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Title: A STATISTICAL STUDY OF OREGON COASTAL WINDS

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The data recorded between March 3, 1969, and October 31, 1969, by a wind gauge installed at the South Jetty, Newport, Oregon, were analyzed. The components of each observation were treated as if they were an independent, normal, bivariate distribution and standard statistical procedures were applied. It was found that the wind gauge is obscured by the land to the southeast and that the adjacent land has the effect of channelling the wind so that it comes from the north, the east, and the south.

The seasonal and diurnal wind shifts were observed and described. It was noted that the orientation of the diurnal shift changed with time; it rotated clockwise from March to July and counterclockwise from July to October.

A Statistical Study of
Oregon Coastal Winds

by

John Henry Detweiler

A THESIS

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I. INTRODUCTION

This paper is a study of the winds recorded by a wind gauge located near the mouth of Yaquina Bay, Oregon, from March 3, 1969, to October 31, 1969.

The purposes of the paper are two. The first is to describe the wind gauge and to report the effects that the adjacent topography had on the wind data recorded. The second is to discuss some significant periodic changes which occurred in the wind regime during the interval of time under study.

This study is limited in time by the facts that the gauge was installed on March 3, 1969, and that only the first eight months of data had been digitized by the time I started the analysis. This period includes the period of coastal upwelling. Upwelling is the most significant oceanographic phenomenon observed along this coast. For this reason, many other types of data which may be correlated with local winds were also recorded, and appreciable interest in the use of these data by other investigators has already been expressed.

The paper first discusses the literature describing upwelling and the relationships between wind and the flow of ocean waters. It then considers what is known about the factors affecting coastal wind (principally pressure and local topography). The next section discusses the location and the operation of the gauge. Following this is a description of the data and an explanation of the statistics which were used in the analysis. Section six describes the results of the analysis. Section seven contains the conclusions and section eight contains the recommendations.

II. LITERATURE REVIEW

Wind Data as a Factor in Oceanographic Studies

An understanding of the horizontal surface wind regime is needed so that the correlation between wind and currents, including upwelling, can be studied. Smith (1968) gave an excellent review of upwelling and showed that there is a large body of literature on the subject. He and later, Fisher (1970), reviewed the theories on coastal upwelling and concluded that the wind was very important, if not the most important factor in coastal upwelling.

The wind enters the theory of upwelling as friction at the air-sea interface. According to Sverdrup (1957), the horizontal components of the equation of motion for most oceanographic applications are:

$$\frac{Du}{DT} = -\alpha \frac{\partial p}{\partial x} + fv + \alpha R_x ,$$

and

$$\frac{Dv}{DT} = -\alpha \frac{\partial p}{\partial y} - fu + \alpha R_y .$$

In these expressions, f is the coriolis parameter and α is the specific volume of sea water. R_x and R_y represent the friction, and when evaluated at the surface equal the x and y components of the wind stress. This substitution follows the suggestion by Taylor (1916) who said that the skin friction on the earth's surface is proportional to the square of the wind velocity.

Smith (1968) indicated that the wind stress cannot be directly measured and that the only suitable formula for computing wind stress is:

$$\vec{\tau} = \rho_a C_D \vec{U} | \vec{U} |.$$

Here $\vec{\tau}$ is wind stress, ρ_a is density of air, C_D is coefficient of drag, and $\vec{U}$ is vector wind. Smith, Pattullo, and Lane (1966) applied this formula in their calculation of Ekman transport. They found that the amount of transport depended on the source of wind data.

Montgomery (1936) felt that if the wind observations were few in number that it was better to use wind computed from surface pressure charts than to use sparse direct measurements. The first comparison of winds computed from pressure measurements off the Oregon Coast and winds measured at sea was conducted by Panshin in 1967. He concluded that winds observed aboard the YAQUINA (Oregon State's research vessel) were in good agreement with the computed winds, but that winds recorded on WODECO III differed markedly. The discrepancies noted may be due to differences in locations of the vessels, but I suspect that the principal cause was the quality of the observational procedures used. Panshin validly pointed out that direct wind measurements along the coast are rare.

The first comparison of winds computed from pressure measurements off the Oregon Coast and winds measured on the coast itself was conducted by Fisher in 1970. He concluded that the winds computed from weather maps drawn at six hours intervals were in good agreement with the winds computed from maps displaying monthly mean surface pressure distributions, both differed markedly with winds recorded by the U. S. Coast Guard in their observation post at Yaquina Bay. Fisher felt that this discrepancy was due to the orographic effects in the vicinity of the observation post.

It is apparent that a reliable wind source, which is a good indicator of the coastal wind regime, is necessary in the study of local oceanographic phenomena, it has not yet been adequately determined here.

Influences on Oregon Coastal Winds

The pressure distribution causes the prevailing winds to come from the southwest in winter and from the northwest in summer. During spring and fall the wind is in a state of transition from one prevailing wind to the other prevailing wind (Kendrew, 1942). Cooper (1958) arrives at basically the same conclusion which is that the wind is from the southwest in the winter and from the northwest in the summer. He further concludes that in the winter easterly breezes are most frequent, but are low in speed, and that the winter southwesterly winds are less frequent than the summer northwesterly winds, but are higher in speed.

The difference between the frictional effects of the sea and the frictional effects of the land will affect the surface wind at the coast. If the wind at the coast is produced by a cyclonic wind regime centered off the coast it will have a tendency to converge at the coast producing southerly winds with higher speeds. If the wind at the coast is produced by an anticyclonic wind regime centered off the coast it will have a tendency to diverge at the coast producing northerly winds with lower speeds (Elliott, 1969).

Lowry (1962) conducted a quantitative study of the sea breeze in Northwest Oregon, an area of complex topography along a straight coast, in mid-latitude. He concluded that in July and August the sea breeze was one of the predominant factors in the area's climate. Haurwitz (1947) set up an analytical model of the sea-land breeze which is a function of temperature difference between land and sea, the friction of the land, Coriolis force, and the diurnal change in temperature difference. The model produces a rotating sea-land breeze vector, the locus of end points of which form an ellipse. Haurwitz showed that his model agreed with observed data. The sea-land breeze effect here is thus superimposed upon the prevailing winds.

III. LOCATION AND OPERATION OF THE WIND GAUGE

The cup aneomemeter and the vane are located 125 feet south of the South Jetty on the permanent berm. The South Jetty is the southern jetty of Yaquina Bay which is approximately 95 miles south of the mouth of the Columbia River. The mast is approximately twenty-eight feet high and the ground elevation is approximately twenty-five feet above sea level (Oregon State University, 1968). Vegetation in the immediate vicinity is beach grass and small shrubs. There are two sectors which contain possible obstructions to the wind pattern. The first, between 006° and 032°, includes the city of Newport which is at an approximate range of 3500 feet from the wind gauge. The second, between 076° and 183°, includes a series of densely wooded hummocks which are oriented approximately north-northeast and sourth-southeast and are at an approximate range of 1800 feet from the wind gauge. A map of the area is shown in Figure 1.

The wind gauge consists of two separate systems, one for direction and one for speed. Once every minute the direction subsystem recorded the wind direction. If the wind blew from within $67\frac{1}{2}^{\circ}$ of a cardinal point it was recorded as having a componenet from that cardinal point (Burdwell, 1970). Figure 2 shows the recording arcs of the direction subsystem. The series of Fortran program (included in Appendix A) which I developed compute the mean direction, accurate

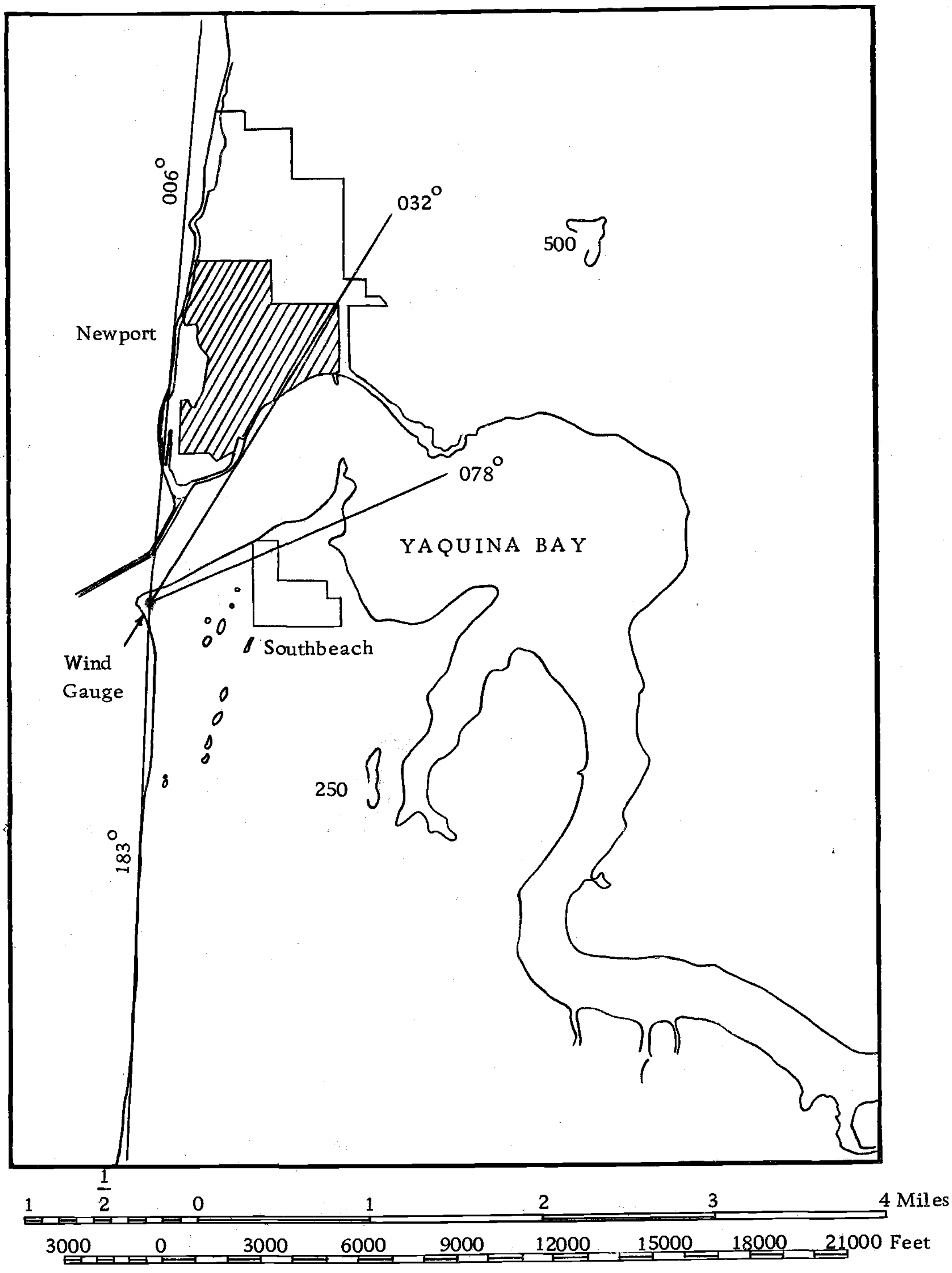
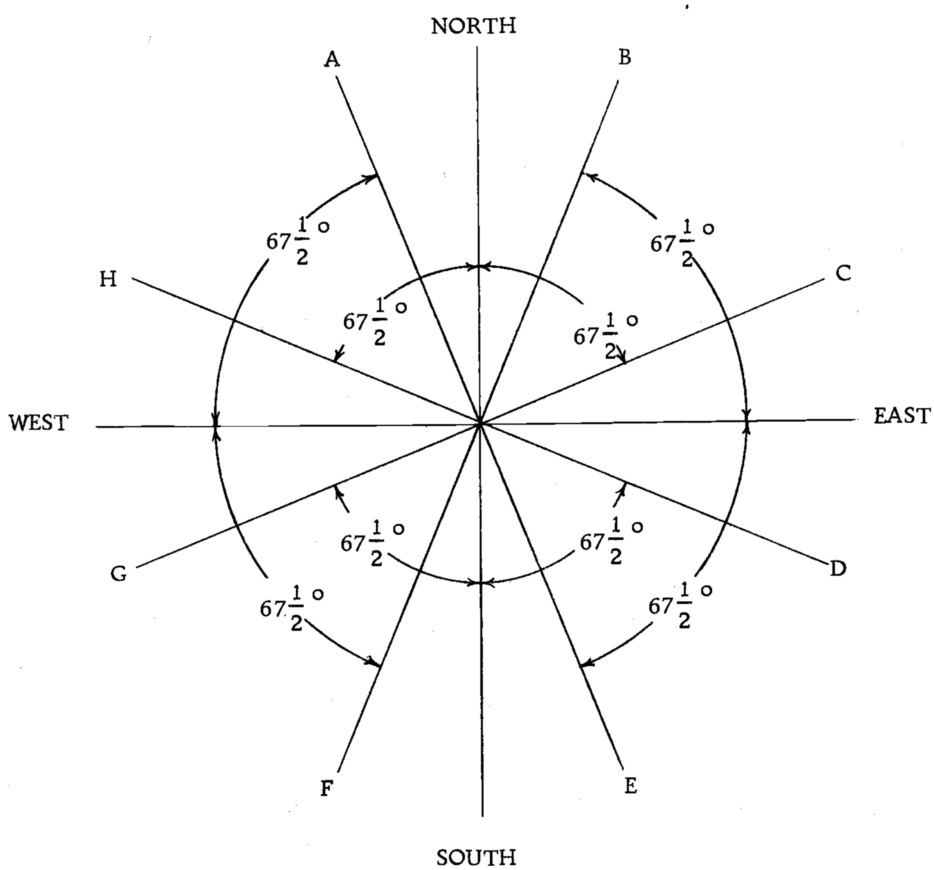


Figure 1. Area in vicinity of Yaquina Bay.



RECORDING ARCS	COMPONENTS RECORDED			
	N	E	S	W
A-B	x			
B-C	x	x		
C-D		x		
D-E		x	x	
E-F			x	
F-G			x	x
G-H				x
H-A	x			x

Figure 2. Recording arcs for direction subsystem of the wind gauge at the South Jetty.

to within $\pm 22\frac{1}{2}^{o}$, that the wind came from during the hour. The mean direction is the direction of the vector sum of four vectors (north, east, south, and west). The number of minutes that the wind blew from each cardinal point is used as the vector length.

The speed subsystem indicated the passage of every mile of wind. The series of Fortran program which I developed use the recorded number of miles per hour and a calibration correction provided by U. S. Department of Commerce et al. (1970) as the mean scalar speed.

The recorder is located at the Marine Science Center, Newport, Oregon. It is an Esterline Angus Model AW Operation Recorder which can be used to record any time dependent event. The record is made on a strip chart which is driven past a series of pens. The device can operate up to twenty pens; however, during the period under study four pens were used for recording the direction and one pen was used for recording the speed.

The record is punctuated with missing data due to malfunctions of various components. At times both direction and speed subsystems were out of order, at other times only one was out of order. The direction subsystem was out of order in 2.7% of all observations. The speed subsystem was out of order in 10.7% of all observations. The entire system was out of order in 11.3% of all observations.

IV. THE DATA

The data consisted of 5000 hourly observations. In order to examine wind changes with time I decided to select suitable sets from among this large initial sample. First I compiled all data taken during a given month. Then I divided this set into three subsets, each including all data collected during a specified time interval eight hours in length. I had noticed early in the experiment that there were marked changes in wind around 0800 and also close to 1600 each day. I used these times and, applying symmetry, 2400 as the end-points of the intervals. 0100 to 0800 is called the morning interval, 0900 to 1600 the midday interval, and 1700 to 2400 the evening interval. My large initial sample has thus been subdivided into thirty-two subsamples which can be compared.

V. STATISTICS USED IN THE ANALYSIS

This section discusses the statistical tools which were used in the analysis of the data.

The mean, variance, and standard deviation were calculated for each of the following variables: direction, speed, and the U and V components of speed. The formulas used for these statistics are:

$$\text{mean} \quad \bar{x} = \frac{1}{n} \sum_{i}^{n} x_i \quad ,$$

$$\text{variance} \quad s^2 = \frac{1}{n-1} \sum_{i}^{n} (x_i - \bar{x})^2 \quad ,$$

$$\text{standard deviation} \quad s = \sqrt{s^2} \quad .$$

Where x_i is an observation and n is the number of observations (Wine, 1964).

I decided to use the statistics of U and V for the basis of my analysis, since they tend to be normally distributed (Brooks and Carruthers, 1953). I further assumed that U and V were independently distributed. This makes it possible to use well known techniques for the statistical analysis. Unfortunately when I computed the U and V correlation and autocorrelation coefficients for the months of June and July they turned out to be significant. This implies that a better procedure for future studies would be to use time series analyses. In this thesis U and V are treated as an independent, normal, bivariate distribution.

I computed the 95% confidence intervals for the true means of all the U's and V's of all the various subsets of data. The formula used for the 95% confidence interval is:

$$\bar{x} - t_{(.025)}(n-1)\sqrt{\frac{s^2}{n}} < \mu < \bar{x} + t_{(.025)}(n-1)\sqrt{\frac{s^2}{n}} .$$

μ equals the true mean. $t_{(.025)}(n-1)$ equals the Student 't' statistic with (n-1) degrees of freedom. The probability of 't' being greater than $t_{(.025)}(n-1)$ or less than $-t_{(.025)}(n-1)$ is .05. n equals the number of observations in the set, s^2 equals the variance, and $\bar{x}$ equals the sample mean (Wine, 1964).

In order to determine if there was a significant difference between the morning, midday, and evening mean wind vectors and the monthly mean wind vector, I computed the following contrasts between the components which are distributed with the Student 't' distribution (Wine, 1964):

$$'t'\left(\sum_{i}^{3} n_i - 3\right) \sim \frac{\sum_{i}^{3} m_i \bar{x}_i}{s_p\sqrt{\sum_{i}^{3} \frac{m_i^2}{n_i}}} .$$

Where $t\left(\sum_i^3 n_i - 3\right)$ equals the Student 't' statistic with $\left(\sum_i^3 n_i - 3\right)$ degrees of freedom.

Contrast \ X_i	m_i: $\overline{U}$ or $\overline{V}_{morning}$	$\overline{U}$ or $\overline{V}_{midday}$	$\overline{U}$ or $\overline{V}_{evening}$
1	2	-1	-1
2	-1	2	-1
3	-1	-1	2

$$s_p = \sqrt{\frac{(n_1-1)s_1^2 + (n_2-1)s_2^2 + (n_3-1)s_3^2}{n_1 + n_2 + n_3 - 3}} \quad ,$$

s_1^2 = variance of morning U or V ,

s_2^2 = variance of midday U or V ,

s_3^2 = variance of evening U or V,

n_1 = number of observations in morning set of U or V,

n_2 = number of observations in midday set of U or V,

n_3 = number of observations in evening set of U or V,

In this case $\sum_i^3 m_i\overline{x}$ equals $3(z-\overline{z})$ where z equals the $\overline{x}_i$ in which

m_i equals two and $\overline{z}$ equals the monthly mean. Therefore the morning, midday, and evening means are actually compared to the monthly mean.

I also tested the possibility of the monthly mean U and the monthly mean V being equal to zero, where I felt that the vector (composed of U and V) might reasonably be expected to be the null vector, with the Student 't' statistic (Wine, 1964).

The final statistic I used in the evaluation of this data was the constancy indicator 'q' which is defined by Brooks, Durst, and Carruthers (1946) as:

$$'q' = \frac{|\vec{r}|}{\overline{s}} \quad .$$

Where $|\vec{r}|$ equals the magnitude of the mean wind vector and $\overline{s}$ equals the mean scalar speed. Brooks (1946) used the constancy indicator as a means to determine the wind rose for upper air observations based on a few representative observations. Brooks (1953) states that in a normal circular distribution the square of 'q' gives the approximate proportion of vector ends lying within a circle of $|\vec{r}|$ from the center of the distribution (end of $\vec{r}$). I interpret 'q' as being a measure of the size of the mean angle between the individual wind vectors and the mean wind vector, weighted more heavily by the stronger winds. In equation form

$$'q' = \overline{\ell_i \cos B_i} \quad .$$

Where ℓ_i equals $\frac{s_i}{\bar{s}}$, s_i equals the magnitude of the i^{th} wind vector, $\bar{s}$ equals the mean scalar speed, and B_i equals the angle between the mean wind vector and the i^{th} wind vector. My interpretation is developed in Appendix B.

The parameter 'q' is not dependent upon the number of vectors and therefore can be used to compare any set of wind vectors with any other set of wind vectors. 'q' will equal zero if the mean wind is the null vector, and it will equal one if all the wind is in the same direction.

VI. RESULTS OF ANALYSIS

The steadiest wind occurred in July when it was from the north. Between July and September it shifted from steadily north to unsteadily south. The wind in October was less variable than the wind in September and it was from the southeast. The wind in March was very unsteadily from the north; there is insufficient evidence to say that the monthly wind vector was not the null vector at the 10% level. Between April and July the wind shifted from steadily southwest to steadily north, it was relatively unsteady in May and June. The wind speed generally decreased from March to August and increased slightly in September and October.

The U and V 95% confidence intervals for the components of wind vectors were plotted on U-V fields producing rectangular areas which I have called confidence areas. The confidence areas of the monthly mean wind vectors, for each month, are displayed in Figure 3. Figure 4 displays monthly constancy indicator 'q' and monthly mean scalar speed, both versus month. The scalar speed and the U-V components are in knots; the U component is positive towards the east and the V component is positive towards the north.

In order to determine if the wind regime in 1969 was unusual, I compared it to data taken at Newport between 1936 and 1942. This data is the only summarized data available for Newport (Pacific

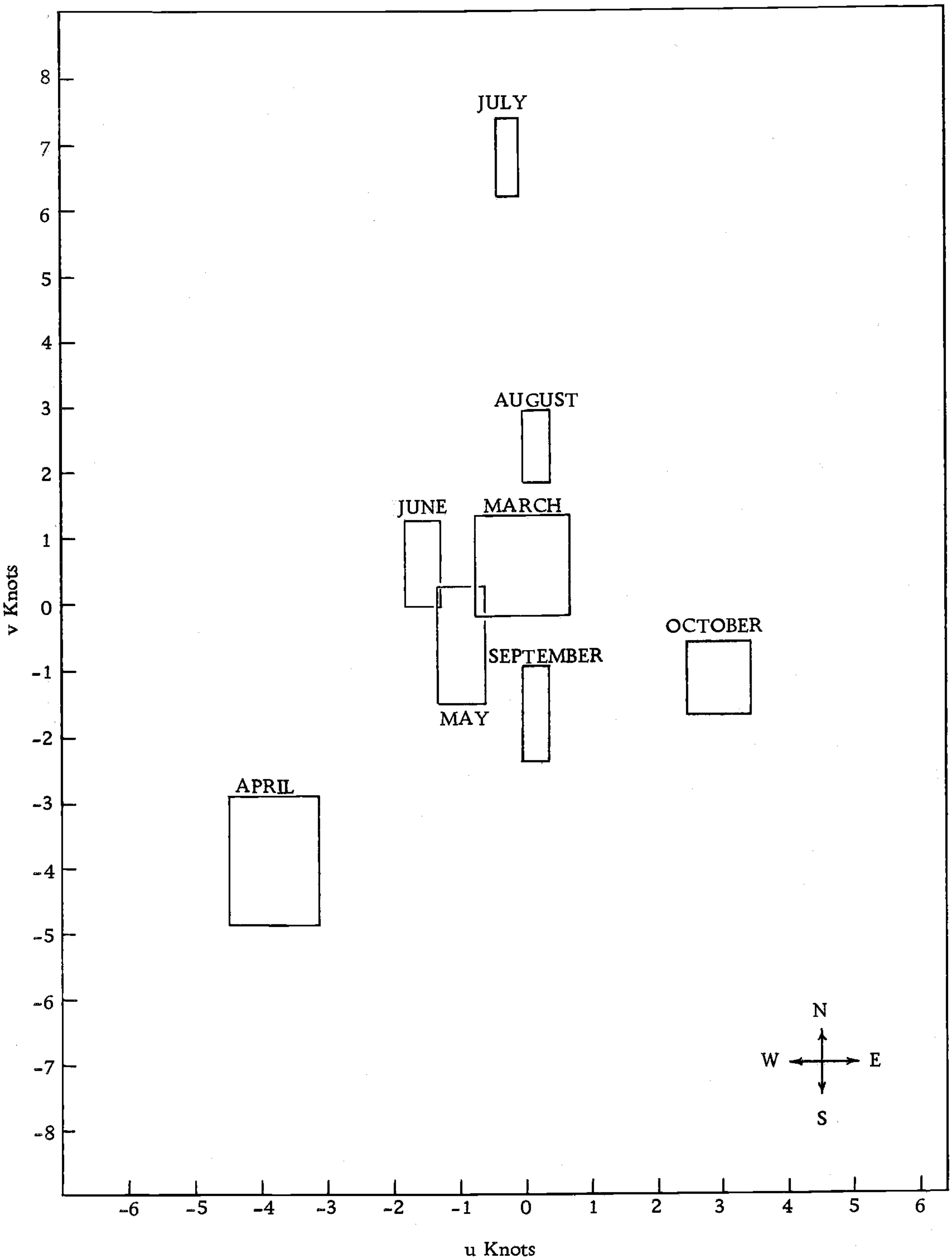


Figure 3. Confidence areas of the monthly mean wind vectors.

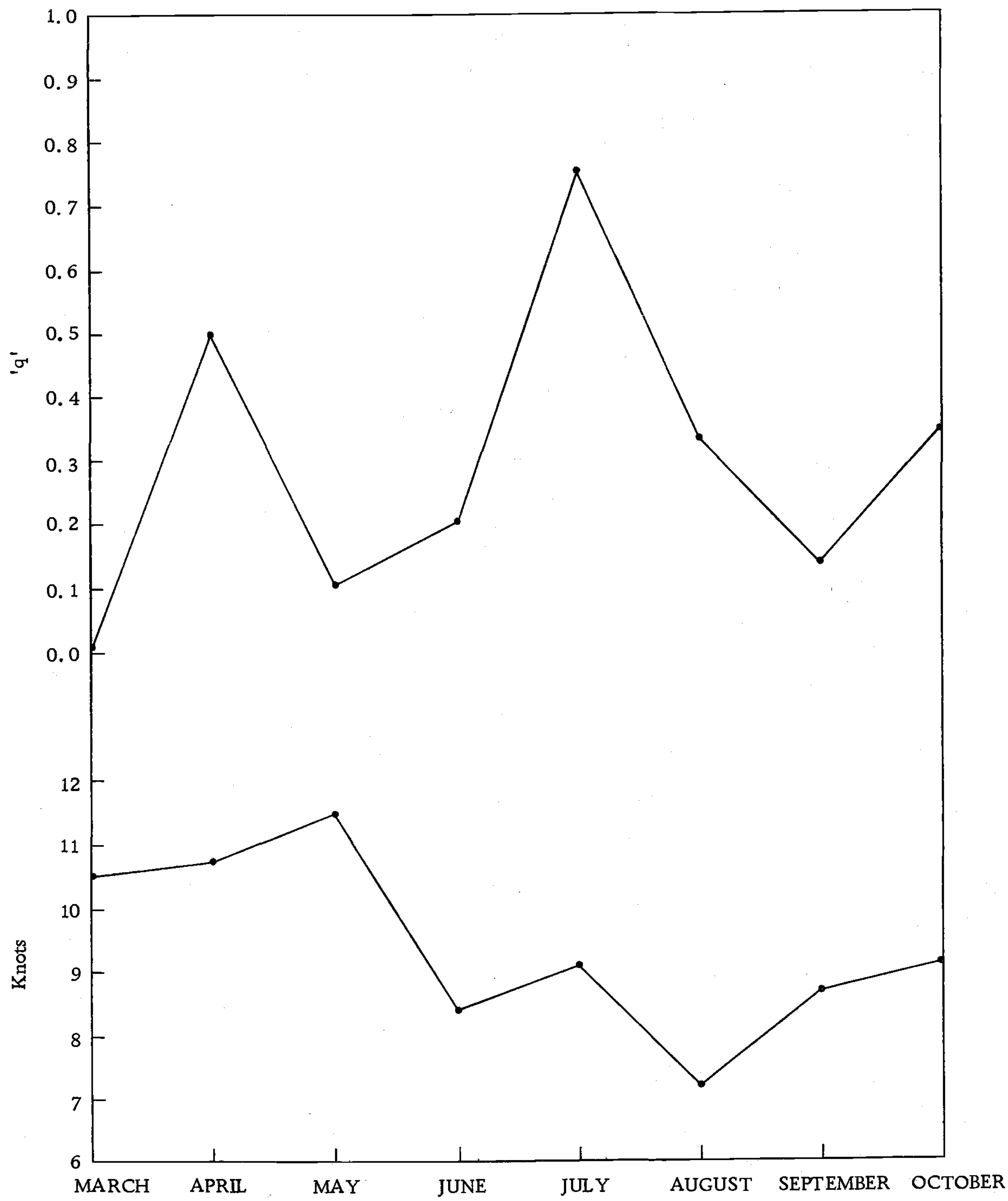


Figure 4. Monthly constancy indicator 'q' and monthly mean scalar speed versus month.

Northwest River Basins Committee, 1968). I summarized the data recorded by the South Jetty wind gauge in the same manner as was done for the data taken between 1936 and 1942, which was a bivariate (direction and speed) percentage frequency summary. Unfortunately I do not know where in Newport the data was taken between 1936 and 1942 so I do not know anything about the possible orographic effects.

For each month (March through October), I compared the percentage frequencies for each of eight points between the 1936-1942 data and the South Jetty wind gauge data. I did not see any differences greater than 20% except in three (out of sixty-four) cases. The wind blew from the north at the South Jetty wind gauge 28.3% more of the total time during July, 1969, than it blew from the north during July, 1936-1942. The wind blew from the south at the South Jetty wind gauge 22.3% more of the total time during September, 1969, than it blew from the south during September, 1936-1942. The wind blew from the east at the South Jetty wind gauge 32.2% of the total time during October, 1969, than it blew from the east during October, 1936-1942. This may be due to the exposure at the South Jetty wind gauge to the north, the east, and the south as compared to the possible exposure of the gauge in the city of Newport between 1936 and 1942.

I also compared the percentage of scalar speeds in each of four speed classes for each month. I did not see any differences larger than 20% except in three (out of thirty-two) cases. The wind blew 23%

less in the three to thirteen knot class at the South Jetty wind gauge than it did during April, 1936-1942. The wind blew 20.5% less in the three to thirteen knot class at the South Jetty wind gauge than it did during May, 1936-1942. In May it also blew 23.3% more in the fourteen to twenty-seven knot class at the South Jetty wind gauge than it did between 1936 and 1942. This tends to indicate that the wind had a higher speed during April and May, 1969, than during April and May, 1936-1942. However, the mean wind vector for April and May came from the southwest which is an exposed direction at the South Jetty wind gauge. The location of the gauge between 1936 and 1942 may not have been as exposed to the southwest as the one at the South Jetty.

Frequency versus direction histograms of March, April and July show the possibility of a wind obstruction at 025°; histograms of all eight months show a possibility of an obstruction between 110° and 140°. Seven months show a maximum or high local maximums in the frequency versus direction histograms between 000° and 019° and between 080° and 099°. All eight months show a maximum or a high local maximum in the frequency versus direction histograms between 180° and 199°. The frequency versus direction histograms are included as Appendix C.

All eight months data were characterized by a diurnal shift in the wind. At least one component of the morning and the midday mean wind vectors was rejected as being equal to a component of the monthly mean wind vector at the .05% significance level. At least one component of the evening mean wind vector was rejected as being equal to a component of the monthly mean wind vector at the 10%, or lower, significance level. In the morning the mean wind vector relative to the monthly mean wind vector generally came from the east or southeast. During the midday it came from the west or northwest, except in April and September when it was slightly south of west. In the evening it came from the northwest or north-northwest, except in June when it was slightly east of north. The orientation of the diurnal shift, relative to the monthly mean, changed each month. This can be seen by examination of the orientation of the morning, midday, and evening confidence areas relative to the monthly confidence areas which are shown for each month in Appendix D. The significance levels at which the morning and midday mean V components were rejected as being equal to the monthly mean V component (in favor of their being less or greater respectively) were lower in the summer than they were in the spring and fall.

Sine waves which represent single oscillations with a known frequency can be computed from any two known points (Doodson and Warburg, 1941). This technique can be applied to find sine curves representing the mean diurnal shift in U and V. These sine curves can be plotted on a U-V field producing an ellipse which represents the mean diurnal fluctuation of the wind vector.

In most every month there are at least a few data points which were missing due to malfunctions. In March approximately nine days were missing direction, speed, or both. In April the speed measuring subsystem was virtually inoperable for the first one half of the month; the statistics actually represent the wind regime for the second one half of the month. In May there were seven observations in which direction was not recorded. In June there were no missing observations. In July there were approximately four days during which speed was not recorded. In August there were four observations in which both direction and speed were missing. In September there were fifteen observations in which direction was not recorded. In October there were twelve observations in which both direction and speed were missing.

VII. CONCLUSIONS

The wind had a tendency to come from the north, the east, and the south which leads me to conclude that the adjacent land has the effect of channelling the wind into these directions. There was a definite lack of recorded wind between 110° and 140° in all the frequency versus direction histograms, which was especially disturbing when the vector mean wind came from the southeast; this leads me to conclude that the land to the southeast of the wind gauge obstructs southeast winds. The obscured sector to northeast was not as pronounced as the obscured sector to the southeast; in only three of the frequency versus direction histograms was there a definite lack of recorded wind at 025°. In one of these months, April, the mean wind vector was from the southwest which indicates that there was a paucity of wind from the northeast regardless of the presence of the land. Therefore, I can only conclude that the city of Newport has a very small obstructing effect on the wind gauge, if it has any obstructing effect at all. The city of Newport only fills a twenty-six degree sector and it is not a high rise city, so its obstructing characteristics may not be readily apparent on frequency diagrams with nineteen degree class intervals. There is no reason to suspect that westerly winds, except winds slightly west of south, are influenced by the topography.

After examination of a topographical map of the area, I have come to the conclusion that the only thing which can be done about the problem of obscured sectors is to be aware of their presence. The topography rises to 250 feet at a distance of 1.6 miles to the southeast. It also rises to 500 feet at a distance of 3.3 miles to the northeast.

There is insufficient evidence to infer that the data taken at the wind gauge between March 3, 1969, and October 31, 1969, is not typical of the wind regime at Newport. The seasonal wind shift during 1969 generally conformed to Kendrew's (1942) and Cooper's (1958) work. The prevailing wind shifted from southwest in the last two weeks of April to slightly west of north in July and then to slightly east of south in September. The wind in March had a relatively high scalar speed and was very unsteady. The October mean wind vector was from the east-southeast; the October winds were steadier than the September winds.

The diurnal shift in wind was apparent in all eight months and was characteristic of a sea-land breeze relative to the prevailing wind. Therefore, I can conclude that there is a prominent sea-land breeze effect in the Newport wind regime between March and October. However, I can not say that it is a summer time phenomenon as opposed to one which is present throughout the year. The orientation of the confidence areas of the morning, the midday, and the evening mean wind vectors, relative to the confidence area of the monthly mean wind vector, generally rotates clockwise between March and July and counter clockwise between July and October. This rotation appeared to be a seasonal change; however, I can not conclude that it is part of a yearly cycle as this paper does not encompass a full year's data.

I originally divided each month into three sets of numbers, each composed of measurements takenduring the same period of the day for the entire month, to show the diurnal changes that I had qualitatively observed in the Newport area. If I had wanted to show the sea-land breeze explicitly it would have been better to divide the month into more sets of measurements such as six, twelve, or possibly twenty-four. This would show the mean diurnal path of the wind vector in more detail. However, a figure containing six, twelve, or twenty-four confidence areas for each month might not be as meaningful as the confidence intervals would tend to be larger because there would be less observations in each set.

A change in the wind direction and speed due to the frictional differences between the land and the sea, as the wind passes over the coast line, was not readily apparent. However, the difference in the mean scalar speed between April and July could have been partly due to this effect. In April the mean wind vector was from the southwest and in July it was from the north;. the mean scalar speed in April was greater than the mean scalar speed in July.

The most useful statistics to me were: the means of the scalar speed, the means and variances of the components, and the constancy indicator 'q'. The statistics of the direction as I computed them represent the statistics of a set of numbers between zero and 360 rather than the statistics for a radial set of measurements in which 000^{o} equals 360^{o}. Therefore, they are not very useful in the study of a set of vectors.

VIII. RECOMMENDATIONS

The wind gauge should be connected to a recording device which is compatible to the Oregon State University computer. This would obviate the necessity of manually digitizing and key punching the data. Digitizing and key punching are the principle sources of error now. If an automated system were installed, these particular functions would be eliminated and, hopefully, most of the errors in the data would be also.

This study should be continued to complete a year when the data has been digitized and key punched. The complete year should commence May 1, 1969, and continue until April 30, 1970, in order to have a complete year without April, 1969. The data of April, 1969, only represents the second one half of the month.

The winds observed at the South Jetty wind gauge should be compared with other coastal sources in order to better understand the spacial variability of the Oregon coastal winds. They should also be compared with geostrophic winds computed from pressure charts in order to better understand the relationship between geostrophic winds and observed winds. Hasse and Wagner (1970) made such a study in the German Bight (approximately Latitude 54°N and Longitude 7°E) in which they found three linear relationships between the geostrophic wind and the observed wind. They suggest testing their results in a different wind regime at a different latitude.

BIBLIOGRAPHY

Brooks, C. E. P., C. S. Durst, and N. Carruthers. 1946. Upper winds over the world, Part I, The frequency distribution of winds at a point in the free air. Quarterly Journal of the Royal Meteorological Society. 73:55-73.

Brooks, C. E. P., N. I. Carruthers. 1953. Handbook of statistical methods in meteorology. London, Her Majesty's Stationery Office. 412 p. (M. O. 538).

Burdwell, Gerald B. 1970. Advisory Marine Meteorologist, Oregon State University Marine Science Center. Personal communication. Newport.

Cooper, William S. 1958. Coastal sand dunes of Oregon and Washington. New York, Geological Society of America. 169 p. (The Geological Society of America Memoir 72)

Doodson, A. T., and H. D. Warburg. 1941. Admiralty Manual of Tides. London, Her Majesty's Stationery Office. 270 p.

Elliott, William P. 1969. Class notes. Oc 577: Marine climatology. Corvallis, Oregon State University.

Fisher, Carl E. 1970. A statistical study of winds and sea water temperatures during Oregon coastal upwelling. Master's thesis. Corvallis, Oregon State University. 67 numb. leaves.

Friez Instrument Division, Bendix Aviation Corporation. 1943. Instructions for the installation, operation and maintenance of the Friez contacting anemometer nos. 343, 343-N, and 347. Baltimore. 7 p. (instruction book no. 73)

Hasse, L., and V. Wagner, 1970. On the relationship between geostrophic and surface wind at sea. Monthly Weather Review (in preparation).

Haurwitz, Bernard. 1947. Comments on the sea breeze circulation. Journal of Meteorology. 4:1-8.

Kendrew, W. G. 1942. The climates of the continents. 3d ed. New York. Oxford University Press. 473 p.

Lowry, William P. 1962. The sea breeze of Northwest Oregon and its influence on forestry operations. Ph. D. Thesis. Corvallis, Oregon State University. 216 numb. leaves.

Montgomery, R. B. 1936. Transport of surface water due to the wind system over the North Atlantic. Papers in Physical Oceanography and Meteorology 4(3):23-30.

Oregon State University Physical Plant. 1968. Marine science center cable way. Corvallis. 1 sheet. (Physical plant job no. 9543)

Pacific Northwest River Basins Committee. 1968. Meteorology Committee. Climotological Handbook, Columbia Basin States Hourly Data, Vol. 3, Part A. 341 p.

Panshin, Daniel A. 1967. Sea level, winds, and upwelling along the Oregon coast. Master's thesis. Corvallis, Oregon State University. 71 numb. leaves.

Smith, Robert L., June G. Pattullo, and Rober K. Lane. 1966. An investigation of the early stage of upwelling along the Oregon coast. Journal of Geophysical Research 71:1135-1140.

Smith, Robert L. 1968. Upwelling. Oceanography and Marine Biology, Annual Review 6:11-46.

Sverdrup, H. U. 1957. Oceanography. In: Encyclopedia of physics, ed. by S. Flügge, Berlin, Germany, Springer-Verlag. p. 608-670.

Taylor, G. I. 1916. Skin friction of the wind on the earth's surface. Proceedings of the Royal Society of London, Ser. A, 92:196-199.

U. S. Department of Commerce, U. S. Department of Defense and U. S. Department of Transportation. 1970. Federal Meteorolgical Handbook no. 1, Surface Observations. Effective January 1. Washington, D. C.

U. S. Environmental Science Services Administration. 1969. Unpublished raw data recorded at the South Jetty wind gauge, March 3 through October 31. Newport, Oregon.

Wine, R. Lowell. 1964. Statistics for scientists and engineers. Englewood Cliffs, Prentice-Hall Inc. 671 p.

APPENDICES

APPENDIX A

Programs

1. Program WINDCOM. This program computes the mean direction and mean speed, resolves them into components, and points out possible errors.

```
      PROGRAM WINDCOM
C EQUIP THE FOLLOWING,10=FILE,2=LP,1=INPUT FILE,4=FILE
      DIMENSION ANOR(24),EAS(24),SOU(24),WES(24),
     1DIR(800),AMILE(24),UCOM(800),VCOM(800),PUCOM(800),
     2PVCOM(800),DUCOM(800),DVCOM(800),KK(800),L(800),
     3MM(800),UER(800),VER(800),AKNOT(800),IHR(24)
      K=0
   25 READ(1,5)
    5 FORMAT(1H )
      IF(EOF( 1))GO TO 141
      READ(1,1) (ANOR(I),EAS(I),SOU(I),WES(I),AMILE(I),I=1,24)
    1 FORMAT(40F2.0)
      IF(EOF(1))GO TO 141
      DO 140 I=1,24
      K=K+1
      IF(ANOR(I).EQ.SOU(I).AND.EAS(I).EQ.WES(I))GO TO 40
      VICT=ABS(ANOR(I)-SOU(I))
      UNIF=ABS(EAS(I)-WES(I))
      IF(VICT.EQ.0.0)GO TO 10
      GO TO 20
   10 TDIR=1.570796
      GO TO 30
   20 TDIR=ATAN(UNIF/VICT)
   30 IF(ANOR(I).GT.SOU(I).AND.EAS(I).GE.WES(I))DIR(K)=TDIR
      IF(SOU(I).GT.ANOR(I).AND.EAS(I).GE.WES(I))DIR(K)=3.141592-TDIR
      IF(SOU(I).GE.ANOR(I).AND.WES(I).GT.EAS(I))DIR(K)=3.141592+TDIR
      IF(ANOR(I).GT.SOU(I).AND.WES(I).GT.EAS(I))DIR(K)=6.283184-TDIR
      IF(ANOR(I).EQ.SOU(I).AND.EAS(I).GT.WES(I))DIR(K)=1.570796
      GO TO 50
   40 DIR(K)=999.0
   50 IF(AMILE(I).EQ.99.0) GO TO 60
      IF(AMILE(I).LE.16.0)GO TO 51
      IF(AMILE(I).GE.17.0.AND.AMILE(I).LE.26.0) GO TO 59
      IF(AMILE(I).GE.27.0.AND.AMILE(I).LE.35.0) GO TO 52
      IF(AMILE(I).GE.36.0.AND.AMILE(I).LE.44.0) GO TO 53
      IF(AMILE(I).GE.45.0.AND.AMILE(I).LE.52.0) GO TO 54
      IF(AMILE(I).GE.53.0.AND.AMILE(I).LE.61.0) GO TO 55
      IF(AMILE(I).GE.62.0.AND.AMILE(I).LE.70.0) GO TO 56
      IF(AMILE(I).GE.71.0.AND.AMILE(I).LE.79.0) GO TO 57
      IF(AMILE(I).GE.80.0.AND.AMILE(I).LE.87.0) GO TO 58
   51 AMILE(I)=AMILE(I)+1.0
      GO TO 59
   52 AMILE(I)=AMILE(I)-1.0
      GO TO 59
   53 AMILE(I)=AMILE(I)-2.0
      GO TO 59
   54 AMILE(I)=AMILE(I)-3.0
      GO TO 59
   55 AMILE(I)=AMILE(I)-4.0
      GO TO 59
   56 AMILE(I)=AMILE(I)-5.0
      GO TO 59
   57 AMILE(I)=AMILE(I)-6.0
      GO TO 59
   58 AMILE(I)=AMILE(I)-7.0
   59 AKNOT(K)=0.8684*AMILE(I)
      GO TO 70
   60 AKNOT(K)=99.0
   70 IF(DIR(K).GT.988.0.OR.AKNOT(K).GT.98.0) GO TO 150
      UCOM(K)=AKNOT(K)*SIN(DIR(K))
```

```
      VCOM(K)=AKNOT(K)*COS(DIR(K))
      DIR(K)=DIR(K)*57.284
      GO TO 140
  150 UCOM(K)=VCOM(K)=9.9E 99
      IF(DIR(K).LT.998.0)DIR(K)=DIR(K)*57.281
  140 CONTINUE
      GO TO 25
  141 WRITE(61,4) K
      WRITE(10,4) K
    4 FORMAT(I4)
      REWIND 1
      J=K-3
      DO 200 I=4,J
      N=I-3
      M=I-1
      DO 250 LL=N,M
      IF(UCOM(LL).GE.9.800E 99) GO TO 260
  250 CONTINUE
      N=I+1
      M=I+3
      DO 270 LL=N,M
      IF(UCOM(LL).GE.9.800E 99) GO TO  260
  270 CONTINUE
      PUCOM(I)=0.75*(UCOM(I-1)+UCOM(I+1))-0.30*(
     1UCOM(I-2)+UCOM(I+2))+0.05*(UCOM(I-3)+UCOM(I+3))
      GO TO 200
  260 PUCOM(I)=9.900E 99
  200 CONTINUE
      PUCOM(1)=PUCOM(2)=PUCOM(3)=PUCOM(J+1)=PUCOM(J+2)
     1=PUCOM(J+3)=9.900E 99
      DO 300 I=4,J
      N=I-3
      M=I-1
      DO 350 LL=N,M
      IF(VCOM(LL).GE.9.800E 99) GO TO  360
  350 CONTINUE
      N=I+1
      M=I+3
      DO 370 LL=N,M
      IF(VCOM(LL).GE.9.800E 99) GO TO  360
  370 CONTINUE
      PVCOM(I)=0.75*(VCOM(I-1)+VCOM(I+1))-0.30*(
     1VCOM(I-2)+VCOM(I+2))+0.05*(VCOM(I-3)+VCOM(I+3))
      GO TO 300
  360 PVCOM(I)=9.900E 99
  300 CONTINUE
      PVCOM(1)=PVCOM(2)=PVCOM(3)=PVCOM(J+1)=PVCOM(J+2)
     1=PVCOM(J+3)=9.900E 99
      DO 420 I=1,K
      IF(UCOM(I).GE.9.8E 99.OR.PUCOM(I).GE.9.8E 99)GO TO 450
      DUCOM(I)=ABS(UCOM(I)-PUCOM(I))
      GO TO 410
  450 DUCOM(I)=9.9E 99
  410 IF(VCOM(I).GE.9.8E 99.OR.PVCOM(I).GE.9.8E 99)GO TO 451
      DVCOM(I)=ABS(VCOM(I)-PVCOM(I))
      GO TO 420
  451 DVCOM(I)=9.9E 99
  420 CONTINUE
      DO 500 I=4,J
      UER(I)=VER(I)=0.0
```

```
      KK(I)=MM(I)=L(I)=0
      IF(DUCOM(I).GE.9.8E 99.OR.DUCOM(I-1).GE.9.8E 99
     1.OR.DUCOM(I+1).GE.9.8E 99) GO TO 510
      IF(DUCOM(I).GE.DUCOM(I-1).AND.DUCOM(I).GE.DUCOM(I
     1+1))L(I)=11
  510 IF(DVCOM(I).GE.9.8E 99.OR.DVCOM(I-1).GE.9.8E 99
     1.OR.DVCOM(I+1).GE.9.8E 99) GO TO 515
      IF(DVCOM(I).GE.DVCOM(I-1).AND.DVCOM(I).GE.DVCOM(I
     1+1))MM(I)=11
  515 IF(PVCOM(I).LT.9.8E 99.AND.UCOM(I).GT.9.8E 99)MM(I)=3
      IF(PUCOM(I).LT.9.8E 99.AND.UCOM(I).GT.9.8E 99)L(I)=3
      IF(L(I).EQ.11) UER(I)=ABS(DUCOM(I)/((UCOM(I)+PUCOM(I))
     1/2.0))
      IF(MM(I).EQ.11) VER(I)=ABS(DVCOM(I)/((VCOM(I)+PVCOM(I))
     1/2.0))
      IF(MM(I).EQ.11.AND.L(I).EQ.11)KK(I)=11
  500 CONTINUE
      WRITE(4,2)(DIR(I),AKNOT(I),UCOM(I),PUCOM(I),DUCOM(I),L(I),
     1UER(I),VCOM(I),PVCOM(I),DVCOM(I),MM(I),VER(I),KK(I),I=1,K)
    2 FORMAT(F3.0,F2.0,3E10.3,I2,F5.2,3E10.3,I2, F5.2,I2)
      REWIND 4
  700 READ(1,3) NDATE
    3 FORMAT(I6///)
      IF(EOF(1)) GO TO 750
      READ(4,2)(DIR(I),AKNOT(I),UCOM(I),PUCOM(I),DUCOM(I),L(I),
     1UER(I),VCOM(I),PVCOM(I),DVCOM(I),MM(I),VER(I),KK(I),I=1,24)
      IR=0
      DO 740 I=1,24
      IR=IR+1
  740 IHR(I)=IR
      WRITE(10,9)     NDATE,(DIR(I),AKNOT(I),UCOM(I),PUCOM(I)
     1,DUCOM(I),L(I),UER(I),VCOM(I),PVCOM(I),DVCOM(I),MM(I),
     2VER(I),KK(I),I=1,24)
    9 FORMAT(I6,    24(/,F3.0,F2.0,3E10.3,I2,F5.2,3E10.3,
     1I2,F5.2,I2))
      WRITE(2,11)     NDATE,(IHR(I),DIR(I),AKNOT(I),UCOM(I),
     1PUCOM(I),DUCOM(I),L(I),UER(I),VCOM(I),PVCOM(I),DVCOM(I),
     2MM(I),VER(I),KK(I),I=1,24)
   11 FORMAT(1X,I6,    24(/,6X,I2,F5.0,F4.0,3E15.3,I5,F5.2,
     15X,3E15.3,I5,F5.2,I3))
      GO TO 700
  750 REWIND 10
      END
```

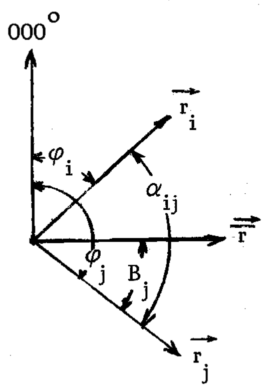
2. Program COMPOSIT. This program creates a final file, which contains date, hour, direction, speed, and components, from the output of the previous program. It also substitutes the prediction (if there is one) of a datum point for missing datum points.

```
CS3 FORTRAN  VERSION 2.1                  10/07/70  1440
      PROGRAM  COMPOSIT
      DIMENSION DIR(24),BKNOT(24),UCOM(24),PUCOM(24),L(24),
     1VCOM(24),PVCOM(24),M(24),AUCOM(24),AVCOM(24),IHR(24)
      N=0
      READ(10,4)K
    4 FORMAT(I4)
  940 READ(10,1)     NDATE,(DIR(I),BKNOT(I),UCOM(I),PUCOM(I),
     1L(I),VCOM(I),PVCOM(I),M(I),I=1,24)
    1 FORMAT(I6,24(/,F3.0,F2.0,2E10.3,10X,I2,5X,2E10.3,
     110X,I2,7X))
      IR=0
      DO930 I=1,24
      IR=IR+1
      IHR(I)=IR
      IF(L(I).EQ.3) GO TO 900
      AUCOM(I)=UCOM(I)
      GO TO 910
  900 AUCOM(I)=PUCOM(I)
  910 IF(M(I).EQ.3) GO TO 920
      AVCOM(I)=VCOM(I)
      GO TO 925
  920 AVCOM(I)=PVCOM(I)
  925 IF(DIR(I).LT.998.0.AND.BKNOT(I).LT.98.0)GO TO 930
      IF(AUCOM(I).GT.9.8E 99.AND.AVCOM(I).GT.9.8E 99) GO TO 930
      IF(DIR(I).LT.998.0) GO TO 934
      TDIR=ATAN(ABS(AUCOM(I)/AVCOM(I)))
      IF(AVCOM(I).EQ.0.0.AND.AUCOM(I).NE.0.0) GO TO 926
      GO TO 927
  926 TDIR=1.57096
  927 IF(AVCOM(I).GE.0.0.AND.AUCOM(I).GE.0.0)GO TO 928
      IF(AVCOM(I).GT.0.0.AND.AUCOM(I).LT.0.0)GO TO 929
      IF(AVCOM(I).LT.0.0.AND.AUCOM(I).GT.0.0)GO TO 931
      IF(AVCOM(I).LT.0.0.AND.AVCOM(I).LT.0.0)GO TO 932
  928 DIR(I)=TDIR
      GO TO 935
  929 DIR(I)=6.283184-TDIR
      GO TO 935
  931 DIR(I)=3.141592-TDIR
      GO TO 935
  932 DIR(I)=3.141592+TDIR
  935 DIR(I)=DIR(I)*57.281
      IF(BKNOT(I).LT.98.0)GO TO 930
  934 BKNOT(I)=SQRT(AUCOM(I)**2+AVCOM(I)**2)
  930 CONTINUE
      WRITE(11,2)  NDATE,(DIR(I),BKNOT(I),AUCOM(I),
     1AVCOM(I),I=1,24)
    2 FORMAT(I6,24(/,F3.0,F2.0,2E10.3))
      WRITE(2,3)  NDATE,(IHR(I),DIR(I),BKNOT(I),AUCOM(I),
C     EQUIP 2,2,2 TO THE LINE PRINTER>>>>>
     1AVCOM(I),I=1,24)
    3 FORMAT(1X,I6,24(/,5X,I5,5X,2F5.0,5X,2E15.3))
      N=N+24
      IF(N.GE.K) GO TO 950
      GO TO 940
  950 ENDFILE 11
      REWIND 11
      END
```

APPENDIX B

Constancy Indicator 'q'

Constancy indicator 'q' is an indicator of the variability of a given set of wind vectors which varies between zero and one.



$$'q' = \frac{|\vec{r}|}{\overline{s}} = \overline{\ell_j \cos B_j}$$

$$\vec{r}_i = f(s_i, \varphi_i)$$

$$s_j = \ell_j \overline{s}$$

$\overline{s}$ = mean scalar speed

The following is the development of my interpretation of 'q'.

By definition:

n = number of wind vectors

$$'q' = \frac{|\vec{r}|}{\overline{s}} \qquad \overline{u} = \frac{\sum_i^n s_i \sin\varphi_i}{n}$$

$$= \frac{(\overline{u}^2 + \overline{v}^2)^{1/2}}{\overline{s}} \qquad \overline{v} = \frac{\sum_i^n s_i \cos\varphi_i}{n}$$

$$(\overline{u}^2 + \overline{v}^2)^{1/2} = \left(\frac{\sum_i^n \sum_j^n s_i s_j \sin\varphi_i \sin\varphi_j}{n^2} + \frac{\sum_i^n \sum_j^n s_i s_j \cos\varphi_i \cos\varphi_j}{n^2} \right)^{1/2}$$

$$= \frac{1}{n}\left[\sum_{i}^{n}\sum_{j}^{n} s_i s_j \cos\left(\varphi_i - \varphi_j\right)\right]^{1/2}$$

(a) $$\left(\bar{u}^2 + \bar{v}^2\right)^{1/2} = \frac{1}{n}\left[\sum_{i}^{n}\sum_{j}^{n} s_i s_j \cos\alpha_{ij}\right]^{1/2}$$

$$\vec{\bar{r}} = \bar{u}\hat{i} + \bar{v}\hat{j}$$

$$= \frac{\sum_{i}^{n} s_i \sin\varphi_i}{n}\hat{i} + \frac{\sum_{i}^{n} s_i \cos\varphi_i}{n}\hat{j}$$

$$\vec{r}_j = s_j \sin\varphi_j \hat{i} + s_j \cos\varphi_j \hat{j}$$

$$\vec{r}_j \cdot \vec{\bar{r}} = \frac{\sum_{i}^{n} s_i s_j \sin\varphi_i \sin\varphi_j}{n} + \frac{\sum_{i}^{n} s_i s_j \cos\varphi_i \cos\varphi_j}{n}$$

$$\sum_{j}^{n} \vec{r}_j \cdot \vec{\bar{r}} = \frac{1}{n}\sum_{i}^{n}\sum_{j}^{n} s_i s_j \cos\alpha_{ij}$$

$$n\sum_{j}^{n} \vec{r}_j \cdot \vec{\bar{r}} = \sum_{i}^{n}\sum_{j}^{n} s_i s_j \cos\alpha_{ij}$$

From (a)

(b) $$\left(\bar{u}^2 + \bar{v}^2\right)^{1/2} = \frac{1}{n}\left[n\sum_{j}^{n} \vec{r}_j \cdot \vec{\bar{r}}\right]^{1/2}$$

$$(\bar{u}^2 + \bar{v}^2)^{1/2} = \frac{1}{n}[n\,|\bar{\vec{r}}|\sum_{j}^{n} s_j \cos B_j]^{1/2}$$

$$= \frac{1}{n}[n\,|\bar{\vec{r}}|\,\bar{s}\sum_{j}^{n} \ell_j \cos B_j]^{1/2}$$

$$= \frac{1}{n}[n^2\,|\bar{\vec{r}}|\,\bar{s}\;\overline{\ell_j \cos B_j}\,]^{1/2}$$

$$'q' = \frac{[\,|\bar{\vec{r}}|\,\bar{s}\;\overline{\ell_j \cos B_j}\,]^{1/2}}{\bar{s}} = \frac{|\bar{\vec{r}}|}{\bar{s}}$$

$$\bar{s}\;\overline{\ell_j \cos B_j} = |\bar{\vec{r}}|$$

$$\therefore\quad 'q' = \overline{\ell_j \cos B_j}$$

In several months the number of valid wind vectors was less than the number of valid scalar speeds due to vane malfunctions. The various statistics were calculated with all the available valid data.

Starting with (b):

$$(\bar{u}^2 + \bar{v}^2)^{1/2} = \frac{1}{n}[n\sum_{j}^{n} \vec{r}_j \cdot \bar{\vec{r}}\,]^{1/2}$$

Redefining n = number of $\vec{r}_j$, (not s_j):

$$|\vec{r}_j| = \ell_j \overline{|\vec{r}|}$$

$$\overline{|\vec{r}|} = A\bar{s}$$

$$(\bar{u}^2 + \bar{v}^2)^{1/2} = \frac{1}{n}[n\overline{|\vec{r}|}\ |\bar{\vec{r}}| \sum_j^n \ell_j \cos B_j]^{1/2}$$

$$= \frac{1}{n}[n^2 A\bar{s}\ |\bar{\vec{r}}|\ \overline{\ell_j \cos B_j}\ ]^{1/2}$$

$$'q' = A\ \overline{\ell_j \cos B_j}$$

If the missing values of $|\vec{r}_j|$ are normally distributed about $\overline{|\vec{r}_j|}$

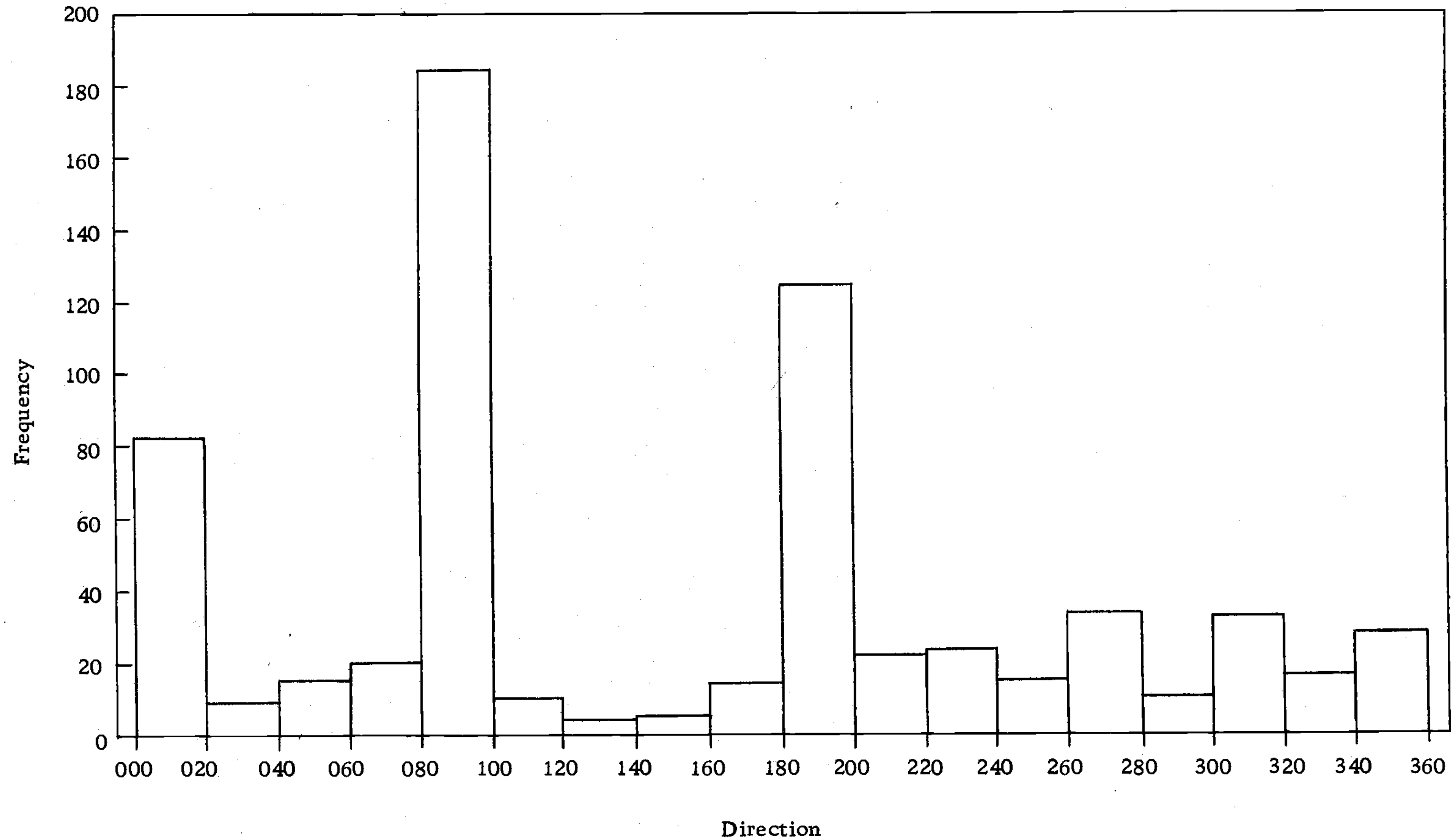
$$\overline{|\vec{r}_j|} \approx \bar{s} \quad \text{and} \quad A \approx 1$$

$$\therefore\ 'q' \approx \overline{\ell_j \cos B_j}$$

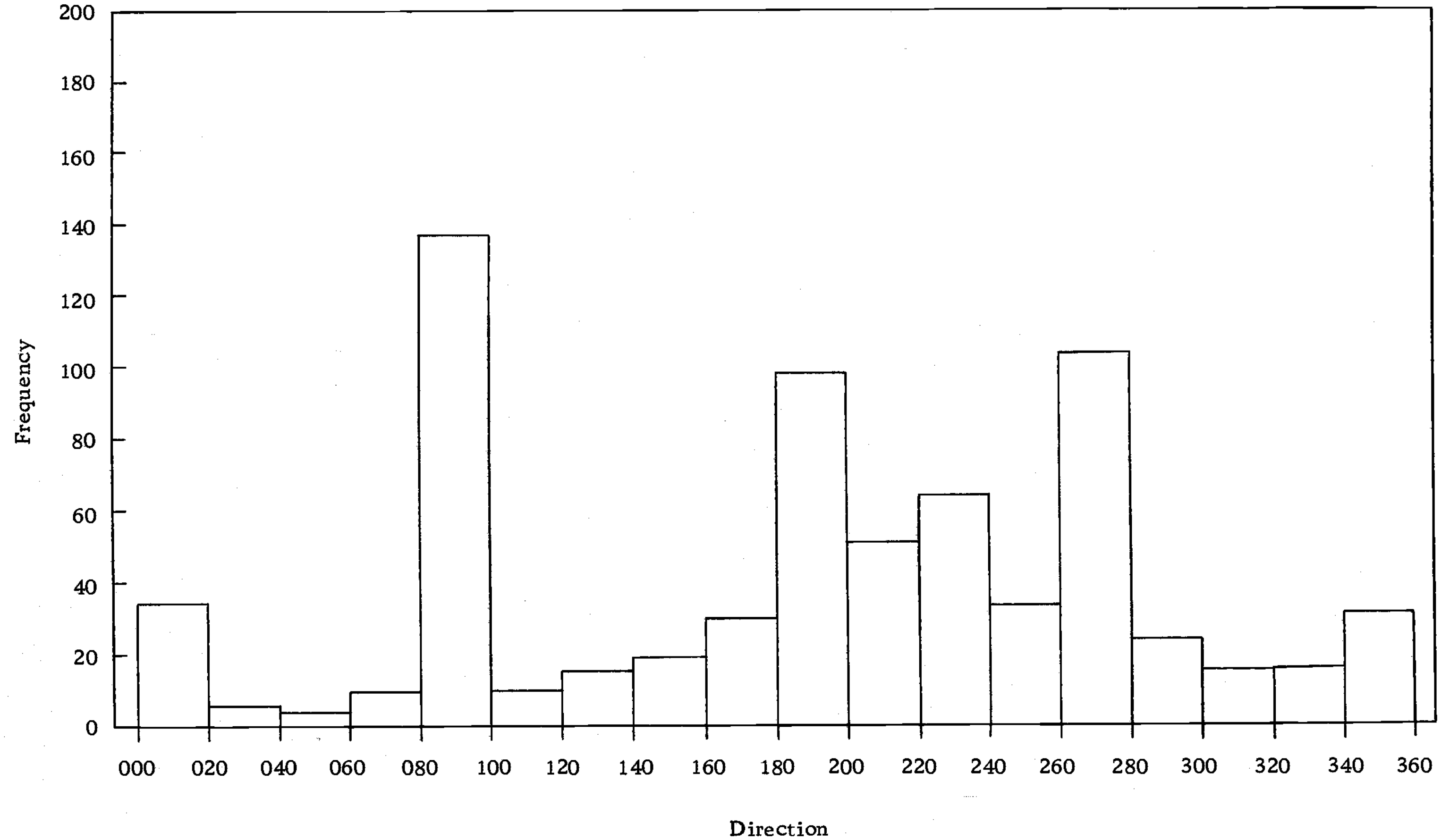
For the purposes of this study the difference in $\overline{|\vec{r}|}$ and $\bar{s}$ are negligible. The worst ratio of the number of wind vectors to the number of scalar speeds is 0.947 which occurs in March. The only other value of 'q' which is affected is May.

APPENDIX C

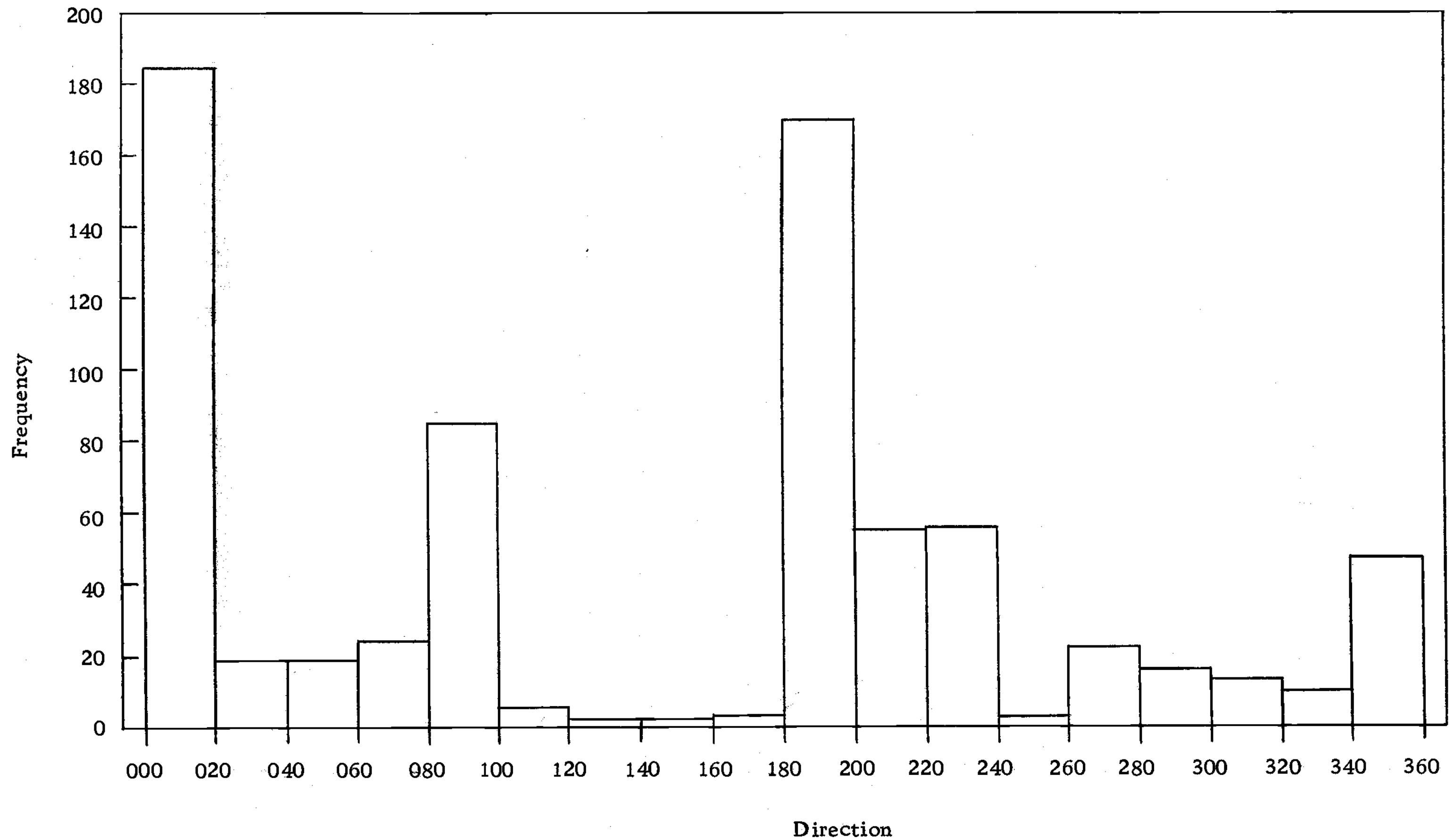
Frequency Versus Direction Histograms



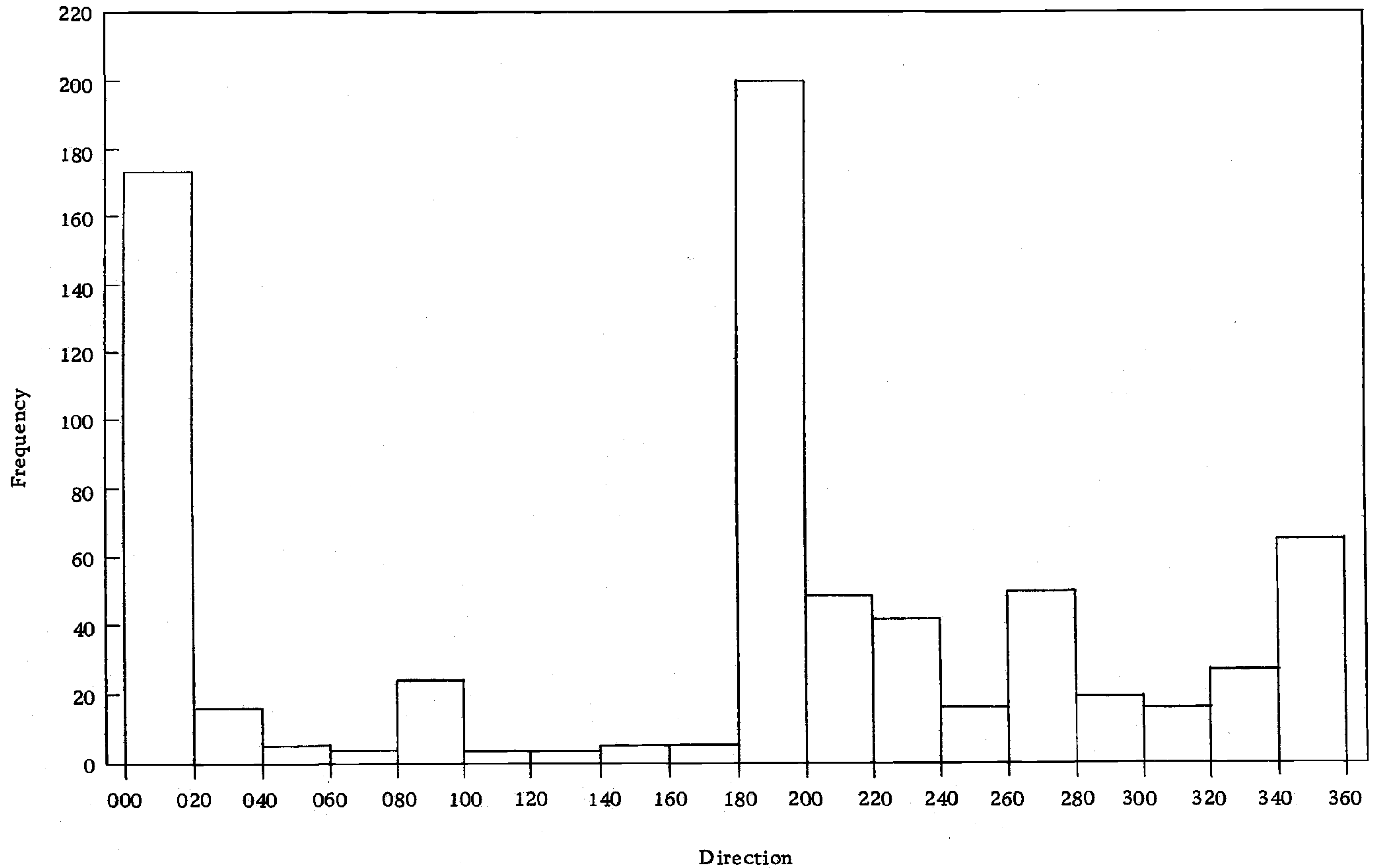
March Frequency Versus Direction



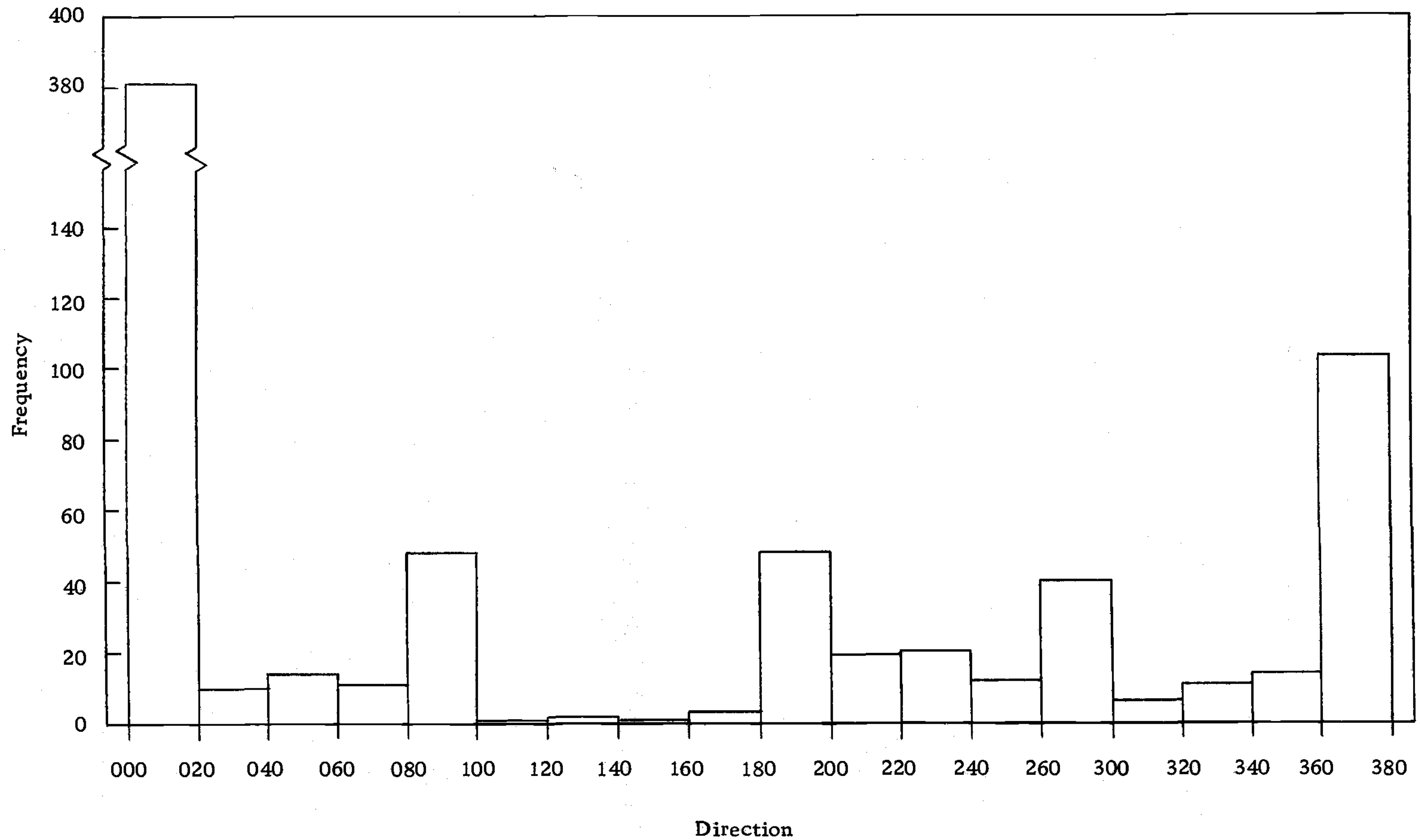
April Frequency Versus Direction



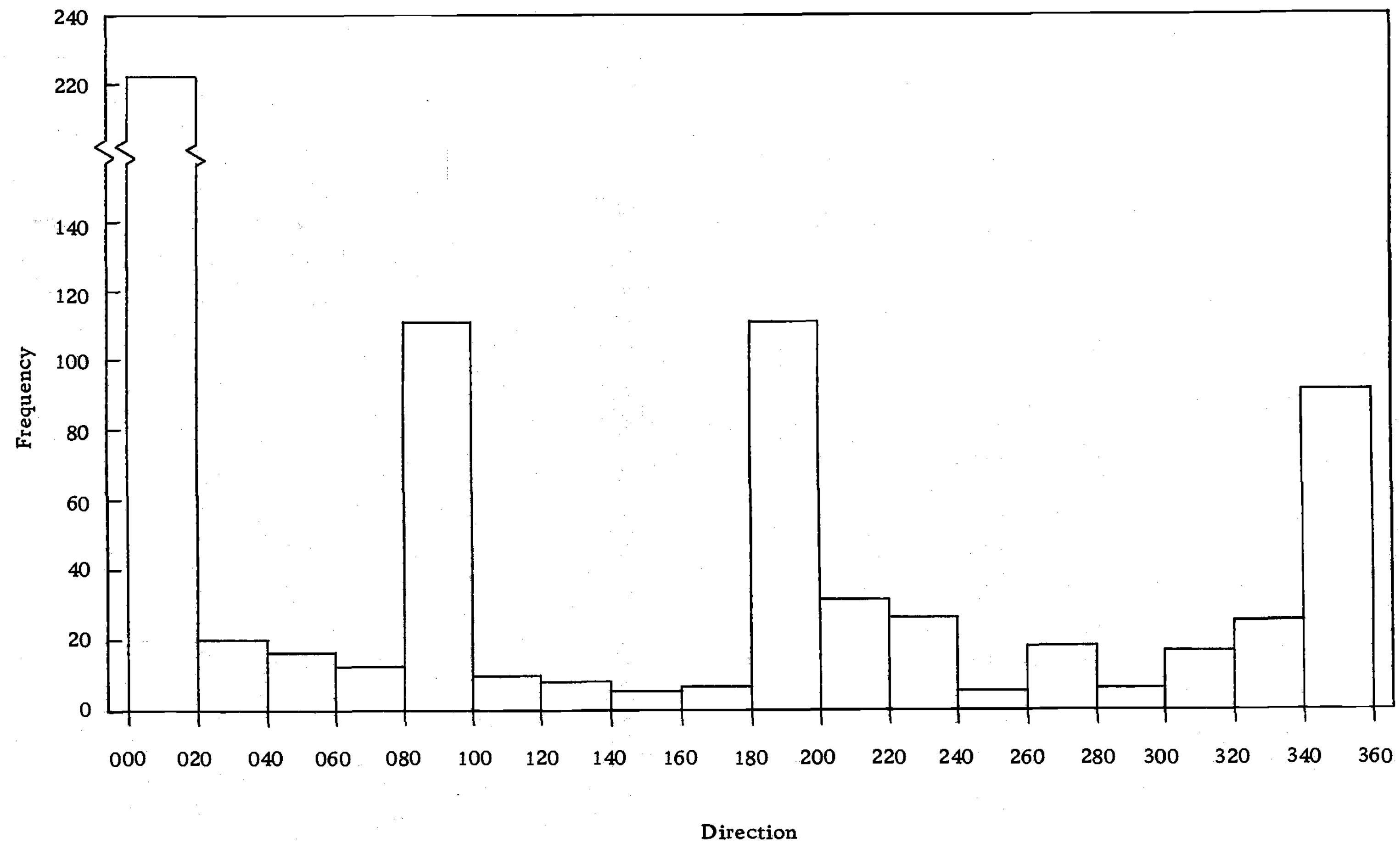
May Frequency Versus Direction



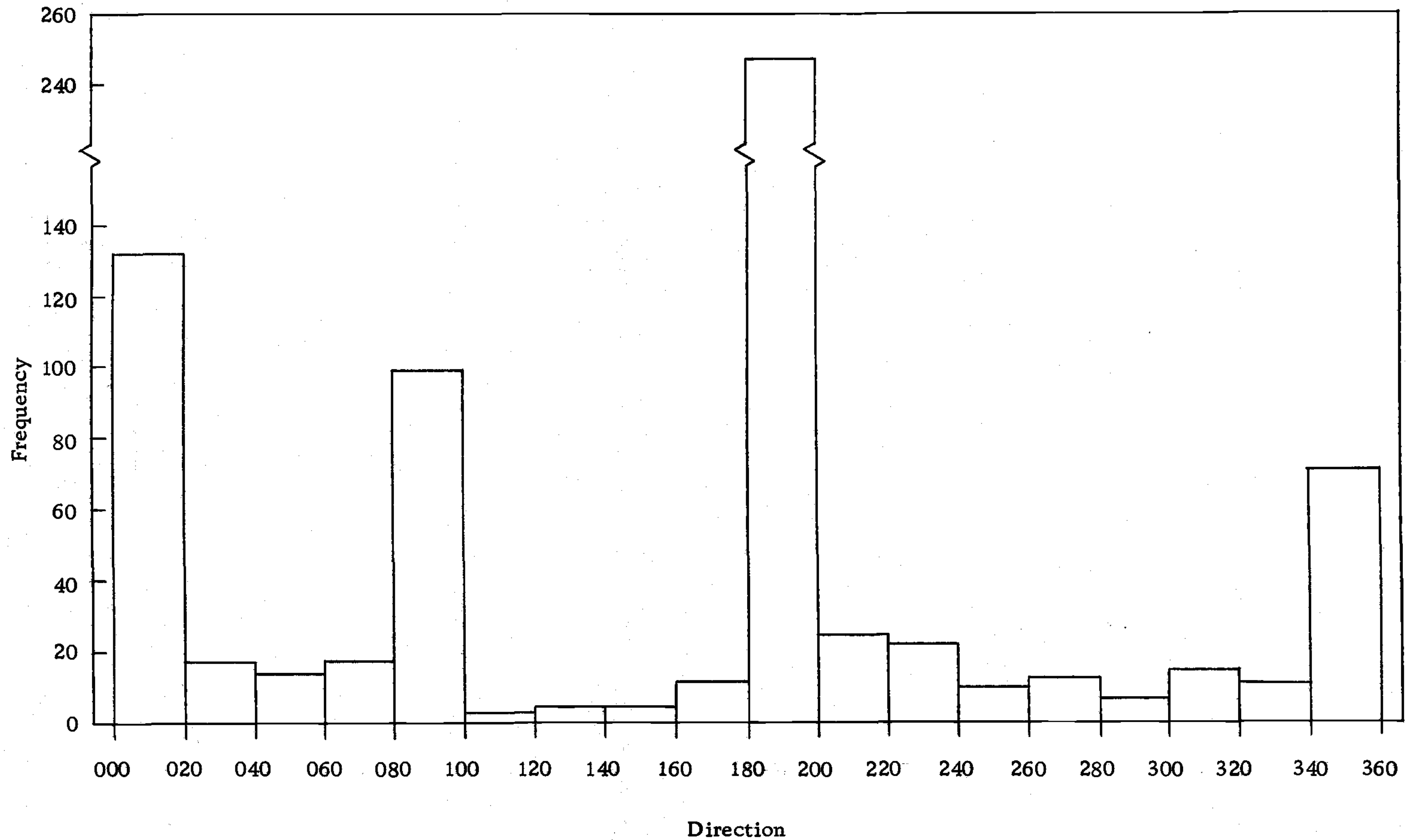
June Frequency Versus Direction



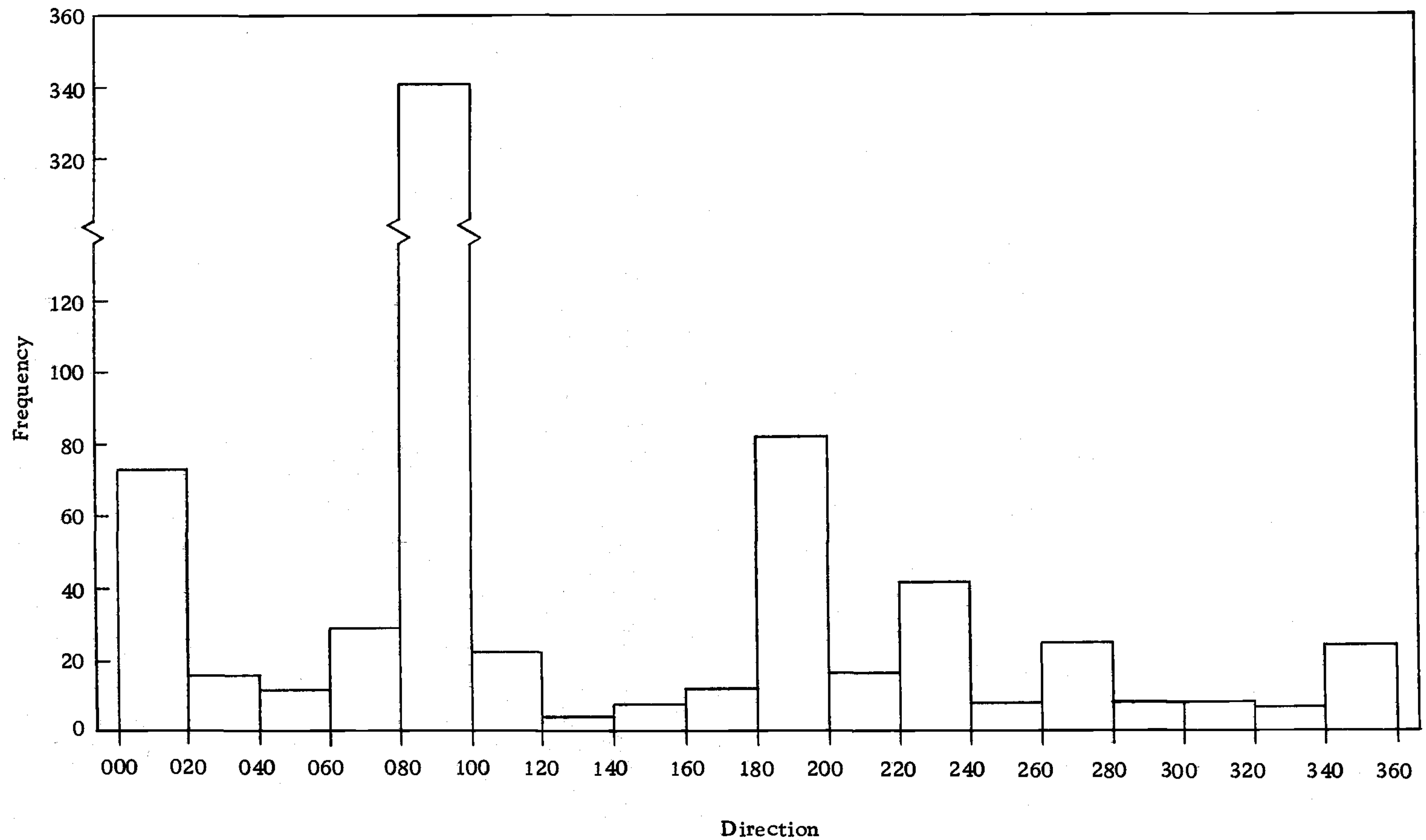
July Frequency Versus Direction



August Frequency Versus Direction



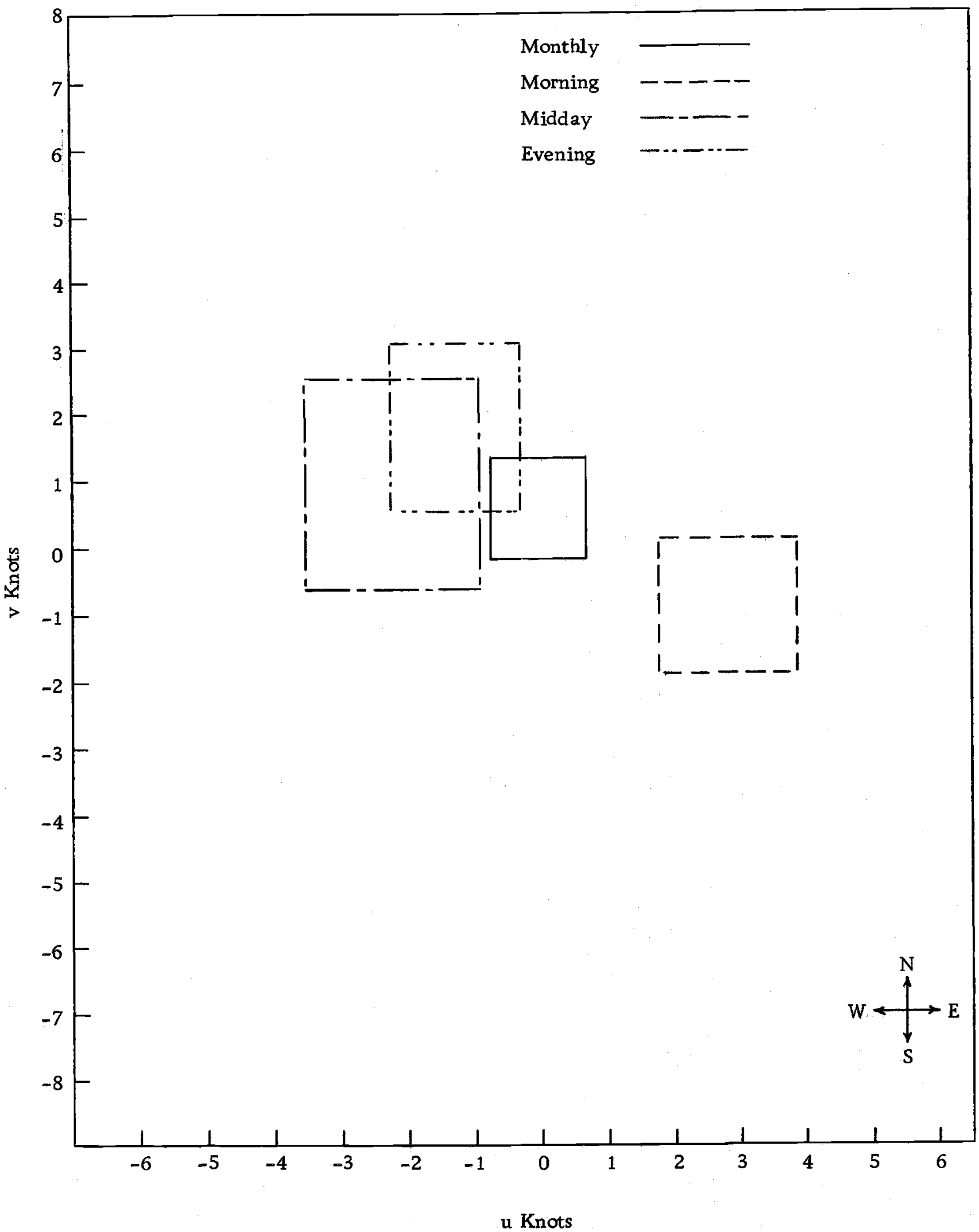
September Frequency Versus Direction



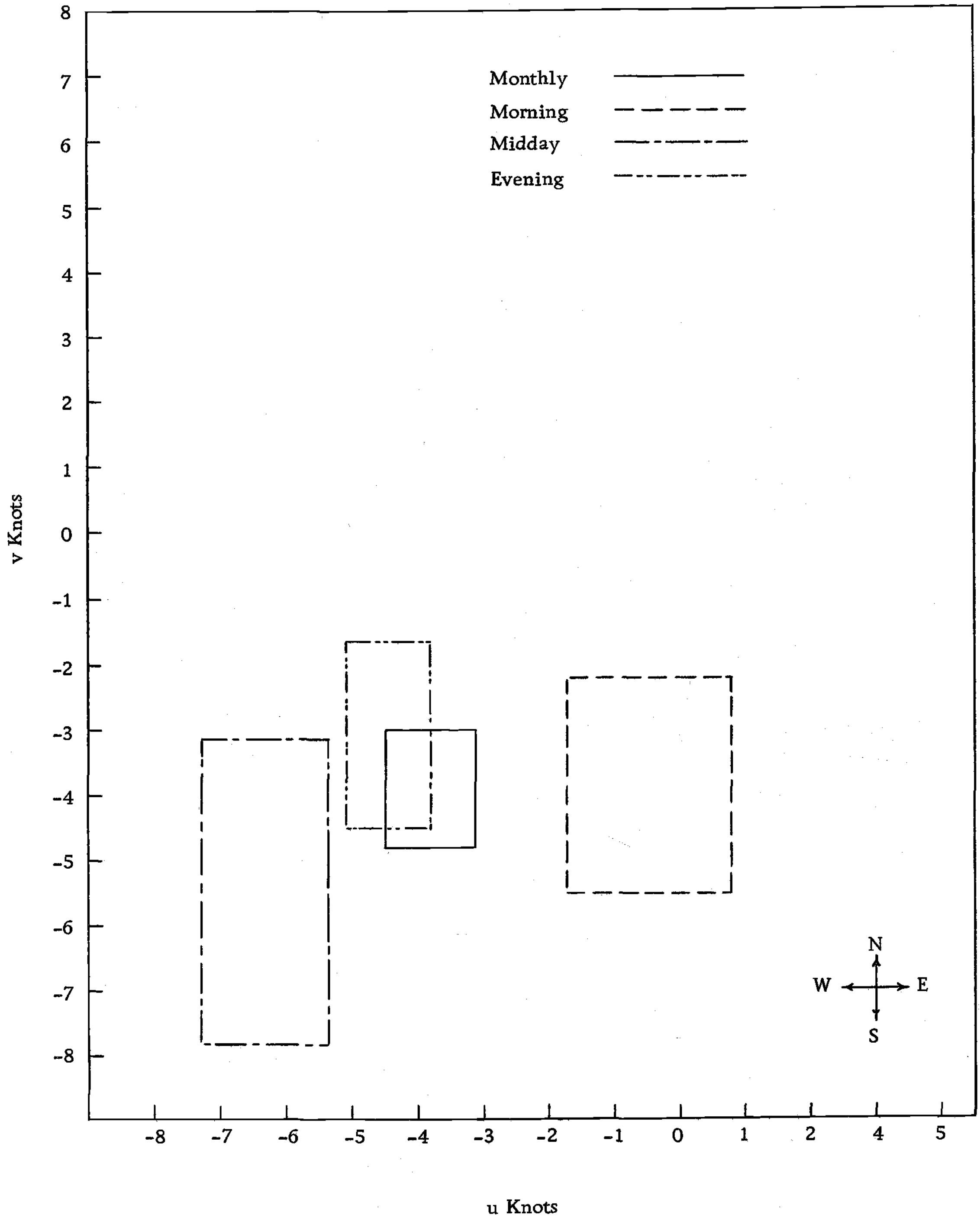
October Frequency Versus Direction

APPENDIX D

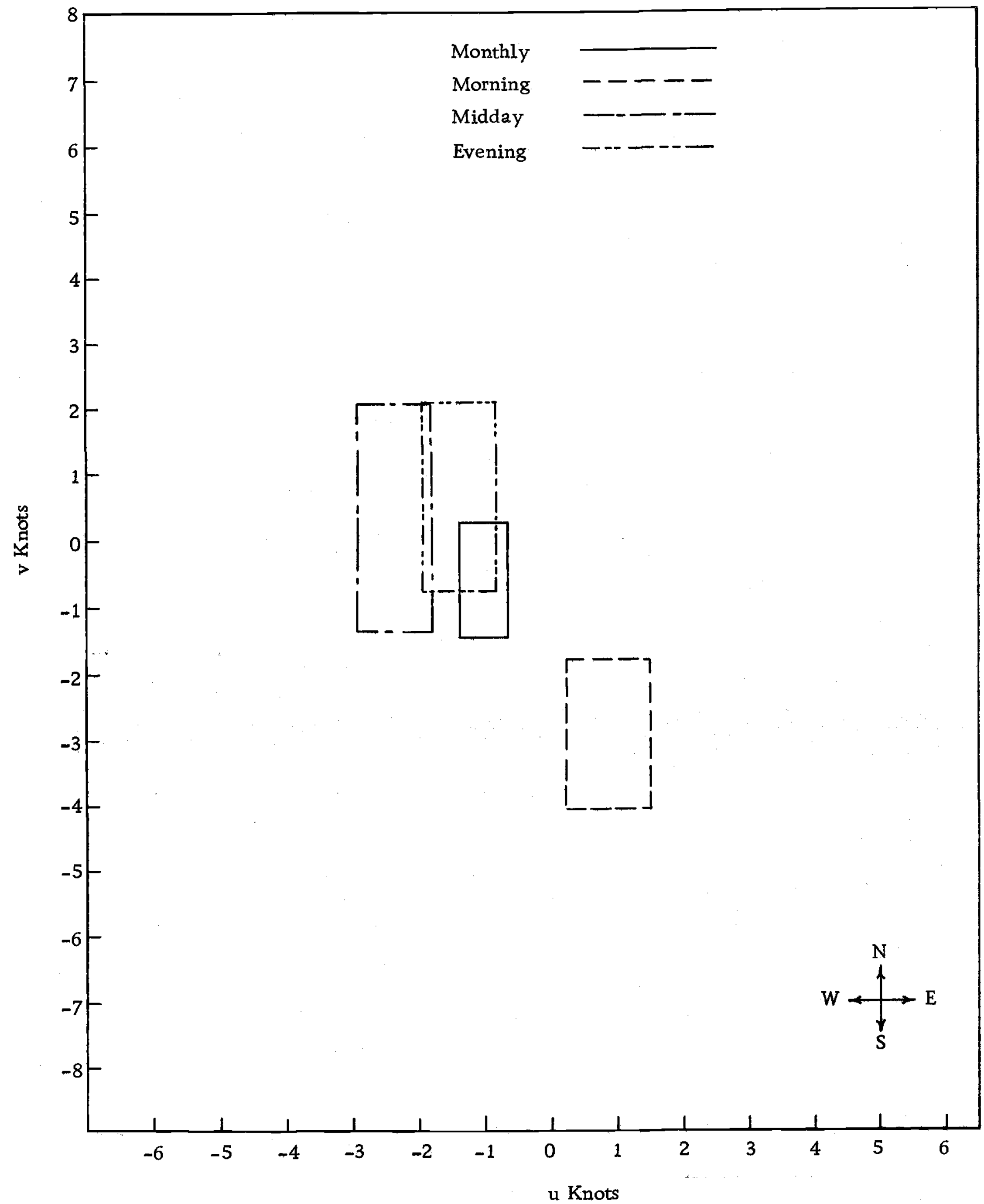
Morning, Midday, Evening and Monthly Confidence Areas



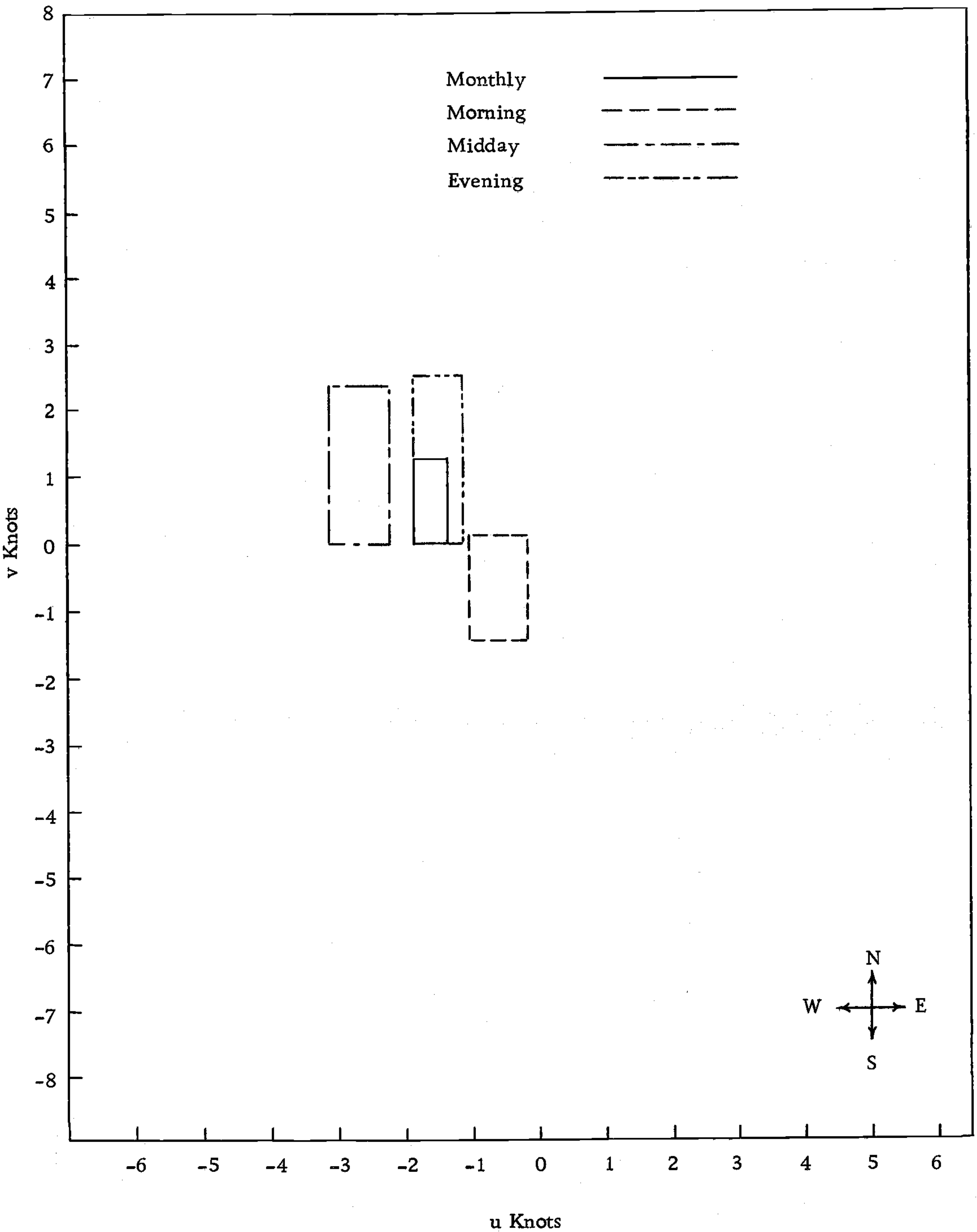
March Confidence Areas



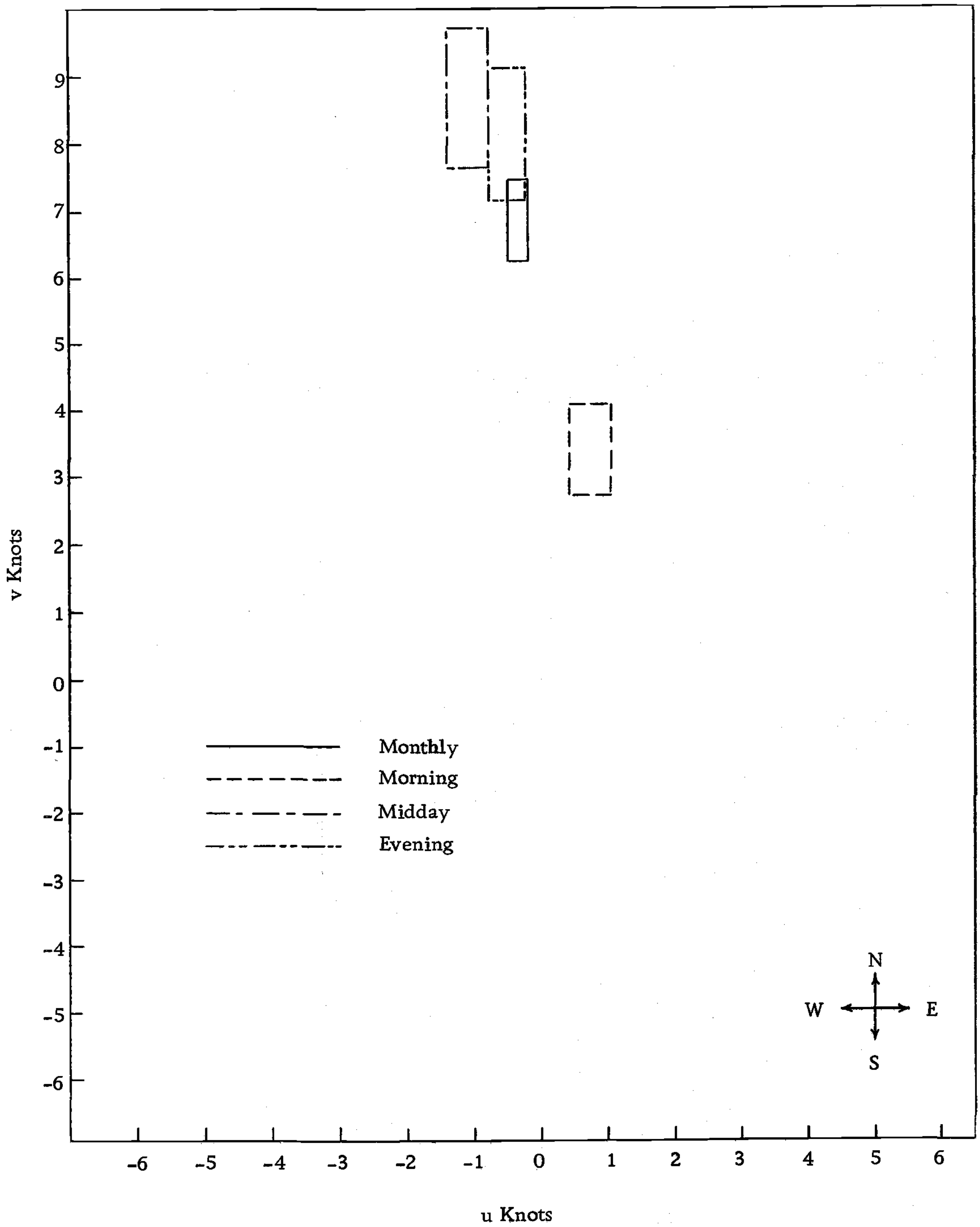
April Confidence Areas



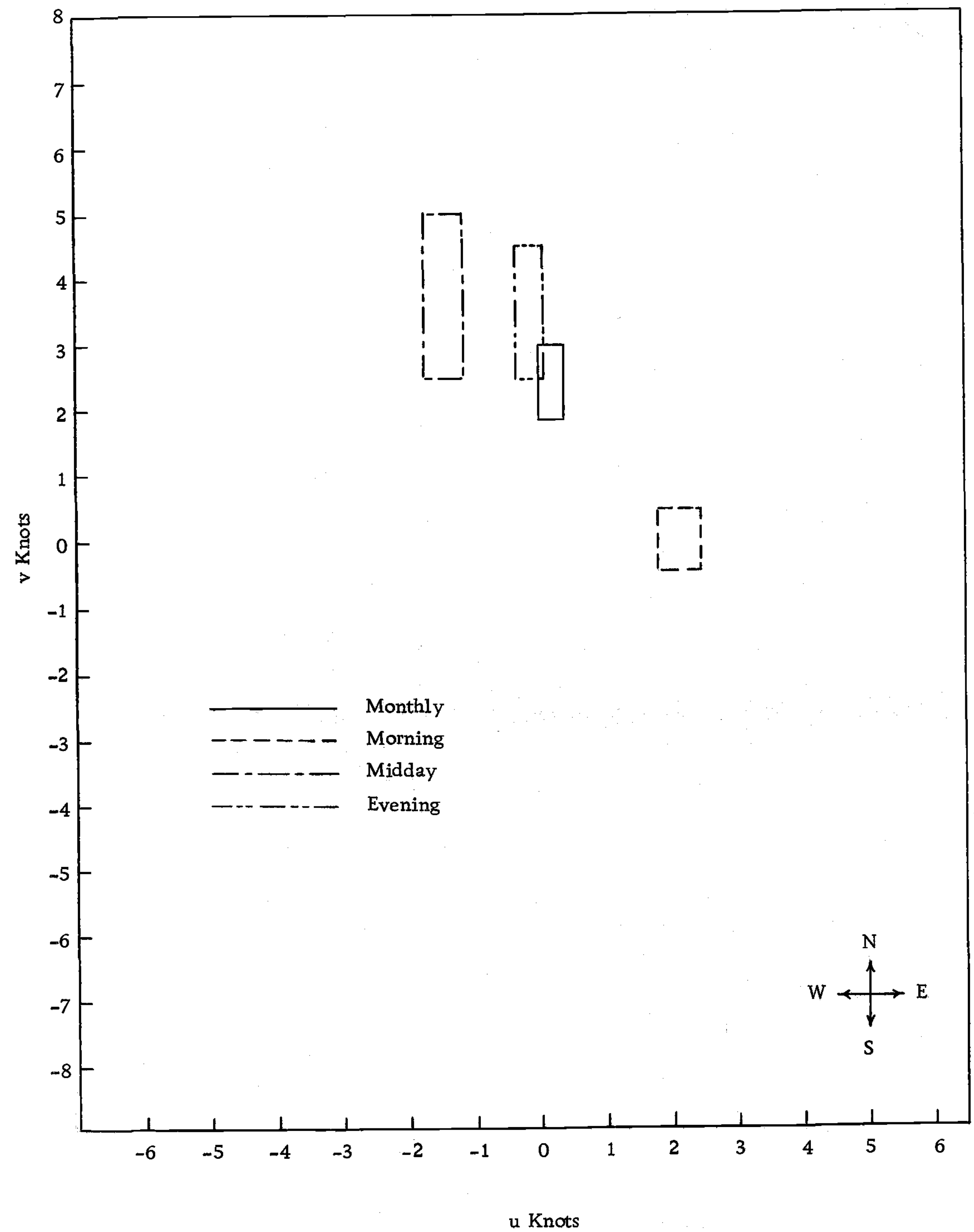
May Confidence Areas



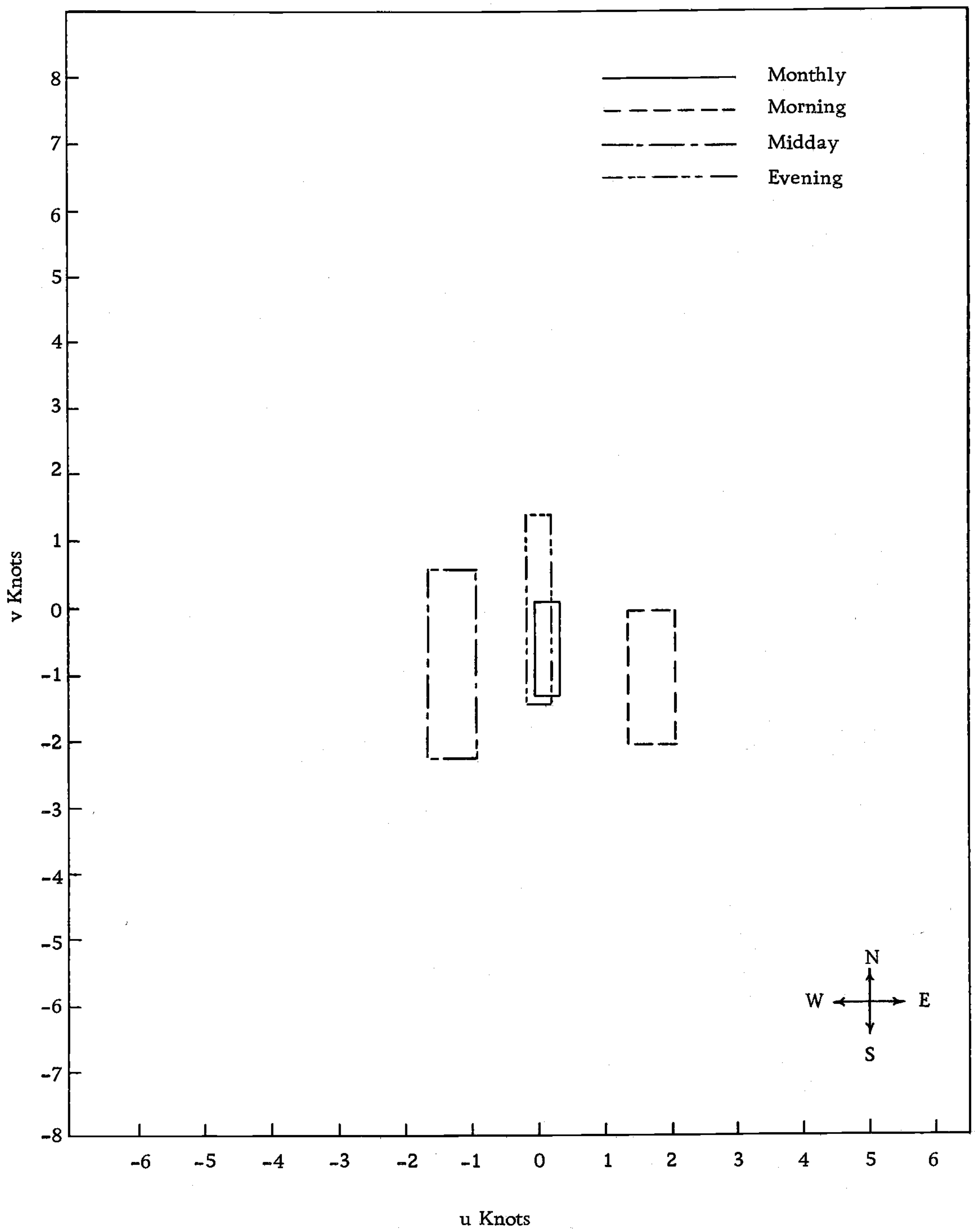
June Confidence Areas



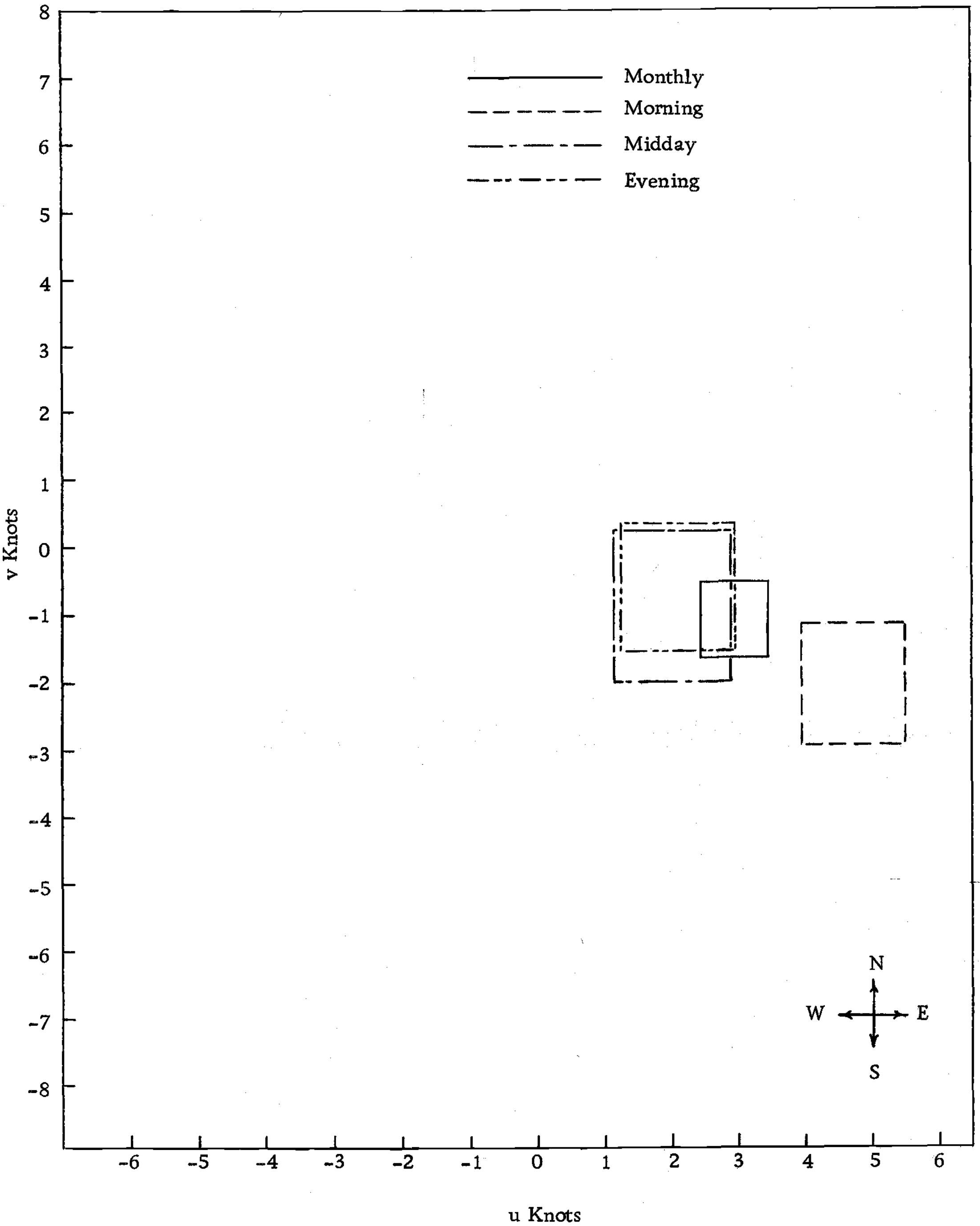
July Confidence Areas



August Confidence Areas



September Confidence Areas



October Confidence Areas