GROUND FOR 2315 PST AUGUST 2, 1971.

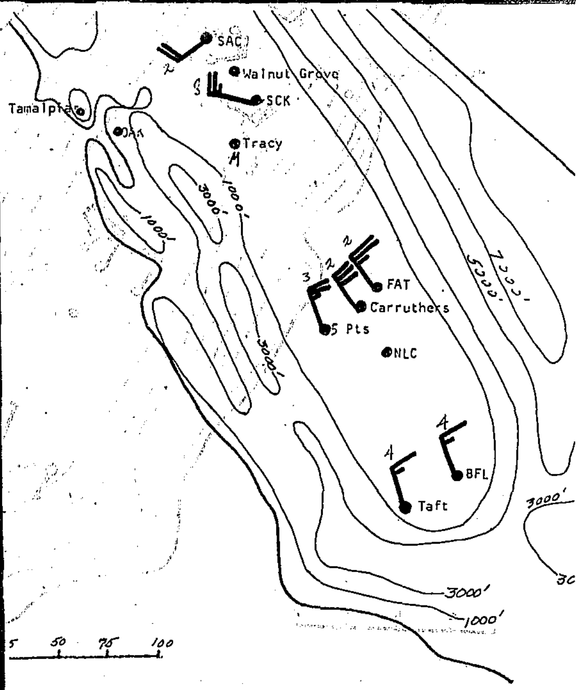

FIGURE 12H. WINDS AT 293 M. ABOVE GROUND FOR 0015 PST AUGUST 3, 1971.

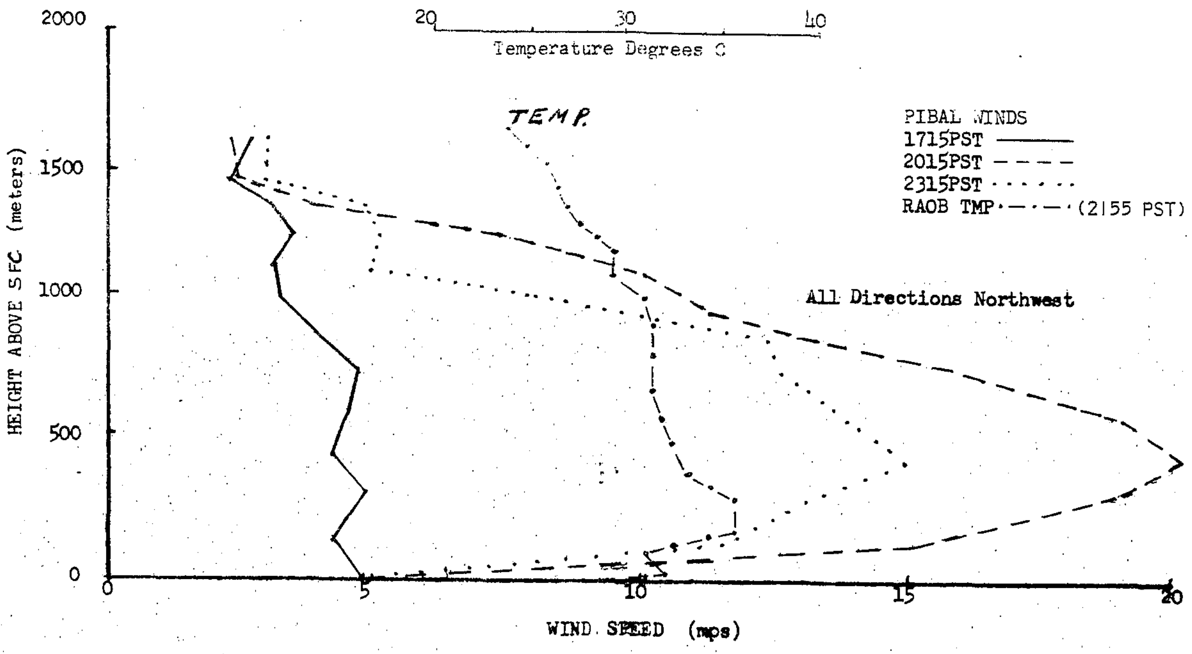

FIGURE 13. FRESNO TEMPERATURE, WIND SPEED PROFILES, AUGUST 2, 1971.

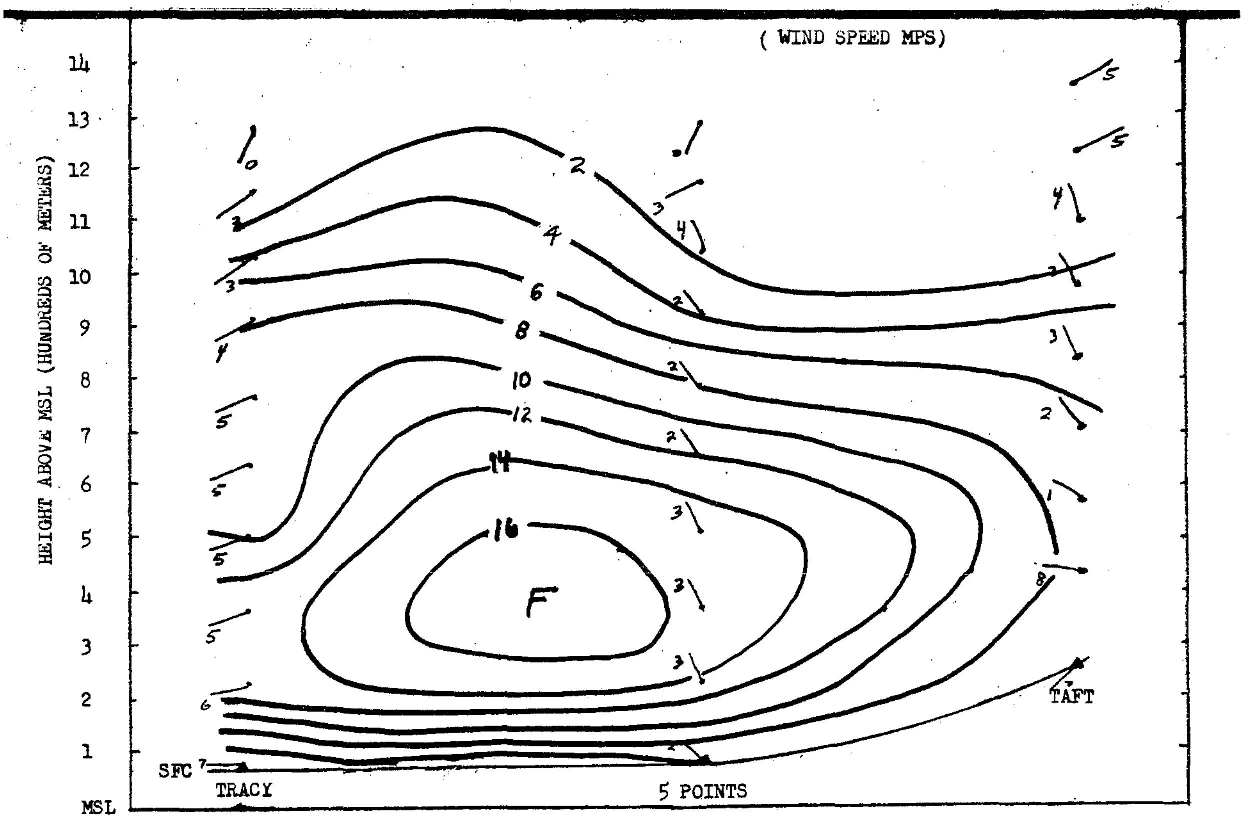

FIGURE 14. LONGITUDINAL SECTION THROUGH TRACE-TAFT FOR 2115 PST AUGUST 2, 1971.

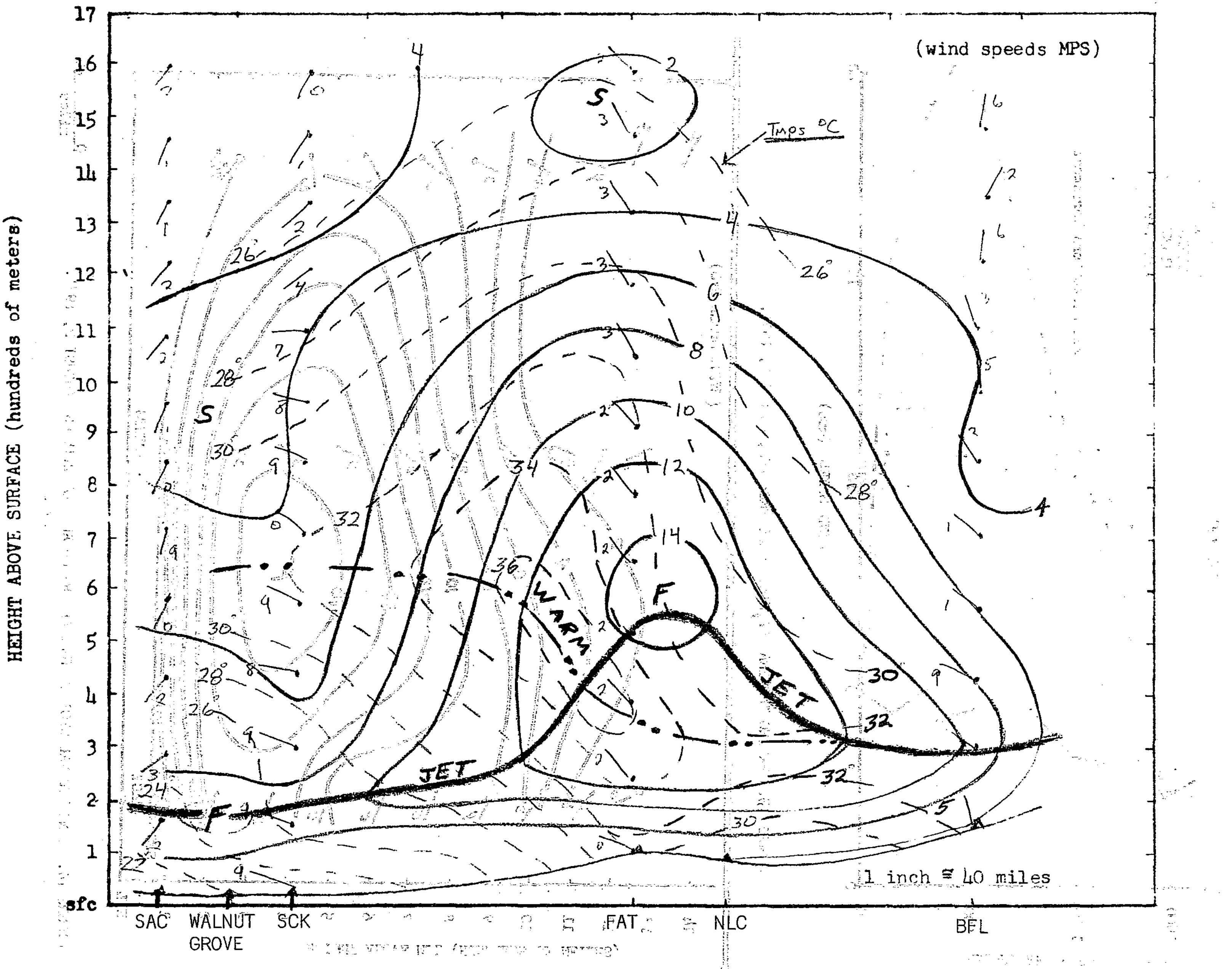

FIGURE 15. LONGITUDINAL SECTION, SACRAMENTO-BAKERSFIELD, 2115 PST AUGUST 2, 1971. SOLID LINES REPRESENT WIND SPEED IN MPS; DASHED LINES, TEMPERATURE DEGREES C.; DASHED-DOT LINE, INVERSION; AND HEAVY SOLID LINE, JET AXIS.

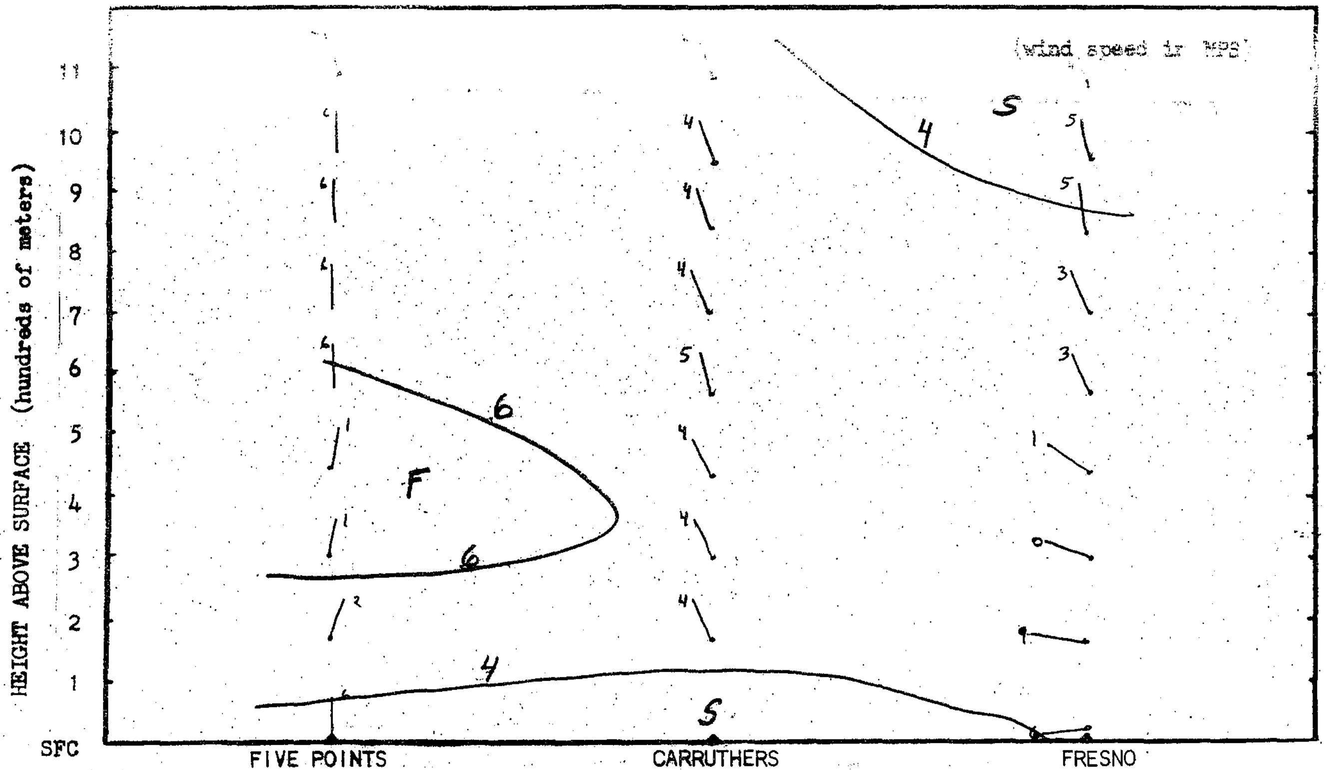

FIGURE 16A. CROSS SECTION FROM FIVE POINTS TO FRESNO FOR 1715 PST AUGUST 2, 1971. LINES ARE ISOPLETHS OF WIND SPEED (MPS). WINDS BLOW TOWARD DOT, DIRECTION IN TENS OF DEGREES.

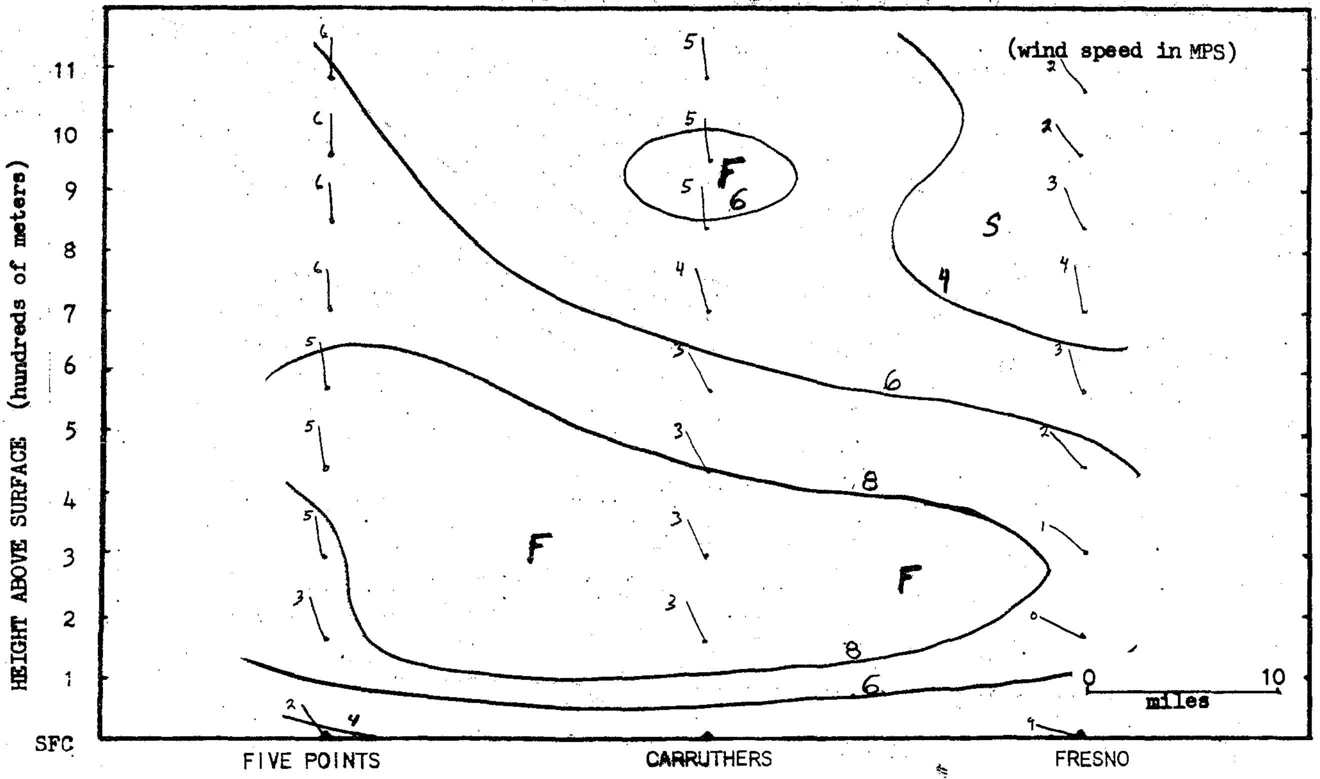

FIGURE 16B. CROSS SECTION FROM FIVE POINTS TO FRESNO FOR 1815 PST AUGUST 2, 1971.

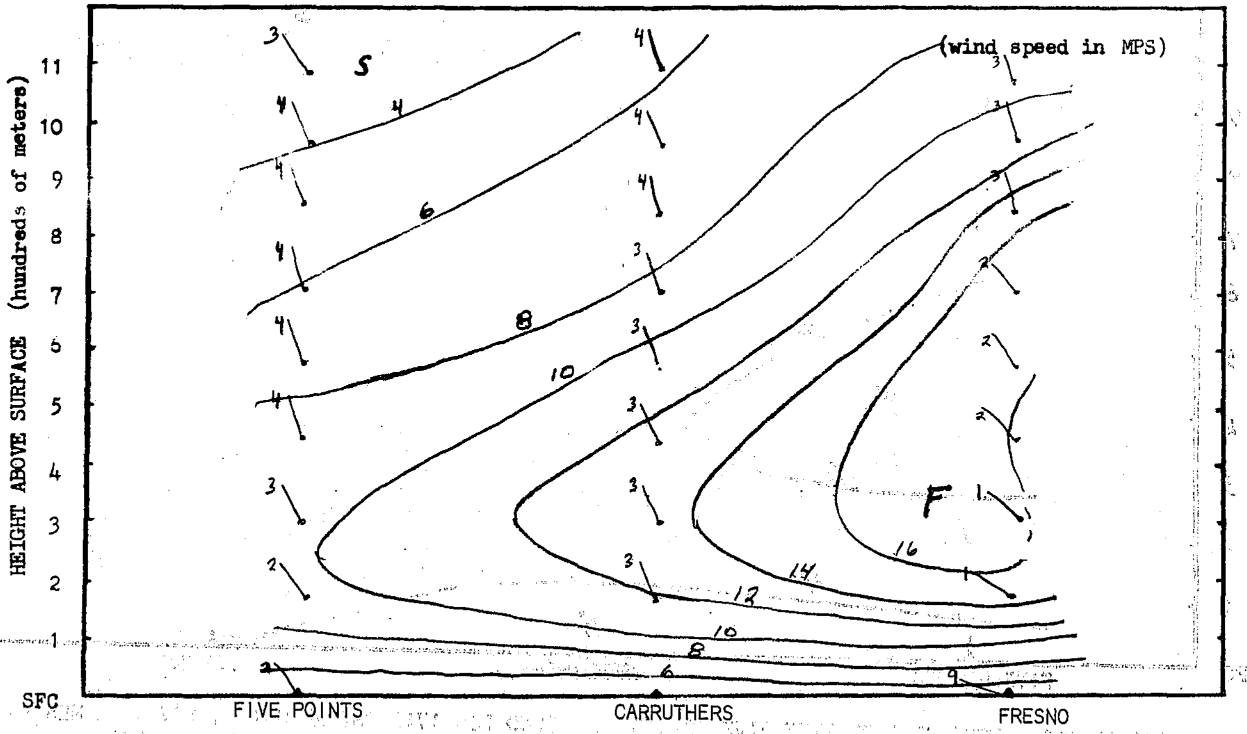

FIGURE 16C. CROSS SECTION FROM FIVE POINTS TO FRESNO FOR 1915 PST AUGUST 2, 1971.

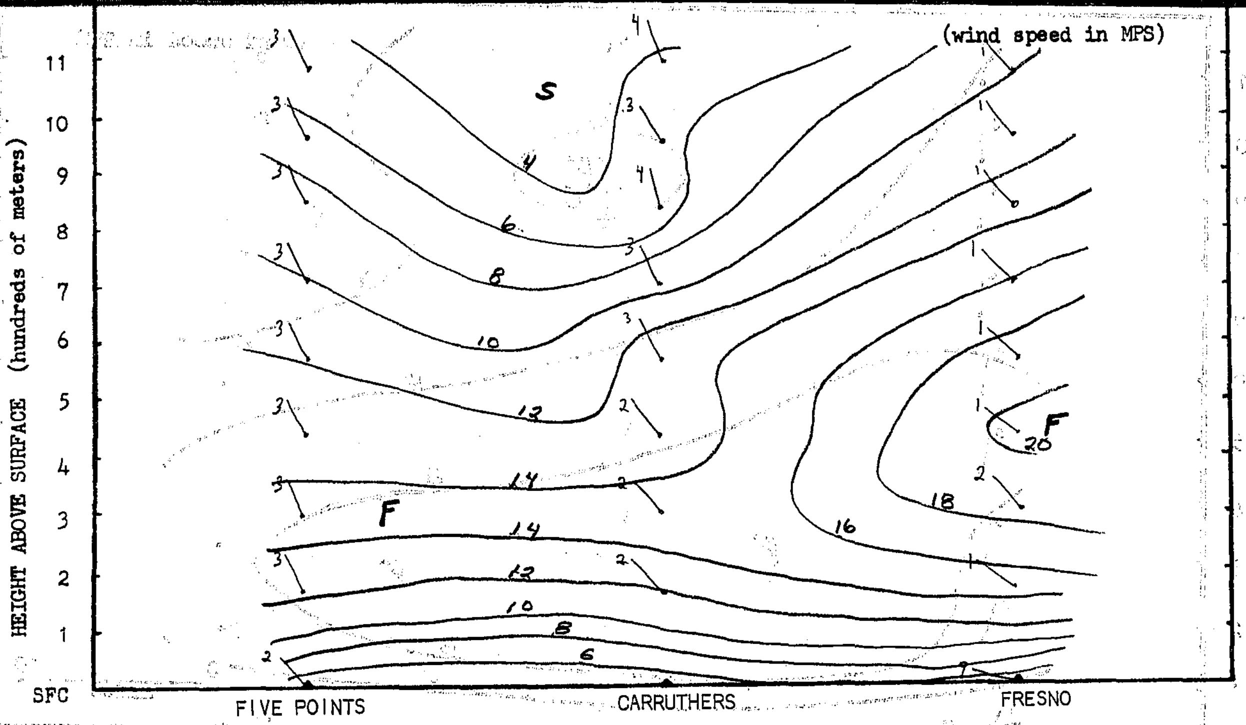

FIGURE 16D. CROSS SECTION FROM FIVE POINTS TO FRESNO FOR 2015 PST AUGUST 2, 1971.

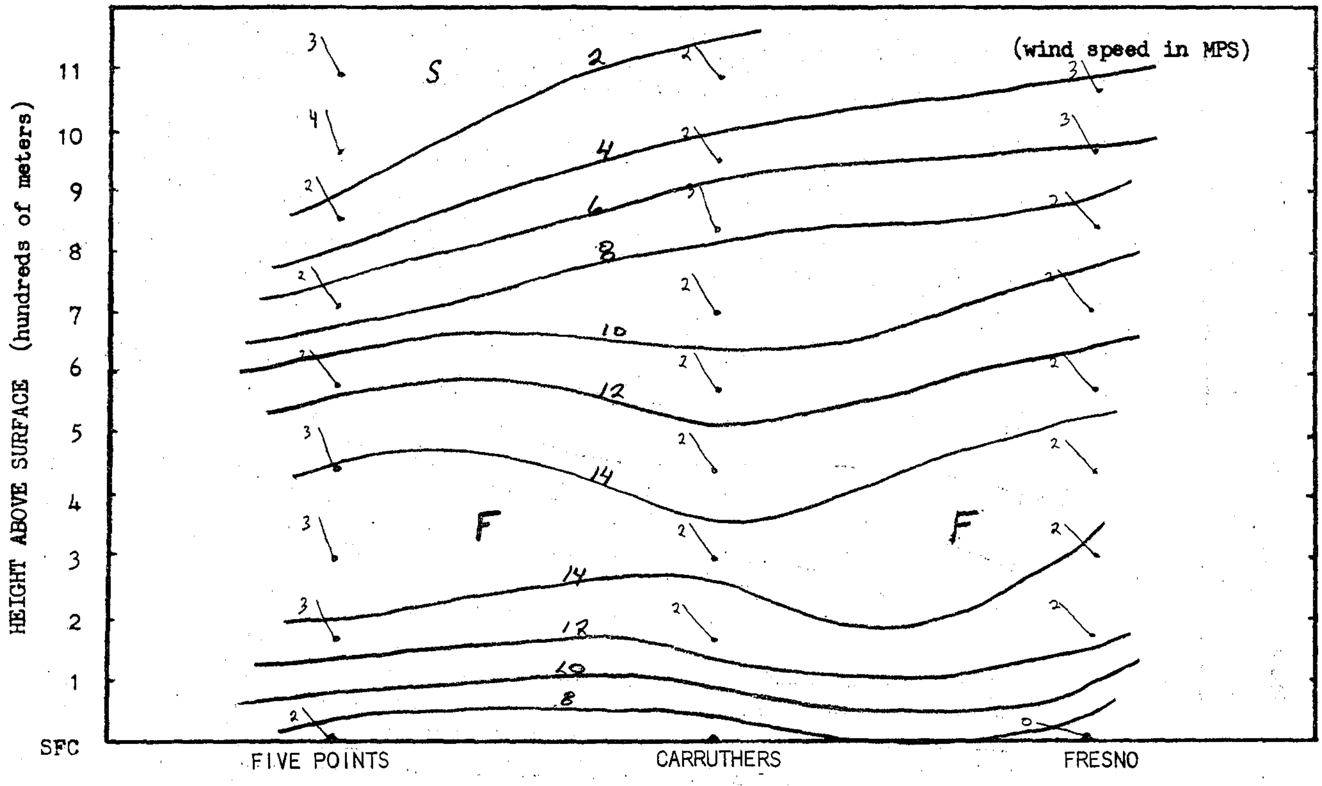

FIGURE 16E. CROSS SECTION FROM FIVE POINTS TO FRESNO FOR 2115 PST AUGUST 2, 1971.

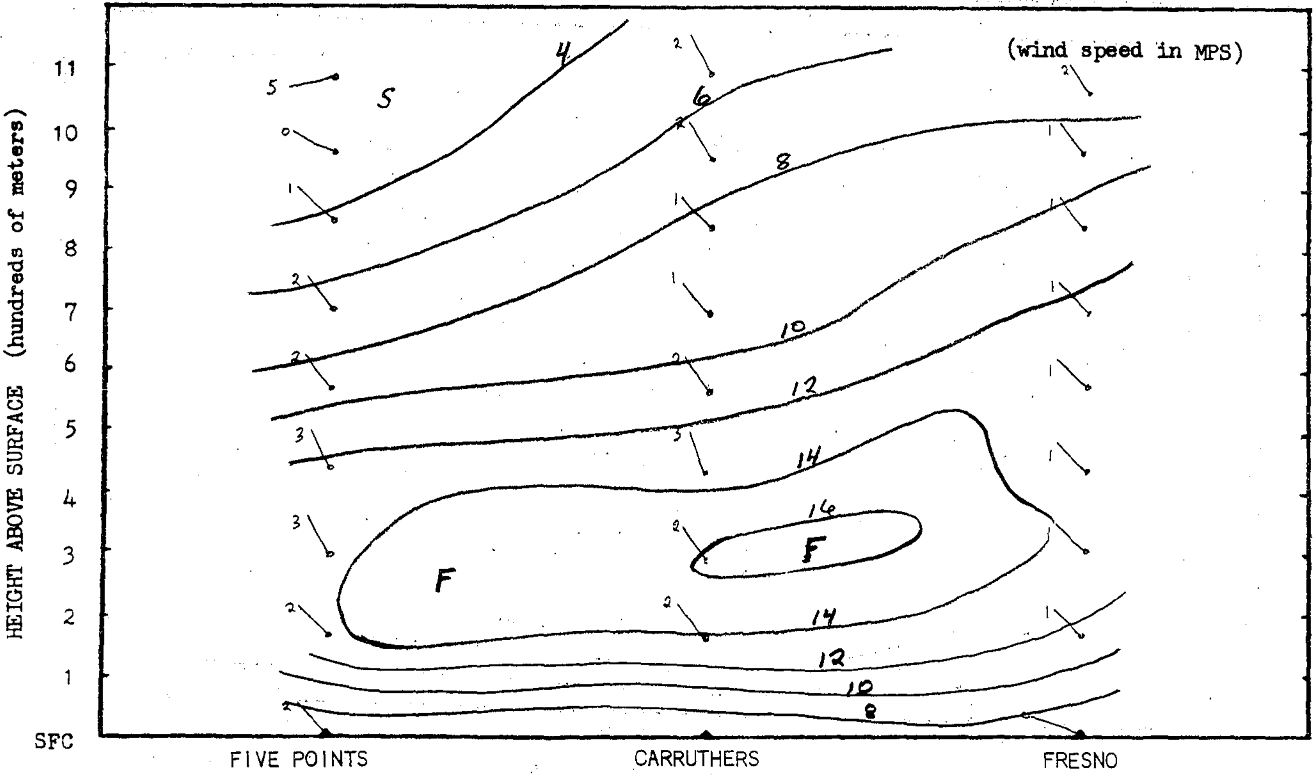

FIGURE 16F. CROSS SECTION FROM FIVE POINTS TO FRESNO FOR 2215 PST AUGUST 2, 1971.

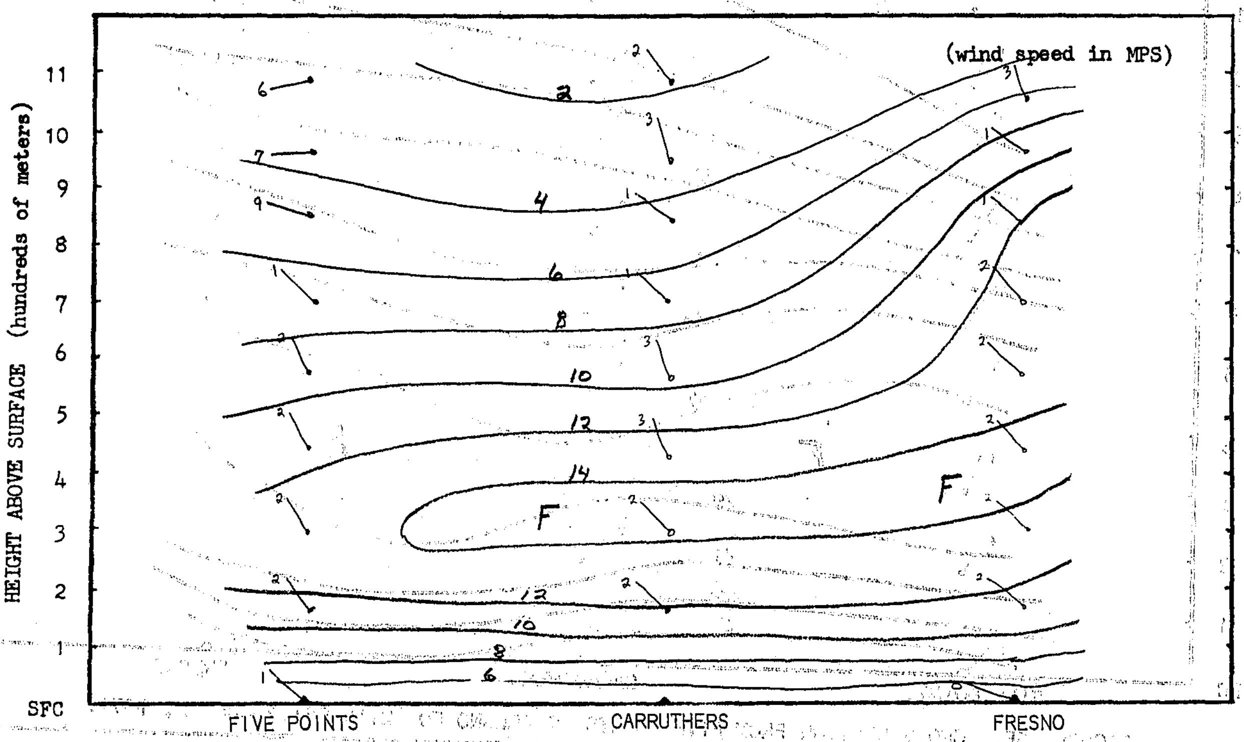

FIGURE 16G. CROSS SECTION FROM FIVE POINTS TO FRESNO FOR 2315 PST AUGUST 2, 1971.

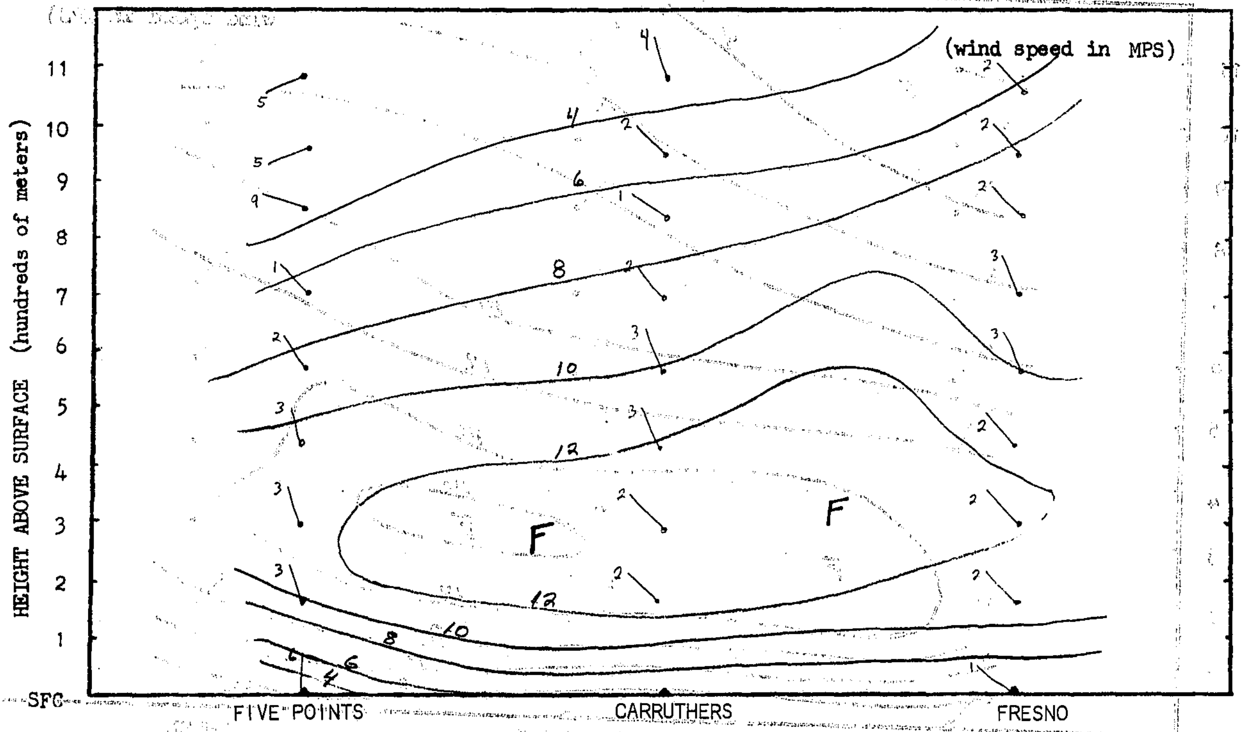

FIGURE 16H. CROSS SECTION FROM FIVE POINTS TO FRESNO FOR 0015 PST AUGUST 3, 1971.

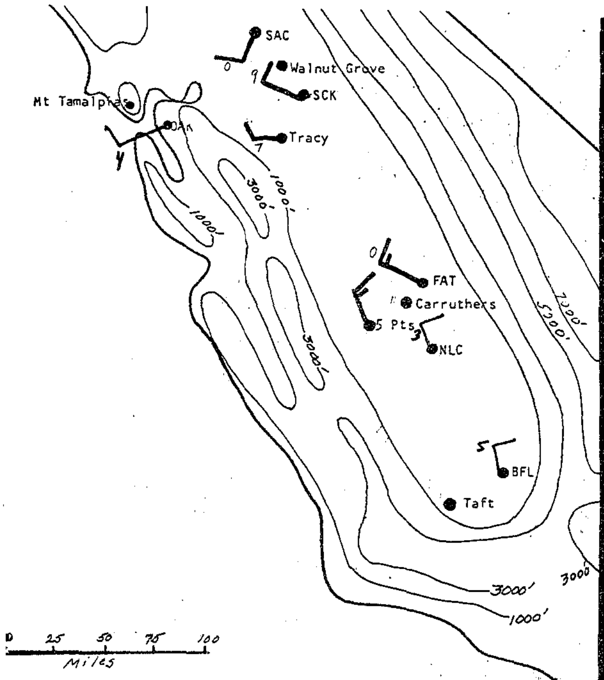

FIGURE 17A. SURFACE WINDS AT 2115 PST AUGUST 2, 1971. FULL BARB REPRESENTS 5 MPS NUMBERS INDICATE DIRECTION TO TENS OF DEGREES.

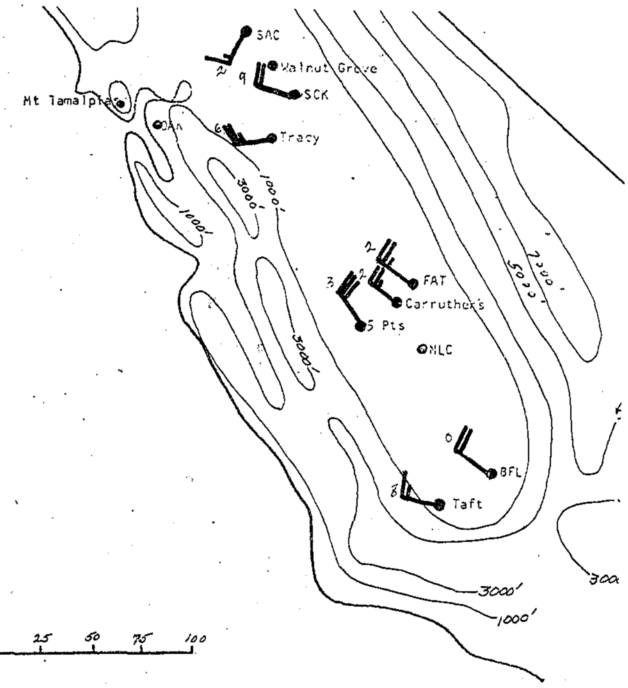

FIGURE 17B. WINDS 152 M. ABOVE GROUND LEVEL AT 2115 PST AUGUST 2, 1971.

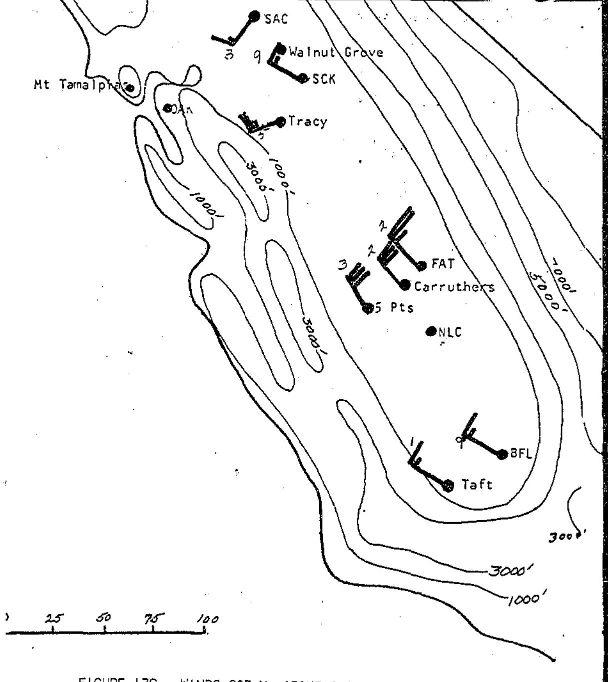

FIGURE 17C. WINDS 293 M. ABOVE GROUND LEVEL AT 2115 PST AUGUST 2

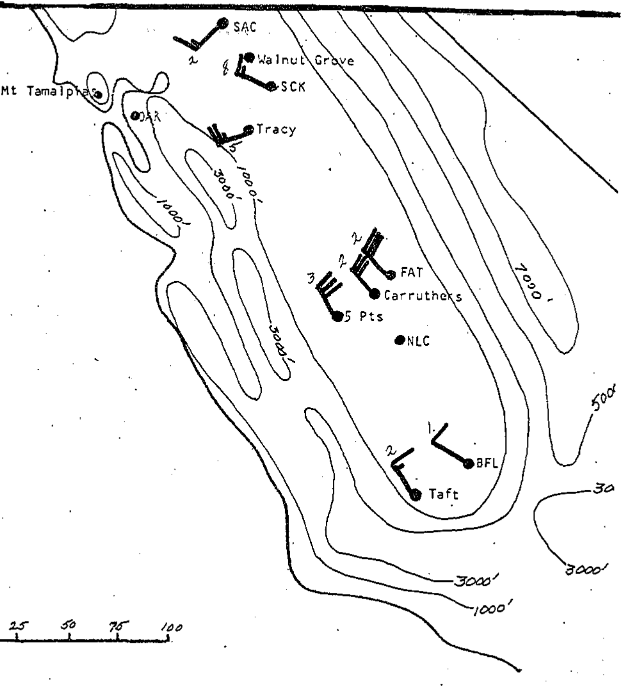

FIGURE 17D. WINDS 433 M. ABOVE GROUND LEVEL AT 2115 PST AUGUST 2, 1971.

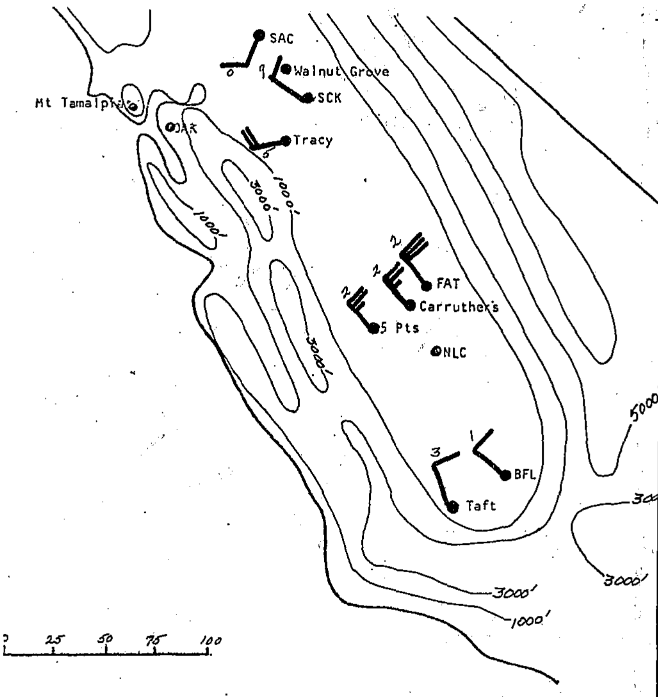

FIGURE 17E. WINDS 573 M. ABOVE GROUND LEVEL AT 2115 PST AUGUST 2, 1971.

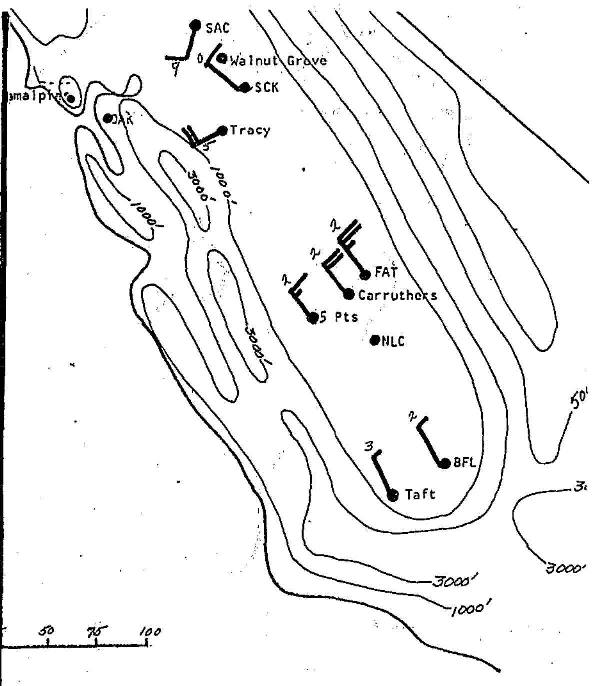

FIGURE 17F. WINDS 701 M. ABOVE GROUND LEVEL AT 2115 PST AUGUST 2, 1971.

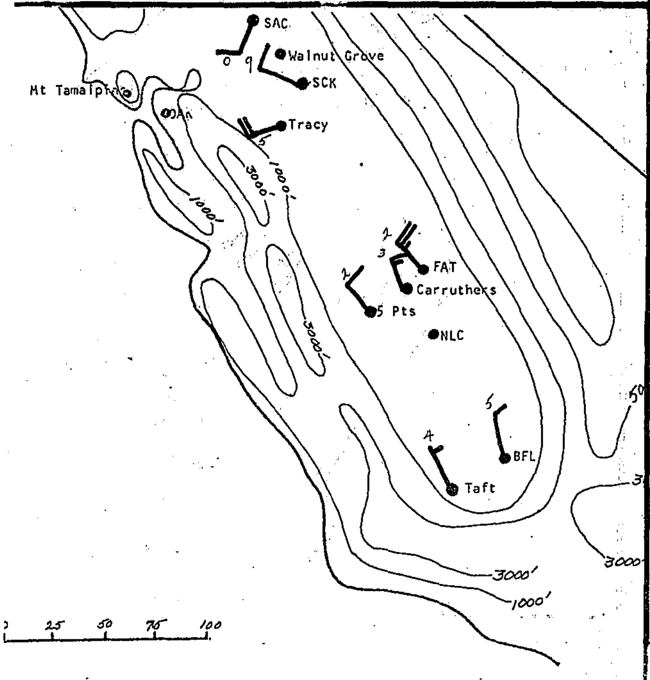

FIGURE 17G. WINDS 829 M. ABOVE GROUND LEVEL AT 2115 PST AUGUST 2, 1971.

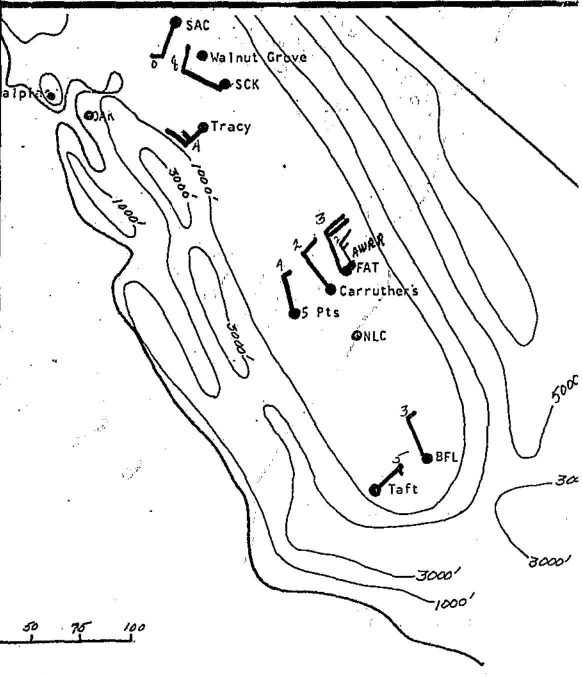

FIGURE 17H. WINDS 957 M. ABOVE GROUND LEVEL AT 2115 PST AUGUST 2, 1971.

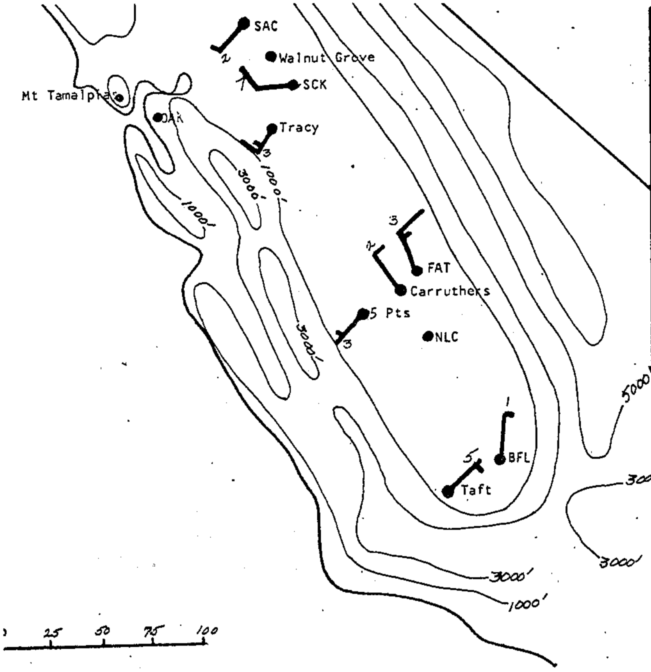

FIGURE 17I. WINDS 1085 M. ABOVE GROUND LEVEL AT 2115 PST AUGUST 2, 1971.

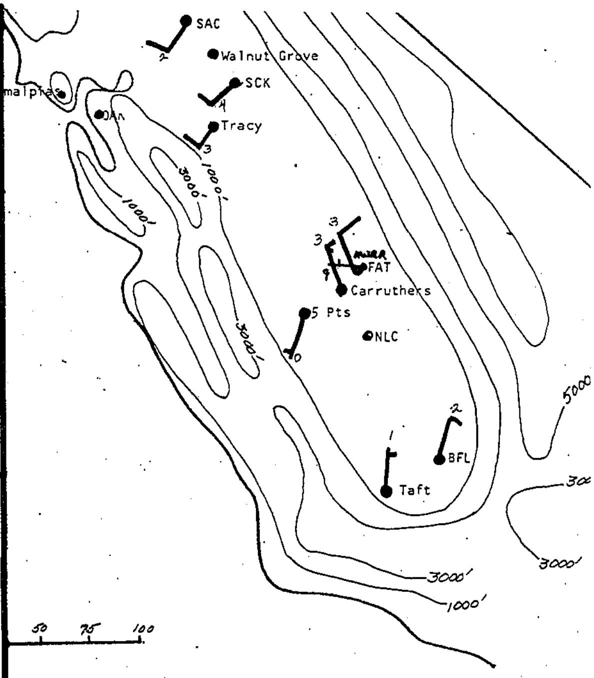

FIGURE 17J. WINDS 1213 M. ABOVE GROUND LEVEL AT 2115 PST AUGUST 2, 1971.

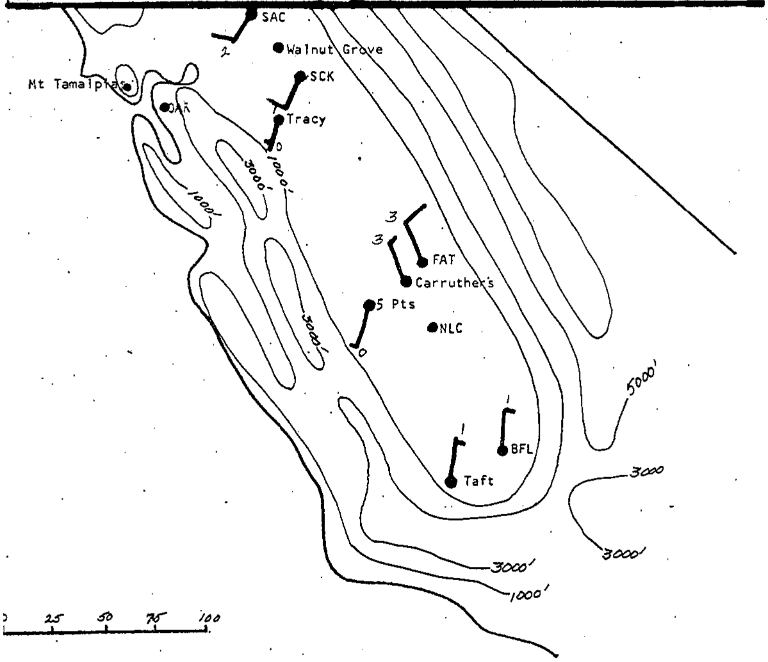

FIGURE 17K. WINDS 1341 M. ABOVE GROUND LEVEL AT 2115 PST AUGUST 2, 1971.

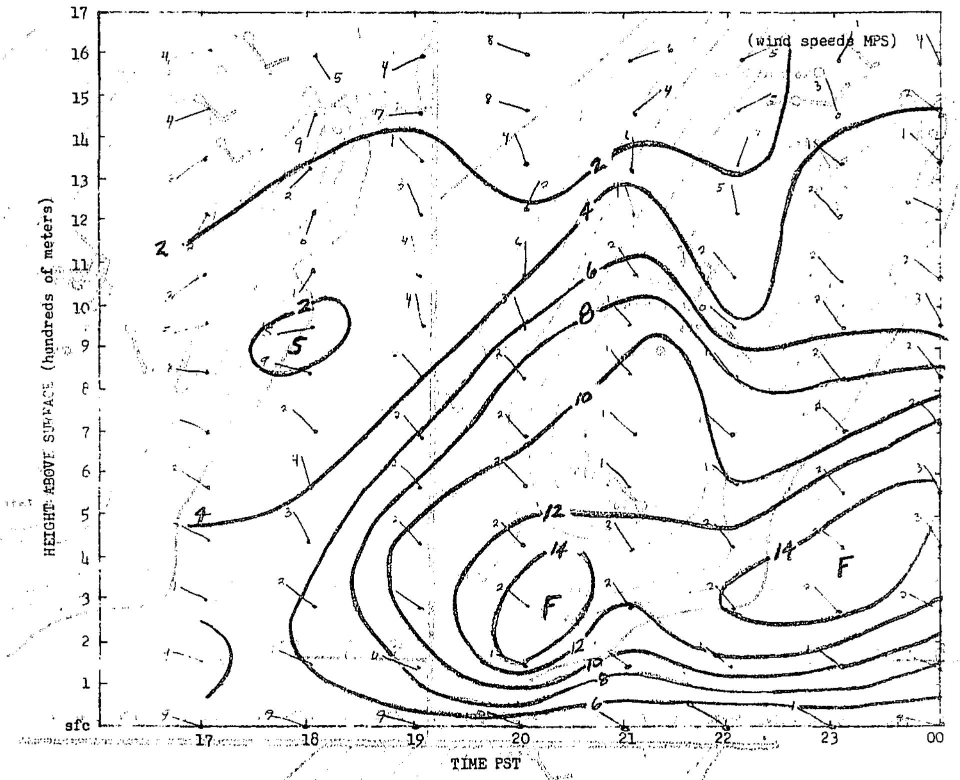

FIGURE 18A. TIME SECTION FOR FRESNO, AUGUST 3, 1971. LINES ARE ISOPLETHS OF WIND SPEED (MPS). WINDS BLOW TOWARD DOT, DIRECTION IN TENS OF DEGREES.

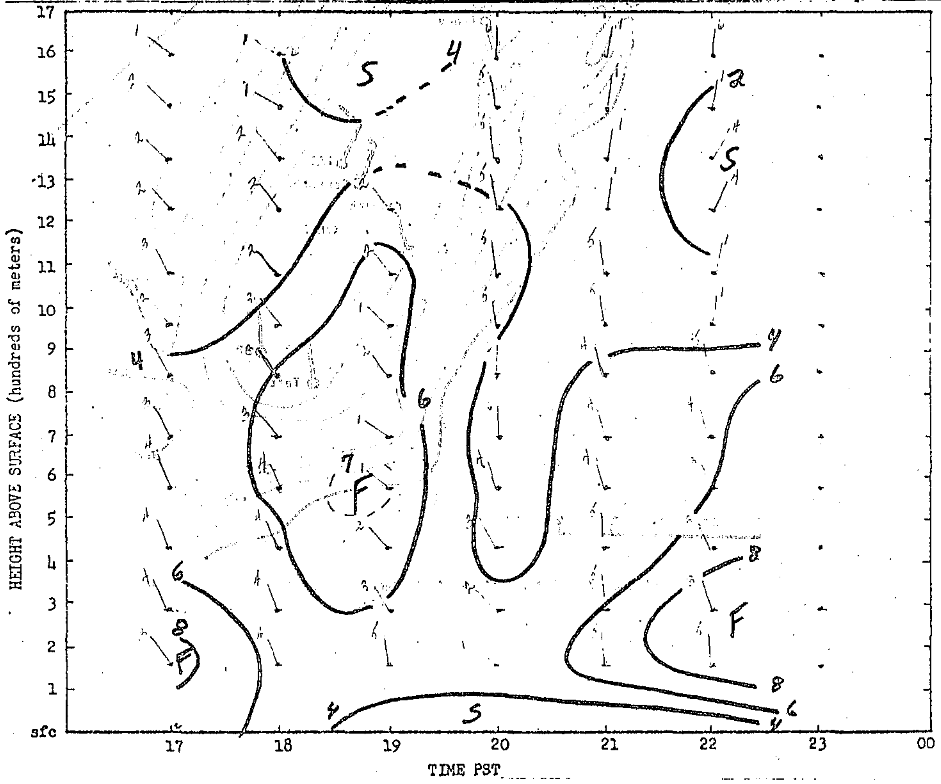

FIGURE 18B. TIME SECTION FOR BAKERSFIELD, AUGUST 3, 1971.

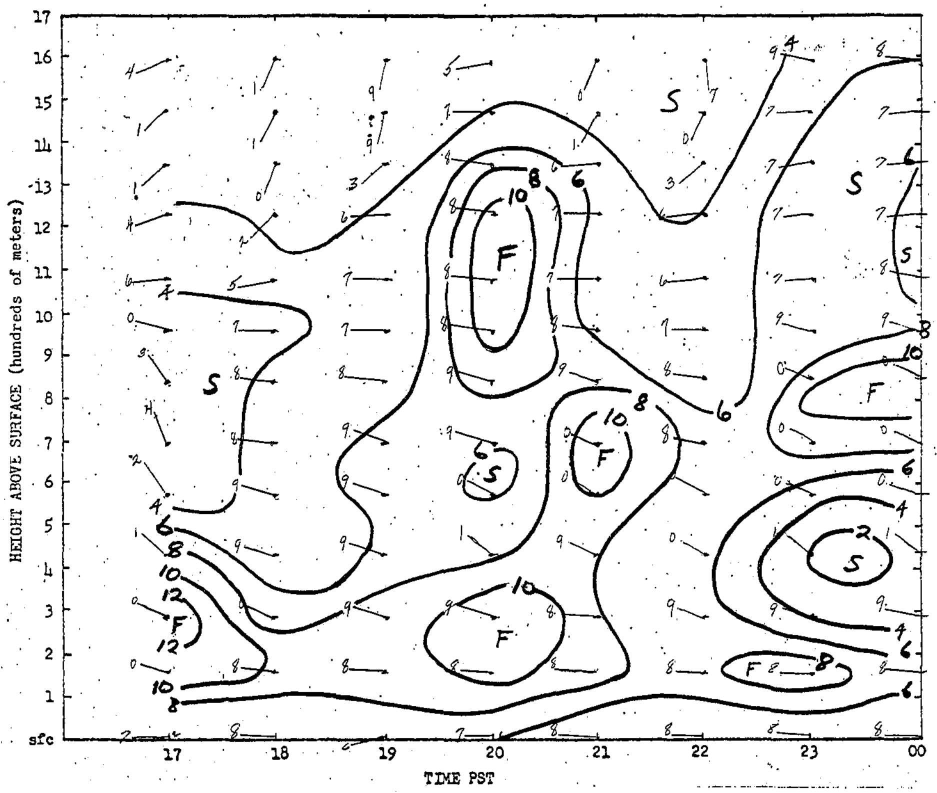

FIGURE 18C. TIME SECTION FOR STOCKTON, AUGUST 3, 1971.

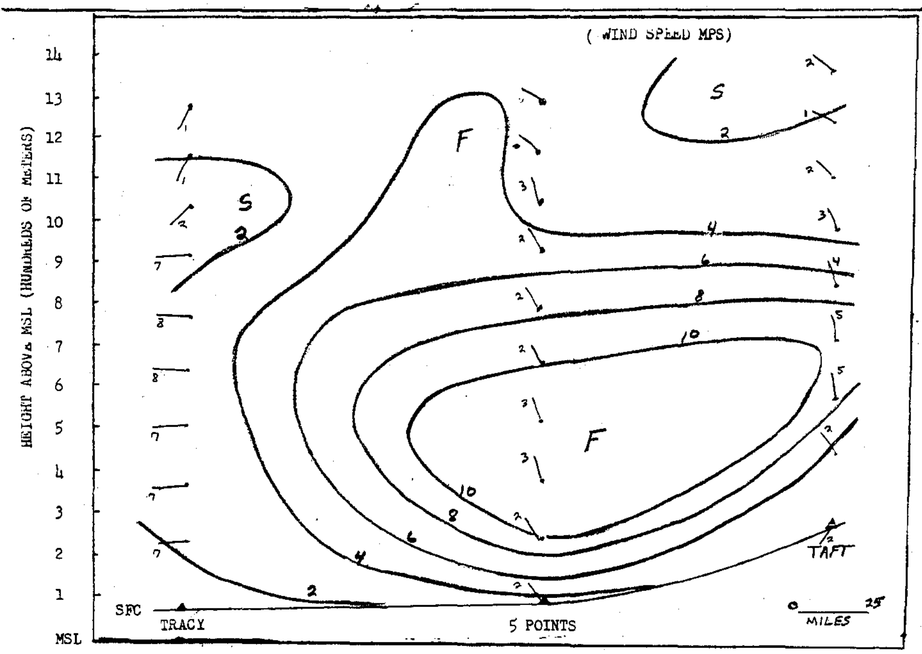

FIGURE 19. LONGITUDINAL SECTION, TRACY-TAFT, 2115 PST AUGUST 3, 1971.
SOLID LINES REPRESENT WIND SPEED IN MPS;

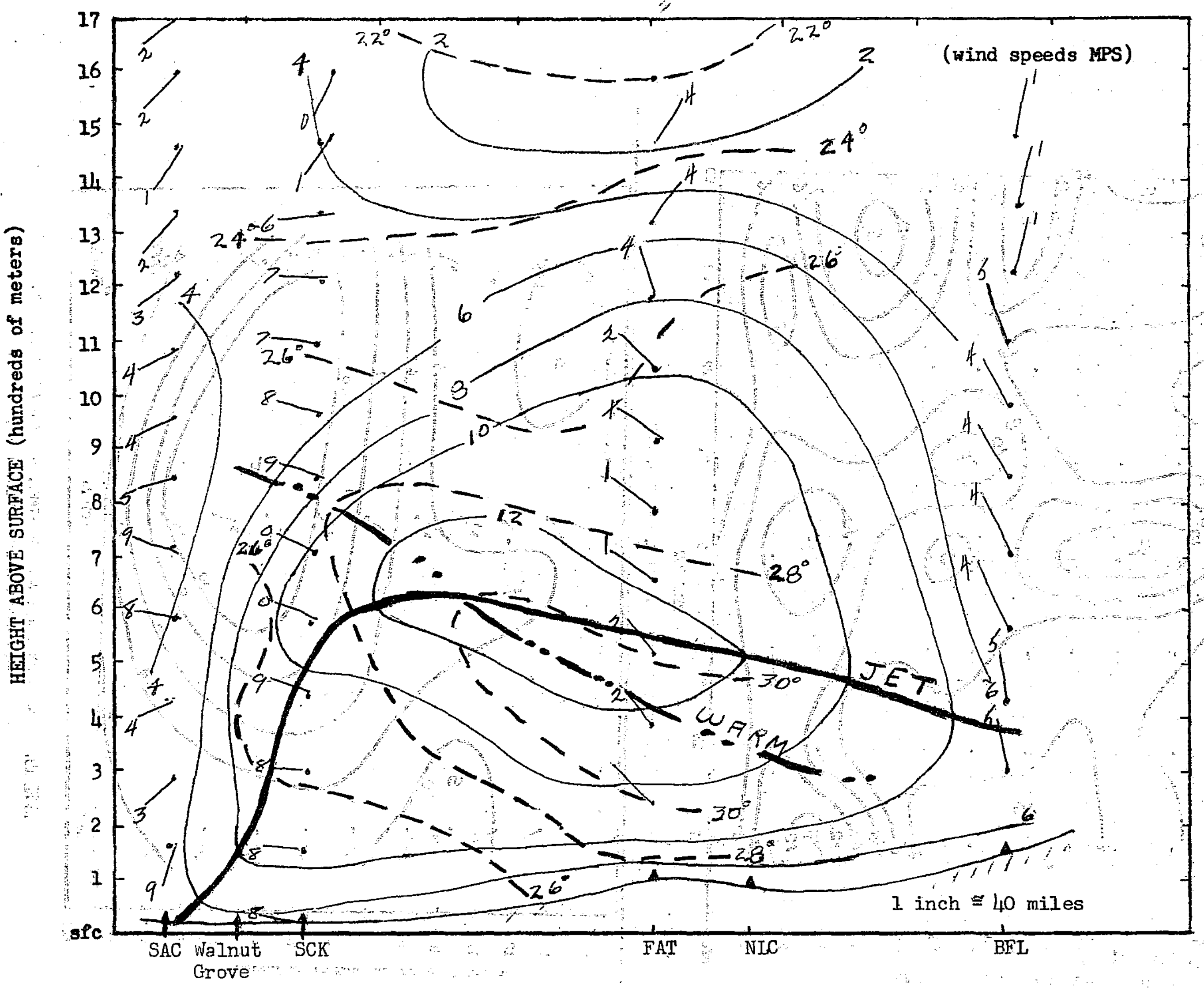

FIGURE 20. LONGITUDINAL SECTION, SACRAMENTO-BAKERSFIELD, 2115 PST AUGUST 3, 1971. SOLID LINES REPRESENT WIND SPEED IN MPS; DASHED LINES, TEMPERATURE DEGREES C.; DASHED-DOT LINE, INVERSION; AND HEAVY SOLID LINE, JET AXIS.

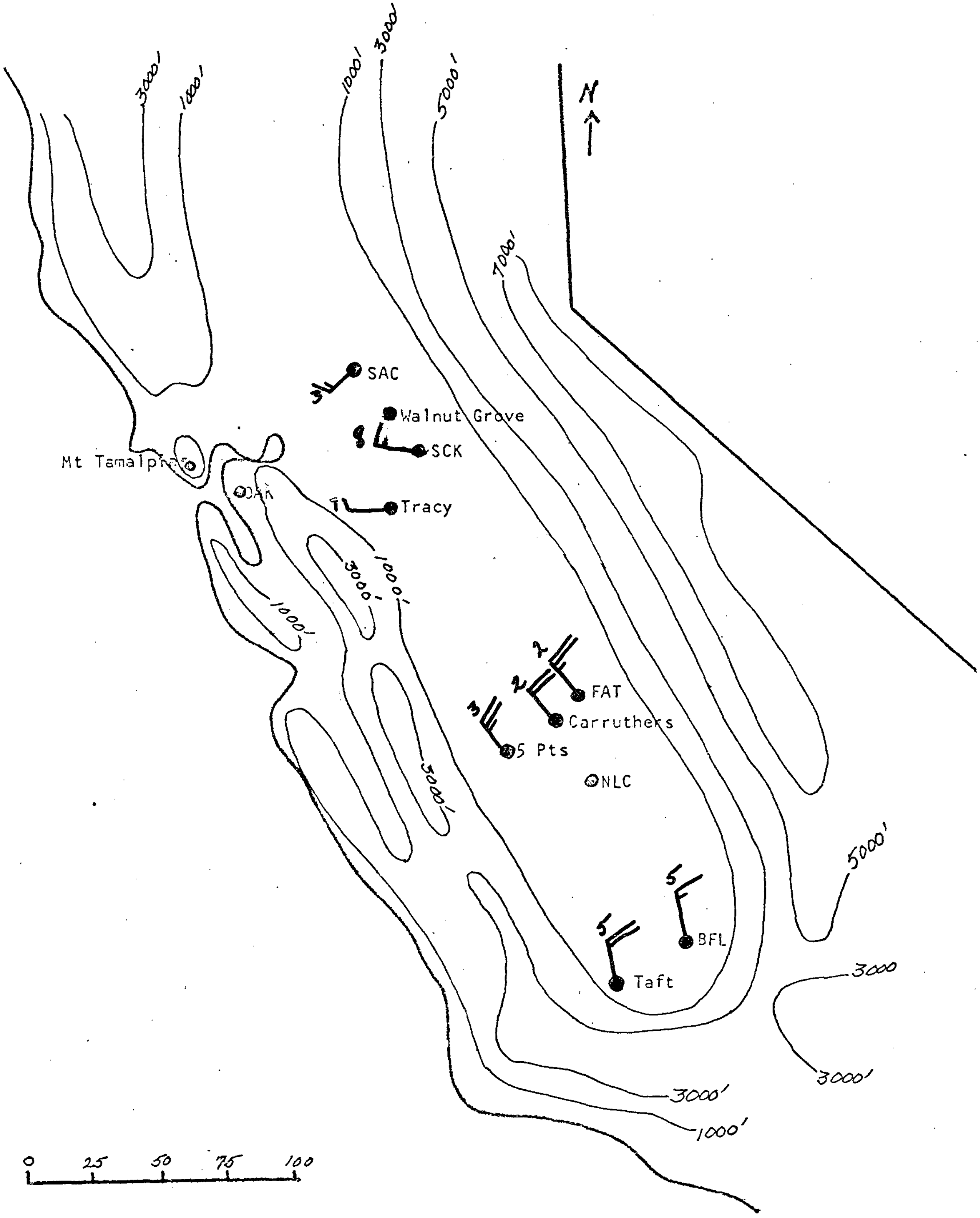

FIGURE 21. WIND FLOW OVER SAN JOAQUIN VALLEY AT 293 M., 2115 PST AUGUST 3, 1971. FULL BARB REPRESENTS 5 MPS. NUMBERS INDICATE DIRECTION TO TENS OF DEGREES.

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