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California State Air Resources Board

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Meso-climatic Wind Patterns and Their Application for Abatement of Air Pollution in the Central California Valley

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Abstract

Although the weather in Central California is frequently dominated by subsidence inversions, the occurrence of serious air pollution episodes is relatively small. This is especially true for the summer months. Inversions are practically permanent, but an unusual amount of windiness can be held responsible for low air pollution values. This windiness is primarily produced by the strong influx of marine air from the Pacific Coast into the Great Central Valley. When this flow enters the valley through the Carquinez Straits, it was discovered from recordings at the Walnut Grove T.V. Tower to be especially strong at night, at heights between 500 and 1000 feet. It was also found to be very variable, not only from day to day, but also in its diurnal cycle, a fact which high importance must be given in determining air pollution potentials and for scheduling releases of air pollutants. The present report is, therefore, an attempt to describe the character of the flow of marine air further inland, namely in the Sacramento and San Joaquin Valleys. Numerous valley bottom stations indeed revealed an afternoon and evening marine flow which is southerly in the Sacramento Valley and northwesterly in the San Joaquin Valley. However, the surface velocities mostly are weak, especially during the night hours in the Sacramento Valley because of increased friction near the ground. But the results at the Walnut Grove T.V. Tower proved that surface winds can be a poor indication of conditions only a few hundred feet aloft. In lieu of a tower in the Sacramento Valley, upper wind information during the night hours was obtained by balloon observations and two mountain stations in the Sutter Buttes. The intrusion of the marine air reached beyond the Sutter Buttes, with highest velocities of 35 mph found between 500 and 1000 feet as far

north as Biggs. However, much weaker velocities were found near the western borders of the valley (at Glenn and at Norman). Whereas balloon soundings can only give a limited sampling of the conditions, continuous recording of wind direction and velocity was obtained in 1971 from two freely exposed locations in the Sutter Buttes. These revealed a strong influx of marine air at the lower station at the 600-ft. height, as was experienced at the T.V. Tower 75 miles to the south. Strong southerly winds lasted practically all night in the summer months, but declined to half of all winds in the fall. The peak station at 2000 feet also showed the marine air characteristics as was found at the T.V. Tower, where the vertical depth in summer appeared to be near 2000 feet before midnight, but 1000 feet during the rest of the night. Accordingly, the 2000-ft. peak showed frequent southerly winds before midnight only. In fall they are greatly reduced, but a significant number can still be noticed at that height.

In the San Joaquin Valley, basically similar results were obtained, however, with some significant differences versus the Sacramento Valley. The balloon soundings revealed cases of marine air penetration as far south as Five Points, with strong maximum speeds between 500 and 1000 feet from the northwest. Most relevant were the various knoll and ridge stations, where high velocities were registered after sunset, and in addition, they indicated a marine air influx also through gaps in the coastal mountains. This seems to appear primarily on days with thick marine layers. It also occurs in somewhat smaller occurrences after midnight, although the depth of the marine layer usually decreases after midnight. Also, only the high locations on the western side registered this strong flow. The large width of the southern San Joaquin Valley probably causes gradual fading of the marine flow. However, it still is found on the east side in the northern

-3-

half. Our station on Green Mountain at 1270 feet, 25 miles northeast of Madera, shows strong northwest directions from 6:00 P.M. until after midnight. This station also reveals other peculiarities, especially during the summer months. Although about 30 miles away from the Sierra Range, daytime upslope winds from the west are predominent, whereas in the late night hours, easterly gravity winds are registered after the impact of the intruding marine air from the northwest has weakened. Similar results were obtained at the higher locations on the east side in the southern part of the San Joaquin Valley. The High Sierra Range obviously produced a strong development of daytime upslope and nightly downslope air movements. This fact may be a considerable contribution to the ventilation of this area which unfortunately does not seem to be significantly affected by the marine air influx. Whereas in the San Joaquin Valley the southeastern corner has the least benefit from the oceanic air, it is the northwest corner of the Sacramento Valley which seems to be the least affected region in the north.

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Conclusions

The need for this extensive survey project emerged with the establishment of the meteorological unit of the Air Resources Board. In prior years, California farmers could only rely in their operation of agricultural waste burning on the "Ventilation Factor". This factor, a nationally accepted criterion for air pollution issued daily, had proved insufficient in the case of the field burning problem. Especially the city of Sacramento experienced serious smoke episodes. As an early result of this project, it was recognized that the above mentioned conventional criteria can only be applied for air pollutants produced within cities. In the case of field burning, the prime concern should be preventing the smoke from drifting into the cities. A fortunate situation was known to exist in the lower Sacramento Valley where the influx of marine air showed a daily cycle of great magnitude, which could be utilized to the advantage of various agricultural operations, and especially the "burn-no burn" forecasts. It had been learned that the marine air influx in the Sacramento area has its weakest development during the morning hours, and lulls occur frequently, sometimes lasting till noon. On such days, conventional air pollution criteria would often yield unfavorable burning conditions. However, these morning lulls are followed by the strong influx of the marine air which produces a pronounced increase in pollutants dispersal, especially since it is found to last all night. The dispersal chances are even further increased during the night since velocities recorded along the 1500-ft. T.V. Tower at Walnut Grove regularly reached values of 25 mph and more at about the height of 600 feet throughout the night. The vertical extension of the intruding marine air usually is near 2000 feet until about midnight, after which it becomes shallower. These

strong velocities appear to have a great cleansing effect and may serve as an explanation of the result of an 8-year smoke statistic for Sacramento which shows smoke occurrence only during the lulls before noon, but sharp reduction from the afternoon hours until next morning. The questions to be answered next were how strong and to which extension the intruding marine air would affect the wind and dispersal conditions in the upper Sacramento Valley and San Joaquin Valley. Twentyfive monitoring stations in 1971, 1972, and 1973, and over 200 nightly balloon observations, provided the following answers.

The marine air penetrates the greatest part of the Sacramento Valley with almost the same intensity as at the Walnut Grove T.V. Tower. The recordings at the high locations in the Sutter Buttes, 75 miles north of the T.V. Tower which is near the entrance of the marine air into the Central Valley, were very similar in all respects. The balloon observations on various nights south and north of the Buttes confirmed this picture. However, the marine air influence appeared to fade in the northwestern corner of the Sacramento Valley. Despite the large size of the San Joaquin Valley, evidence was obtained of similar appearance of the marine air up to almost Fresno. On the west side, our high locations recorded marine air influx (with high velocities) also, through various gaps in the Coastal Ranges. Only the southeast corner of this valley does not seem to be directly affected by marine air. Instead, all our recordings on the east side showed pronounced developments of nightly downslope winds, and upslope winds in the daytime caused by the huge Sierra slopes and canyons. The contribution of these winds cannot be neglected as dispersal factors.

Recommendations

The areas least affected by the marine air might need a more extended monitoring of windiness. The northwestern corner of the Sacramento Valley might not be a serious problem with regard to air pollution potential because field burnings mostly take place in midsummer. The relatively few burnings in fall could be regulated by taking into account the storm activity which is likely to occur in that area. However, the southeast corner of the San Joaquin Valley would deserve more attention. The "local" wind situation is different at various spots. The marine air, even if not detected so far by balloon observations or mountain stations, might still have some influence on air pollution amounts, because deeper marine layers mean higher subsidence inversion bases. These cannot be much different in Oakland, Santa Maria, or Bakersfield, and can therefore influence the air pollution situation indirectly. Also, the nearness of high mountain ranges was found to involve parts of this area in the local "mountain-valley" wind system. The extent of its contribution to air exchange of this basin could be determined in a future study.

In the year 1964, pibal ascensions carried out 4 times a day at airports by Weather Bureau personnel were reduced to one per day. With the new air pollution problems and their abatement tasks, four slow-rise but short duration balloon releases daily at airports such as Bakersfield, Fresno, and others, might be desirable again.

The great opportunity for field burning on days with marine air influx requires careful scheduling. Burning may be recommended during the lull hours, so that the smoke is kept over the burn site where it can rise to higher levels, because one has to realize that a field burn is, by contrast to others, a hot pollution source. Late morning hours should be preferred to early morning hours, not only because of the drier material, but because

natural convection currents will provide an additional uplift of the smoke. The smoke might thus be brought near the levels of the wind maximum of the expected marine air where it would experience a thorough dispersal not alone by the high nightly speeds, but also because of increased turbulence from wind shear, since the velocities decline so rapidly from their maximum level toward the ground as well as upward. The same conclusion might be considered for the late fall months when the marine air influx is infrequent. Cyclonic activity is beginning at that time which produces good dispersal conditions. In some cases, it might be possible for the forecaster to permit burning during the "quiet before the storm".

The required forecasting of the expected appearance and strength of the marine air is delicate because the magnitude of its influx sometimes depends only on very small barometric differences between the Valley and off-shore areas. The differences can vary from hour to hour so that during a short morning a "burn" situation can change into a "no-burn", and vice-versa. The author has once tried to correlate--as a potential forecasting tool--the strength of the marine air at the end of the night at the Walnut Grove tower with the strength during the following evening, but no connection was found. For the same reason, use of early morning criteria for forecasts of burnings later in the day might sometimes not be satisfactory. The United States Weather Bureau, in its early attempt to help the rice growers in the decision making, often found it necessary to modify the early morning ventilation forecasts at noon, which was a very useful step. Since the ARB, due to its greatly expanded activity might not consider a similar step as practicable, the following compromise solution is suggested. Since two reasons were just mentioned in favor of delaying of burning until late morning or afternoon, issuing of forecasts could be postponed until midmorning. This would permit collecting of additional observations which would especially be helpful in the fall when good burning opportunities are rare in some years.

Introduction and Background

Wind studies have been conducted by the Agricultural Engineering Department at Davis in the past in various districts of the Central Valley where problems of wind erosion, drift of agricultural chemicals, and the selection of frost protection devices were of major concern. Inspection of available data with regard to air pollution abatement indicated that in certain weather patterns, good opportunities seem to exist for releasing air pollutants without causing any health hazard or public nuisance. There are periodic local wind conditions in the central part of the Great Valley which appear especially suitable for dispersing pollutants from agricultural burning. These occasions are connected with strong inflows of maritime air in late afternoon and night. However, these strong winds are preceded by morning and early afternoon lulls which could easily be designated as air pollution "builders" if they were not of short duration. The late afternoon influx of maritime air has been observed to last almost all night, contrary to the wind conditions in the coastal areas of Southern California where daytime sea breezes are replaced with reversed land breezes at night. The vertical structure of this maritime flow is of special interest, since "low level jet" type velocity maxima have been observed aloft at the Walnut Grove T.V. Tower. These maxima, besides having velocities of 25 mph, and more, can provide rather effective dispersion of air pollutants also by mechanical turbulence. The questions needed to be answered for air pollution problems are the duration and the depth of penetration of the marine air into the Sacramento and San Joaquin Valleys. In an early study for the purpose of intelligent scheduling of pesticide application by aircraft on rice fields, information on ground wind conditions in summer could be summarized as

demonstrated in the example given in Figure 1. It shows that the incoming marine air at its weakest stage is slowly circling around in the lower Sacramento Valley, resulting in northwesterly directions in Davis when southwesterly directions still prevail in Sacramento. This figure further shows that on this day, a very typical case, the marine air invades the whole valley in early afternoon and continues flowing during the night. In another phase of work, instruments at the Walnut Grove 1500-ft T.V. Tower provided information on the vertical structure of the marine air. The location of the Tower, 25 miles south of Sacramento, can be seen in Figure 1 by the station arrow showing southwesterly wind, although the direction at higher levels at the Tower were west. Figure 2, a typical example, shows that toward the height of about 600 feet, the marine air influx increases rapidly to a velocity maximum of more than 20 mph around sunset time. These high speeds are maintained until the end of the night while the velocities near the ground remain low. Another typical feature, as can be seen in Figure 2, is the vertical depth to remain at about 2000 feet until midnight, after which it becomes shallower. This wind pattern might explain Figure 3, where 8 years of hourly smoke observations at Sacramento show a high occurrence during the late morning hours, contrary to the usual experience elsewhere, where visibilities improve with increasing sun's height. In spring and summer, practically no smoke observations can be found from the afternoon on, the time when the marine air flow is gaining strength. The curve for the fall months, however, shows that this "clean-out" which practically always exists in spring and summer, does not occur on all days in fall and winter. T.V. Tower summaries indicate a gradual decline of marine air influx to about 25% of the days. But it is worth mentioning that the vertical wind pattern demonstrated in Figure 2 was found in every month of the

year. Even monthly averages for the various levels at the T.V. Tower showed maximum wind speeds between 500 and 1000 feet in all months.

Although the previous investigation, see Figure 1, has covered the major part of the Sacramento Valley rice growing area, the monitoring work was extended in the present survey toward areas near Chico and into the San Joaquin Valley. Also, the fall months were included, since these are the most critical with respect to air quality. The greatest efforts, however, appeared necessary for obtaining information aloft, preferably between the heights of 500 to 2000 feet.

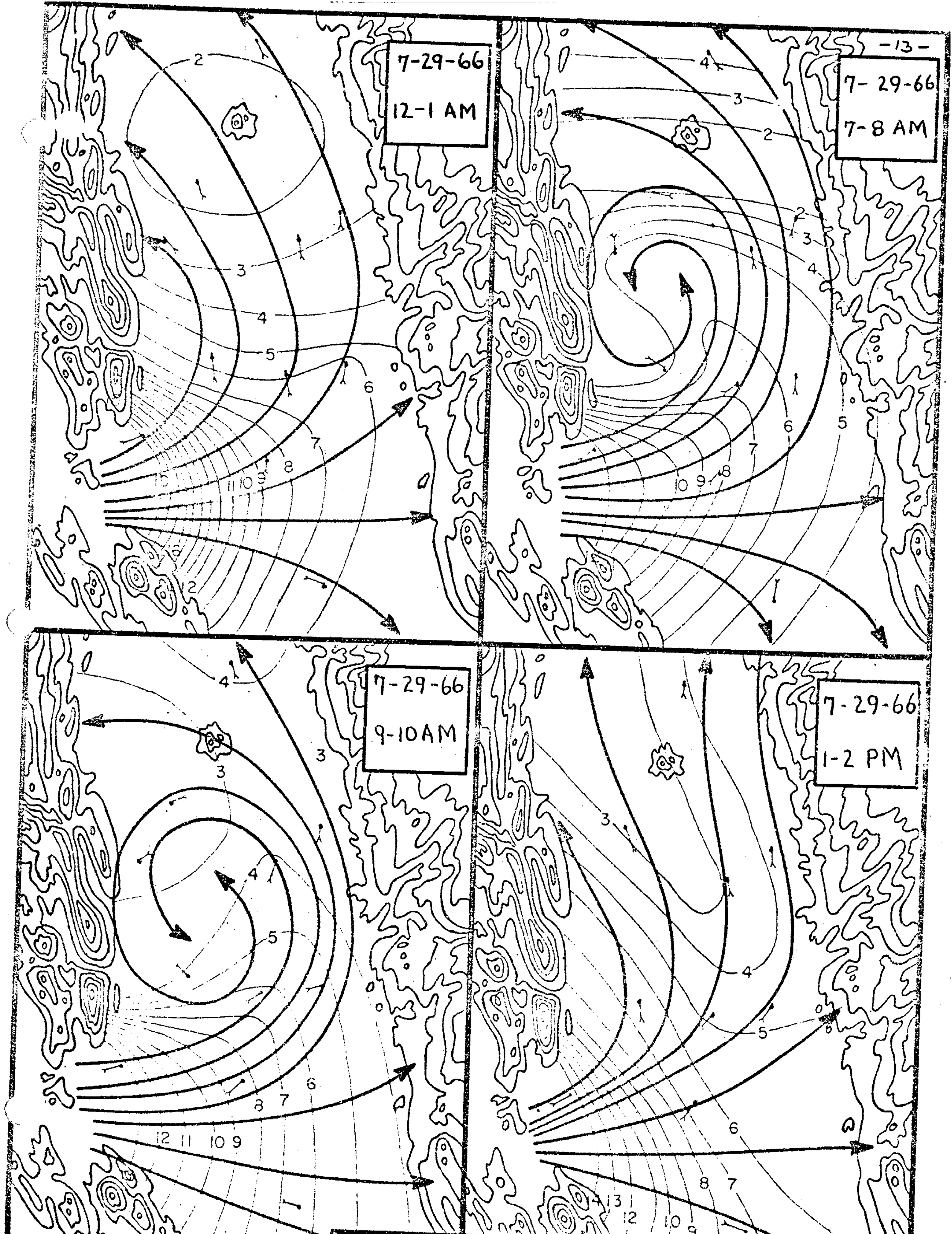
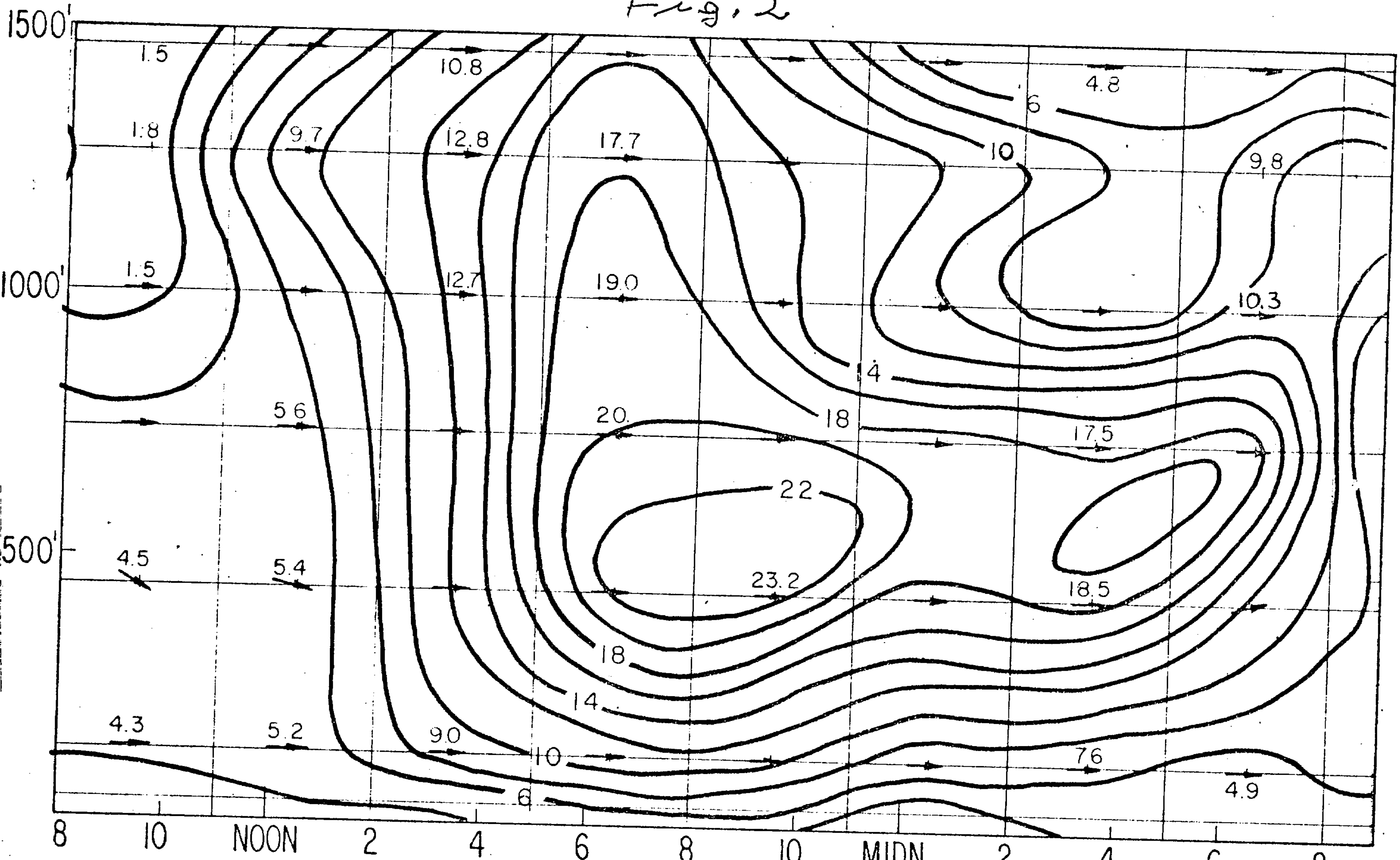


Fig. 1

Fig. 2



WIND-TIME SECTION AT TV TOWER
WALNUT GROVE, CALIF.
AUGUST 18-19, 1967

Fig. 2

Hourly Smoke Observations, Executive Airport Sacto
(1957-64)

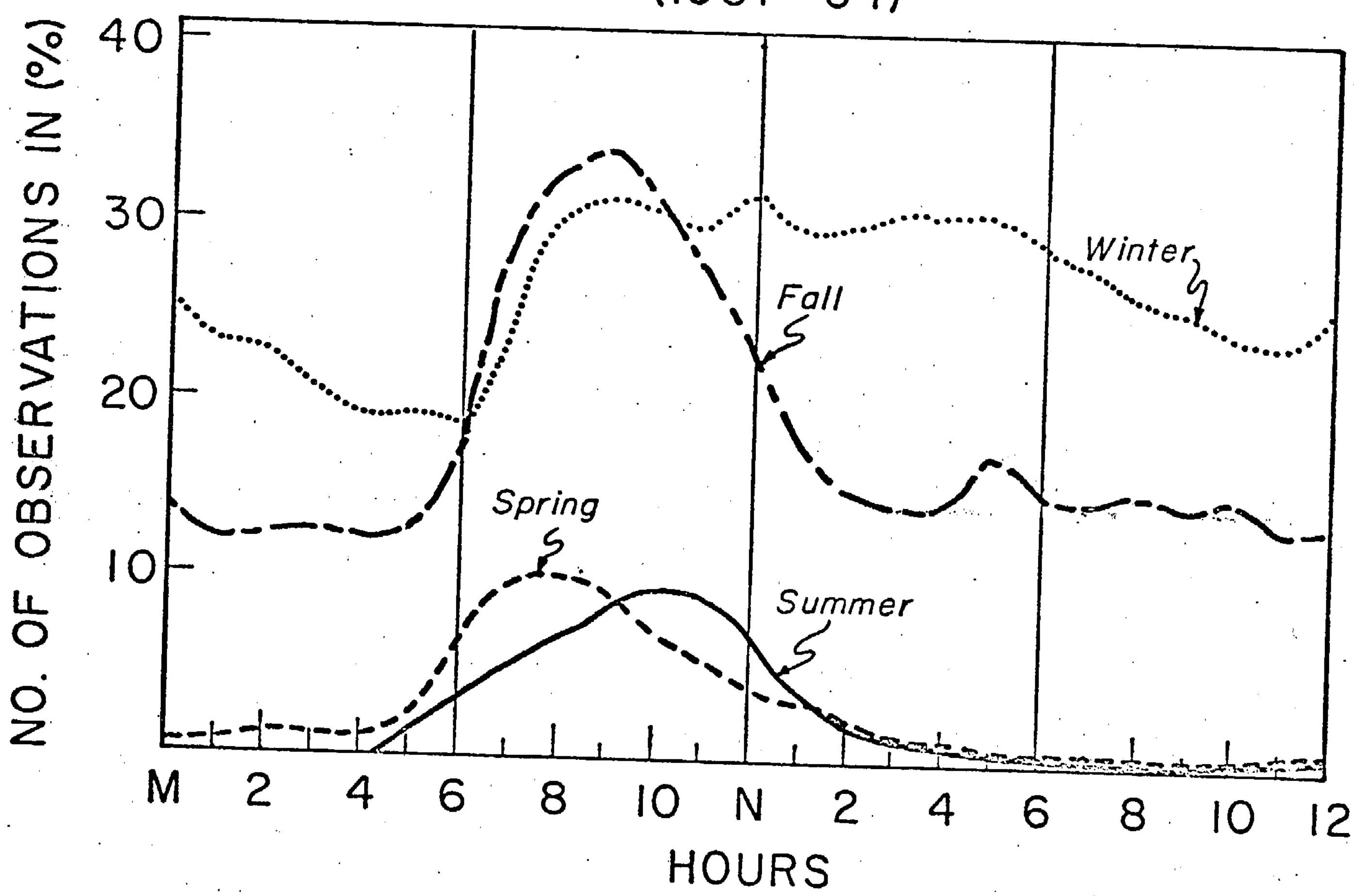


Fig. 3.

Materials and Methods

The backbone of this monitoring project was the climate recording stations owned by the Department of Agricultural Engineering. These were developed to serve the various field projects with environmental information on the spot. They were made portable, mechanically operated, and included wind registering. Not needing commercial power, they can be installed at remote locations. This provides the opportunity of choosing exposures most suitable to any project, and in the case of wind surveys, spots as free of obstructions as possible. About 12 of these "spot climate recorders" were in operation at various places, which were changed more or less often, depending on the relevance of the information. Some of the stations did not yield any usable data at all, others had breaks at times for various reasons, e.g. instrument failure or absence of cooperator. All stations which furnished a sufficient number of hourly data for reliable summarizing are listed in two tables, Table 1 for Sacramento Valley, and Table 2 for San Joaquin Valley Stations. Included in the listing are the major airports, data of which were used only as far as considered necessary. Since valley bottom stations were expected to be less relevant with respect to wind velocities, any accessible knoll or ridge location was tried. At places where collecting of data was successful, location and elevation were added in Tables 1 and 2. Although mountain stations can furnish erroneous information, e.g. due to deflection of the airstream or eddying, the results obtained appear sufficiently accurate for the present purpose. The Sutter Buttes in the Sacramento Valley were ideally located just on the axis of the valley halfway up its length, 75 miles north of the Walnut Grove T.V. Tower. Several exposures had to be explored until two locations were finally

selected. In the San Joaquin Valley, several "high" locations were found. Although not in the center of the Valley, all of these were 20-30 miles away from either the High Sierra or the Coastal Range, see Table 2. The locations of the San Joaquin Valley Stations and their elevation are shown on the map at the beginning of the section: Streamlines in San Joaquin Valley. For the Sacramento Valley, every third streamline page contains a station location map.

Over 200 nightly balloon releases were carried out which are listed in Tables 3 and 4. Since the first 3000 feet were of prime interest, some skills were developed to read the theodolites every half, sometimes even every quarter of a minute. The ascension rate of the balloons equipped with flashlights was held at 650 feet per minute. This was determined empirically by measuring the elapsed time of balloons released at the foot of the T.V. Tower until they reached the 1450-ft. level. This was done on two nights with temperature lapse rate conditions as would be expected on the various test nights. In the Sacramento Valley, various locations were explored, see Table 3, sometimes on the same nights, moving with a van completely equipped. This will be discussed later. One of these "moving runs" had the idea to look for verification data for the recordings of the Sutter Buttes stations. In the San Joaquin Valley, balloon observations were only undertaken at the University of California West Side Field Station near Five Points. The results look excellent, and no other location was considered comparable with respect to working and resting conditions during night-long field work. Economic advantages are also worth mentioning.

Near the end of the contract period in 1974, exploratory balloon observations were carried out at Shafter on three nights, partly in cooperation with Fresno State University (Dr. D. L. Morgan). The results are shown among the wind-time sections attached at the end of this volume. Of special interest should be Figure 24a, giving the wind-time section for Shafter for the same night as Figure 24 does for Five Points.

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Table 1

Stations in Sacramento Valley Used for Construction of Wind Roses

Sacramento Airport	July to November 1971
Wheatland	July to November 1971
Sutter Buttes Peak	2000 feet elevation, July to October-November 1971
Sutter Buttes West Ridge	600-ft. high spot on the farthest western extension, July to October 1971
Biggs	September to November 1971
Glenn	September to November 1971
Norman	August to November 1971
Orland	October to November 1971
Chico	October to November 1971
Red Bluff	July to November 1971

TABLE 2

Stations in San Joaquin Valley Used for Monthly Frequency Tables of Wind Speed and Directions

Stockton Airport	June to October 1973.
Green Mountain	Fire Lookout, 1370 feet, 12 miles southwest of Mariposa, July 11, 1972, to October 23, 1973.
Fresno Airport	June to September 1972, June to October, 1973.
Lemoore	NAS, June to November, 1972.
Kettleman Hills	1225 feet, 3 miles east of Avenal, August, 1972, to November, 1973.
Cottonwood	Fire station 5 miles west of Kettleman City, 800 feet, July, 1972, to November, 1972, August, 1973, to October 12, 1973.
Devils Den	600 feet high knoll 12 miles south of Kettleman City, July 12 to November 26, 1972.
Corcoran	June to November 1972.
Horseshoe Ranch	1350 feet, 10 miles west of Famoso, August 8 to November, 1973.
Shafter	June to November, 1972, June to October, 1973.
Bakersfield	Airport, June to November, 1972, June to September, 1973.
Caliente	600 feet high knoll 20 miles east of Bakersfield, April 23 to November 30, 1973.
Wind Gap	At California Aquaduct Pumping Plant near Grapevine, September 20, 1972, to September 4, 1973.
Elk Hills	1275 feet, 20 miles west of Bakersfield, July 17 to December 17, 1973.

Table 3

Dates of Nightly Observation of Pilot Balloons at Various Locations in Sacramento Valley

Night of	No. of Balloon Releases	Location
7-15-70	2	Davis
7-23-70	3	Davis
8-18-70	7	Colusa
8-31-70	1	Elkhorn
9-1-70	10	Elkhorn
9-5-70	5	Elkhorn
9-13-70	3	Davis
7-7-71	6	Colusa
7-28-71	11	Glenn and Colusa
7-29-71	6	Norman
8-3-71	9	Biggs and Glenn
8-11-71	11	Biggs and Glenn
8-19-71	9	Biggs and Norman
8-27-71	11	Biggs and SE edge of Sutter Buttes
9-21-71	2	Biggs
9-24-71	7	SE edge of Sutter Buttes, Colusa, Glenn, and Norman

Table 4

Dates of Nightly Observations of Pilot Balloons at the University of California, Westside Field Station Near Five Points, San Joaquin Valley

Night of	No. of Balloon Releases
6-28-72	7
6-29-72	2
7-11-72	2
7-12-72	2
7-19-72	6
8-1-72	5
8-2-72	3
8-15-72	6
8-16-72	5
8-29-72	5
8-30-72	4
9-12-72	5
9-13-72	5
10-6-72	3
10-7-72	5
11-17-72	4
1-27-73	2
3-22-73	4
7-2-73	4
7-16-73	2
7-17-73	5
7-18-73	2
8-7-73	6
8-22-73	3
8-23-73	5
9-12-73	1
6-11-74	4
6-12-74	5
6-25-74	5
6-26-74	5
7-15-74	5
7-16-74	5
7-15-74 Shafter	4
8-12-74 "	2
8-13-74 "	3

Evaluation

The recordings obtained from the various locations were abstracted from the charts and tabulated by hours in monthly tables. For discerning any diurnal wind patterns, monthly frequencies of directions where determined for every hour of the day. These are plotted as hourly wind roses, 24 of these for every month on a single sheet. They are filed in the appendix in the same sequence as they are listed in Table 1 for the Sacramento Valley. For the greater number of San Joaquin Valley stations a more condensed arrangement was chosen by presenting the direction frequencies in wind roses containing 3 hours each. To provide still easier inspection of the diurnal wind variation as the year progresses, two successive months were combined into one diagram. Thus, in a case that data were available solidly, e.g., during the months of June and July 1972 and 1973, 366 data could be utilized for constructing one wind rose. The bi-monthly wind roses for every three hours are filed in the same station sequence in the appendix as listed in Table 2. In the same fashion, and for the same San Joaquin stations, frequency tables were prepared that include directions and velocities, which are presented in the appendix. Since almost half of the San Joaquin stations were installed on hills, the information on wind speeds produced there by the marine air flow appears essential. In the Sacramento Valley the two Sutter Butte's stations were given even greater attention. Velocity frequencies are presented in histogram form (with columns rounded) for every hour and for individual months. However, the directions were arranged only by northerly and southerly directions ~~only~~ for the peak station, and by northerly and southeasterly direction for the 600-ft. ridge station. This kind of treatment resulted in 8 very revealing diagrams presented in Figures 4 to 11.

The number of balloon releases on various nights (see Tables 3 and 4)

usually depended on two factors. One was the daytime work load on the crew which required a certain amount of rest so that only two to four night runs were made. Nights with only one or two releases were those in stagnant conditions. After computing the results of each sounding was plotted on velocity-height diagrams. Figure 12 is an example of two runs during one night at a Sacramento Valley station. Figure 13 contains examples of two different nights at Five Points, one obtained during the influx of the marine air, the second curve on a night in stagnant conditions. The wind directions are written along the velocity profiles. In Figure 12, however, extra curves were drawn for the directions. Amazingly, a great number of nights were experienced with similar wind profiles as at the T.V. Tower, although the locations were about 100 miles away, both to the north as well as to the south. The results could, therefore, be summarized in wind-time sections as in Figure 2. These are presented at the end of this volume. Some especially interesting cases were selected for Figures 14 to 19 from the Sacramento Valley, and for Figures 20 to 24a from the San Joaquin Valley.

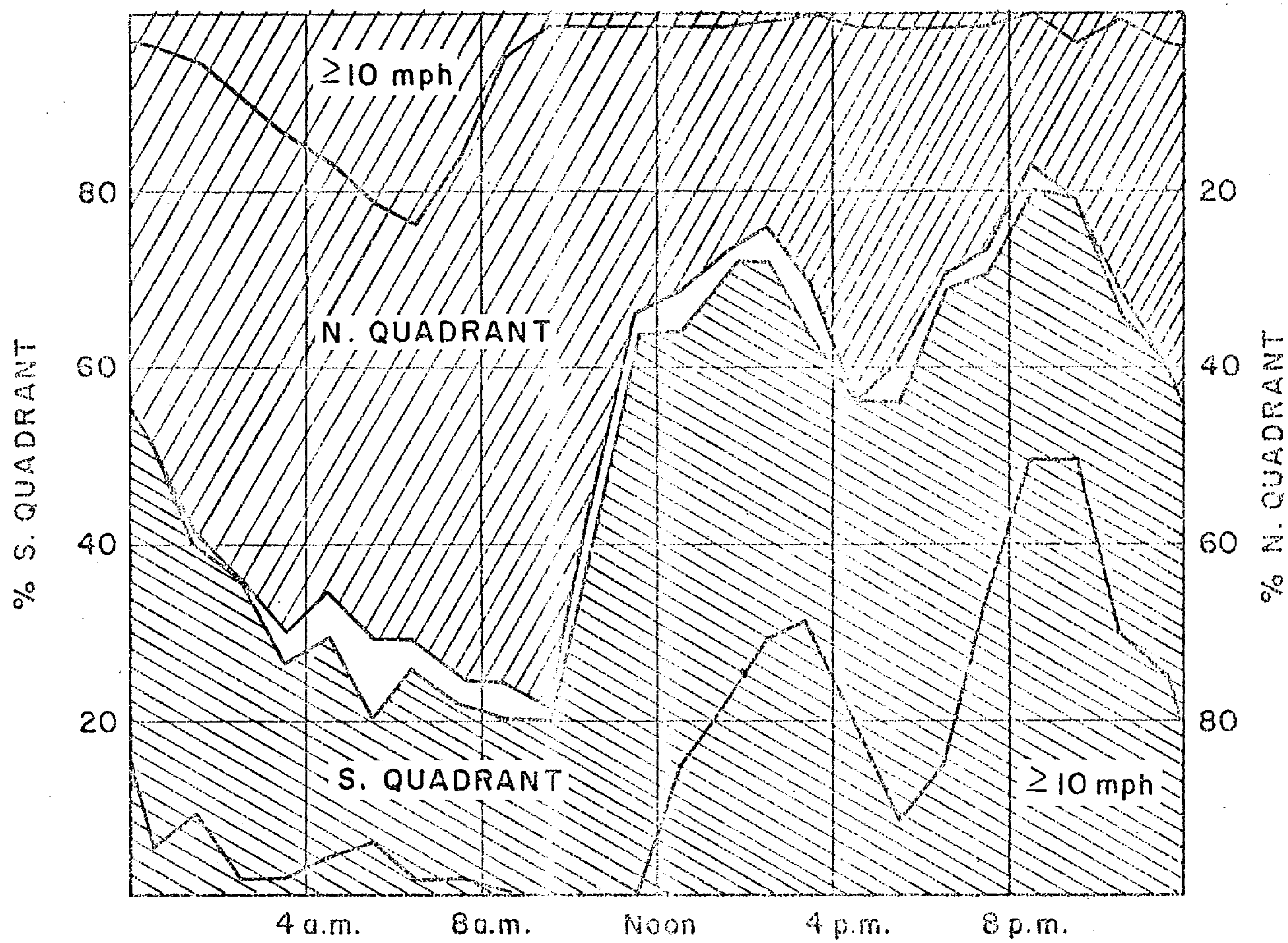


Fig. 4, HOURLY DISTRIBUTION IN % OF WIND DIRECTIONS
SUTTER BUTTES PEAK, 2000', JULY

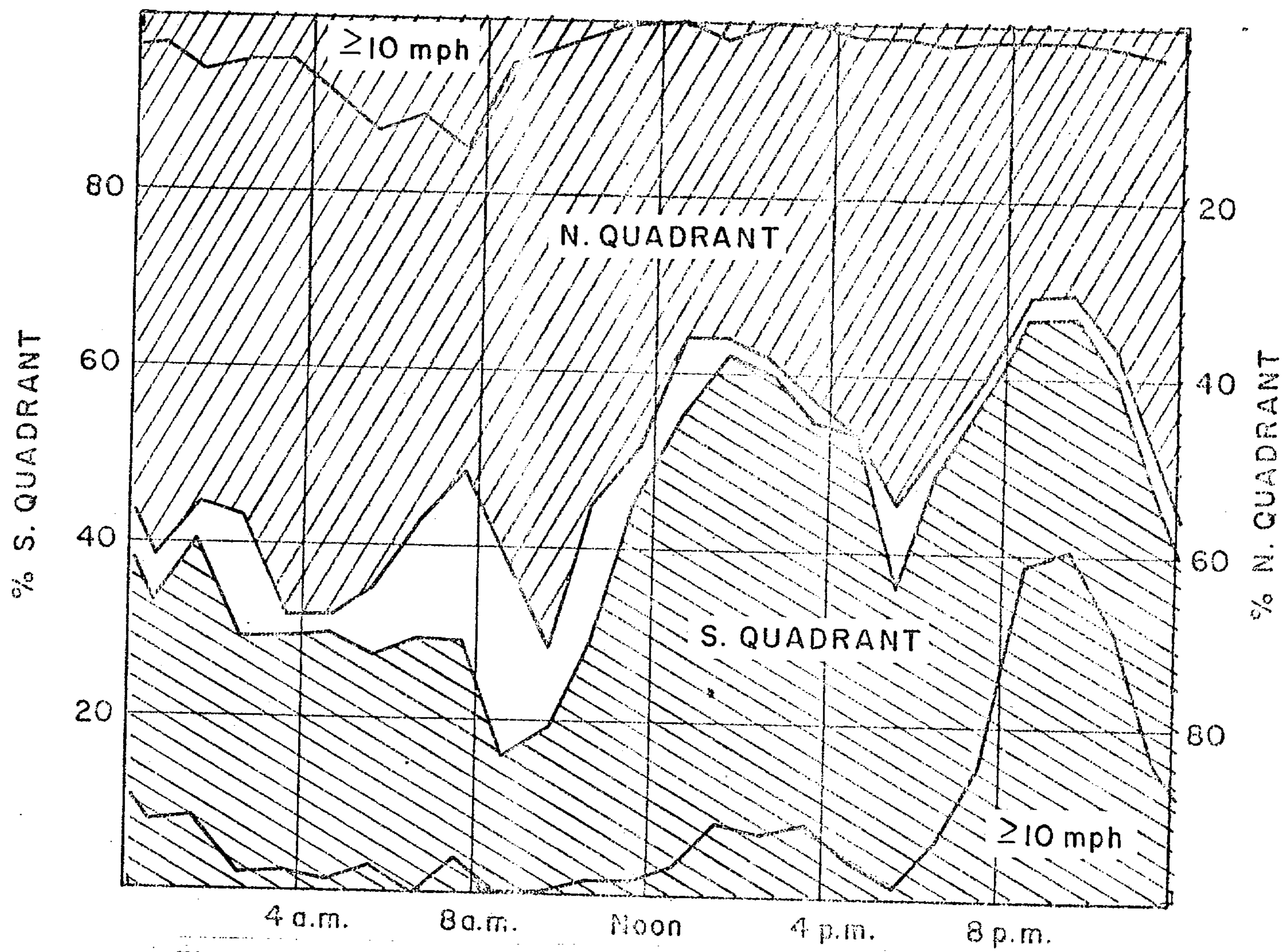


Fig. 5, HOURLY DISTRIBUTION IN % OF WIND DIRECTIONS
SUTTER BUTTES PEAK, 2000', AUGUST

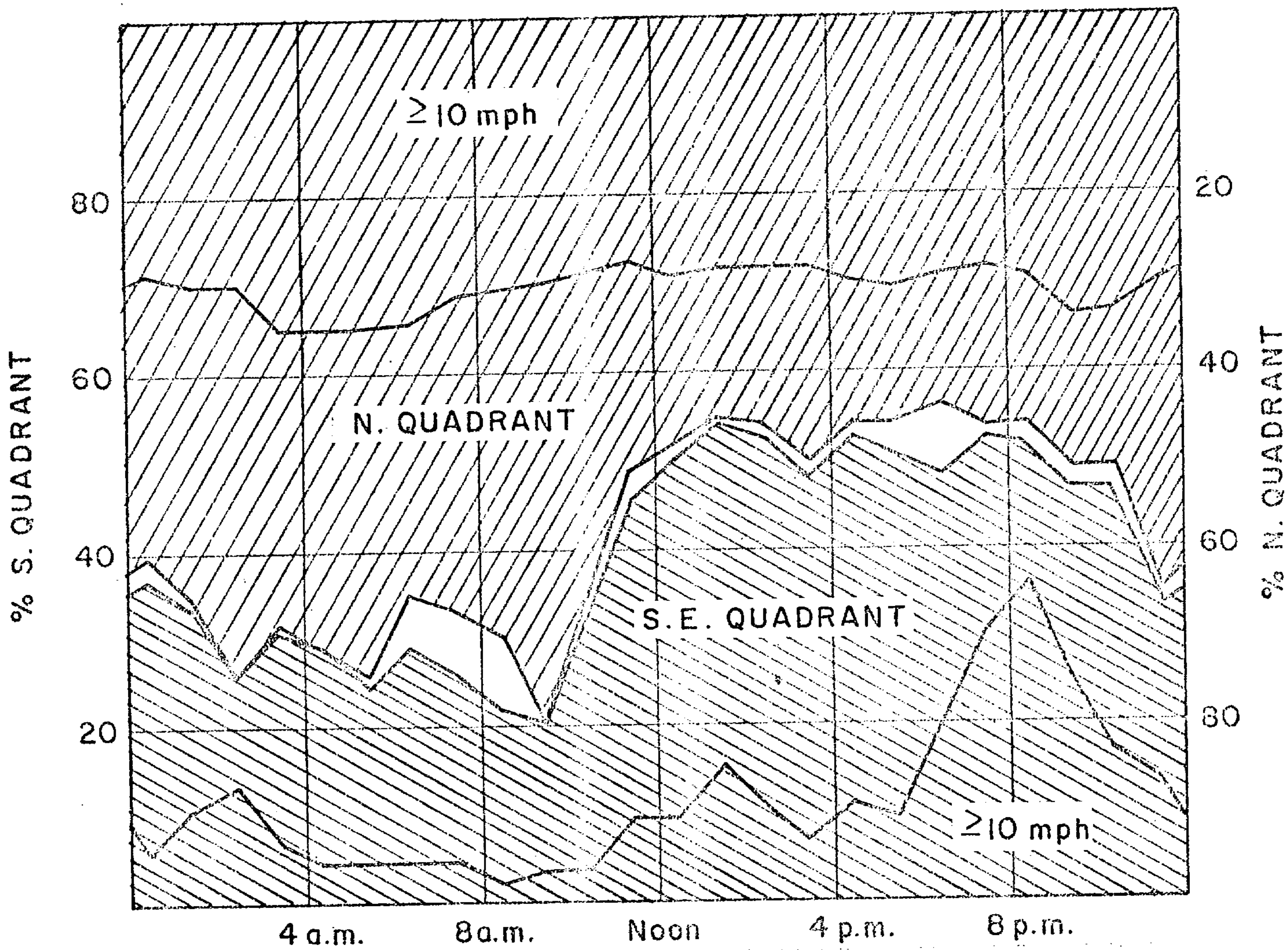


Fig. 6, HOURLY DISTRIBUTION IN % OF WIND DIRECTIONS
SUTTER BUTTES PEAK, 2000', SEPTEMBER

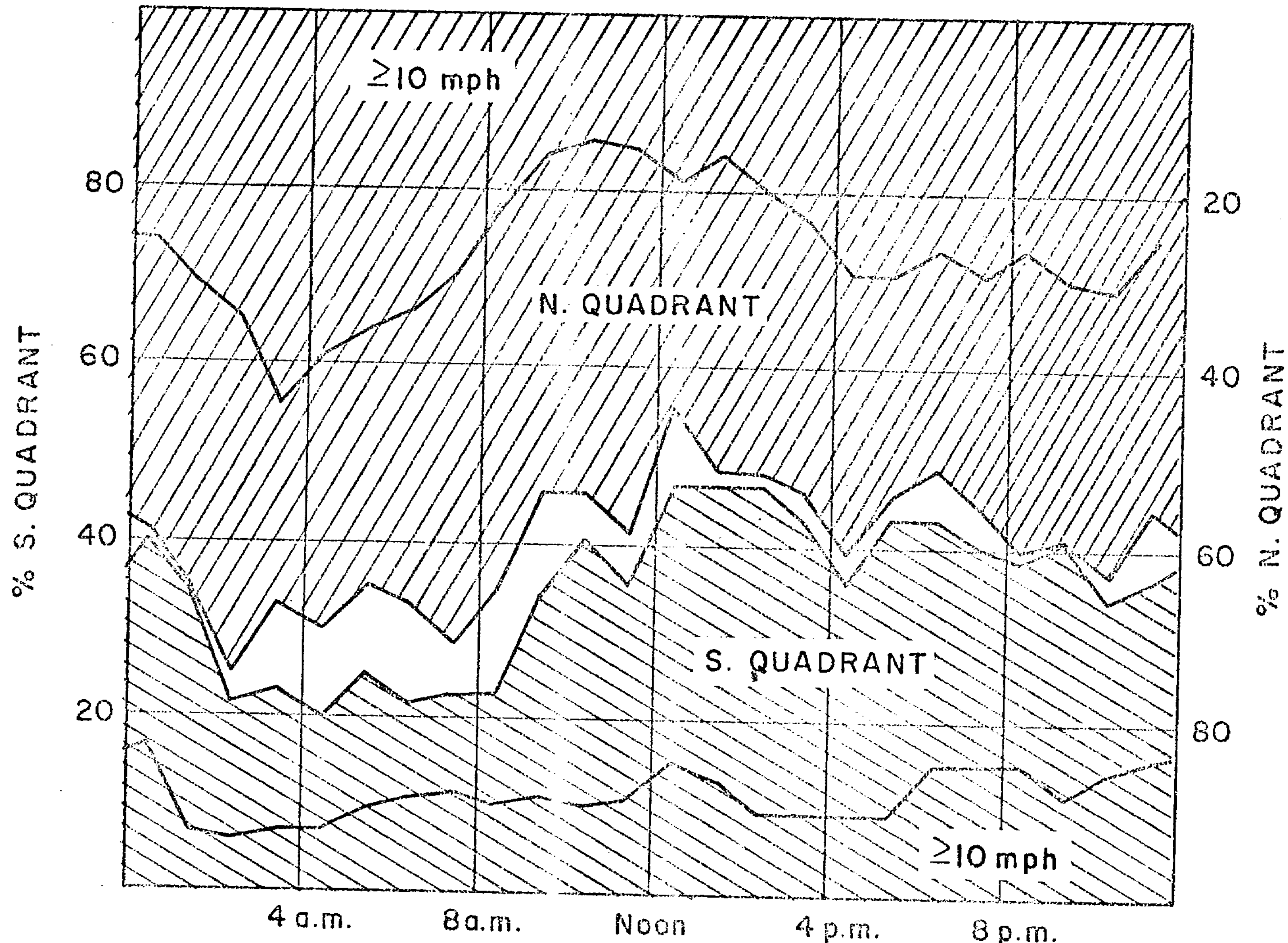


Fig. 7, HOURLY DISTRIBUTION IN % OF WIND DIRECTIONS
SUTTER BUTTES PEAK, 2000', OCTOBER

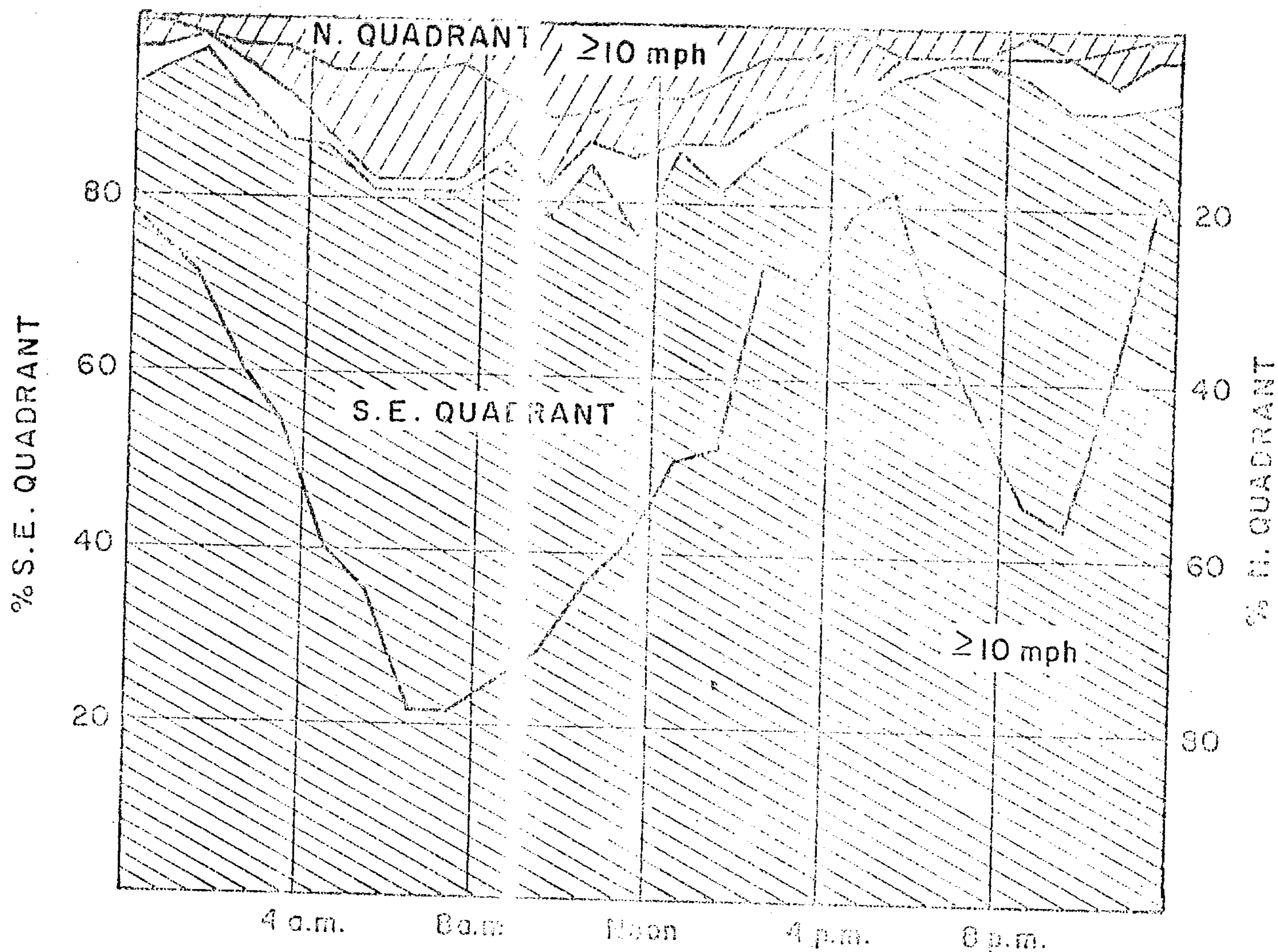


Fig. 8, HOURLY DISTRIBUTION IN % OF WIND DIRECTIONS
SUTTER BUTTES WEST RIDGE, 600', JULY

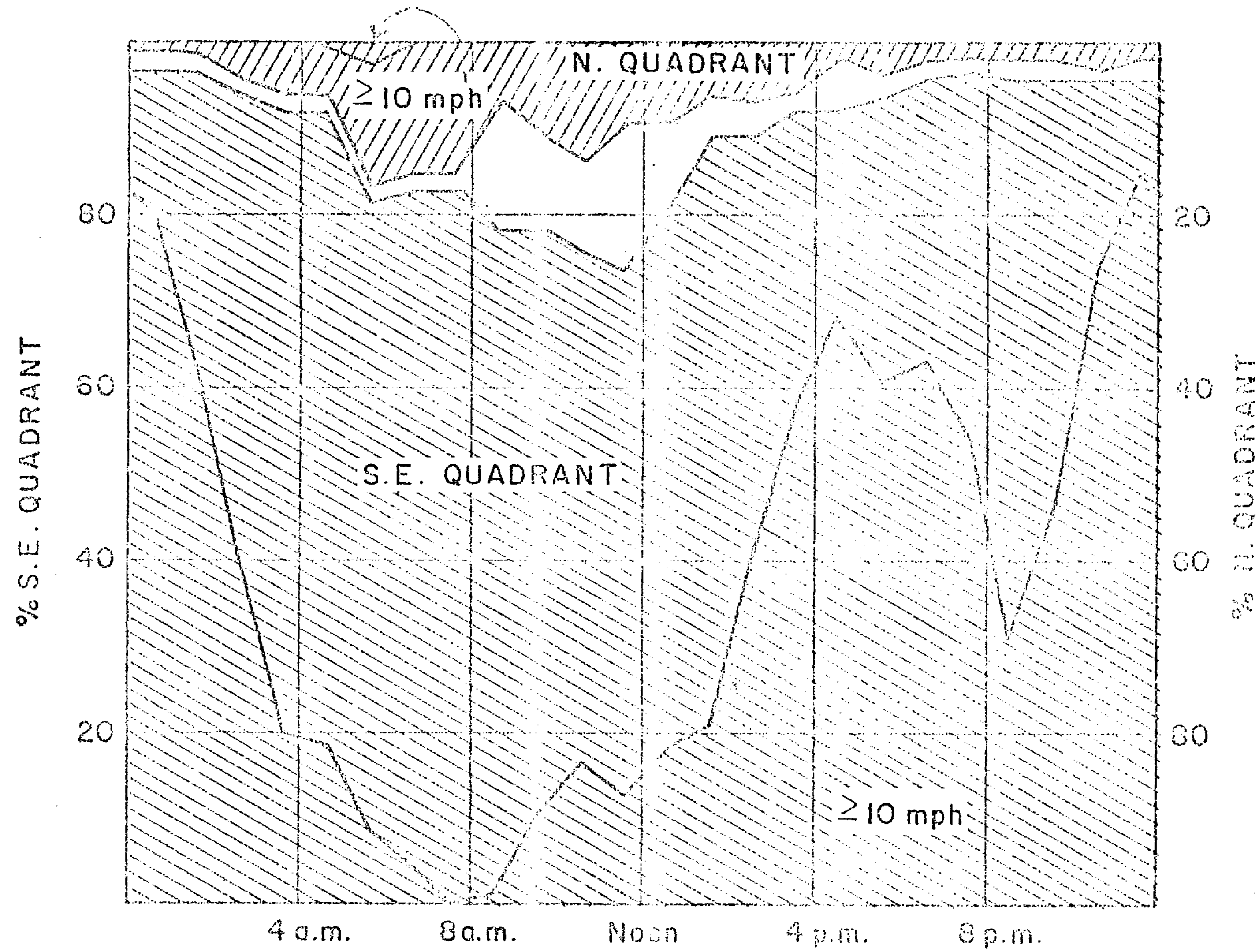


Fig. 9, HOURLY DISTRIBUTION IN % OF WIND DIRECTIONS
SUTTER BUTTES WEST RIDGE, 600', AUGUST

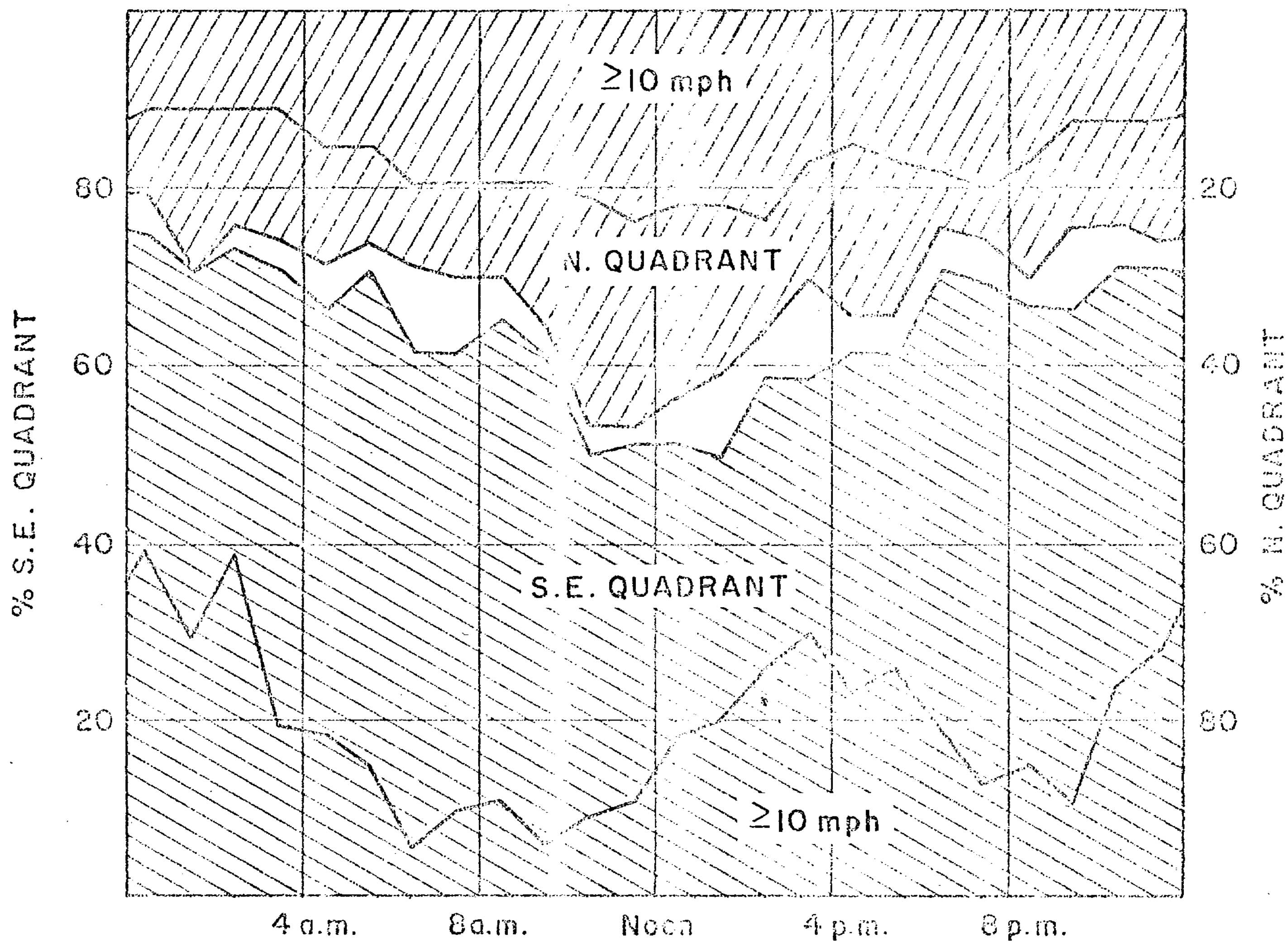


Fig. 10, HOURLY DISTRIBUTION IN % OF WIND DIRECTIONS
SUTTER BUTTES WEST RIDGE, 600', SEPTEMBER

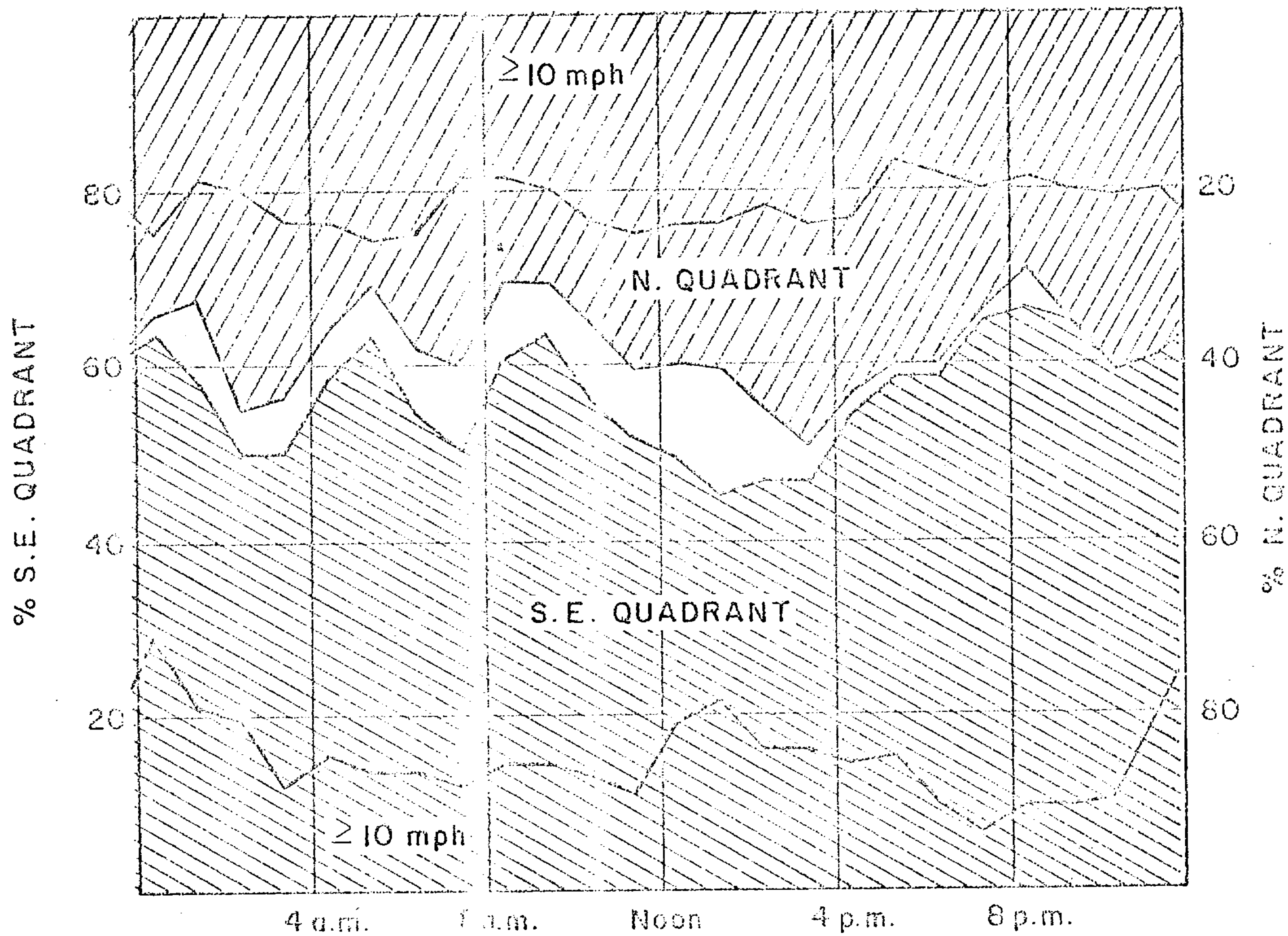


Fig. II, HOURLY DISTRIBUTION IN % OF WIND DIRECTIONS

SUTTER BUTTES WEST RIDGE, 600', OCTOBER

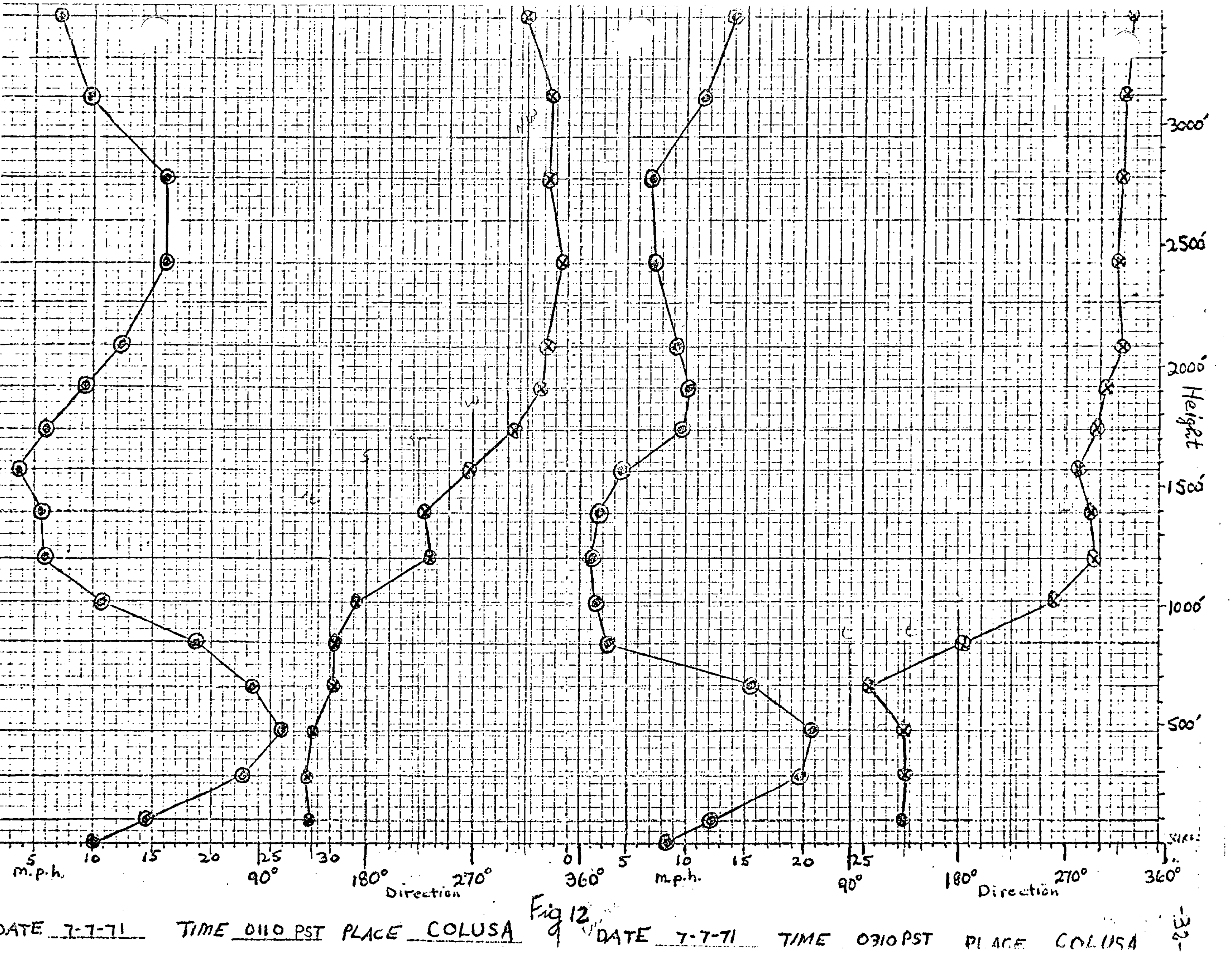

Height
3000'
2500'
2000'
1500'
1000'
500'
SFC
5
10
15
20
25
30
m.p.h.
90°
180°
270°
360°
0
Direction
DATE 7-7-71 TIME 0110 PST PLACE COLUSA
DATE 7-7-71 TIME 0310 PST PLACE COLUSA

Fig 12

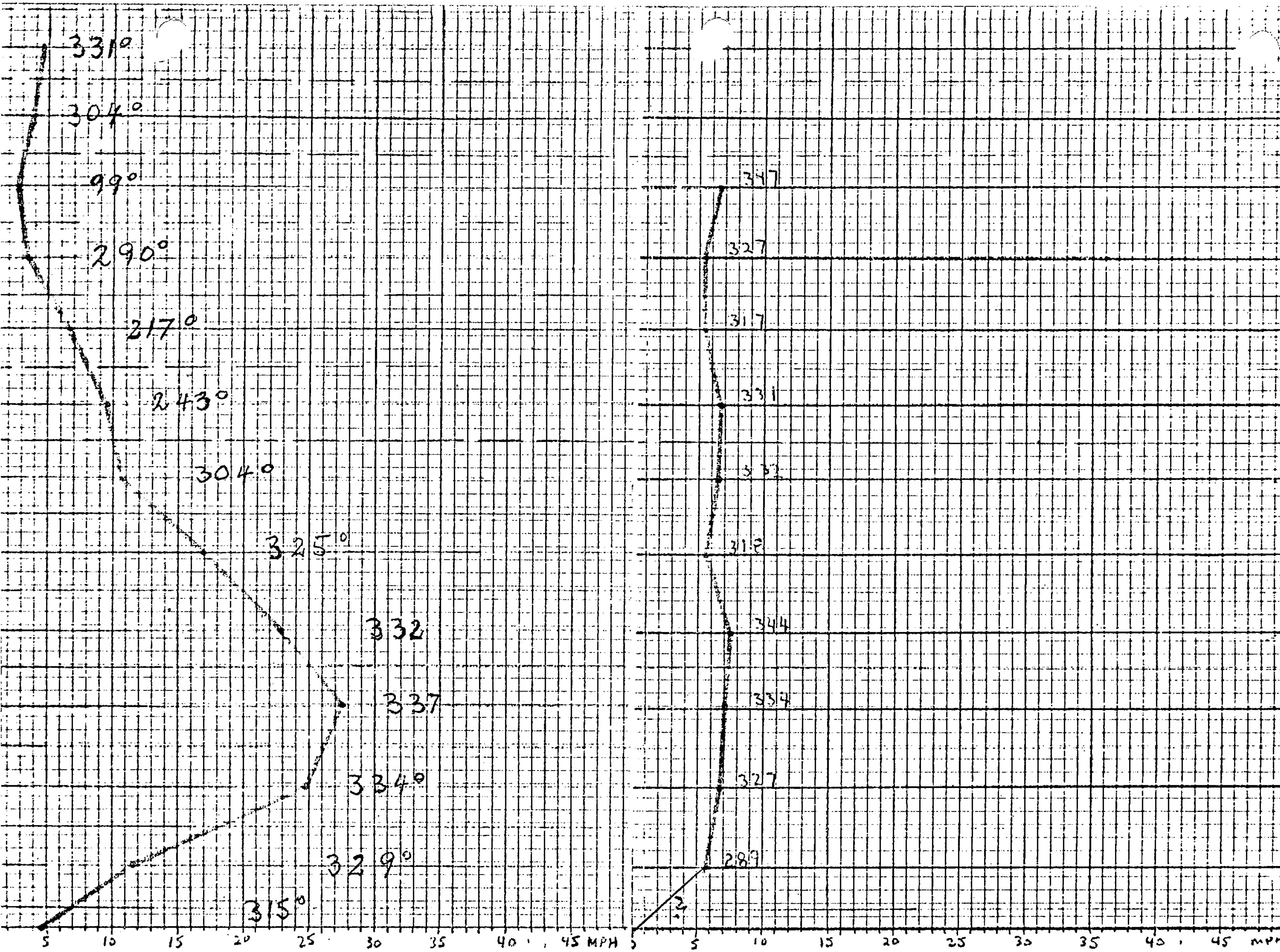


Fig. 13

DATE 9-11-73 TIME 1:45 AM PLACE Five Points

DATE 9-12-73 TIME 1230 AM PLACE FIVE POINTS

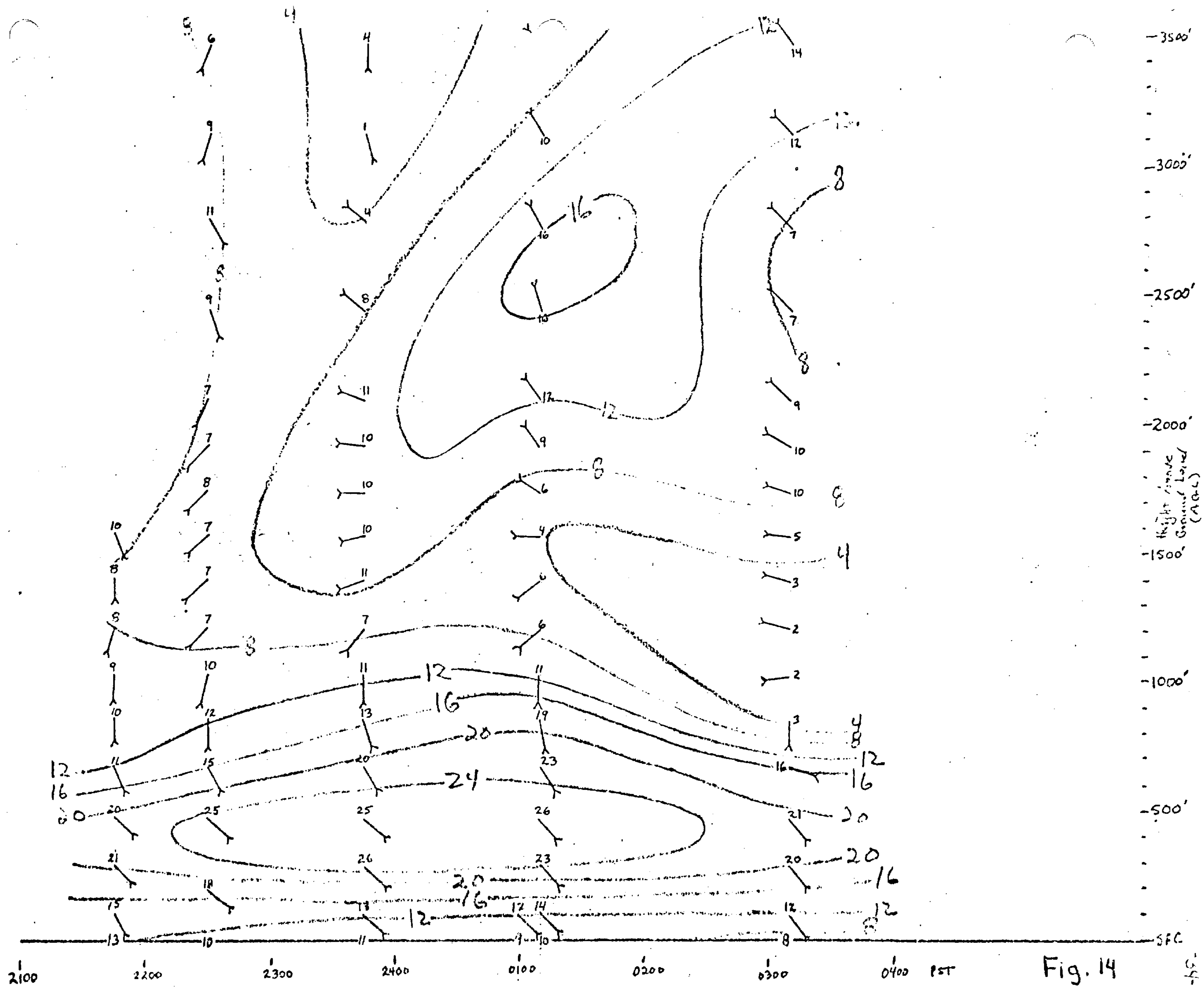


Fig. 14

Wind-Time Section, Colusa, July 7-8, 1971

Ti[illegible] [illegible]ection of Pibal Results at Biggs, August 3-4, 1971

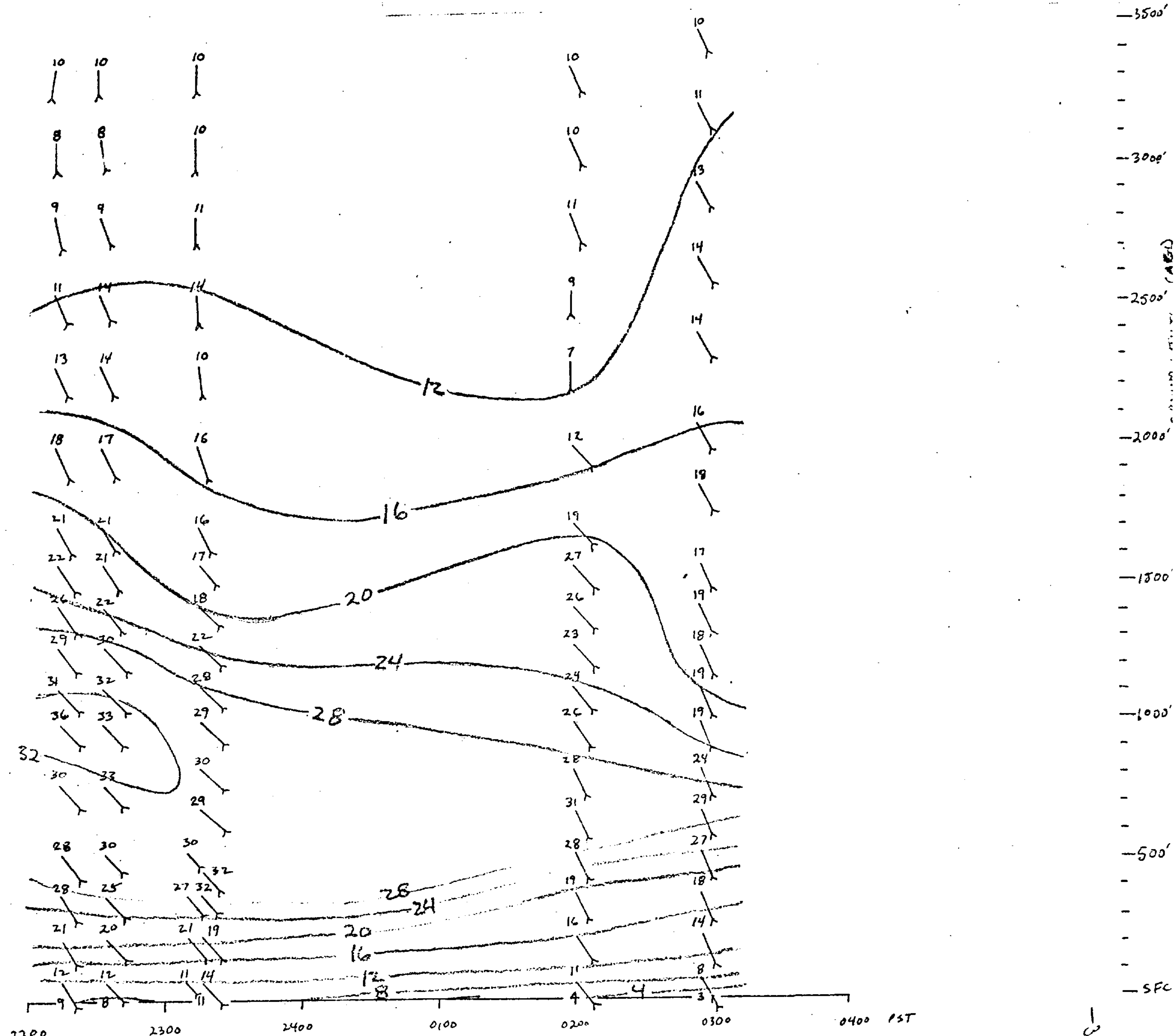
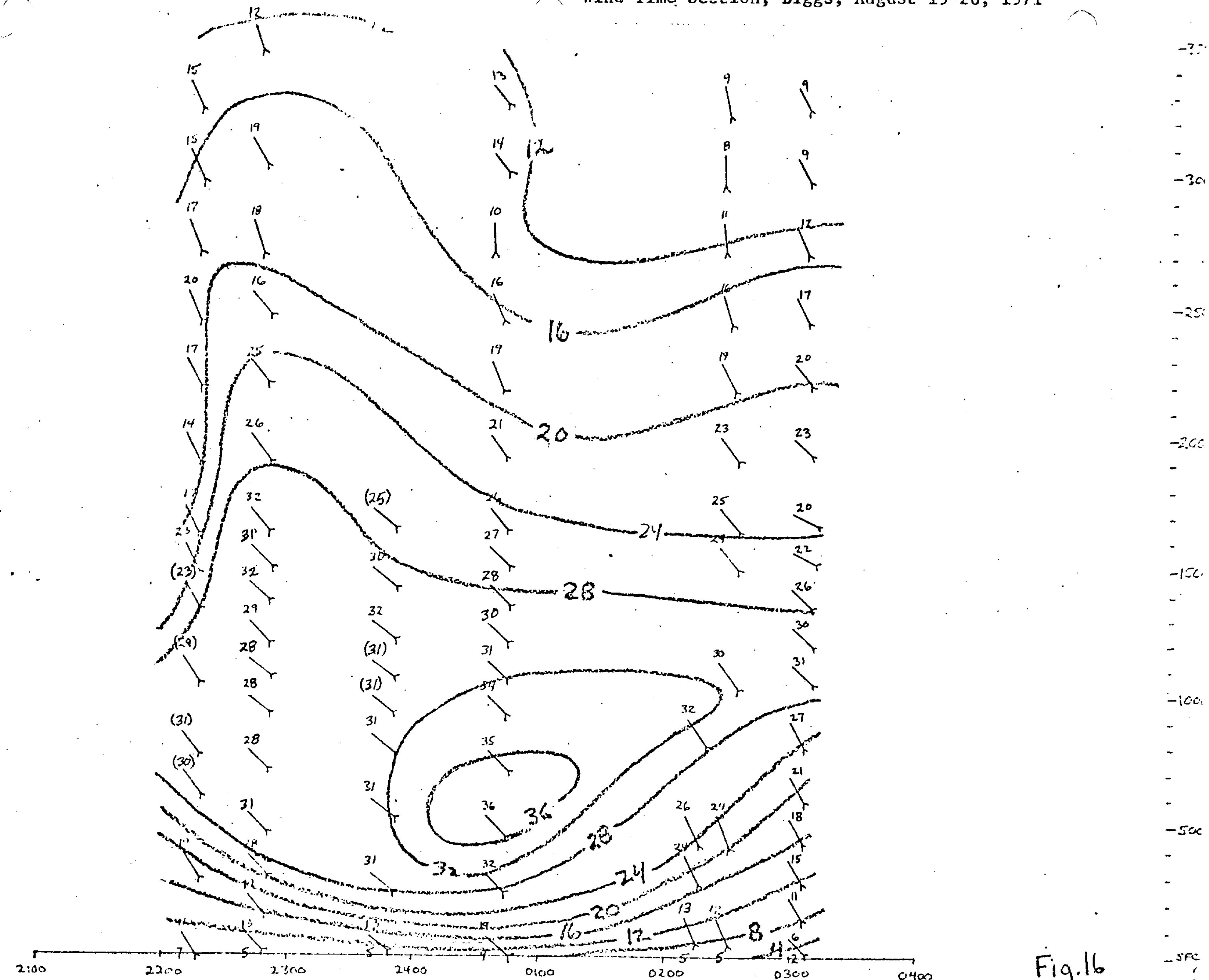


Fig. 15 Wind-Time Section mph, Biggs, August 3-4, 1971

Wind-Time Section, Biggs, August 19-20, 1971



Wind-Time Section, Biggs, August 19-20, 1971

Fig.16

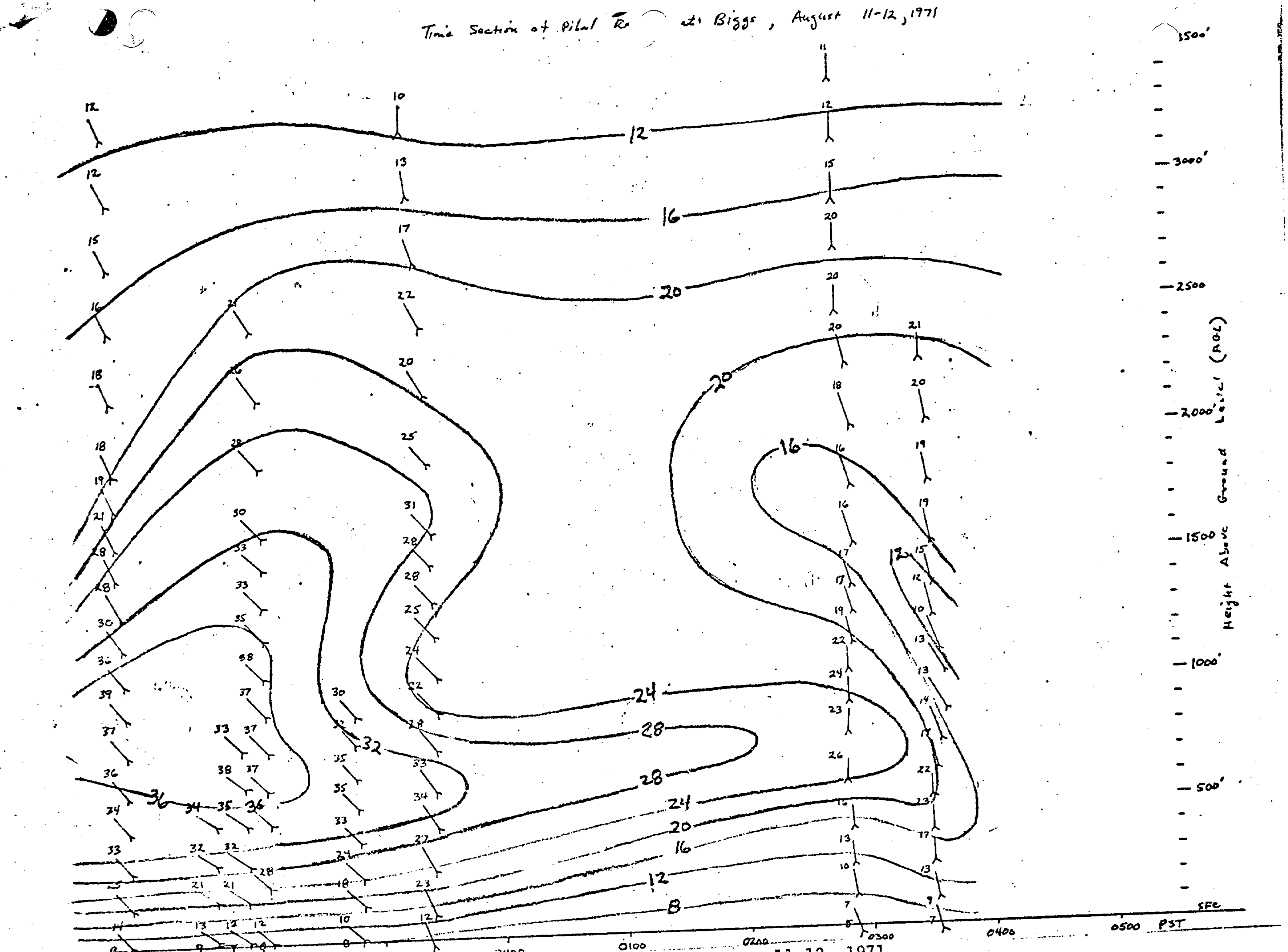


Fig. 17, Wind-Time Section mph, Biggs, August 11-12, 1971

Time Section of Pibal Results at Glenn July 28-29, 1971

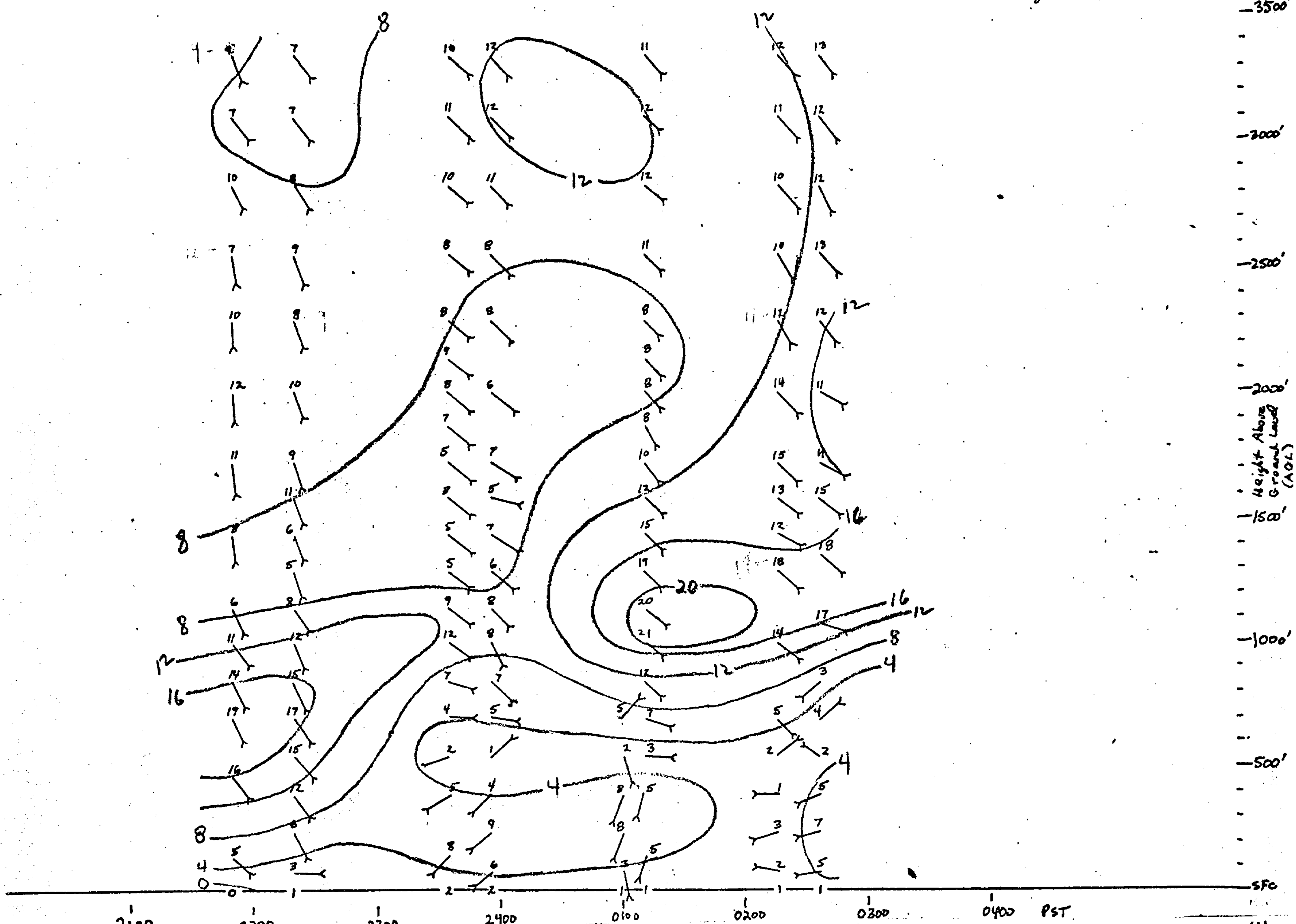


Fig. 19 Wind-Time Section mph, Glenn, July 28-29, 1971

Time Section Pibal Results at Norman, July 29-30, 1971

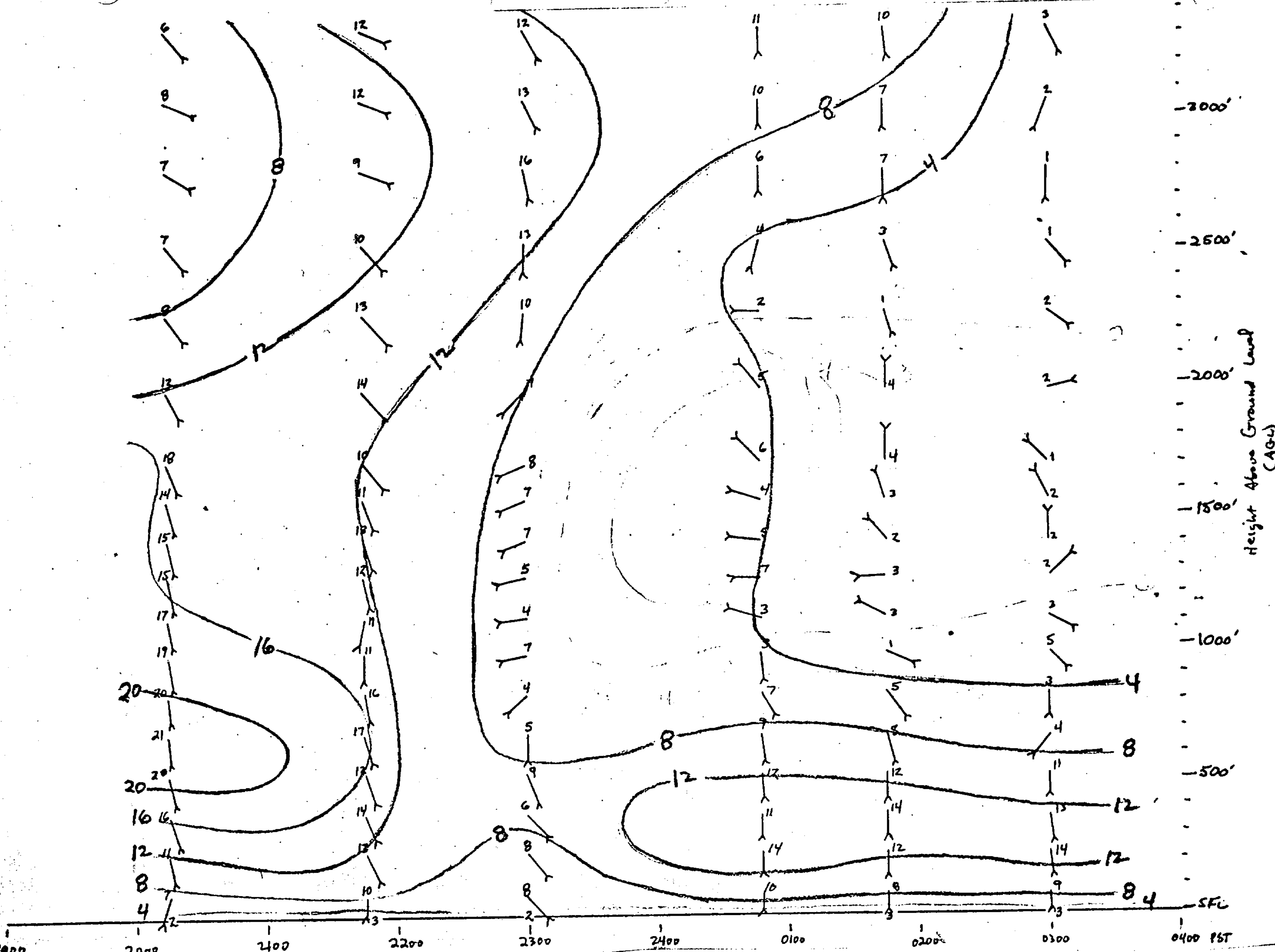


Fig. 19 Wind-Time Section mph, Norman, July 29-30, 1971

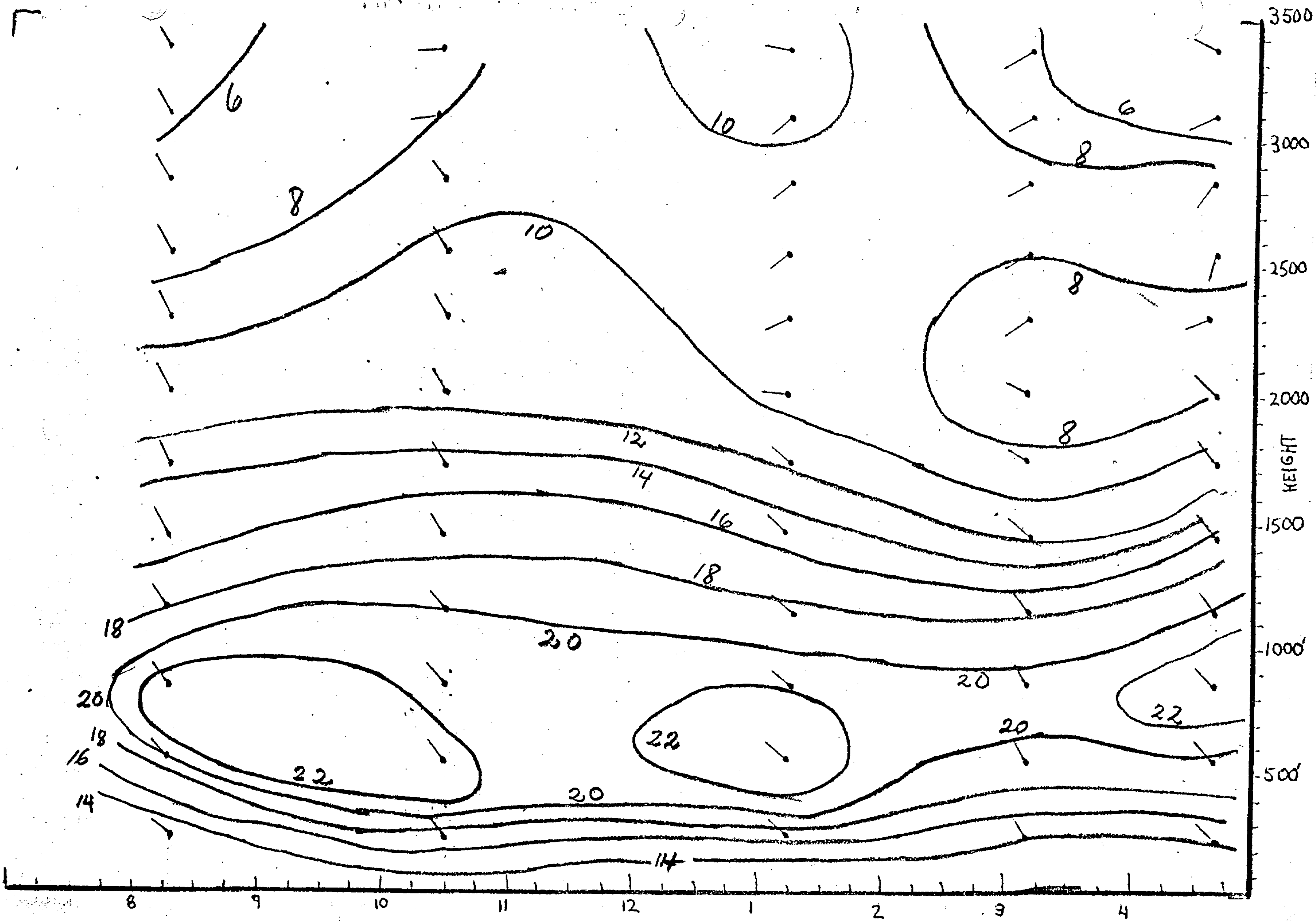


Fig 20

Wind Time Section, mph, Five Points, July 17-18, 1973

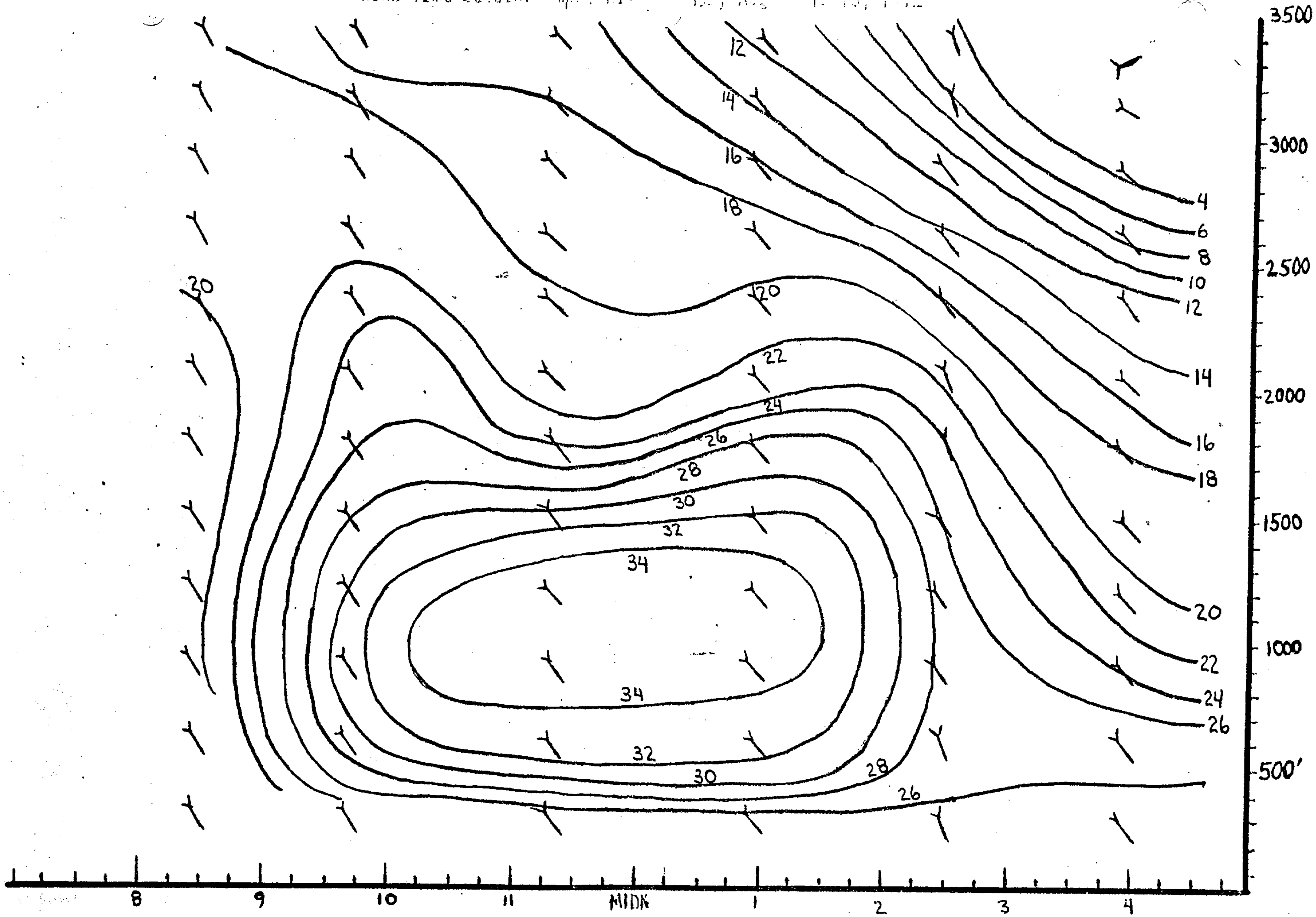


Fig 21
Wind-Time Section mph, Five Points, August 15-16, 1972

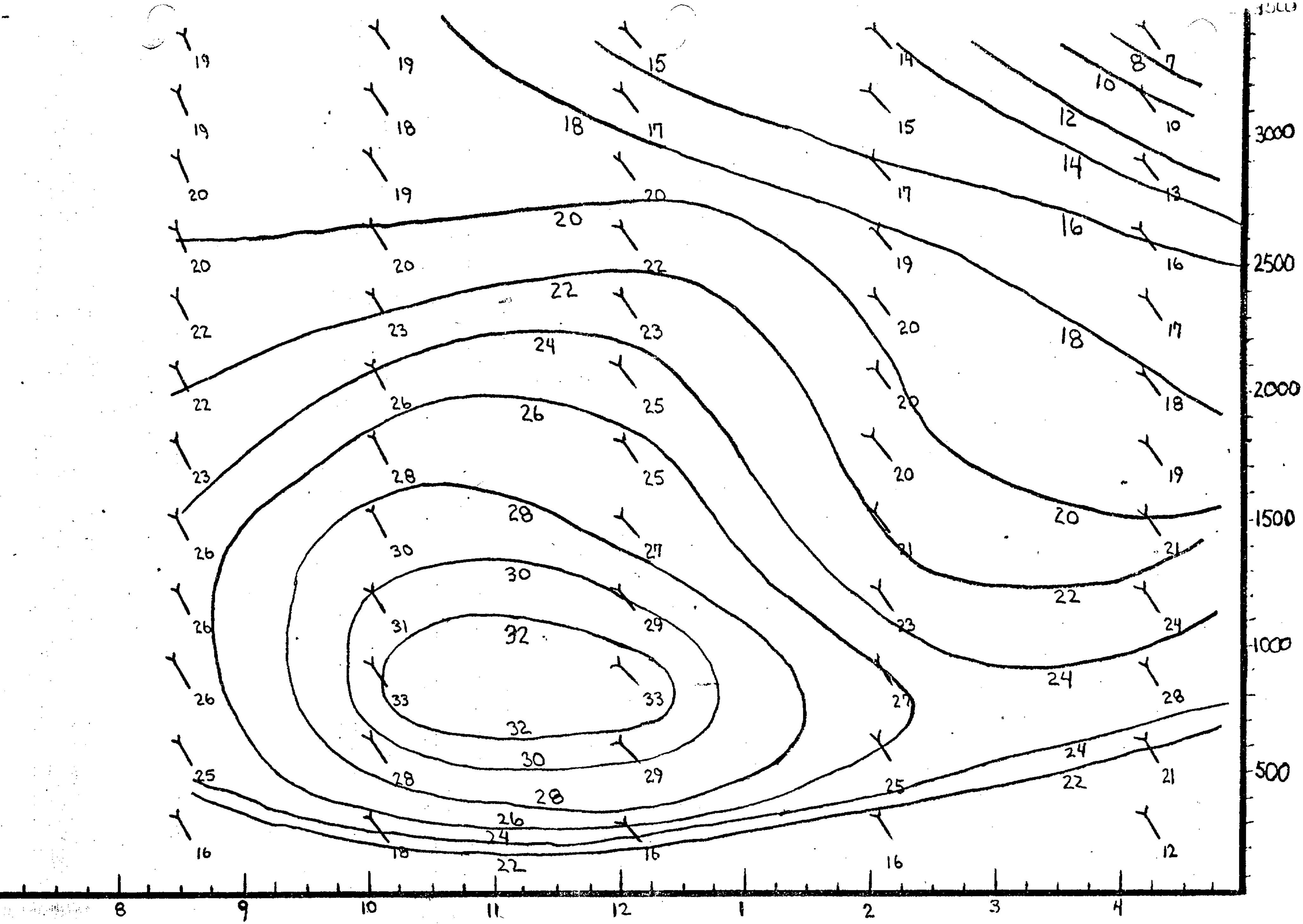


Fig 22
Wind-Time Section mph, Five Points, August 16-17, 1972

August 27 72

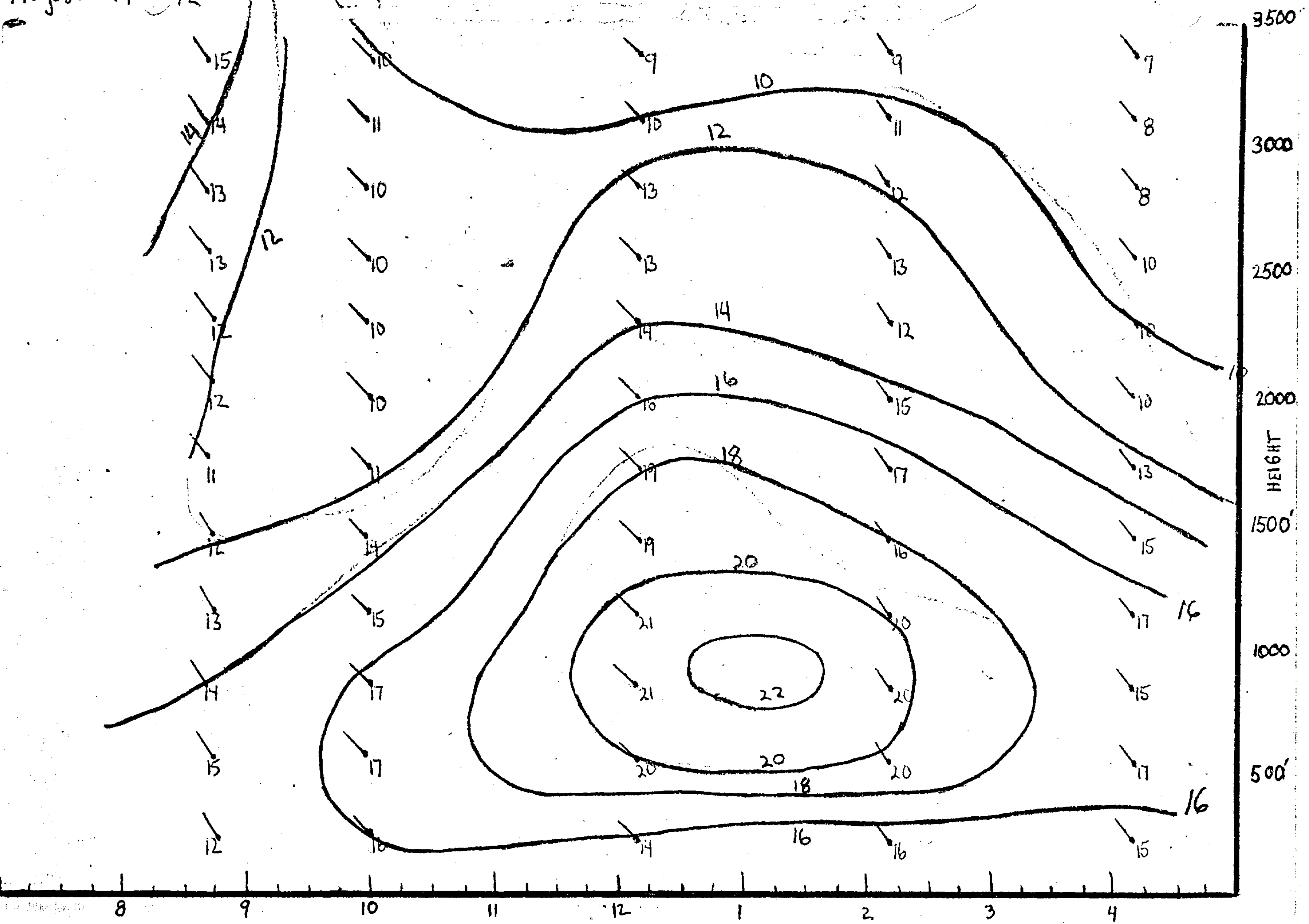


Fig. 23

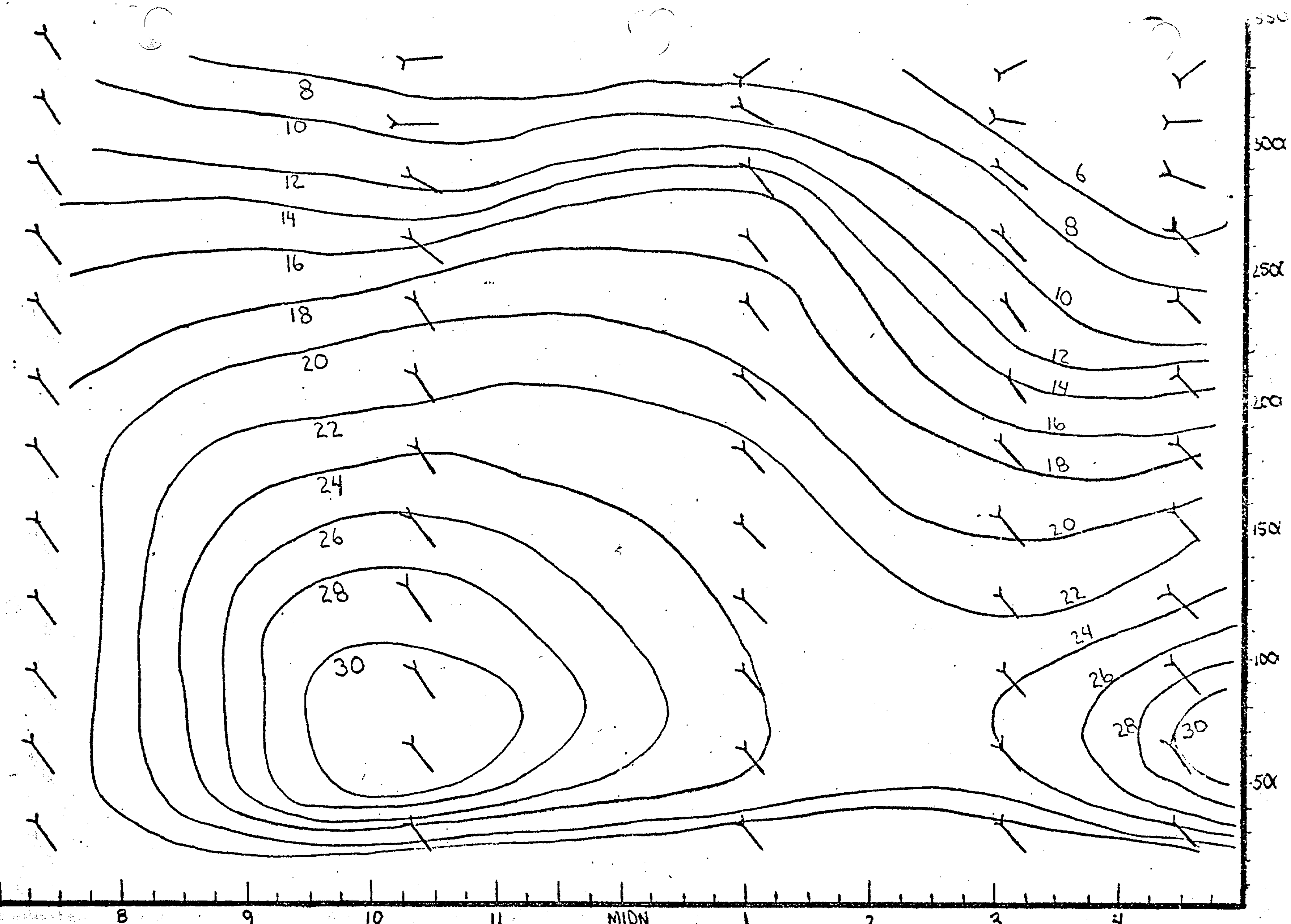

8
10
12
14
16
18
20
22
24
26
28
30
6
300
250
200
150
100
50
8
9
10
11
MIDN
1
2
3
4

Fig 24

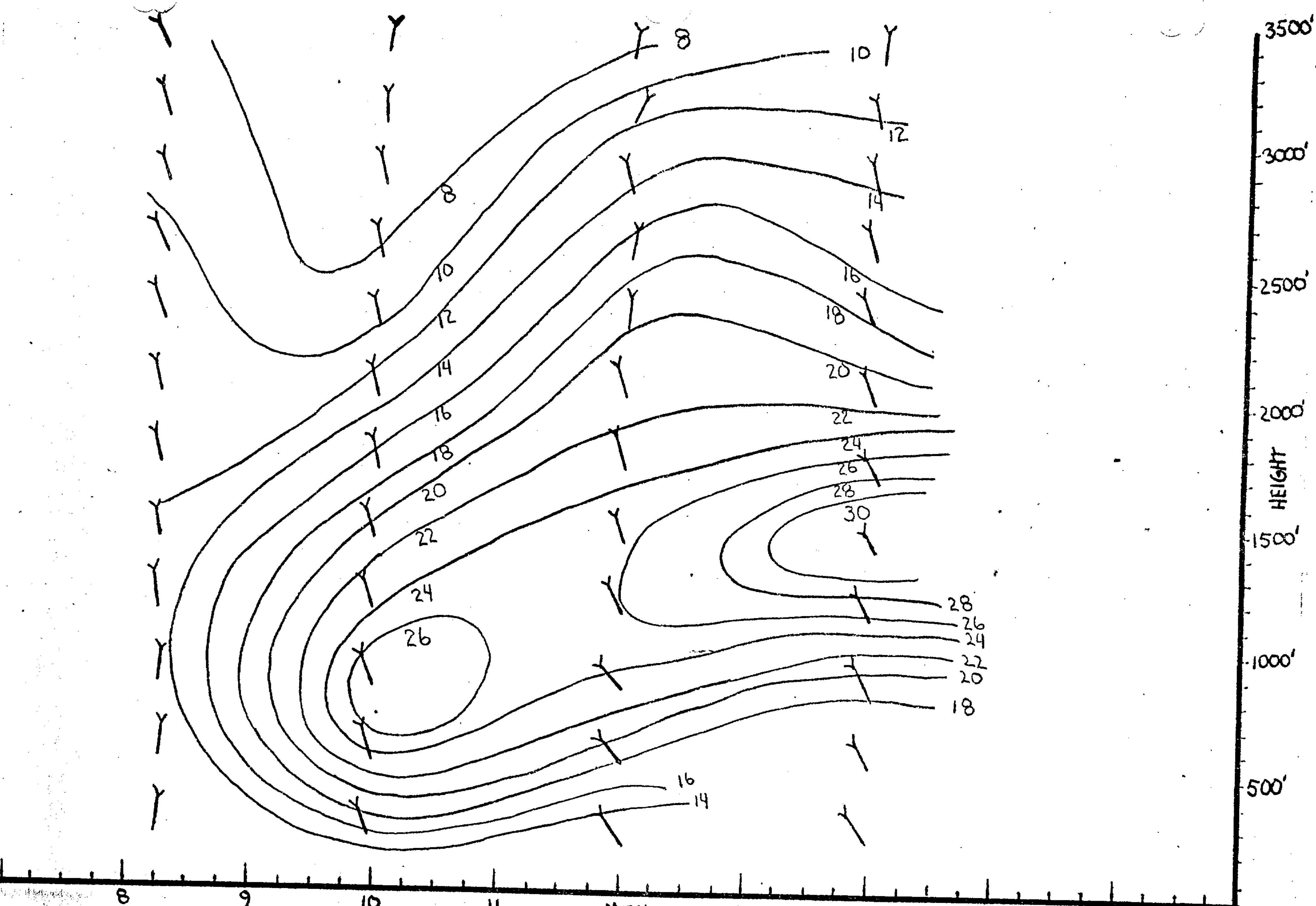

HEIGHT
3500'
3000'
2500'
2000'
1500'
1000'
500'
8
9
10
11
MIDN
1
2
3
4
8
10
12
14
16
18
20
22
24
26
28
30

Fig. 24α

Discussion

A. Sacramento Valley

In the preceding paragraphs various reasons were mentioned for examining the wind conditions in the inner valleys, especially the need for verifying the spectacular finding at the T.V. tower about the nightly wind increase at about 600 feet, often referred to as low level jet stream, Fig. 2. Inspection of early pibal data available for the 10 p.m. hour at the Sacramento Executive Airport before 1965 did not reveal too much similarity with the tower profile. It was suspected that little attention was paid at the airport to the lowest levels. Also detection of similar profiles might not have been possible with fast rising balloons. In addition, it is known that ascension rates are rather uncertain in the first 2000 feet. Exploratory pibal releases were, therefore, established in 1970, heeding all the precautions mentioned in the paragraph on materials and methods. Evening and night pibals were tracked at Davis and in the Woodland area in 1970 before this project was financed. All of these showed that the southerly influx of marine air in the lower Sacramento Valley had a vertical profile remarkably similar to that found at the Walnut Grove T.V. tower. The speed rapidly increased from surface values of 5 to 10 mph to a maximum of 20 to 30 mph at about 500 feet. Above this level the wind speed decreased. In addition, a series of pibals released some distance up the Sacramento Valley, at Colusa 50 miles north of Davis, also detected a well-developed low level jet of over 30 mph.

In 1971 the pibal releases were expanded including Colusa, Biggs, Glenn, and Norman. The latter three observation stations form an east-west transect 15 miles north of the Sutter Buttes. The pibal results at these locations, Figures 14-19, revealed that even at this considerable distance up the Sacramento Valley, a well-developed low level jet exhibits many of the

characteristics found at Walnut Grove. These common features again include a rapid increase in wind speed with height to a low level maximum, a deep vertical development before midnight, a marked decrease in vertical extent but only a slight decrease in maximum speed after midnight, and a fading out at sunrise.

The low level wind maximum was strongest at Biggs toward the east of the Sacramento Valley when it reached values exceeding 35 mph between 500 and 1000 feet above the surface. An additional distinguishing characteristic at Glenn was the particularly weak and variable winds below the "low level jet." A wind maximum at 500 feet was found at Norman on the west side of the Valley. However, it was considerably weaker than at Biggs and even Glenn. All pibal results, besides those in Figures 14 to 19, can be inspected at the end of this report.

Since balloon releases can only provide samples, though still good evidence, the continuous recordings at the two levels of the Sutter Buttes furnished the highly desirable complementary information. This can be seen by the wind roses in the Appendix, and even better in Figures 4 through 11. These figures are sort of wind rose summaries for northerly and southerly directions grouped together (southeasterly for the lower station), since other directions hardly occur because of the Valley formation running NW-SE. For more reliable presentation, 1970 data obtained prior to the present project were combined with the 1971 recordings. The histogram format was used--the lengths of the columns shown by points--giving the frequencies of occurrence in percent. The small white area on each diagram dividing the north and south directions represents other directions or missing data. This simplication permitted 24 daily wind roses to be condensed into one diagram, even including velocities. For the sake of clearness the latter were only divided for speeds below and above 10 mph.

The conditions plotted in Figures 8 and 9 for the summer months at the 600-ft. station, near the low-level jet height show southerly directions throughout the 24 period, as should be expected by looking at the summer streamlines in the Buttes area (Figure 1 on p. 13). Very striking, however, is the curve for the southerly velocities over 10 mph. They are almost non-existing between

7 and 9 a.m., but increase to over 80% in late afternoon and last into early morning. Very pronounced is the oscillation during the night, showing that the marine air influx occurs in surges. In Figures 10 and 11, the marine air influx during the fall months declines to about half of the days. But a slight maximum of strong velocities can still be discerned during some night hours, demonstrating that the possibility for smoke dispersal is not nil. This will also be revealed by an example in the streamlines section.

The streamline examples at the end of this volume show first a three-day period of northerly winds typical for the fall season. They can temporarily increase to high velocities, as can be seen at the Buttes Station. But as can also be seen, they decline into stagnancy during the following night which could produce a smoke problem in Sacramento and neighboring cities, if on the previous day field burning were permitted. The following streamlines example for a rather stagnant day shows more or less local air movements caused by mountains, but also a weak influx of marine air which ended shortly after noon. In this case for the fall season, using the morning hour wind as signal for expecting stronger "sea-breezes" later in the day would fail, although this criterion can work so well in the summer. The good south flow in the following example is one of the rare cases of excellent air pollutant dispersal. Such situations develop in connection with storm activity to the north.

Figures 4 to 7 give the 24 hourly wind roses summarized on one diagram per month for the Sutter Buttes peak level. Inspecting Figure 2 on page 14, the peak of 2000 feet should seem somewhat too high for obtaining significant data on the marine flow. The northerly directions are predominant indeed. However, the surges of the marine air at this high level and despite the rather distant location which is 75 miles north

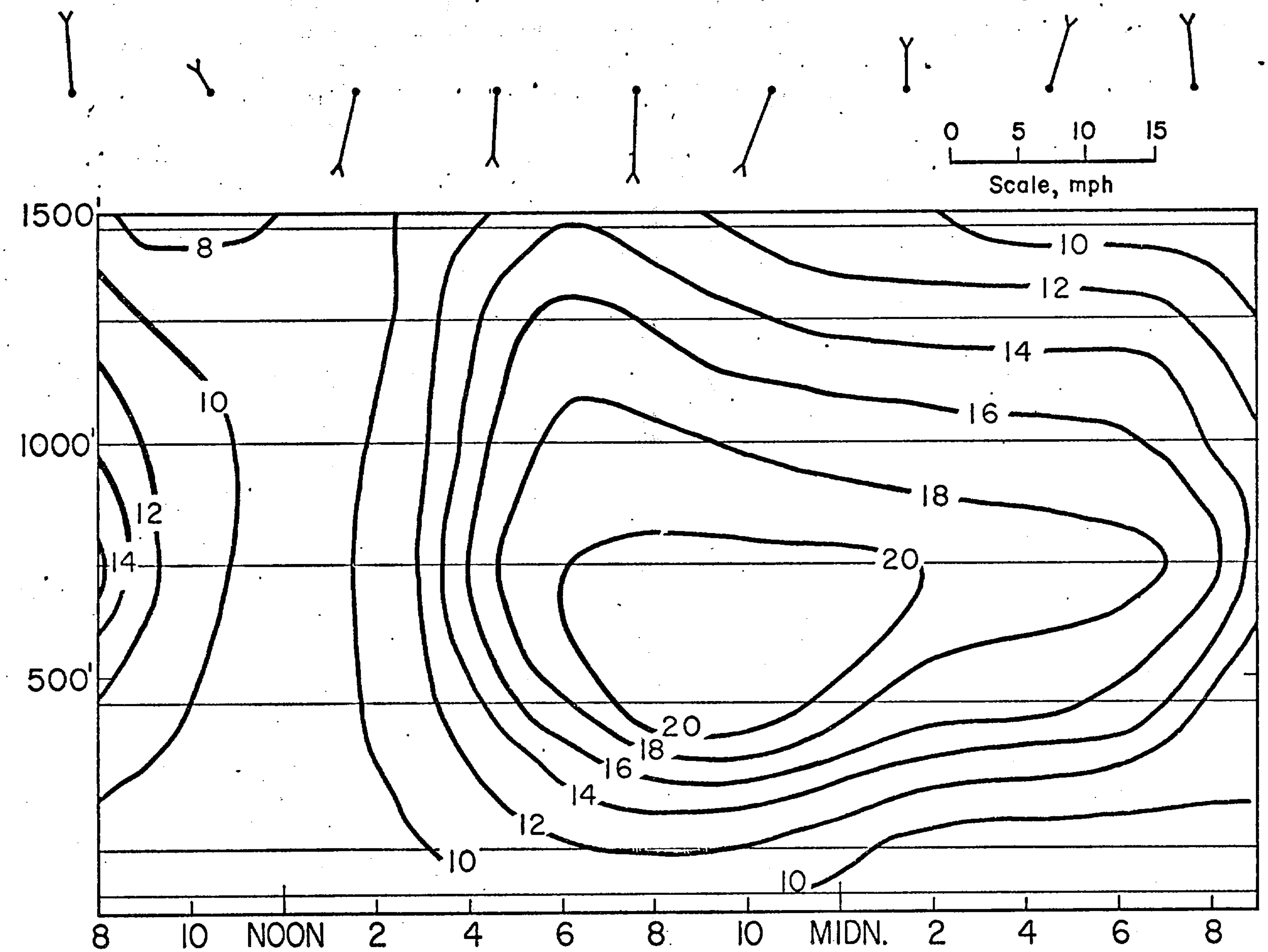
of Walnut Grove, or about the entrance of the marine air at the Carquinez Straits, are sharply evident, most pronounced in July, and gradually less in the following months. Another attempt of presentation is Fig. 25, containing monthly vectorial averages, computed for every three hours for August, which are superimposed on a time section for August, 1964 at the Walnut Grove tower, showing a practically perfect agreement. All four Figures (4-7) show a south wind minimum around 9 a.m., the time known for minimum marine air influx.

The maximum toward midnight is smaller in October, but not zero, which is a challenge to the forecaster. October is the month with the greatest number of stagnancies. In Fig. 26 it can be seen that this is the case mainly in the second half. In November, the dispersal conditions are improving because of increased storm activity. In Fig. 26, the percentage of storm-related winds changed from 7% in the first half of October to 22% in the first half of November.

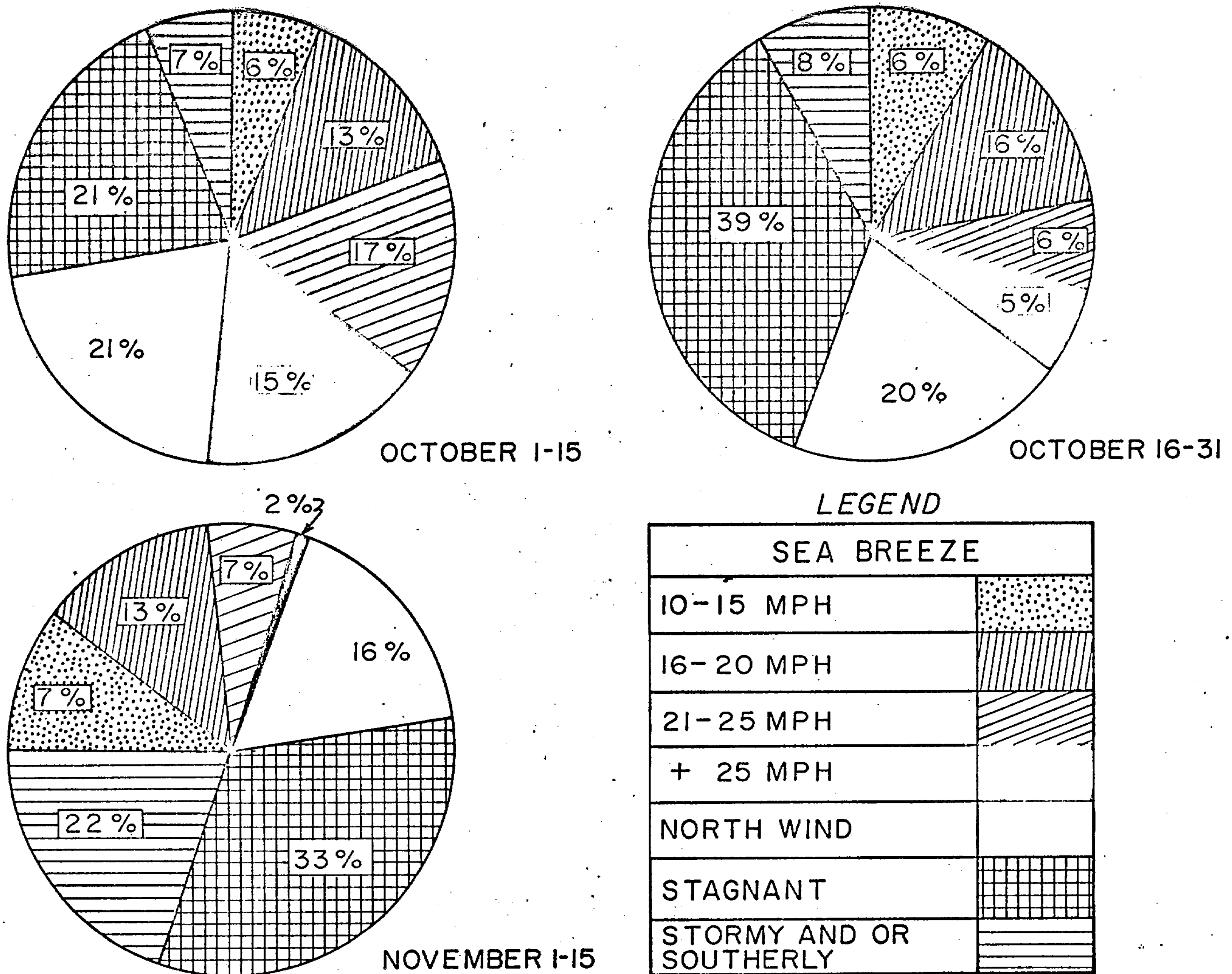
The data from eight surface stations on the floor of the Sacramento Valley are summarized in hourly wind rose diagrams for various months during the summer and fall of 1971. They are arranged in the Appendix in the same sequence as listed in Table I. The wind roses for Sacramento during the summer months show that the flow of marine air blowing from the west through the Carquinez Straits continues in the Sacramento Valley as southerly up-valley flow practically during all hours, especially during the afternoon and evening. Further up the Valley at Wheatland, southern winds prevail to only a little lesser degree (compare with Fig. 1), especially in the morning hours. At Red Bluff, however, the farthest station north, late night and morning northerly winds are more frequent. However, there is still a pronounced dominance of the up-valley marine flow during the rest of the day.

The characteristic of the September, October, and November wind roses is the gradually reduced frequency of southerly winds and corresponding increase

Resultant wind at top of Sutter Buttes, 2000 ft. - July, 1971



Daily Cycle of Wind Velocity in August 1964, m.p.h., Walnut Grove T.V. Tower.



WIND CONDITIONS AT WALNUT GROVE TELEVISION TOWER (1964-1967)

in northerly winds throughout the Sacramento Valley. The results from Sacramento indicate that the flow of marine air enters the Sacramento Valley on only about 50% of the days during these fall months. Of the three months, October has the lowest frequency of southerly winds and the highest frequency of calm periods. In the central part of the Valley there is also a marked decrease in the frequency of up-valley southerly winds. Wheatland, Biggs, Norman, and Glenn all had more northerly winds than southerly winds in September, October, and November. Among these four stations, Biggs which is located on the east side of the Sacramento Valley, had the highest frequency of southerly winds with a 40% rate of occurrence. In addition, the lowest frequency of southerly winds and highest frequency of calm periods at Biggs occurred in October, as was the case in Sacramento and was also seen in the Sutter Buttes data and in more detail in Fig. 26. Norman and Glenn which are located in the western and central parts of the Sacramento Valley had significantly fewer southerly winds in September, October, and November than Biggs, especially in evening hours.

The September, October, and November wind roses from the three stations in the northern-most part of the Sacramento Valley - Chico, Orland, and Red Bluff - exhibit a further marked decrease in southerly up-valley winds, especially in the evening. Southerly winds occurred on approximately 30% of the days during these months. October again is found to be the month with the lowest frequency of southerly winds and highest frequency of calm periods. In November, gradually increasing winter storm activity improves the dispersal conditions, as was already shown in Fig. 26.

B. Theoretical Considerations

Before discussing the conditions in the San Joaquin Valley, some general remarks might be in order here regarding the complex origin of the marine air

intrusion. Designating it solely as a sea-breeze (as was done in Fig. 26) is only partially correct because the nightly reversal does not occur. Another factor, a thermal valley low due to daytime heating certainly is another factor, which was shown in M. D. Fitzwater's thesis. But, he had to evaluate a series of microbarograph recordings in the Sacramento Valley in a very delicate fashion, e.g. working with thousandths of mb, to provide proof, especially for the southeasterly directions. However, the primary factor is often overlooked, namely the synoptic situation, generally requiring higher pressure over the ocean and lower pressure over the western part of the continent (Monsoon). Without terrain obstructions, the summer winds would almost always be between NW and N, as they are observed along the coast, and were also found in this study at the Sutter Buttes Peak, except for the few hours before midnight when the marine air surge extends above the 2000-ft level. Besides Fitzwater's thermal low finding, the south winds undercutting the northerly flow might also be caused by the coastal mountain barrier forcing the basic NW-flow into the Valley as a south wind. Many wind roses in the Appendix, and some streamlines in Fig. 1, show, therefore, easterly components. Whereas the onshore winds are rather regular in summer, the synoptic situations for this phenomenon are infrequent in fall. However, they do exist, but might often be difficult to foresee. This certainly is highly desirable and a great challenge to a forecaster. The turning of the NW-direction into the southerly flow after entering the Sacramento Valley might be compared with the Catalina eddy in the south.

C. San Joaquin Valley

The influx of the marine air appears to be greater in the San Joaquin Valley probably because of less modification of the basic NW-flow, which can be seen on all wind roses and frequency tables in the Appendix. This is true

especially for the afternoon and evening hours. Balloon observations at Five Points (Figures 20 to 24) show the same low level jet phenomenon as Figures 2 and 26. However, through cooperation with a Fresno State University project, the maximum velocities were found to be weaker there and at somewhat greater heights. The same seems to be true for Shafter, as can be seen in Figure 24a by comparison with Figure 24 for Five Points. However, the appearance of the "low level jet" so far south is impressive. The two other Shafter balloon nights shown at the end of this volume show similar results.

According to the discussions under "B", the marine air penetration should be more pronounced in the San Joaquin Valley, although the larger width and depth of this Valley might invite the fear of an early "diluting" from spreading (divergent flow). This does not seem to happen as can be seen by all Valley floor station wind roses. They show higher occurrences of marine flow directions (N and NW) especially in afternoon and evenings and in all seasons. The reason for this could be additional marine air intrusion through some passes in the Coastal Ranges. The knoll and ridge stations indicate this trend in the afternoons and evenings (Kettleman Hills, Cottonwood, Devils Den, Elk Hills). This can also be seen in the following streamline diagrams for "class A" for very strong marine air influx. Expecially the station farthest south at the Aquaduct Pumping plant "Wind Gap" still recorded a northerly direction from 6-7 p.m., the time when usually a Tehachapi drainage flow is established.

The knoll stations that were established in the southeastern part of the San Joaquin Valley did not record any marine air advection. Caliente and Horseshow Ranch instead show strong development of up-Sierra winds in the daytime and drainage flows at night. These can, to a good extent, contribute to some Valley ventilation. The Green Mountain location, at 1270 feet and farther north, experienced a strong air movement from the ocean, although the

Sierra slope winds were also strongly developed. There, the nightly easterly drainage winds were suppressed almost until 3 a.m. by the northwesterly marine flow. On most of the "higher" stations, the velocities are rather strong, depending on the nearness to the wind speed maximum zone. These locations offer possibilities for wind generation of electric power.

On the other hand, wind velocities on the Valley floor primarily are low, perhaps with the exception of Stockton. The good Stockton velocities, seen in the frequency tables in the Appendix, benefit from the nearness to the entrance of the marine air, but also from the higher installation of an airport anomometer. As a whole, the Valley floor winds are especially weak, as it should be expected, during the morning hours. Similar to the Sacramento Valley (Fig. 1) there is a trend of a slow circling of air in some 9 a.m. to noon wind roses and frequency tables: Lemoore shows northerly directions, whereas westerly directions appear at Corcoran and southerly ones at Fresno. Although in the Sacramento Valley this weak eddying is a regular phenomenon in summer, it seems to occur only occasionally in the San Joaquin Valley. An attempt was made to construct such eddies on some of the streamline maps during the morning hours for the classes "C" and "D," chosen to represent cases with rather weak marine air flow or none at times. These eddies do not appear very convincing.

The San Joaquin Valley streamline maps, constructed for the purpose of complementing the previous discussion, were arranged in somewhat different fashion than those for the Sacramento Valley. Twelve cases were selected for forming four groups of 3 days with a rather similar weather type and these 3 days were plotted side by side for every 3 hours on one page. Class "A" demonstrates very strong marine air influx, whereas the 3 days of Class "B," also showing strong marine air flow, do not experience any penetration into the Valley through the coastal mountain passes on the west. The Classes "C" (light marine air flow) and "D" (primarily stagnation) are greatly

influenced by aerographically caused "local winds," upslope air motion in the daytime, and downslope cold air drainage at night. It must be suspected that the morning hour "eddies" might also be caused by terrain influence, especially the south-easterly directions at Fresno from 9-10 a.m., or noon to 1 p.m.

The southern-most station "Wind Gap," located at the bottom of the Tehachapis, which appears most influenced by the upslope-downslope wind system, shows an anomaly difficult to explain at this time. On all streamline maps a westerly flow appears at the 9-10 p.m. hour plotting. The wind roses for Wind Gap also contains west directions at other night hours. A more detailed study in this area should produce some answers in the future.