UNIVERSITY OF CALIFORNIA
Department of Meteorology
Los Angeles

SURFACE WIND PATTERNS IN THE LOS ANGELES BASIN DURING "SANTA ANA" CONDITIONS

James G. Edinger
Roger A. Helvey
David Baumhefner

Reprinted for official use by
Pacific Southwest Forest and Range Experiment Station
Forest Service, U.S. Department of Agriculture
Berkeley, California
September 1964

AVAILABILITY OF COPIES

SURFACE WIND PATTERNS IN THE LOS ANGELES BASIN
DURING "SANTA ANA" CONDITIONS

Prepared by

Department of Meteorology, University of California at Los Angeles

in cooperation with

Pacific Southwest Forest and Range Experiment Station
Forest Service, U.S. Department of Agriculture
Berkeley, California 94701

as

Part I of Final Report on USFS Research Project No. 2606
Supplement No. 49, USFS-UC Contract No. A5FS-16563
under OCD contracts OCD-OS-62-143 and OCD-PS-64-24

for

Office of Civil Defense
Office of the Secretary of the Army
Washington, D.C. 20310

OCD Review Notice

This report has been reviewed in the Office of Civil Defense as an accessory to "Synoptic Weather Types Associated with Critical Fire Weather," by the U.S. Forest Service and the U.S. Weather Bureau. The study reported herein is an example of studies which can be locally done to provide descriptions of local fire weather conditions that will be useful to the fire services. This report is approved for publication.

ACKNOWLEDGMENTS

The statistical treatment of the large volume of data was accomplished by the U.C.L.A. Computing Facility without whose assistance such an ambitious chore could not have been attempted. Special recognition is due the Los Angeles County Air Pollution Control District for making available its large collection of local wind records.

CONTENTS

BLANK PAGE

CHAPTER I

INTRODUCTION

Local weather conditions are recognized as having a very important influence on the inception and behavior of wild fires. In particular, strong surface winds, low humidities, and low vertical stability favor the rapid development of a minor blaze into a full-blown conflagration. On five or ten occasions each year such winds and humidities are experienced in the greater Los Angeles area, defined here as the coastal plains and valleys oceanward of the San Gabriel, San Bernardino and San Jacinto mountains of southern California. Frequently they fan a small flame into a thousand acre brush fire. Sometimes they create monsters such as the 1961 Bel Air conflagration that consume hundreds of homes. But these weather conditions, without which the conflagration can neither develop nor survive, are not uniformly distributed over the coastal plains and valleys. This is especially true of the wind which reaches peak values in some areas, downwind of passes, for instance, and is brought to a near standstill in other places in the lee of the mountains. These strong dry wind situations in southern California have come to be known as "Santa Anas", in honor of the Santa Ana Canyon which for generations has been recognized as one of the gaps through which the dry desert winds rush in their dash to the sea.

This study concerns itself with the distribution of the surface winds over the densely populated coastal plains and valleys of the greater Los Angeles area during the fire weather, "Santa Ana", situations. This area is particularly favored as the locale for a fire wind investigation not only by virtue of the meteorology of the area but also because an unusually dense network of surface wind stations exists here. This network was installed by the Los Angeles County Air Pollution Control District for the purpose of measuring the movement of polluted air across the Los Angeles basin during smog situations. In this research project we use it to investigate quite another type of weather situation, one in which, incidentally, high winds prevent the accumulation of man-made air pollution but often introduce in its place dust and blowing sand and sometimes even the smoke and ash from wild fires.

The purpose of the study is to provide descriptions of the local winds during "Santa Anas" that will be useful to those responsible for the prevention and control of conflagrations. Of course, it will be more useful to officials in the Los Angeles area than to those elsewhere. However, it is hoped that some general information concerning the effect of terrain on strong surface winds will emerge and thus will find wider application.

The investigation was carried out in two phases, the first in which several selected fire weather "Santa Ana" cases were examined in all possible detail and the second in which all

"Santa Ana" days in the period 1956 to 1962, 149 days in all, were lumped together and examined statistically to provide the mean picture. The case studies were a necessary prelude to the statistical work because, among other things, they provided the criteria required for the selection of the Santa Ana days for which the means were determined. In the interest of clarity of presentation, however, the results will be presented in the opposite order. First the general picture, provided by the statistical investigation, will be described. The major features of the flow pattern and its variations with the time of day will be evident. Then this over-simplified picture of the flow will be augmented by a selection of actual patterns from the case studies. These will suggest the range and nature of the deviations of the actual situations about the mean picture.

CHAPTER II

TOPOGRAPHY

A necessary preliminary to the consideration of the relatively complex flow that occurs over the Los Angeles area during strong north and northeasterly winds is a general understanding of the terrain that the air encounters in its transit across the area, from desert to ocean. See figure 1. First the air encounters a chain of three relatively high mountain ranges standing shoulder to shoulder to form the northern and eastern perimeter of the area. These are the San Gabriels to the north, the San Bernardinos to the northeast and the San Jacinto mountains to the east. All three have peaks reaching above 10,000 ft. Next the air comes to a secondary arc or mountains, much lower and approximately parallel to the first. This arc stands midway between the high mountains and the coast. It consists of the Santa Monica mountains, the Puente Hills, the Chino Hills, and the Santa Ana mountains.

Having identified the major obstacles to the Santa Ana winds let us now call attention to the major gaps through which the air is funneled at accelerated speeds. Through the high mountains, moving from the west to the east, there is the Soledad Canyon - Weldon Canyon area that empties into the San Fernando Valley and the Cajon and San Gorgonio Passes that empty into the

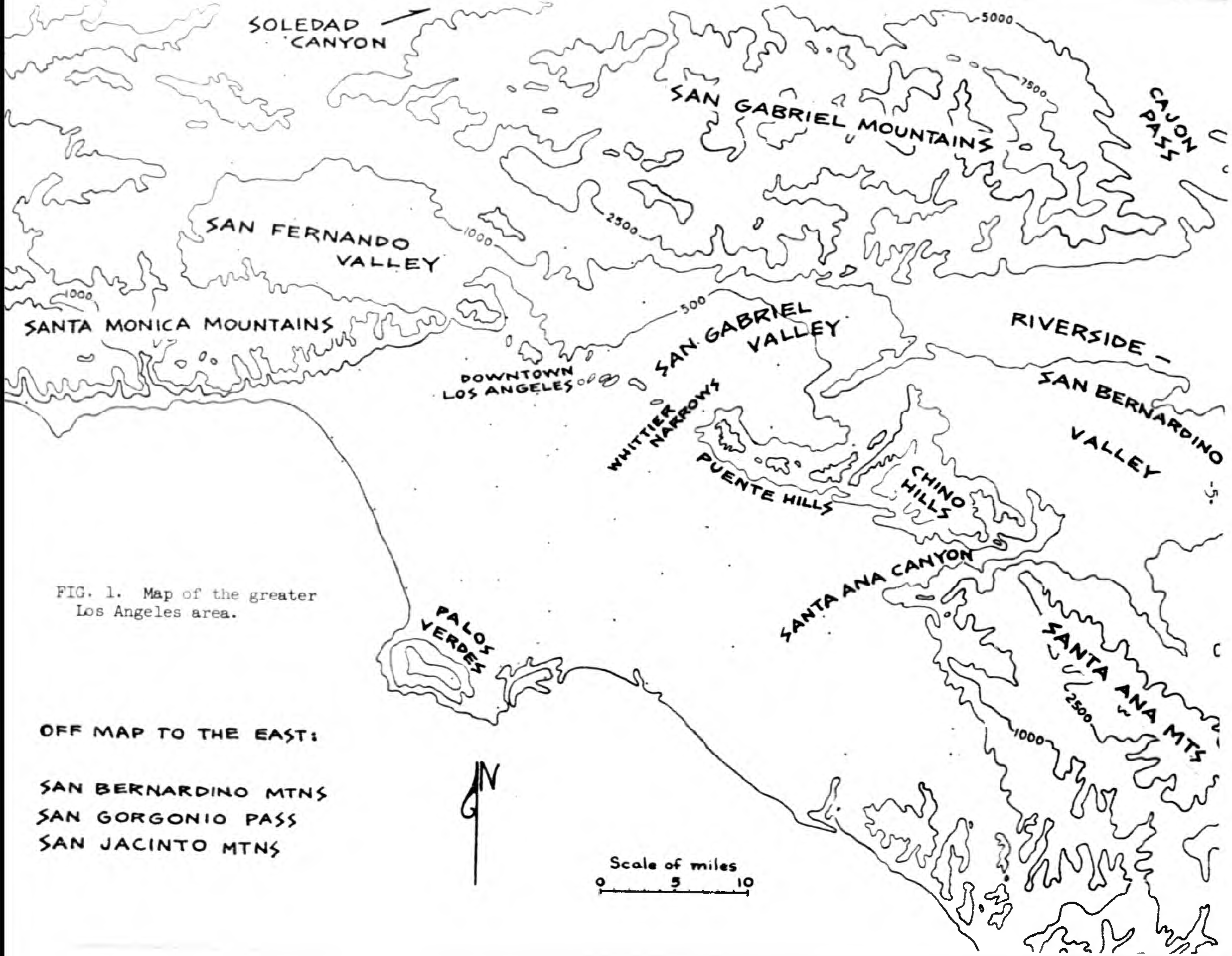


FIG. 1. Map of the greater Los Angeles area.

Riverside - San Bernardino Valley. Gaps in the lower secondary arc of mountains are not as well defined nor have as conspicuous an influence on the flow with the possible exception of the narrow canyon whose name these strong northeasterly winds bear, Santa Ana Canyon, in the southeastern corner of the area.

CHAPTER III

MEAN WIND PATTERNS

The purpose of this phase of the research, as mentioned above, is to discover the average behavior of the Santa Ana wind situations. As one might expect, the examination of individual wind patterns indicated that each occurrence of the warm dry northeasterlies was an individual unto itself. No carbon copies of situations were found. Each Santa Ana had its own unique features, a certain orientation of the jets downwind of the passes, its own, often complex and rapidly changing, pattern in the wake of the San Gabriels. But if the fingerprints varied from case to case, the same could not be said for the number of fingers. Each had the same basic anatomy. This common anatomy is expressed in this chapter in terms of preferred wind directions and average wind speeds. A discussion of the unique features, distinguishing one case from another, will be presented in the next chapter of this report.

Before an average could be struck or a preferred direction determined, a body of Santa Ana cases on which to operate had to be selected, and before this, a definition of a Santa Ana decided upon. As it turned out, the definition developed as the list of candidates was sifted and resifted and was hardly firm before the list of 149 days was itself finalized. The details of the process of choosing these 149 Santa Ana days from 7 years of hourly wind records (1956-62) for over 100 different observing stations are given in a report by David Baumhefner entitled, "An Objective Method for Selecting a Set of Foehn or 'Santa Ana' Days in the Los Angeles Basin". Here we will offer a brief summary of the procedure.

To avoid the completely unrealistic task of constructing streamline charts for all 2557 days of the 7 year period, a list of likely "Santa Ana credentials" based upon readily available synoptic weather records was developed. As finally constituted this list included: (a) a 3 mb or greater increase in msl pressure from Santa Monica to Palmdale in the desert to the northeast, (b) a 15°F or greater decrease in temperature from Santa Monica to Palmdale, (c) wind speeds from a northerly direction of 10 mph or greater in the San Fernando Valley and of 30 mph or greater in the Riverside - San Bernardino Valley, and (d) relative humidities of 30% or less in the Los Angeles area.

Situations claiming more than one or two of these criteria were subjected to a checking procedure involving the examination of: (a) the vertical wind profile, (b) the configuration of the isobars on the surface weather map, (c) the sky condition, and (d) the streamline pattern over the entire basin for 1300 PST. Fortunately almost all of the days selected for having the requisite "credentials" also passed the test, and the task of constructing an undue number of streamline maps was avoided.

In the last analysis, then, the acceptance of a day as a Santa Ana day was contingent upon the existence of a recognizable foehn flow in the basin. The choice of the 1300 PST streamline map as the check was not arbitrary. Preliminary case studies had revealed a marked diurnal oscillation in pattern. Daytime thermal effects opposing the northeasterly flow are found to be sufficiently strong to cause a reversal of the flow in the wake of the San Gabriel mountains, frequently all the way from the mountains to the sea. In the event that this reversal also occurred immediately downwind of any of the major passes at 1300 PST, when the thermal effects are near peak strength, the day was rejected as having an insufficiently strong northeasterly current.

The hourly wind speeds and directions for the 149 selected days were processed by IBM 7090 to provide mean wind speeds and percent frequency distributions of wind direction for each station in the area. We now turn to a discussion of the resultant statistics.

Figure 2 is a streamline map drawn for the most frequently observed wind at each station in the area. Entered on the map also are the mean speeds for the preferred direction at these stations. Data representing all hours, day and night, are lumped together to provide the pattern shown. It is a fairly simple flow pattern: (a) strong northerly flow, 10 to 25 mph around the western

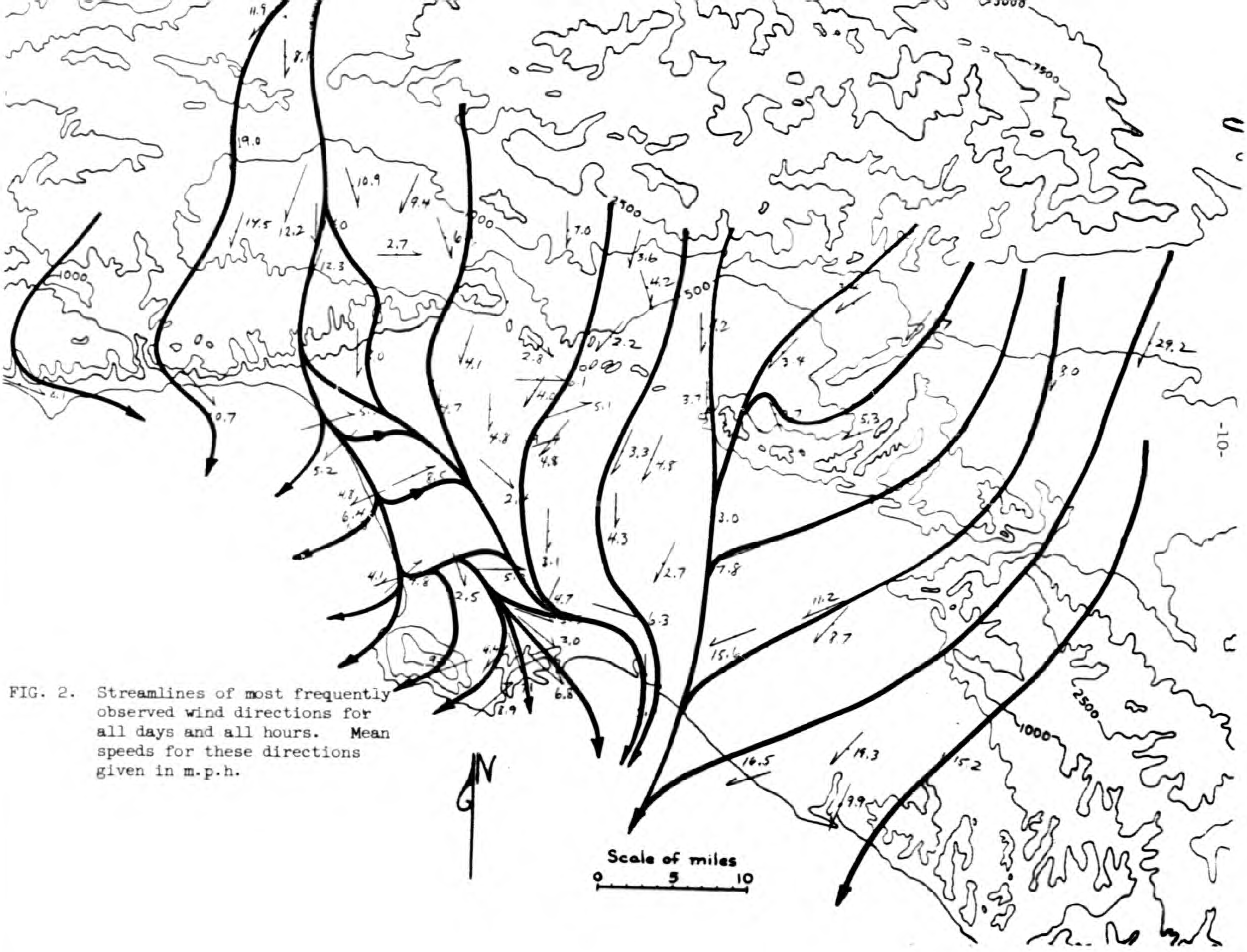


FIG. 2. Streamlines of most frequently observed wind directions for all days and all hours. Mean speeds for these directions given in m.p.h.

end of the San Gabriel mountains and across the western half of the San Fernando Valley then over the Santa Monica mountains to the sea, (b) strong northeasterly flow, 10 to 30 mph, from Cajon Pass at the eastern end of the San Gabriel mountains across the Riverside - San Bernardino Valley, through the Santa Ana Canyon and across the coastal plain to the sea, and (c) a considerably weaker flow in between these two strong currents originating on the southern slopes of the San Gabriels and moving generally toward the sea. The most conspicuous deviation from this north to south flow is the narrow area just inland of the western beaches where on-shore (westerly) winds occur.

The influence of the San Gabriel mountains as an obstacle to the flow is apparent. They cast a wind shadow of diminished winds that stretches all the way to the southern beaches, and they produce strong narrow streams at each flank that converge somewhat downwind, acting as lateral boundaries for the wind shadow. The lesser mountains and hills interior to the basin also produce their own effects. There is a divergence of the streamlines upwind of the Santa Monicas accompanied by an appropriate convergence in their lee. And, on the other hand, there is an equally appropriate convergence of streamlines upwind and divergence downwind of the passes such as the Whittier Narrows and the Santa Ana Canyon.

So the mean field, although smoothing out many features of the real wind patterns, retains the basic dynamic effects of obstacles on fluid flow. But the dry northeasterlies are subject to other effects also associated with the terrain, namely the differential heating and cooling of valley vs. slope, land vs. sea. The disturbances to the foehn flow introduced by these thermal forces can be discerned by classifying the data according to time of day and then forming mean speeds and frequencies of occurrence of wind directions for each hour of the day. This was done. The results of the computations are represented in figures 3 through 11 consisting of a series of streamline maps spaced 2 hours apart in time from before sunrise (0500 PST) to after sunset (2100 PST).

The most striking feature on these maps is the complete reversal of wind direction in the wind shadow of the San Gabriel mountains during the mid-day hours, 1100 through 1500 PST. After 1500 PST the reverse flow systematically erodes, disappearing completely by 2100 PST. At all other hours only winds with northerly components occur in the basin.

The air flow in the area of reversal develops in much the same pattern as does the typical sea breeze on non-foehn days in the Los Angeles basin, particularly as regards the direction of flow. The speeds involved, however, are reduced by a factor of two or three. The flow starts as southwesterly across the western beaches, turns as the day progresses to a westerly. It bifurcates where it encounters the San Gabriel mountains, one branch proceeding to the northwest up into the eastern end of the San Fernando

Valley, the other turning toward the east through the San Gabriel Valley. All these features it shares with the typical (non-foehn) sea breeze in this area. Here the similarity stops, however. Whereas the normal sea breeze continues up through the passes at each end of the San Gabriels, being augmented by the differential heating of desert interior and coastal plain, the weak sea breeze in the wind shadow of the San Gabriels terminates short of the passes in the face of the strong northerly flow there.

Another striking dissimilarity between this reverse flow and the normal sea breeze is the absence of any on-shore flow across the southern beaches. The northeasterly current through the Santa Ana Canyon is sufficiently strong here to overcome the opposing daytime thermal effects. And a final characteristic that sets it apart from the normal sea breeze is its rather short duration time, the normal sea breeze flow starting several hours earlier and lasting several hours longer than does its Santa Ana counterpart.

So, the wind shadow of the San Gabriels, protected as it is from the full strength of the dry northeasterlies, is fertile ground for the usual thermal circulations that follow diurnal heating and cooling patterns. Since these effects are sufficiently robust to reverse the circulation in the shadow, one might expect that they would appear at least as a daytime diminution of the speed of the northerly currents through the passes as well. A diurnal change is unmistakable in the data, but it is

180° out of phase with that expectation. The strong northerly flow gets measurably stronger during the daylight hours, even in the coastal plain downwind of the Santa Ana Canyon!

This suggests that there is another, and more potent, thermal effect acting in the region of the stronger northerlies, an effect that opposes and overcomes the differential surface heating effects. A likely candidate is daytime thermal convection that enhances the downward turbulent transfer of northerly momentum from the wind maximum aloft. A transfer of equivalent strength is not effected in the wind shadow presumably because the winds aloft, like those at the surface, are much weaker there and provide only a meager supply of northerly momentum aloft.

Accepting the fact that the hourly mean streamline maps reveal an unmistakable diurnal oscillation in the surface flow pattern during Santa Ana situations, one that features a surprisingly distinct land-sea breeze regime, it is important that we realize that these maps do not correspond to any one real situation. They are fiction representing only a super position of 149 actual cases. One doesn't know how often a sea breeze actually invades the wind shadow. One knows only that it appears more frequently than do the northerlies between the hours of 1100 and 1900 PST. The statistics, however, can be presented in such a way that some impression of the nature of the variability about the most frequently observed conditions can be gained. This is done in figures 13, 15, 17, 19, 21, 23, 25, 27, and 29 where the

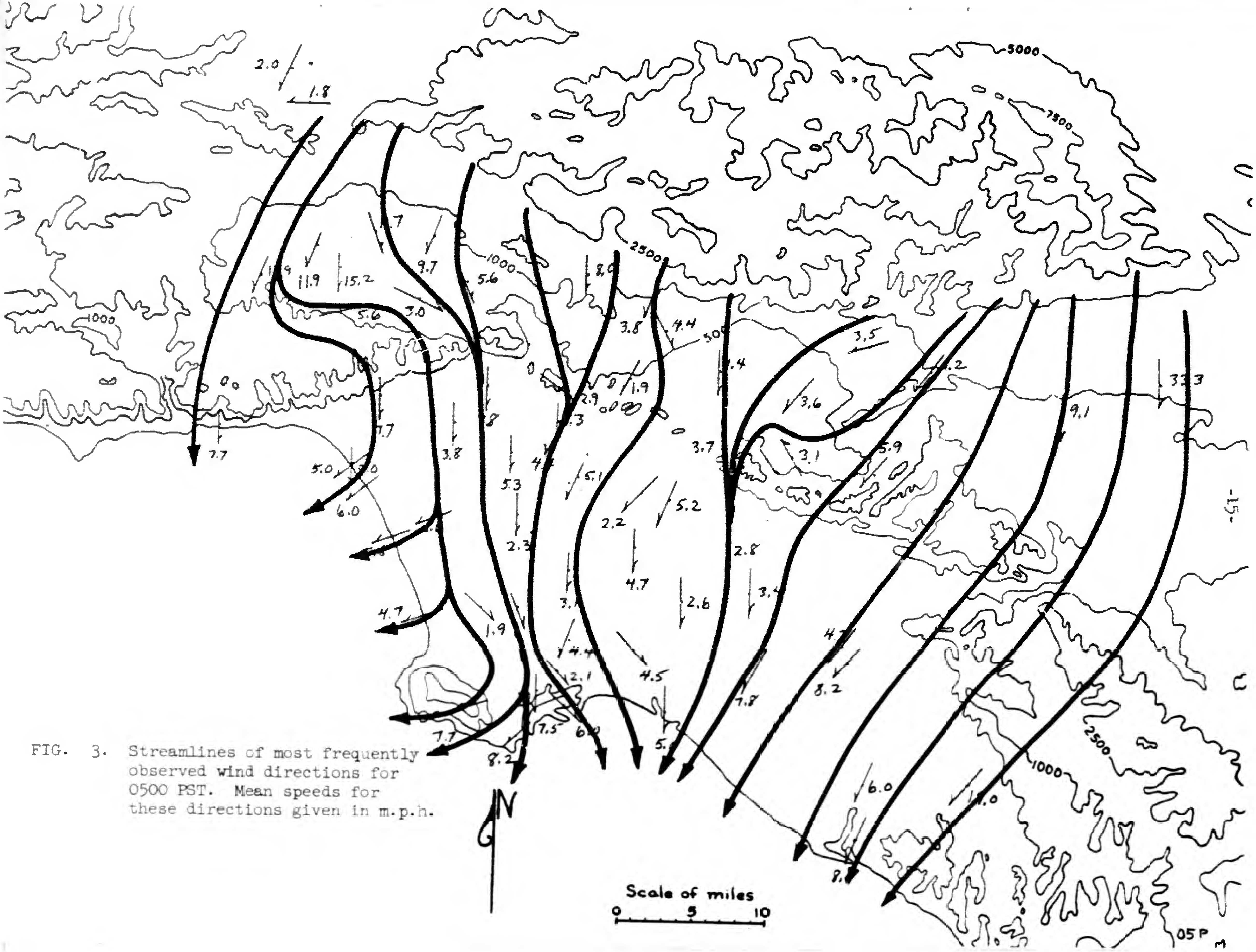


FIG. 3. Streamlines of most frequently observed wind directions for 0500 PST. Mean speeds for these directions given in m.p.h.

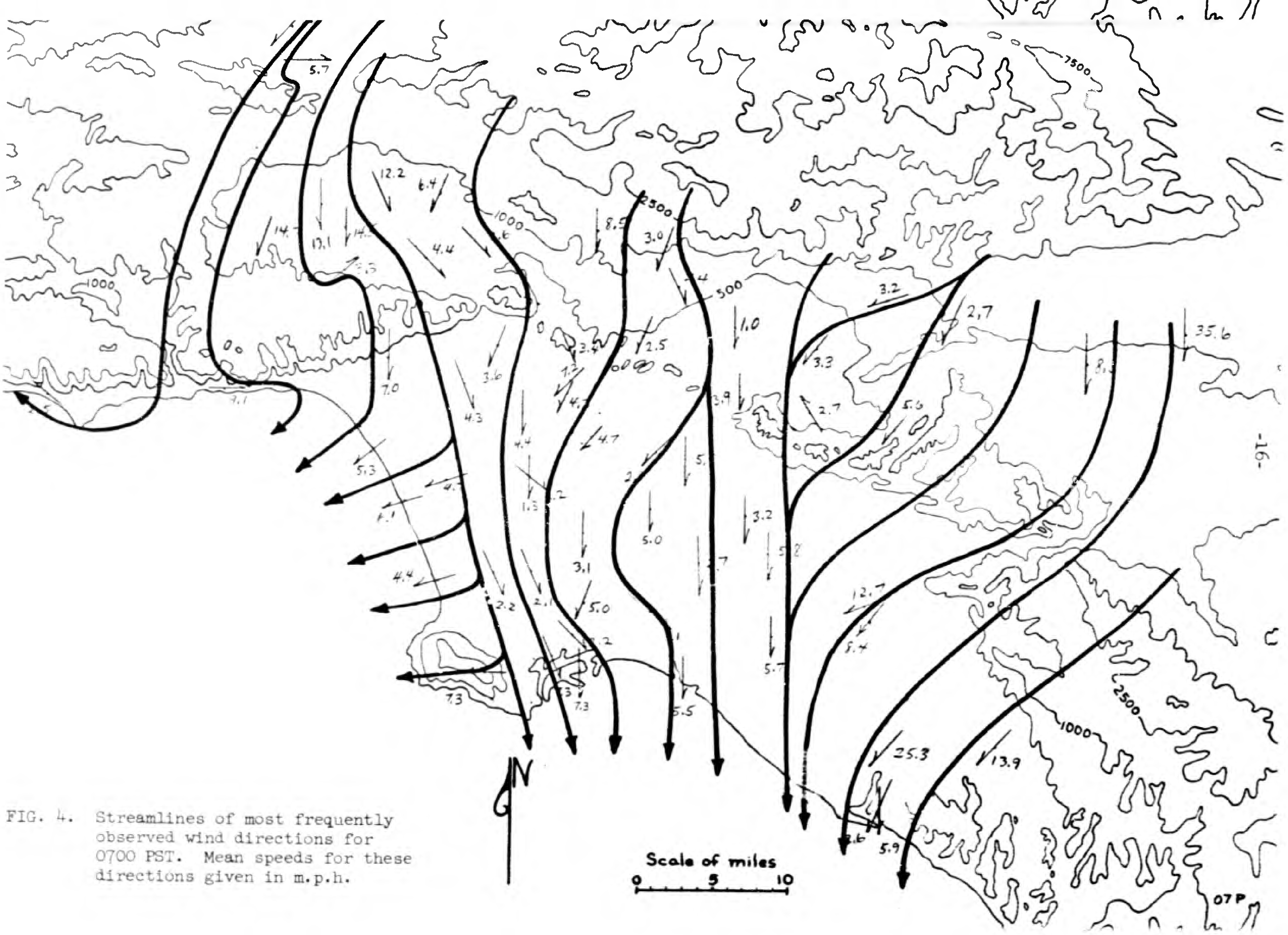


FIG. 4. Streamlines of most frequently observed wind directions for 0700 PST. Mean speeds for these directions given in m.p.h.

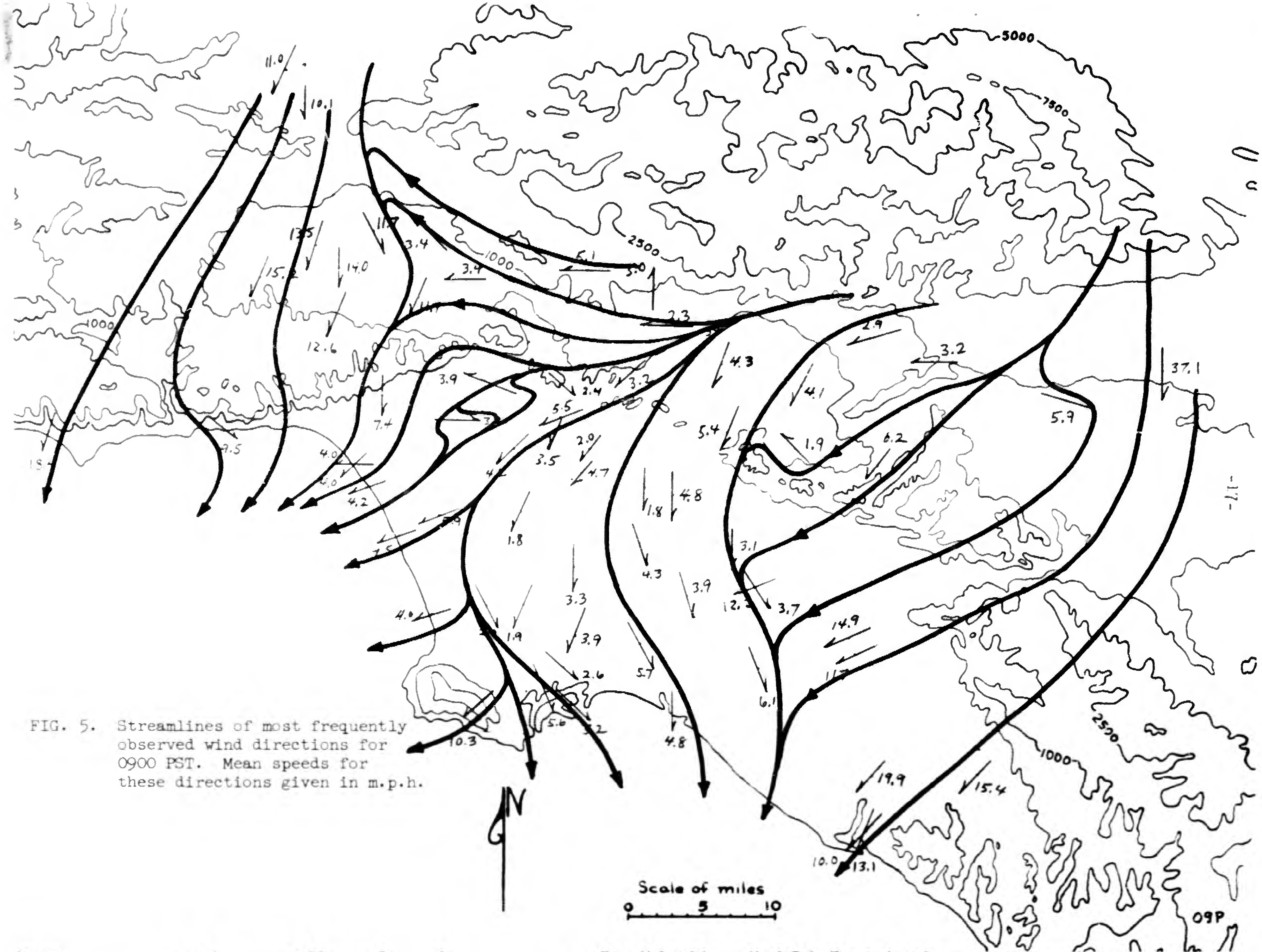


FIG. 5. Streamlines of most frequently observed wind directions for 0900 PST. Mean speeds for these directions given in m.p.h.

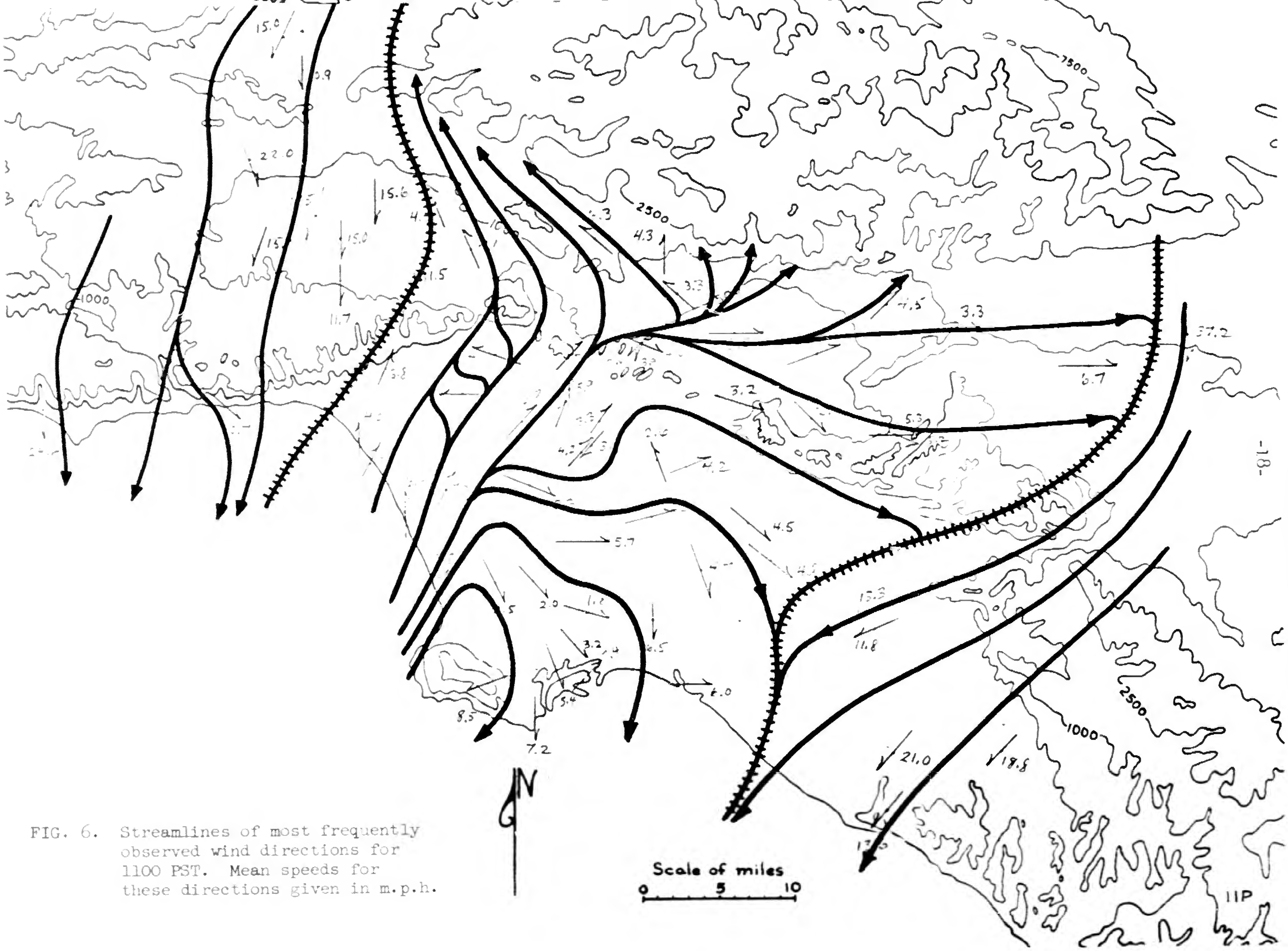


FIG. 6. Streamlines of most frequently observed wind directions for 1100 PST. Mean speeds for these directions given in m.p.h.

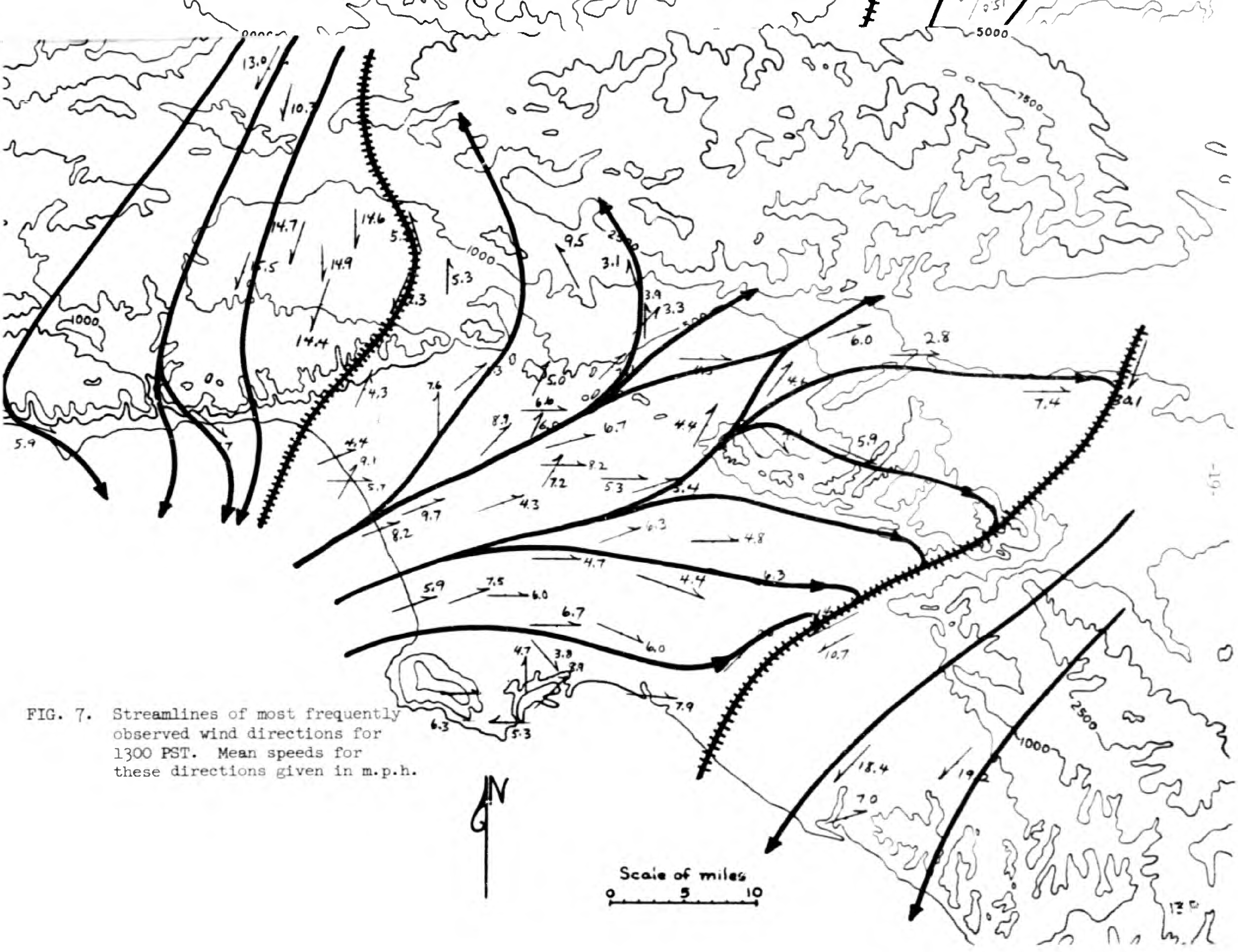


FIG. 7. Streamlines of most frequently observed wind directions for 1300 PST. Mean speeds for these directions given in m.p.h.

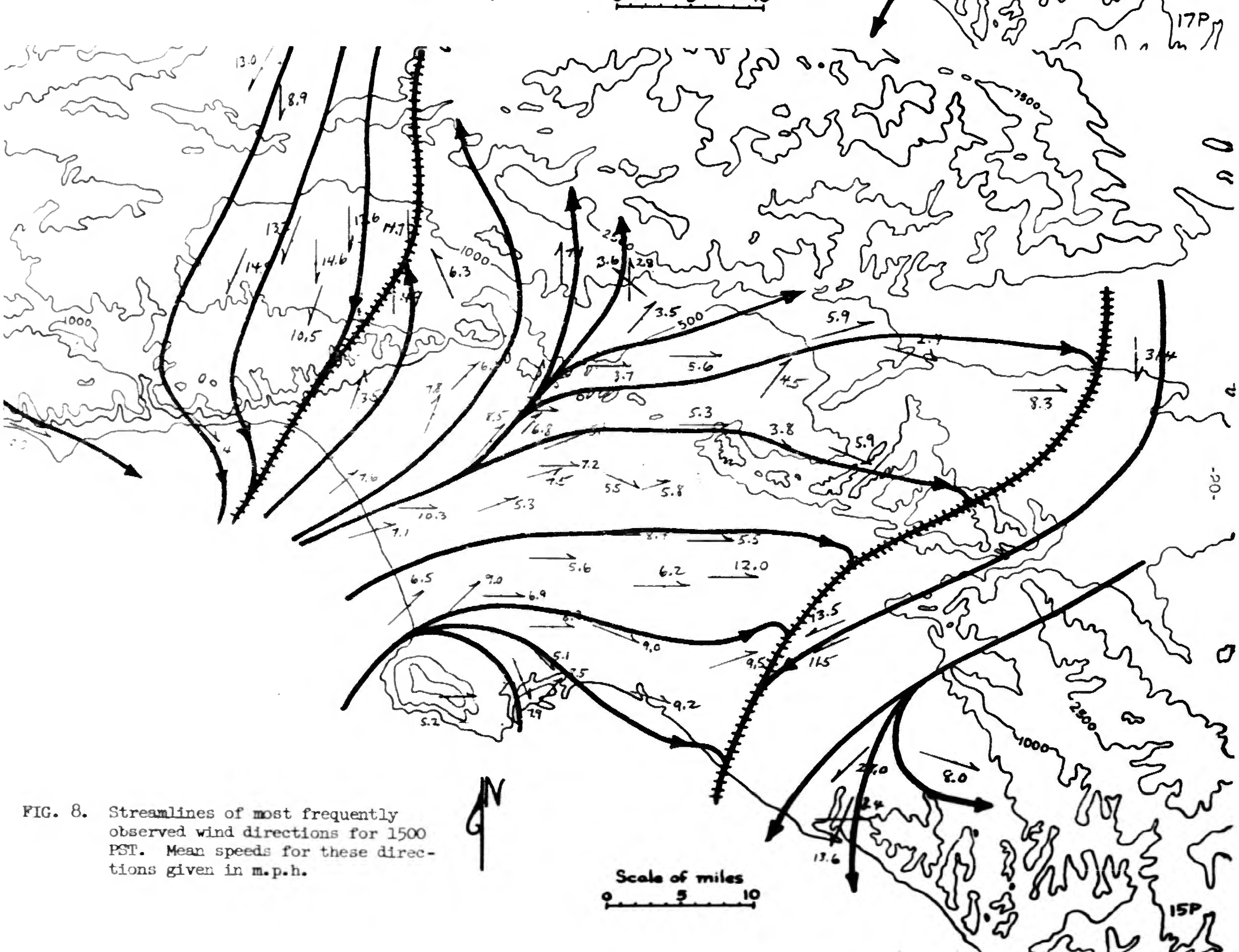


FIG. 8. Streamlines of most frequently observed wind directions for 1500 PST. Mean speeds for these directions given in m.p.h.

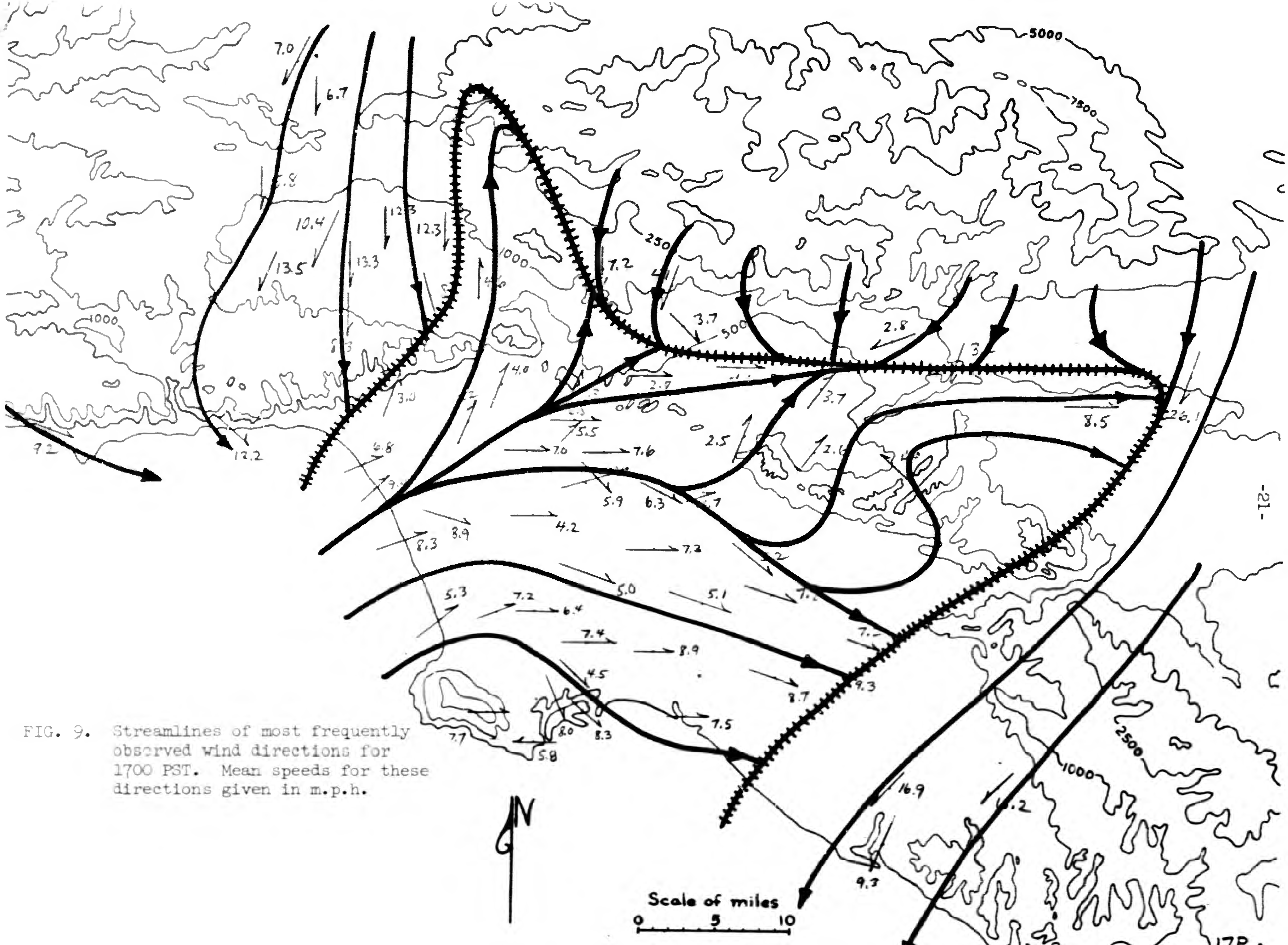


FIG. 9. Streamlines of most frequently observed wind directions for 1700 PST. Mean speeds for these directions given in m.p.h.

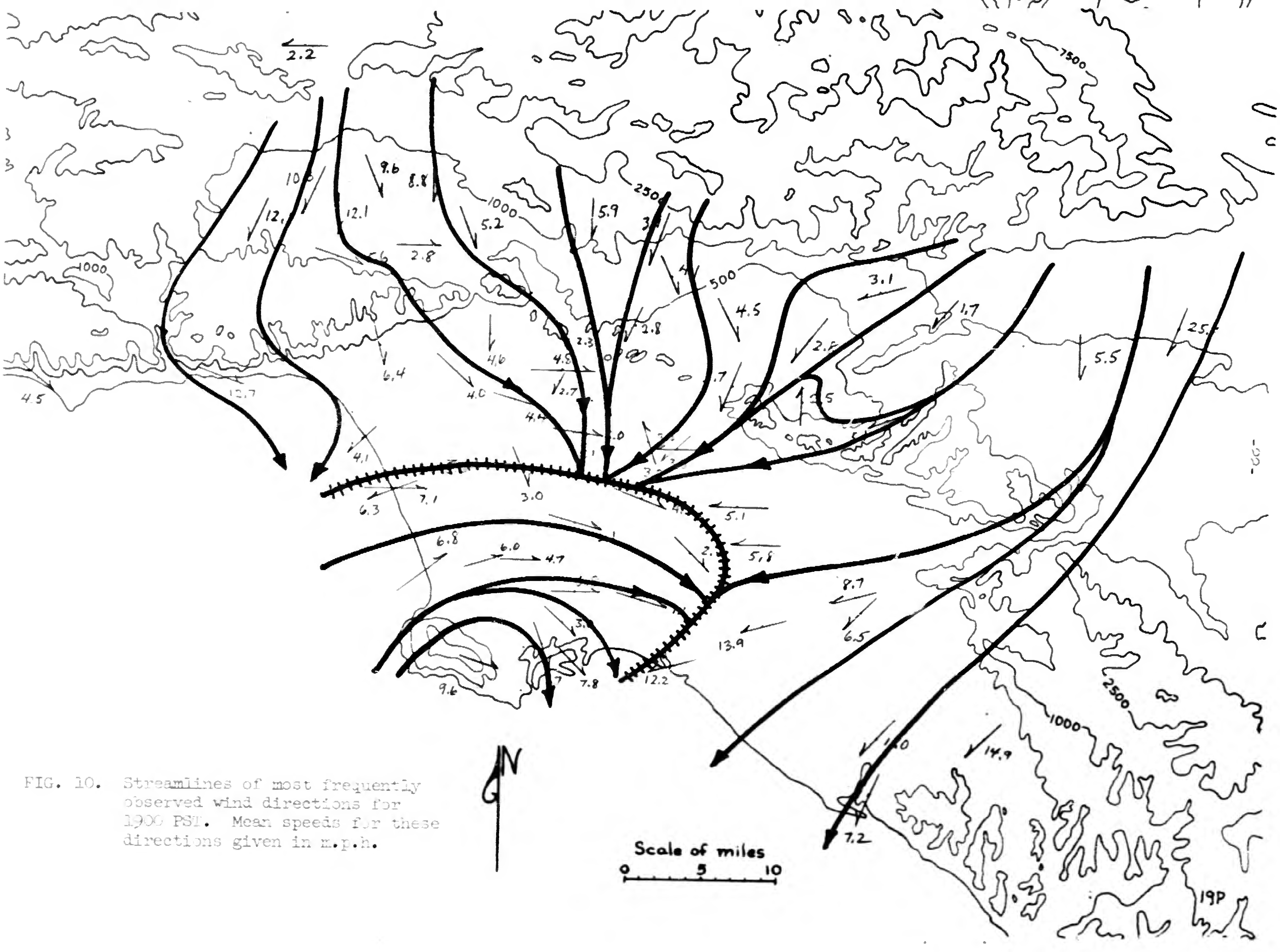


FIG. 10. Streamlines of most frequently observed wind directions for 1900 PST. Mean speeds for these directions given in m.p.h.

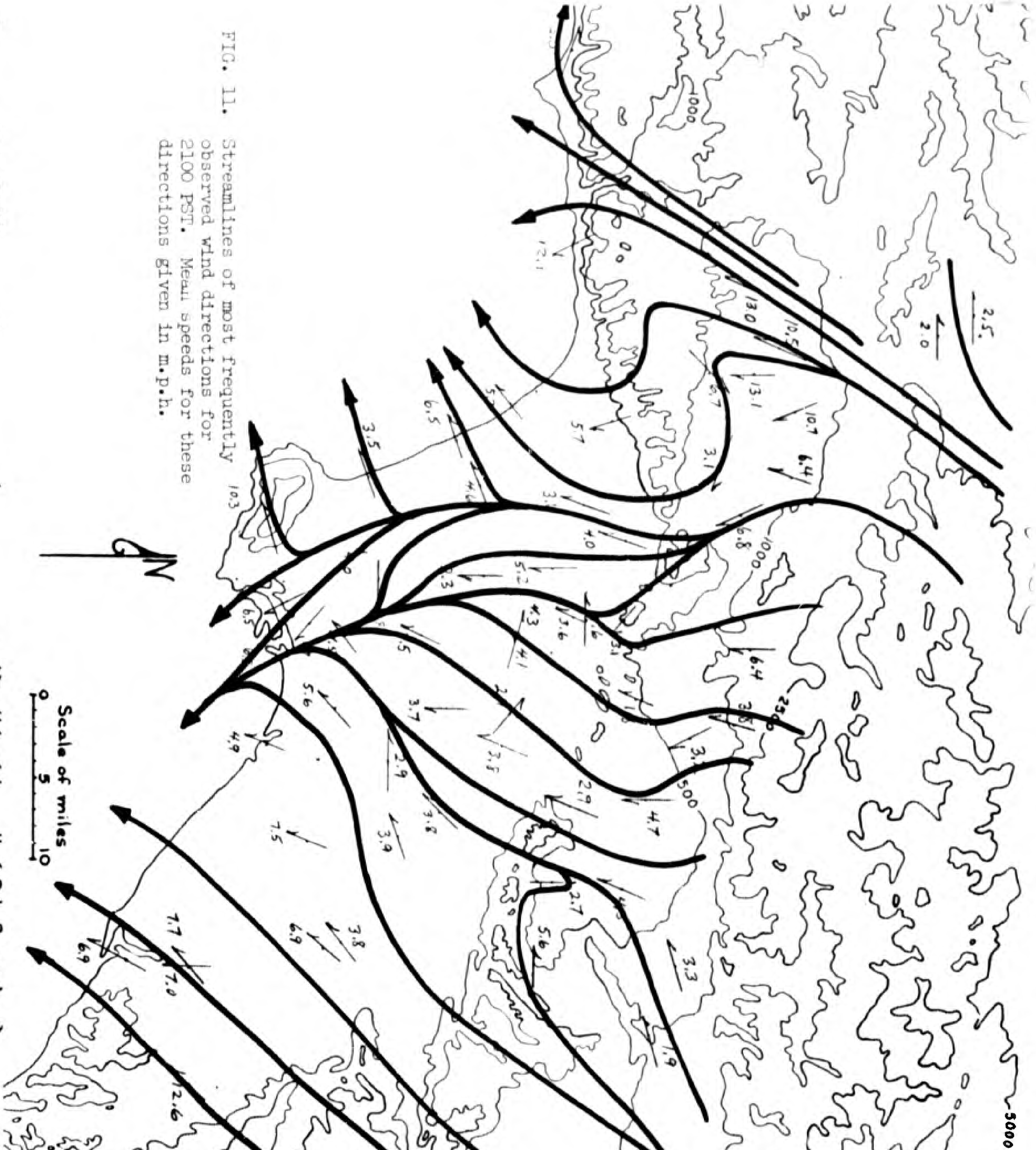


FIG. 11. Streamlines of most frequently observed wind directions for 2100 PST. Mean speeds for these directions given in m.p.h.

percent frequency of occurrence of wind direction for each of the 16 points of the compass are expressed graphically as a closed curve around each station. The distance of the curve from the station in a given direction is proportional to the percent frequency with which the wind was observed to be blowing in that direction. Each scale division corresponds to 2% relative frequency. So a circle with the station located at its center would represent wind direction equally distributed from all 16 points of the compass. An ellipse with the station location near one end would indicate that the wind blew from each of the 16 directions at one time or another but most frequently blew <u>in</u> the direction in which the ellipse pointed. Of course, the curves seldom describe anything as regular as a circle or an ellipse but typically resemble amoebas in outline.

The "amoeba" maps are constructed for the same times as the mean streamline maps, 0500 PST to 2100 PST at 2 hour intervals. In general, they show that the major features of the flow pattern are surprisingly similar from one Santa Ana day to the next. Perhaps most impressive is the almost universal existence of the sea breeze on all afternoon maps. The amoebas indicate that the northerlies are virtually non-existant at stations in the central basin between the hours of 1300 and 1700 PST on every one of the 149 days! So the fiction of the mean maps comes closer to the truth than we thought, at least in this regard. The daytime sea breeze or reverse flow must be accepted as the companion of almost all Santa Anas.

But, on the other hand, the amoebas reveal that the areal extent of the sea breeze does vary a great deal from one case to the next as does its time of onset and cessation. The map for 1100 PST, figure 19, dramatizes the effect of different times of onset on the wind direction distributions for stations in the wind shadow. The amoebas show that at 1100 PST it is almost equally likely that the flow be from the land or from the sea. Actually the sea to land direction wins by a narrow margin at almost every station, thus the convincing looking sea breeze on the 1100 PST mean streamline map, figure 6. But how misleading! There's obviously a pretty good probability that at 1100 PST on a given Santa Ana day, northerly winds will be blowing at any given station in the wind shadow.

The amoebas also reveal the nomadic nature of the boundaries of the wind shadow. Note the marked double structure of the direction distribution at the stations south of the Santa Ana Canyon for times 1100 through 1700 PST. These stations almost split their time evenly between the off-shore and on-shore flow during sea breeze hours presumably as a result of the shifting back and forth of the eastern boundary of the wind shadow. A similar effect can be seen in the eastern San Fernando Valley, the locale of the wind shadow's western boundary.

The amoebas, however, say nothing about wind speeds, only wind directions. Figures 12, 14, 16, 18, 20, 22, 24, 26, and 28, the transluscent overlays of the amoeba maps, make up for this deficiency by presenting the mean wind speed for each of the 16 directions for each station. Shafts radiate from each station in as many directions as were represented in the observations. The lengths of these shafts are proportional to the mean wind speed (2 mph for each scale division on the amoeba maps), for air moving in the direction toward which the shaft points (away from the station). These mean speeds can be misleading, particularly at those stations and at those times when the wind is predominantly from one sector. The mean speeds for winds in the predominant direction may represent the average of 100 observations while the mean for a wind in the opposite direction may represent only one or two observations. So, for the prevailing directions the mean speeds are quite trustworthy but for the infrequently observed directions they may be misleading.

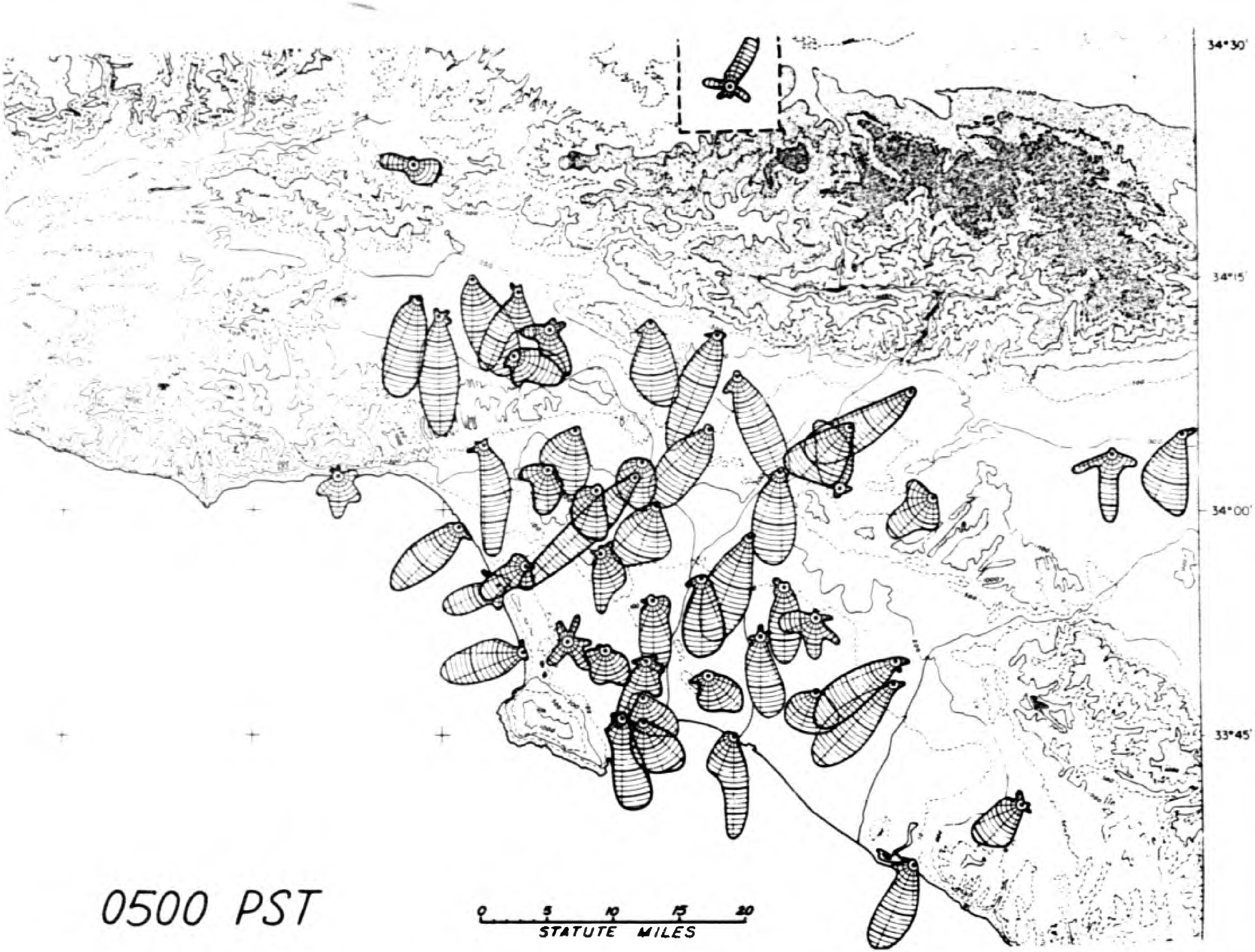
The most conspicuous feature of these maps is the previously mentioned tendency for stronger winds during the daylight hours. They also indicate that most stations in the wind shadow do occasionally get a gust from the north or northeast, even in the mid-afternoon, and when they do it is usually a stronger wind than average. The most asymmetrical distribution of wind speeds around the compass occur downwind of the major passes. This effect shows even as far downwind as the Palos Verdes peninsula where the occasional strong easterly occurs. Cajon Pass' jet is extended that far.

The combination of the amoeba maps and these mean speed overlays provide an easy reference for answers to questions about probable wind directions and mean speeds for all parts of the basin and all times of the day. They summarize the statistics for surface air motion during Santa Ana conditions. But they define no real wind situation. All these features of the flow pattern that we have discussed are simplified approximations to the real flow. To discover the patterns that the real flow takes as the air moves across the basin we must analyze individual (not mean) data, hour by hour, day by day. And in the next chapter we do this; thereby setting the stage for the comparison of the composite picture of the Santa Ana developed in this chapter with the real facts of surface flow as they occur in the greater Los Angeles area.

FIG. 12. (overlay) Mean wind speed as a function of direction for 0500 PST. 2 mph per scale division. Direction of flow given by direction of shaft from center outward.

FIG. 13. (underlay) Percent frequency of wind direction for 0500 PST. 2% per scale division.

BLANK PAGE



0500 PST

FIG. 14. (overlay) Mean wind speed as a function of direction for 0700 PST. 2 mph per scale division. Direction of flow given by direction of shaft from center outward.

FIG. 15. (underlay) Percent frequency of wind direction for 0700 PST. 2% per scale division.

BLANK PAGE

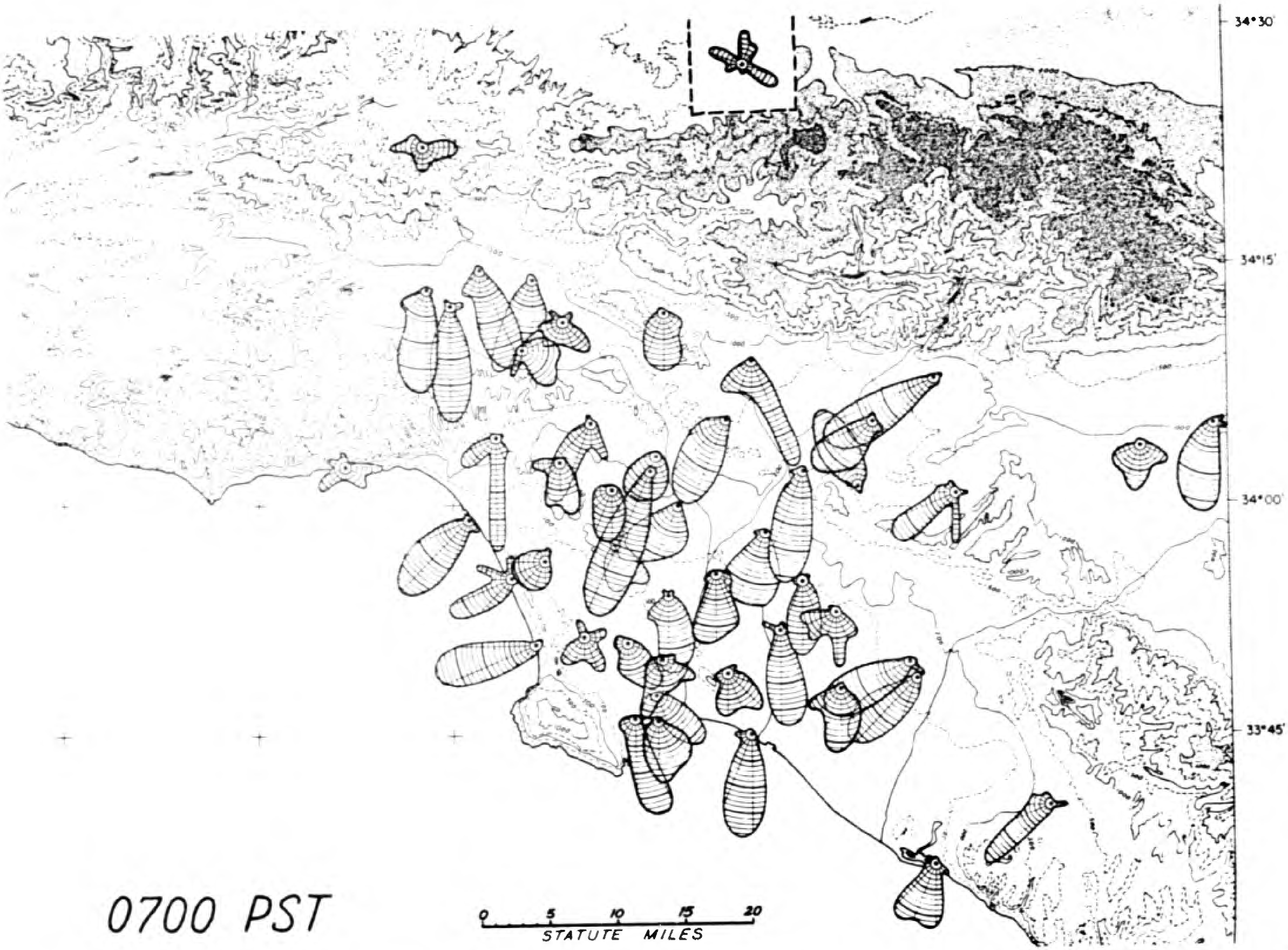

0700 PST

FIG. 16. (overlay) Mean wind speed as a function of direction for 0900 PST. 2 mph per scale division. Direction of flow given by direction of shaft from center outward.

FIG. 17. (underlay) Percent frequency of wind direction for 0900 PST. 2% per scale division.

BLANK PAGE

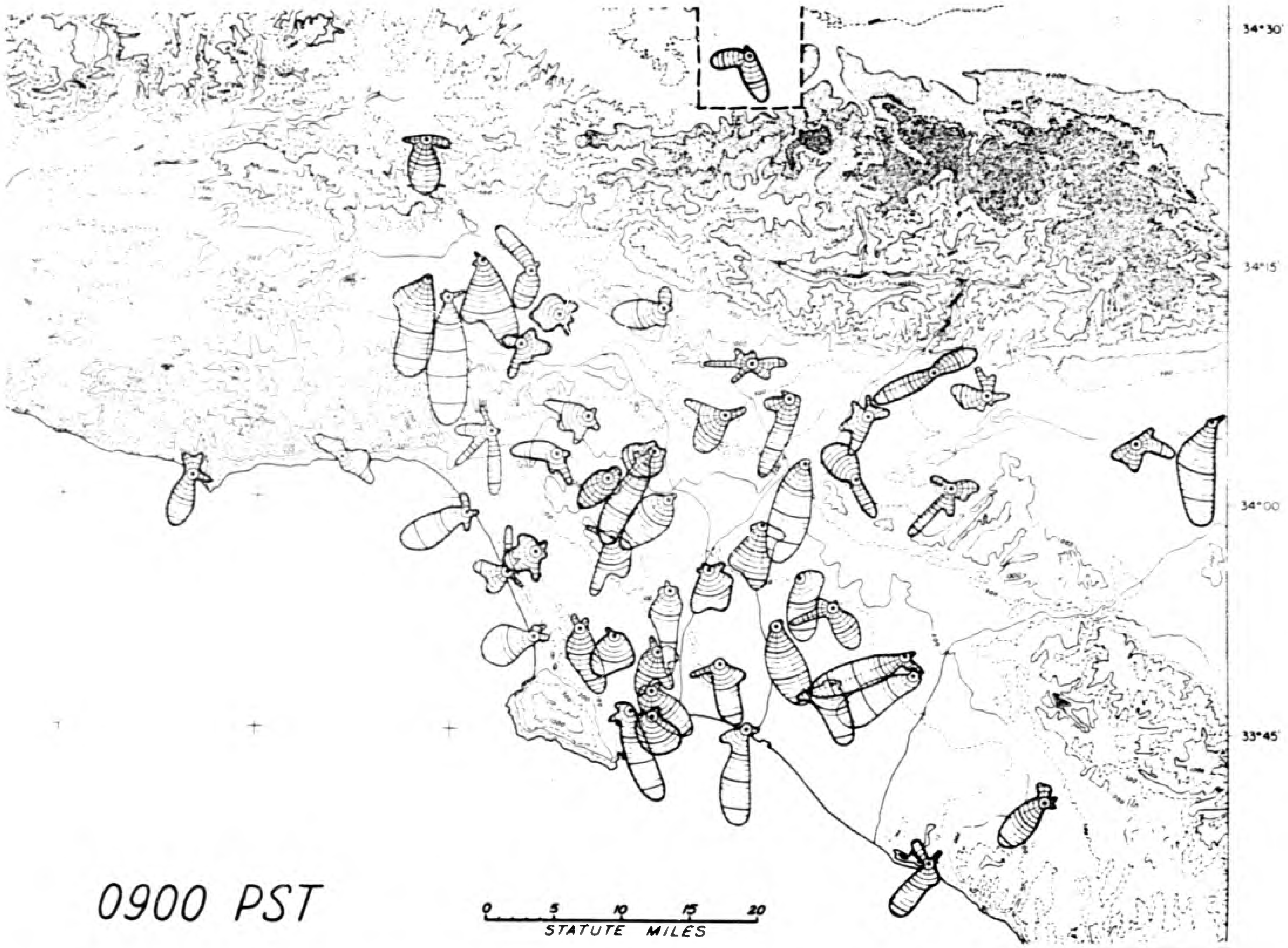
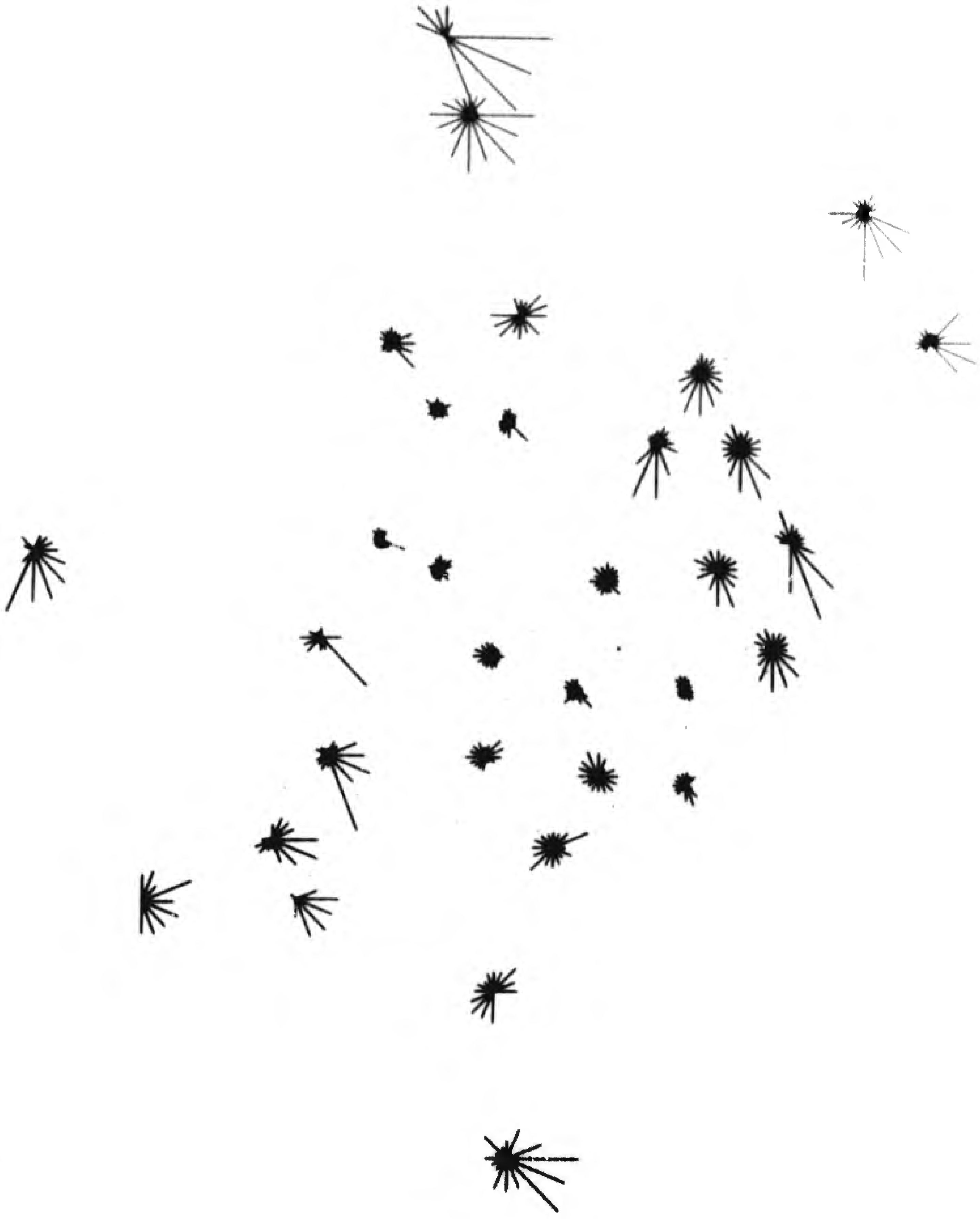
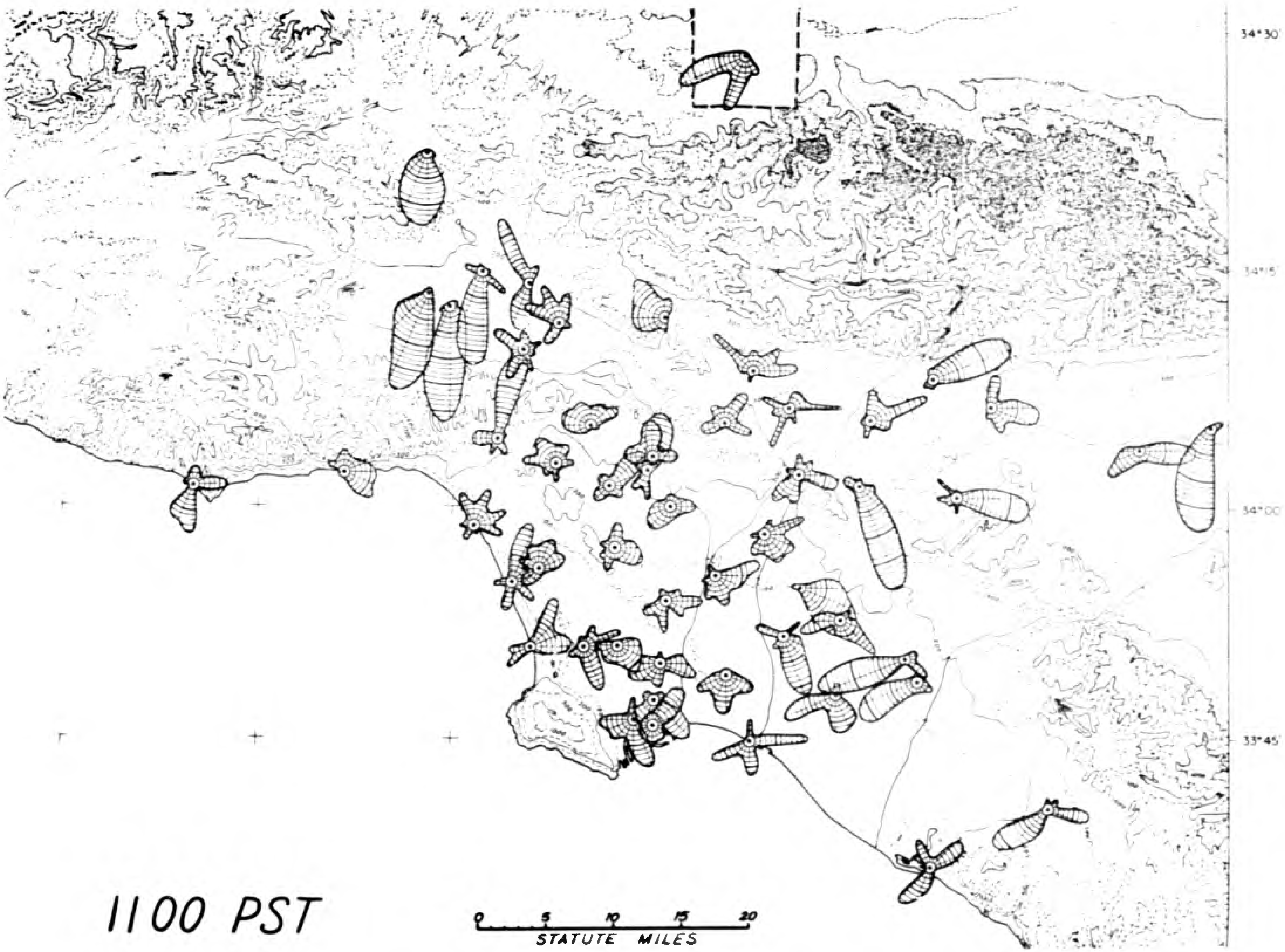

0900 PST
0
5
10
15
20
STATUTE MILES
34°30'
34°15'
34°00'
33°45'

FIG. 18. (overlay) Mean wind speed as a function of direction for 1100 PST. 2 mph per scale division. Direction of flow given by direction of shaft from center outward.

FIG. 19. (underlay) Percent frequency of wind direction for 1100 PST. 2% per scale division.



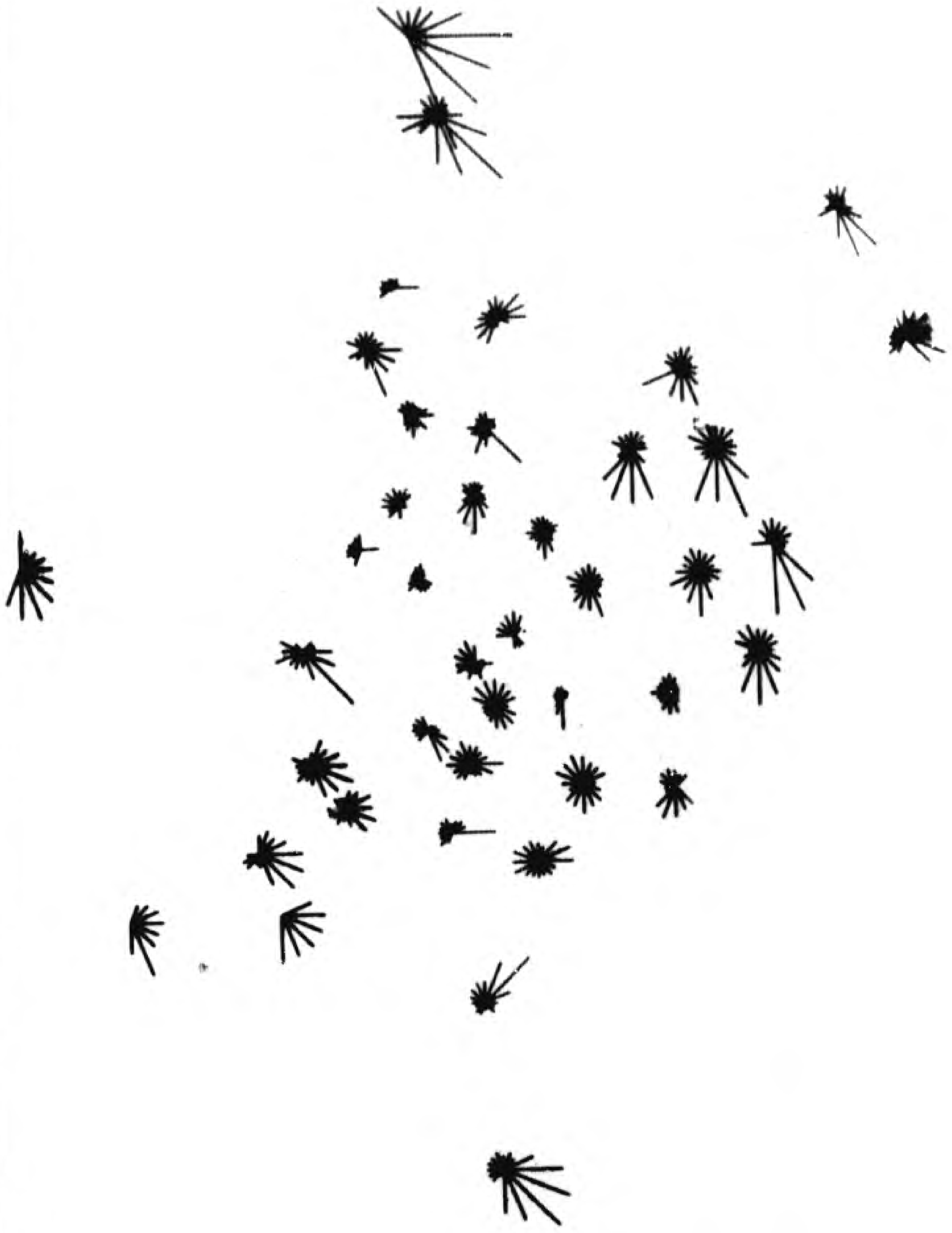
BLANK PAGE



1100 PST

FIG. 20. (overlay) Mean wind speed as a function of direction for 1300 PST. 2 mph per scale division. Direction of flow given by direction of shaft from center outward.

FIG. 21. (underlay) Percent frequency of wind direction for 1300 PST. 2% per scale division.



BLANK PAGE

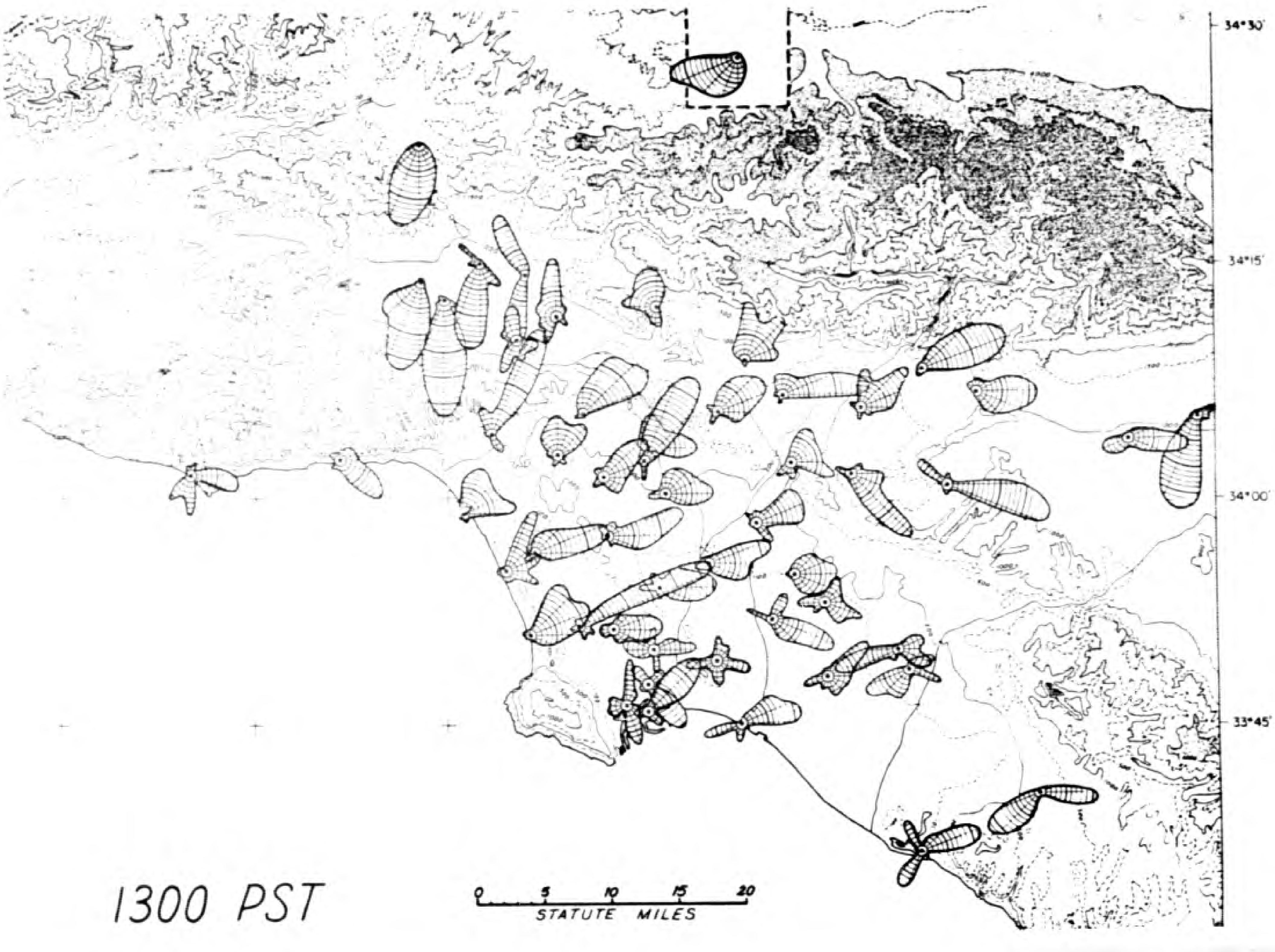
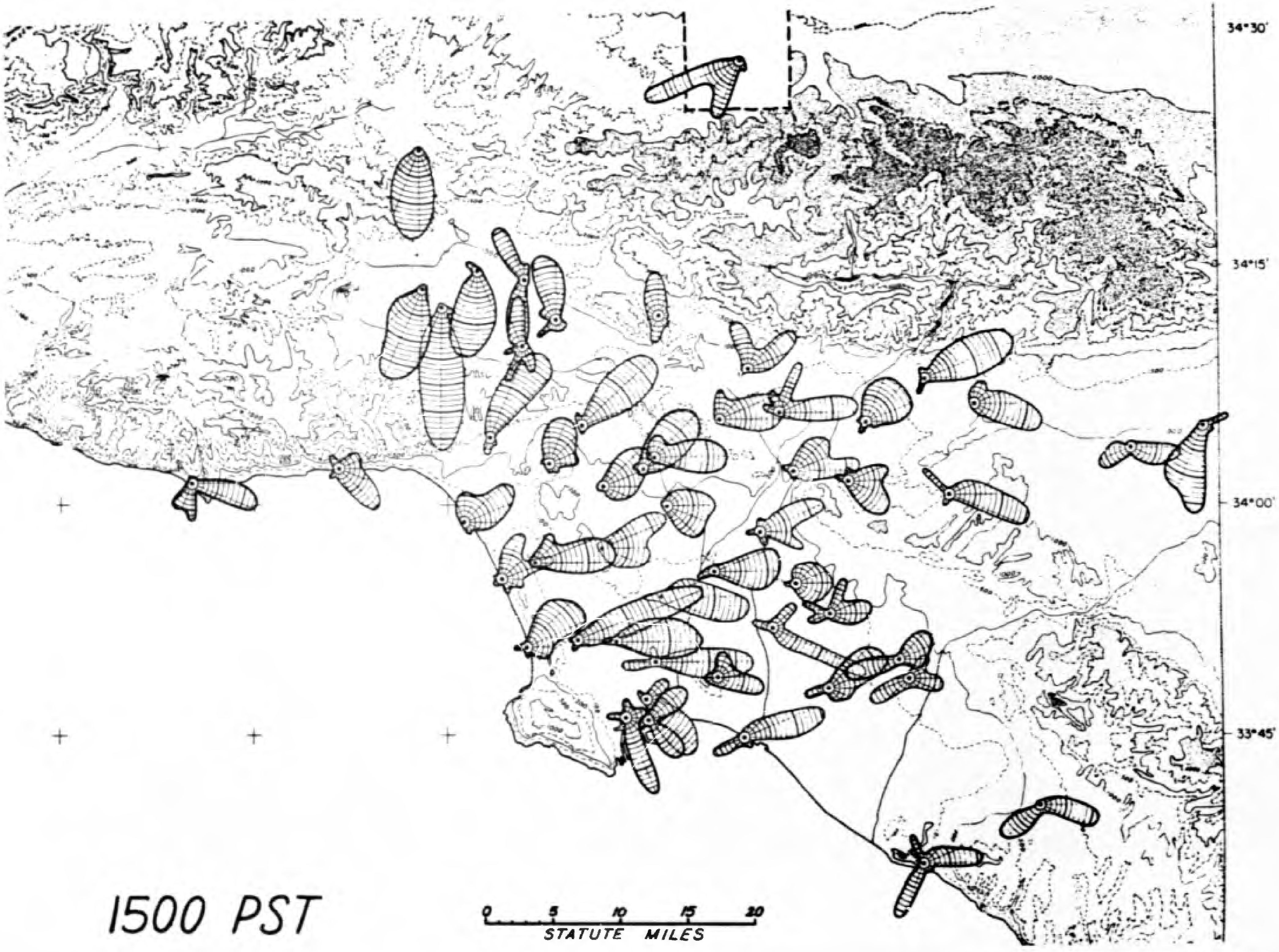

34°30'
34°15'
34°00'
33°45'
0
5
10
15
20
STATUTE MILES
1300 PST

FIG. 22. (overlay) Mean wind speed as a function of direction for 1500 PST. 2 mph per scale division. Direction of flow given by direction of shaft from center outward.

FIG. 23. (underlay) Percent frequency of wind direction for 1500 PST. 2% per scale division.



1500 PST

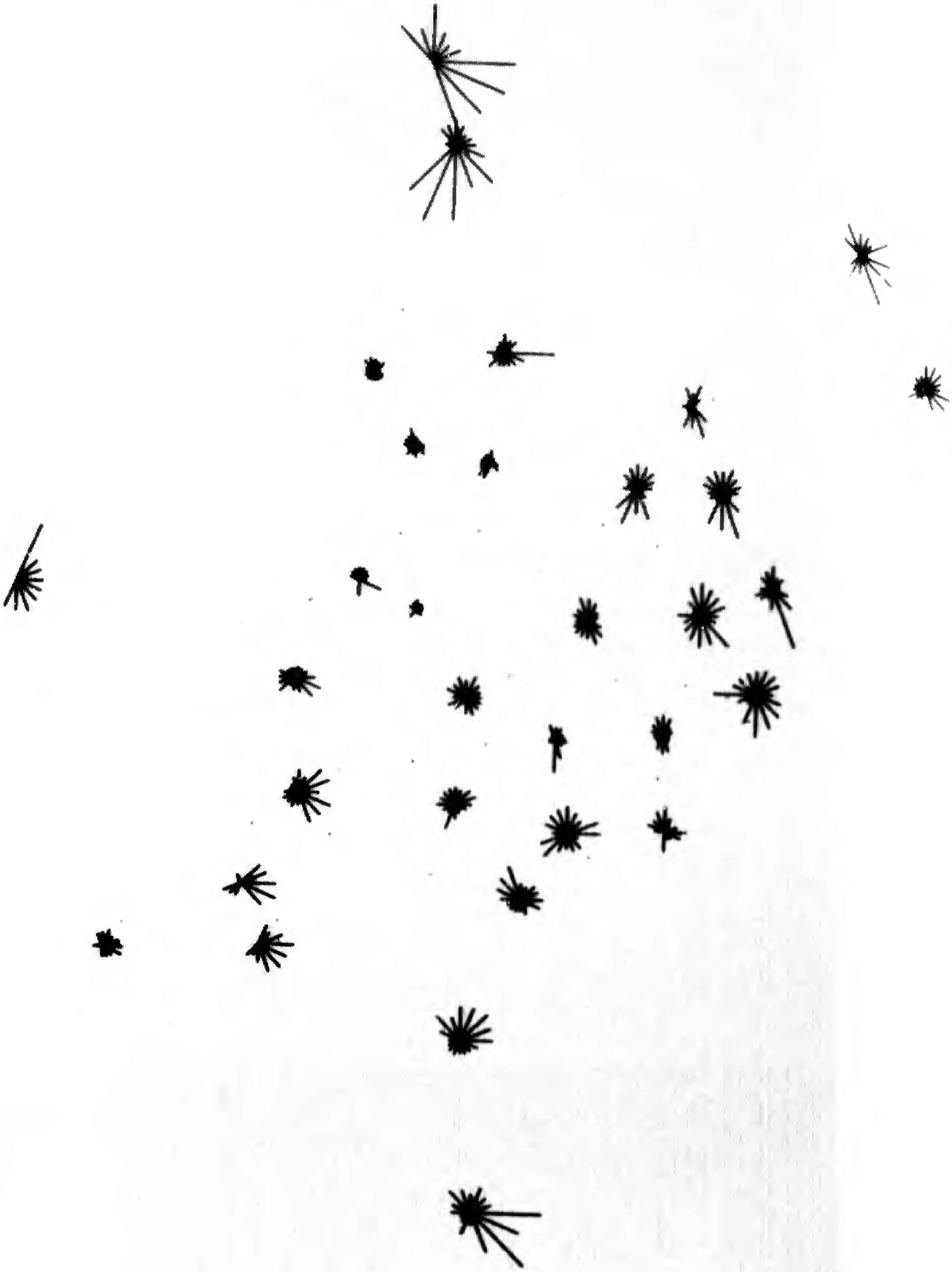


FIG. 24. (overlay) Mean wind speed as a function of direction for 1700 PST. 2 mph per scale division. Direction of flow given by direction of shaft from center outward.

FIG. 25. (underlay) Percent frequency of wind direction for 1700 PST. 2% per scale division.

BLANK PAGE

BLANK PAGE

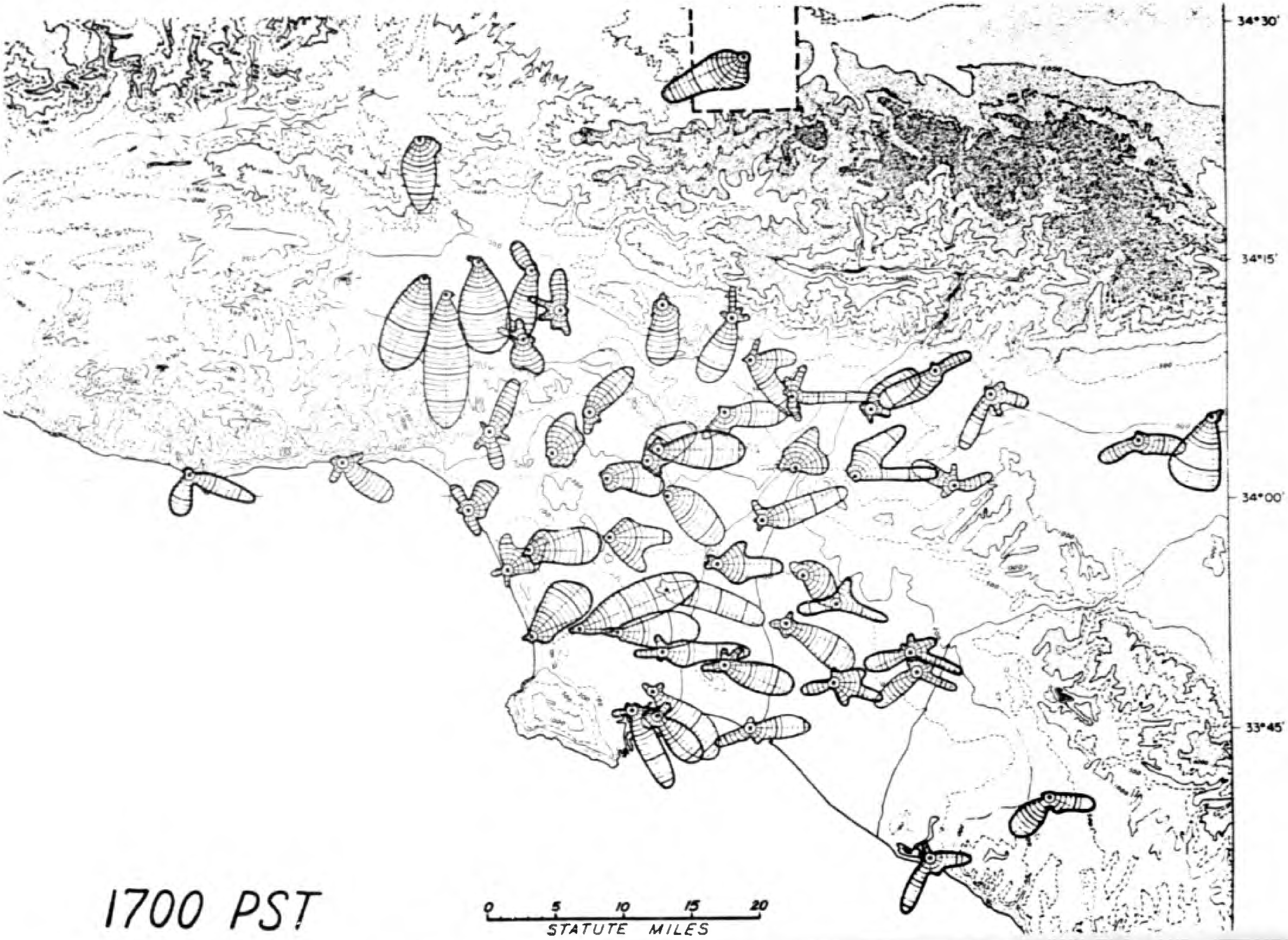
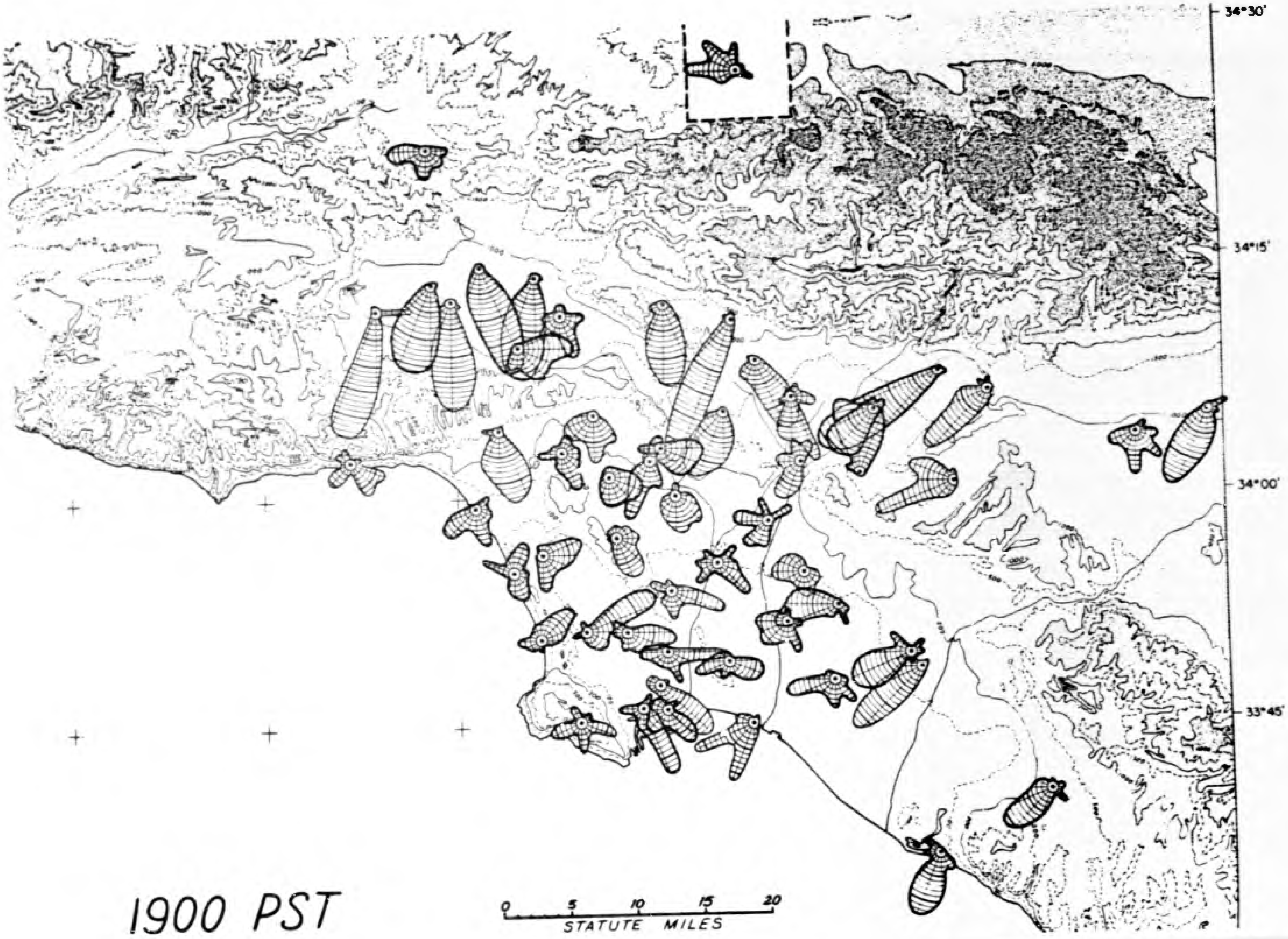

1700 PST
0
5
10
15
20
STATUTE MILES
34°30'
34°15'
34°00'
33°45'

FIG. 26. (overlay) Mean wind speed as a function of direction for 1900 PST. 2 mph per scale division. Direction of flow given by direction of shaft from center outward.

FIG. 27. (underlay) Percent frequency of wind direction for 1900 PST. 2% per scale division.

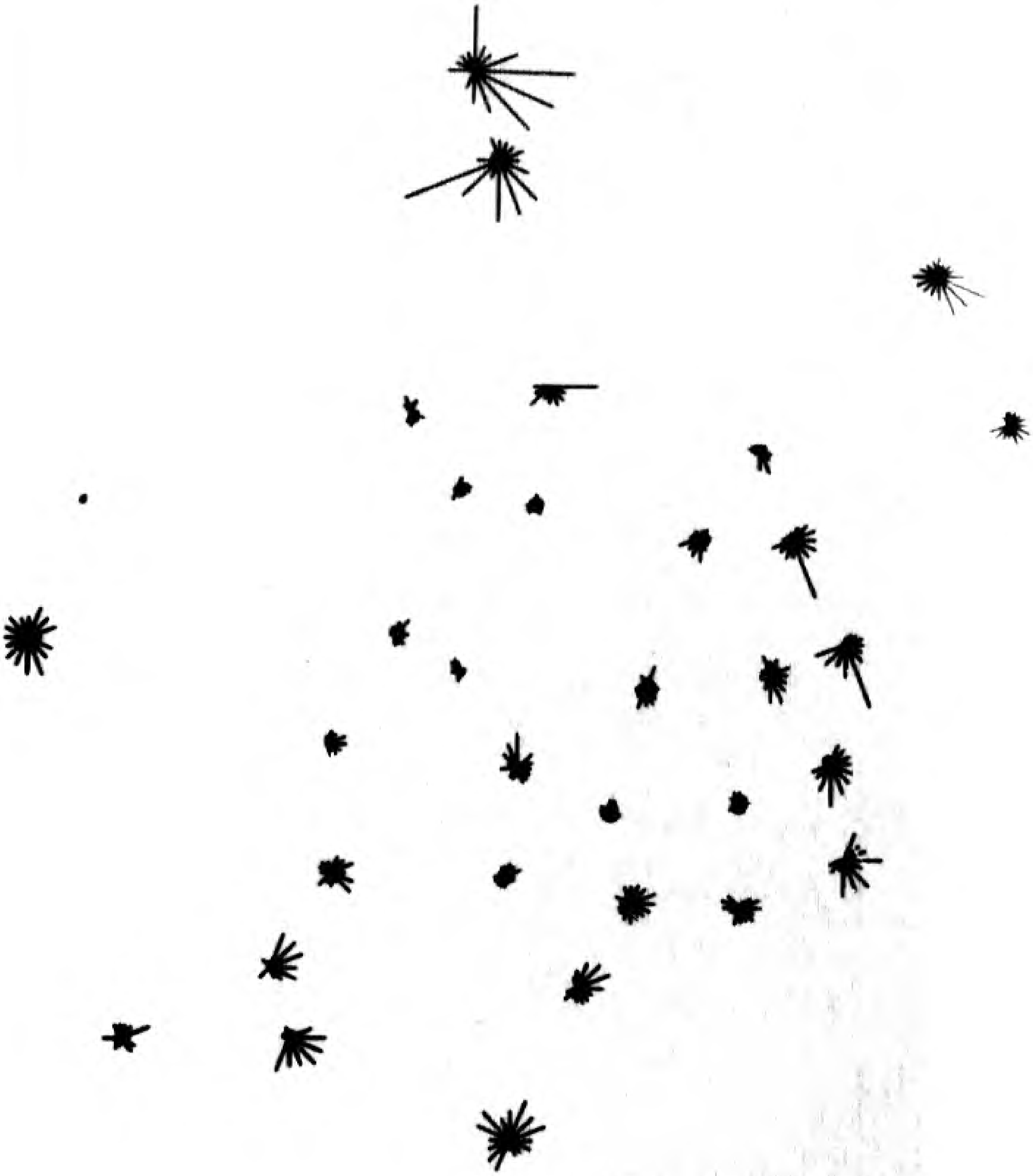
BLANK PAGE



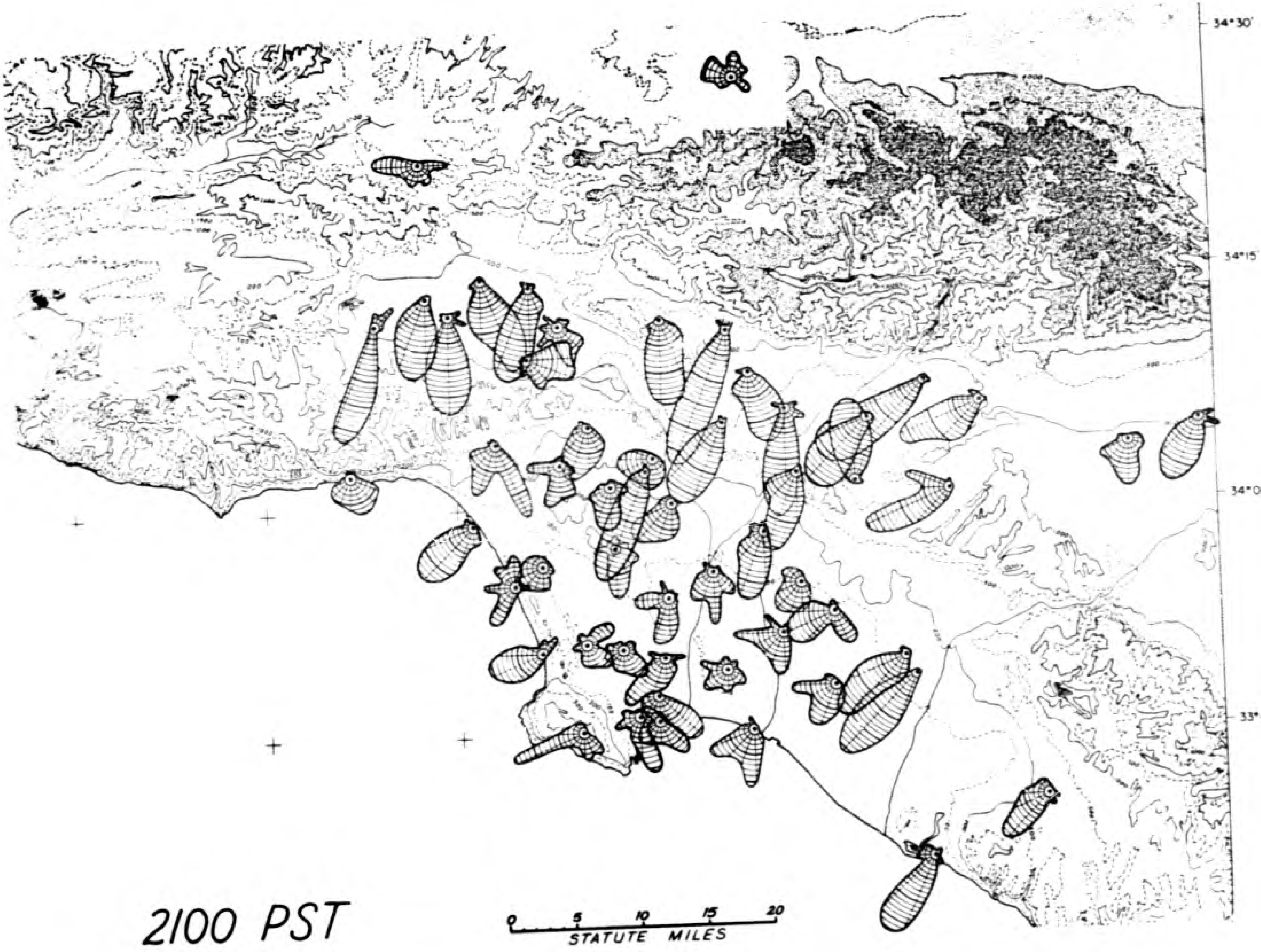
1900 PST

FIG. 28. (overlay) Mean wind speed as a function of direction for 2100 PST. 2 mph per scale division. Direction of flow given by direction of shaft from center outward.

FIG. 29. (underlay) Percent frequency of wind direction for 2100 PST. 2% per scale division.



BLANK PAGE


34°30'
34°15'
34°00'
33°45'
2100 PST
0
5
10
15
20
STATUTE MILES

CHAPTER IV

INDIVIDUAL CASE STUDIES

In the previous chapter we have developed a relatively simple conception of the Santa Ana surface flow across the greater Los Angeles area. We recognize that by invoking a statistical treatment of a large number of foehn occurrences we have smoothed out and lost many of the details and much that is transcient in the flow pattern. The purpose of this chapter is to discover some of these details by examining three separate Santa Ana situations: Feb. 1 and 2, 1956, Nov. 21 and 22, 1957, and Nov. 4, 5, 6, and 7, 1961. The last of these was the occasion of the notorious Bel-Air fire that destroyed so many homes on the south slopes of the Santa Monica mountains.

Streamline maps are constructed for each hour of the eight days comprising the three cases. Although more than 200 maps were constructed, only 12 will be reproduced here as typical examples of actual flow patterns. A detailed description of the analysis, including the complete file of maps, is described in an interim report by Roger A. Helvey entitled, "Some Analysis of Surface Air Flow in the Los Angeles Basin".

A quick glance at the 12 selected maps, figures 30 through 35 and 38 through 43, reveal that the large-scale features of the flow described by the statistical analysis are evident on almost every map. To be sure, some embroidery is added and the general configuration is sometimes deformed, but these added effects fail to camouflage those familiar features of the mean pattern, the wind shadow and its two companions, the strong currents on its flanks.

The first six of these maps, figures 30 through 35, are selected as examples of the completely off-shore type of flow, typical of the night-time and cooler daytime hours, when the wind shadow shows only reduced speeds but no organized reverse flow.

Figure 30 shows a shadow filled with a number of separate swirls and eddies. It is an early evening map, 1900 PST. It is possible that some remnants of the sea breeze may be contributing to the mild chaos, but the predominant flow is from the mountains toward the sea. The next chart, also a 1900 PST map, on the other hand, shows a much more ordered wind shadow comprised almost exclusively of northeast winds sweeping from the San Gabriels all the way down to the western beaches. Only a small area west of downtown Los Angeles is in a reversed flow. As in the previous case we might have here a last remnant of the sea breeze. In this case winds on both flanks of the San Gabriels are unusually strong exceeding 50 mph and having a strong easterly component. The stream of strong winds from the Cajon Pass extends all the way to the Palos Verdes peninsula where 22 mph winds are reported.

Figure 32, a late evening map, 2300 PST, shows another fairly strong Santa Ana case, and it reveals yet another kind of pattern within the wake of the San Gabriels. The strong current through Cajon Pass has its maximum extension, loops completely around the basin on the south and confronts the San Fernando northerlies head-on along the south side of the Santa Monicas. The wind shadow behind the San Gabriels is basically a weak northerly but with several separate eddies contained within it.

As an example of an early morning map, we move now to a 0500 PST case, figure 33. Here is an example in which the two strong currents bracketing the San Gabriel mountains are of almost identical strength. The wind shadow, though basically consisting of weak northerlies, contains one large eddy which covers the area all the way from downtown Los Angeles to the Palos Verdes peninsula.

The next illustration shows one of the simplest of the flow patterns observed, figure 34. It portrays the flow at the time of sunrise, 0700 PST. The wind shadow is a well-ordered flow from the San Gabriel mountains to the sea with no eddying motion in evidence. The flow diverges upwind of the Palos Verdes peninsula, one stream moving across the western beaches the other across the southern. The jets around the flanks of the San Gabriel are well developed and curve in behind the mountains to narrow down the wind shadow at mid-basin to provide it with a shape best described as "hour-glass".

Figure 35, the last of this series of maps exemplifying cases where the wind shadow is participating in the off-shore flow, is notable because it, unlike any of the other 5 maps, has strong winds coming down off the lee slopes of the San Gabriels as well as around its eastern and western extremities. Thus the wind shadow appears as an area completely detached from the San Gabriel mountains. The line of separation between the northerlies over the ridges and the weak winds in the shadow usually does not appear on our maps. Presumably it occurs somewhere between the ridge line and the base of the mountains, an area where no data exists to betray its existence.

This line of separation probably has a marked diurnal oscillation as well as variations from one Santa Ana case to the next. This case represents one extreme where the strong northeasterlies scour out the entire lee face of the mountains including the first five or ten miles of adjacent flat terrain. Figure 36 is a schematic sketch of postulated flow patterns in a vertical cross-section normal to the mountains, patterns that have different points of separation between strong northerlies and the wind shadow. The lack of data in this area is particularly unfortunate since an understanding of the behavior of this line of separation between extremely hazardous ridge winds and the less dangerous winds in the lee shadow would be of great significance to fire fighters. The experiences of fire fighters on these slopes as well as of residents of the area indicate the strong winds frequently invade the slopes. These cases studied here seem to indicate, however, that it is unusual for them to cover the entire slope and proceed out onto the valley floor.

It is not easy to leave this rather elegant surface streamline pattern of 1000 PST, Nov. 21, 1957, without inferring something about the vertical component of the flow, particularly in the wind shadow. If we move from southeast to northwest along a line just on shore we first encounter a line of convergence at the southeast boundary of the wind shadow, then a line of divergence exactly in the center of the lee shadow, and finally another convergence line at its northwest boundary. This implies rising air at the boundaries and sinking air in the middle, the sort of pattern that a vortex pair with horizontal axes stretching out downwind of the San Gabriels would provide. The schematic sketch in figure 37 attempts a visualization of such a 3-dimensional wind pattern.

The consideration of these six actual cases has demonstrated that the weak northerly flow in the wind shadow during the nighttime and early morning hours can take on a variety of patterns, some simple, some complex. Very few of them would be confused with ordinary drainage winds that occur on most non-foehn clear nights. The normal nocturnal drainage winds are much weaker and much more under the influence of the terrain within the basin.

We now turn to a consideration of 6 case studies involving the reverse flow in the wind shadow, figures 38 through 43. This reverse flow also takes on many forms, these bearing varying degrees of resemblance to the conventional daytime sea breeze. The first map, figure 38, a noon situation, really classifies as a transition

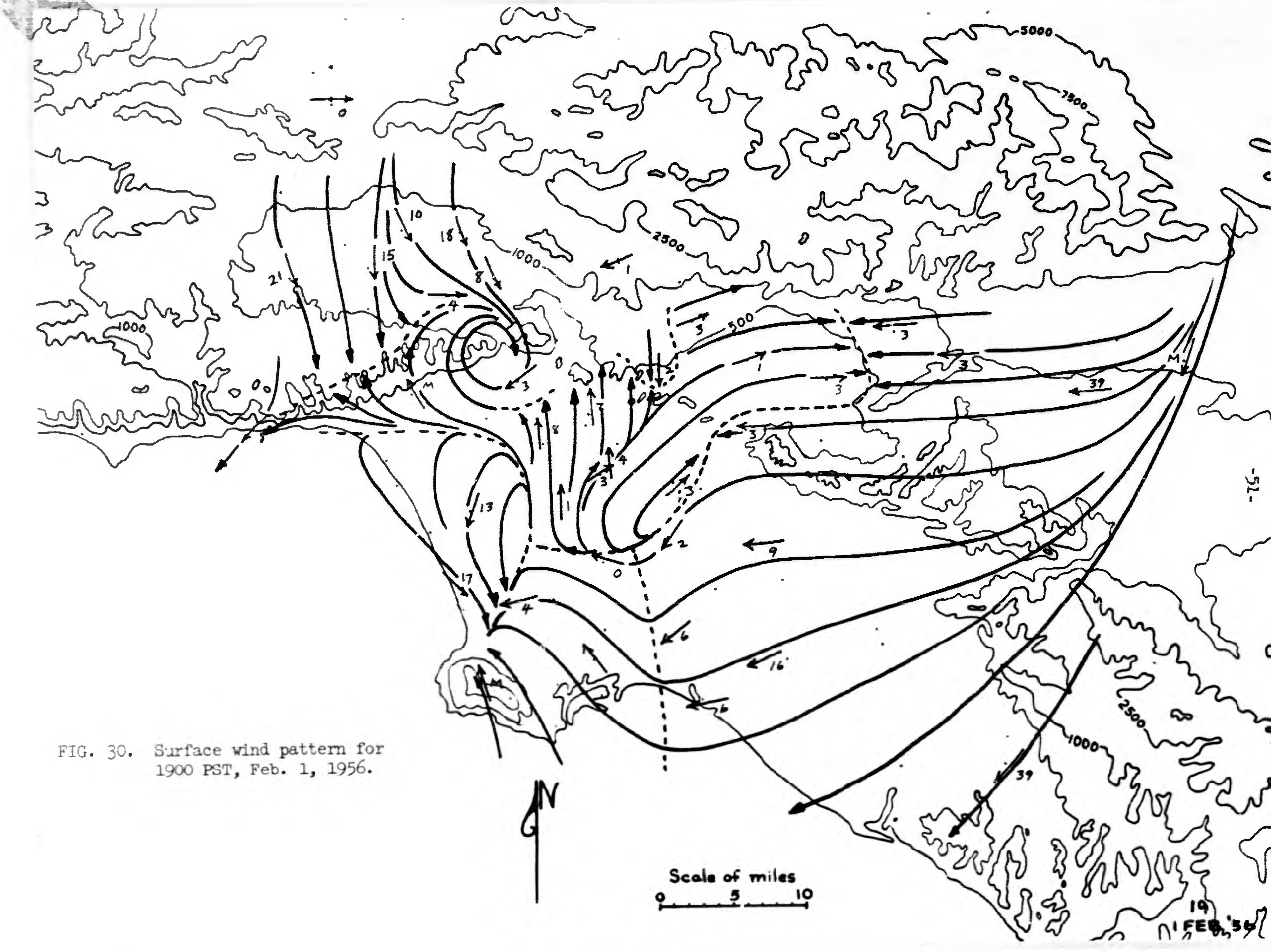


FIG. 30. Surface wind pattern for 1900 PST, Feb. 1, 1956.

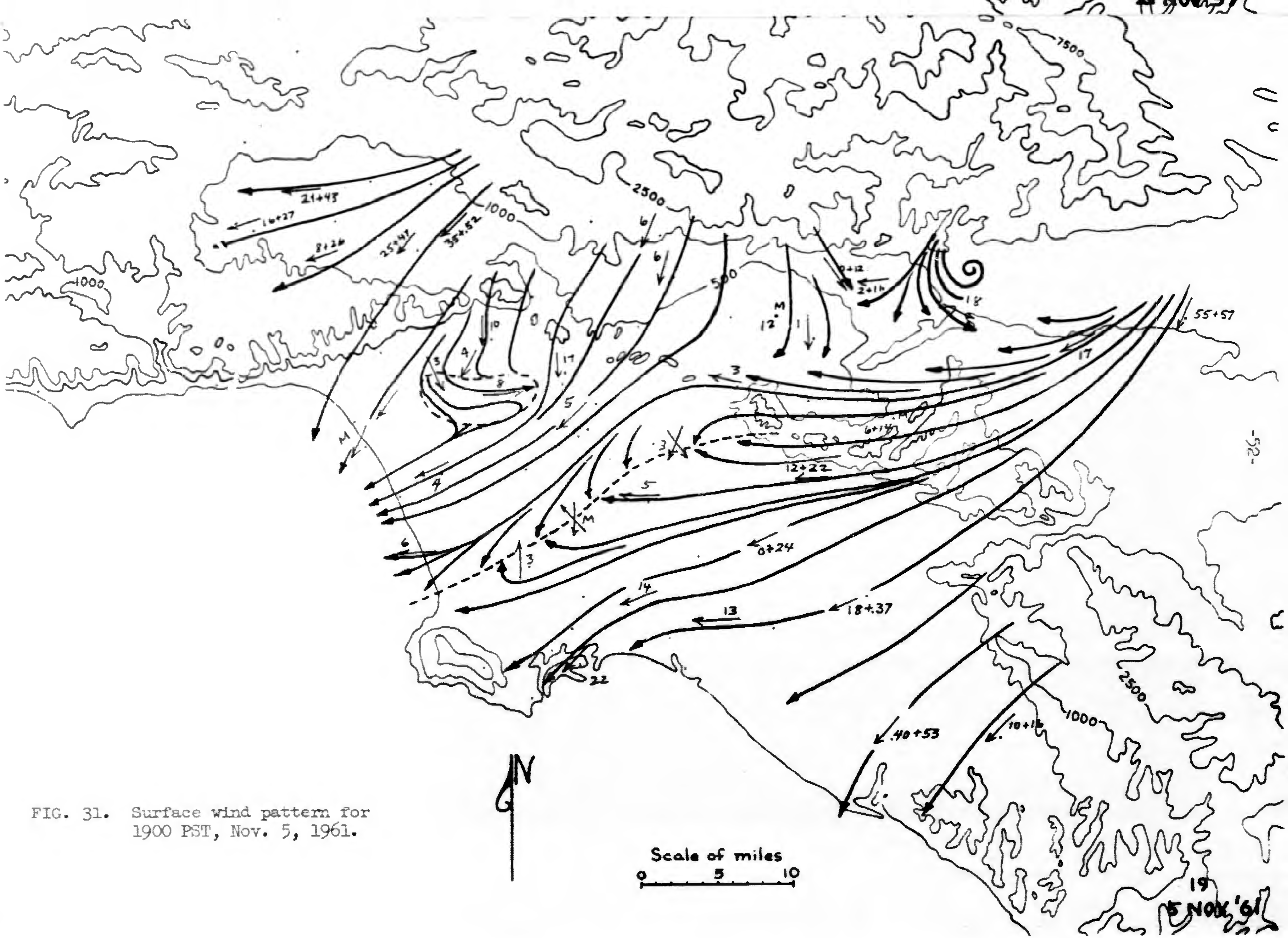


FIG. 31. Surface wind pattern for 1900 PST, Nov. 5, 1961.

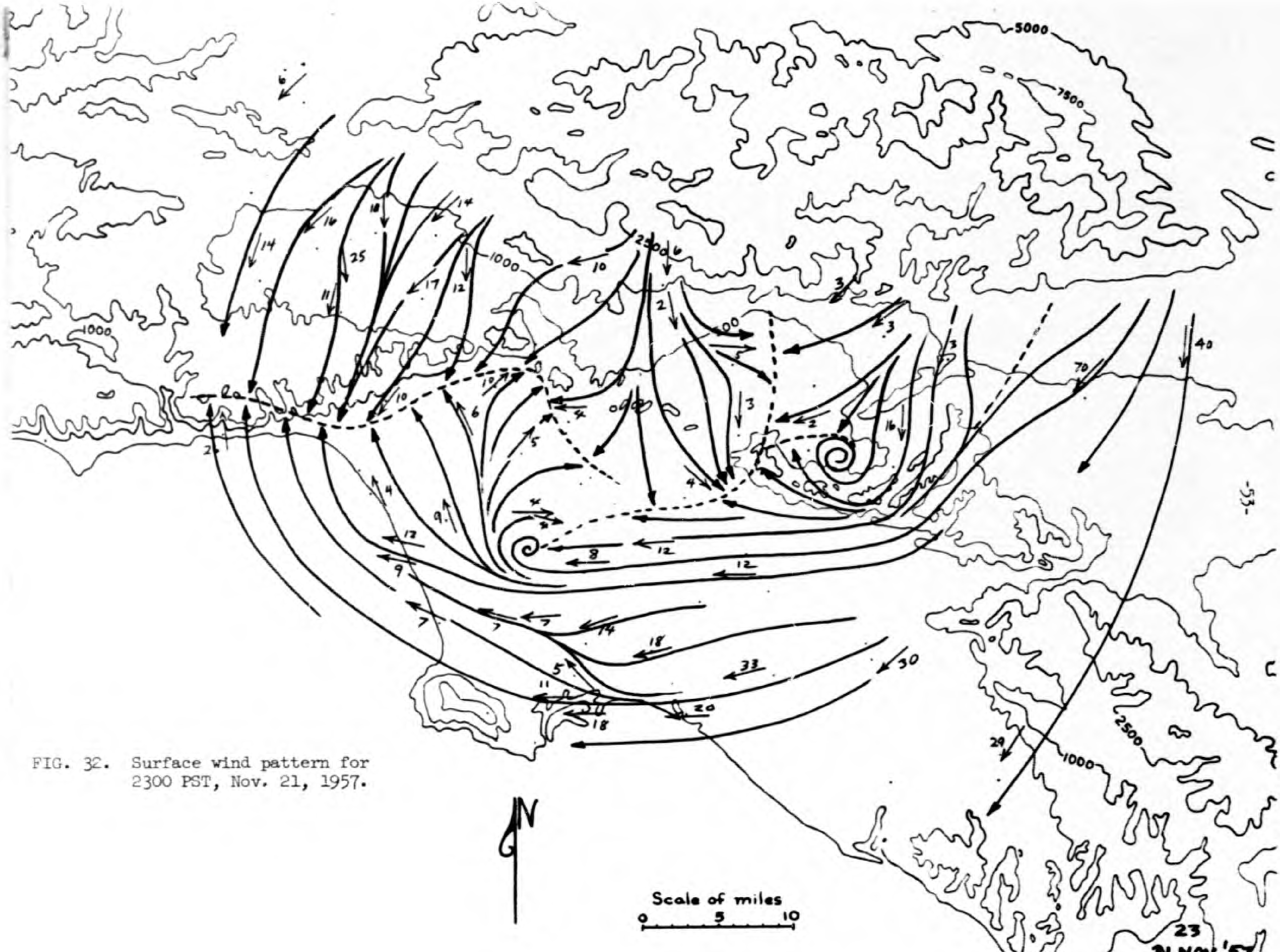


FIG. 32. Surface wind pattern for 2300 PST, Nov. 21, 1957.

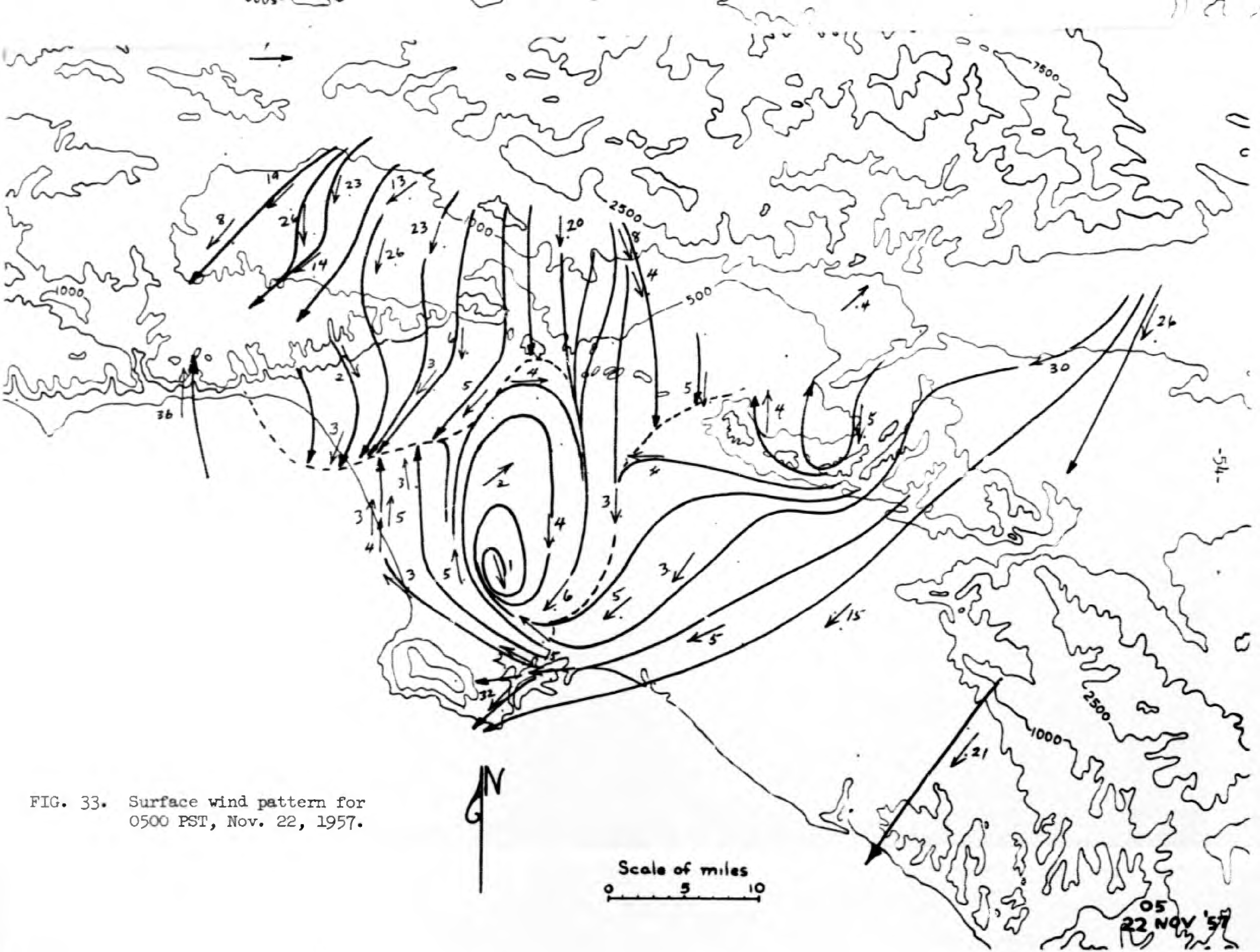


FIG. 33. Surface wind pattern for 0500 PST, Nov. 22, 1957.

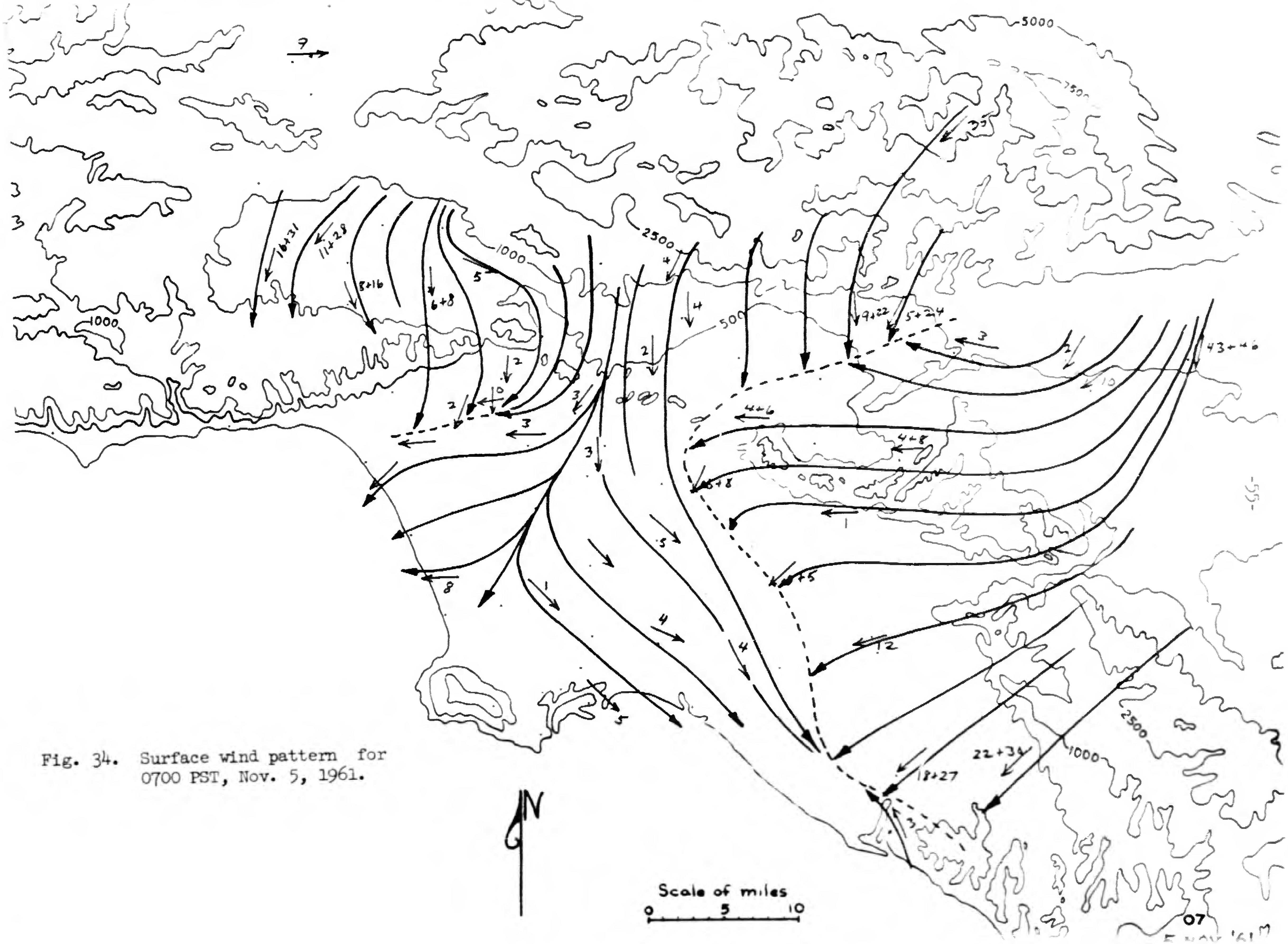


Fig. 34. Surface wind pattern for 0700 PST, Nov. 5, 1961.

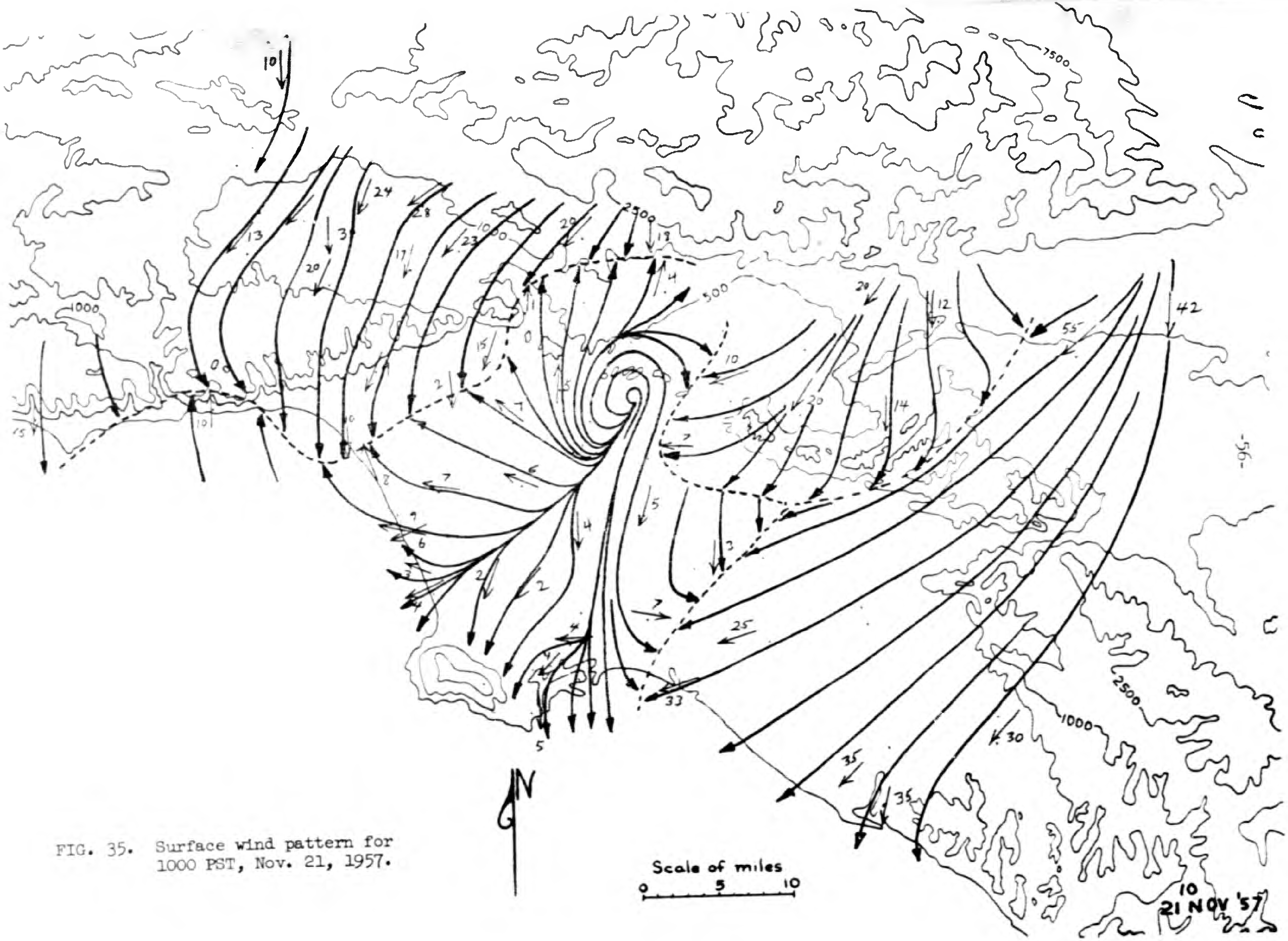


FIG. 35. Surface wind pattern for 1000 PST, Nov. 21, 1957.

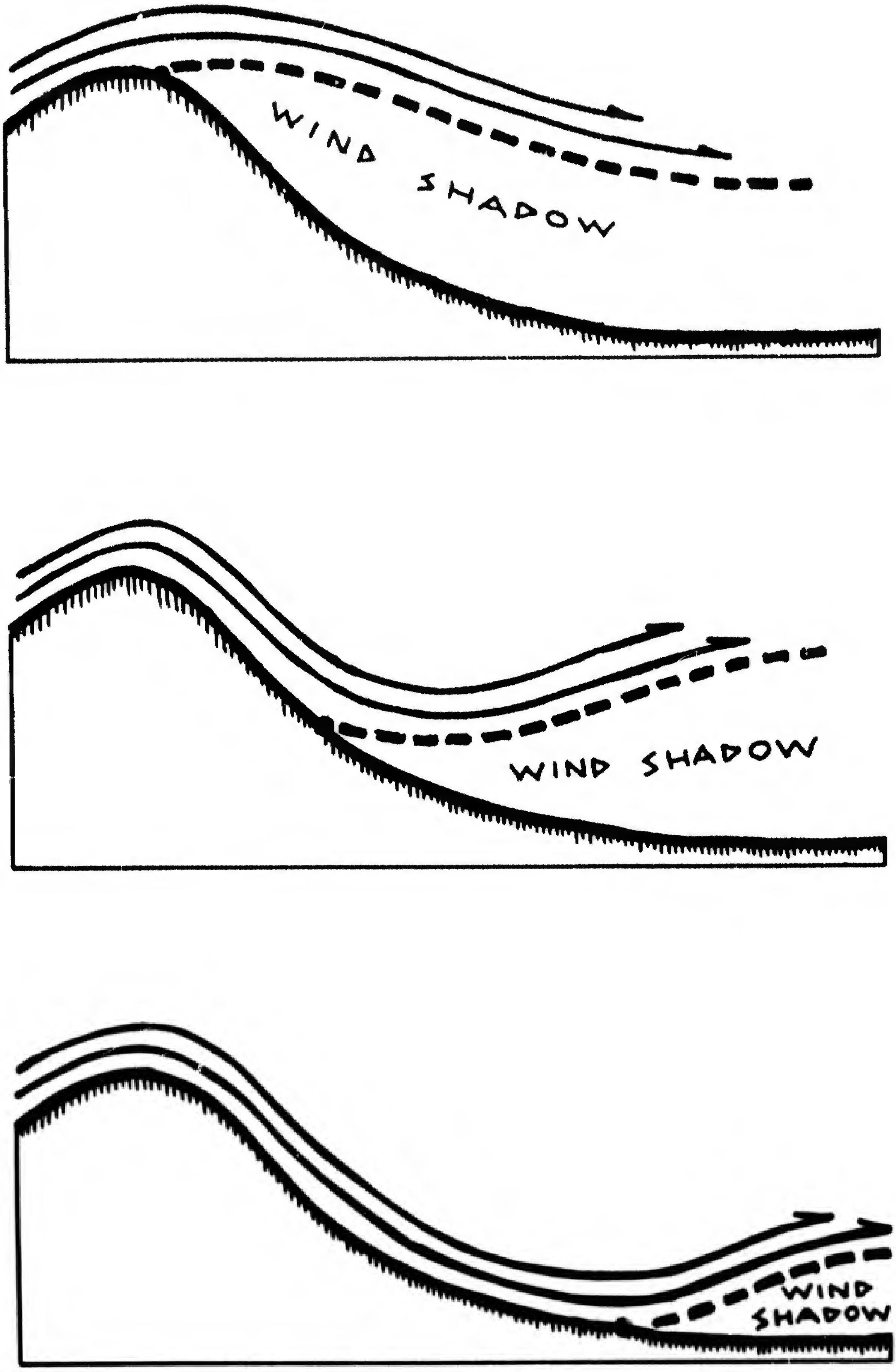


FIG. 36. Schematic of possible flow over the San Gabriels in a vertical cross-section.

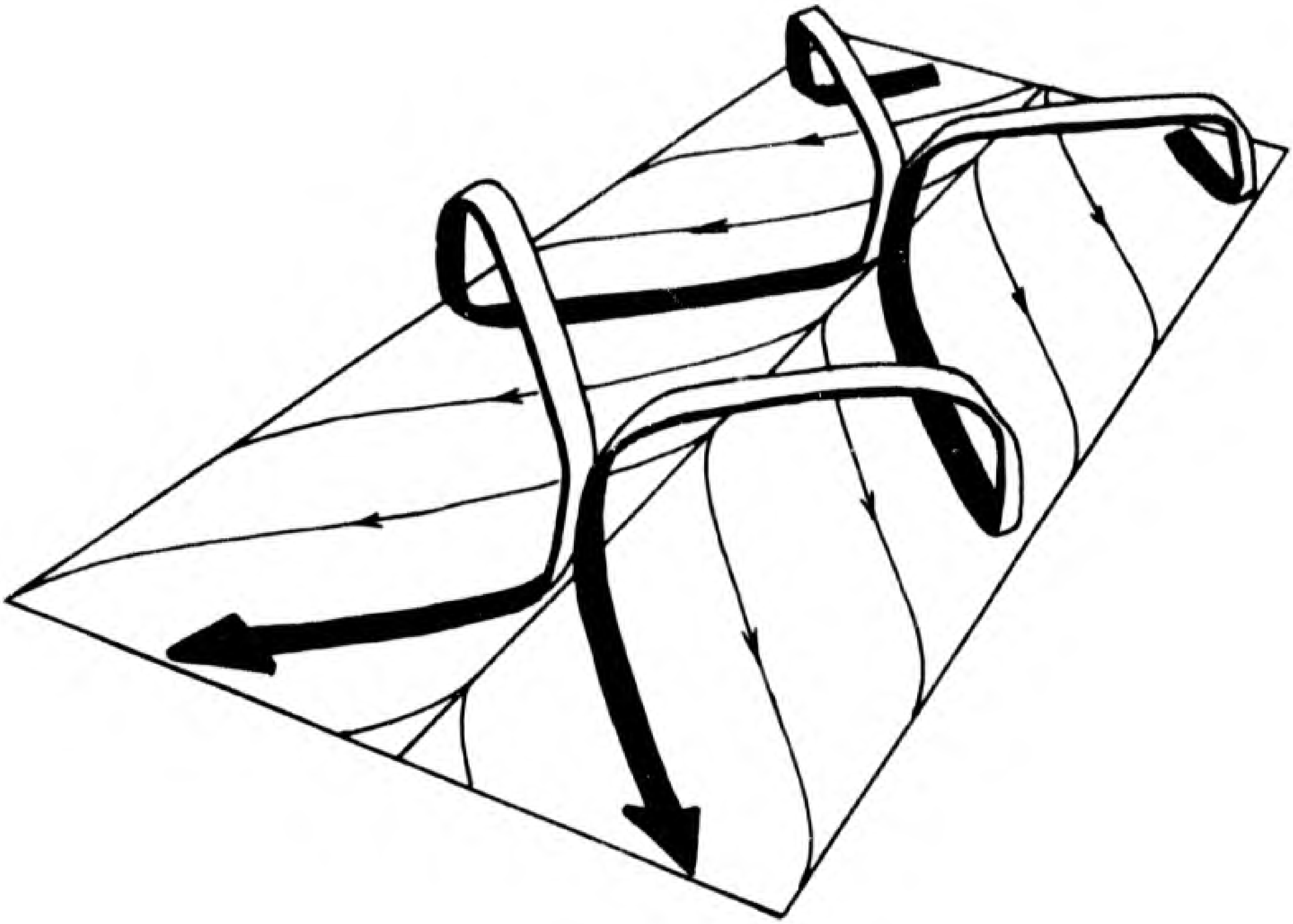


FIG. 37. Vortex pair with horizontal axes parallel to general flow.

map. The reverse flow is just beginning, appears at only one station along the western beaches. Actually this map is for the same day as the last map discussed, the one with the strong winds all the way down the lee slopes of the San Gabriels and with the vortex pair stretching off downwind. In the two hour interval between the maps the wind shadow is practically eliminated as the strong flow around each end of the mountains converges to meet in mid-basin. Perhaps the small pocket of weak winds in the downtown area is the last remnant of the previous wind shadow. This map represents the closest approach to the complete absence of a wind shadow that was encountered.

Two hours later on the same day, figure 39, a corridor of reverse flow, ten miles wide, has developed; one which extends all the way from the western beaches to the foothills back of downtown Los Angeles, an interesting demonstration of the rate at which the flow pattern can change in the lee of the mountains.

The next three maps, figures 40, 41, and 42, complete the spectrum of reverse flow corridor sizes and configurations. Figure 40 illustrates a case where an unusually extensive jet around the west end of the San Gabriels teams up with the usual jet extending from Cajon Pass to the southern beaches to confine the reverse flow to a narrow corridor, only 10 miles wide, having a rather unusual orientation, south to north from southern beaches to mountain slopes.

Figure 41 shows a somewhat wider area of return flow, 15 to 20 miles across, that has the usual southwest-northeast orientation and stops just short of the San Gabriels where it encounters the strong northerlies that in this case have proceeded all the way down the slopes and half the way across the San Gabriel Valley. This very dangerous fire weather situation represents the conditions just 17 hours before the onset of the Bel-Air fire.

Figure 42 was chosen as the pattern with the most extensive return flow. Except for its termination short of the Cajon Pass and the northern part of the San Fernando Valley, it has the appearance of the standard, non-foehn, sea breeze map. The characteristic convergence line inland of Palos Verdes, the southeasterly flow from downtown Los Angeles up into the mouth of San Fernando Valley, the westerly current from the San Gabriel Valley into the Riverside - San Bernardino Valley - all these features are hallmarks of the typical summer sea breeze. Only the lower wind speeds in the basin, together with the northerly currents through the passes, set it apart.

To complete the gallery of individual flow patterns another map with interesting implications concerning the vertical component of the flow is presented. Figure 43 shows another very expansive wind shadow, a noon-time sea breeze that covers most of the basin. It is the lines of convergence and divergence parallel to the mountains that betray the existence of vertical motions organized along the same lines. They suggest a long vortex, its axis horizontal, parallel to and in the lee of the mountains. The inset in figure 43 shows a sketch of a vertical cross-section normal to the sea breeze just inland of the western beaches and extending northwest across the Santa Monica mountains. Such a section intersects first a line of convergence, then one of divergence, and finally another line of convergence atop the Santa Monica mountains. The existence of this vortex in the lee of the mountains is, of course, inferred, but, if real, serves to isolate the lee slopes of the mountains from the strong northerlies; thus providing, at this moment at least, a reduction in the fire hazard.

BLANK PAGE

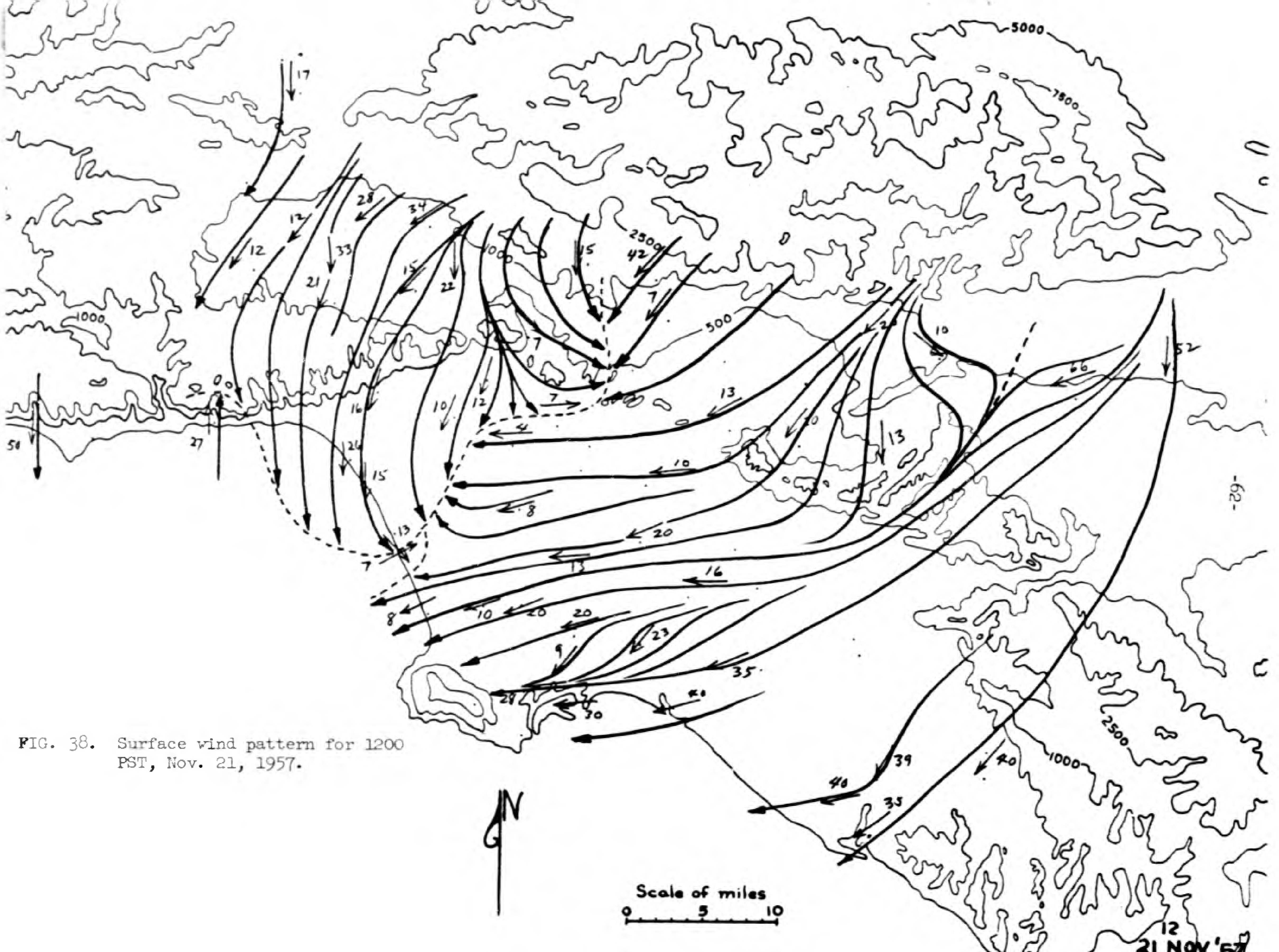


FIG. 38. Surface wind pattern for 1200 PST, Nov. 21, 1957.

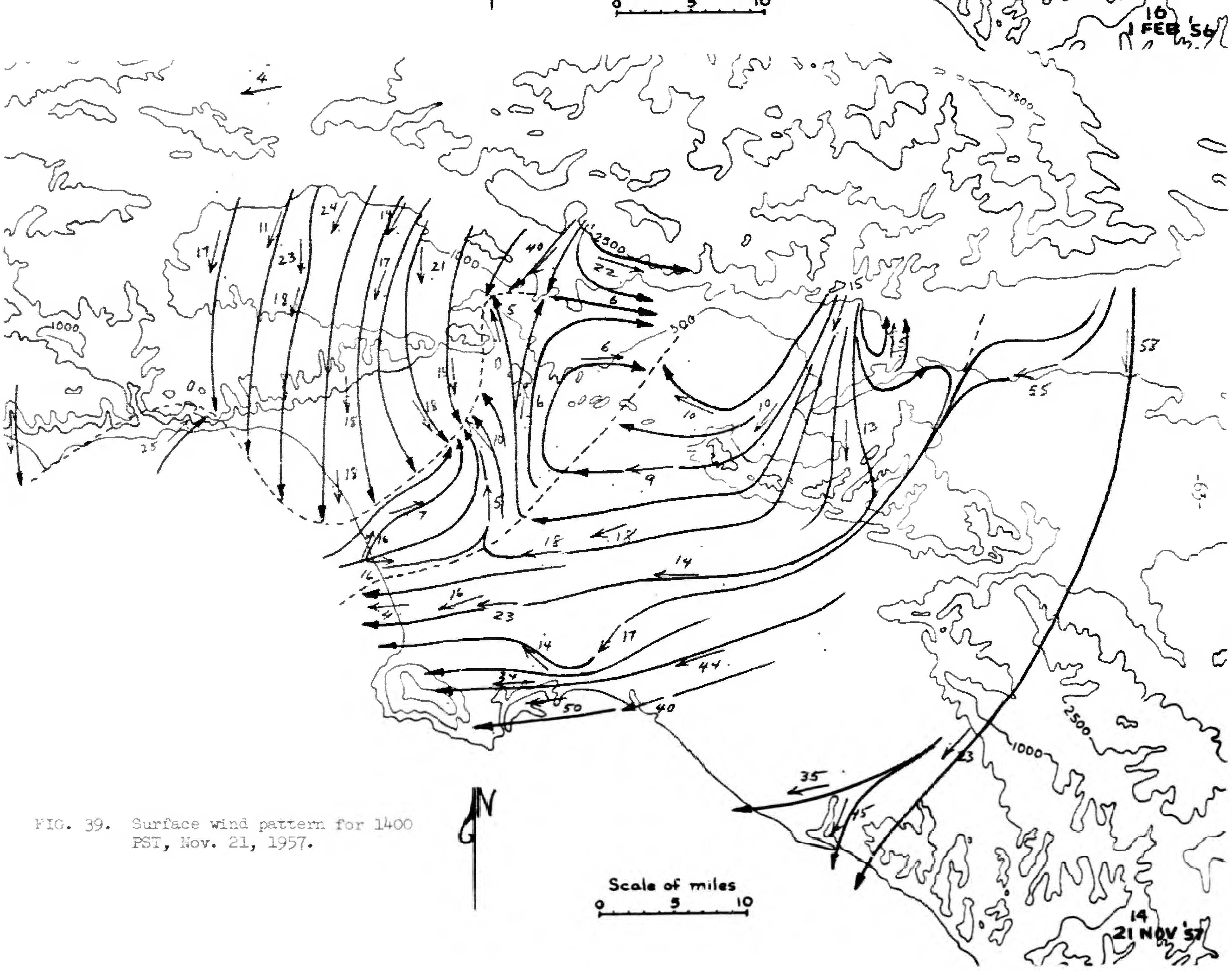


FIG. 39. Surface wind pattern for 1400 PST, Nov. 21, 1957.

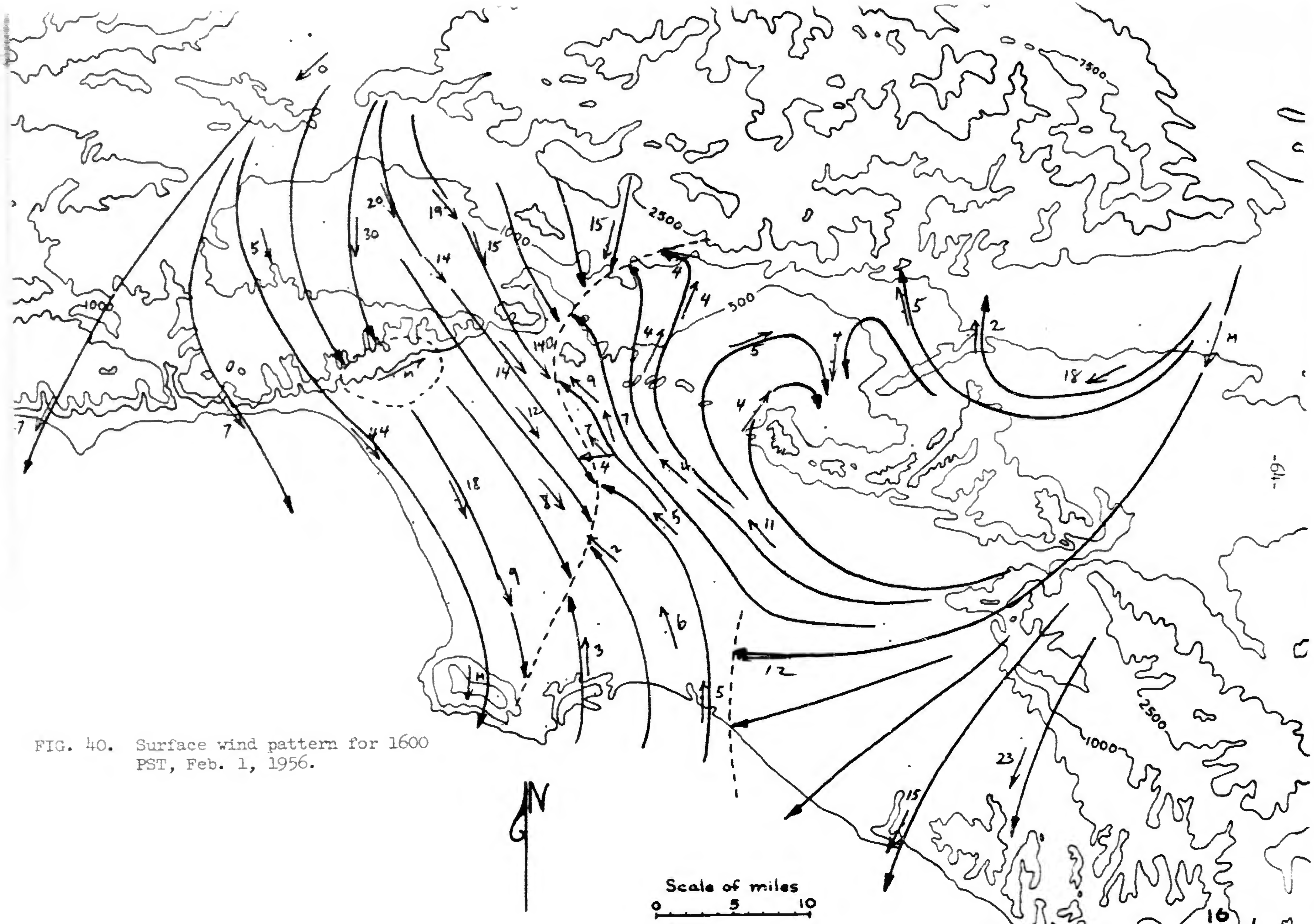


FIG. 40. Surface wind pattern for 1600 PST, Feb. 1, 1956.

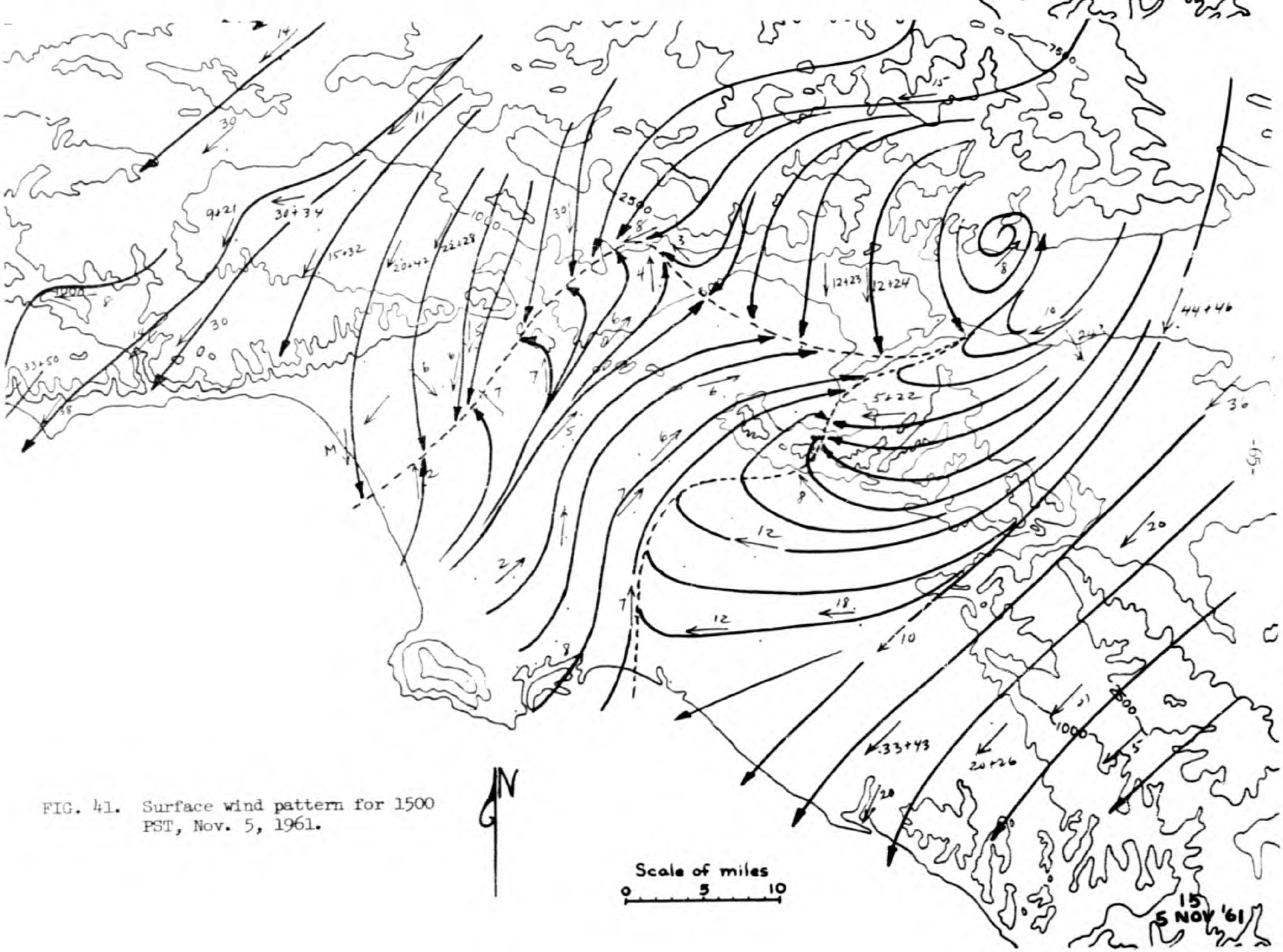


FIG. 41. Surface wind pattern for 1500 PST, Nov. 5, 1961.

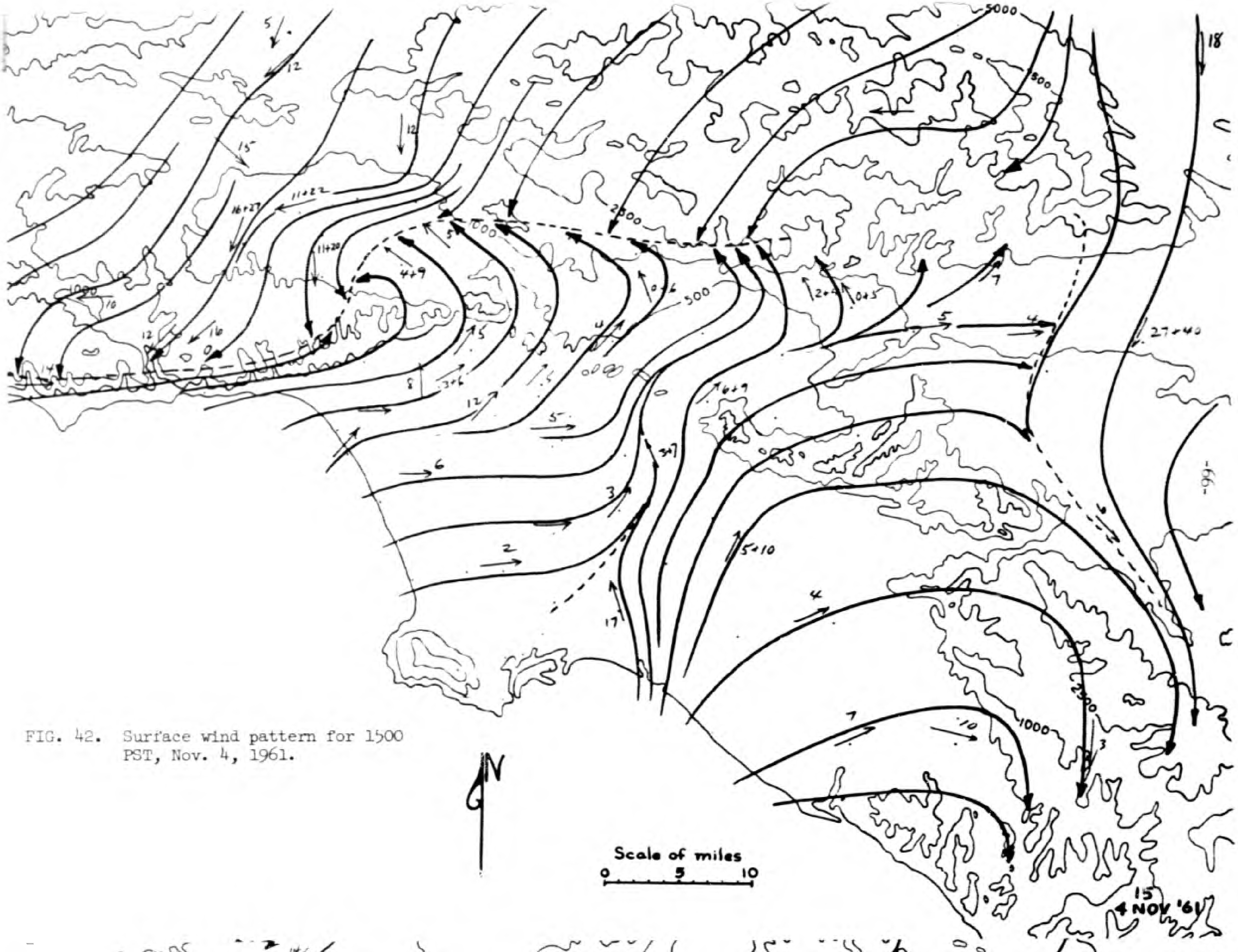


FIG. 42. Surface wind pattern for 1500 PST, Nov. 4, 1961.

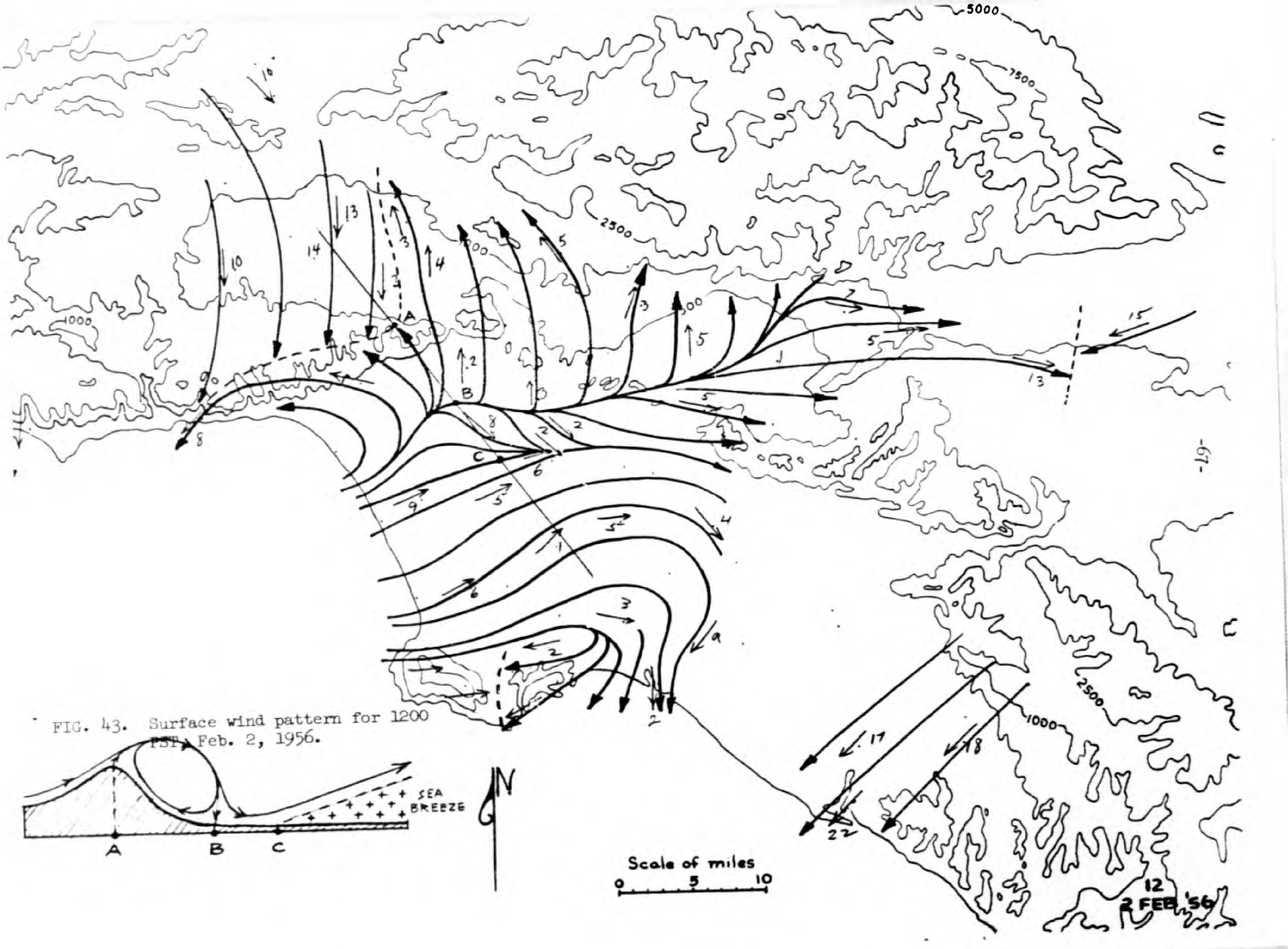


FIG. 43. Surface wind pattern for 1200 PST Feb. 2, 1956.

CHAPTER V

CONCLUSIONS

The results presented have spelled out the striking influence that terrain features exert on the surface wind field, mountains as obstacles, passes as preferred channels and accelerators of flow, and plains and slopes as the instigators of diurnal thermal circulations. One would have expected the data to reveal all of these effects, but the surprise that the maps provided was the magnitude of the effects, in particular the size and character of the wind shadow cast by the San Gabriel mountains, an area of about 1000 sq mi so effectively sheltered from the characteristically vigorous Santa Ana winds that it has its own daytime sea breeze every day, almost without exception. Whether it should be called a sea breeze can be argued. For a fire fighter who would like to think of the sea breeze as bringing in cool humid air from the ocean, it is no sea breeze! Humidities are observed to be only slightly higher and the temperature slightly lower in this returning foehn air than it is in the newly arrived air from the northeast. But the fire fighter can take some comfort in the fact that the winds are light in the wind shadow. Also he may be able to capitalize on the 180° wind shifts that can be depended upon around mid-day and again near sunset in the wind shadow.

Aside from a knowledge of these changes of flow pattern with time of day, he also may find useful the delineation of the areas of strong wind. The boundary separating the strong winds through the passes from the weak winds in the lee of the mountains is well defined in certain areas. For example, the western San Fernando Valley is scoured out by the gusty dry northerlies and northeasterlies day and night while the eastern end of the valley feels only the diurnal ebb and flow of the much weaker winds in the shadow of the San Gabriels. A similar boundary is located at the eastern end of the San Gabriels some miles west of Fontana.

But if the boundaries of the strong wind areas on the flanks of the mountains are well defined, their location upwind and downwind of the wind shadow are uncertain at best. Only occasionally did these boundaries occur within the data network. On the south it was at sea and on the north it was up on the slopes of the mountains. In neither place were there observing stations. Not being interested in fires at sea, we can forgive the lapse in data coverage there, not so the vacuum that leaves undescribed the place where the strong winds over the ridges finally separate from the slopes and ride out over the wind shadow.

Perhaps this lack of surface wind information on these south-facing slopes of the San Gabriels is the single most serious deficiency in this study, and the one most deserving of rectification. But running a close second would be the lack of upper air data. Although fires burn at the surface in accordance with surface winds, to a large extent the surface flow feeds on the momentum of the upper flow and in some instances is overpowered by descending upper currents. The fancied vortices with horizontal axes hypothesized in the previous chapter, if true, are good examples of the intimate bond between upper and lower flow patterns. After all, it is really one current, one with depth as well as width, capable of moving in the vertical as well as the horizontal. One may hope, with some justification, we believe, that the three-dimensional description of this Santa Ana flow will lend simplicity, rather than complexity, to the overall picture by providing understandable upper level links between the apparently disparate flows at the surface.

DISTRIBUTION LIST

Copies	
	Department of the Army:
60	Assistant Director of Civil Defense (Research)
3	The Adjutant General (AGAL-CD)
	Department of Defense:
20	Defense Documentation Center, Alexandria, Va.
1	Library, Weapons Systems Evaluation Group
1	Chief, Missile Phenomenology Branch, ARPA
1	Director for Remote Area Conflict, ARPA/AGILE
1	Chief, Mechanics Branch, ARPA/BMD
1	Weapons Systems Evaluation Group
1	Defense Intelligence Agency (DIAAF-1K2)
1	Chief, NMCSSC
1	Thermal Effects Branch, Defense Atomic Support Agency
1	Technical Library, Field Command, DASA, Albuquerque, N.M.
1	Technical Library, Defense Atomic Support Agency
	Department of the Army:
1	Assistant for Research, Office of Assistant Secretary of the Army (R&D)
1	Joint Civil Defense Support Group, Gravelly Point, Va.
1	Technical Library, Army Engineer Research and Development Lab., Fort Belvoir, Va.
1	Library, The Engineer School, Fort Belvoir, Va.
1	Library, Army War College, Carlisle Barracks, Pa.
1	Library, The National War College
1	Technical Library, Army Nuclear Defense Laboratory, Edgewood, Md.
1	Strategic Planning Group, Army Map Service
1	Atomic Office, Office of Chief of Research and Development
	Department of the Navy:
1	Technical Library, Naval Applied Science Laboratory, Brooklyn, N.Y.
1	Technical Library, Naval Civil Engineering Laboratory, Port Hueneme, Calif.
1	Technical Library, Naval Research Laboratory
1	Technical Library, Naval Radiological Defense Laboratory, San Francisco, Calif.
1	Dr. M. G. Gibbons, U.S. Naval Radiological Defense Laboratory, San Francisco, Calif.
1	Chief, Bureau of Medicine and Surgery
1	Chief, Bureau of Supplies and Accounts (Code L12)
1	Chief, Bureau of Yards and Docks (Code 74)
1	Chief, Bureau of Naval Weapons (Code RRRE-5)
1	Director, Special Projects Office (Code SP-114)
1	Chief, Bureau of Ships (Code 203)
1	Coordinator, Marine Corps Land Force Development Activities, Quantico, Va.
1	Chief of Naval Research (Code 104)
1	Chief of Naval Operations (Op 07T10)
	Department of the Air Force:
1	Assistant Secretary of the Air Force (Research and Development)
1	Technical Library, Office of Scientific Research
1	Headquarters, U.S. Air Force (AFGOA)
1	Library, Air University, Maxwell Air Force Base, Ala.
1	Library, Air Force Special Weapons Center, Kirtland Air Force Base, N.M.
1	Gifford Cook, Fire Protection Group, Headquarters, U.S. Air Force
1	B. Botteri, Air Force Aero Propulsion Laboratory, Dayton, Ohio
1	Civil Engineering Center, Air Force Institute of Technology, Wright Patterson Air Force Base, Ohio
1	Technical Training Directorate, Air Training Command, Randolph Air Force Base, Tex.
1	Department of Fire Fighting Training, Chanute Air Force Base, Ill.
1	Marvin Tyler, Directorate of AGE and Crew Systems Engineering (SEMSA), SEG, RTD, AFSC, Wright Patterson AFB, Ohio

	Atomic Energy Commission:
1	Technical Information Service
1	Industrial Safety and Fire Protection Branch
1	Civil Effects Branch
1	Division of Biology and Medicine (E201)
1	Report Library (G-017)
	Department of Agriculture:
1	Forest Fire Research, U.S. Forest Service
1	Intermountain Forest and Range Experiment Station, Missoula, Mont.
1	Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.
	Miscellaneous Government Agencies:
1	Director, Office of Emergency Planning
1	Joseph D. Coker, Office of Emergency Planning
11	Committee on Fire Research, National Academy of Sciences-National Research Council
1	Richard Park, National Academy of Sciences-National Research Council
1	Library, Woods Hole Institute of Oceanography, Woods Hole, Mass.
3	Federal Fire Council
150	Scientific Documentation Division, U.S. Weather Bureau
	Miscellaneous Non-Government:
1	Chief, EPS Division, Institute for Defense Analysis
1	Chief, R&E Support Division, Institute for Defense Analysis
1	Library, Institute for Defense Analysis
1	American Institute for Research, Pittsburg, Pa.
1	American Municipal Association
1	Dikewood Corp., Albuquerque, N.M.
1	Dunlap & Associates, Inc., Stamford, Conn.
1	Civil Defense Library, University of Florida, Gainesville, Fla.
1	R. Meyerott, Lockheed Missiles and Space Co., Palo Alto, Calif.
1	Civil Defense Library, University of Georgia, Athens, Ga.
1	Advance Research, Inc., Needham Heights, Mass.
1	Hudson Institute, Harmon-on-Hudson, N. Y.
1	Ionics, Inc., Cambridge, Mass.
1	General American Transporation Corp., Niles, Ill.
1	National Fire Protection Association Library, Boston, Mass.
1	Operations Research, Inc., Silver Spring, Md.
1	Operations Research, Inc., Santa Monica, Calif.
1	Planning Research Corporation, Englewood Cliffs, N.J.
1	Research Triangle Institute, Durham, N.C.
1	Director, Operations Planning Research Center, Stanford Research Institute, Menlo Park, Calif.
1	Director, Civil Defense Technical Office, Stanford Research Institute, Menlo Park, Calif.
1	System Development Corp., Santa Monica, Calif.
1	William N. Cox, Jr., Georgia Institute of Technology, Atlanta, Ga.
1	Keith Royer, Iowa State University, Ames, Iowa
1	Robert C. Byrus, University of Maryland, College Park, Md.
1	Elmer L. Johnson, Oklahoma State University, Stillwater, Okla.
1	John Bryan, University of Maryland, College Park, Md.
1	G. L. Maatman, Illinois Institute of Technology, Chicago, Ill.
1	Robert E. O'Brien, Bio-Dynamics, Inc., Cambridge, Mass.
1	J. C. Robertson, Internat. Society of Fire Service Instructors, College Park, Md.
1	J. B. Smith, Factory Mutual Research Corp., Norwood, Mass.
1	Mathew M. Braidech, National Board of Fire Underwriters, New York, N.Y.
1	Library, Factory Insurance Association, Hartford, Conn.
1	Library, Underwriters' Laboratories, Inc., Chicago, Ill.
2	American Mutual Insurance Alliance, Chicago, Ill.
1	National Safety Council, Chicago, Ill.
1	Technical Operations, Inc., Burlington, Mass.
1	United Research Services, Inc.
1	Director, Civil Defense Research Center, IIT-Research Institute, Chicago, Ill.
1	The RAND Corporation, Santa Monica, Calif.
1	Engineering Library, University of Maryland, College Park, Md.
1	T. Y. Lin and Associates, Van Nuys, Calif.

Edinger, James G., Helvey, Roger A., and Baumhefner, David.
1964. SURFACE WIND PATTERNS IN THE LOS ANGELES BASIN DURING "SANTA ANA" CONDITIONS. Los Angeles: Department of Meteorology, University of California at Los Angeles, 72 pp., illus.

ABSTRACT: The results of an analysis of seven years of "Santa Ana" wind situations is presented. The surface wind field over the greater Los Angeles area is presented first in statistical terms, percentage frequency of wind directions and mean wind speeds, and then as streamline analyses of individual situations. Areas of strong flow and weak flow are delineated as well as the diurnal fluctuations of the major features in the surface flow pattern.

Descriptors:
Meteorology
Atmospheric Motion
Weather Forecasting
Air Moisture Analysis
Wind
Gusts

Edinger, James G., Helvey, Roger A., and Baumhefner, David.
1964. SURFACE WIND PATTERNS IN THE LOS ANGELES BASIN DURING "SANTA ANA" CONDITIONS. Los Angeles: Department of Meteorology, University of California at Los Angeles, 72 pp., illus.

ABSTRACT: The results of an analysis of seven years of "Santa Ana" wind situations is presented. The surface wind field over the greater Los Angeles area is presented first in statistical terms, percentage frequency of wind directions and mean wind speeds, and then as streamline analyses of individual situations. Areas of strong flow and weak flow are delineated as well as the diurnal fluctuations of the major features in the surface flow pattern.

Descriptors:
Meteorology
Atmospheric Motion
Weather Forecasting
Air Moisture Analysis
Wind
Gusts

Edinger, James G., Helvey, Roger A., and Baumhefner, David.
1964. SURFACE WIND PATTERNS IN THE LOS ANGELES BASIN DURING "SANTA ANA" CONDITIONS. Los Angeles: Department of Meteorology, University of California at Los Angeles, 72 pp., illus.

ABSTRACT: The results of an analysis of seven years of "Santa Ana" wind situations is presented. The surface wind field over the greater Los Angeles area is presented first in statistical terms, percentage frequency of wind directions and mean wind speeds, and then as streamline analyses of individual situations. Areas of strong flow and weak flow are delineated as well as the diurnal fluctuations of the major features in the surface flow pattern.

Descriptors:
Meteorology
Atmospheric Motion
Weather Forecasting
Air Moisture Analysis
Wind
Gusts

Edinger, James G., Helvey, Roger A., and Baumhefner, David.
1964. SURFACE WIND PATTERNS IN THE LOS ANGELES BASIN DURING "SANTA ANA" CONDITIONS. Los Angeles: Department of Meteorology, University of California at Los Angeles, 72 pp., illus.

ABSTRACT: The results of an analysis of seven years of "Santa Ana" wind situations is presented. The surface wind field over the greater Los Angeles area is presented first in statistical terms, percentage frequency of wind directions and mean wind speeds, and then as streamline analyses of individual situations. Areas of strong flow and weak flow are delineated as well as the diurnal fluctuations of the major features in the surface flow pattern.

Descriptors:
Meteorology
Atmospheric Motion
Weather Forecasting
Air Moisture Analysis
Wind
Gusts

BLANK PAGE