AN ABSTRACT OF THE THESIS OF

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Title: On the Relationship Between Winter Storms, Strong Winds, and the Associated Pressure Field Along a Rugged Western Coast

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Fred W. Decker

Two successive years of wind speed and direction data, from January 1973 through December 1974, have been measured and recorded at Yaquina Head, 6 km north of Newport, Oregon. Analysis of the data permitted 65 cases of strong wind to be isolated and separated into four distinct wind speed categories. With the aid of surface charts, upper air sounding, and sea level pressures from several stations, numerous meteorological events, occurring concurrently with peak winds at Yaquina Head, have been evaluated for a significant contribution to the local wind.

Cyclone centers associated with strong coastal wind have been plotted and analyzed with regard to location, speed and direction of motion, sea surface pressure, and pressure change during periods of strong winds. The result of this analysis indicates that many cases of strong coastal wind measured at Yaquina Head are associated with

cyclones located southwest of Vancouver Island, British Columbia. The pressure change experienced by these cyclones is related to the strength of the observed wind at Yaquina Head. Likewise, the locations of these pressure centers are related to the duration of strong wind measured at Yaquina Head. The direction of motion of the cyclones and the value of the sea surface pressure at the center of the cyclones seem unrelated to local wind speed.

Frontal zones associated with cases of strong wind have been evaluated with regard to type, speed, and direction of motion prior to strong surface winds. No relationship was found between these factors and the strength of the wind.

The direction of the wind versus the speed of the wind was reviewed and the results were separated into several classes. The result of this classification indicated that in 73 percent of the cases the measured peak wind occurred prior to an abrupt veering of the wind. Only 21 percent of the cases lacked this wind shift.

The local pressure field was examined for pressure differences which might result in a strong coastal wind flow. Station pressures from three locations were used as well as barograms from Newport, Oregon, in describing the pressure field. No correlation between these pressures differences and the strength of the local wind could be found. Finally, the north-south component of the geostrophic wind was calculated and compared with speed of the measured wind. No consistent agreement could be established between the measured surface wind speed and the calculated north-south component of the geostrophic wind.

The lack of data west of Yaquina Head and Oregon Coast continue to present a problem for those who consider coastal winds.

On the Relationship Between Winter Storms, Strong Winds, and the Associated Pressure Field Along a Rugged Western Coast

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u	Eastward component of velocity
v	Northward component of velocity
u_g	Geostrophic eastward speed
v_g	Geostrophic northward speed
p	Pressure
t	Time
c_x	Cartesian component of velocity in the eastward direction
f	Coriolis parameter
ρ	Surface air density
n	A natural coordinate
x, y	Eastward and northward cartesian coordinates
$\overline{\nabla} p$	Pressure gradient

ON THE RELATIONSHIP BETWEEN WINTER STORMS, STRONG WINDS, AND THE ASSOCIATED PRESSURE FIELDS ALONG A RUGGED WESTERN COAST

I. INTRODUCTION

The purpose of this study is to examine several elements of extratropical disturbances related to strong winds measured from a selected site on the Oregon Coast. Two years of wind data were available for this study from January 1973 through December 1974, and 65 cases of strong wind have been identified for this analysis. The data obtained from these wind measurements have been evaluated with the following objectives:

1. Classify those meteorological factors which occur concurrently with strong coastal winds.

2. Provide techniques for identification of those storms which may produce strong coastal winds.

3. Demonstrate a relationship between the pressure field and strong surface winds.

Forecasting strong winds along this western coast presents several problems. Raynor (1968) suggests that convergence in the southerly flow between the storm system and coastal mountains, off the coast of British Columbia, "accentuates and probably distorts" the sea level pressure gradients. Measurements of surface pressure and wind are rare along the Northwest coast and nearly absent from areas offshore. A technique for better forecasting of strong coastal winds will serve not only those who live along the coast but also those who navigate the waters in the Eastern North Pacific. Burt (1958) showed that severe midlatitude storms in the Gulf of Alaska produce higher waves for a longer period of time than do tropical storms and hurricanes in the Gulf of Mexico.

The results presented here may not be conclusive due to the short period of observation and the small number of strong wind cases. These results, however, represent a first attempt to document many storm related events which occur concurrently with strong coastal winds.

II. NORTHWEST CLIMATOLOGY

Variations in the amplitude of the Rossby waves result in a great variety of weather conditions for mid-latitude areas. During the summer this upper level flow is weak and is mostly zonal. The jet stream is positioned north of 60° N. and any frontal depressions associated with it are confined to the higher latitudes. On the surface, the Pacific Anticyclone is well developed and is located far enough north to dominate the weather in the Northwest. Surface winds for July are generally from the north and northwest with an average velocity of 10 kt in the vicinity of Newport, Oregon (Cooper, 1958). During the early autumn the Pacific Anticyclone begins to weaken and is located progressively south of its summer position. The amplitude in the waves of the Westerlies becomes more pronounced, and consequently frontal depressions begin to encounter the coast farther south. By mid-winter the polar jet has migrated south across Oregon and into Northern California where it reaches its southern limit (Riley and Spalton, 1974). On the surface the Aleutian Low, which has either been absent or very weak during the summer, becomes a firmly established synoptic feature. During autumn, winter, and spring there are large variations in the surface wind direction due to the motion of pressure centers at these latitudes (Haurwitz and Austin, 1944). It is during these months that episodes of strong surface wind are most often observed.

Strong coastal winds are usually associated with extratropical cyclones which originate, as Petterssen (1940) indicates, off the east coast of Asia or over the central part of the North Pacific. The prevailing direction for these strong surface winds is almost always south and parallel to the coastline. Raynor (1968), Elliott (1970), and Burdwell (1972) suggest that surface friction produced by coastal land masses causes surface wind, associated with Pacific storms, to converge along the coastline resulting in a strong southerly flow.

Some Pacific storms are more severe than others. Smith (1950) presented a case study of a severe Pacific coast storm which produced widespread damage in October, 1950. Danielsen et al. (1957) studied the frequency of intense storms which have occurred in the Gulf of Alaska over a period of 52 years. They suggested that there is some evidence which indicates severe storms occur every 12 years. Lynott and Cramer (1966) examined the Columbus Day windstorm of 1962 which affected both Oregon and Washington. As a part of their detailed analysis, the authors have made some simple comparisons of this storm to other severe storms of the Pacific Northwest.

The seasonal variation in surface wind speeds occurring along the Northwest Coast is summarized in Table 1 which lists the mean monthly scalar wind speed for several coastal sites. It is apparent

Table 1. Monthly mean wind speed (knots) at selected northwest coast sites (after Burke, 1971, and Hewson, et al. 1976).

Station a. Source of Data b. Bibliographic Reference No.	Period of Record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Quillayute, Washington a. Weather Bureau b. (4)	1966-1969	7.6	6.4	6.7	6.5	5.9	5.5	5.5	5.4	4.9	6.2	6.2	7.3
Umatilla Lightship a. Nat. Weather Record Center b. Bourke et al.	1961-1965	16	14	12	13	11	10	9	6	7	11	14	15
Hoquiam, Washington a. Weather Bureau b. (15)	1953-1958	9.9	9.9	9.7	9.0	8.4	8.3	7.9	7.2	7.0	8.2	9.5	10.3
North Head, Cape Disappointment Washington a. Weather Bureau b. (16) and (18)	44 years	13.8	12.7	12.3	12.0	11.5	12.0	10	9.7	10.2	11.1	13.5	14.1
Columbia River Lightship a. Nat. Weather Record Center b. Bourke, et al.	1953-1966	16	14	13	11	10	9	9	9	10	12	15	15
Astoria, Oregon a. Weather Bureau b. (19)	11 years	7.7	7.6	7.6	7.4	7.3	7.3	7.4	6.7	6.3	6.6	7.4	7.6
Yaquina Head, Ore. Comm. St. a. O.S.U. b. Hewson et at.	1973-1975	17.2	15	13.7	11	10.6	10.4	10.3	10.8	9.7	10	16.3	17.1
North Bend, Oregon a. Weather Bureau b. (15)	1937-1942	8.2	7.3	7.8	8.0	8.7	8.4	10.2	8.5	6.7	5.9	6.3	7.2

from Table 1 that variations in the scalar wind speed between sites do occur during the same months. These differences may be attributed to the influence of the local topography upon the wind regime. Each station, however, exhibits similar changes in the monthly mean wind speed from month to month caused by seasonal variations in the climate.

The climate of Oregon and the atmospheric processes which produce it are not unique. The Oregon coastline, being similar to that of Great Britain, Norway, and Chile, may display effects found on other west coasts. The results obtained here, too, may possibly pertain to other locations.

III. LITERATURE REVIEW

Coastal winds of the Pacific Northwest have been examined by several authors. Fisher (1970) and Detweiler (1971) both examined the summer wind regime in the vicinity of Newport, Oregon, as part of a study dealing with coastal upwelling. Bourke et al. (1971) summarized the data pertaining to surface wind observations in the Pacific Northwest. He rightly points out that very few wind data for this region have been analyzed or published. Raynor (1968) has made a comparison between coastal winds measured from Vancouver Island, British Columbia, and winds measured 13 km offshore. He concluded that winds were 26 percent higher offshore than along the coast for a period of five months beginning in November of 1968.

Several wind atlases present wind data for the North Pacific. The Climatological and Oceanographic Atlas for Mariners, Vol. II, North Pacific Ocean (U. S. Department of Commerce, 1961) and the U. S. Navy Marine Climate Atlas of the World, Vol. II, North Pacific Ocean (U. S. Department of the Navy, 1958) both present information on winds over the ocean and adjacent to the West Coast of North America. McGary et al. (1957) likewise present monthly wind data for coastal waters for mid-latitudes. Each atlas describes only the general variations in surface wind speed over large areas of the ocean.

IV. BACKGROUND FOR STUDY

Beginning in 1971 research on available wind power at several selected sites in Oregon and Washington was initiated by E. Wendell Hewson, Chairman of the Department of Atmospheric Sciences at Oregon State University in Corvallis. This research was supported by four Oregon Public Utility Districts. In the early stages of the research, wind records from existing coastal stations were gathered and reviewed. Several "wind power" sites were examined along the Oregon Coast and Columbia River Valley; and beginning in 1972, 11 stations were established on the coast from Florence to Astoria.

By the summer of 1976, only four coastal "wind power" sites remained. Several stations were abandoned due to poor wind distribution or turbulent wind characteristics (Hewson et al., 1976). One coastal site, Yaquina Head, 6 km north of Newport, Oregon, continues to provide "wind power" researchers with valuable wind data (Figure 1).

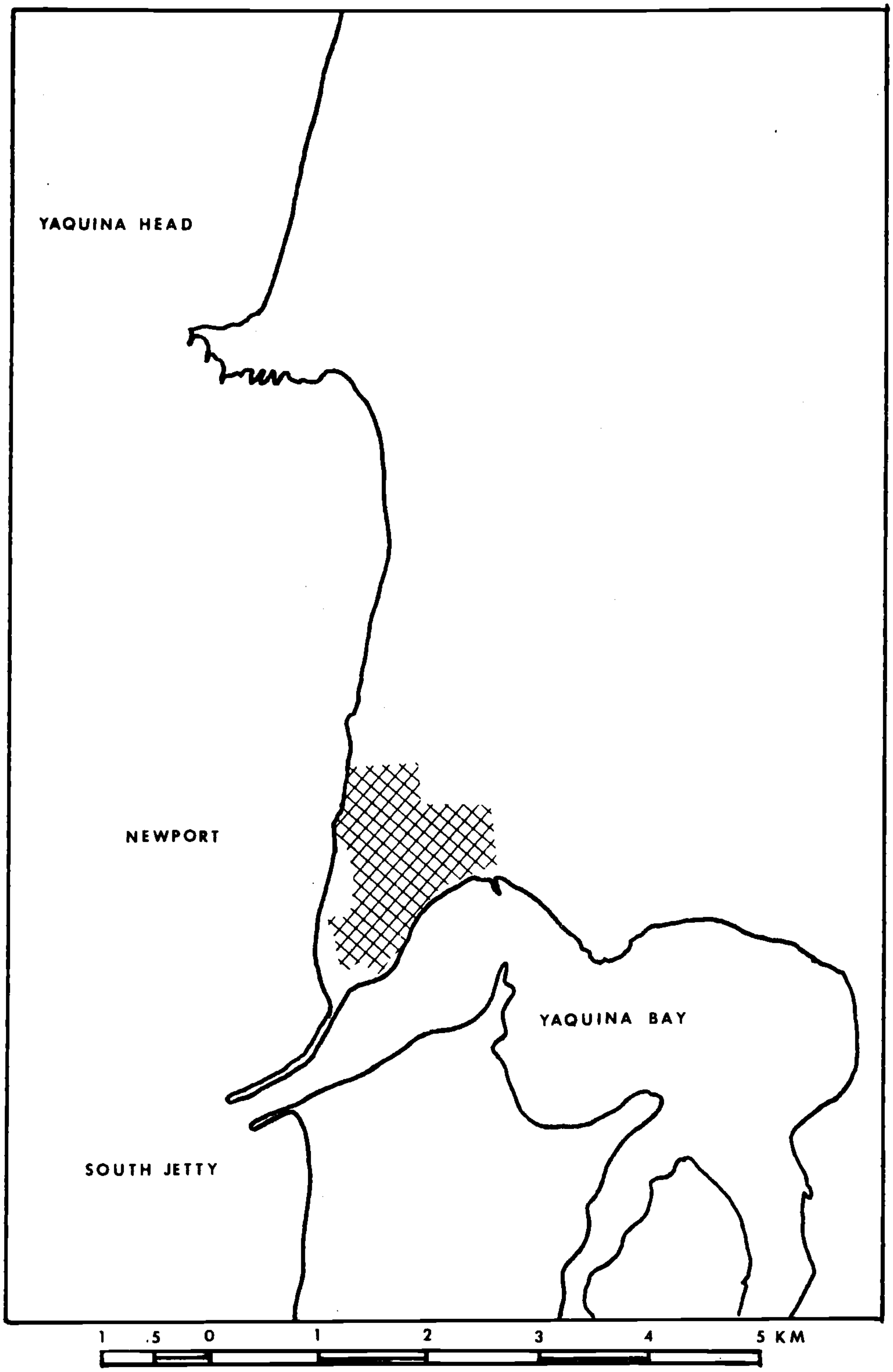


Figure 1. Map of the Oregon Coast including Newport, Yaquina Head, and the South Jetty.

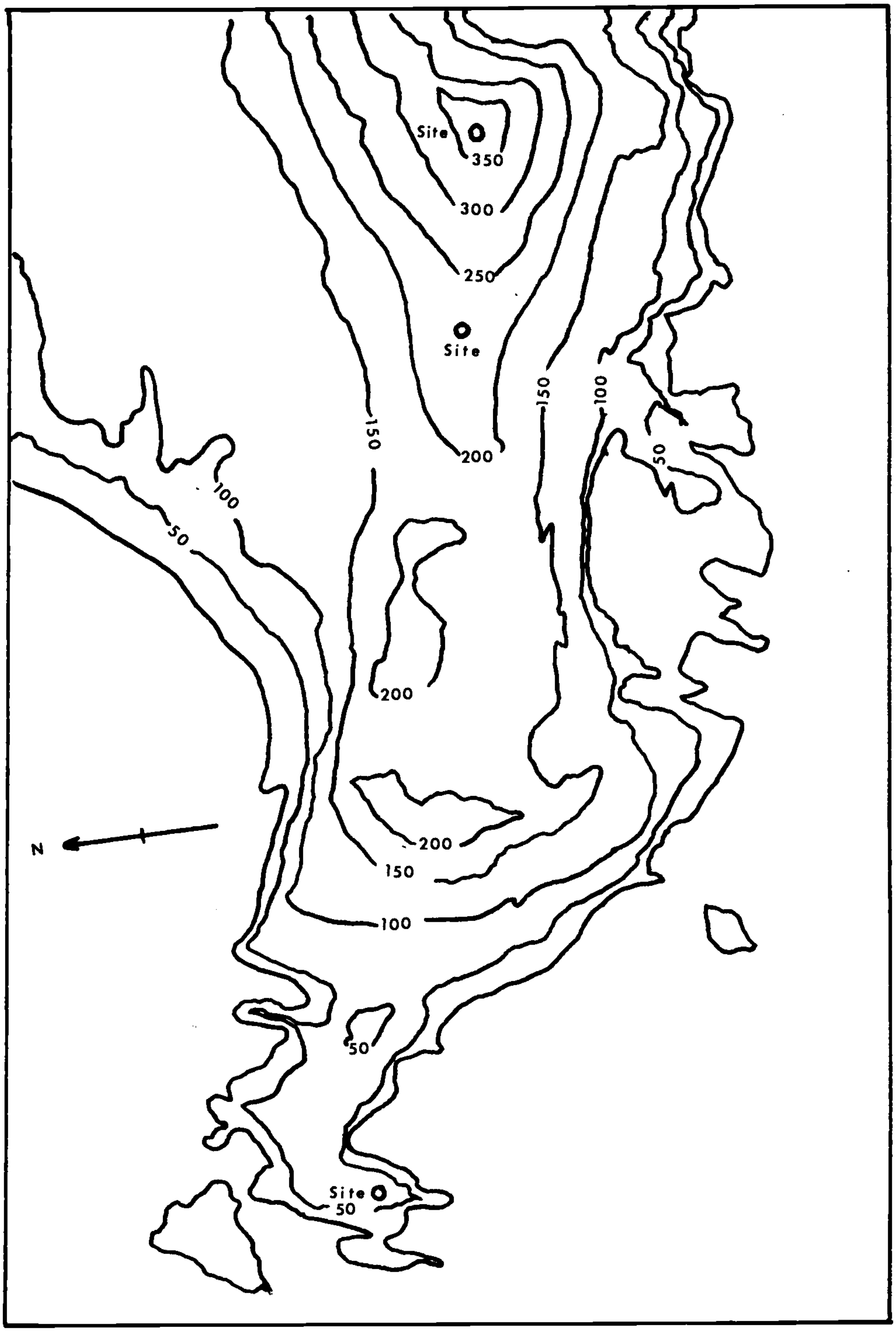
V. SITE DESCRIPTION

Yaquina Head is located at 44°44'10" N. and 124°4'50" W., just north of the city of Newport, Oregon. The Head is surrounded by water on three sides as it projects 1.3 km west of the north to south orientation of the Oregon coastline. Winds on the Head are measured by wind sensors at three separate locations: one on the western edge of the Head near the Yaquina Head lighthouse, and two on a ridgeline above and to the east of the lighthouse (Figure 2).

The wind gauge located near the lighthouse is a windmill type anemometer supported by a 12 m mast. The ground elevation in the vicinity of this wind sensor is 22 m above sea level.

In a natural saddle, 73 m above sea level, a 30 m tower supports two wind gauges which were installed during the summer of 1975. One anemometer has been placed at the 30 m level while the other is located closer to the ground at 10 m. Each gauge is a windmill type anemometer.

East of this tower, at an elevation of 112 m above sea level, is the third installation established in January of 1973 just as the wind gauge near the lighthouse became operable. Winds are measured here also by a windmill type anemometer which is located 10 m above the ground. The recorder is housed inside a shelter operated by the U. S. Coast Guard as a communication center. This site is well



Elevation in intervals of 50 ft.

Figure 2. Map of Yaquina Head (after Hewson, 1976).

exposed to the wind, especially from the south where the slope of the hillside extends up from the sea (Figure 2). Wind data for this study have been taken from the recorder located here since they give a more complete record of the wind during the period January 1973 through December 1974.

VI. INSTRUMENTATION

The wind transmitter adjacent to the communication center, Belfort Model L, measures both wind speed and direction sumultaneously. Wind speed is sensed by a three-bladed impeller mounted on the shaft of a direct current generator. The voltage output varies linearly with the measured wind speed (Belfort Instrument Company, 1971). The speed threshold for this sensor is 3.8 mph, and the distance constant is 4.5 m. Gill et al. (1972) describe the distance constant of any anemometer to be the length of fluid flow past the sensor required to cause the sensor to respond to 63.2 percent of a step function change in either the speed or direction of the wind. The overall accuracy of the speed transmitter is ±1 percent (Belfort Instrument Company, 1971).

Wind direction is sensed by the large vane attached to the fuselage of the anemometer. Changes in wind direction are translated by a torque synchro transmitter within the shaft housing of the vane. The sensitivity of the direction transmitter is 8° at 5 mph (Belfort Instrument Company, 1971). The distance constant is approximately 10 m and the overall accuracy of the direction sensor is 3° (Belfort Instrument Company, 1971).

The wind direction and speed recorder, Monmouth RO-2c/GMQ, consists of both wind direction and speed mechanism, chart drive mechanism, pens, charts, and case. The strip type chart is divided into two channels, one each for wind speed and direction. The wind speed channel is graduated every two miles per hour from 0 to 100 mph. The wind direction channel has a range of 540° and is graduated for every 10°. This channel is labeled at each cardinal point (Figure 24). The entire chart is 100 ft long and 10 3/8 in wide. Time lines appear every 20 minutes and are labeled every hour. Since the chart advances 1 1/2 in per hour, one chart can serve for more than 33 days. Normally each recorder is serviced once a month.

The wind direction pen follows the transmitter within $\pm 4^{\circ}$, while the wind speed pen records wind speed to within ± 1 percent of full scale (Bendix Aviation Corporation, 1954).

The combined accuracy of the sensor and recorder for measuring wind direction is to within 7°, while a maximum error of ± 2 percent exists in measuring wind speed.

The wind speed sensor and recorder set has been calibrated several times during its period of operation. It was first calibrated in the laboratory before being assembled in the field. While in operation at the communication center, during the summer of 1974, the speed transmitter agreed well with readings made from a hand-held anemometer placed at the same level as the wind sensor. Later, that following spring, the entire system was dismantled and placed in a wind tunnel on the Oregon State University campus where tests have verified the precision of the system.

VII. ANALYSIS OF LOCAL WINDS

The surface winds measured at the lighthouse during the same period, January 1973 through December 1974, averaged 20 percent less than those measured from the communication center. Winds measured from the wind gauge atop the 30 m tower, however, were 11 percent higher than those recorded from the communication center, above, for the year 1975 (Hewson et al., 1976). It is reasonable to ascribe these differences to variation in the topography of Yaquina Head.

Beginning in March 1969, wind data have been gathered by researchers at the Oregon State University Marine Science Center from a wind gauge placed 40 m south of the South Jetty adjacent to the mouth of Yaquina Bay (Figure 1). The installation has been described by Detweiler (1971) as a part of a study pertaining to coastal upwelling during the period March through October 1969. Detweiler found that the winds measured at the South Jetty during the first eight months of its operation were within 20 percent of the scalar wind speeds measured from an unspecified location in Newport during the period 1936 through 1942. In a similar manner, several months of wind data for 1973 obtained from the South Jetty have been compared with data taken from the installation near the lighthouse on Yaquina Head (Figure 3). Three months of data are

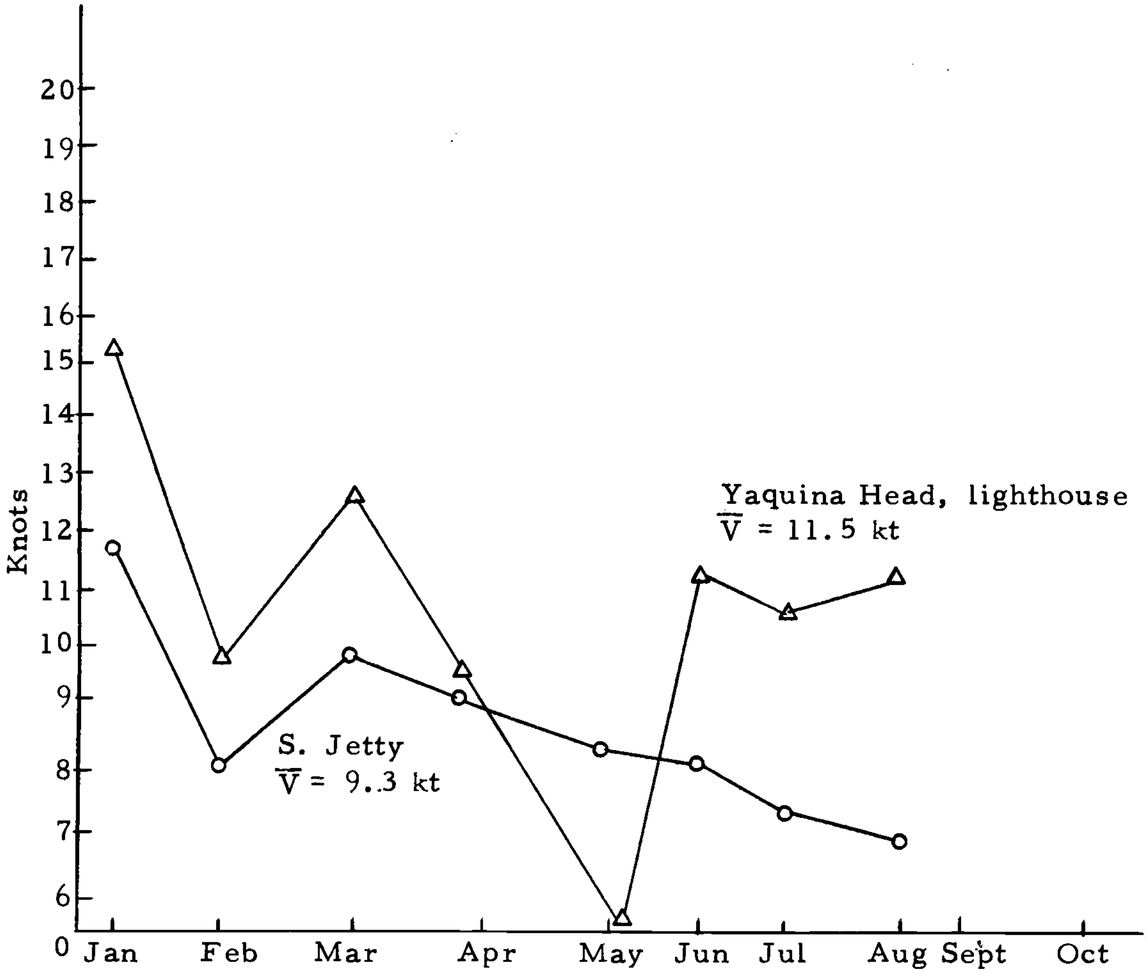


Figure 3. A comparison of the monthly mean wind speed for 1973 from two selected sites in the vacinity of Newport, Oregon.

missing due to instrument failure. The average wind speed for these nine months of comparison is 19 percent higher for the observations taken from Yaquina Head. The difference between these two sets of readings must be ascribed to the effect of local topography on the two wind instruments.

VIII. EVALUATION OF MAXIMUM STORM WINDS

Analysis of Data

Many periods of strong surface wind were measured and recorded by the instruments on Yaquina Head during the first two years of observation. For the years 1973 through 1975, winds were observed to be 35 kt or higher 4 percent of the time (Hewson et al., 1976).

To separate the data and to evaluate each case of strong wind, a wind speed of 35 kt maintained for a period of one hour was chosen as a threshold point. This threshold closely approximates Beaufort force number 8 which is described as a gale (Petterssen, 1941).

The recorded wind speeds and direction values have been averaged over one hour intervals and the results tabulated. This was accomplished by visually estimating a wind speed and direction mean over the given interval of time from the wind charts. Those values equal to or greater than the threshold value of 35 kt are generally the result of a major synoptic event rather than a short lived, localized phenomenon. Based upon this criterion of case selection, 65 periods of strong wind have been identified and will be analyzed (Appendix A).

Of the 65 selected cases, 17 (or 25.8 percent) occurred during the period September through November, 34 (or 51.5 percent) occurred during the three months of December, January and February, and 15 (or 22.6 percent) have occurred during March through May. No cases of strong wind were recorded during the two summers.

The tendency for strong winds to occur more frequently during the winter months (December through February) has been noted by McGary et al. (1957). They showed that the frequency of winds 35 kt or above for the winter months (December through February) for waters adjacent to the Pacific Northwest Coast was $\geq$ 5 percent, while for the other two seasons, autumn and spring, the percentage frequency was $\leq$ 5 percent. He likewise showed that the percent frequency of these winds during the summer months was very low. These conclusions have been drawn from data covering a sixty year period ending in 1955.

To evaluate each period of strong wind, each case was assigned to one of four speed categories:

Category 1	35 to 39 kt
Category 2	40 to 44 kt
Category 3	45 to 49 kt
Category 4	$\geq$ 50 kt

This places 19 cases within category 1, 18 cases within category 2, 16 cases within category 3 and 13 cases within category 4.

Each case of strong surface wind measured at the communication center was compared to similar values recorded at the South Jetty with the result that the winds observed atop Yaquina Head were 24 percent higher. The prevailing direction for these strong winds varies from 140° to 210°. The higher observed wind values for Yaquina Head may be attributed to the effect of this southerly flow accelerating over the top of Yaquina Head.

Surface charts prepared by the National Weather Service have served as an aid in analyzing these cases of strong wind. For this study, maps drawn every 6 hours for synoptic data at 0400, 1000, 1600, and 2200 Pacific Standard Time were used.

For this analysis, strong coastal winds are considered as a dependent variable while other meteorological factors are viewed as independent variables. The following is a list of the meteorological factors viewed as independent variables and analyzed with the use of surface weather charts:

1. Longitude and latitude of cyclone centers.
2. Central pressure within each cyclone center.
3. Six hour pressure change within cyclone center.
4. Direction of motion for cyclone centers.
5. Type of frontal structure associated with strong surface wind.
6. Speed and direction of frontal movement.

Three additional factors were examined which required data not found on surface charts:

1. Length of time in hours that the surface wind stayed above the threshold point.

2. Speed and direction of the wind at the 850 mb level measured above Salem, Oregon.

3. Wind speed versus wind direction.

The results of the analysis will be reviewed in the order as they appear above.

Location of Cyclone Centers

A review of the synoptic data presented by the surface charts indicated that each case of strong surface wind was due to the presence of a front structure, a center of low pressure, or both. The location of each center of low pressure has been recorded and plotted with the use of the surface charts occurring nearest in time to the strong wind (Figure 4). A large population of cyclone centers is bounded roughly by the 5° quadrangle from 45° N. to 50° N., and 125° W. to 130° W. The remaining cyclone centers are located all along the coast into the Gulf of Alaska. The fact that most cyclone centers are located west of the coast during episodes of strong wind has been recognized by Klein (1957) and Hare (1963). Each author has noted that centers of low pressure associated with Pacific storms stagnate offshore in the Gulf of Alaska while their fronts cross the

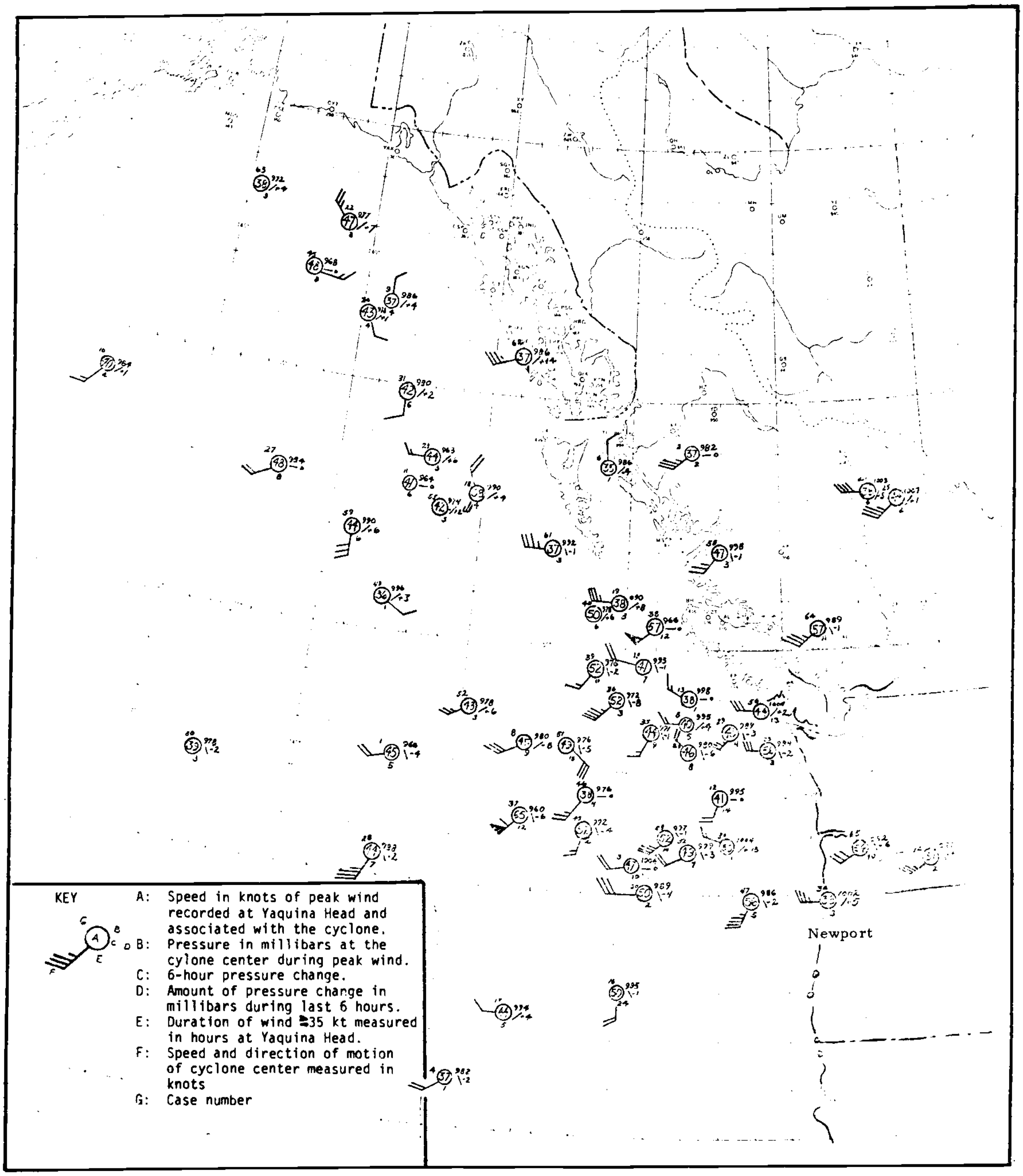


Figure 4. Plotted cyclone position during peak winds at Yaquina Head showing speed and direction, estimated surface pressure, 6 hr. pressure tendency of cyclone centers.

coast farther to the south. Carpenter (1945) identifies the center of maximum cyclone frequency near Vancouver Island as the terminus of many storms originating in the Eastern Pacific.

The percent population of cyclone centers per 5° quadrangle (adjusted to a quadrangle centered at 45° N.) illustrates the maximum of concentration southwest of Vancouver Island (Figure 5) as do isopleths of equal cyclone concentration (Figure 6). A series of weather charts from Klein (1957) and based upon data from 1909-1914 and 1924-1937, identifies the same area southwest of Vancouver Island as a region of high cyclone frequency for three selected months (October, January, and April). On each chart (Figures 7, 8, and 9) the presence of the Aleutian Low is evident. However, during the winter months (December through March), characterized here by the January map, a second maximum of concentration appears near Vancouver Island. These findings basically agree with the results of two other studies conducted by Petterssen (1950) and Reitan (1974).

A second series of maps (Figures 10, 11, and 12) from Klein (1957) illustrate the principal tracks followed by sea level cyclones during three selected months (October, January, and April). The heavy solid lines denote primary tracks, while dashed lines denote secondary tracks. Arrow heads end in areas where cyclone frequency is a local maximum. It is evident from these two sets of maps that the cyclones associated with strong coastal winds are located in

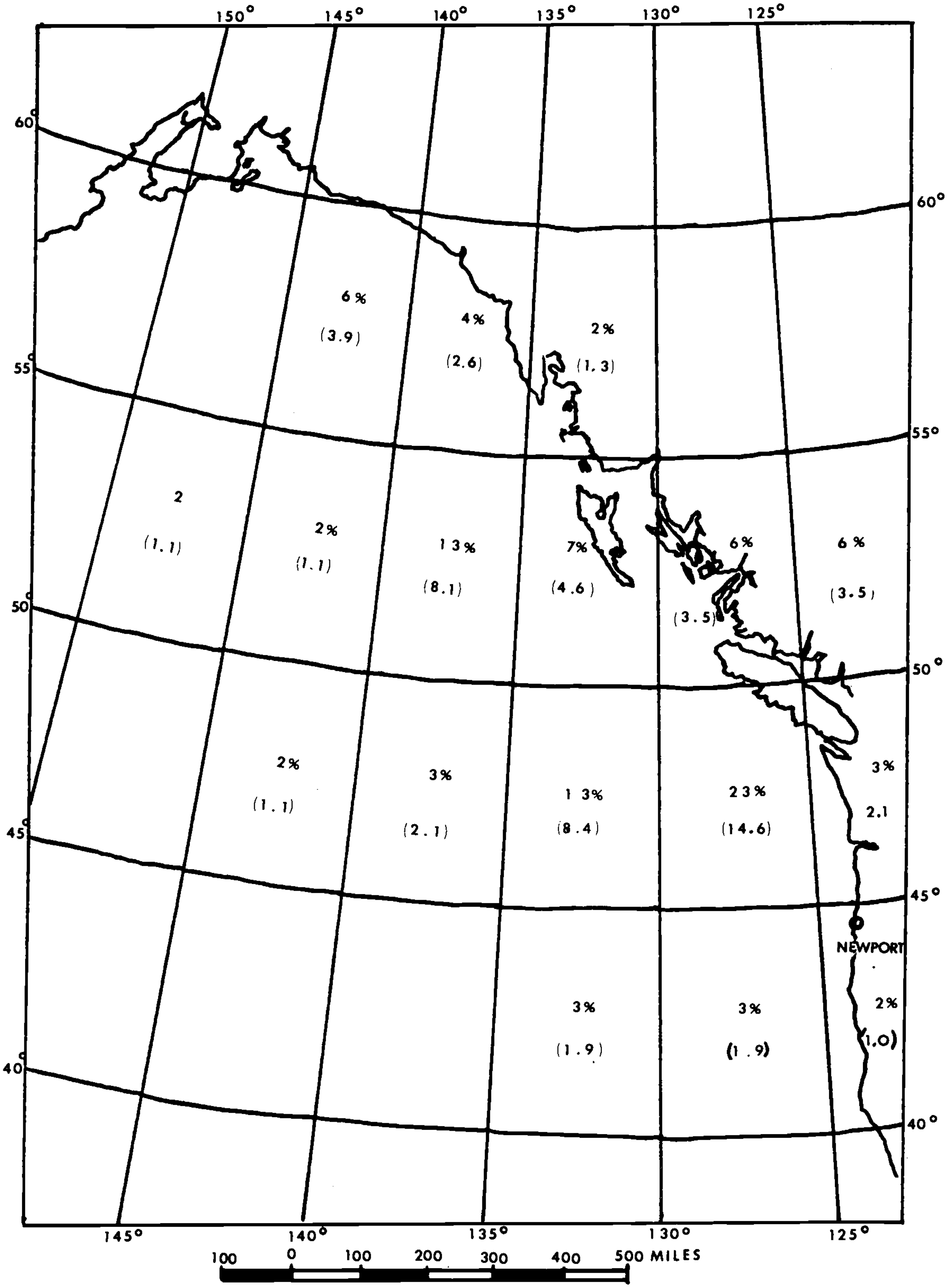


Figure 5. Cyclone concentration per 5° quadrangle (adjusted to a 5° quadrangle centered on 45° N.) with actual number of cyclone centers shown in parentheses.

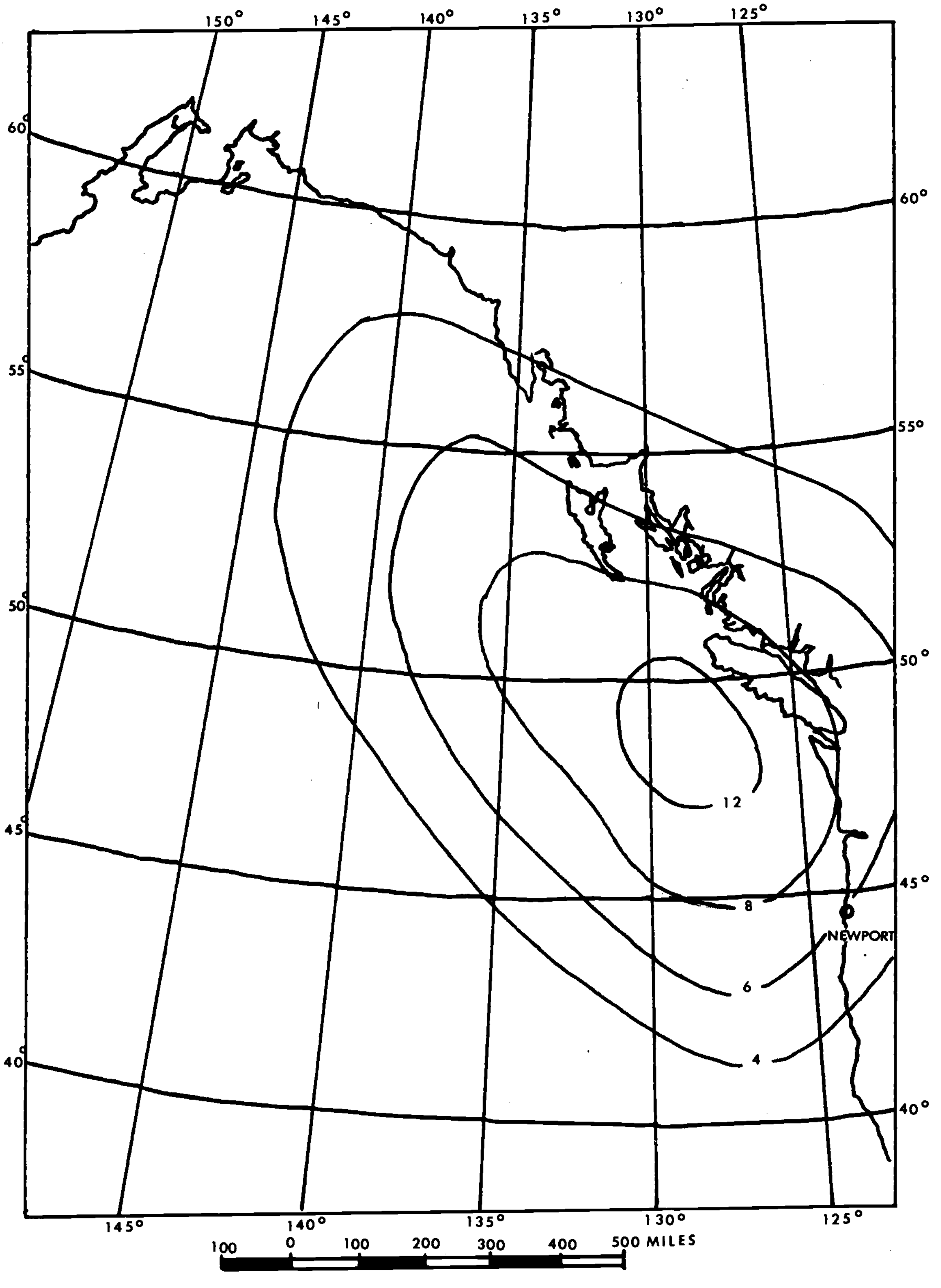


Figure 6. Number of cyclones associated with peak winds at Yaquina Head. Isopleths are lines of equal cyclone concentration with actual number shown.

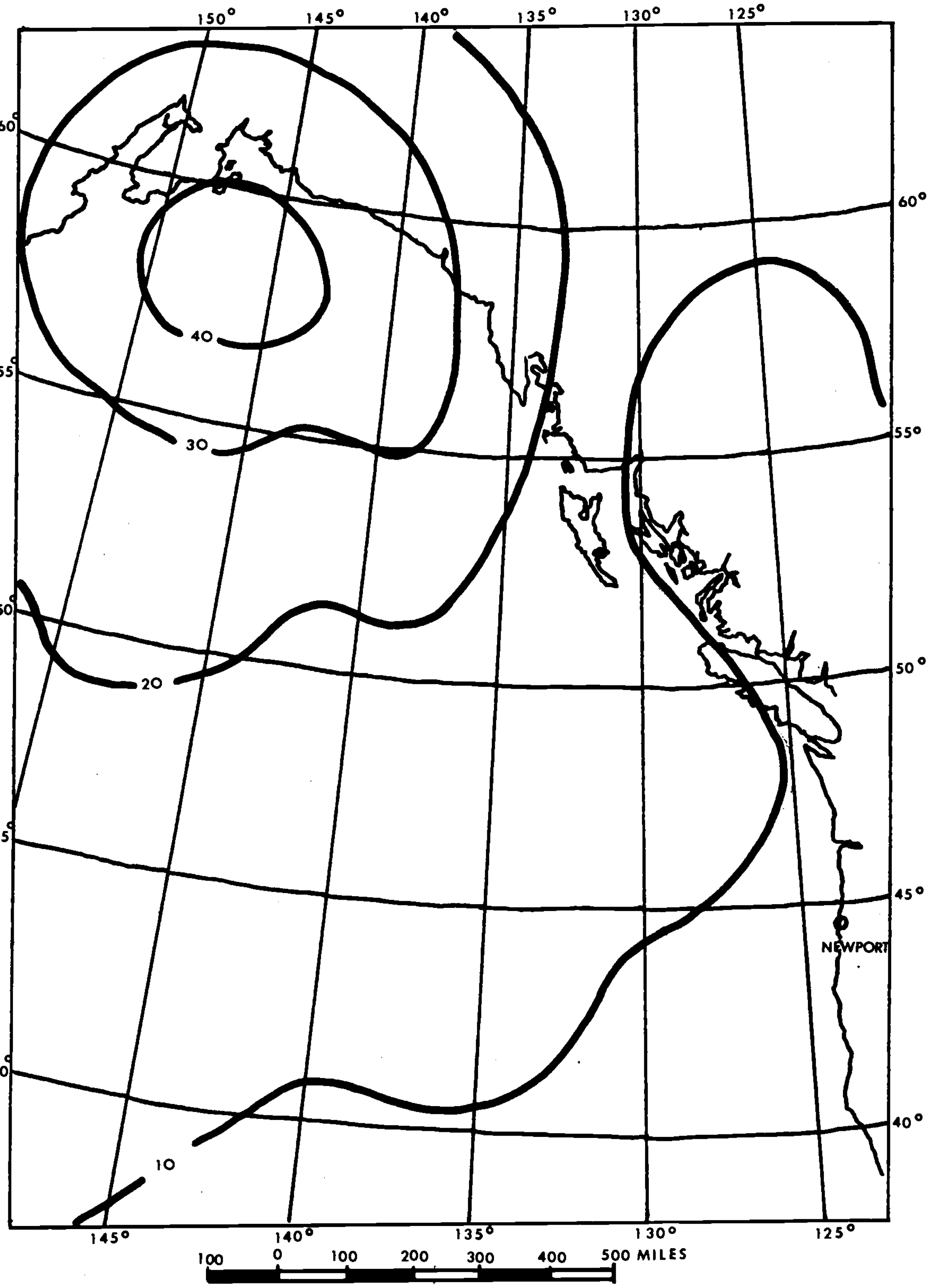


Figure 7. Number of lows for October for the period 1909-1914 and 1924-1937. Isopleths are lines of equal concentration of lows with actual number shown (from Klein, 1957).

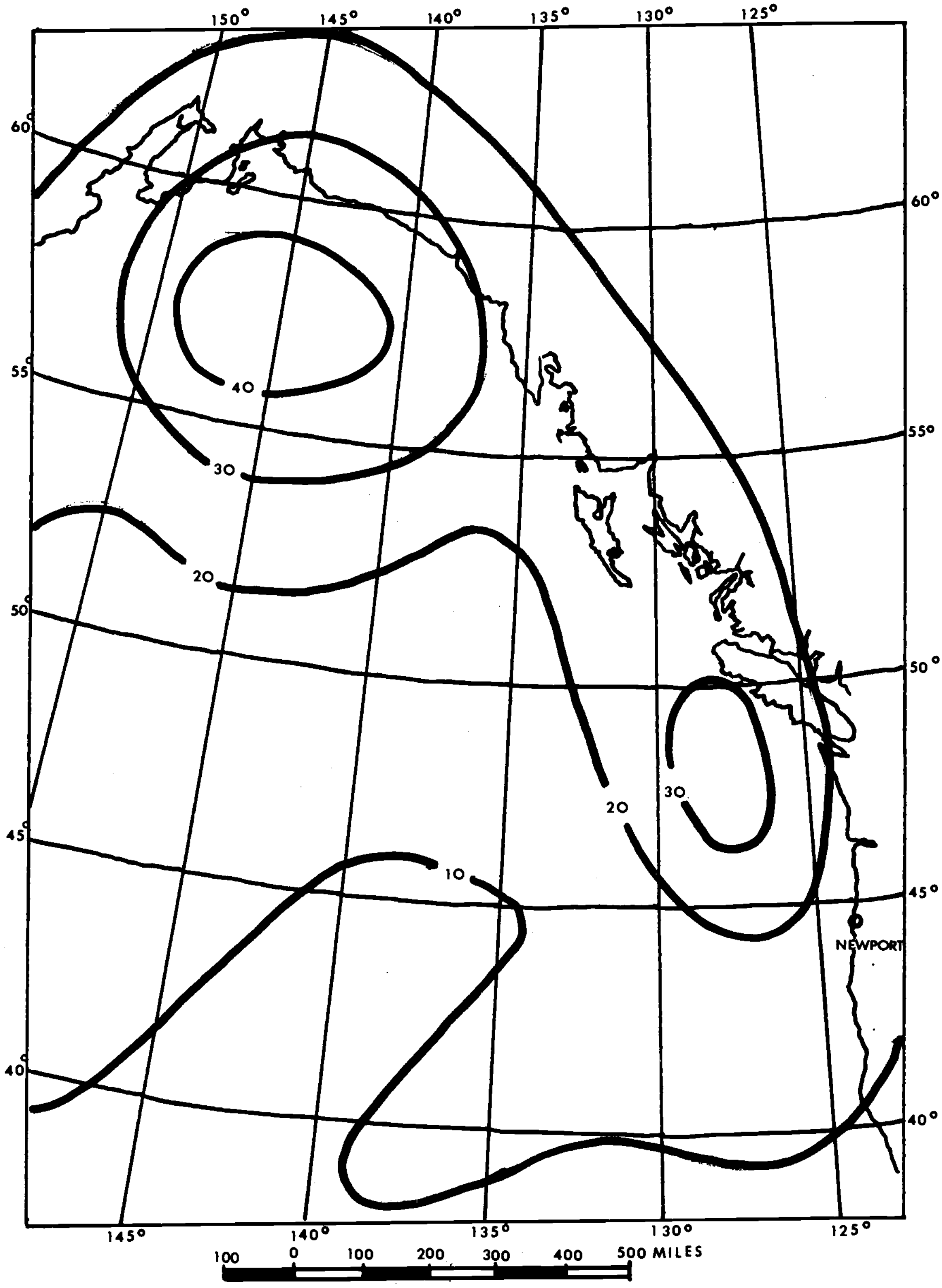


Figure 8. Number of lows for January for the period 1909-1914 and 1924-1937. Isopleths are lines of equal concentration of lows with actual number shown (from Klein, 1957).

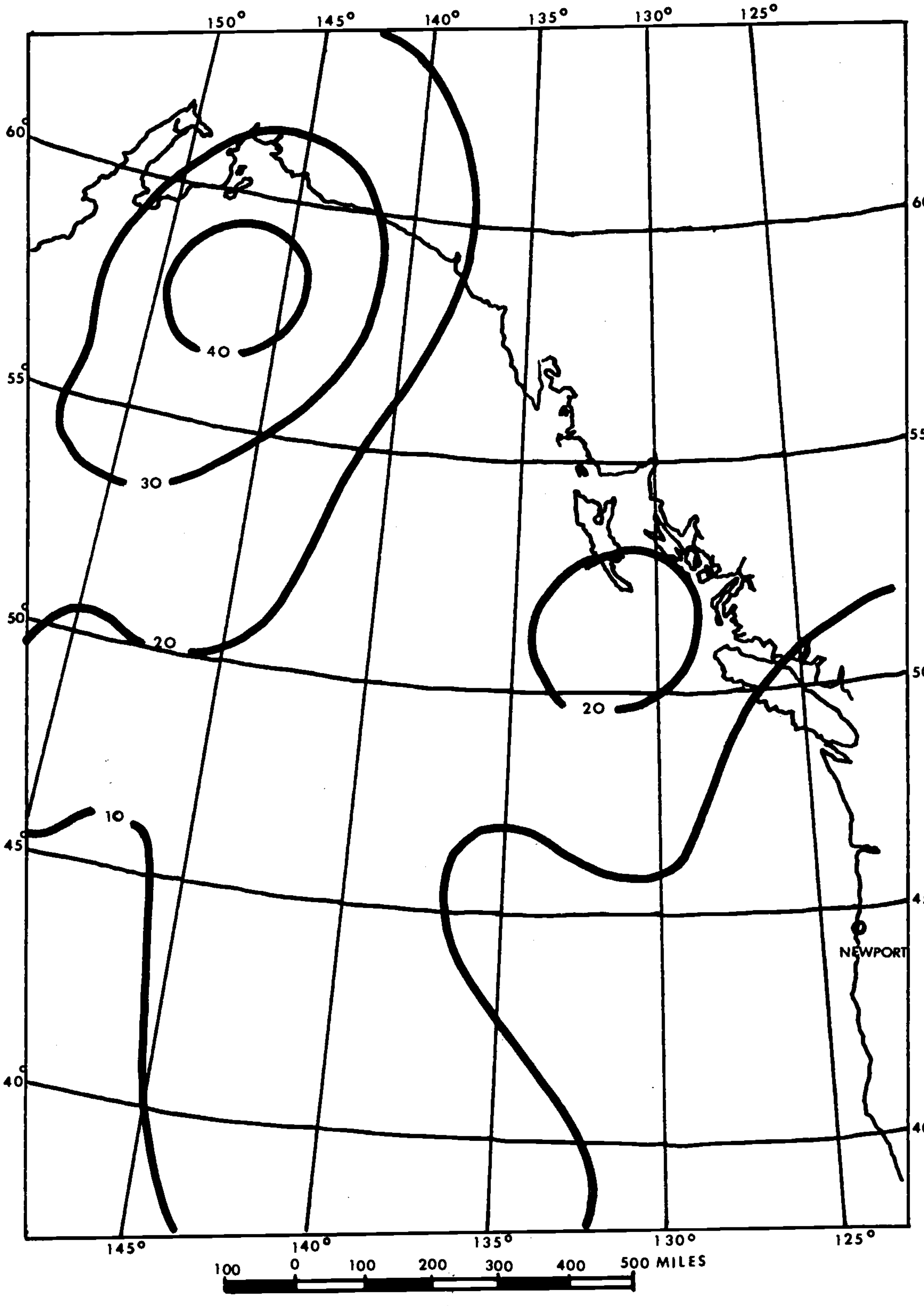


Figure 9. Number of lows for April for the period 1909-1914 and 1924-1937. Isopleths are lines of equal concentration of lows with actual number shown (from Klein, 1957).

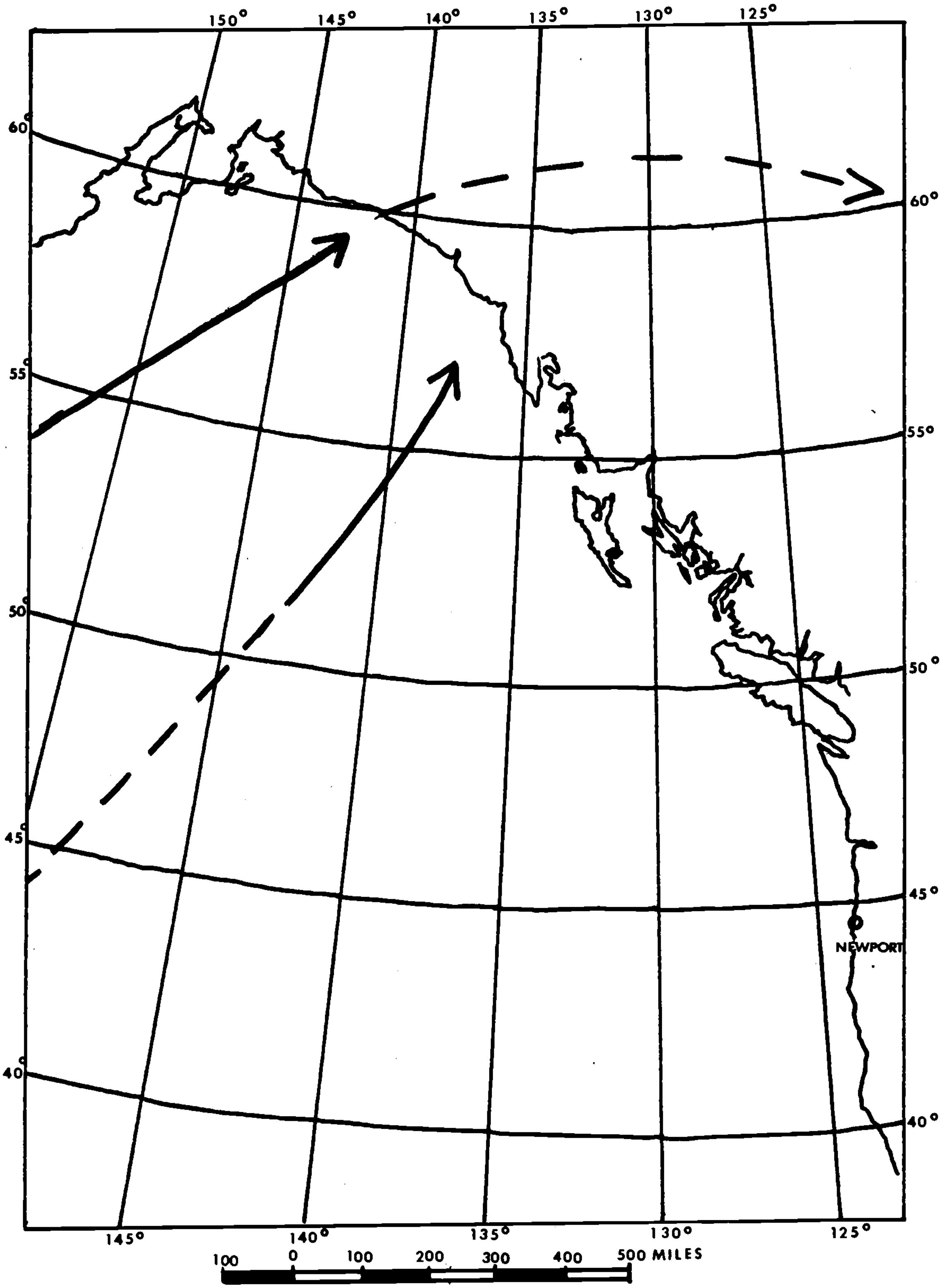


Figure 10. Principal tracks of lows for October for the period 1909-1914 and 1924-1937. Solid lines are primary tracks while dashed lines are secondary tracks (from Klein, 1957).

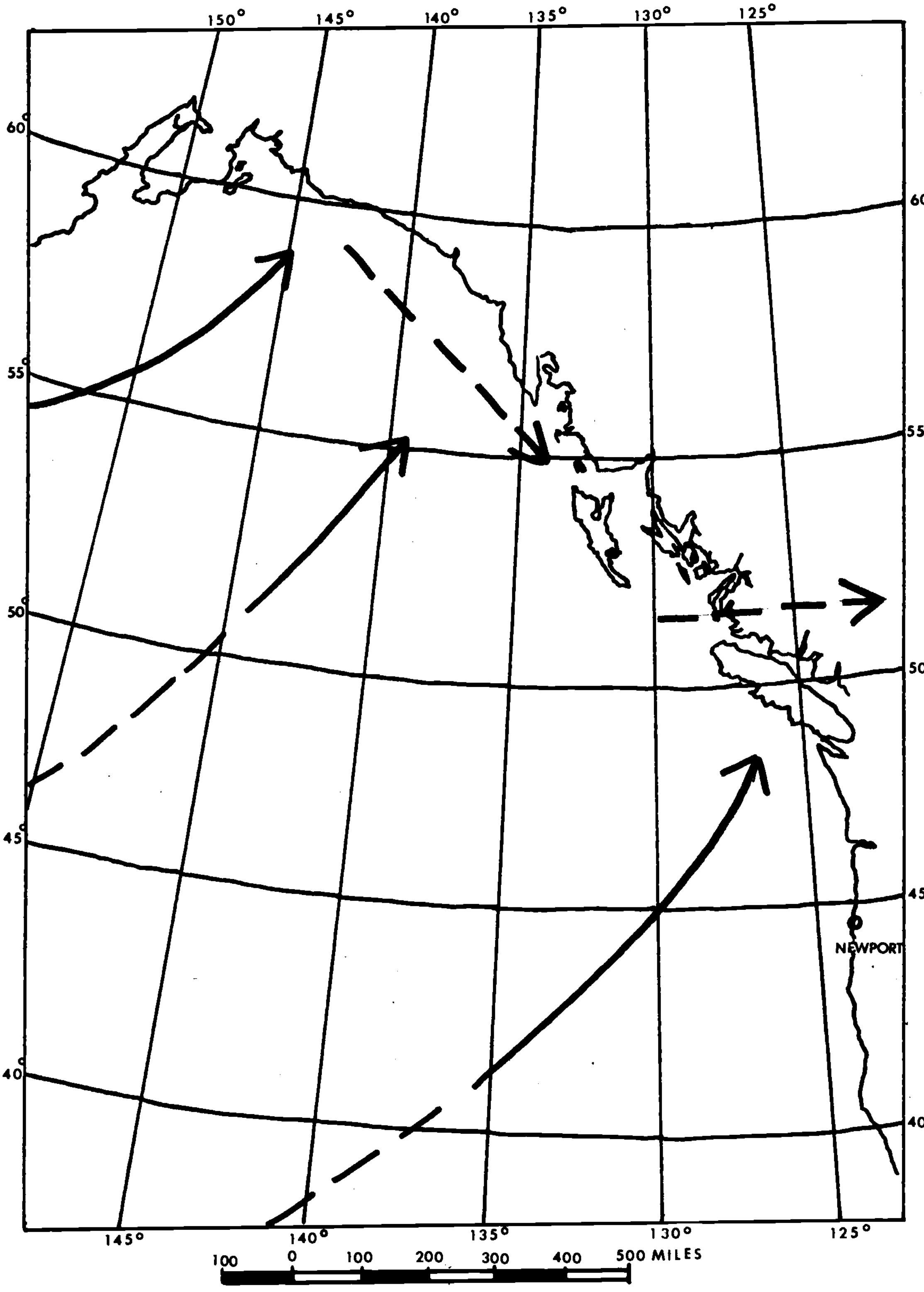


Figure 11. Principal tracks of lows for January for the period 1909-1914 and 1924-1937. Solid lines are primary tracks while dashed lines are secondary tracks (from Klein, 1957).

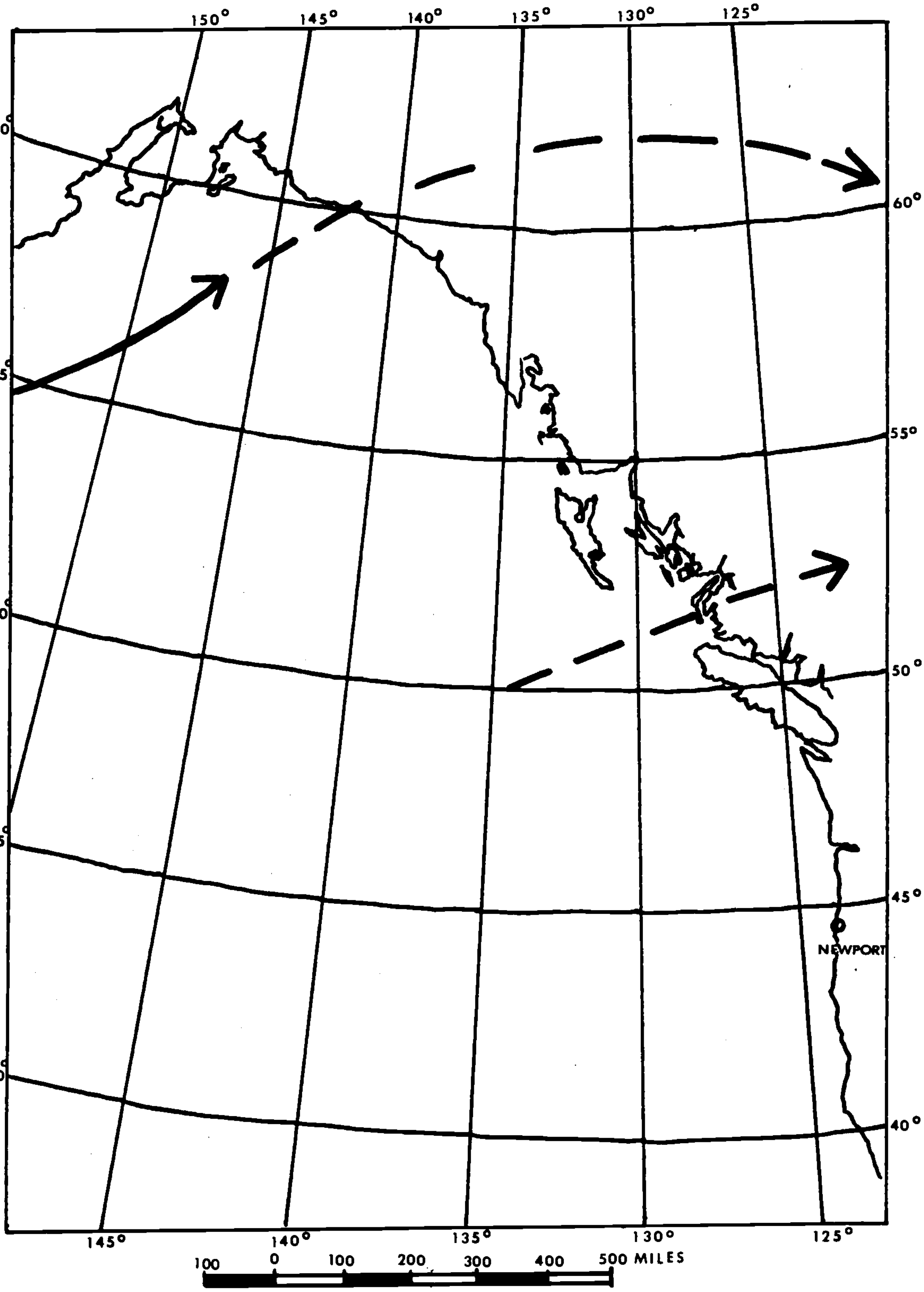
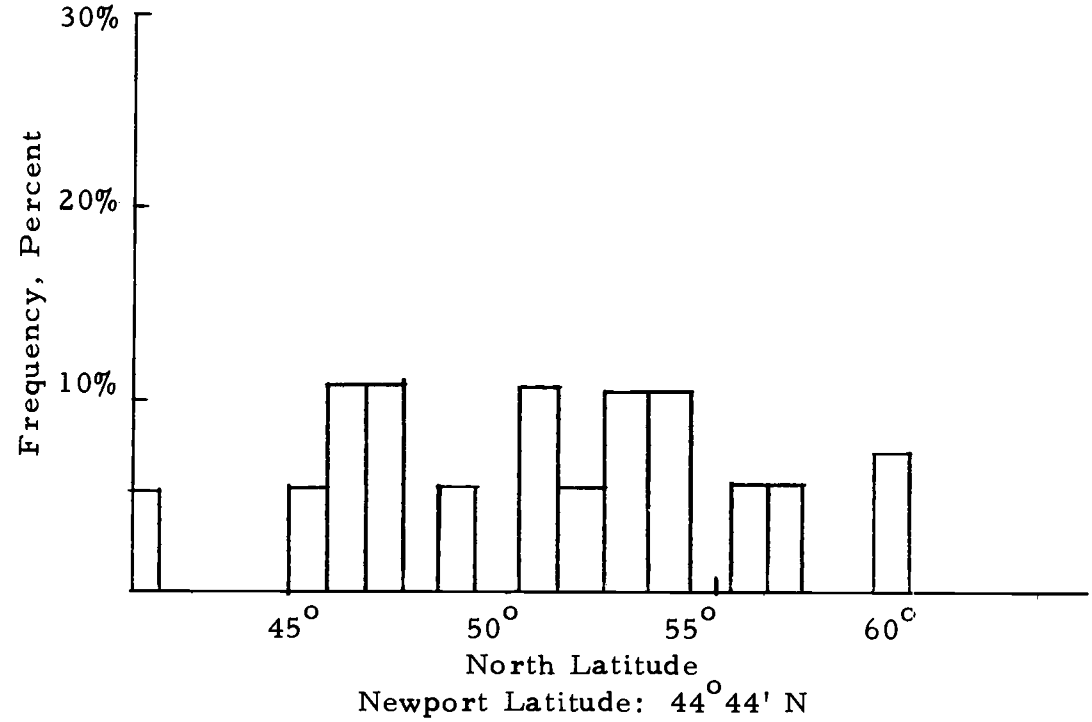


Figure 12. Principal tracks of lows for April for the period 1909-1914 and 1924-1937. Solid lines are primary tracks while dashed lines are secondary tracks (from Klein, 1957).

regions of maximum cyclone frequency and in routes normally followed by cyclones affecting the Pacific Northwest.

The relationship between the location of cyclone centers and the magnitude of the recorded peak winds was next examined. The percent population of cyclone centers along lines of latitude and longitude for the four wind speed categories are shown in Figures 13 through 16. Each figure also displays the average distance from Newport to the particular group of cyclones within the speed category. It can be seen that as the wind speed category increases from 1 to 4, the area bounding these pressure systems, centered on Newport, decreases. Furthermore, the stronger cases of wind, measured at Yaquina Head, were associated with the nearer cyclones.

To test the relationship between cyclone location and the wind speed category, a contingency table was constructed (Table 2). Each contingency table used in this study is a 2 x 2 contingency table with columns, rows, and total appropriately labeled. This contingency table is used to test the null hypothesis which asserts that the rows and columns are independent. In this instance, we are testing whether the wind speed category belonging to the four groups of cyclones is related to their proximity to Newport. Each cell is assigned the observed value O_i along with an expected value E_i. The expected value in each cell is the product of the marginal totals divided by the grand total. To test the validity of the null hypothesis



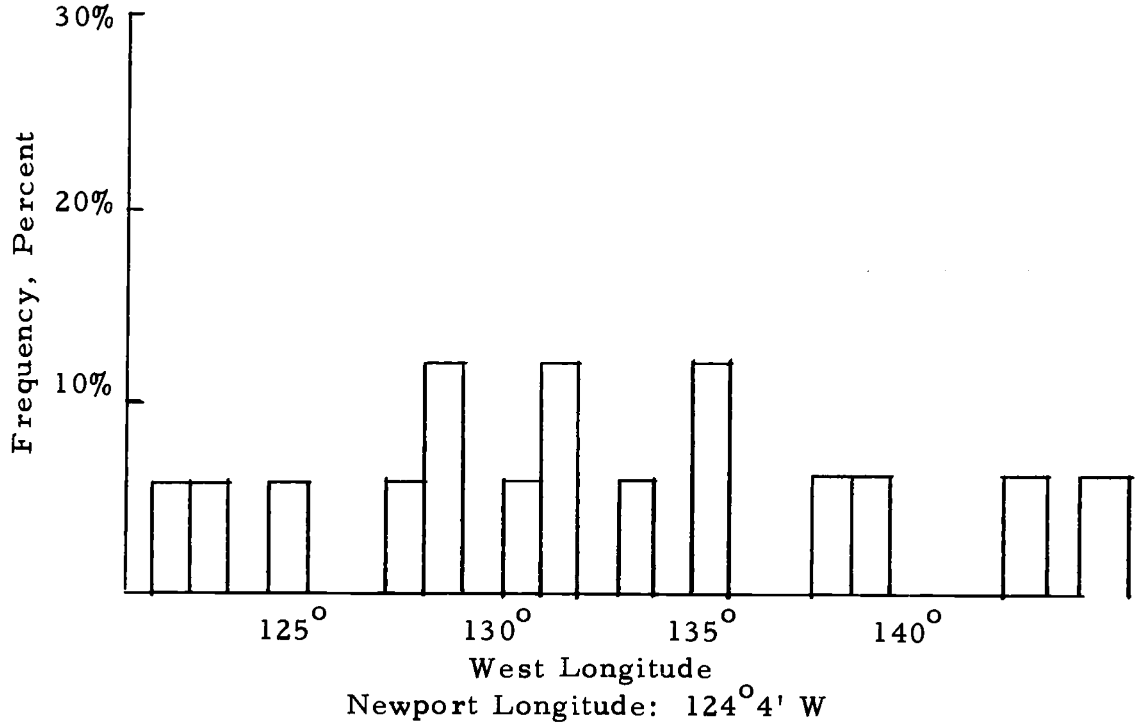
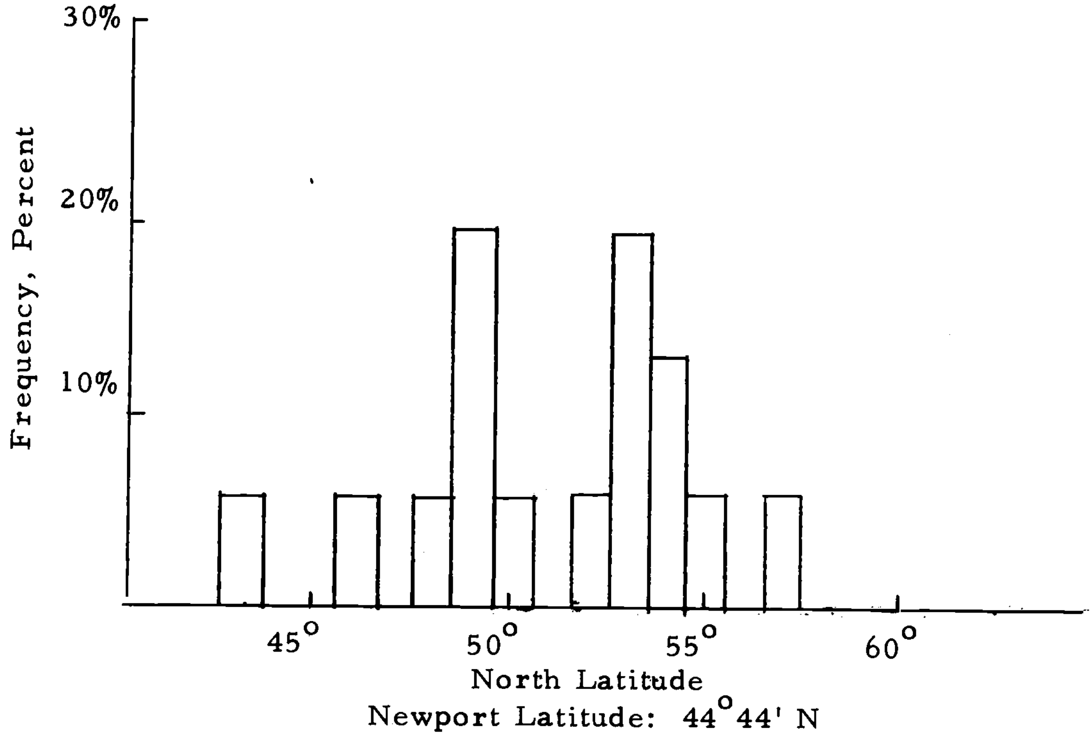


Figure 13. Location of lows associated with winds 35 kt to 39 kt. Average distance from Newport, Oregon, to all cyclones within this category is 1000 km.



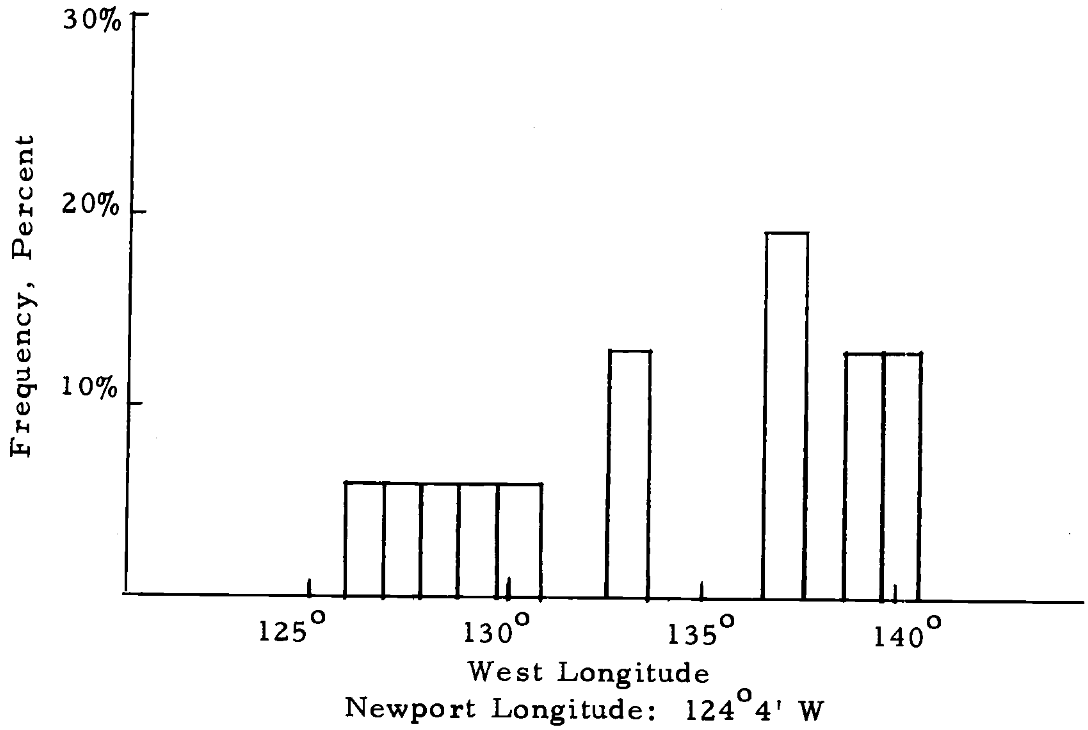
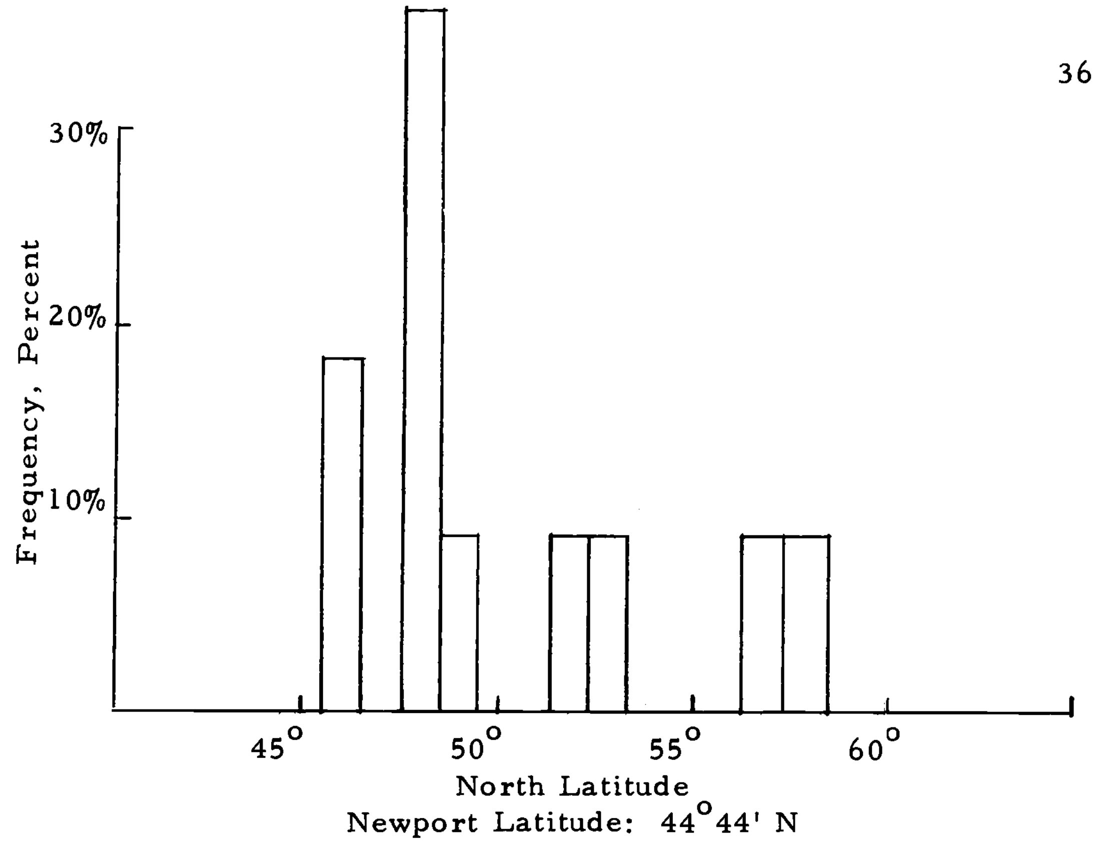


Figure 14. Location of lows associated with winds 40 kt to 44 kt. Average distance from Newport, Oregon, to all cyclones within this category is 1050 km.



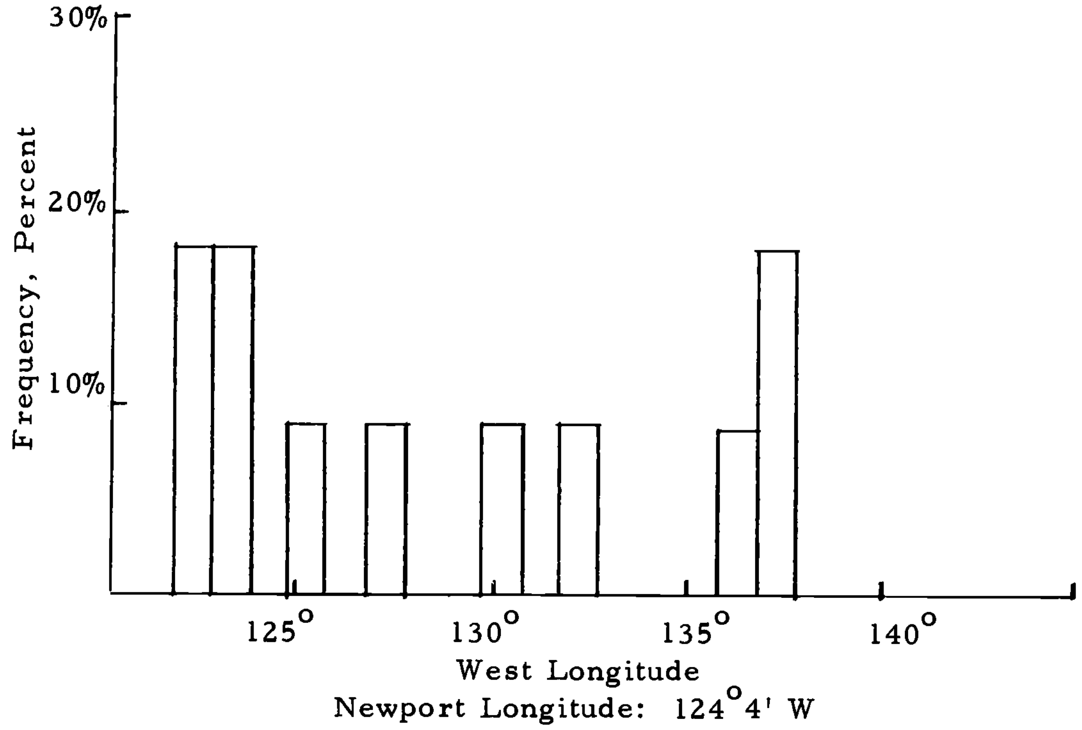
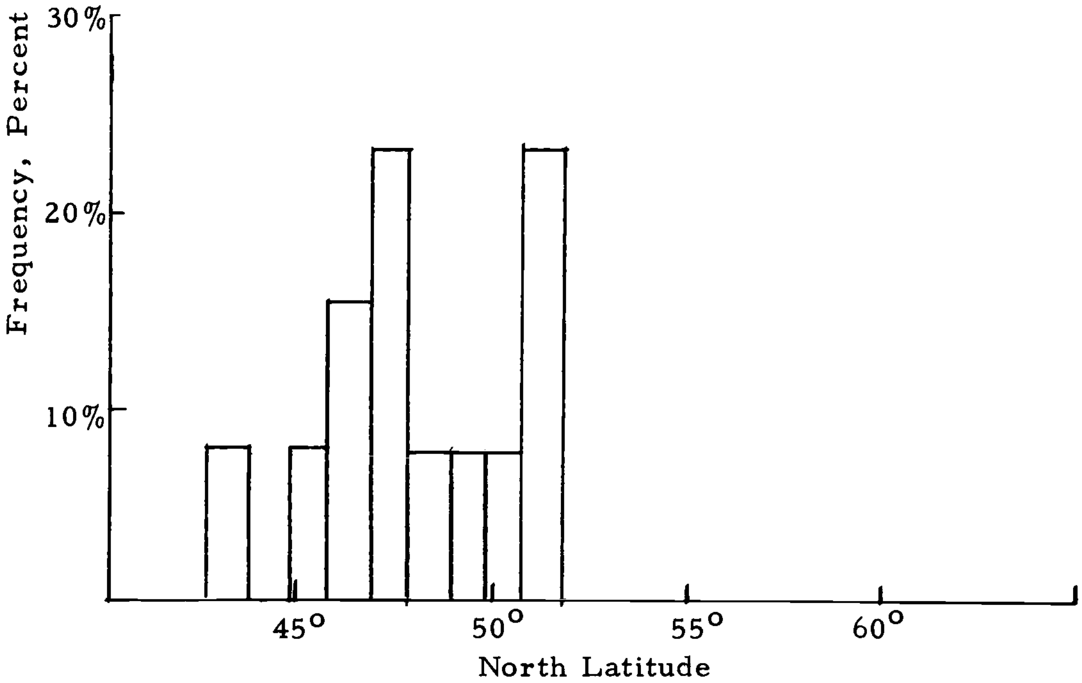


Figure 15. Location of lows associated with winds 45 kt to 49 kt. Average distance from Newport, Oregon, to all cyclones within this category is 970 km.



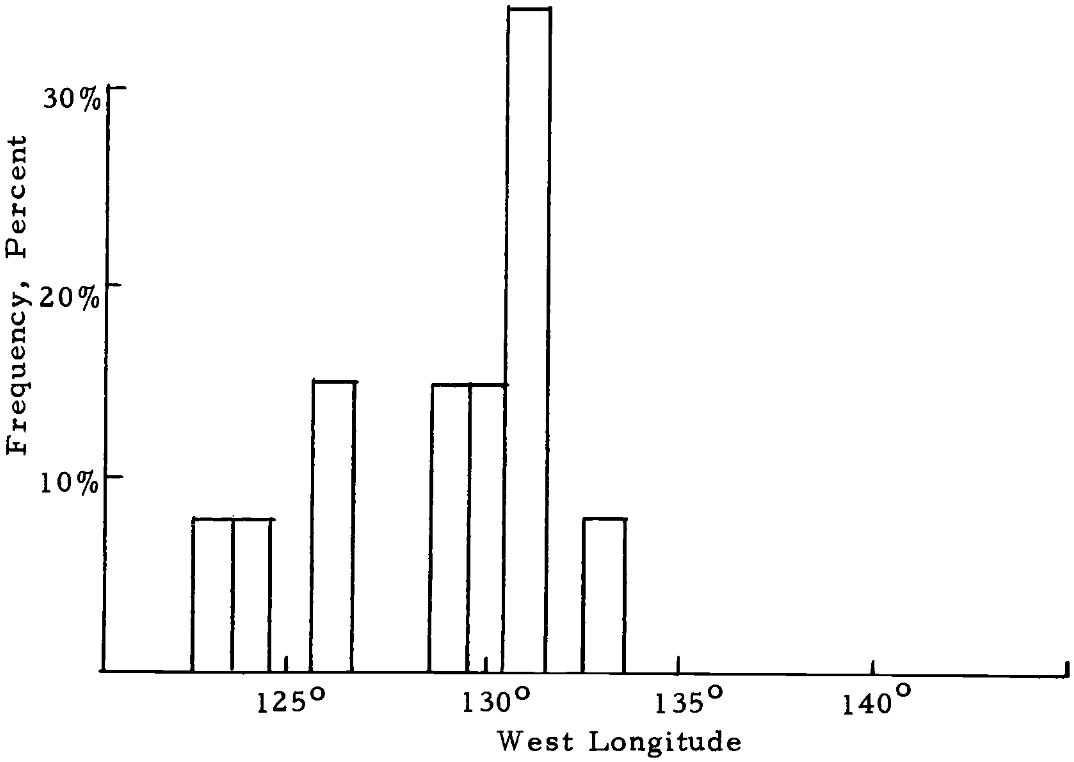


Figure 16. Location of lows associated with winds greater than or equal to 50 kts. Average distance from Newport, Oregon, to all cyclones within this category is 540 km.

Table 2. A 2 x 2 contingency table comparing cyclone proximity to Newport, Oregon, and the wind speed category.

Wind Speed Category	Proximity to Newport, Oregon		Total
	Near	Far	
< 45 kt	$O_i = 11$ $E_i = 16$	$O_i = 21$ $E_i = 16$	32
$\geq$ 45 kt	$O_i = 18$ $E_i = 13$	$O_i = 7$ $E_k = 12$	25
Total	29	28	57

$$\sum_{i=1}^{m} \left[\frac{(O_i - E_i)^2}{E_i} \right] = 7.9$$

$$\chi^2 (7.94) < 1\%$$

the observed values and expected values of each cell are placed into the test statistic

$$\sum_{i=1}^{m} \frac{(O_i - E_i)^2}{E_i}$$

which is known to have a chi square (χ^2) distribution with one degree of freedom (Panofsky et al., 1965). Here m is the number of categories, in this instance 4. The degree of freedom is given by:

(number of rows - 1) (number of columns - 1)

For this contingency table, the columns are labeled with the distance category, "near" and "far." Cyclone position was determined by dividing the entire population of pressure systems into two parts by drawing an arc centered upon Newport. The radius of this arc was found to be 822 km (Figure 17). The result of this division allowed 29 cyclones to be considered as "near" and 28 cyclones to be labeled as "far." The appropriate row of the contingency table was labeled with the speed category < 45 kt or ≥ 45 kt. The calculated value for the test statistic is 7.9 (Table 2) which exceeds the critical value in a chi squared distribution at the one percent level. Rejecting the null hypothesis and accepting the alternate hypothesis, we then conclude that the wind speed classes are related to the proximity of the cyclone center to Newport.

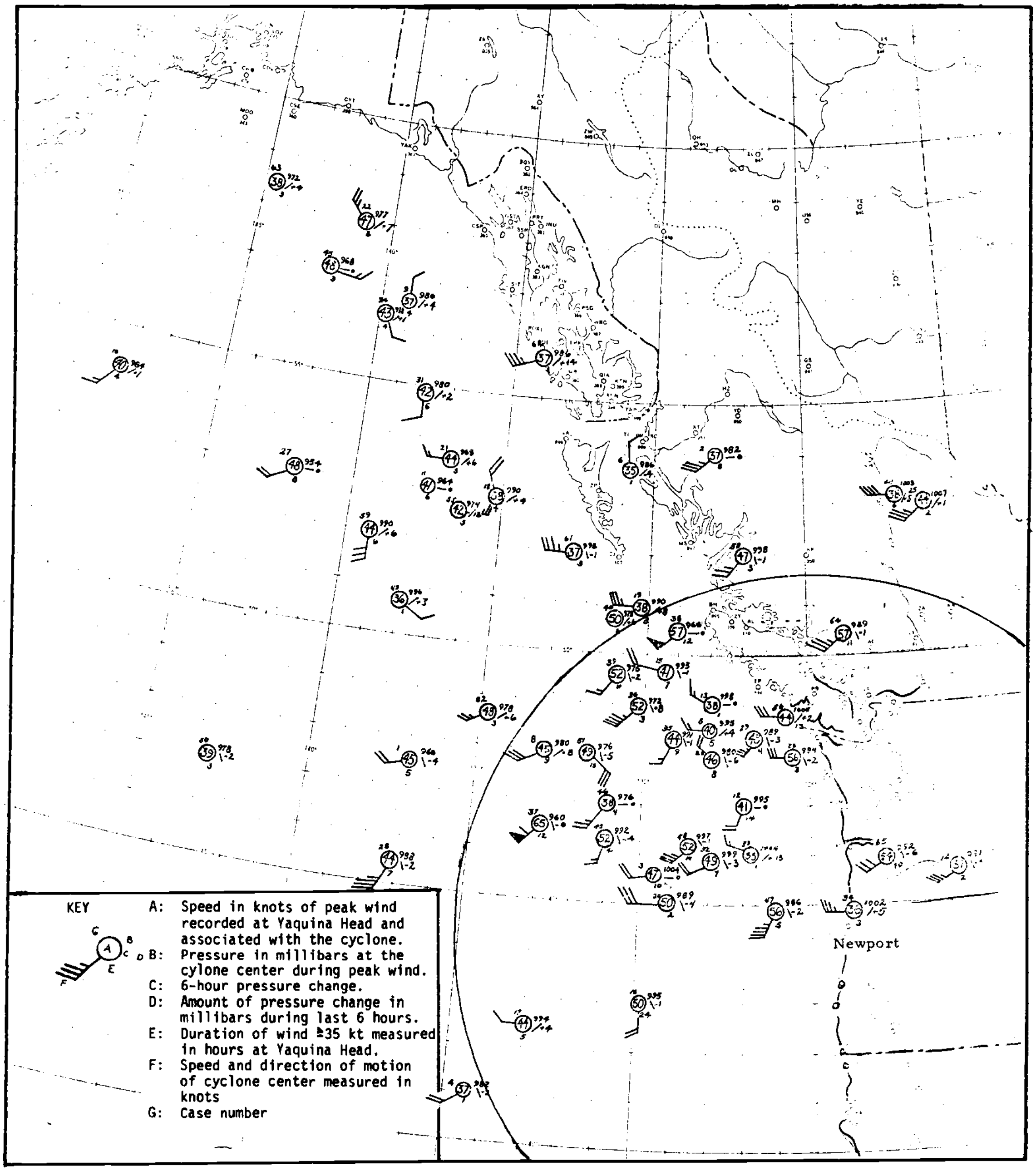


Figure 17. Two classes of cyclone location: those within 820 km, and those beyond 820 km from Newport, Oregon.

Cyclone Central Pressure

The relationship between the sea level pressure found at the center of the cyclones and the four wind speed categories was examined next. Only pressure centers with at least one enclosed isobar and lasting for at least 12 hours were considered. The values for central pressure were recorded from surface charts nearest in time to the observed strong winds at Yaquina Head. The range of central pressure varied from 954 mb in case number 27 to 1007 mb in case number 25. For each of the four wind cases, five pressure categories were constructed: $\leq$ 970 mb, 971 mb to 980 mb, 981 mb to 990 mb, 991 mb to 1000 mb, and > 1000 mb. Four of the five pressure categories are represented for each wind speed case with the category 991 mb to 1000 mb appearing most frequently (Figures 18 and 19). A relationship between observed strong winds and the value of pressure found at the cyclone center does not appear likely from this body of data since a pattern has failed to appear.

Cyclone Pressure Change

The change in surface pressure within the cyclone center was likewise examined and attempts were made to find a correlation between these pressure changes and the observed strong coastal winds. The pressure change for each cyclone was determined by subtracting

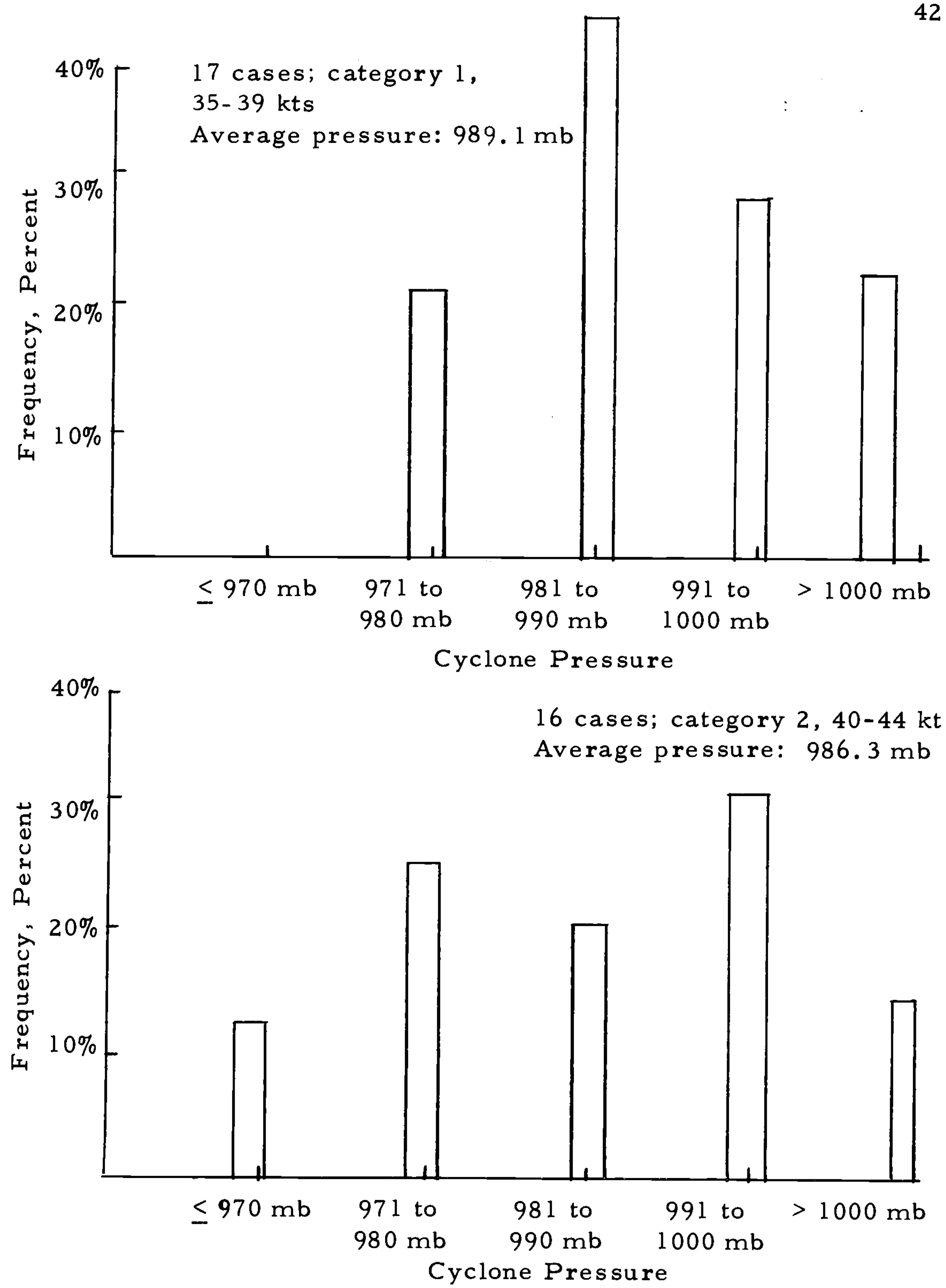
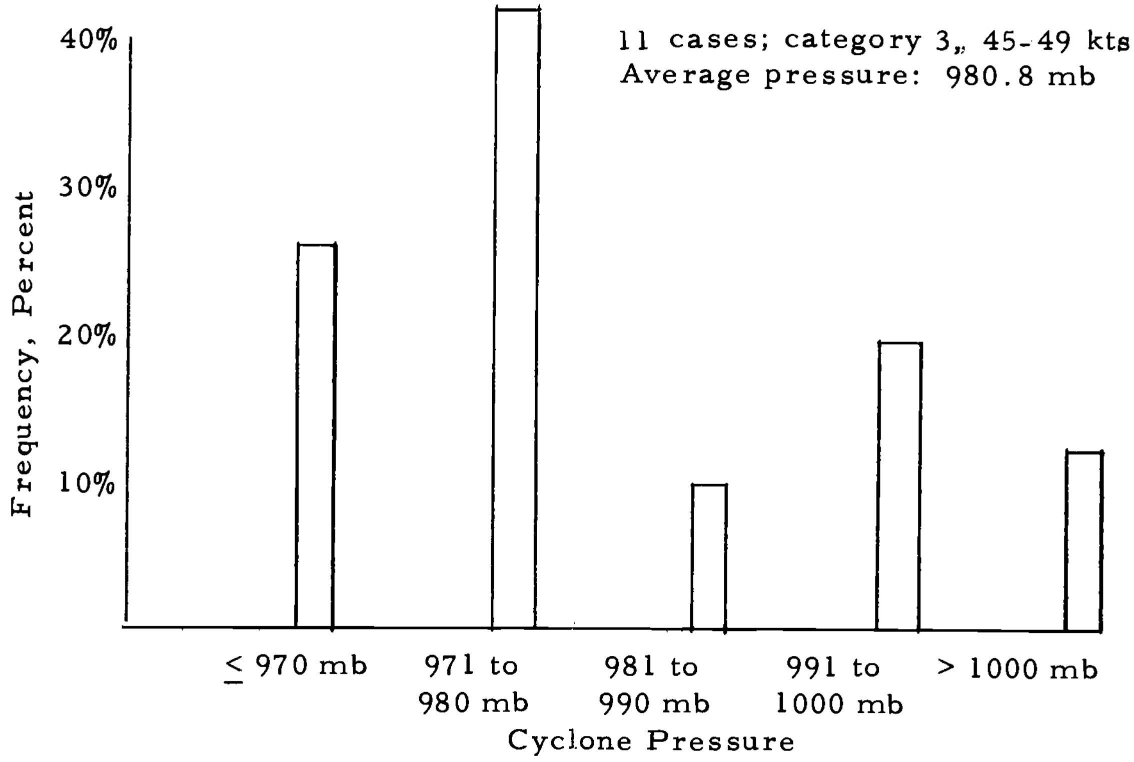


Figure 18. The percent frequency of pressure values assigned to cyclone centers for two wind speed categories.



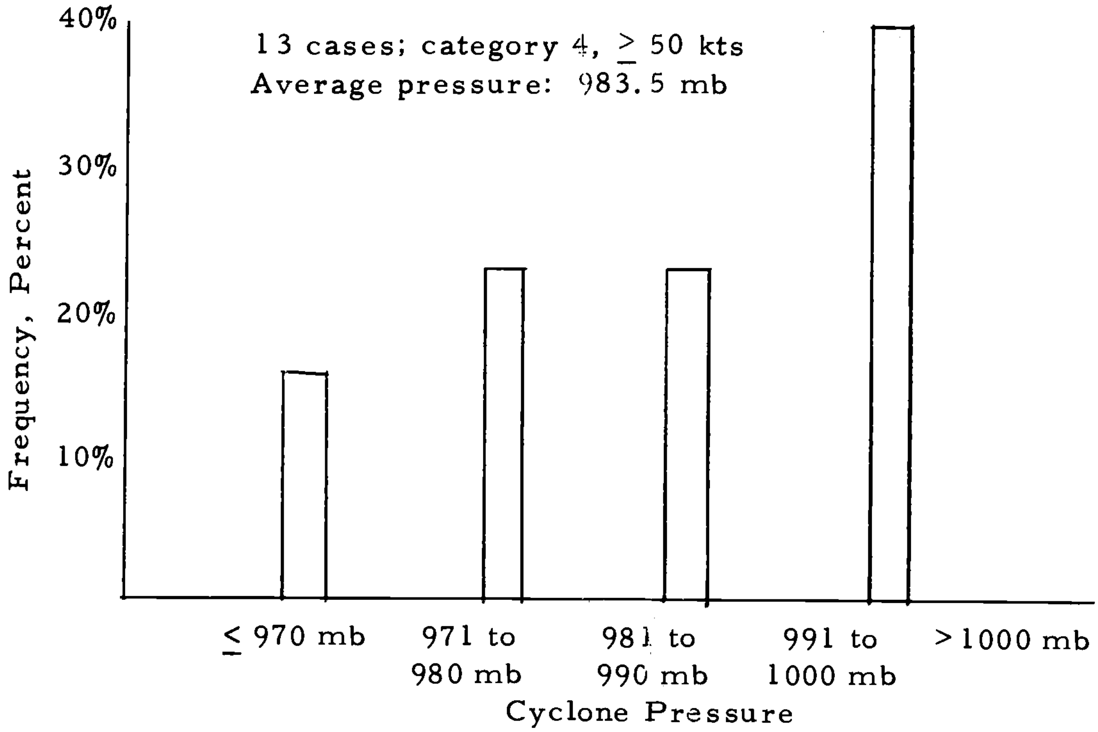


Figure 19. The percent frequency of pressure values assigned to cyclone centers for two wind speed categories.

the value of central pressure, obtained from the 6 hourly surface chart at the time of the observed strong wind, from the value of central pressure obtained from the chart appearing 6 hours earlier. (These pressure changes are displayed as a part of Figure 4). An analysis of the data suggests that many of the stronger wind cases are associated with deepening pressure systems.

To test the relationship between pressure change and the wind speed classes, a contingency table has been constructed (Table 3). The rows are labeled with the appropriate wind speed classification, < 45 kt and ≥ 45 kt, while the columns are assigned the terms "filling" and "deepening." The calculated value from the test statistic is 16.8 which exceeds the critical value in a chi squared distribution at the one percent level. Rejecting the null hypothesis and accepting the alternate hypothesis, we may then conclude that the wind speed classes are related to pressure changes at the associated cyclone.

Several more contingency tables have been constructed based upon the proximity of the cyclone to Newport. The first table was constructed to test whether nearby cyclones have a greater tendency towards deepening. The columns are labeled as "near" or "far" while the rows are assigned the conditions of pressure change (Table 4). The value from the test statistic is 12.00, large enough to permit us to reject the null hypothesis and accept the alternate one. By accepting this alternate hypothesis we will be wrong less than 0.1

Table 3. A 2 x 2 contingency table comparing the 6-hr. pressure tendency of cyclones to the wind speed category.

Wind Speed Category	6 hr. Pressure Tendency Filling	Deepening	Total
< 45 kt	$O_i = 21$ $E_i = 14$	$O_i = 7$ $E_i = 14$	28
$\geq$ 45 kt	$O_i = 3$ $E_i = 10$	$O_i = 17$ $E_i = 10$	20
Total	24	24	48

$$\sum_{i=1}^{m} \left[\frac{(O_i - E_i)^2}{E_i} \right] = 16.8$$

$$\chi^2_{(1)} \; (16.8) \; < 0.1\%$$

Table 4. A 2 x 2 contingency table comparing cyclone proximity to Newport, Oregon, to the 6-hr. pressure tendency of the cyclones.

Pressure Tendency	Proximity to Newport, Oregon		Total
	Near	Far	
Deepening	$O_i = 18$ $E_i = 12$	$O_i = 6$ $E_i = 12$	24
Filling	$O_i = 6$ $E_i = 12$	$O_i = 18$ $E_i = 12$	24
Total	24	24	48

$$\sum_{i=1}^{m} \left[\frac{(O_i - E_i)^2}{E_i} \right] = 12.0$$

$$\chi^2_{(1)} \quad (12.0) \quad < 0.1\%$$

percent of the time. It appears, then, that for many nearby cyclones, mainly the large population southwest of Vancouver Island which are associated with the winds $\geq$ 35 kt measured at Yaquina Head, the chance is high that the system is deepening. This finding is in agreement with studies by Carpenter (1945) and data published by the U. S. Navy (Figure 20).

It might follow from the above findings that the higher wind speed cases are associated more often with "nearby" deepening cyclones. A 2 x 2 contingency table constructed for the above conditions resulted in the null hypothesis being rejected and the alternative hypothesis accepted, which would be wrong less than 1 percent of the time (Table 5). In a similar manner the "far" cyclones were examined to determine what relationship the 6-hour pressure change had to their speed categories (Table 6). The result of a contingency table produced a test statistic of 0.7. The null hypothesis could not be rejected since we would be wrong 10 percent of the time.

The above results suggest that for the more distant cyclones, between 820 km and 2100 km from Newport, the 6-hour pressure change experienced by the cyclones has little affect on surface winds measured at Yaquina Head. For cyclones within 820 km, however, this may not be the case. Just how the local winds are affected by a deepening cyclone offshore is not totally clear. It would be expected that, as the pressure gradient increased locally in time due to a

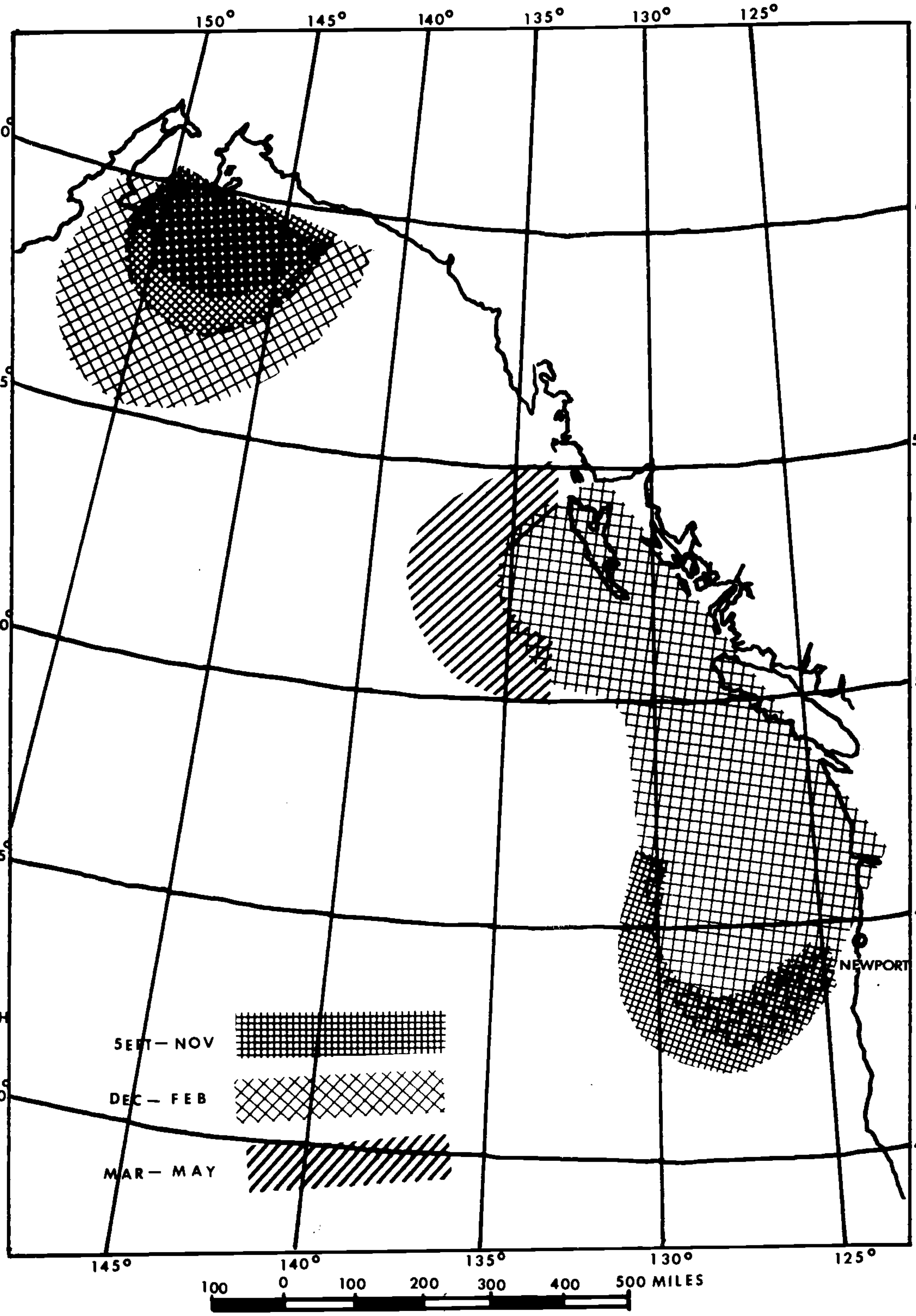


Figure 20. Principal areas of cyclogenesis (after U. S. Department of the Navy, 1957).

Table 5. A 2 x 2 contingency table comparing the 6-hr. pressure tendency of near cyclones to the wind speed categories.

Speed Category	6-hr. Pressure Tendency for Near Cyclones		Total
	Filling	Deepening	
< 45 kt	$O_i = 5$ $E_i = 2$	$O_i = 4$ $E_i = 7$	9
$\geq$ 45 kt	$O_i = 1$ $E_i = 4$	$O_i = 14$ $E_i = 11$	15
Total	6	18	24

$$\sum_{i=1}^{m} \left[\frac{(O_i - E_i)^2}{E_i} \right] = 7.2$$

$$\chi^2_{(1)} \quad (7.2) \quad < 1\%$$

Table 6. A 2 x 2 contingency table comparing the 6-hr. pressure tendency of far cyclones to the wind speed category.

Wind Speed Category	6-hr. Pressure Tendency for Far Cyclones		Total
	Filling	Deepening	
< 45 kt	$O_i = 15$ $E_i = 14$	$O_i = 4$ $E_i = 5$	19
$\geq$ 45 kt	$O_i = 3$ $E_i = 4$	$O_i = 2$ $E_i = 1$	5
Total	18	6	24

$$\sum_{i=1}^{m} \left[\frac{(O_i - E_i)^2}{E_i} \right] = 0.7$$

$$\chi^2_{(1)} \ (0.7) > 10\%$$

deepening cyclone, the local winds would likewise increase in time. Surface charts used in this study lack significant detail to be analyzed to the degree necessary in order to answer this question.

Direction of Motion of Cyclone Centers

The direction of motion for the sea level cyclone centers associated with strong coastal winds have been recorded and plotted with other sea level data (Figure 4) and a summary appears in Table 7. Of the 57 plotted cyclones, 40 percent are moving toward the northwest. Within the 10° quadrangle (adjusted to two 5° quadrangles centered on 45° N.) adjacent to Vancouver Island and bounded by 40° N. to 50° N., 125° W. and 135° W., 54% are moving northeast, 23% are moving east, 15% are moving southeast, and 4% are moving

Table 7. Direction of cyclones associated with peak winds measured at Newport, Oregon.

Direction of Motion	Number of Cases
Northeast	23
East	12
North	6
Southeast	5
South	2
Northwest	4
Stationary	5

north. It has been shown (Figure 11) that a major storm track is located in the vicinity of Vancouver Island and directed toward the northeast. No relationship, however, has been discovered that would indicate that the direction of motion for the cyclone centers has any influence upon the speed of the winds measured at Yaquina Head.

Type of Frontal Structure

Nearly every case of strong surface wind was associated with the passage of some kind of frontal structure. For the cases of strong winds in this study the surface charts showed fronts as follows: 28 occluded fronts, 27 cold fronts, and 1 stationary front. In 9 cases, no front was indicated. It was found that strong wind cases associated equally with occluded and cold frontal systems.

Speed and Direction of Fronts

The speed and direction of fronts, like the speed and direction of motion for cyclone centers, were determined from surface charts and variously categorized. Frontal positions over the ocean unfortunately lack sufficiently accurate positions on surface charts to provide a reliable basis for analysis and correlation. An analysis was nevertheless made. No relationship could be found between the recorded wind speeds and the speed and direction of the associated frontal structure.

Duration of the Wind

Along with the other variables, the duration of the wind above the threshold value revealed some interesting results. The range of values extends from a duration of 1 hour to a duration of 24 hours. Care has been taken to avoid a situation where the strong wind from one case blends into the strong wind of the next developing case thus affecting these results. An examination of Figure 4 will reveal that many of the longer periods of high wind are associated with "near" cyclones. To test this, a contingency table was constructed with the columns assigned the terms "near" and "far," as before, and the rows labeled with the duration in hours above and below 6 hours (Table 8). The 6-hour duration is the median value for all observations. The calculated value of the test statistic is 22.9. If the null hypothesis is rejected, and the alternative hypothesis is accepted, it would be in error less than 0.1 percent of the time. Therefore, those cyclones "near" to Yaquina Head have a higher probability of producing longer periods of strong wind over the established threshold value.

Two cases have been selected to represent the synoptic condition governing both long and short periods of wind duration. Case number 62 will serve as an example of a cyclone which was associated

Table 8. A 2 x 2 contingency table comparing cyclone proximity to Newport, Oregon, to the duration of high wind recorded in the 65 cases.

Duration of High Wind	Proximity to Newport, Oregon		Total
	Near	Far	
≤ 6 hrs	$O_i = 14$ $E_i = 20$	$O_i = 26$ $E_i = 20$	40
>6 hrs	$O_i = 15$ $E_i = 9$	$O_i = 2$ $E_i = 8$	17
Total	29	28	57

$$\sum_{i=1}^{m} \left[\frac{(O_i - E_i)^2}{E_i} \right] = 22.9$$

$$\chi^2_{(1)} \quad (22.9) \quad < \; 0.1\%$$

with a short period of high wind measured at Yaquina Head, and case number 16 will illustrate an example of a cyclone related to a long period of strong wind along the coast.

For case number 62, occurring on Saturday, December 13, 1974, a center of low pressure is located at 50.5° N., 137.5° W. and is moving toward the northeast at 35 kt (Figure 21). As this low continues to advance to the northeast, it begins to stagnate and fill from 972 mb to 986 mb. Sometime near 0400 PST on December 14, the front associated with this cyclone advanced eastward across the Oregon Coast and into Eastern Oregon (Figures 22 and 23). Threshold winds were observed at Yaquina Head near midnight on December 13 and were maintained for one hour (Figure 24). The wind direction during these peak winds was 150°. By 0140 PST on December 14, the wind speed has dropped to 17 kt and veers to 195°. The threshold winds displayed on the strip chart occur concurrently with rapidly changing surface pressure (Figure 25). As the front migrated eastward, the coastal winds relaxed and veered toward the west as the pressure rose and the pressure gradient became reoriented.

As a contrast to case number 62, case number 16 produced threshold winds of long duration. On Thursday, November 8, 1973, a low center of pressure was located at 43° N., 130° W. and was traveling toward the north at 15 kt (Figure 26). During the next 12 hours it moved north to 46° N., 130° W. at 20 kt (Figures 27 and 28).

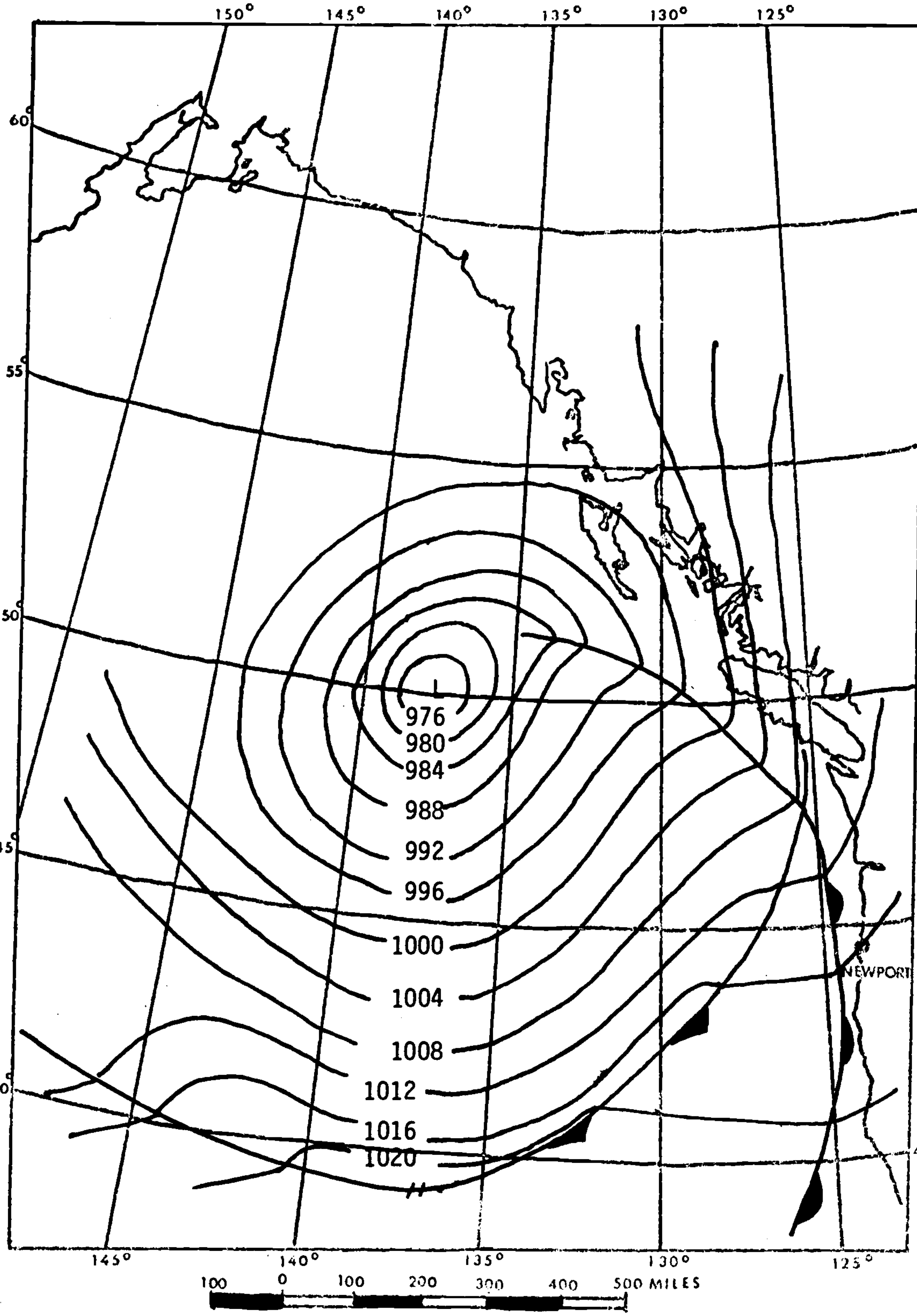


Figure 21. Surface isobar and frontal analysis for 0600Z, Saturday, December 14, 1974.

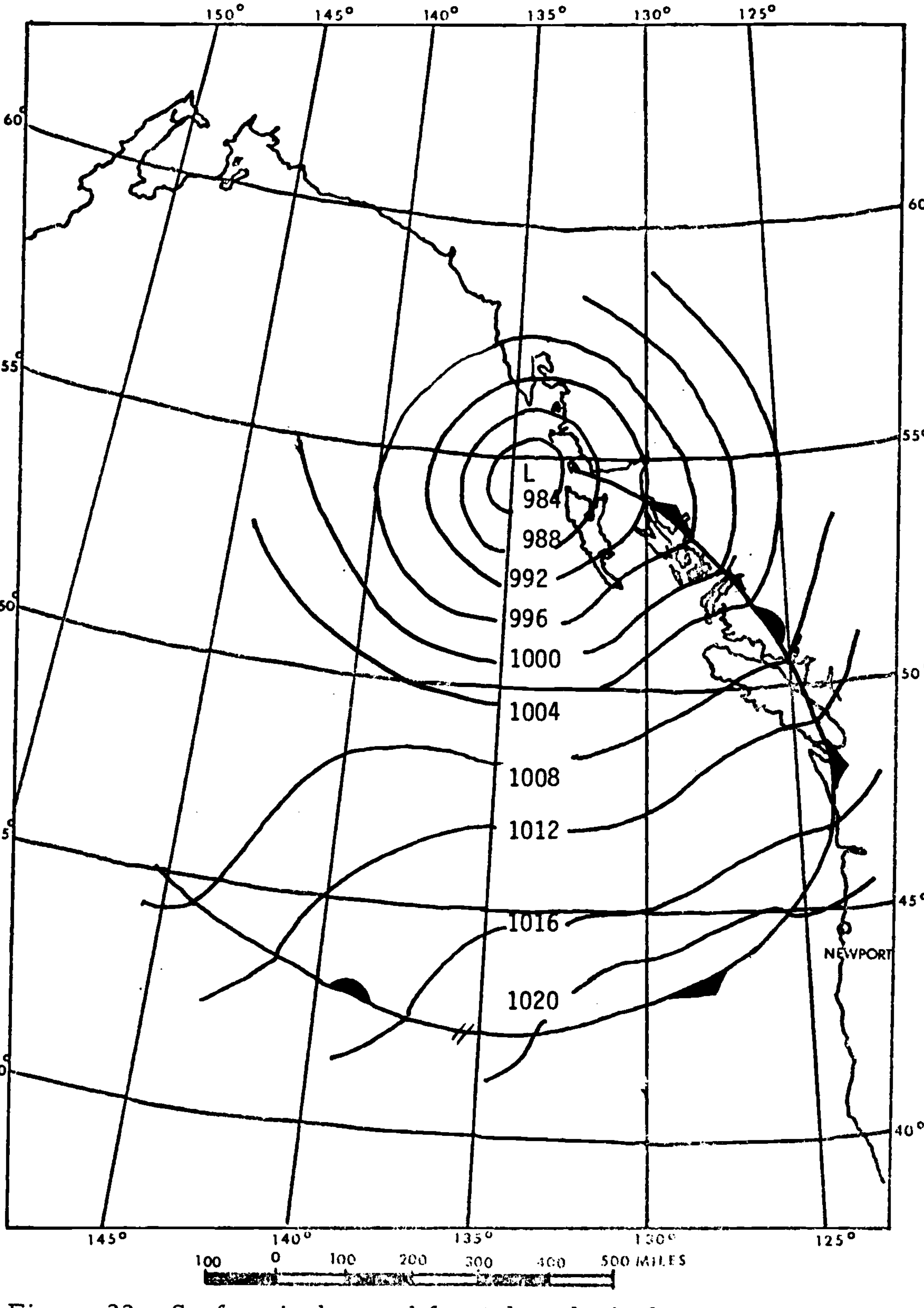


Figure 22. Surface isobar and frontal analysis for 1200Z, Saturday, December 14, 1974.

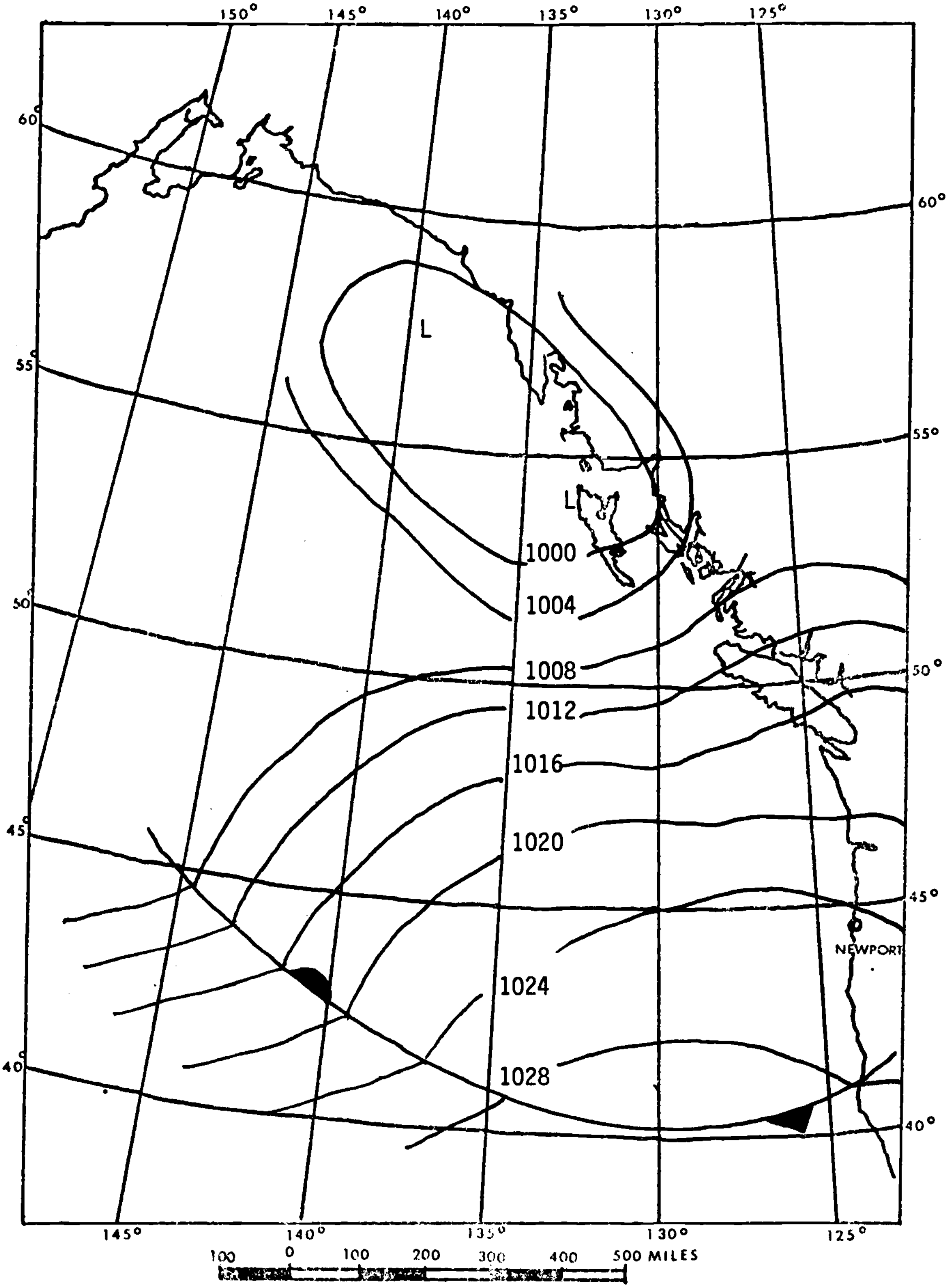


Figure 23. Surface isobar and frontal analysis for Saturday, December 14, 1974.

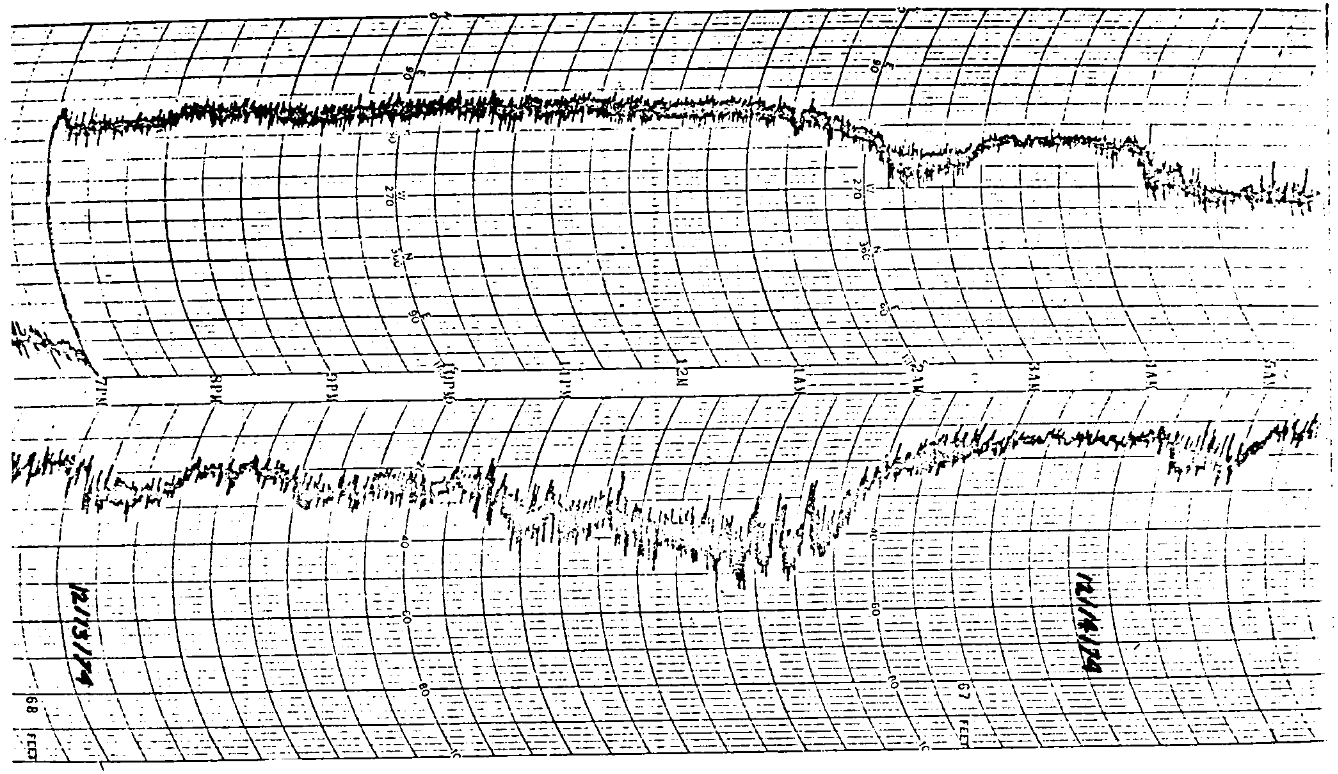


Figure 24. Wind speed (lower graph) in mph and wind direction (upper graph) in degrees for Yaquina Head.

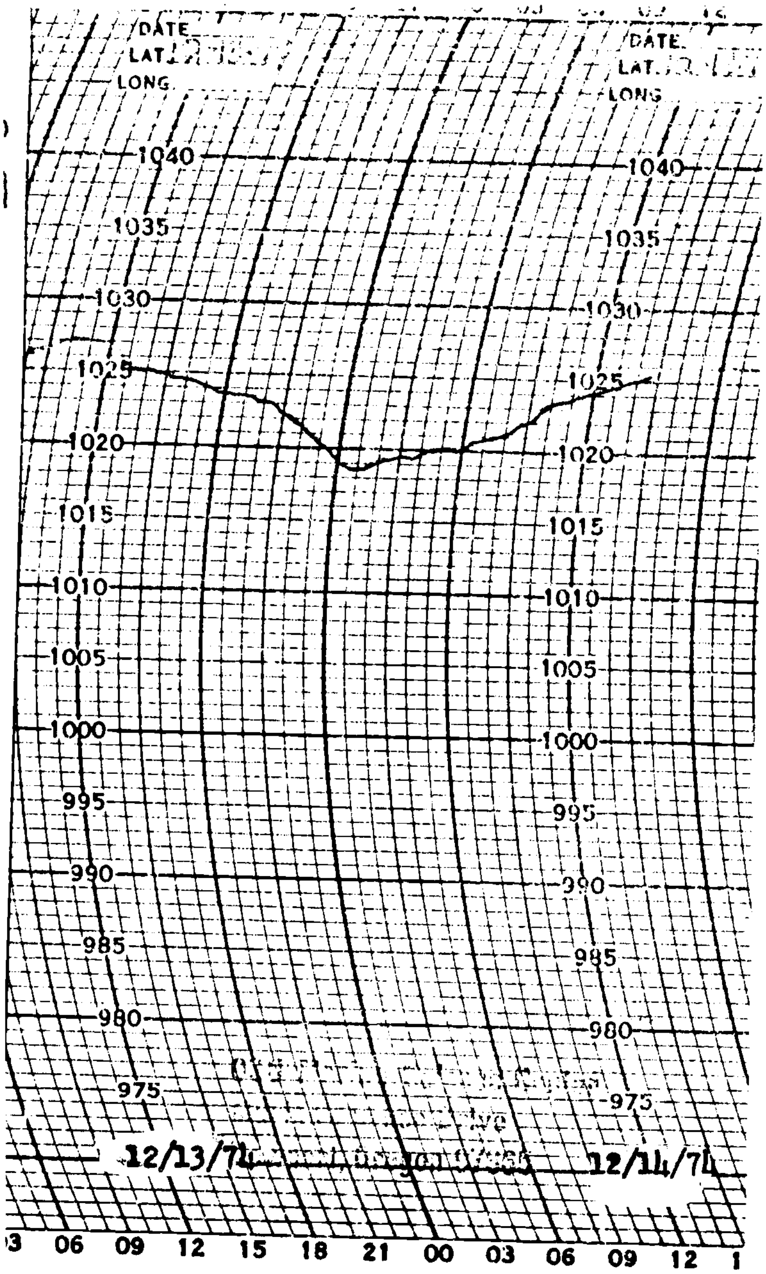


Figure 25. Surface barometric trace from Marine Science Center, Newport, Oregon, for high wind case number 62 for Saturday, December 14, 1974.

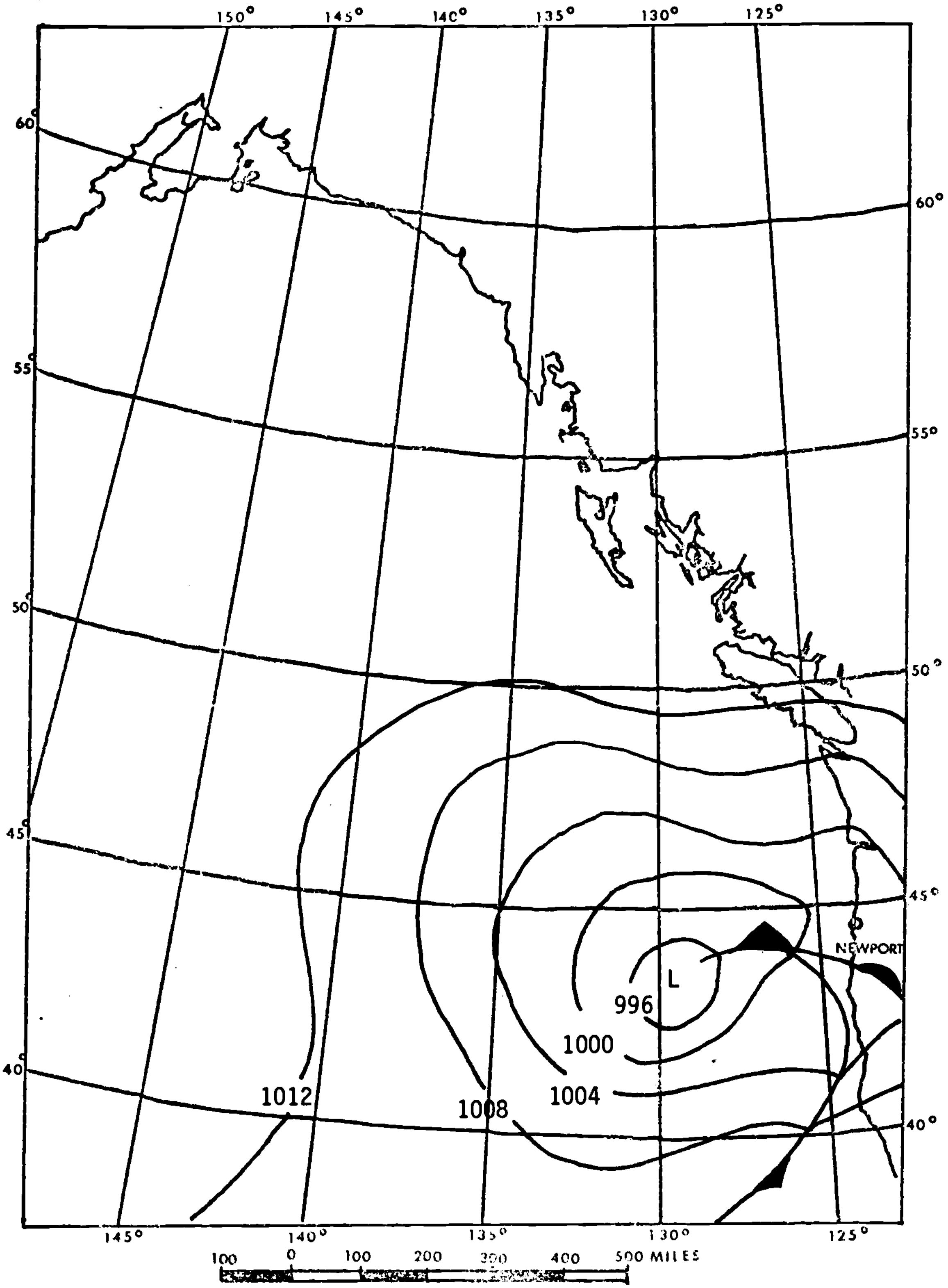


Figure 26. Surface isobar and frontal analysis for 0600Z on Friday November 9, 1973.

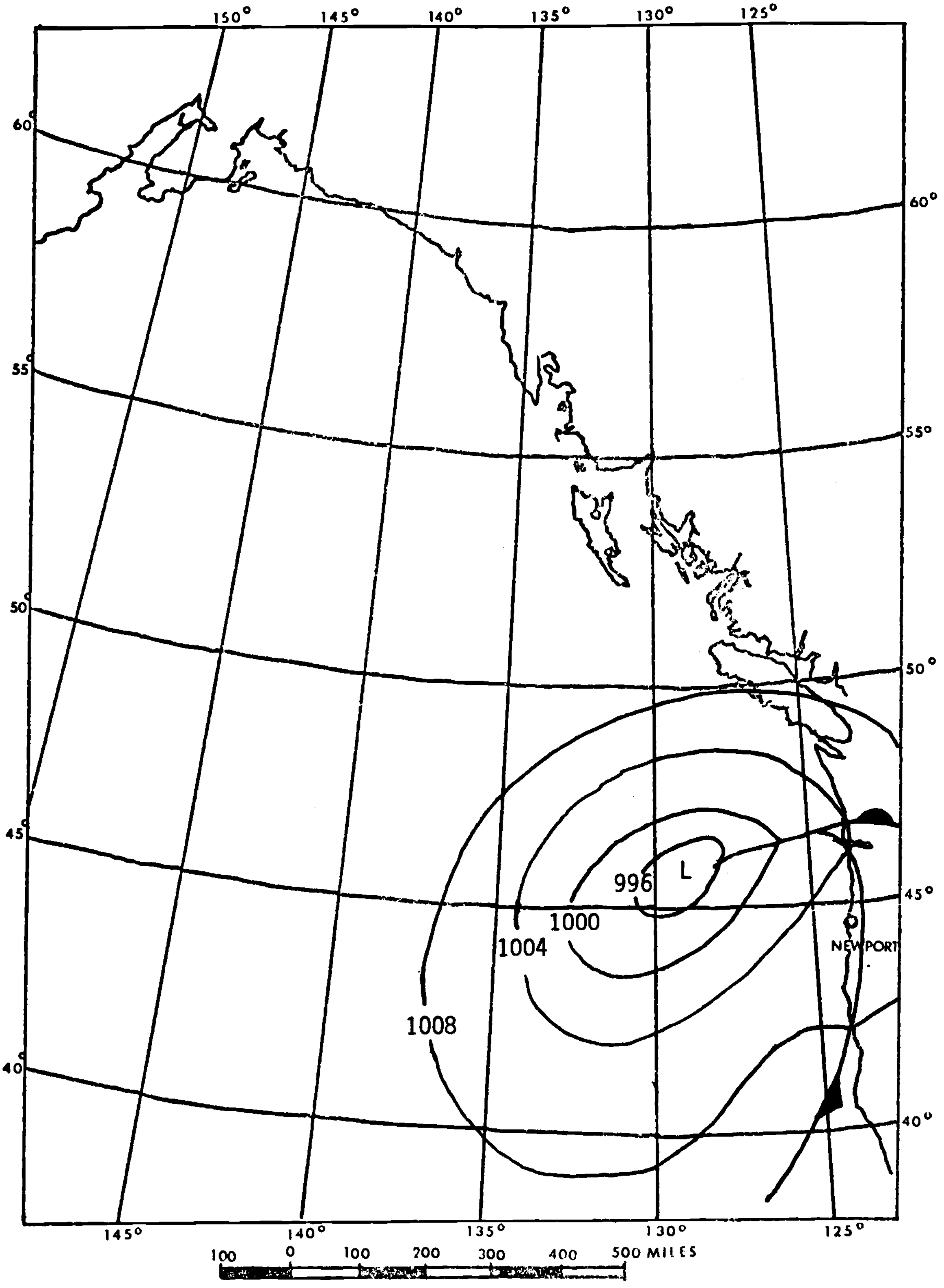


Figure 27. Surface isobar and frontal analysis for 1200Z on Friday, November 9, 1973.

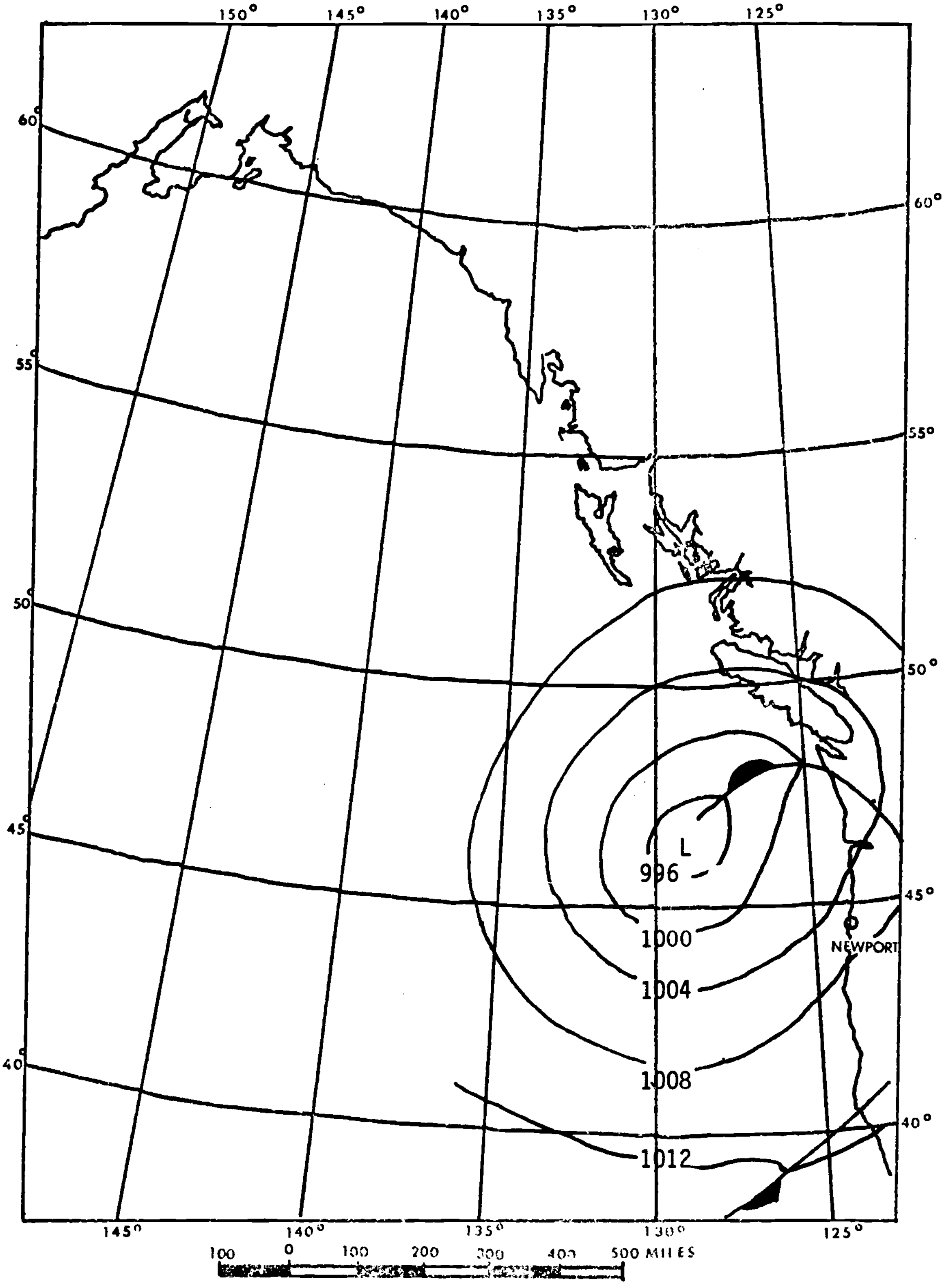


Figure 28. Surface isobar and frontal analysis for 1800Z on Friday, November 9, 1973.

The central pressure of the cyclone remained near 995 mb during that period. By 1300 PST on November 8, the cyclone center was located at 47.5^{o} N., 138^{o} W. and at 49^{o} N., 125^{o} W. at 1000 PST on November 9. The cold front with this cyclone traveled across the Oregon Coast at 0400 PST on November 9 and swept eastward across the State. At 1300 PST, on Friday, November 9, a trailing portion of the front was across the Oregon Coast (Figure 29). By 2200 PST the entire frontal system was inland (Figure 30). Threshold winds were observed at Yaquina Head at 1900 PST on November 8 and continued for 24 hours through 1900 PST on November 9 (Figure 31). There were two occasions when the instantaneous wind speed fell below the threshold value of 35 kt. Due to the averaging method earlier described, these two periods have been disregarded in smoothing. The wind direction remained generally south throughout the entire period except for a slight veering in the wind direction during the frontal passage at 0620 PST on November 9. This long period of strong surface wind occurred concurrently with falling pressure, and several hours later subsided during rising pressure (Figure 32).

The close proximity of cyclone centers to Yaquina Head contributed to the longer period of time winds remained upon the threshold value. Short periods of strong surface wind were the result of frontal systems associated with cyclones far to the north. The longer periods of high wind, however, were maintained after a frontal

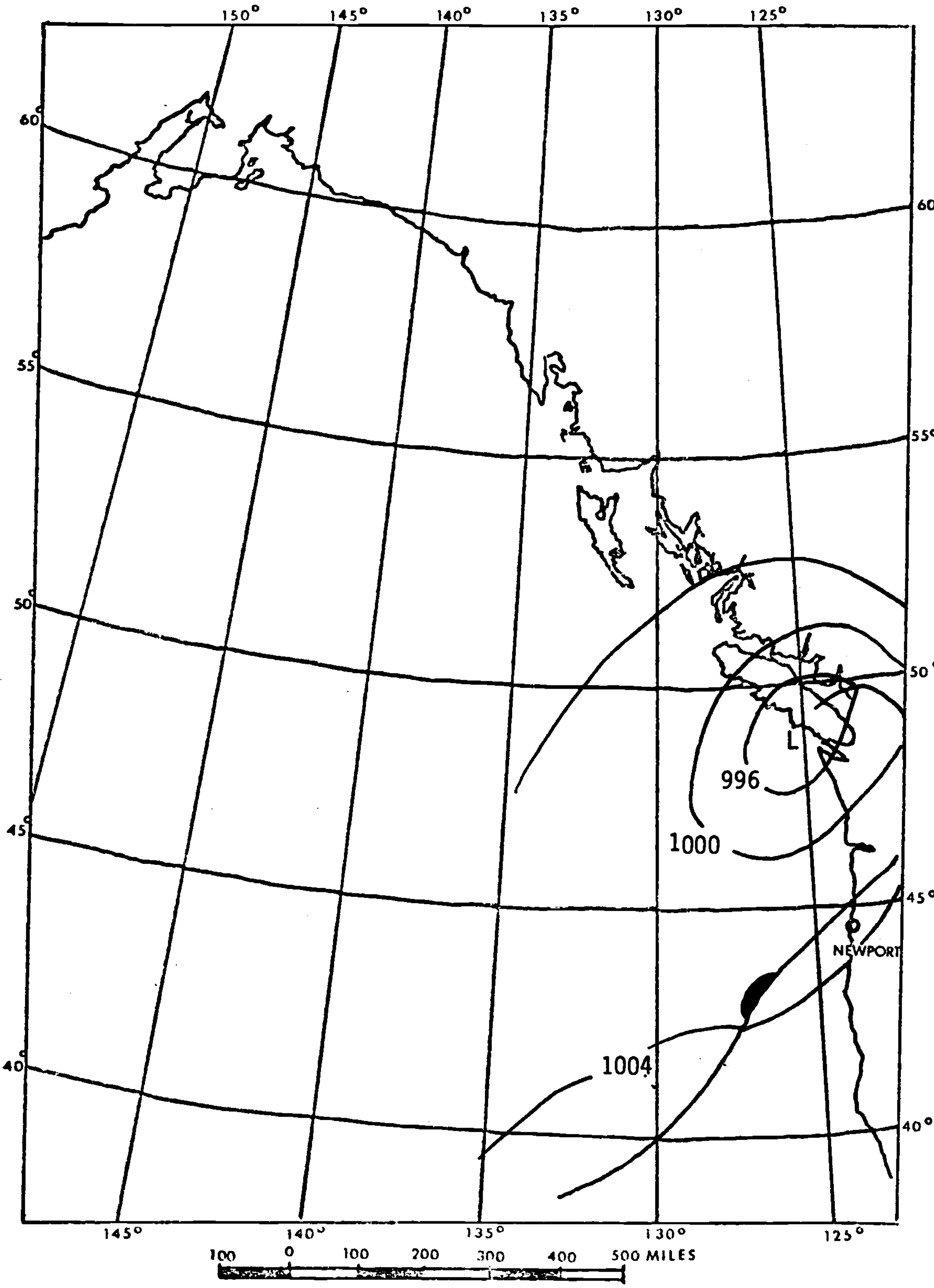


Figure 29. Surface isobar and frontal analysis for 2100Z on Friday, November 9, 1973.

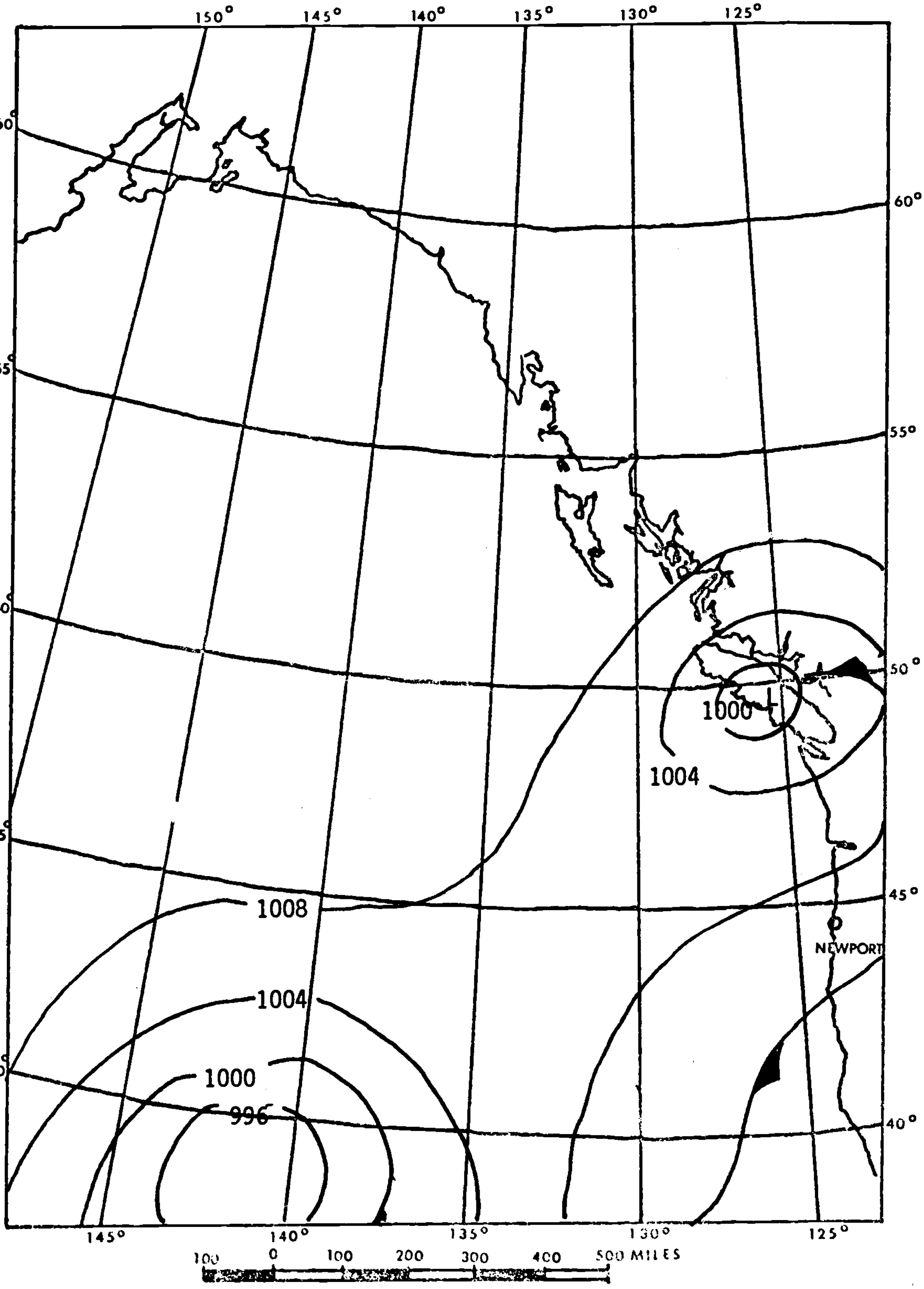


Figure 30. Surface isobar and frontal analysis for 0000Z on Saturday, November 10, 1973.

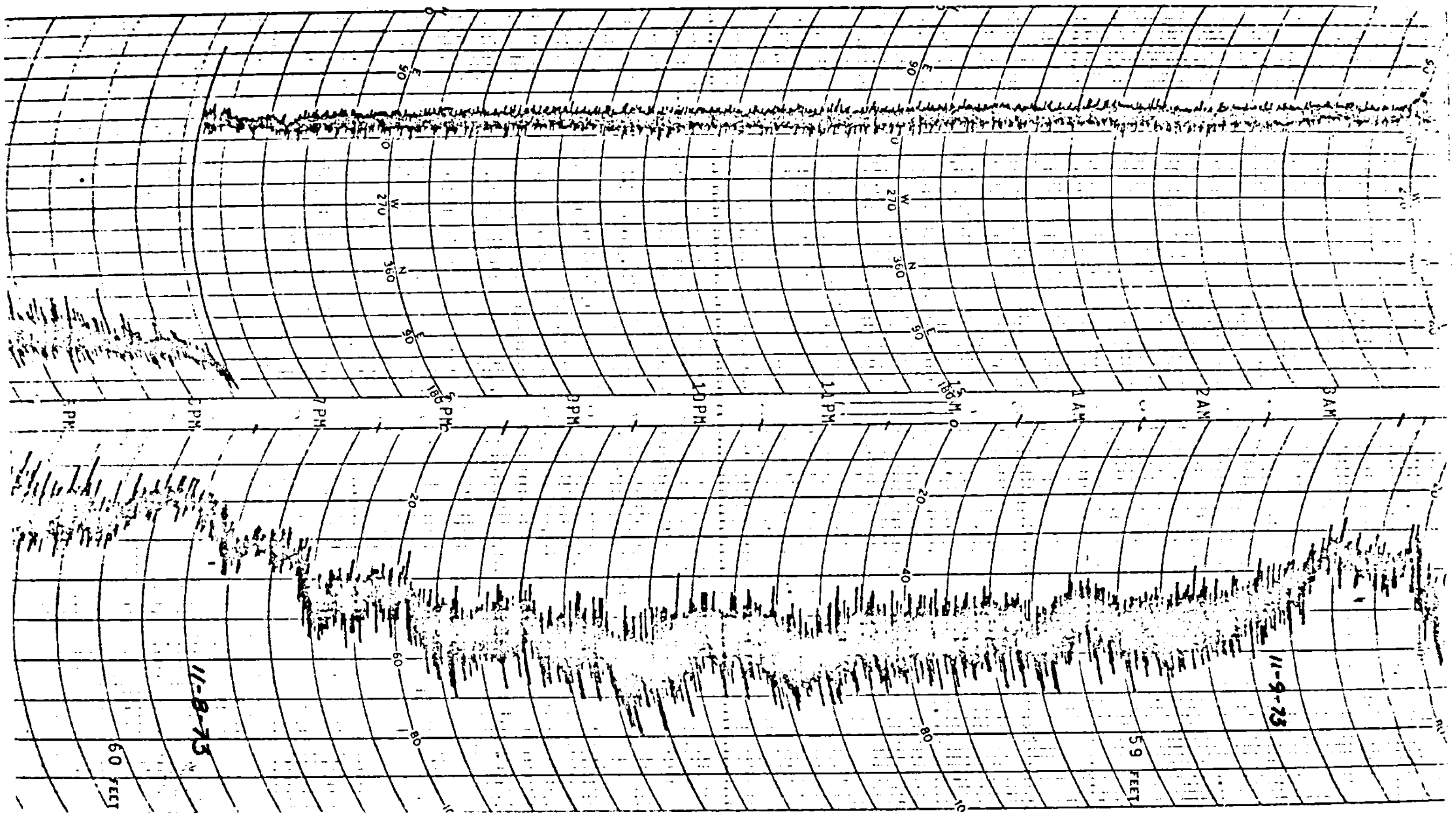


Figure 31. Wind speed (lower graph) and wind direction (upper graph) for case number 16, Friday, November 9, 1973, for Yaquina Head.

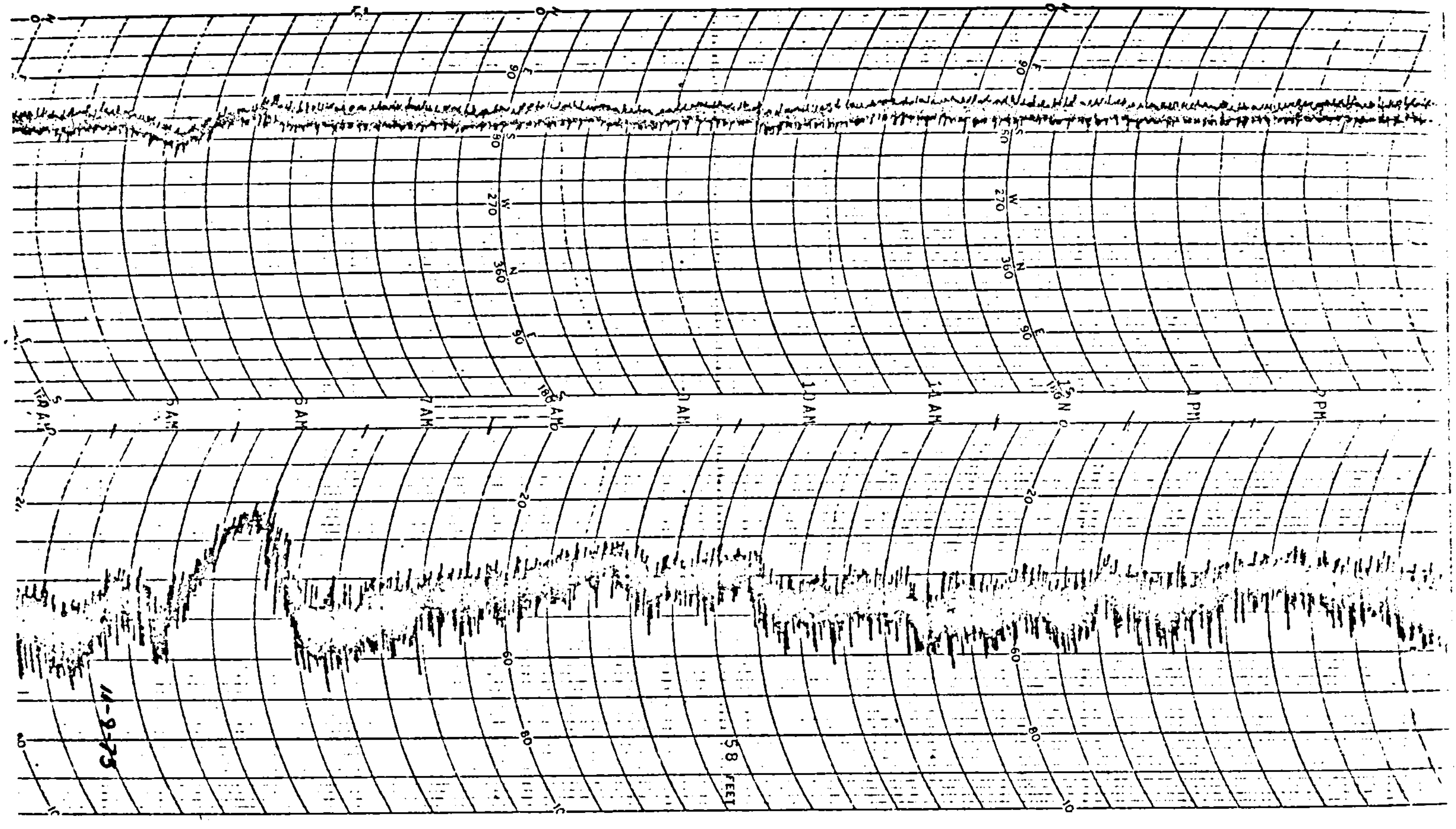


Figure 31 continued.

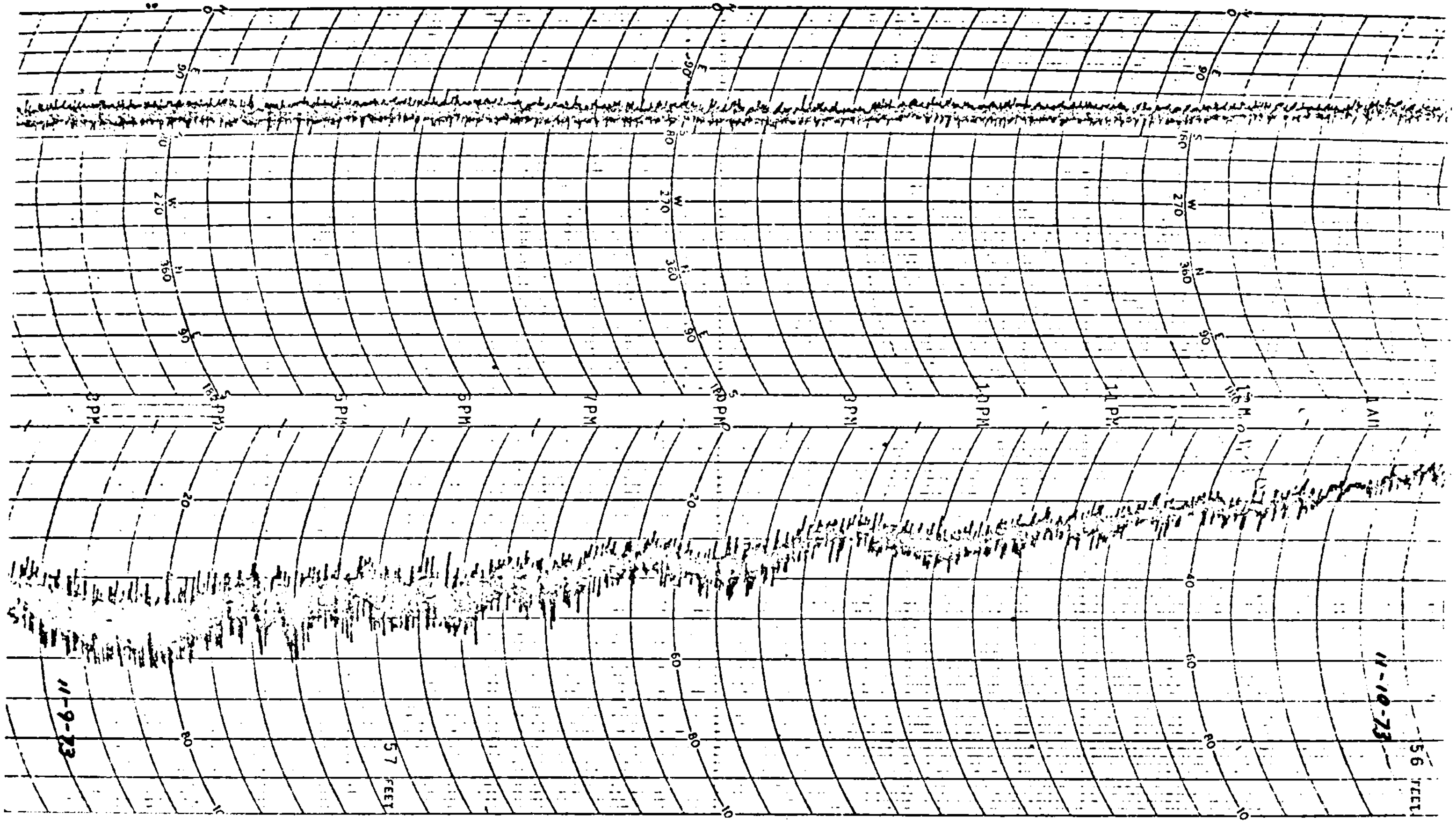


Figure 31 continued.

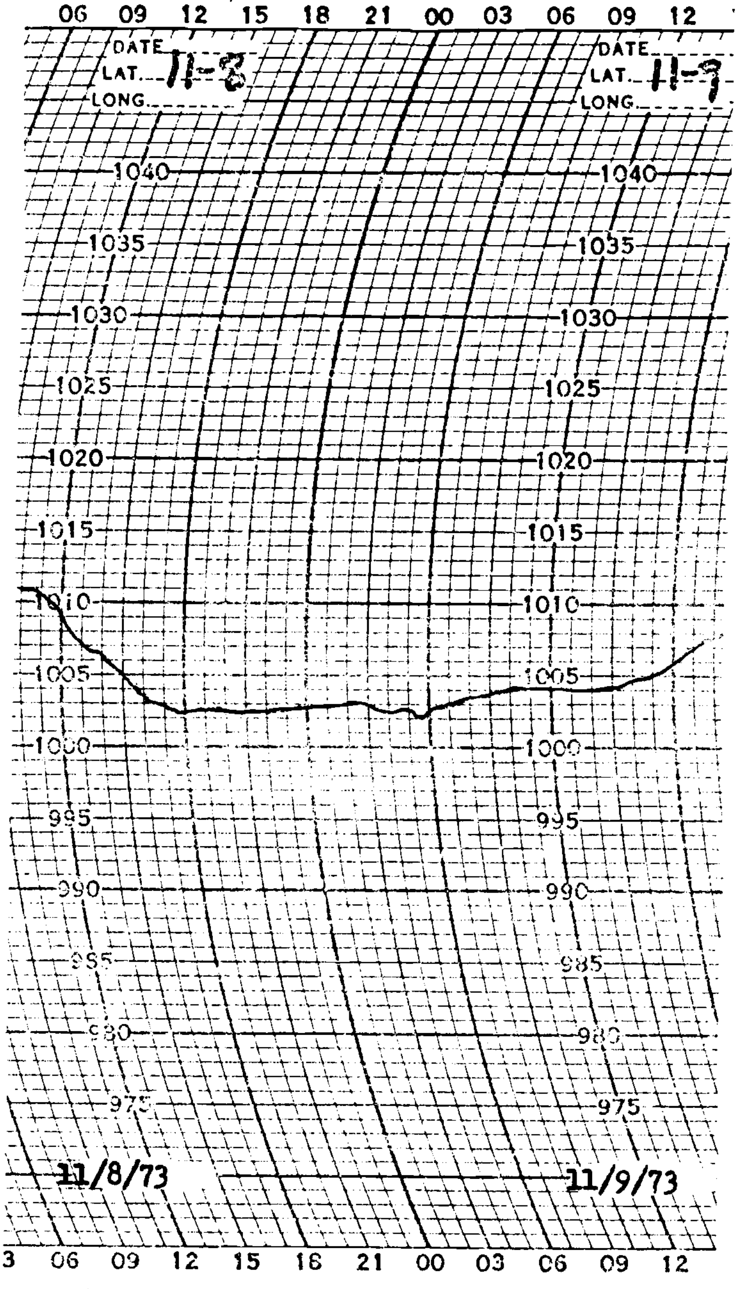


Figure 32. Surface barograph from Marine Science Center, Newport, Oregon, for high wind case number 16 for Friday, November 9, 1973.

passage by strong pressure gradient due to the presence of a "nearby" cyclone.

Winds Aloft at 850 mb

The search for a relationship between surface winds measured at Yaquina Head and other synoptic events has been limited to the availability of surface data. The contribution made by the upper level flow to the surface wind velocity is difficult to describe due to the absence of all upper wind measurements over the ocean. Some data are available to the northeast from Salem, Oregon, a distance of 87 km. These upper air winds are viewed as another variable which may influence the magnitude of the surface flow by a downward transfer of positive momentum during appropriate stability conditions. It is not the purpose of this study, however, to present the dynamic processes which produce strong surface winds but rather to show a concurrence of events. Therefore, upper level winds over Salem were examined during periods of strong surface winds at the coast.

All upper level readings were taken from the 850 mb level (approximately 1500 m above sea level) since these measurements would sample the flow from a surface above the coastal mountains yet near enough to the ground so that a momentum transfer could make a significant contribution. Upper air soundings occur twice daily at Salem at 0400 PST and 1600 PST. Since strong surface winds have been observed at all hours, only a few upper air wind velocity reports are close enough in time to sample the associated 850 mb flow. As a result, this type of analysis has limitations both in time and space. However, as the following description shows, this analysis produces some important insights into a possible correlation between surface and upper level winds.

To test for a relationship between surface and upper level winds, several regression lines were constructed from available data for observations covering various periods of time (Figure 33 through 36). The abscissa for each graph represents the surface speed in knots measured at Yaquina Head, while the ordinate represents the wind speed above Salem, also measured in knots.

In the first analysis, strong wind cases were matched with an upper level sounding from Salem which occurred within the 12 hour (6 hours before or 6 hours after) of the surface observation (Figure 33). To test the significance of the regression, the F-ratio test produced 12.88 as a calculated result. For 1 and 48 degrees of freedom the 1 percent level of significance occurs at less than 7.31. The regression is therefore statistically significant and we may assume a genuine relationship exists between the two levels of flow.

The observations were then divided into two categories, those which occurred before the surface wind observation on the coast and those which came during and after. A regression line is shown for

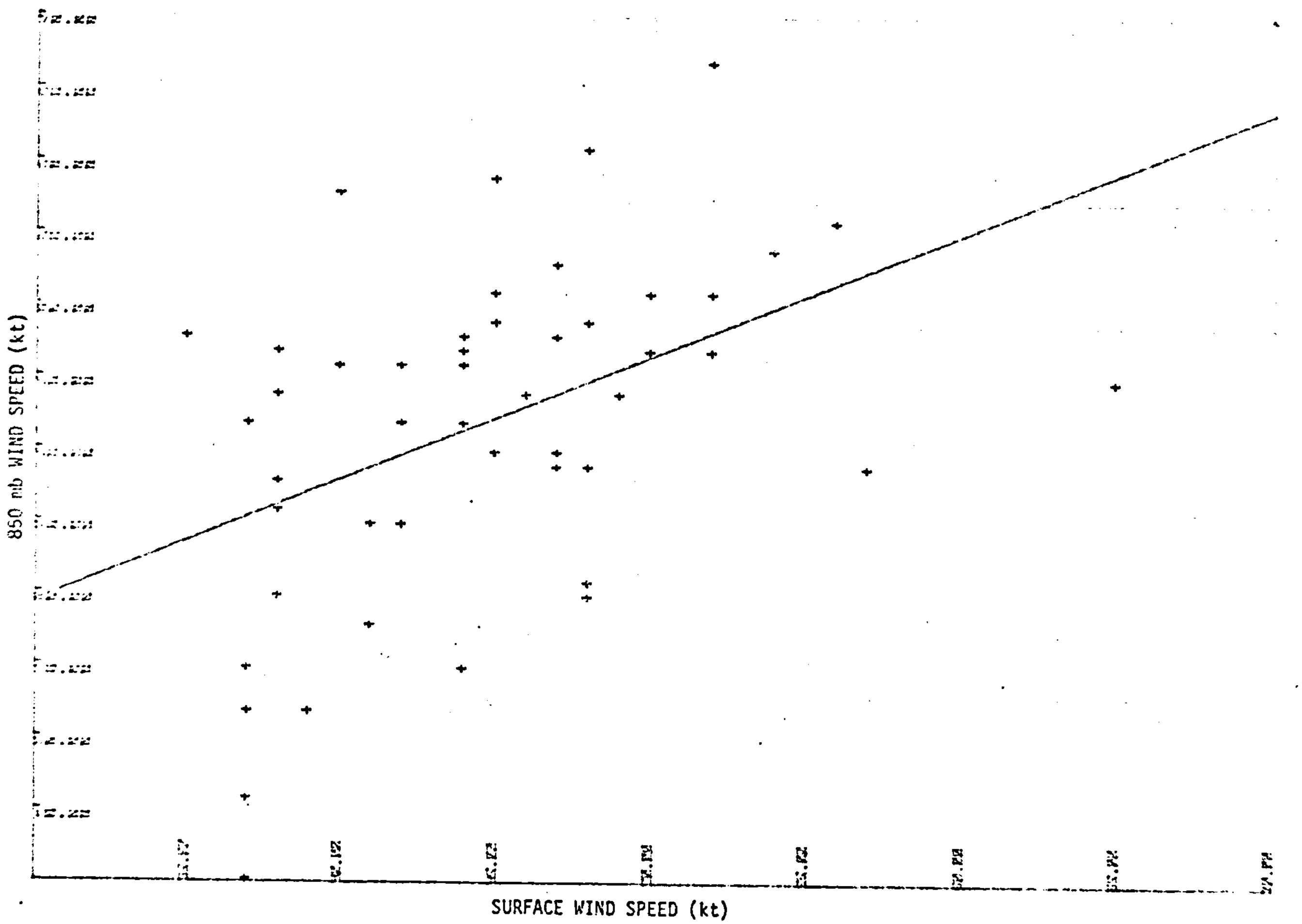


Figure 33. All cases of upper air observation within 12 hours of coastal observations.

each category (Figure 34). For those observations made from Salem before the peak winds occurred at the coast, the F-ratio test produced a value of 5.91 which is significant only at the 5 percent level since the critical value here is less than 4.35 for 1 and 20 degrees of freedom. The correlation coefficient squared (R^2) indicates that 23 percent of the variance is explained by the regression line. For the wind observation measured over Salem during and after periods of strong coastal winds, the F-ratio test yields 5.67. Similarly, this line is significant only at the 5 percent level for 1 and 26 degrees of freedom. The correlation coefficient squared indicates that 18 percent of the variance can be explained by the regression line.

Further regression analysis was conducted on data where upper level soundings which occurred within 6 hours (3 hours before or 3 hours after) of surface wind cases (Figure 35). The F-ratio test produced a value of 16.38. For 1 and 33 degrees of freedom, the critical value at the 1 percent level is less than 7.56, which indicates that the regression is significant. This regression line explains 33 percent of the variance.

As before, this analysis was redone in order to separate upper air soundings which occurred before coastal wind measurements from those which were obtained after. For soundings which occurred 3 hours before the surface winds, the F-ratio test produced a value of 7.13. For 1 and 13 degrees of freedom, the critical value at the 5

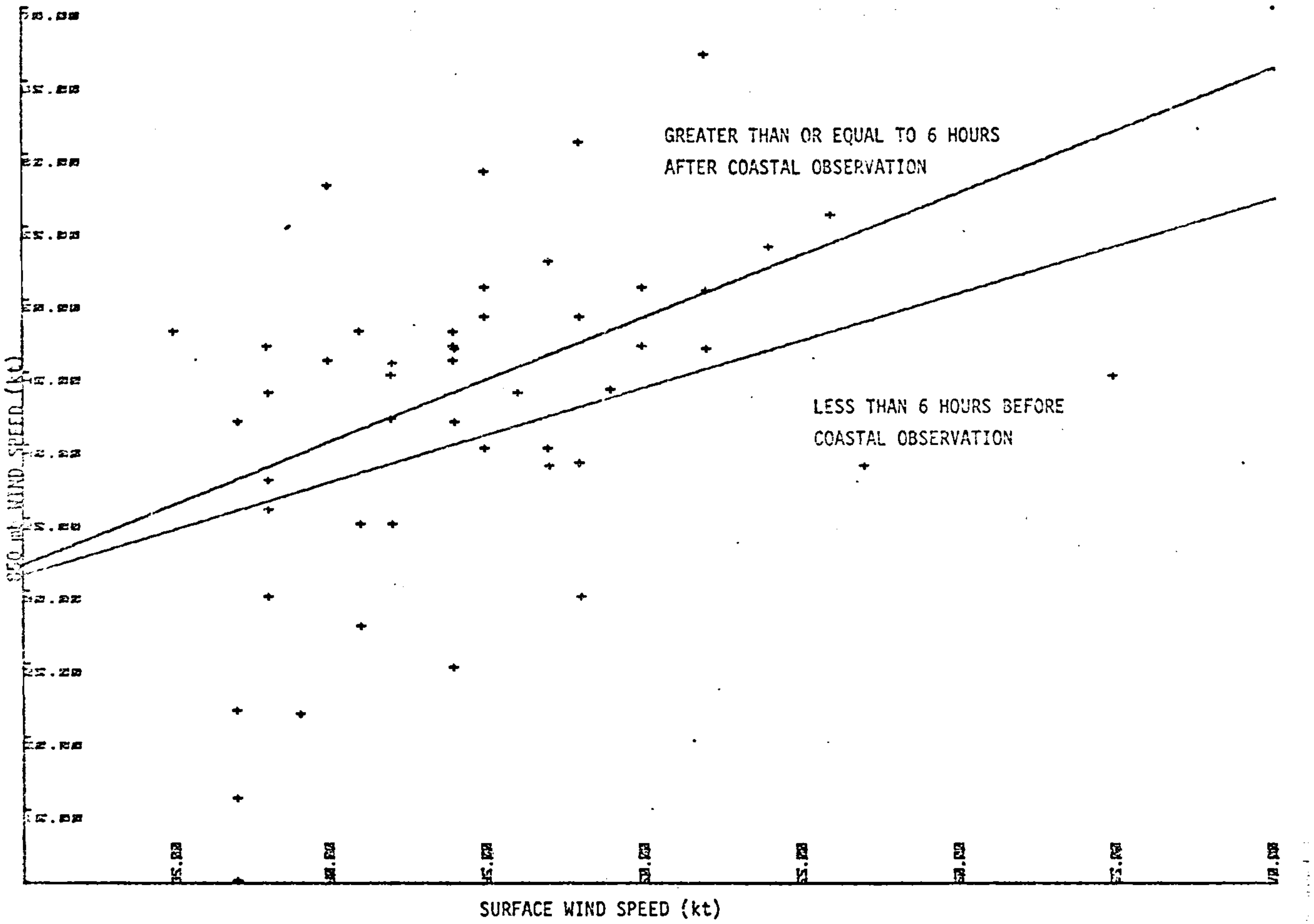


Figure 34. All observations within 12 hours of coastal peak winds.

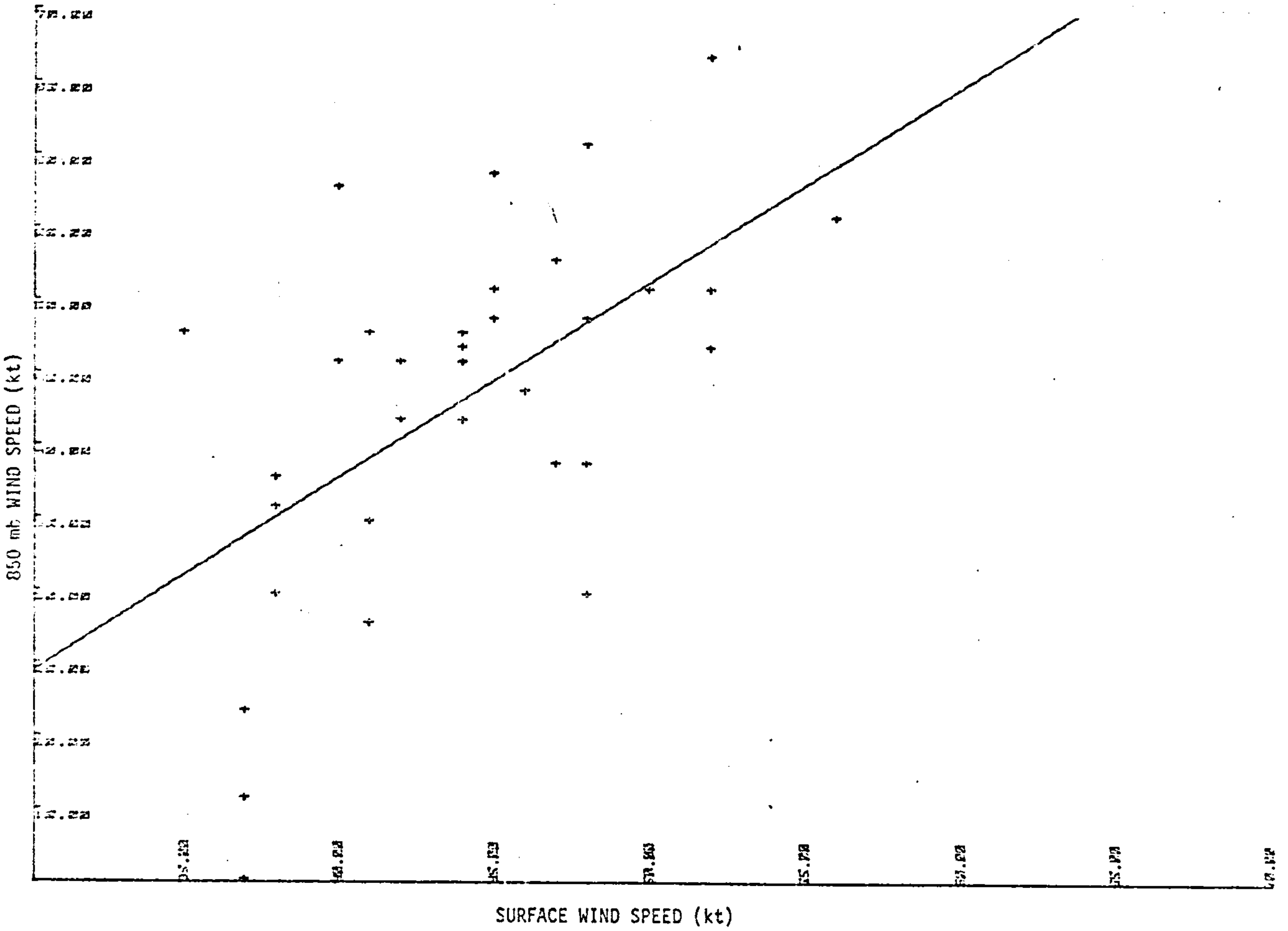


Figure 35. All observations within 6 hours of coastal winds.

percent level is less than 4.75, and this regression line explains 35 percent of the variance (Figure 36). The F-ratio test yields 11.83 for those upper air soundings which were obtained during surface wind cases and up to 3 hours later. For 1 and 18 degrees of freedom, the critical value at the 1 percent level of significance is less than 8.10, and the regression line is capable of explaining 40 percent of the variance.

An attempt has been made to show a relationship between the upper level flow at 850 mb and the surface wind flow. Statistically, a relationship does exist for observations which occur within 3 and 6 hours of peak winds at the coast. The correlation between these two variables can be improved by limiting upper level readings to within 3 hours of the surface observations. These results seem reasonable, since strong coastal winds are associated with a migrating cyclonic pressure pattern.

Wind Speed Versus Time of Wind Shifts

In this analysis the original wind records themselves were used exclusively to represent the wind pattern at Yaquina Head. Each case of strong wind was carefully examined for the prevailing wind direction prior to and following peak winds at the coast. The results were plotted on a hodograph, and similar cases were separated into groups for further analysis. Each plotted case appears on a polar diagram

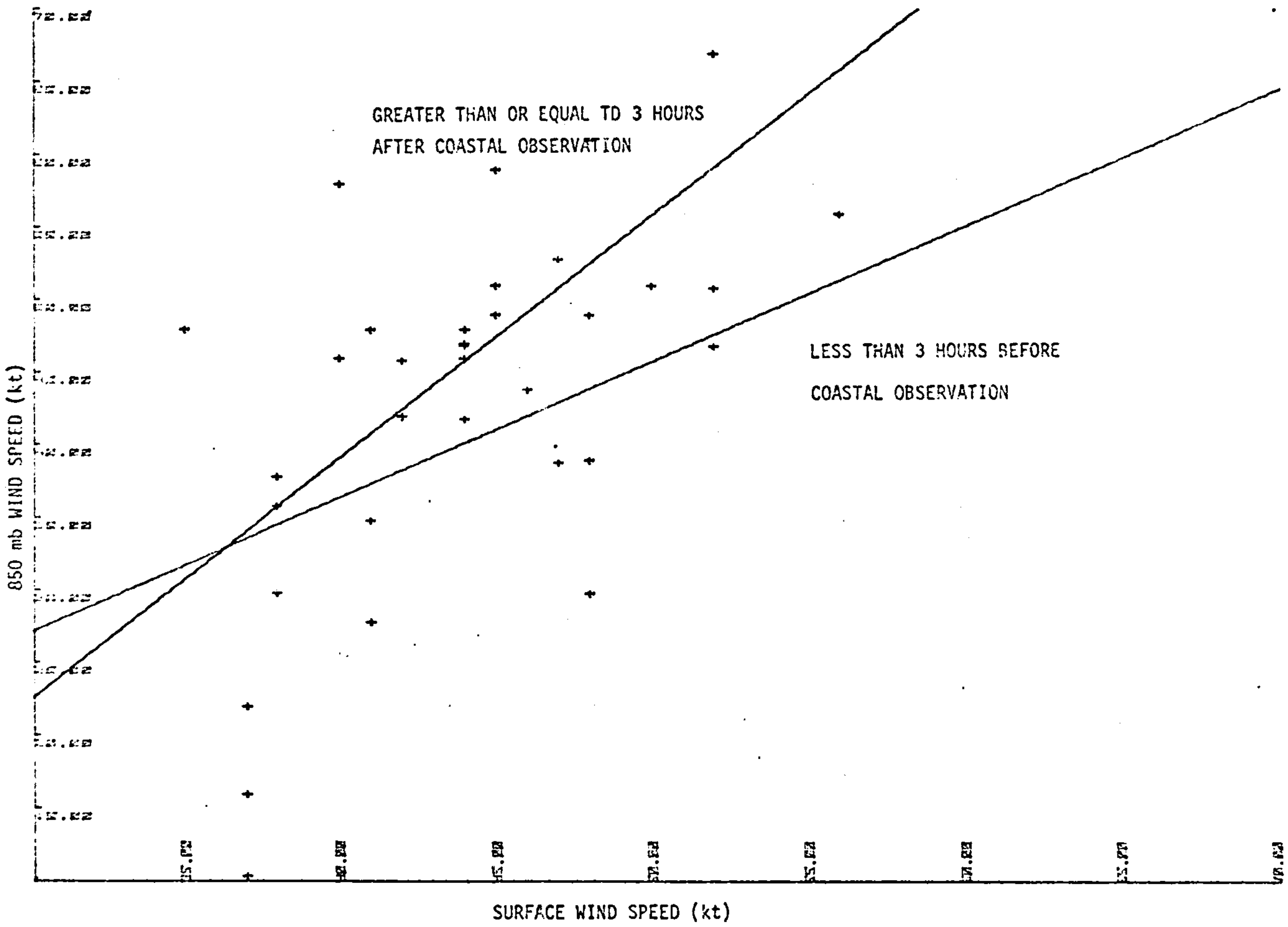


Figure 36. All observations within 6 hours of coastal observations.

with the circumference graduated in degrees for azimuth wind direction, and the radius graduated in knots.

A point plotted on this diagram represents the velocity if one visualizes a velocity vector with its tail at that plotted position and with the point of the vector at the center of the polar diagram. A succession of hourly plotted points will display visually the history of change in the wind velocity during a case.

Of 62 plotted cases, 45 (or 73 percent) periods of strong wind occurred prior to a wind shift of at least 20^{o}. Of these, 35 (or 56 percent) cases occurred before an abrupt veering of the wind which lasted at least two hours (Figure 37). The remaining 10 cases exhibited a more gradual veering of the wind (Figure 38). A third class of cases was identified and is represented by the tendency of the peak wind to occur at least 5 hours before any veering of the wind direction (Figure 39). Four cases of this type have been found. In all the above cases where the wind shifted after peak wind speeds, the shift occurred from the southeast to the southwest or west. However, for the remaining 13 (or 21 percent) cases, no veering of the wind was observed either immediately after or long after the recorded peak winds at Yaquina Head (Figure 40).

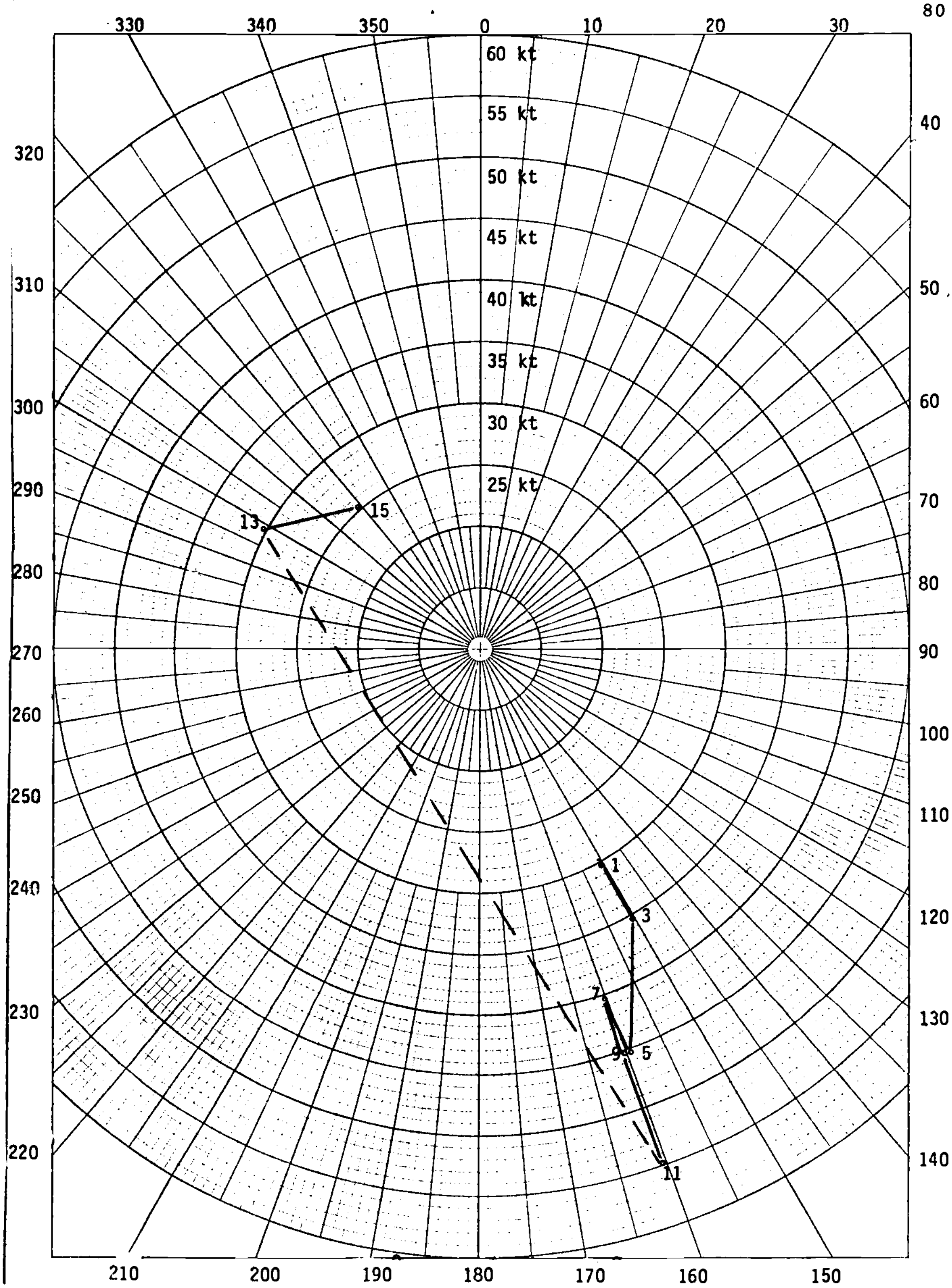


Figure 37. Wind speed (in knots) plotted in 2 hour intervals versus wind direction (in degrees) for case number 65.

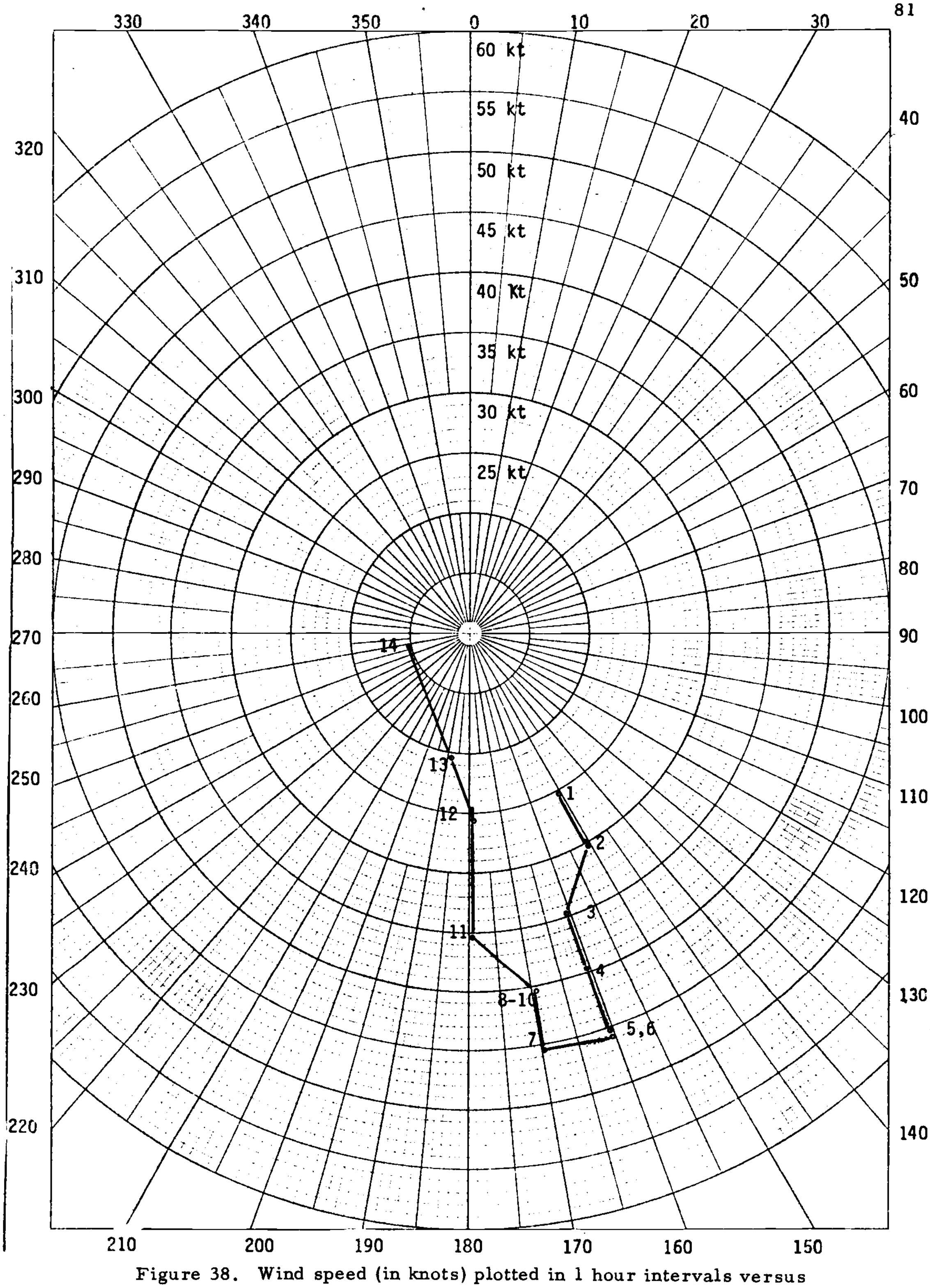


Figure 38. Wind speed (in knots) plotted in 1 hour intervals versus wind direction (in degrees) for case number 60.

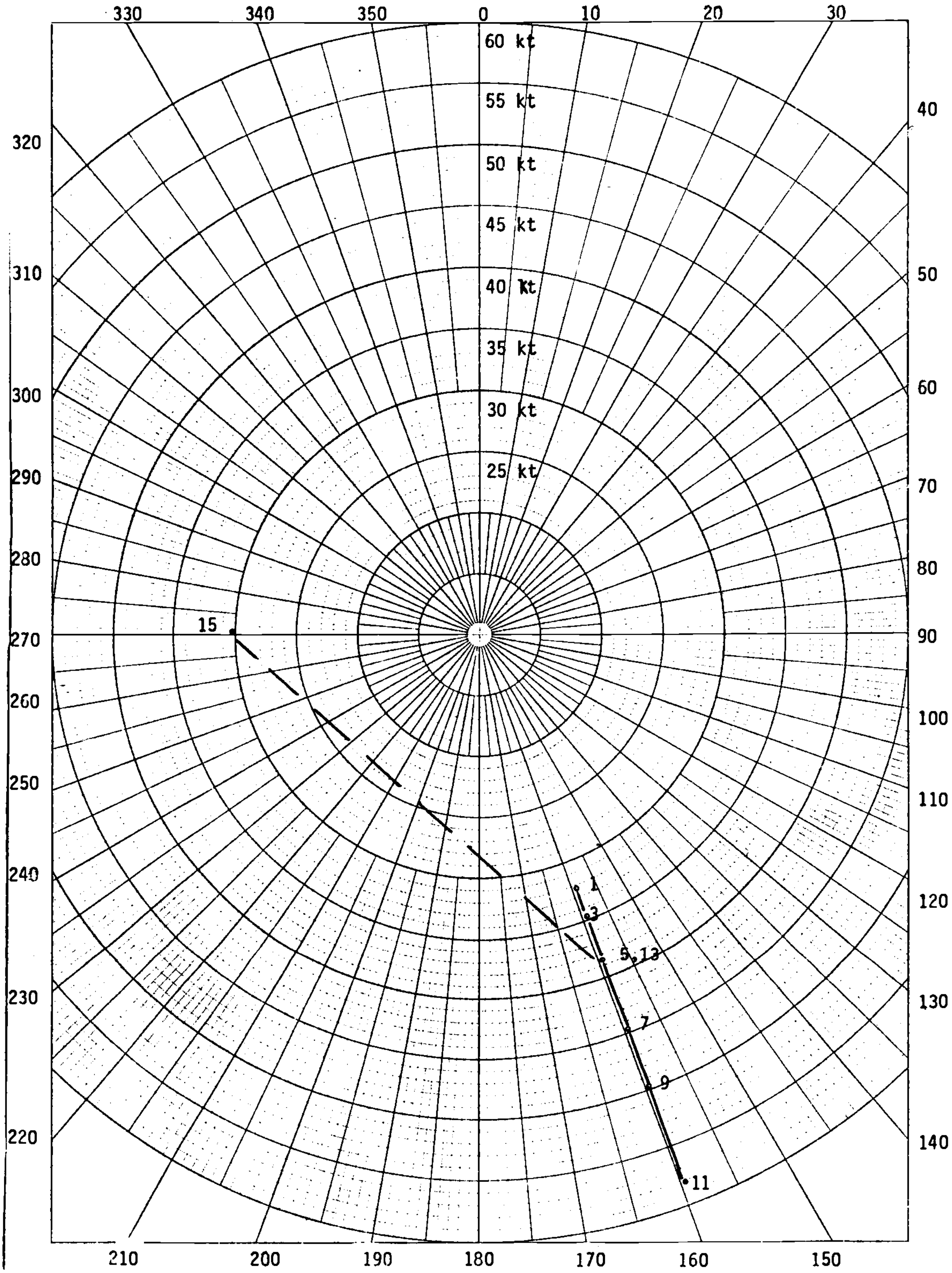


Figure 39. Wind speed (in knots) plotted in 2 hour intervals versus wind direction (in degrees) for case number 64.

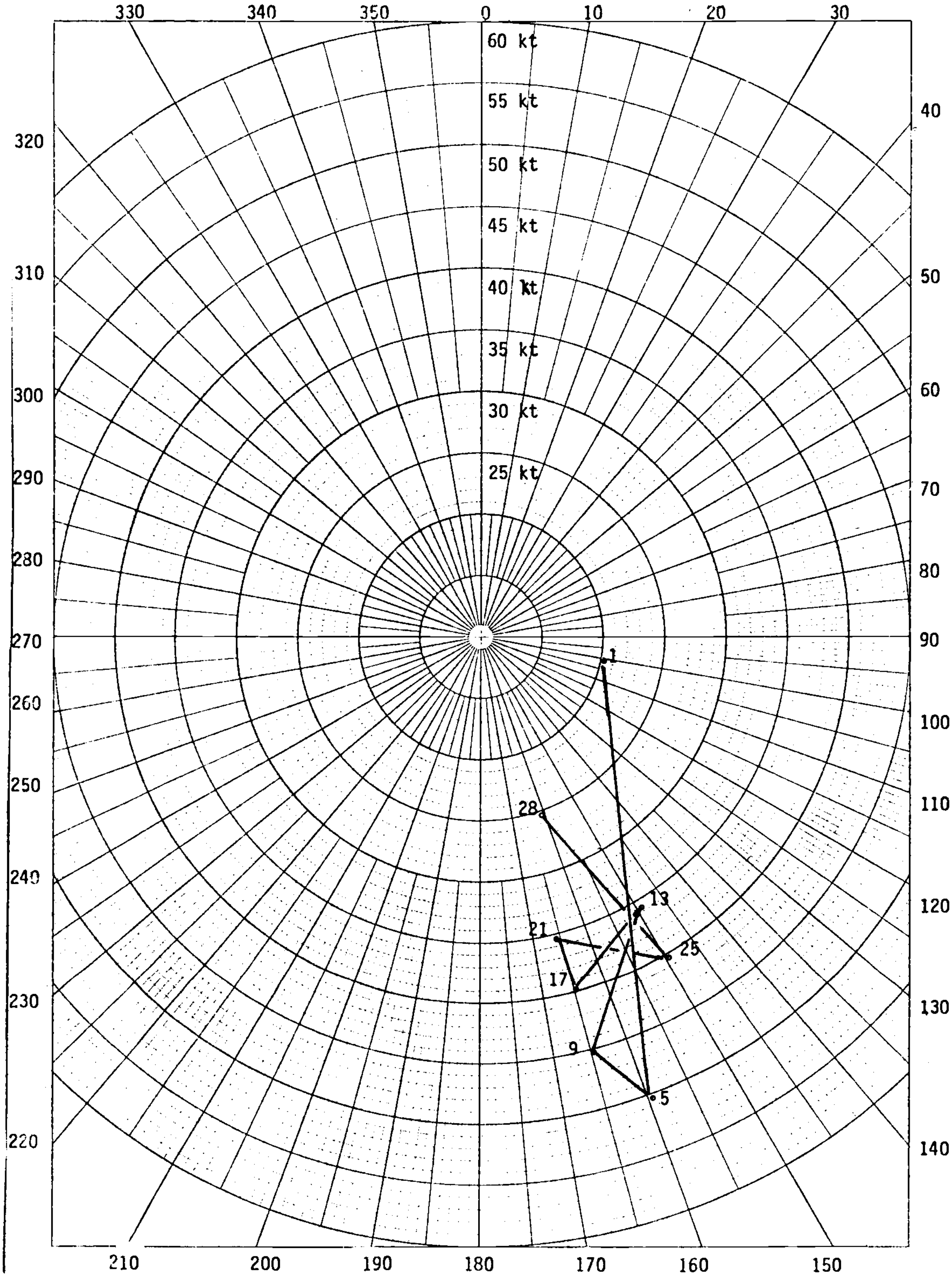


Figure 40. Wind speed (in knots) plotted in 4 hour intervals versus wind direction (in degrees) for case number 16.

IX. WIND AND PRESSURE RELATIONSHIP

This survey of the winter wind regime observed and measured from Yaquina Head includes an analysis of the pressure field. Here, too, data are limited to those stations east of the coastline and widely spaced from one another.

Barogram Analysis

An attempt was made to relate the strong surface winds at Yaquina Head to the local pressure field by the use of barograms recorded by a microbarograph stationed at the O. S. U. Marine Science Center in Newport. This instrument, which is currently on loan from the National Weather Service, is capable of recording four successive days of pressure values. Each chart ranges from 965 mb to 1050 mb in 1 mb increments (Figure 40). Time lines are printed at one-hour intervals and labeled every 3 hours.

Of the 65 separate wind cases, 51 cases could be analyzed with the use of barograms. Fourteen wind cases could not be analyzed since the barograms were unavailable. As the periods of strong wind were located on the barograms, it became obvious that separate classes existed within the 51 cases. For 32 cases, peak wind occurred concurrently with pressure troughs characterized by rapidly falling pressure followed by a sharp pressure rise (Figure 41).

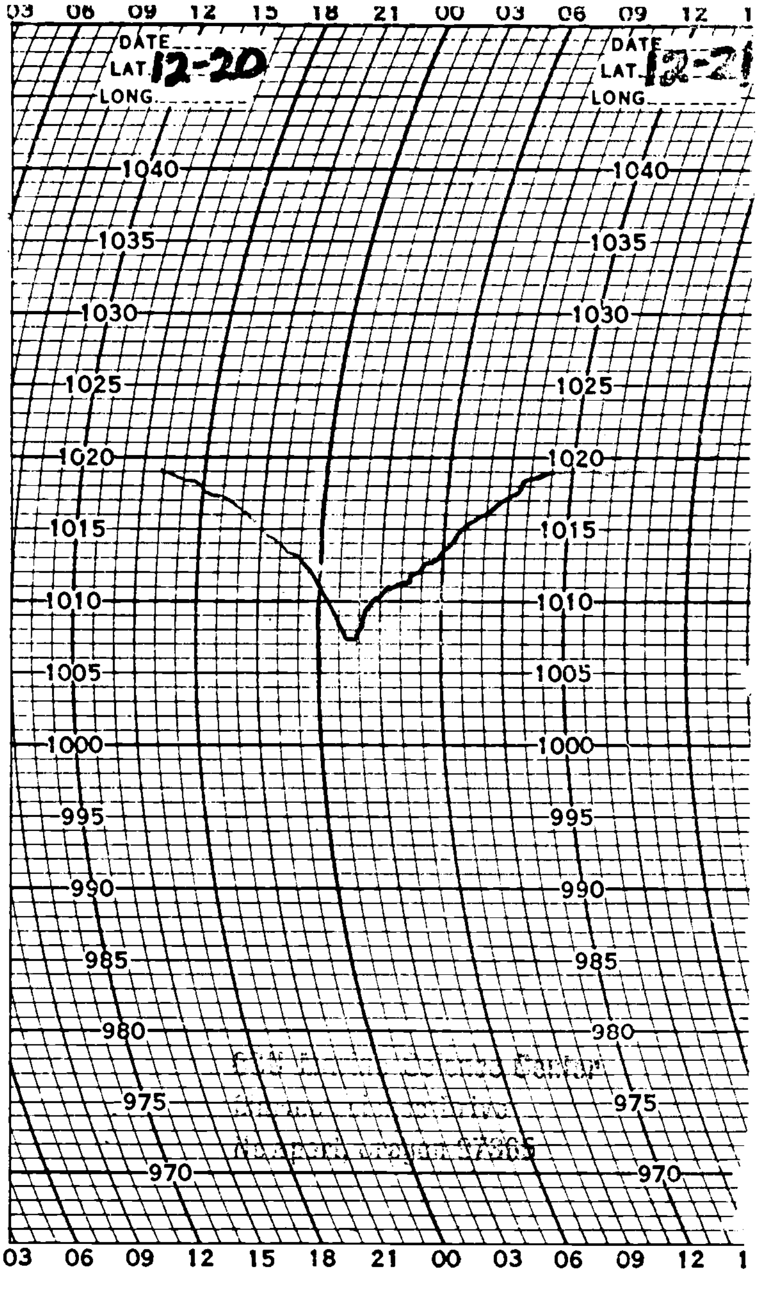


Figure 41. Barogram for December 20, 1974, Newport, Oregon, which represents a class of wind cases which is associated with rapidly falling pressure and then rapidly rising pressure.

Similarly, nine additional cases of strong wind occurred with pressure troughs showing at least a 3-hour period separating the falling from the rising pressures (Figure 42). For the remaining barograms, two cases were characterized by falling pressure only, five cases were associated with rising pressure, and three cases were related to unchanging pressure (Figure 43, 44, and 45).

Of the 51 traces available for this analysis, 41 (or 80 percent) are associated with a pressure trough, 32 (or 63 percent) of which may indicate the presence of a frontal zone. In two (or 4 percent) additional cases, winds are related to falling pressure but not necessarily a trough.

That 80 percent of all barograms relate a pressure trough with peak winds is evidence that much of the strong surface flow along the coast is due to a rapidly changing pressure field.

Analysis of the Pressure Field

An attempt was made to correlate strong surface winds observed at Yaquina Head with the barometric pressure recorded at several locations along the coast and within the Willamette Valley. Since Yaquina Head is located at the western edge of the continent, there is a lack of stations reporting surface pressure west of Yaquina Head. North of Yaquina Head, at a distance of 178 km, surface pressure is recorded in Astoria by the National Weather Service. This

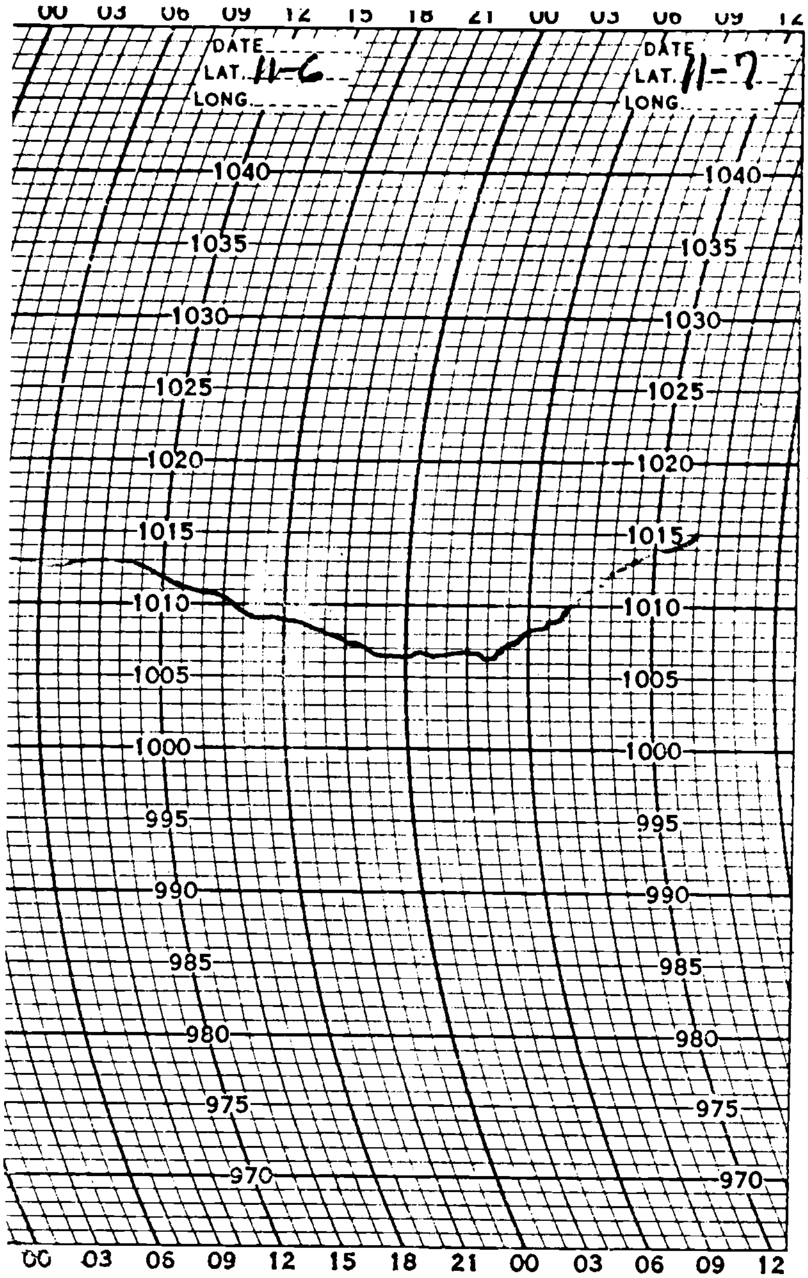


Figure 42. Barogram for February 27, 1974, which represents a class of wind cases which occur with at least a 3 hour period separating falling and rising pressure.

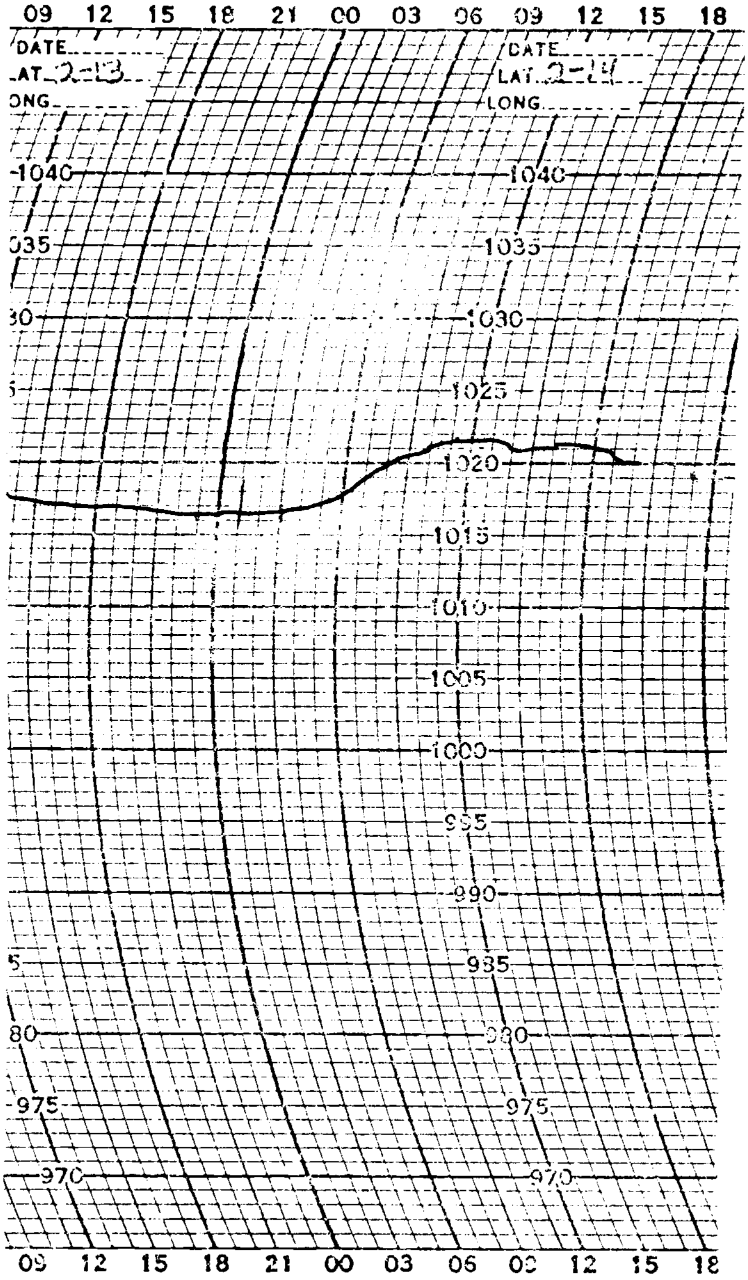


Figure 43. Barogram for November 6, 1974, which represents a class of wind cases which occur with falling pressure only, several hours ahead of any pressure trough.

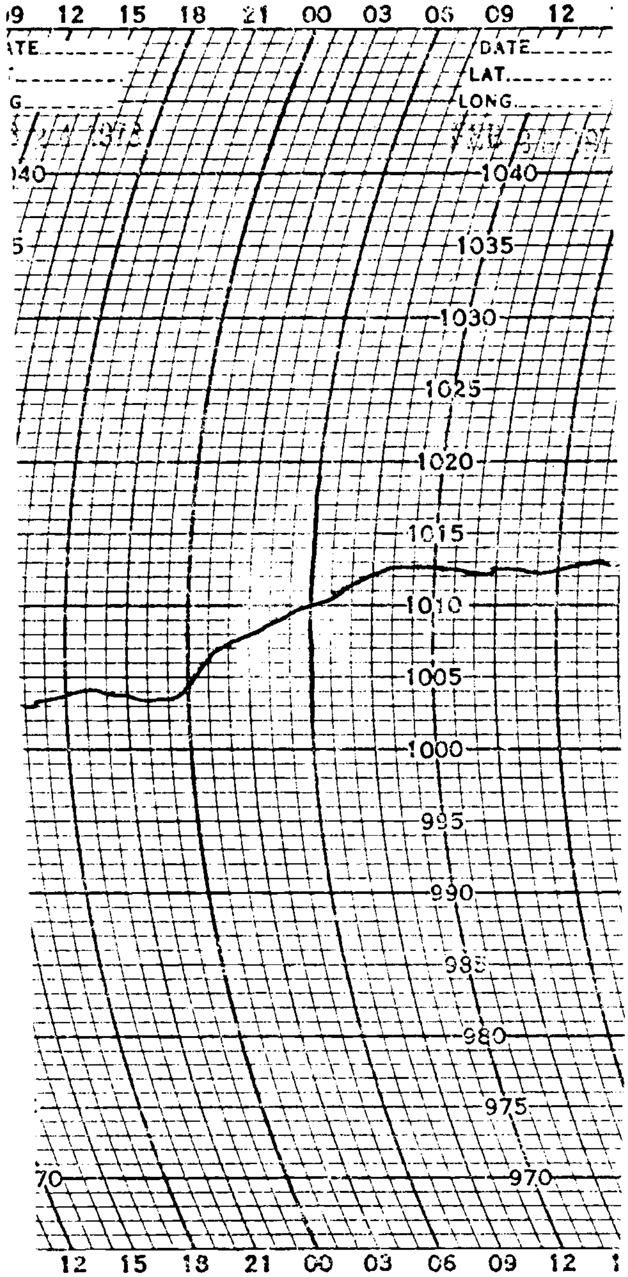


Figure 44. Barogram for February 25, 1973, which represents a class of wind cases which occur with rising pressure only, several hours after a pressure trough.

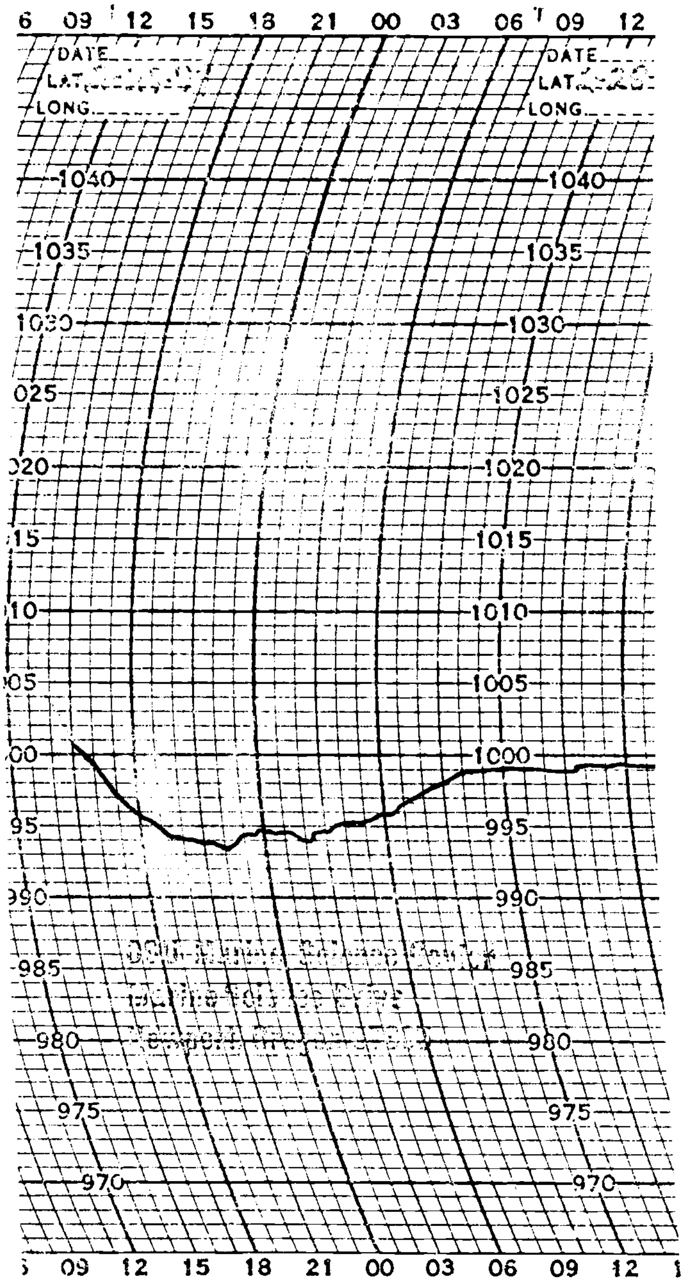


Figure 45. Barogram for February 14, 1974, which represents a class of wind cases which occur with little or no pressure change.

government agency likewise records pressure at North Bend, 138 km south; Salem, 89 km northeast; and Eugene, 83 km southeast. At each of the above locations, surface pressures are obtained visually from a precision aneroid barometer by a trained observer a few minutes before each hour. Surface pressure is also measured at two Oregon State University facilities, the Marine Science Center, in Newport, and the National Weather Service office, Corvallis. Each facility records pressure on a microbarograph which is a standard device used by the National Weather Service.

Without pressure data west of Yaquina Head, it is impossible to calculate the average east-west pressure gradient at Yaquina Head at the time of strong surface wind. Similarly, the value of the north-south pressure gradient is meaningless due to the broad spacing between stations recording pressure along the coast. Since the local pressure gradient in the vicinity of Newport could not be satisfactorily calculated, the magnitude of the observed wind was correlated with the differences in surface pressure between several pairs of stations. The north-south component of the geostrophic wind, given by

$$v_g = \frac{1}{\rho f} \frac{\partial p}{\partial x}$$

demonstrates that the magnitude of a northward directed flow on a frictionless surface is proportional to the east-west pressure gradient. Similarly, the east-west component of the geostrophic wind, given by

$$u_g = \frac{1}{\rho f} \frac{\partial p}{\partial y}$$

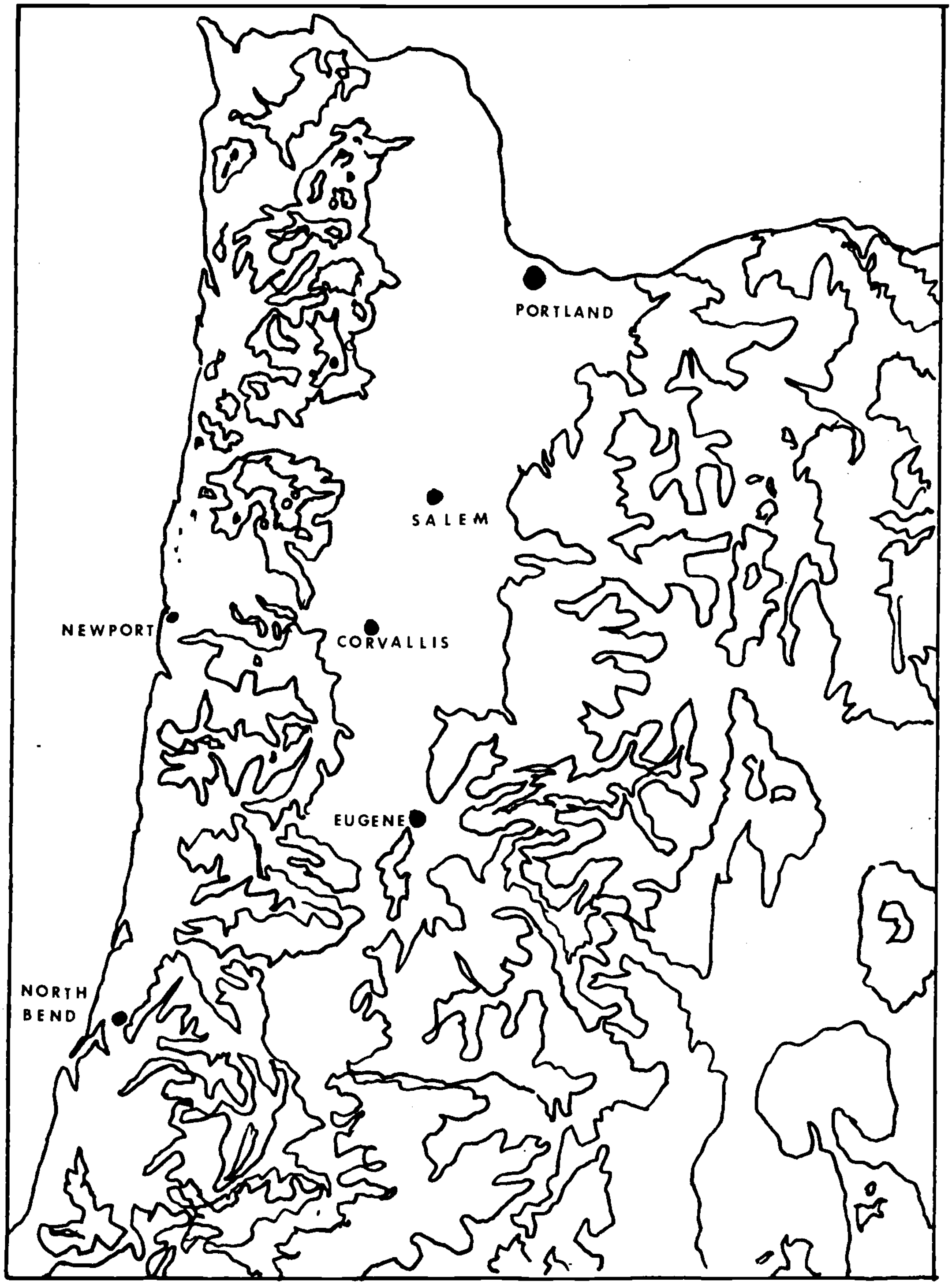
implies that the magnitude of an eastward directed flow on a frictionless surface is proportional to the north-south pressure gradient. A large difference, then, in surface pressure between two adjoining stations will result in a strong geostrophic wind between the stations.

Based upon the geostrophic wind equations, three sets of stations were used to correlate the magnitude of the observed strong wind at Yaquina Head to the recorded surface pressure. All pressure measurements were recorded during the time of maximum wind observed at Yaquina Head.

The first set of pressure differences occurred between Corvallis and Newport along a line which approximates an east-west axis (Figure 46). The second set of pressure differences occurred between North Bend and Newport on a line which approximates a north-south axis. Finally, a third line was constructed between North Bend and Eugene on a northeast-southwest axis. This last axis is neither north-south or east-west and therefore any proportionality between the magnitude of the wind and the pressure gradient is based upon the geostrophic wind equation given by

$$\overline{V}_g = \frac{1}{f\rho} \overline{\frac{\partial p}{\partial n}}$$

The data from each pair of stations, and the pressure differences



Scale: 1 inch is approx. 50 km and contour interval is in meters.

Figure 46. Map of western Oregon displaying the four sites which were used in a pressure analysis during strong coastal winds (after Aeronautical Chart and Information Center, 1970).

between the stations compared to the magnitude of the coastal winds are tabulated in Appendix B.

A review of the results in Appendix B will demonstrate the lack of a strong correlation between the magnitude of the wind and the related pressure difference along the three axes. The lack of a correlation may be due to several factors: an absence of pressure data west of the coast, the presence of a mountain range between pressure stations, and a broad spacing between each station.

The lack of data west of Newport prevents us from analyzing the pressure field in a straightforward manner. Surface pressures measured east of the coastline may not accurately represent the actual pressure gradient resulting in strong surface winds at Yaquina Head.

What influence the Coast Range has on the pressure field is not known. However, this range bisects two axis lines constructed for this analysis and therefore any contributions made to the pressure field would affect these results. If, as Raynor (1968) suggests, coastal mountains do distort the sea level pressure field, an analysis of the type conducted above might produce erroneous results.

Finally, the broad spacing between stations reporting pressure may not be fine enough to detect a localized steep pressure gradient capable of producing strong surface winds along the coast. As a result, the relationship between the pressure field and the coastal winds remains undefined.

Derived Local Pressure Gradient and the Geostrophic Wind

The north-south component of the geostrophic wind was calculated in each case where a barogram was available (from the Marine Science Center) and the speed of an associated front or pressure trough could be estimated. First, the value of the east-west pressure gradient was found by the use of the barogram and several assumptions. In order to construct an expression for the east-west pressure gradient, pressure variation was considered in two systems of coordinates, one fixed to the surface and the other moving with the pressure system. Let

$$p = p(x, y, t)$$

describe the pressure distribution. If we differentiate with respect to time, then for a system of fixed coordinates

$$\frac{dp}{dt} = \frac{\partial p}{\partial t} + \bar{v} \cdot \bar{\nabla} P \qquad (1)$$

where $\frac{dp}{dt}$ represents the variation of pressure following the flow, v represents the velocity of a parcel of air moving with the flow relative to the fixed system of coordinates, and $- \bar{\nabla} P$ represents the horizontal pressure gradient. Now, in a similar way, the pressure may be differentiated for a system of coordinates moving with the pressure system.

$$\frac{dp}{dt} = \frac{\delta p}{\delta t} + \bar{v}' \cdot \bar{\nabla} p \tag{2}$$

Here, $\frac{\delta p}{\delta t}$ represents the pressure variation with time for a moving pressure center advancing with the moving pressure coordinates (Petterssen, 1940). When $\frac{dp}{dt}$ is positive $[(\delta p/\delta t) > 0]$ the pressure center is filling, and when it is negative $[(\delta p/\delta t) < 0]$ the pressure center is deepening. Both $\frac{dp}{dt}$ and $-\bar{\nabla} p$ are identical in each equation, (1) and (2). From Equations (1) and (2), we may obtain

$$\frac{\delta p}{\delta t} = \frac{\partial p}{\partial t} + \bar{c} \cdot \bar{\nabla} p \tag{3}$$

where $c = (v - v')$ represents the velocity of the pressure center relative to the fixed coordinate system. Equation (3) indicates that the local pressure change, $\partial p/\partial t$, is a function of two terms, the filling or deepening term of the moving pressure center $\delta p/\delta t$ and the advective term $c \cdot \bar{\nabla} p$. Since most pressure centers approach the Oregon Coast from the west, we may simplify Equation (3) by considering motion on the X-axis only.

$$\frac{\delta p}{\delta t} = \frac{\partial p}{\partial t} + c_x \frac{\partial p}{\partial x} \tag{4}$$

Furthermore, if we assume that the pressure change occurring within the pressure center is slow, then

$$\frac{\delta p}{\delta t} \simeq 0$$

and Equation (4) may be written as

$$0 = \frac{\partial p}{\partial t} + c_x \frac{\partial p}{\partial x}$$

and

$$-\frac{1}{c_x} \frac{\partial p}{\partial t} = \frac{\partial p}{\partial x} \tag{5}$$

Equation (5) implies that the east-west pressure gradient $\frac{\partial p}{\partial x}$ may be approximated by the local change in pressure over an interval of time and the knowledge of the eastward speed of the pressure center. If we substitute Equation (5) into the expression for the north-south component of the geostrophic we obtain

$$v_g = \frac{1}{\rho f} \left(-\frac{1}{c_x} \frac{\partial p}{\partial t} \right) \tag{6}$$

Here the east-west component of the geostrophic wind is not considered since all peak winds measured at Yaquina Head are quasi-meridianal. Since local pressure changes $\partial p/\partial t$ are measured over a one-hour period of time, we may integrate over the same interval and solve for the instantaneous value of the north-south component of the geostrophic wind.

$$\int_{t_1}^{t_2} v_g \, dt = \frac{1}{f\rho} \frac{1}{c_x} \int_{t_1}^{t_2} \frac{\partial p}{\partial t} \, dt \tag{7}$$

Here $t_2 - t_1 = 1$ hour and we have assumed that c_x is a constant. If we complete the integration on the left side of Equation (7) we obtain

$$\int_{t_1}^{t_2} v_g \, dt = \frac{1}{f\rho} \frac{1}{c_x} p \Big]_{t_1}^{t_2}$$

$$= \frac{1}{f\rho} \frac{1}{c_x} (p_{t_2} - p_{t_1})$$

As noted earlier, all reported wind speeds from Yaquina Head are one-hour averages. We may then solve for a one-hour mean value of the north-south component of the geostrophic wind.

$$\frac{1}{\Delta t} \int_{t_1}^{t_2} v_g \, dt = \frac{1}{\Delta t} \frac{1}{f\rho} \frac{1}{c_x} (p_{t_2} - p_{t_1}) \tag{8}$$

It becomes necessary to consider a three-hour period of pressure change on the barograms since the resolution is poor over a one-hour interval. It is assumed that the pressure change is linear over this three-hour period. Then

$$p(t_2) - p(t_1) = p(t_4) - p(t_3)$$

where $t_2 - t_1 = 1$ hour and $t_4 - t_3 = 3$ hours.

The results of this analysis are shown on Table 9. Only those pressure systems that displayed an eastward motion on the surface weather charts were considered. The eastward speed was computed

Table 9. The calculated north-south component of the Geostrophic wind compared with the measured wind at Yaquina Head.

Case Number	Eastward Speed of Pressure System, c_x	$\frac{\Delta p}{\Delta t}$	$\bar{v}_g$	Observed Wind, v
1	34.5 km/hr	.97 $\frac{mb}{hr}$	44.6 kt	43.5 kt
2	45.3 km/hr	.87 $\frac{mb}{hr}$	30.5 kt	38.3 kt
7	27.9 km/hr	.63 $\frac{mb}{hr}$	35.8 kt	34.8 kt
8	31.5 km/hr	.93 $\frac{mb}{hr}$	46.9 kt	44.4 kt
10	31.4 km/hr	.47 $\frac{mb}{hr}$	23.7 kt	40.0 kt
18	30.2 km/hr	1.0 $\frac{mb}{hr}$	52.6 kt	36.5 kt
39	51.8 km/hr	1.4 $\frac{mb}{hr}$	42.9 kt	47.0 kt
40	60.4 km/hr	1.5 $\frac{mb}{hr}$	38.6 kt	49.6 kt
55	44.8 km/hr	1.0 $\frac{mb}{hr}$	36.0 kt	41.7 kt
61	33.6 km/hr	1.3 $\frac{mb}{hr}$	55.7 kt	36.5 kt

from barograms recorded at Newport and Corvallis. Normally the speed of a pressure system could be estimated by the passage of a trough or some other recognizable pressure feature.

In half the cases shown on Table 9, the observed wind is greater than the calculated value of the geostrophic winds. At sea, where surface friction is low, the observed wind can be two-thirds the geostrophic wind (Petterssen, 1940). Under what conditions might the observed wind exceed the geostrophic wind? The topography of Yaquina Head, as described earlier, may have a definite influence on the strength of the observed wind. Winds from the south are forced to rise 350 ft from the surface of the ocean before they can flow over the Communication Center. In doing so, we might expect super-geostrophic wind speeds to be attained as the air accelerates over the summit of the Head.

It is possible that the calculated values of the geostrophic wind are in error. There are two weaknesses in the analysis. First, the population of cases considered is rather small; therefore, it is difficult to evaluate these results. The second problem with this analysis is the lack of a more accurate method with which to measure the eastward speed of the pressure system. A 10-minute error in the reading of the barograms will result in an overall error of 15 percent in the calculated value of the component of the geostrophic.

Until a more accurate method of pressure analysis is developed the results shown on Table 9 must serve as an indication of how well the pressure field is related to the measured wind field.

X. CONCLUSION

Every case of reported strong wind was associated with a front, or a center of low pressure, or both. Those cases displaying peak winds above 45 kt were most often associated with pressure centers within 820 km from Newport, Oregon, while winds of lower speeds were more often related to more distant cyclones. Similarly, the stronger wind cases occurred more often with deepening pressure centers within 820 km of Newport. The pressure change occurring within cyclones beyond 820 km seems unrelated to coastal winds.

No relationship could be established between the speed of the wind measured at Yaquina Head and the value of the sea level pressure at the cyclone center. Likewise, no obvious relationship could be found between the speed and direction of motion of cyclones and frontal zones and the peak winds. The type of frontal zone, whether cold or occluded apparently has little influence of the strength of the wind.

Long durations of strong wind measured above a threshold value of 35 kt were associated more with cyclone centers located within 820 km of Newport. Winds related to more distant pressure systems were more often measured for short durations.

The upper level wind flow at 850 mb was correlated with surface wind during periods of strong coastal wind observations. This relationship was improved by restricting the upper air wind soundings to those which occurred within three hours following coastal wind measurements.

Wind speed and direction traces were examined and analyzed with the result that 73 percent of the measured peak winds occurred prior to an abrupt veering of the wind. However, 21 percent of the cases lacked this wind shift.

The differences in surface pressure were determined for three stations and compared with the concurrent speed of the wind. No relationship could be identified. Barograms obtained at Newport were examined during peak wind flow which revealed that 80 percent of the cases occurred during periods of rapidly changing surface pressure resulting from a trough of low surface pressure. The north-south component of the geostrophic wind was compared with the speed of the measured surface wind. No consistent agreement could be established between the measured surface wind speed and the calculated north-south component of the geostrophic wind.

The conclusions listed above may be of special interest to the marine forecaster. The result that stronger wind cases more often occur with deepening pressure systems located within a limited distance of the coast should aid the forecasters in estimating the strength of coastal winds. Likewise, by noting the proximity of the cyclone to the coast and its direction of motion, forecasters may better recognize those synoptic situations that lead to long periods of strong wind.

The results of this study have been limited by the available surface data. The lack of surface pressure measurements to the west of this coastal site continues to affect adversely the analysis to the pressure field. Until adequate pressure data are available, the episodes of strong wind which occur seasonally along the Oregon Coast will not be fully described.

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APPENDICES

APPENDIX A

List of All Periods of High Wind Recorded at Yaquina Head Over Two Years Which Were Measured Over a Threshold of 35 kts

Case Number	Date of Peak Wind	Time of Peak Wind*	Speed in Knots	Direction in Degrees
1	January 15, 1973	13:30 to 14:30	45	150
2	January 20, 1973	11:30 to 13:30	37	150
3	January 23, 1973	22:30 to 23:30	47	150
4	February 25, 1973	03:30 to 04:30	37	160
5	March 1, 1973	05:30 to 06:30	37	180
6	March 10, 1973	24:30 to 01:30	35	180
7	March 16, 1973	06:30 to 07:30	37	150
8	March 18, 1973	13:30 to 14:30	44	150
9	April 16, 1973	08:30 to 09:30	37	170
10	May 8, 1973	01:30 to 02:30	40	160
11	May 23, 1973	17:30 to 18:30	41	150
12	September 20, 1973	24:30 to 01:30	41	160
13	September 24, 1973	20:30 to 21:30	38	140
14	October 6, 1973	12:30 to 13:30	37	210
15	October 24, 1973	06:30 to 07:30	41	170
16	November 8, 1973	21:30 to 23:30	50	160
17	November 11, 1973	02:30 to 03:30	44	150
18	November 12, 1973	23:30 to 24:30	38	160
19	November 13, 1973	23:30 to 24:30	38	180
20	November 15, 1973	14:30 to 15:30	50	160
21	November 19, 1973	22:30 to 23:30	44	150
22	November 25, 1973	01:30 to 02:30	47	180
23	November 28, 1973	03:30 to 04:30	56	160
24	December 2, 1973	23:30 to 24:30	43	160
25	December 7, 1973	01:30 to 02:30	44	160
26	December 11, 1973	09:30 to 10:30	46	170
27	December 12, 1973	03:30 to 04:30	48	150
28	December 14, 1973	23:30 to 24:30	44	160
29	December 20, 1973	09:30 to 12:30	49	160
30	December 22, 1973	03:30 to 04:30	35	140
31	December 24, 1973	11:30 to 12:30	42	170
32	December 27, 1973	14:30 to 15:30	49	170

* All times are given in Pacific Standard Time.

APPENDIX A (cont.)

Case Number	Date of Peak Wind	Time of Peak Wind	Speed in Knots	Direction in Degrees
33	December 28, 1973	16:30 to 17:30	56	170
34	December 29, 1973	03:30 to 05:30	36	180
35	January 12, 1974	16:30 to 17:30	44	150
36	January 14, 1974	03:30 to 05:30	52	160
37	January 15, 1974	06:30 to 07:30	65	150
38	January 18, 1974	07:30 to 08:30	57	160
39	January 31, 1974	05:30 to 06:30	52	180
40	January 31, 1974	18:30 to 19:30	50	170
41	February 3, 1974	18:30 to 21:30	38	160
42	February 13, 1974	01:30 to 02:30	41	160
43	February 16, 1974	07:30 to 08:30	52	170
44	February 18, 1974	15:30 to 16:30	50	170
45	February 21, 1974	02:30 to 03:30	48	160
46	February 27, 1974	20:30 to 23:30	38	120
47	March 1, 1974	12:30 to 13:30	56	190
48	March 12, 1974	17:30 to 18:30	52	190
49	March 16, 1974	08:30 to 09:30	36	170
50	March 25, 1974	08:30 to 09:30	39	-
51	March 27, 1974	22:30 to 23:30	49	-
52	April 5, 1974	05:30 to 06:30	48	-
53	October 27, 1974	08:30 to 09:30	37	170
54	November 6, 1974	16:30 to 17:30	42	160
55	November 17, 1974	09:30 to 10:30	42	160
56	November 19, 1974	15:30 to 16:30	44	160
57	November 22, 1974	15:30 to 16:30	38	150
58	November 24, 1974	10:30 to 11:30	47	150
59	December 6, 1974	04:30 to 05:30	44	160
60	December 10, 1974	14:30 to 15:30	47	160
61	December 12, 1974	07:30 to 08:30	37	150
62	December 14, 1974	24:30 to 01:30	37	150
63	December 18, 1974	06:30 to 08:30	38	160
64	December 20, 1974	23:30 to 01:30	57	160
65	December 26, 1974	22:30 to 23:30	54	160

APPENDIX B

Sea Level Pressure for Three Stations and the Pressure Difference Between Each Station Compared with the Magnitude of Wind Recorded at Newport, Oregon

Case Number	Sea Level Pressure (mb)	Sea Level Pressure (mb)	Difference (mb)	Wind Speed (kt)
	Eugene (A)	North Bend (B)	(B-A)	
1	998.7	999.3	-0.6	45
2	1015.8	1015.9	-0.1	37
3	1016.6	1018.0	-1.4	47
4	1010.3	1010.2	0.1	37
5	1014.2	1016.3	-2.1	41
7	1016.1	1016.3	-0.2	35
8	1005.7	1007.1	-1.4	44
10	1017.4	1018.6	-1.2	40
11	1009.3	1011.9	-2.6	41
12	1004.8	1006.1	-1.3	42
13	1007.8	1012.5	-4.7	38
14	996.7	1000.0	-3.3	37
15	1018.5	1019.0	-0.5	41
16	1004.8	1004.4	0.4	50
17	1006.6	1006.8	-0.2	44
18	1010.1	1010.2	-0.1	40
19	1006.6	1007.8	-1.2	38
20	999.6	1000.3	-0.7	50
21	1007.2	1010.2	-3.0	44
22	1009.9	1013.2	-3.3	47
25	1013.3	1013.5	-0.2	44
26	997.7	1001.0	-3.3	46
27	1011.4	1010.8	0.6	50
28	1013.8	1014.6	-0.6	47
29	1008.1	1008.8	-0.7	49
31	1018.7	1021.3	-2.6	42
32	1003.6	1005.1	-1.5	49
35	1007.0	1007.1	-0.1	44
36	1002.6	1003.7	-1.1	52
37	998.1	999.0	-0.9	65
38	1001.2	1002.0	-0.8	57

APPENDIX B (cont.)

Case Number	Sea Level Pressure (mb)	Sea Level Pressure (mb)	Difference (mb)	Wind Speed (kt)
39	1002.6	1003.7	-1.1	50
41	1021.7	1023.0	-1.3	38
42	1019.3	1019.3	0.0	40
43	1011.3	1014.6	-3.3	52
44	1000.9	1002.7	-1.8	43
45	1007.8	1008.5	-0.7	36
47	994.0	1001.0	-7.0	49
48	1013.4	1015.0	-1.6	48
52	1008.8	1009.5	-0.7	44
	North Bend (B)	Newport (C)	(B-C)	
1	999.3	999.1	0.2	45
2	1015.9	1013.9	2.0	37
3	1018.0	1016.3	1.7	47
4	1010.2	1009.7	0.5	37
5	1016.3	1012.1	4.2	41
7	1016.3	1014.8	1.5	35
8	1007.1	1005.3	1.8	44
9	1018.6	1015.7	2.9	40
11	1011.9	1008.5	3.4	41
12	1006.1	1003.9	2.2	42
13	1012.5	1006.5	6.0	38
14	1000.0	996.9	3.1	37
15	1019.0	1016.3	2.7	41
16	1004.4	1011.5	-7.1	50
17	1006.8	1006.0	0.8	44
18	1010.2	1007.6	3.6	40
19	1007.8	1009.0	-1.2	38
20	1000.3	997.5	2.8	50
21	1010.2	1005.6	4.6	44
22	1013.2	1007.7	5.5	47
25	1013.5	1012.0	1.5	44
26	1001.0	997.4	2.6	46
27	1010.8	1009.1	1.7	50
28	1017.6	1014.9	2.7	44
29	1008.8	1008.0	0.8	49

APPENDIX B (cont.)

Case Number	Sea Level Pressure (mb)	Sea Level Pressure (mb)	Difference (mb)	Wind Speed (kt)
31	1021.3	1018.0	3.3	42
32	1005.1	1003.0	2.1	49
35	1007.1	1005.1	2.0	44
36	1003.7	1002.6	1.1	52
37	999.0	996.7	2.3	65
38	1002.0	999.8	1.2	57
39	1003.7	1002.4	1.3	50
41	1023.0	1020.6	2.4	38
42	1019.3	1017.3	2.0	40
43	1014.6	1007.9	6.7	52
44	1002.7	999.9	2.3	43
45	1008.5	1009.9	-1.4	36
47	1001.0	999.9	4.6	49
48	1015.0	1010.7	4.3	48
52	1009.5	1009.1	0.4	44
	Corvallis (D)	Newport (C)	(C-D)	
1	992.8	999.1	-6.3	45
2	1009.0	1013.9	-4.9	37
3	1010.4	1016.3	-5.9	47
4	1003.6	1009.7	-6.1	37
5	1006.7	1012.1	-7.4	41
7	999.9	1014.8	-5.1	35
8	1010.4	1005.3	-5.4	35
9	1006.7	1015.7	-5.3	40
12	998.9	1003.9	-5.0	42
15	1012.1	1016.3	-4.2	41
16	998.9	1011.5	-2.6	50
17	1001.6	1006.0	-4.4	44
18	1003.3	1007.6	-4.3	40
19	1000.2	1009.0	-8.8	38