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NOAA Technical Memorandum NWS SOS-8

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service

Thunderstorm Forecasting at Cape Kennedy, Florida, Utilizing Multiple Regression Techniques

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Space Operations
Support Division

SILVER SPRING, MD.

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THUNDERSTORM FORECASTING AT CAPE KENNEDY, FLORIDA, UTILIZING MULTIPLE REGRESSION TECHNIQUES

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THUNDERSTORM FORECASTING AT CAPE KENNEDY, FLORIDA UTILIZING MULTIPLE REGRESSION TECHNIQUES

CHARLES J. NEUMANN

ABSTRACT. One of the major problems concerning meteorologists associated with the space program in the Cape Kennedy area involves the forecasting of thunderstorm activity and associated adverse weather phenomena. This study outlines the development of a system of regression equations designed to compute thunderstorm probabilities and starting times from an observed early morning atmospheric sounding. The equations are based on five nonlinear second and third-order polynomial predictor functions involving the 850-mb wind, the 500-mb wind, the mean relative humidity in the layer 800 to 600 mb, the Showalter stability index, and the day number.

INTRODUCTION

One of the major problems concerning meteorologists having forecast responsibility for the Cape Kennedy area of Florida is the prediction of afternoon convective thunderstorm activity and associated severe weather phenomena. In addition to the obvious effect of such weather on manned and unmanned spacecraft launches, thunderstorms and threats of thunderstorms interfere with normal outdoor support functions and may endanger workers and equipment especially during the main thunderstorm months May through September. Since it is desirable to reduce these risks and work stoppages to a minimum, considerable effort has been expended to develop diagnostic tools to aid the forecaster.

The type of thunderstorm forecast required at Cape Kennedy depends to a large degree on the forecast period itself. Long-range planning forecasts are essentially non-conditional and need present only minor details on thunderstorm-associated weather parameters. Forecasts issued between one and five days prior to a mission [1] are more conditional since

[1] As used herein, the term mission implies any weather sensitive activity whether it be a major event such as the manned launch or a minor event such as routine maintenance on a launch tower.

the forecaster has knowledge of expected tropospheric flow patterns derived from routinely received facsimile products. Forecasts issued on the day of a mission are still more conditional since an observed atmospheric sounding is available. Forecasts issued shortly before a mission (at which time a GO or NO-GO decision on the basis of weather might be made) must give mesoscale details based on an elaborate observational network as well as the meteorologist's short range forecast.

PREVIOUS THUNDERSTORM STUDIES

Previous studies in this series have dealt with various aspects of the thunderstorm problem. Neumann (1968) presents both conditional and non-conditional thunderstorm probabilities at Cape Kennedy based on 13 years of data (1951, 1952, and 1957 through 1967). Figure 1, extracted from this latter study gives the non-conditional thunderstorm probabilities over three different time periods for each day of the year.

Neumann (1970) presents thunderstorm probabilities based on a forecast 3000-foot wind speed and direction. In both of these studies, an afternoon thunderstorm is defined as the occurrence of one or more reports of thunder by the weather observer at the Cape Kennedy [2] weather station between the hours 1000 to 2200 EST.

The purpose of the present study is to derive objective thunderstorm forecasts to be used operationally from the latest available atmospheric sounding. A system of regression equations derived from 13 years of 1200 GMT Cape Kennedy soundings (1957 through 1969) was developed for this purpose. The forecasts are presented on a probability basis.

NONLINEAR MULTIPLE REGRESSION

Multiple regression techniques are widely used to study the joint relationship between a number of independent variables and a single dependent variable. Modern computer technology enables a large number of independent variables to be tested systematically in a stepwise screening procedure so as to produce objectively a single regression equation or set of equations from a given set of learning data.

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[2] The Cape Kennedy observations are taken at the Air Force Eastern Test Range weather station, which is about 1 mile inland from the easternmost point of Cape Kennedy. A map of the area is presented in Neumann (1970).

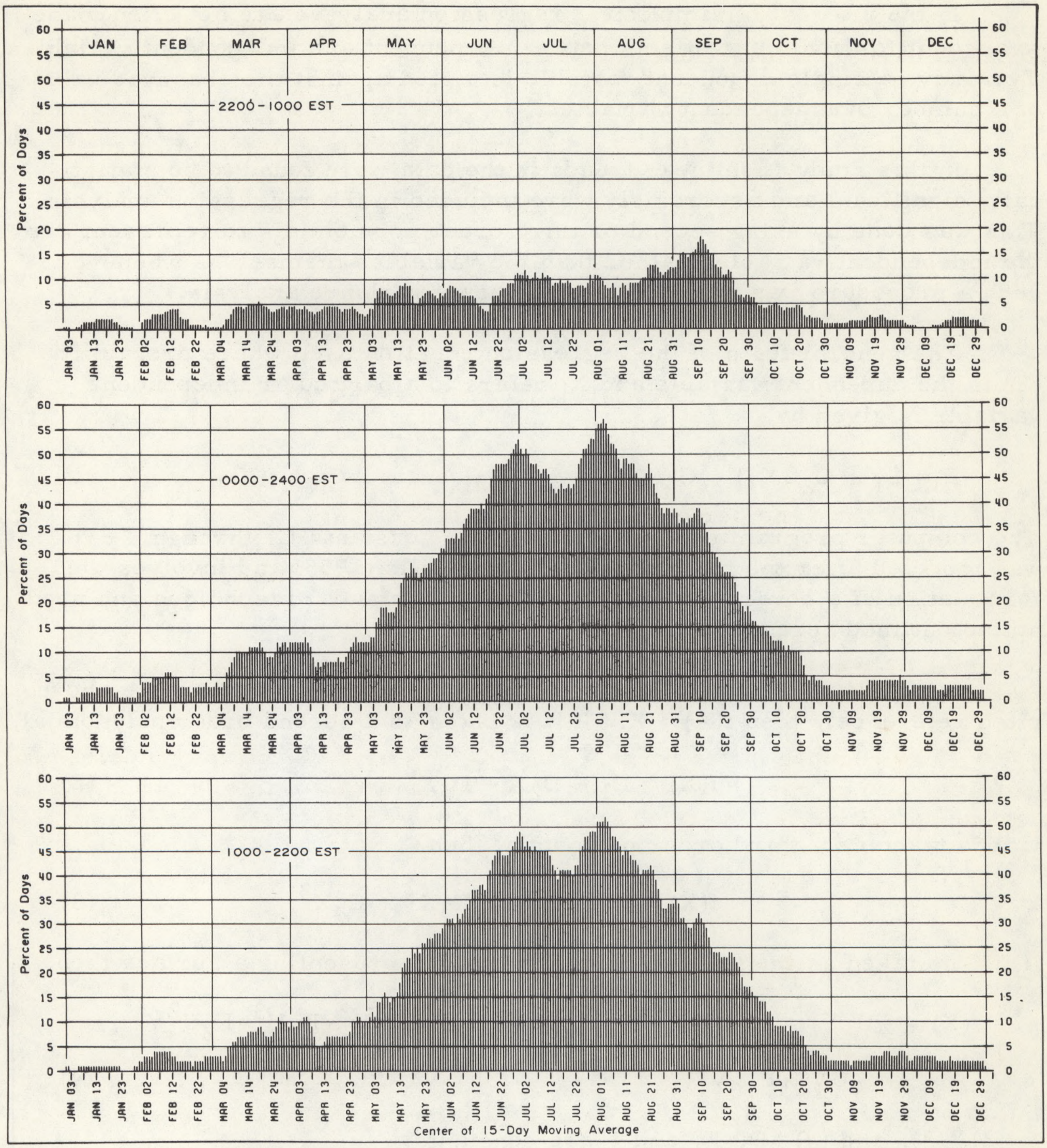

Figure 1. --Fifteen-day moving average of percent of days observing thunderstorms at Cape Kennedy over specified time intervals.

In the interest of simplicity, regression analyses are not often made to account for nonlinear effects between dependent and independent variables. Typically, a single dependent variable is tested against the observed values of a number of independent variables.

In this study, nonlinear trends in the data were found to be statistically significant and accordingly were included in the regression analysis. This was done by using second or third order polynomials to represent the independent variables rather than the variables themselves whenever such a procedure was warranted by the usual variance analysis.

The general form of the regression equation used where probability (P) is the dependent variable and X_i refers to a particular independent variable is given by,

$$P = C_1 + C_2 f(X_1) + C_3 f(X_2) + C_4 f(X_3) \ldots\ldots \; C_{N+1} f(X_N): \qquad (1)$$

The computer program used to solve for the constants C_1 through C_{N+1} was modeled after the method described in Mills (1955) and involves the formulation of a covariance matrix. This is a standard technique and need not be outlined here.

In (1), if f(X) is taken as the predictor itself (as is done in the above cited reference), then f(X) = X. If it is taken as a second order polynomial,

$$f(X) = D_1 + D_2 X + D_3 X^2; \qquad (2)$$

if it is taken as a third order polynomial then,

$$f(X) = E_1 + E_2 X + E_3 X^2 + E_4 X^3; \qquad (3)$$

if f(X) is taken as the third order polynomial representing a surface then,

$$f(X) = f(U, V) = F_1 + F_2 U + F_3 V + F_4 UV + F_5 U^2 + F_6 V^2 + F_7 U^3 + F_8 U^2 V + F_9 UV^2 + F_{10} V^3. \qquad (4)$$

In (2), (3), and (4), D, E, and F are constants.

The concept of probability was introduced into the computations by assigning binomial values to P such that if a thunderstorm did occur, P was assigned a value of 1.0, whereas, if a thunderstorm did not occur, P was assigned a value of 0.0. A separate set of prediction equations was developed for each month. Therefore, if the unconditional probability of a thunderstorm for the month of June is 0.38,

$$1/N \sum_{i=1}^{N} P_i = 0.38$$

where P_i is the binomial probability assignment for a particular day and N is the number of days.

THE REGRESSION ANALYSES

To study the broad-scale relationships between the parameters defining the 1200 GMT sounding and the eventual thunderstorm outcome later that day, first, second, and third order regression equations and the resultant correlation coefficients and correlation indices were derived between the binomial probability assignment and approximately 250 predictors. All predictors were derived from 13 years (1957 through 1969) of 1200 GMT upper air soundings taken at Cape Kennedy. These consisted, for each of 18 levels at 50 millibar intervals ranging from 1000 to 150 mb, of the U (west to east) component of the wind, the V (south to north) component of the wind, the relative humidity, the temperature, and other derived quantities such as thickness, wind shear, stability index, and mean layer values. Climatology was included by using the day number as a predictor and as a derived predictor function. June was selected as a test month. Figure 2 shows graphically the resultant correlation indices between some of the polynomials and afternoon thunderstorm occurrence as represented by the binomial probability assignment.

Generally speaking, figure 2 shows that the indices increase with height reaching a maximum at some point in the lower troposphere and decreasing at still higher levels. The exception is the relative humidity where, at the high levels, the indices show a marked increase. The reason for this is uncertain. However, the number of cases of observed humidity at the high levels is so limited that little statistical significance can be put on the index. Furthermore, humidity measurement at such a high level is subject to error. These two reasons were considered as sufficient cause to cast doubt on the significance of the relative humidity correlation indices at the higher levels.

With this restriction in mind, the prime predictor appears to be the west wind component in the lower 20,000 feet. The south wind component appears to be best correlated at about 5,000 feet and the humidity at 10,000 feet. A still higher humidity index (0.37) was obtained by using vertically

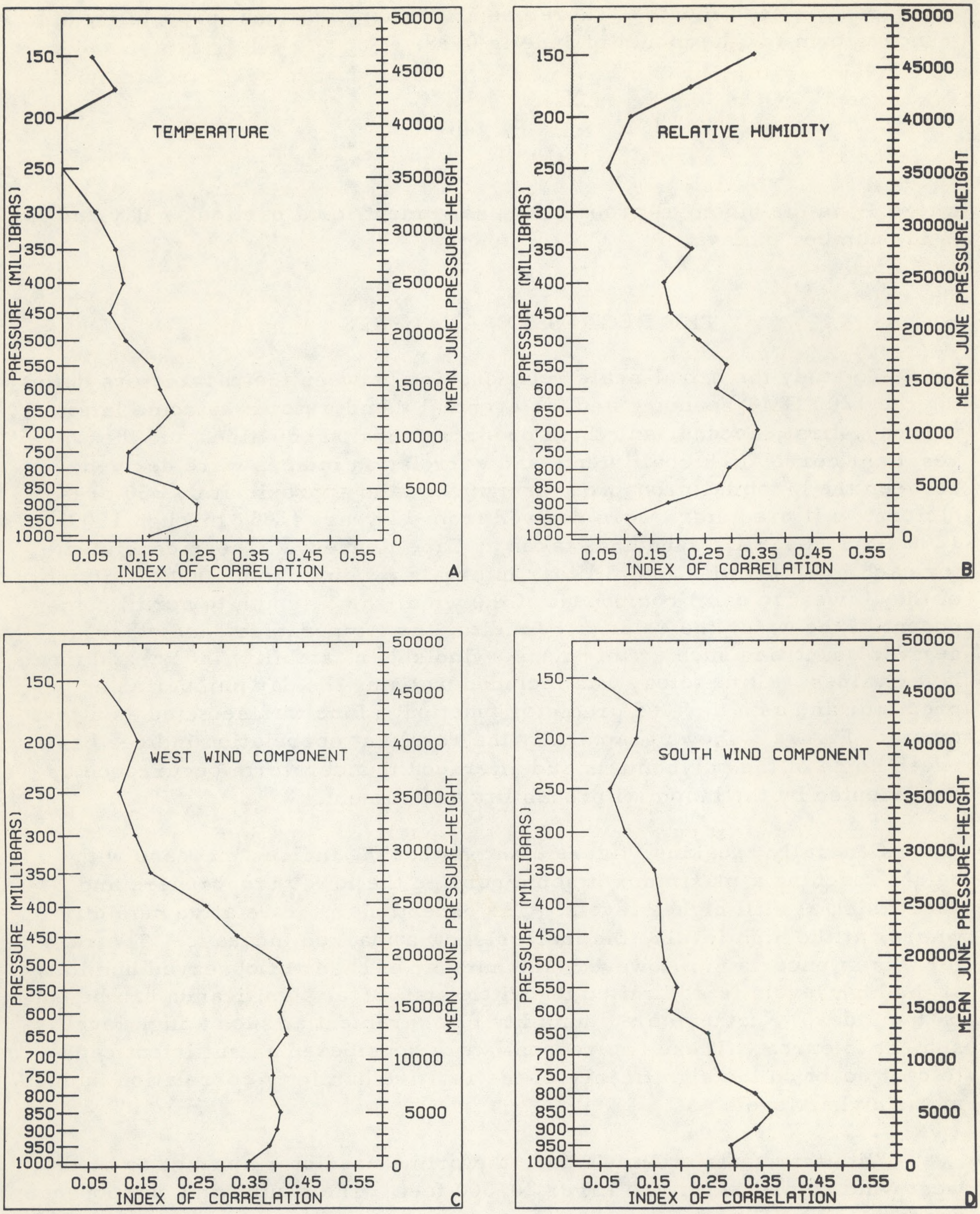

Figure 2. --Correlation indices between afternoon thunderstorm occurrence and specified variable at each millibar level.

averaged humidity in the layer 800 to 600 mb. Using mean layer winds did not increase the correlation indices significantly. The temperature and derived temperature predictors such as thickness were relatively insignificant, except possibly at the 2500-foot level.

The number of significant predictors was eventually narrowed from 250 down to 9. These were the orthogonal wind components at both 850 and 500 mb, the mean relative humidity in the layer 800 to 600 mb, the Showalter stability index, the 900-mb temperature, the 1000- to 850-mb thickness, and the day number. One final refinement involved combining the orthogonal wind components into a single function given by (4). Fitting a set of data to (4) is quite complex since 10 normal equations must be formulated to solve for the 10 unknown constants. The 10 equations are derived in Neumann and Hope (1971) and need not be repeated here. The amount of calculations involved renders the fitting of a large set of data to (4) completely impractical without the aid of a digital computer.

THE PREDICTION EQUATIONS

The terms selected for retention in the prediction equations varied slightly from month to month. However, in the interest of uniformity, all the terms were retained. Figure 3 shows the functions retained in the prediction equations and the relative importance of each term for each month. Also included are the indices of multiple correlation. Because of intercorrelations in the data, inclusion of all five predictor functions in the equations does not lower the variance as much as one might hope. These intercorrelations are given in Appendix I, Table 3. The correlations involving day number were poor enough that this term could have been eliminated from the computations without loss of efficiency. However, inclusion of a day number function helps to avoid sharp discontinuities in going from the last day of one month to the first day of the next month with otherwise similar input data.

The actual prediction equation for the month of June was found to be,

$$P = -.55562 + .61025 f(\overline{X}_1) + .48518 f(\overline{X}_2) + .36560 f(X_3) + .35416 f(X_4) + .63915 f(X_5) \quad (5)$$

where P = Probability ($0 \leq P \leq 1$),

$\overline{X}_1$ = 850-mb wind in kt,
$\overline{X}_2$ = 500-mb wind in kt,
X_3 = Mean relative humidity in layer 800 to 600 mb in percent,
X_4 = Stability index in degrees Celsius,
X_5 = Day number.

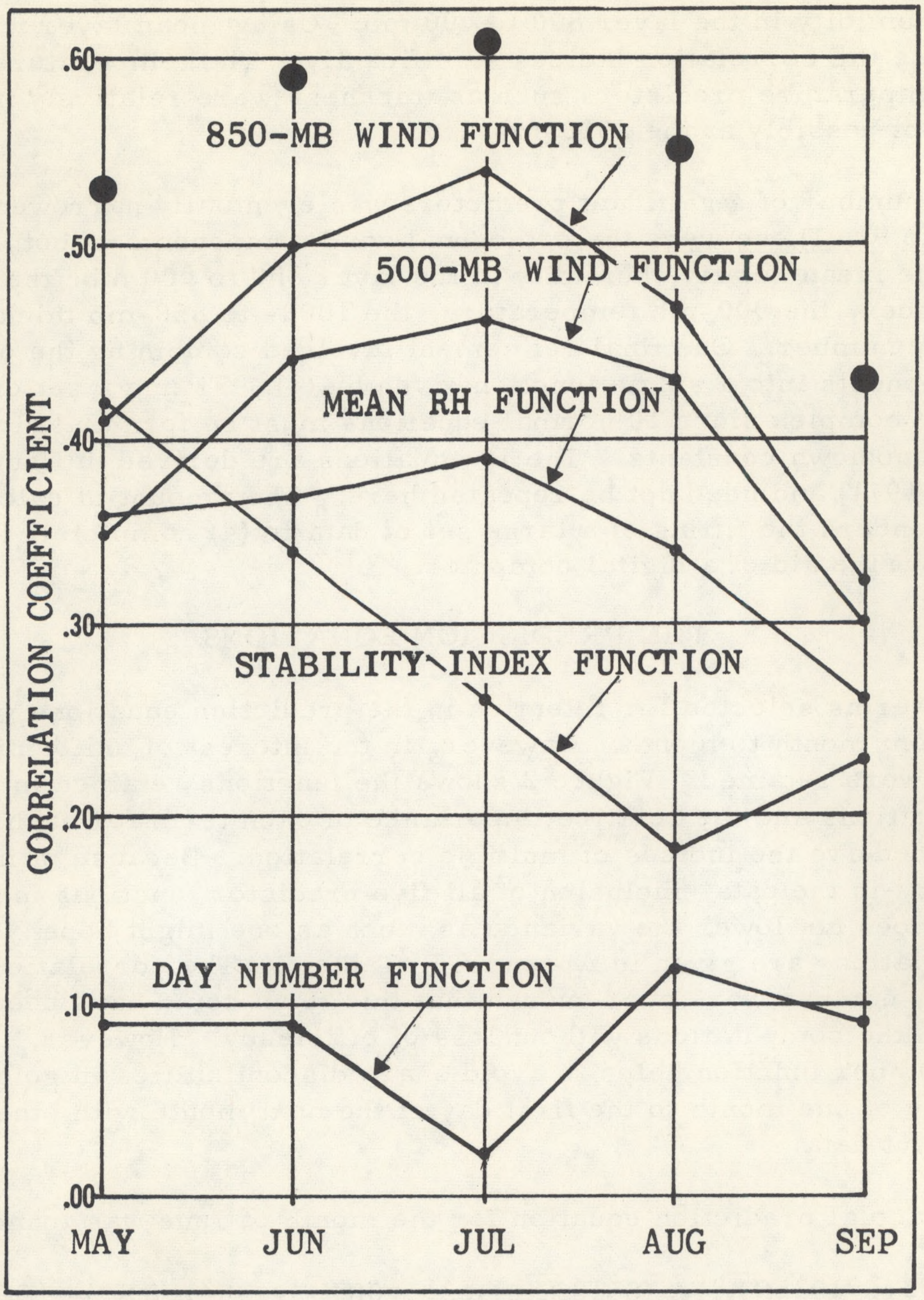

Figure 3. --Correlation coefficients between the predictor functions and afternoon thunderstorm occurrence. Large dots give the index of multiple correlation obtained by combining the five functions into a single regression equation.

The variance ratio F realized from (5) is 40. This value is clearly statistically significant at the 1 percent level using F-test criteria. In (5), the indicated functions are given by,

$$f(\overline{X}_1) = f(s,t) = .3327+.2172s/10+.2163t/10+.3762st/10^3-6836s^2/10^3$$
$$+ .2579t^2/10^3+.1179s^3/10^5+.1438s^2t/10^5-.3374st^2/10^4$$
$$- .2200t^3/10^4, \qquad (6)$$

where s and t are the orthogonal wind components at 850 mb;

$$f(\overline{X}_2) = f(u,v) = .2928+.2638u/10+.1023v/10+.3207uv/10^3+.7055u^2/10^4$$
$$+.1576v^2/10^3-.3090u^3/10^4-.1422u^2v/10^4+.5589uv^2/10^5$$
$$-.9225v^3/10^5, \qquad (7)$$

where u and v are the orthogonal wind components at 500 mb;

$$f(X_3) = .1350-.1999X_3/10+.8151X_3^2/10^3-.6343X_3^3/10^5; \qquad (8)$$

$$f(X_4) = .6102-.8067X_4/10+.2404X_4^2/10^2; \qquad (9)$$

$$f(X_5) = -.1323+.1071X_5/10^2+.1209X_5^2/10^4. \qquad (10)$$

The constants in (6) through (10) were derived by treating the functions as independent predictors of thunderstorm probability using the same set of learning data from which the constants in (5) were evaluated.

Graphical representations of (6) through (10) for June, as well as for the other months are given in figures 4 through 18. These latter figures are made available to the forecaster so that a rapid assessment of the significant parameters can be made. The outer ellipses on the figures depicting the wind functions represent bounds to these functions. Such bounding is required since, having expressed the probability by regression techniques rather than fitting to a probability distribution, nothing can be inferred outside the range of observations of the wind components. Without bounding, unrealistic values of P might be produced by the wind functions with some unusual wind observation. Ezekiel (1941) points out the pitfalls of such practices. The bounding function to (6) for example, is given by an equation of an ellipse in the (s, t) coordinate system,

$$\Phi_{99}(s,t) = ((s-h)\cos\Theta+(t-k)\sin\Theta)^2/(3.035s')^2+((t-k)\cos\Theta-(s-h)\sin\Theta)^2$$
$$/(3.035t')^2 \qquad (11)$$

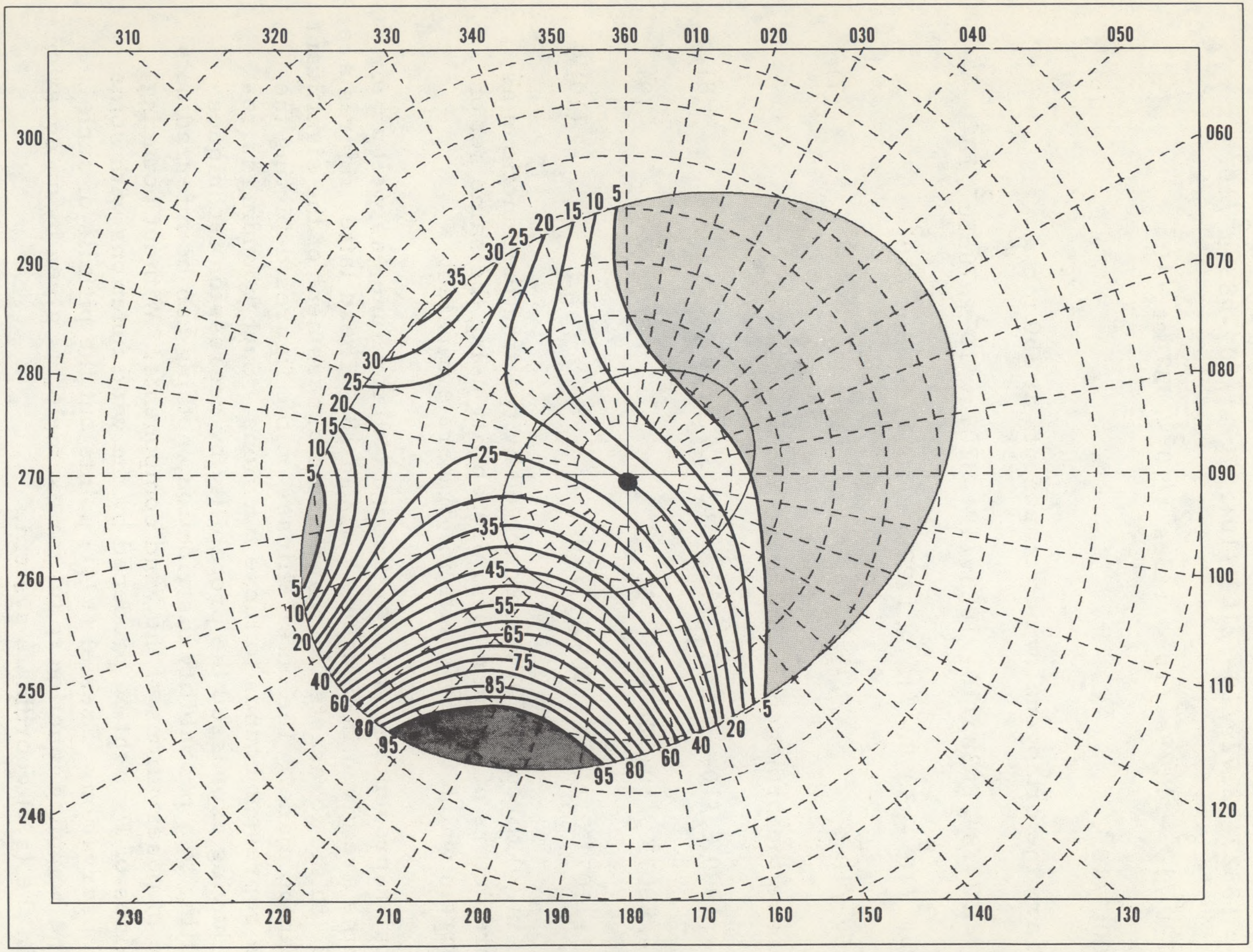

Figure 4. --Percent probability of afternoon thunderstorms in the month of May as a bivariate function of the 850-mb 1200 GMT wind. Concentric dashed circles are drawn at 5 kt intervals. Outer and inner ellipses encompass 99 and 50 percent, respectively, and darkened circle marks centroid of dependent data sample. Light shading shows areas where probability is less than 5 percent while dark shading shows areas where probability exceeds 95 percent.

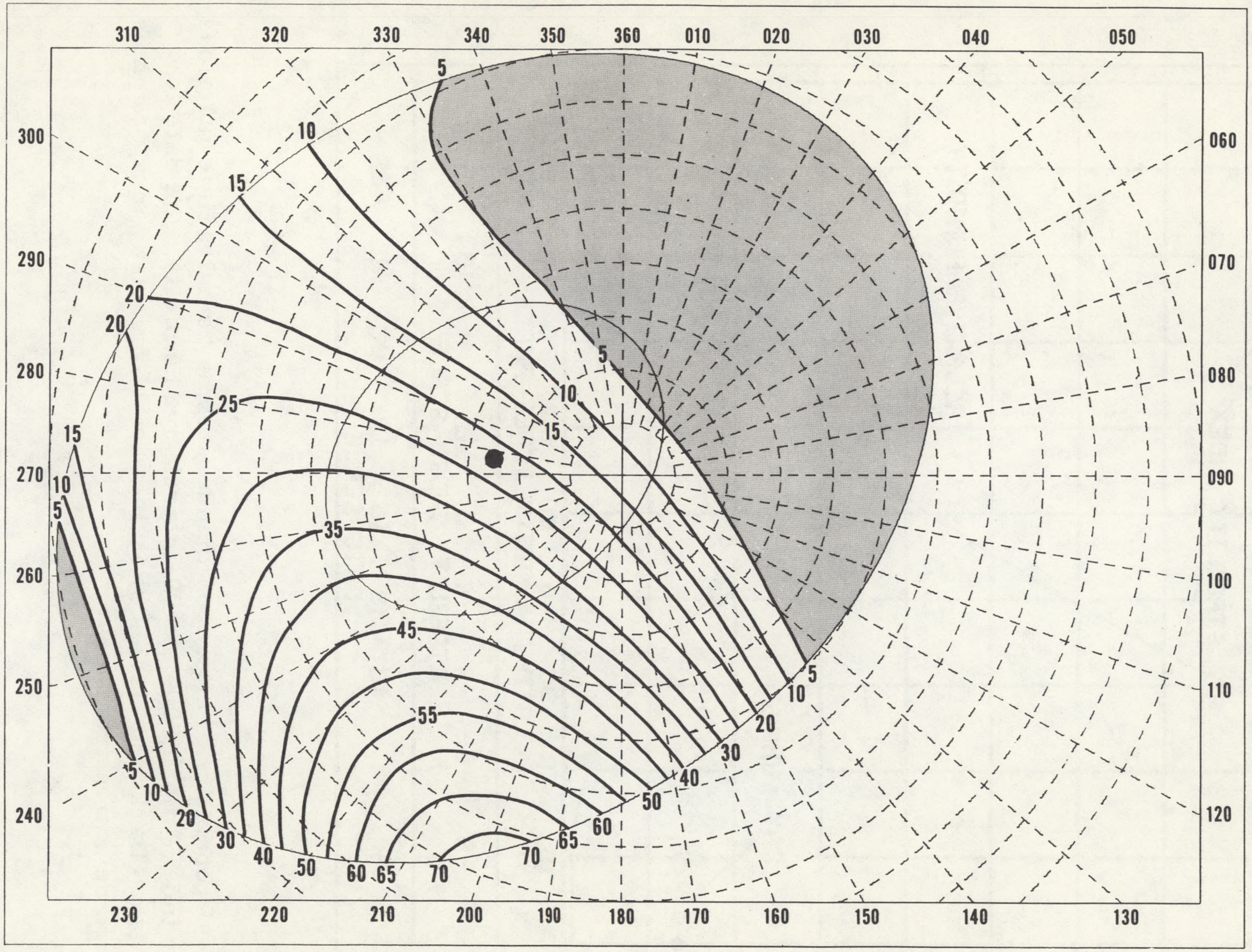

Figure 5.--Percent probability of afternoon thunderstorms in the month of May as a bivariate function of the 500-mb 1200 GMT wind. Concentric dashed circles are drawn at 5 kt intervals. Outer and inner ellipses encompass 99 and 50 percent, respectively, and darkened circle marks centroid of dependent data sample. Shading shows areas where probability is less than 5 percent.

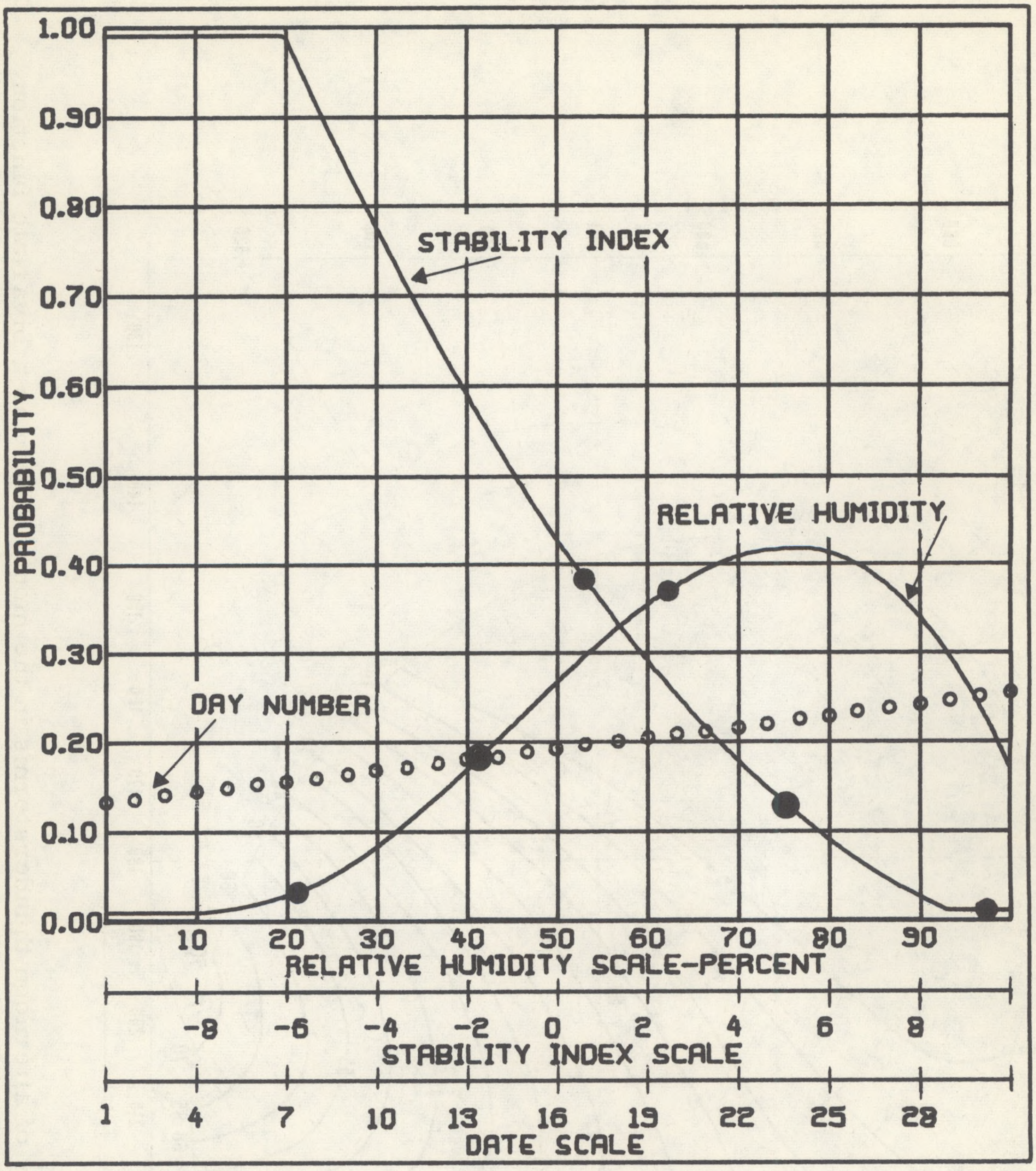

Figure 6. --Probability of afternoon thunderstorms as univariate functions of stability index, mean 800- to 600-mb relative humidity, and date for month of May. Darkened circles show location of mean and plus or minus one standard deviation from mean.

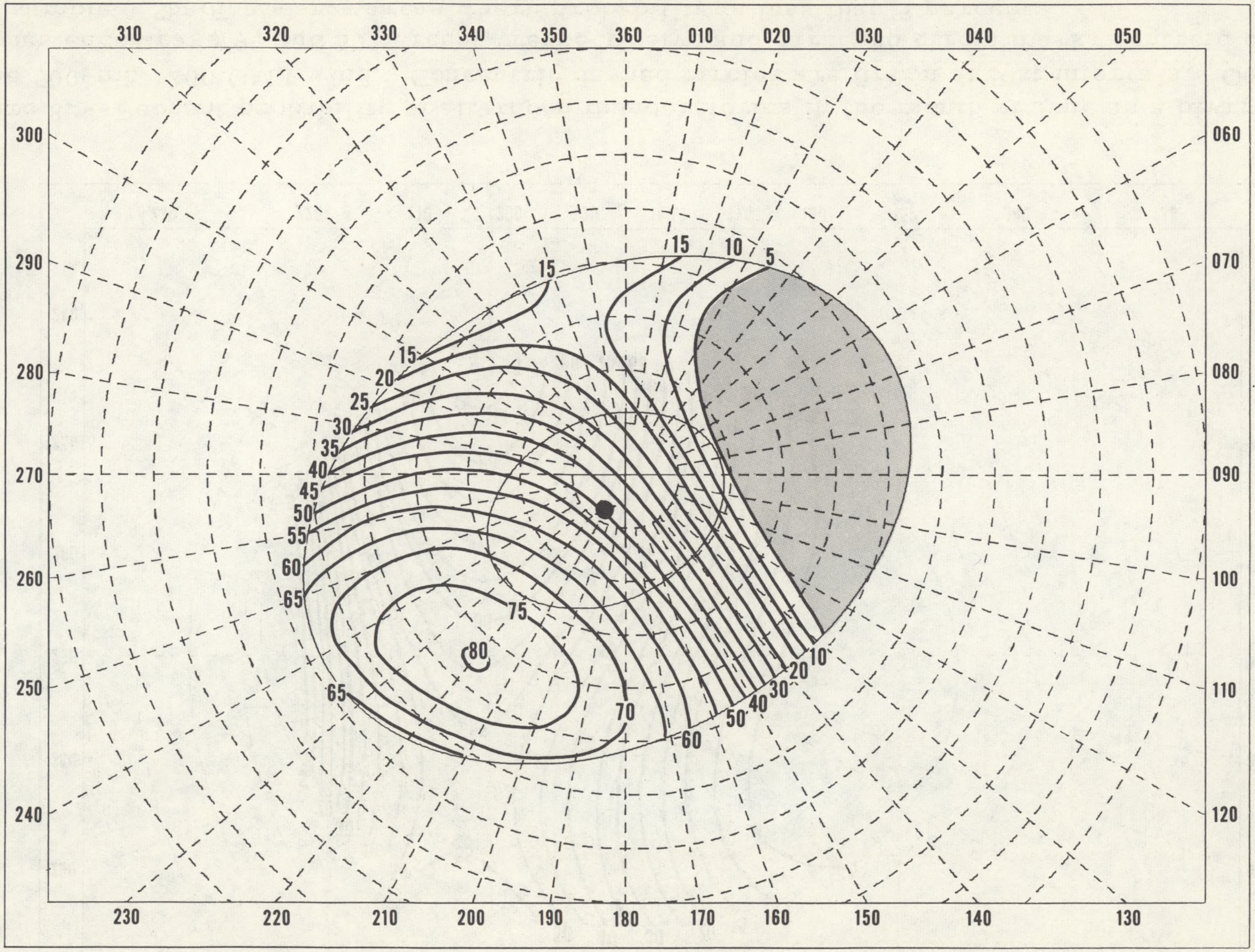

Figure 7. --Percent probability of afternoon thunderstorms in the month of June as a bivariate function of the 850-mb 1200 GMT wind. Concentric dashed circles are drawn at 5 kt intervals. Outer and inner ellipses encompass 99 and 50 percent, respectively, and darkened circle marks centroid of dependent data sample. Shading shows areas where probability is less than 5 percent.

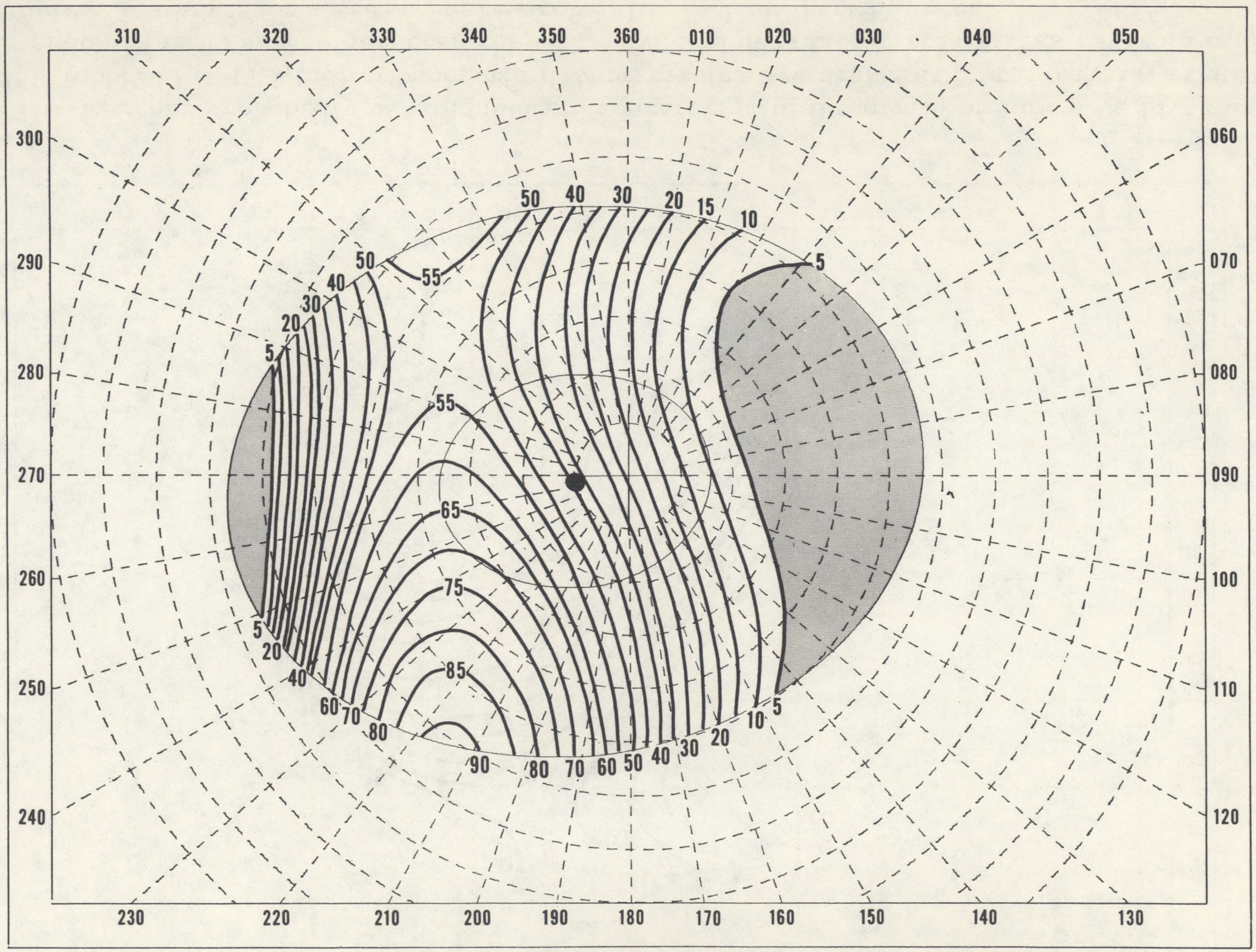

Figure 8. --Percent probability of afternoon thunderstorms in the month of June as a bivariate function of the 500-mb 1200 GMT wind. Concentric dashed circles are drawn at 5 kt intervals. Outer and inner ellipses encompass 99 and 50 percent, respectively, and darkened circle marks centroid of dependent data sample. Shading shows areas where probability is less than 5 percent.

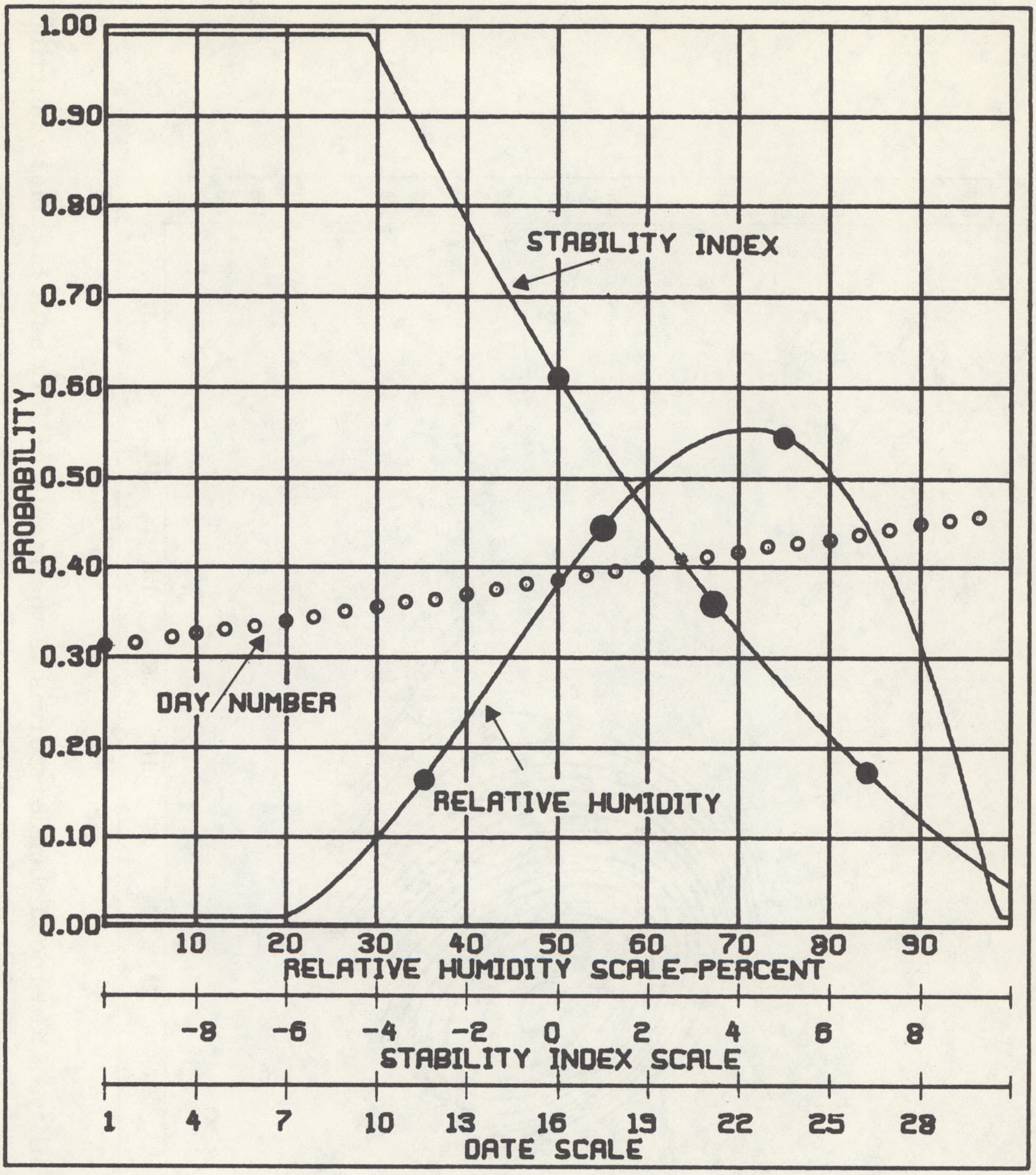

Figure 9. --Probability of afternoon thunderstorms as univariate functions of stability index, mean 800- to 600-mb relative humidity, and date for month of June. Darkened circles show location of mean and plus or minus one standard deviation from mean.

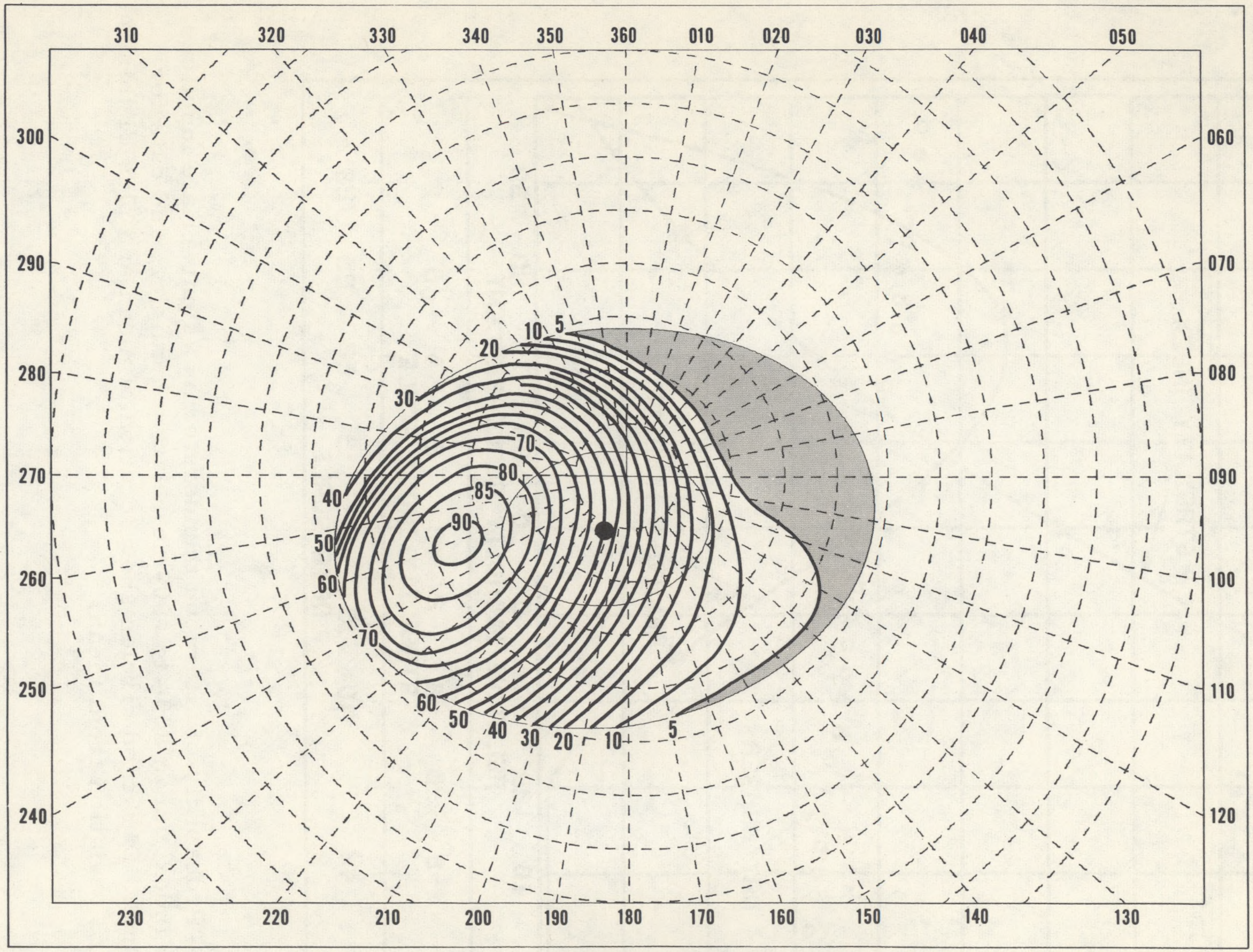

Figure 10. --Percent probability of afternoon thunderstorms in the month of July as a bivariate function of the 850-mb 1200 GMT wind. Concentric dashed circles are drawn at 5 kt intervals. Outer and inner ellipses encompass 99 and 50 percent, respectively, and darkened circle marks centroid of dependent data sample. Shading shows areas where probability is less than 5 percent.

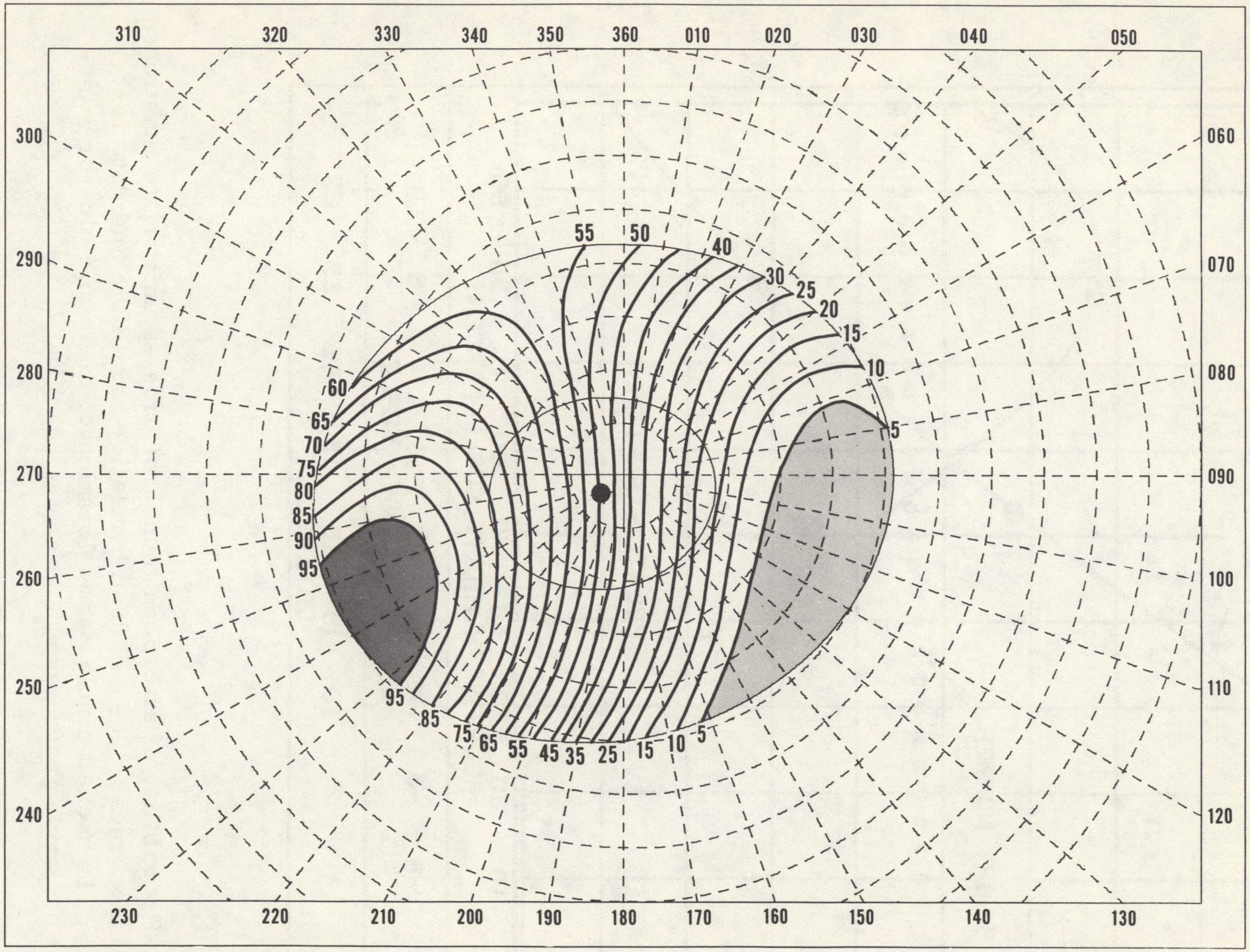

Figure 11. --Percent probability of afternoon thunderstorms in the month of July as a bivariate function of the 500-mb 1200 GMT wind. Concentric dashed circles are drawn at 5 kt intervals. Outer and inner ellipses encompass 99 and 50 percent, respectively, and darkened circle marks centroid of dependent data sample. Light shading shows areas where probability is less than 5 percent while dark shading shows areas where probability exceeds 95 percent.

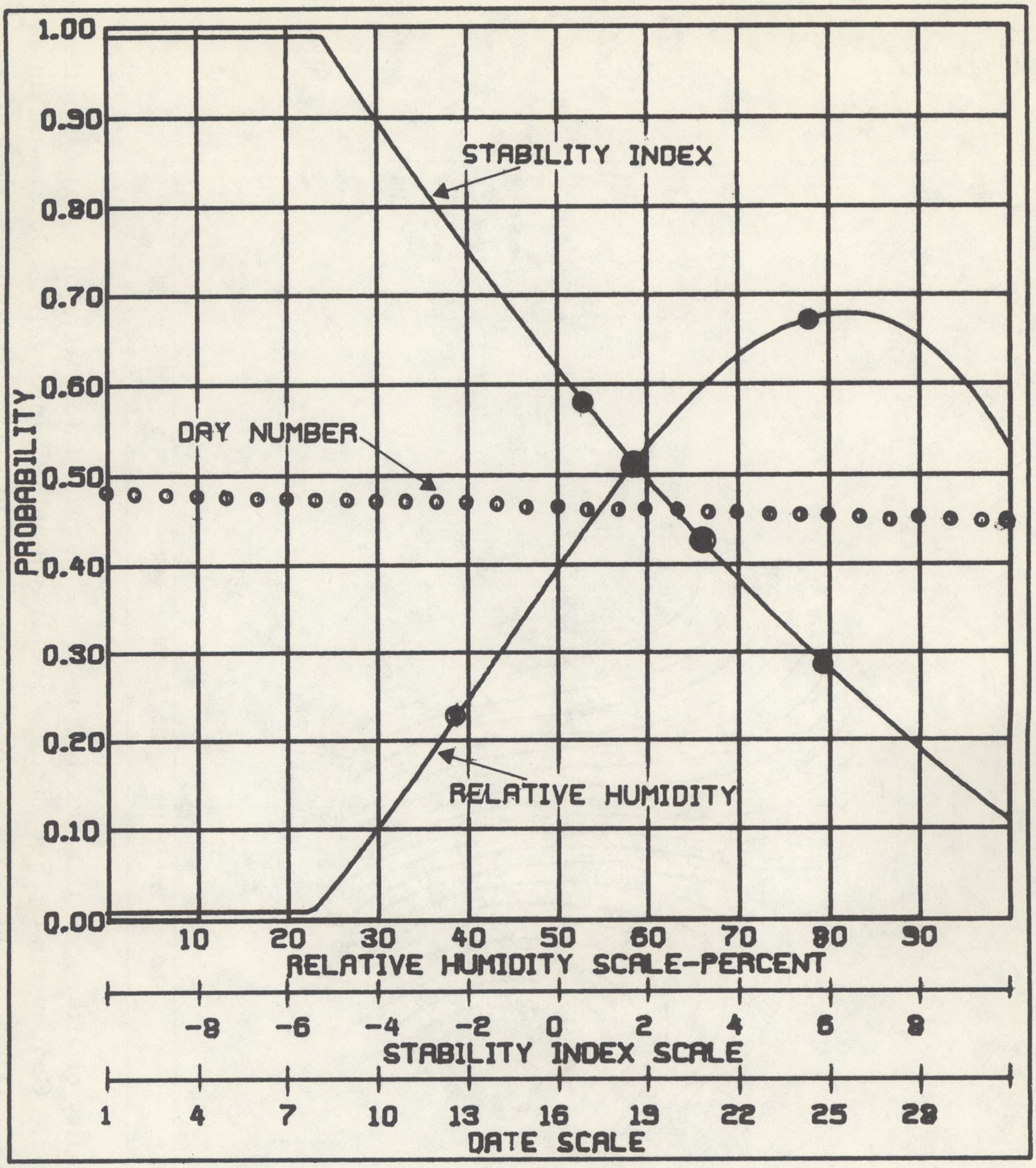

Figure 12. --Probability of afternoon thunderstorms as univariate functions of stability index, mean 800- to 600-mb relative humidity, and date for month of July. Darkened circles show location of mean and plus or minus one standard deviation from mean.

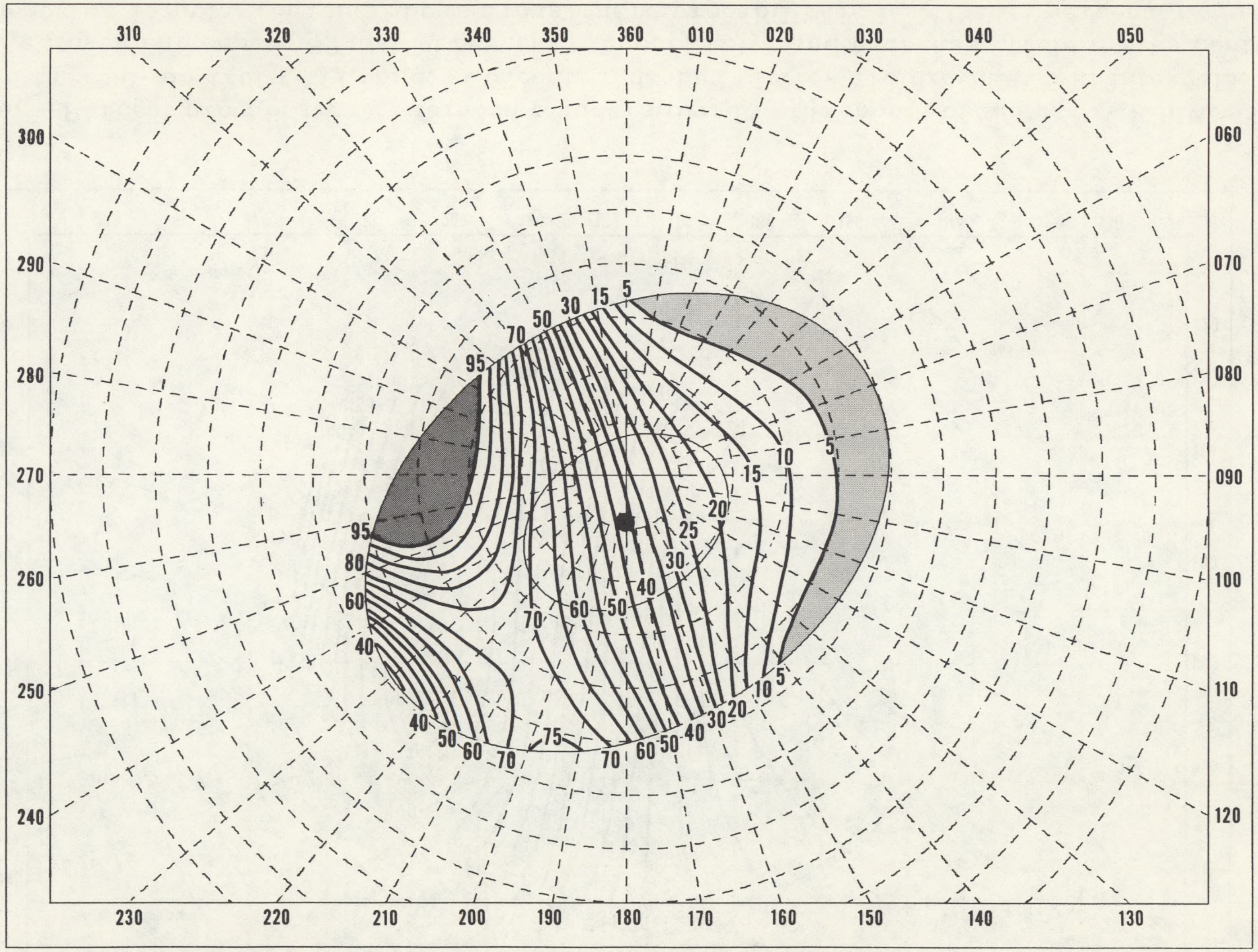

Figure 13. --Percent probability of afternoon thunderstorms in the month of August as a bivariate function of the 850-mb 1200 GMT wind. Concentric dashed circles are drawn at 5 kt intervals. Outer and inner ellipses encompass 99 and 50 percent, respectively, and darkened circle marks centroid of dependent data sample. Light shading shows areas where probability is less than 5 percent while dark shading shows areas where probability exceeds 95 percent.

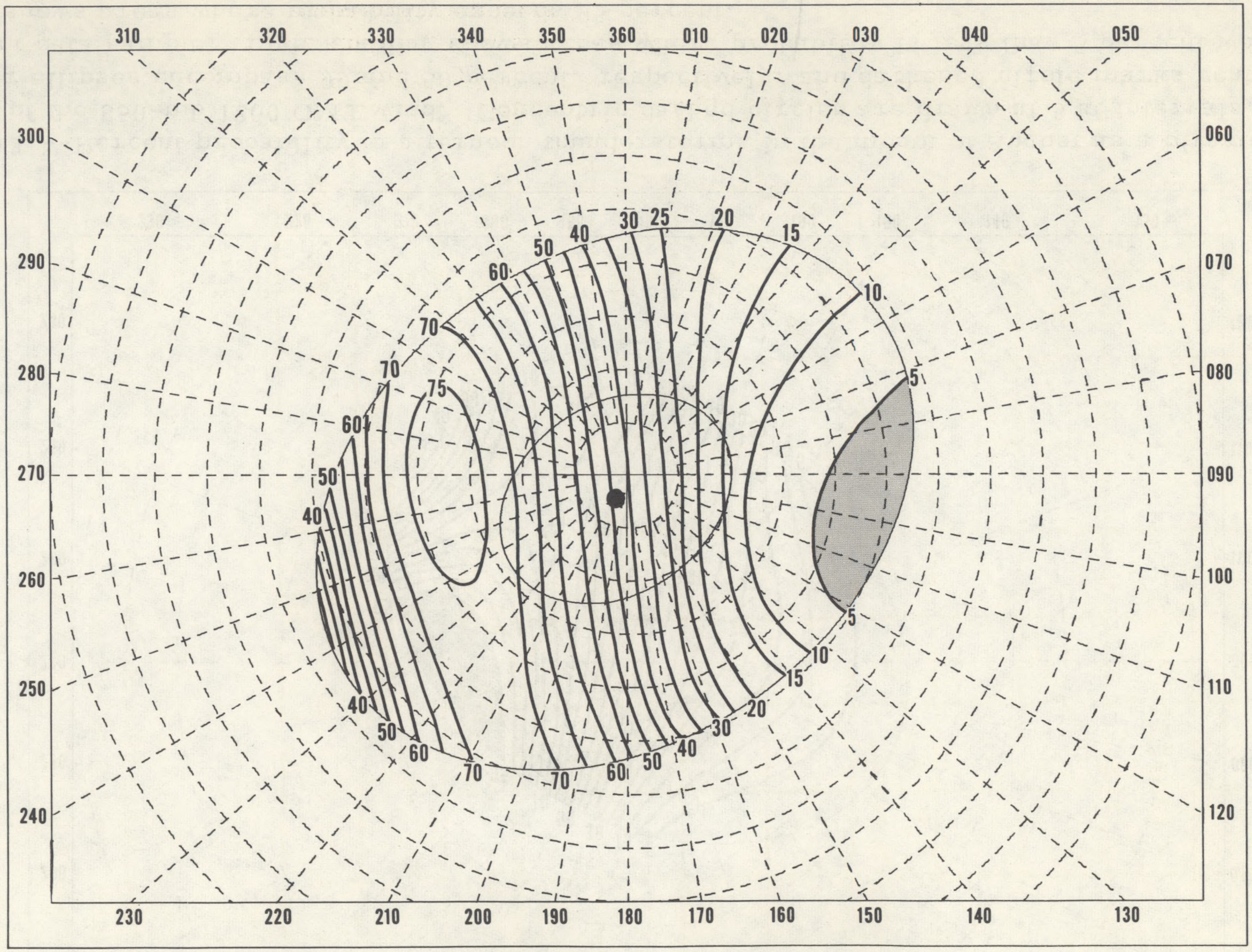

Figure 14. --Percent probability of afternoon thunderstorms in the month of August as a bivariate function of the 500-mb 1200 GMT wind. Concentric dashed circles are drawn at 5 kt intervals. Outer and inner ellipses encompass 99 and 50 percent, respectively, and darkened circle marks centroid of dependent data sample. Shading shows areas where probability is less than 5 percent.

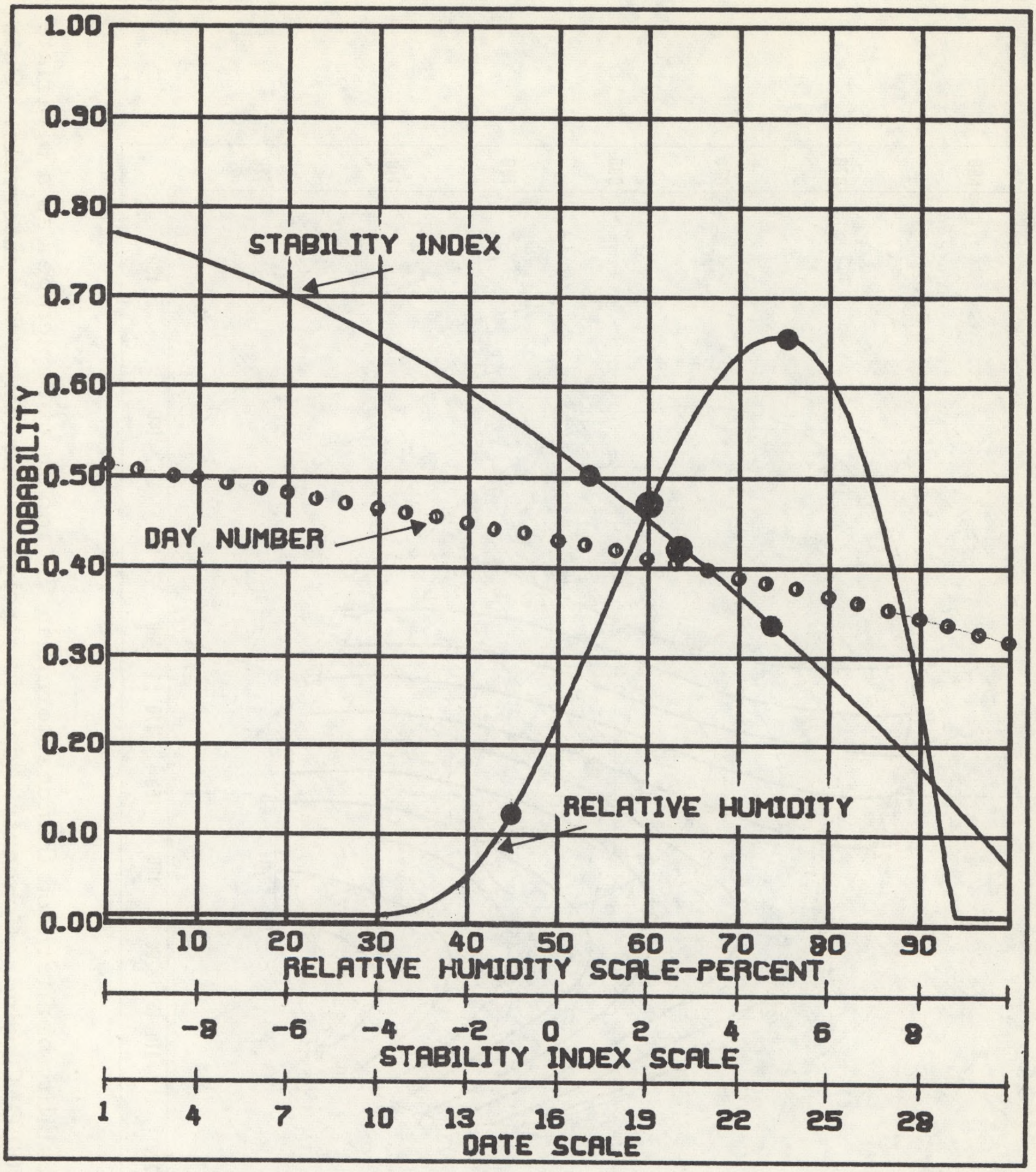

Figure 15. --Probability of afternoon thunderstorms as univariate functions of stability index, mean 800- to 600-mb relative humidity, and date for month of August. Darkened circles show location of mean and plus or minus one standard deviation from mean.

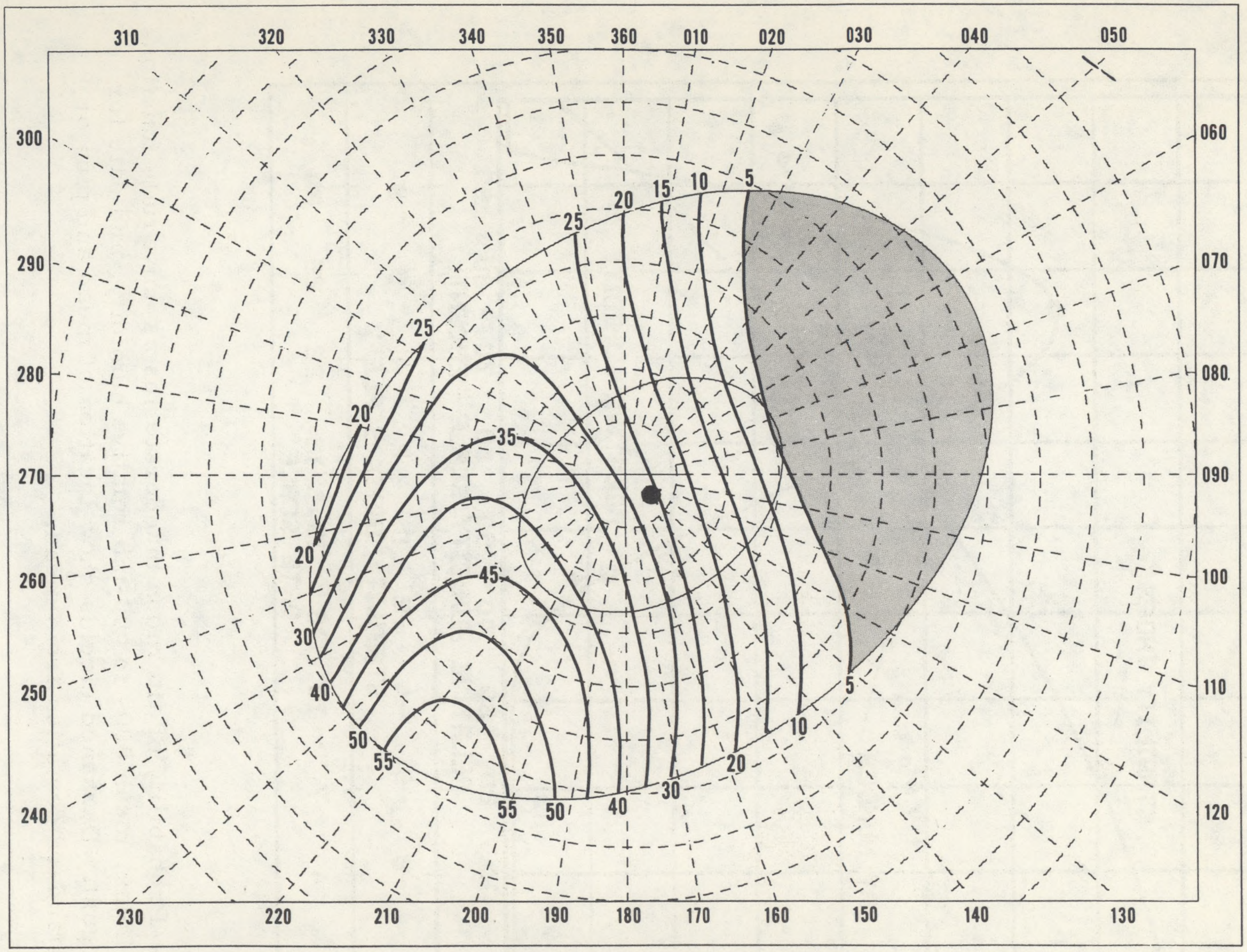

Figure 16.--Percent probability of afternoon thunderstorms in the month of September as a bivariate function of the 850-mb 1200 GMT wind. Concentric dashed circles are drawn at 5 kt intervals. Outer and inner ellipses encompass 99 and 50 percent, respectively, and darkened circle marks centroid of dependent data sample. Shading shows areas where probability is less than 5 percent.

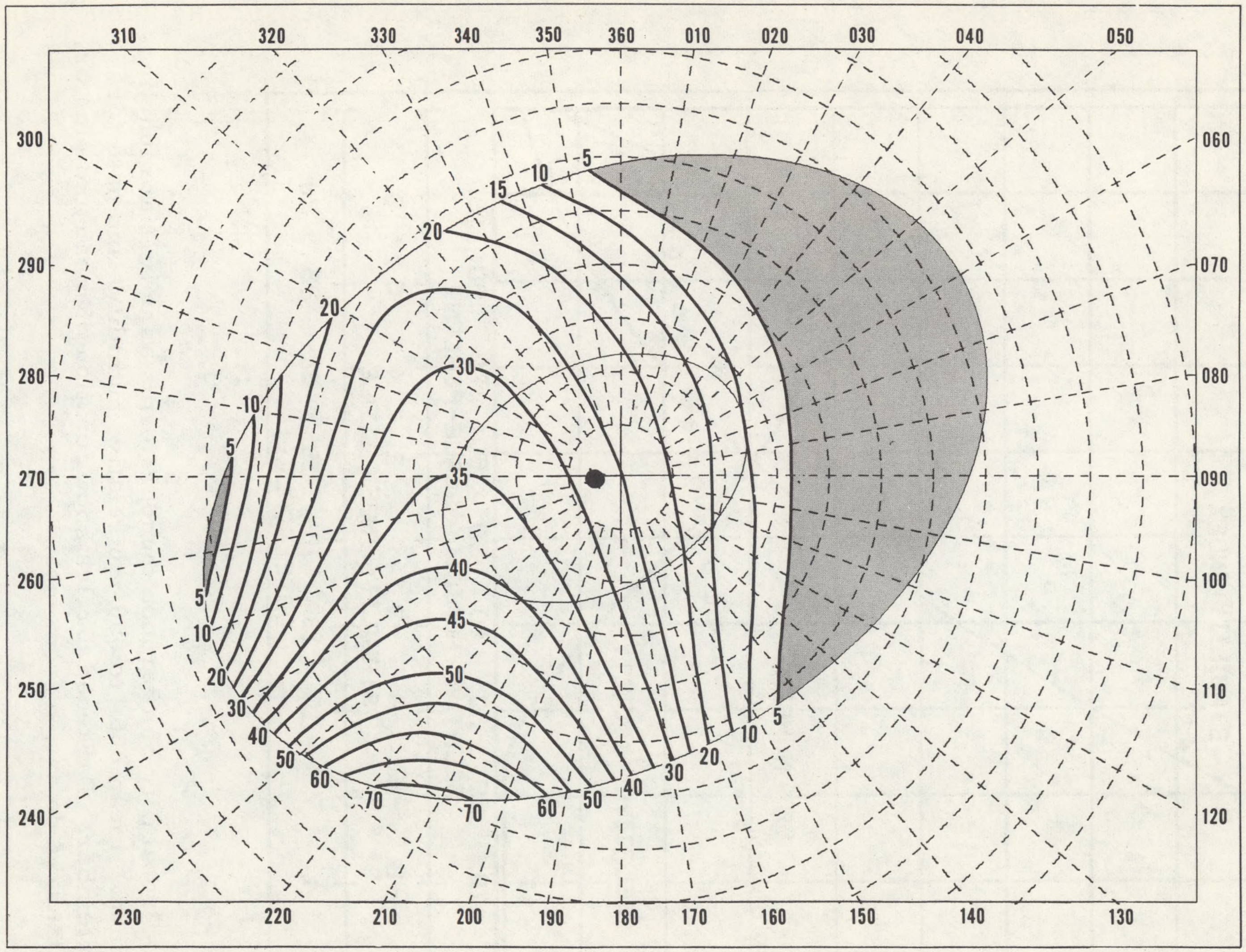

Figure 17. --Percent probability of afternoon thunderstorms in the month of September as a bivariate function of the 500-mb 1200 GMT wind. Concentric dashed circles are drawn at 5 kt intervals. Outer and inner ellipses encompass 99 and 50 percent, respectively, and darkened circle marks centroid of dependent data sample. Shading shows areas where probability is less than 5 percent.

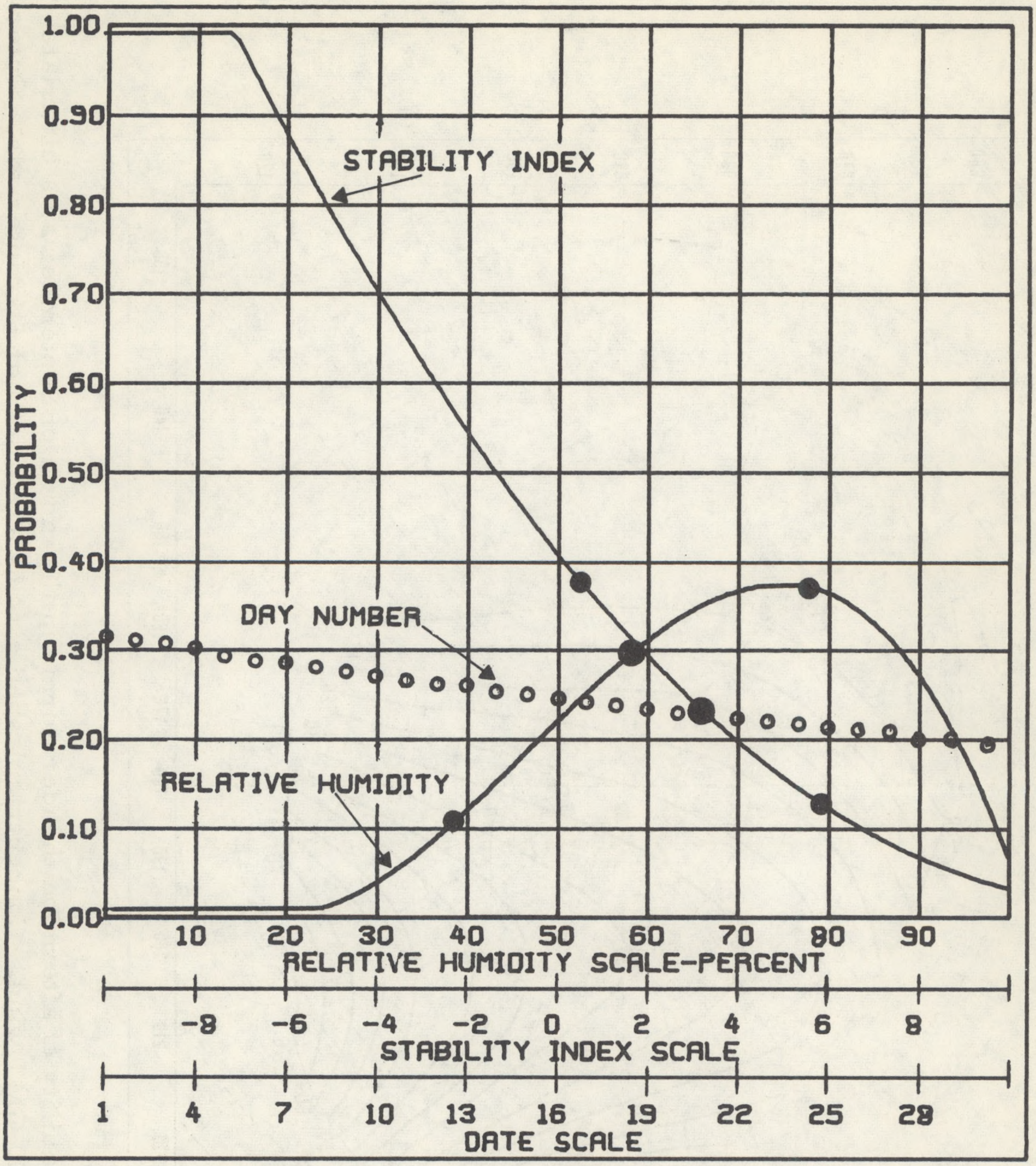

Figure 18. --Probability of afternoon thunderstorms as univariate functions of stability index, mean 800- to 600-mb relative humidity, and date for month of September. Darkened circles show location of mean and plus or minus one standard deviation from mean.

where Θ is the angle of rotation of the major axis of the ellipse from the positive s axis, h and k are the centroids (mean s and mean t) of the ellipse, s' and t' are the standard deviations of the s and t components along the major and minor axes, respectively. Values of s', t', and Θ are obtained by fitting the array of all s and t components to a bivariate normal distribution. Details of this fitting process are given in Hope and Neumann (1970). The constant 3.035 in the denominators of the right side of (11) represents a particular choice of probability such that 99 percent of the dependent data observations should be included in the resultant ellipse. Substituting appropriate values in (11) gives as the bounding function,

$$\Phi_{99}(s,t) = .00128s^2 + .00189t^2 - .00084st + .0021s + .0107t + .020. \quad (12)$$

The outer ellipse in figure 7 represents the locus of all s and t values obtained by setting (12) to unity. As will be pointed out in a subsequent section, the regression program output prints a warning message whenever (12) exceeds unity. The inner ellipses in the 10 figures depicting solution of the wind functions are presented for information only and encompass 50 percent of the cases.

It is obvious from these figures (4, 5, 7, 8, 10, 11, 13, 14, 16, 17) that the relationship between thunderstorm occurrence and the winds is definitely not a linear one. At both the 850- and 500-mb level, southwesterly winds are highly favorable. Speed, though, is also an important factor. In figures 6, 9, 12, 15, and 18, it can be seen that the effect of mean relative humidity is also quite non-linear. Low humidities are indicative of subsidence which suppresses afternoon convection. High humidities at this time of the morning (0700 EST) are indicative of considerable synoptic-scale convergence and excessive cloudiness which also suppress afternoon convection. Mean relative humidities in the range 60 to 80 percent are an optimum value between the two extremes just cited.

Note that some of the humidity and the stability index curves in figures 6, 9, 12, 15, and 18 are discontinuous at P = 0.99 and P = 0.01. These values are beyond the range of the dependent data sample and were assigned using a priori reasoning.

THUNDERSTORM STARTING TIME

The average thunderstorm starting time (TST) over the entire thunderstorm season at Cape Kennedy is 1434 EST. Assuming that these times are normally distributed about the mean, two-thirds ($\pm$ 1 standard deviation) would be expected between the hours 1204 and 1705 EST. It was found that this standard deviation of thunderstorm starting time could be reduced by considering four parameters, that is,

$$TST = f(s, t, P, D) \tag{13}$$

where s and t are the orthogonal wind components at 850 mb, P is the forecast probability (as would be obtained, for example from (5)), and D is the day number. The third-order polynomial expansion of (13) yields 35 normal equations which were solved simultaneously so as to yield values of the 35 constants [3] in the resulting prediction equation. The procedure is analogous to the expansion given in (4) except that four terms are involved instead of two. The actual equation and the 35 constants is given in Appendix II in the Fortran function named ISTART. Most of the reduction in variance of TST is provided by the probability forecast itself, where a high probability yields an early starting time and a low probability yields a late starting time.

By holding two of the four independent variables in (13) constant, TST can be represented graphically in a two-dimensional space. Figures 19, 20, and 21 present three such solutions to (13) obtained by setting the 850-mb wind to 180°/10 kt, 270°/15 kt, and calm, respectively. There are, of course, an infinite number of solutions to (13). The probable error associated with the solution to (13) is plus or minus 1-1/2 hours.

VERIFICATION OF THE FORECAST SYSTEM

Since the thunderstorm forecasts are presented on a probability basis, one would expect a thunderstorm forecast of 0.50 to be correct on half the occasions. Similarly, a probability of thunderstorms of say, .90 should be correct 9 out of 10 times. Table 1 shows the results of the forecast system for the month of June for the dependent data sample extending from 1957 through 1969.

In Table 1, the observed occurrence rate is obtained by dividing the number of thunderstorm occurrences by the total number of cases. Over a long period of time, this observed occurrence rate should approximate the forecast probabilities as given in Column 1. It appears, however, that there is a systematic loss of resolution in the probability forecasts. Forecast probabilities of less than 0.50 are too high and those above 0.50 are too low

---

[3] The number of constants is given by $(V+3)!/6(V!)$ where V is the number of independent variables. V also represents the number of degrees of freedom lost in solving for the constants.

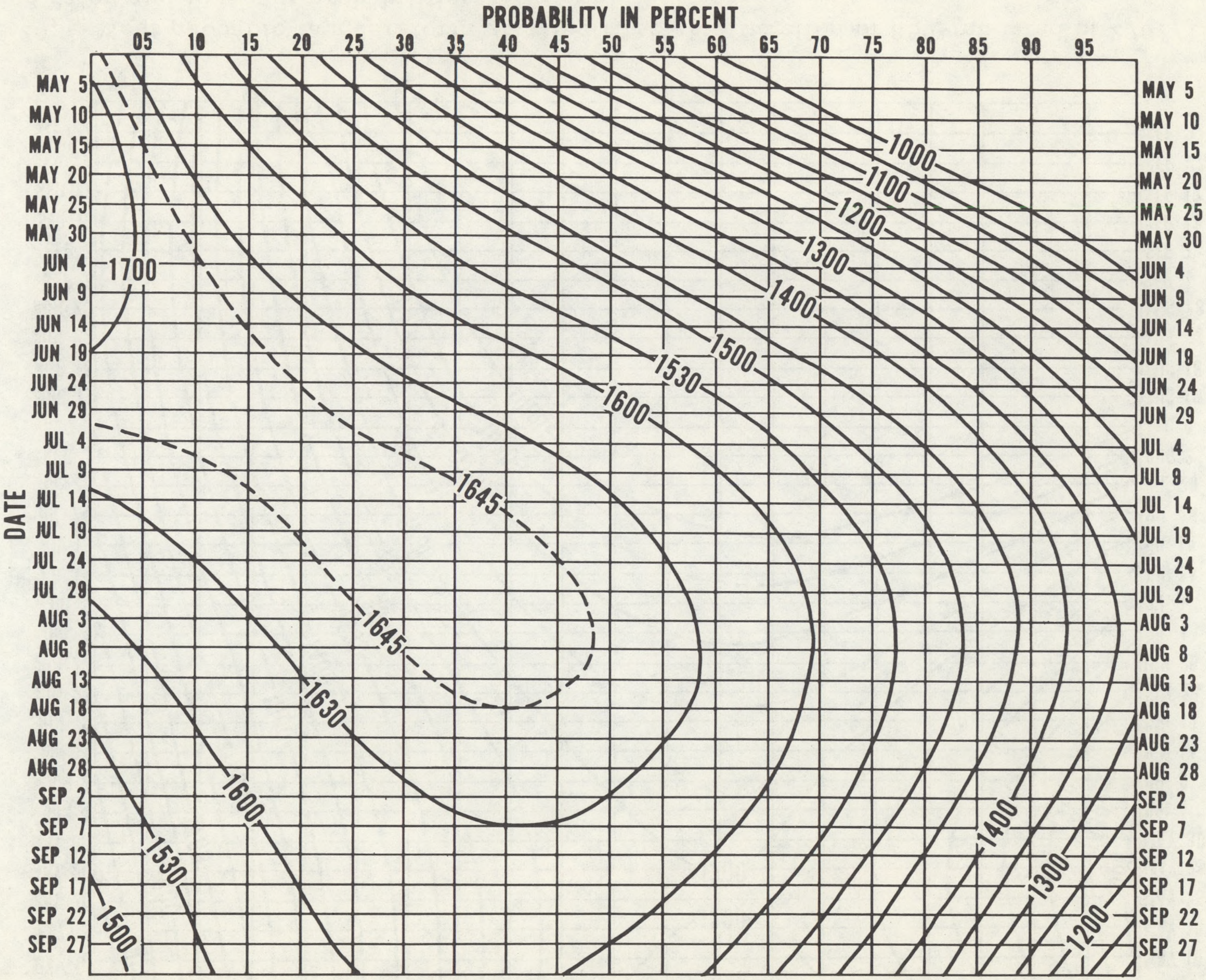

Figure 19.--Most probable thunderstorm starting time as a function of 850-mb wind of 180°/10 kt and specified dates and forecast probabilities.

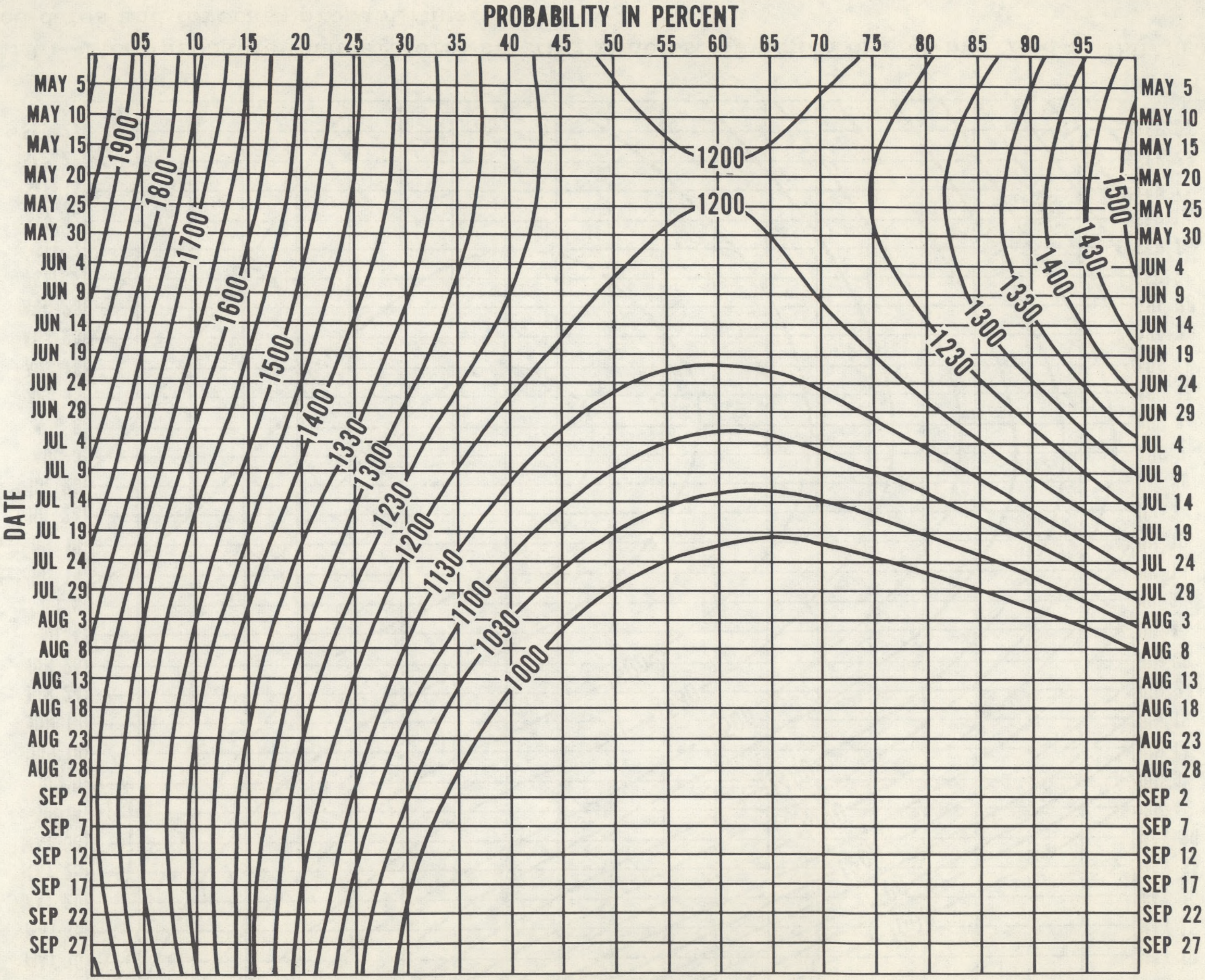

Figure 20. --Most probable thunderstorm starting time as a function of 850-mb wind of 270°/15 kt and specified dates and forecast probabilities.

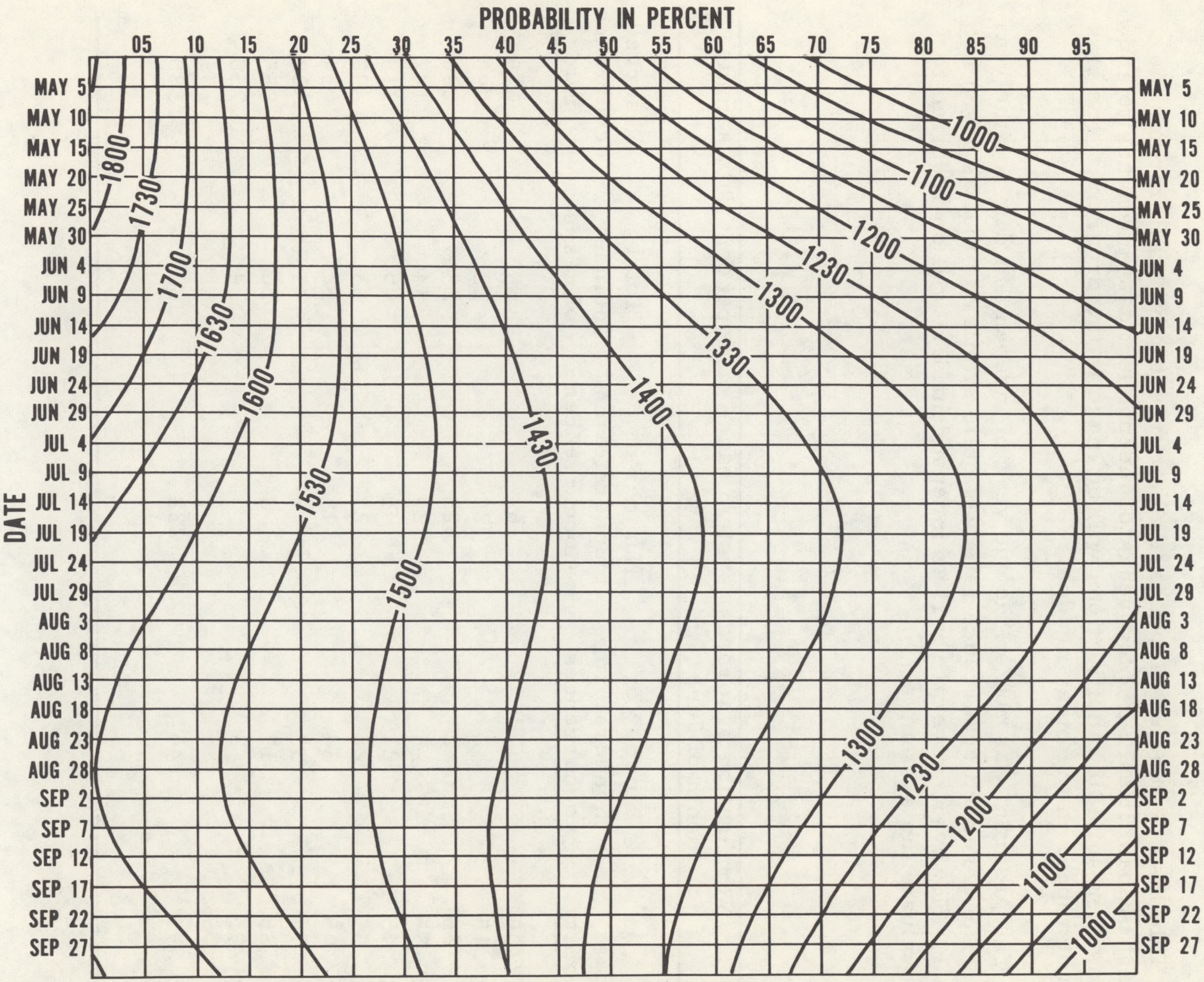

Figure 21. --Most probable thunderstorm starting time as a function of calm 850-mb winds and specified dates and forecast probabilities.

(except in the category .86 to .95 where there are insufficient cases). Forecasts near 0.50 are apt to be correct. The reason for this bias is not clear but is probably associated with the fitting of (5) through (10) using a binomial assignment to represent all possible values of P.

This loss of resolution can easily be corrected by "calibrating" the forecast probabilities. If a few years of independent data continues to show the bias then suitable modifications will be made in the program. The bias does not appear in the other months.

The program was run on the one year of independent data for the year 1970. The observed occurrence rate was quite similar to that as given in Table 1. However, several years of independent data will be required to fully evaluate the system.

Table 1. Verification of forecast system based on dependent data sample for month of June.

Forecast probability	Number of thunderstorm occurrences	Number of thunderstorm nonoccurrences	Total number of cases	Observed occurrence rate
.00 to .05	1	64	65	.015
.06 to .15	2	20	22	.090
.16 to .25	2	23	25	.080
.26 to .35	5	29	34	.147
.36 to .45	21	45	66	.318
.46 to .55	26	27	53	.490
.56 to .65	34	18	52	.654
.66 to .75	35	8	43	.822
.76 to .85	17	3	20	.855
.86 to .95	3	1	4	.750
.00 to .95	146	238	384	.380

PROGRAMMING THE SYSTEM

The system of regression equations was programmed in the Fortran IV computer language for operational implementation on 1 May 1971. The program, consisting of two subroutines and five functions is included as Appendix II. Data are fed directly into the main subroutine PF1970. This subroutine does not have provision for missing data; this must be handled externally. The 180 constants which are required by PF1970 are read from cards each time the program is run. These constants, punched six to a card, are listed on the last page of Appendix II. They are listed in the same format as required by statement 15 in PF1970. The cards are indexed in such a way that they can be read in any order. Thus, should they become mixed inadvertently, the program output is unaffected. The purpose of each subprogram is explained by suitable comments in the program listings.

Sample output from the program is shown in figure 22. In A, the input into PF1970 included an 850-mb wind of 180°/10 kt, a 500-mb wind of 220°/18 kt, a mean relative humidity of 60 percent and a stability index of zero. In this case, the call to PF1970 from a main program would be,

```
CALL PF1970(6, 16, 180., 10., 220., 18., 60.0, 0.0).
```

In figure 22B, the input data are for 25 May 1970. On this date the 850-mb wind was beyond the bounds of the 99 percent ellipse defined by the data for the 13 previous years. This can be verified on figure 4. The forecast probability of 99 percent given by the 850-mb wind function should therefore be questionable. In figure 22C, the input data are for 19 June 1970. In this case, the 500-mb wind was out of bounds. Note that the combined probability is given as less than 5 percent. Fictitious negative probabilities are included in this category. Similarly, probabilities of over 95 percent are categorized as over 95 percent.

DISCUSSION

Insofar as the predictors derived from the 1200 GMT sounding are concerned, the probabilities specified by the system of regression equations represent a logical statement of afternoon thunderstorm potential at or in the immediate vicinity of Cape Kennedy. Since the summertime air mass over the Florida peninsula is typically quite homogeneous, one would expect advection to play only a minor role in producing short-period changes in the sounding. The forecaster should be aware, however, that such a possibility does exist and make suitable adjustment in a probability statement should advection of a different air mass be suspected. Figures 4 through 18 are quite useful in this respect.

The system of regression equations is not claimed to be the most efficient possible, nor is it claimed that additional predictors will not reduce the variance further. It may be possible, for example, to arrive at a single set of prediction equations for the entire thunderstorm season rather than using time steps of one month. Discontinuities from one month to the next with otherwise similar input data would thereby be avoided. Work is continuing to improve the system.

```
AFTERNOON (1000-2200 EST) THUNDERSTORM
PROBABILITY FOR CAPE KENNEDY, 16 JUN
    CLIMATOLOGICAL------------ 38 PERCENT
    850 MB WINDS ONLY --------- 53 PERCENT
    500 MB WINDS ONLY --------- 75 PERCENT
    MEAN RH 800/600 MB ONLY -- 50 PERCENT
    STABILITY INDEX ONLY------ 61 PERCENT
COMBINED PROBABILITY IS 87 PERCENT.
IF AN AFTERNOON THUNDERSTORM OCCURS,
THE ESTIMATED STARTING TIME IS 1240 EST
PLUS OR MINUS 1 1/2 HOURS.
```

```
AFTERNOON (1000-2200 EST) THUNDERSTORM
PROBABILITY FOR CAPE KENNEDY, 25 MAY
    CLIMATOLOGICAL------------ 23 PERCENT
    850 MB WINDS ONLY --------- 99 PERCENT
    500 MB WINDS ONLY --------- 51 PERCENT
    MEAN RH 800/600 MB ONLY -- 36 PERCENT
    STABILITY INDEX ONLY------ 41 PERCENT
COMBINED PROBABILITY IS 93 PERCENT.
IF AN AFTERNOON THUNDERSTORM OCCURS,
THE ESTIMATED STARTING TIME IS 1000 EST
PLUS OR MINUS 1 1/2 HOURS.
THE 850 MB WIND OF 209/37 KNOTS IS BEYOND
THE BOUNDS OF THE 99 PERCENT ELLIPSE
DEFINED BY THE DEPENDENT DATA.
```

```
AFTERNOON (1000-2200 EST) THUNDERSTORM
PROBABILITY FOR CAPE KENNEDY, 19 JUN
    CLIMATOLOGICAL------------ 40 PERCENT
    850 MB WINDS ONLY ---------  1 PERCENT
    500 MB WINDS ONLY ---------  1 PERCENT
    MEAN RH 800/600 MB ONLY -- 27 PERCENT
    STABILITY INDEX ONLY ----- 40 PERCENT
COMBINED PROBABILITY IS LESS THAN 5 PERCENT
IF AN AFTERNOON THUNDERSTORM OCCURS,
THE ESTIMATED STARTING TIME IS 2200 EST
PLUS OR MINUS 1 1/2 HOURS.
THE 500 MB WIND OF 035/27 KNOTS IS BEYOND
THE BOUNDS OF THE 99 PERCENT ELLIPSE
DEFINED BY THE DEPENDENT DATA.
```

Figure 22. --Sample computer printouts for multiple regression program.

REFERENCES

Ezekial, M., Methods of Correlation Analysis, Wiley, New York, N. Y., 347 pp.

Hope, J. R. and Neumann, C. J., "An Operational Technique for Relating the Movement of Existing Tropical Cyclones to Past Tracks," Monthly Weather Review, Vol. 98, No. 12, Dec. 1970, pp. 925-933.

Mills, F. C., Statistical Methods, Third Edition, Holt, Rinehart, and Winston, New York, N. Y., 1955, pp. 612-656, 601, 727-731.

Neumann, C. J. and Hope, J. R., "A Performance Analysis of the HURRAN Tropical Cyclone Forecast System," (submitted in 1971 for publication in the Monthly Weather Review).

Neumann, C. J., "Frequency and Duration of Thunderstorms at Cape Kennedy, Part 1," ESSA Technical Memorandum WBTM SOS-2, Department of Commerce, Washington, D. C., June 1968, 34 pp.

Neumann, C. J., "Frequency and Duration of Thunderstorms at Cape Kennedy, Part 2," ESSA Technical Memorandum, WBTM SOS-6, U. S. Department of Commerce, Washington, D. C., May 1970, 63 pp.

APPENDIX I

REGRESSION EQUATIONS AND RELATED STATISTICAL DATA FOR EACH MONTH

The probability ($0 \leq P \leq 1$) of at least one afternoon (1000-2200 EST) thunderstorm at Cape Kennedy for May is given by,

$$P = -.15896 - .55031 f(\overline{X}_1) + .37382 f(\overline{X}_2) + .32332 f(X_3) + .56569 f(X_4)$$
$$+ .02053 f(X_5); \qquad (14)$$

for June is given by,

$$P = -.55562 + .61025 f(\overline{X}_1) + .48518 f(\overline{X}_2) + .36460 f(X_3) + .35416 f(X_4)$$
$$+ .63915 f(X_5); \qquad (15)$$

for July is given by,

$$P = -.55538 - .63705 f(\overline{X}_1) + .41542 f(\overline{X}_2) + .49820 f(X_3) + .42179 f(X_4)$$
$$+ .23614 f(X_5); \qquad (16)$$

for August is given by,

$$P = -.46230 - .63916 f(\overline{X}_1) + .40614 f(\overline{X}_2) + .42442 f(X_3) + .56766 f(X_4)$$
$$+ .06062 f(X_5); \qquad (17)$$

and for September is given by,

$$P = -.61830 - .52693 f(\overline{X}_1) + .60655 f(\overline{X}_2) + .55390 f(X_3) + .48315 f(X_4)$$
$$+ 1.29491 f(X_5). \qquad (18)$$

The independent variables X_1 through X_5 have the following meaning,

$\overline{X}_1$ is the vector quantity 850-mb wind,
$\overline{X}_2$ is the vector quantity 500-mb wind,
X_3 is the mean relative humidity in the layer 800 to 600 mb in percent,
X_4 is the Showalter stability index in degrees Celsius,
X_5 is the day number, where 121 is May 1, and 273 is September 30.

The functions $f(X_1)$ through $f(X_5)$ are given by,

$$f(\overline{X}_1) = f(s,t) = C(1,J)+C(2,J)s+C(3,J)t+C(4,J)st+C(5,J)s^2$$

$$+C(6,J)t^2+C(7,J)s^3+C(8,J)s^2t+C(9,J)st^2+C(10,J)t^3, \qquad (19)$$

where s and t are the orthogonal wind components at 850 mb in kt;

$$f(\overline{X}_2) = f(u,v) = C(11,J)+C(12,J)u+C(13,J)v+C(14,J)uv+C(15,J)u^2$$

$$+C(16,J)v^2+C(17,J)u^3+C(18,J)u^2v+C(19,J)uv^2+C(20,n)v^3, \qquad (20)$$

where u and v are the orthogonal wind components at 500 mb in kt;

$$f(X_3) = C(21,J)+C(22,J)X_3+C(23,J)X_3^2+C(24,n)X_3^3; \qquad (21)$$

$$f(X_4) = C(25,J)+C(26,J)X_4+C(27,J)X_4^2; \qquad (22)$$

$$f(X_5) = C(28,J)+C(29,J)X_5+C(30,J)X_5^2. \qquad (23)$$

In (19) through (23) the constants C(I, J) are given in Table 5.

The subscript variable J refers to the month where May is month 1 and September is month 5.

Table 2 gives the index of multiple correlation and the variance ratio associated with the regression equations number (14) through (18).

Table 2. Index of multiple correlation and variance ratio for each month

MONTH	May	June	July	August	September
INDEX	0.53	0.59	0.61	0.55	0.43
RATIO	30.2	39.8	46.2	33.3	17.3

Table 3 gives the correlation coefficients between the dependent variable P with each of the independent variables as well as the intercorrelations among the independent variables themselves.

Table 3. Correlation coefficient matrix for each month

		P	$f(X_1)$	$f(X_2)$	$f(X_3)$	$f(X_4)$	$f(X_5)$
	P	1.00	0.41	0.35	0.36	0.42	0.09
	$f(X_1)$	. . . .	1.00	0.52	0.32	0.34	0.09
	$f(X_2)$	. . . .	. . . .	1.00	0.28	0.29	0.06
MAY	$f(X_3)$	. . . .	. . . .	. . . .	1.00	0.55	0.19
	$f(X_4)$	. . . .	. . . .	. . . .	. . . .	1.00	0.17
	$f(X_5)$	. . . .	. . . .	. . . .	. . . .	. . . .	1.00
	P	1.00	0.50	0.44	0.37	0.34	0.09
	$f(X_1)$	. . . .	1.00	0.52	0.34	0.29	0.08
	$f(X_2)$	. . . .	. . . .	1.00	0.28	0.27	-0.10
JUN	$f(X_3)$	. . . .	. . . .	. . . .	1.00	0.52	0.12
	$f(X_4)$	. . . .	. . . .	. . . .	. . . .	1.00	0.09
	$f(X_5)$	. . . .	. . . .	. . . .	. . . .	. . . .	1.00
	P	1.00	0.54	0.46	0.39	0.21	0.02
	$f(X_1)$	. . . .	1.00	0.60	0.36	0.11	0.07
	$f(X_2)$	. . . .	. . . .	1.00	0.27	0.18	0.06
JUL	$f(X_3)$	. . . .	. . . .	. . . .	1.00	0.26	-0.05
	$f(X_4)$	. . . .	. . . .	. . . .	. . . .	1.00	-0.12
	$f(X_5)$	. . . .	. . . .	. . . .	. . . .	. . . .	1.00
	P	1.00	0.47	0.43	0.34	0.18	0.12
	$f(X_1)$	. . . .	1.00	0.64	0.29	0.06	0.21
	$f(X_2)$	. . . .	. . . .	1.00	0.26	0.11	0.10
AUG	$f(X_3)$	. . . .	. . . .	. . . .	1.00	0.25	0.13
	$f(X_4)$	. . . .	. . . .	. . . .	. . . .	1.00	0.09
	$f(X_5)$	. . . .	. . . .	. . . .	. . . .	. . . .	1.00
	P	1.00	0.32	0.30	0.26	0.23	0.09
	$f(X_1)$	. . . .	1.00	0.63	0.17	0.10	-0.02
	$f(X_2)$	. . . .	. . . .	1.00	0.14	0.12	-0.18
SEP	$f(X_3)$	. . . .	. . . .	. . . .	1.00	0.51	0.04
	$f(X_4)$	. . . .	. . . .	. . . .	. . . .	1.00	0.04
	$f(X_5)$	. . . .	. . . .	. . . .	. . . .	. . . .	1.00

The means and the standard deviations of the predictors are given in Table 4. Also included in the table are the correlation coefficients between orthogonal wind components at each level. The meanings of s, t, u and v as well as X_1 through X_5 are the same as previously specified. Note that the mean probability P is equal to the means of the various functions.

Table 4. Miscellaneous statistical data

	MAY	JUN	JUL	AUG	SEP
Mean P, $f(X_1)$, $f(X_2)$, $f(X_3)$, $f(X_4)$, $f(X_5)$	0.19	0.38	0.46	0.42	0.25
Mean s (kt)	- .1	1.9	2.1	0.1	- 2.6
Mean t (kt)	.6	3.3	4.9	4.4	1.9
Standard deviation of s	± 10.3	± 9.6	± 8.5	± 8.2	± 10.9
Standard deviation of t	± 8.9	± 7.9	± 6.2	± 7.1	± 9.4
Correlation coefficient between s, t	0.30	0.27	0.11	0.29	0.32
Mean u (kt)	12.3	5.1	2.0	1.0	2.6
Mean v (kt)	1.5	0.5	1.7	2.2	0.3
Standard deviation of u	± 13.8	± 11.0	± 9.2	± 9.4	± 12.4
Standard deviation of v	± 12.5	± 8.5	± 7.7	± 8.4	± 10.0
Correlation coefficient between u, v	0.25	0.08	0.08	0.26	0.31
Mean X_3 (percent)	41.7	55.3	57.0	60.1	58.4
Standard deviation of X_3	± 20.7	± 20.1	± 16.6	± 15.3	± 19.6
Mean X_4 (degs. C)	5.0	3.5	2.8	2.7	3.2
Standard deviation of X_4	± 4.4	± 3.3	± 2.0	± 2.0	± 2.7
Mean X_5	0.19	0.38	0.46	0.42	0.25

TABLE 5

LIST OF CONSTANTS C(I,J), WHERE I REFERS TO ROW NUMBER (1 THROUGH 30) AND J REFERS TO COLUMN NUMBER (1 THROUGH 5).

ROW	COLUMN 1 (MAY)	COLUMN 2 (JUNE)	COLUMN 3 (JULY)	COLUMN 4 (AUGUST)	COLUMN 5 (SEPTEMBER)	ROW	APPLICABLE FUNCTION
1	0.1787416E 00	0.3326784E 00	0.4307867E 00	0.3627524E 00	0.2816768E 00	1	850-MB WIND
2	0.1074020E-01	0.2172438E-01	0.4366697E-01	0.3272211E-01	0.1256518E-01	2	
3	0.1365651E-01	0.2162950E-01	0.1055475E-01	0.1085207E-01	0.5804330E-02	3	
4	0.4523660E-03	0.3762057E-03	-0.3983281E-04	-0.5623187E-04	0.1096534E-03	4	
5	-0.1802959E-03	-0.6835819E-03	-0.3116464E-03	0.1038914E-02	-0.2671096E-03	5	
6	0.3397791E-03	0.2579025E-03	-0.1888946E-02	-0.3726890E-03	0.1469291E-04	6	
7	-0.1051838E-04	0.1179003E-05	-0.5616630E-04	-0.3354726E-04	-0.1099520E-04	7	
8	-0.3954365E-04	0.1437934E-05	0.7757703E-04	-0.1055251E-03	0.2925611E-05	8	
9	0.3376410E-04	-0.3373770E-04	-0.5417380E-04	-0.6772391E-05	0.3228711E-05	9	
10	0.1677435E-05	-0.2199710E-04	0.3519052E-04	0.1606763E-04	-0.3325703E-05	10	
11	0.1206249E 00	0.2927881E 00	0.4145883E 00	0.3932798E 00	0.2527479E 00	11	500-MB WIND
12	0.1080646E-01	0.2638450E-01	0.3166340E-01	0.3119719E-01	0.1084204E-01	12	
13	0.1001964E-01	0.1023307E-01	-0.7151263E-03	0.2545731E-02	0.3136786E-02	13	
14	0.2794513E-03	0.3206672E-03	0.5390949E-03	0.1592548E-03	0.1899334E-03	14	
15	-0.1012098E-03	0.7055070E-04	0.4251009E-04	0.9662809E-04	-0.2175208E-03	15	
16	0.1964561E-03	0.1576005E-03	-0.5091108E-04	0.2887852E-04	-0.3547891E-04	16	
17	-0.1929388E-05	-0.3090317E-04	-0.2425545E-04	-0.3745135E-04	-0.5449894E-05	17	
18	-0.1095389E-04	-0.1422489E-04	0.1581159E-04	-0.1717337E-04	-0.4427336E-05	18	
19	-0.6512554E-05	0.5588606E-05	-0.2172134E-04	-0.1704165E-04	0.6122512E-05	19	
20	-0.1931907E-05	-0.9225416E-05	-0.1060904E-04	0.4082921E-05	0.5412232E-05	20	
21	0.1037449E 00	0.1350110E 00	-0.1029031E 00	0.2562493E 01	0.1736004E 00	21	MEAN RELATIVE HUMIDITY
22	-0.1196854E-01	-0.1999291E-01	-0.2906759E-02	-0.1702073E 00	-0.1918291E-01	22	
23	0.4832994E-03	0.8150658E-03	0.4229306E-03	0.3551389E-02	0.6220711E-03	23	
24	-0.3570443E-05	-0.6342578E-05	-0.3308301E-05	-0.2161341E-04	-0.4414412E-05	24	
25	0.4273235E 00	0.6102192E 00	0.6177575E 00	0.5271789E 00	0.4078606E 00	25	STABILITY INDEX
26	-0.7480210E-01	-0.8066761E-01	-0.6421018E-01	-0.3530199E-01	-0.6376678E-01	26	
27	0.3056700E-02	0.2403756E-02	0.1310411E-02	-0.1094883E-02	0.2571961E-02	27	
28	-0.5430778E 00	-0.1323037E 00	0.9355280E 00	-0.4163536E 00	0.3758034E 01	28	DAY NUMBER
29	0.6855603E-02	0.1070858E-02	-0.3771816E-02	0.1394724E-01	-0.2287890E-01	29	
30	-0.1053707E-04	0.1208962E-04	0.6918594E-05	-0.4493189E-04	0.3598785E-04	30	

NOTE: .3425658E-03 is equivalent to .0003425658

APPENDIX II

FORTRAN PROGRAM AND INPUT DATA

```
      SUBROUTINE PF1970(MO,KDA,DIR8,SPD8,DIR5,SPD5,RH,SI)
C....APPLICABLE MAY 1 THROUGH SEPTEMBER 30 ONLY.............
C THIS PROGRAM COMPUTES THE PROBABILITY OF THUNDER BEING RECORDED AT
C LEAST ONCE BETWEEN THE HOURS 1000 AND 2200EST AT THE OFFICIAL WEATHER
C OBSERVATION SITE AT CAPE KENNEDY, FLORIDA. THE PROBABILITY IS COMPUTED
C USING A SYSTEM OF REGRESSION EQUATIONS BASED ON FUNCTIONS DERIVED FROM
C THE FOLLOWING INPUT DATA FROM THE 1200GMT SOUNDING.
C
C WIND DIRECTION AT 850 MBS IN WHOLE DEGREES----------DIR8
C WIND SPEED AT 850 MBS IN KNOTS----------------------SPD8
C WIND DIRECTION AT 500 MBS IN WHOLE DEGREES----------DIR5
C WIND SPEED AT 500 MBS IN KNOTS----------------------SPD5
C NOTE.....ABOVE WINDS ARE CONVERTED TO U/V COMPONENTS
C MEAN RELATIVE HUMIDITY 800/600MBS IN PERCENT--------RH
C SHOWALTER STABILITY INDEX IN DEGS C-----------------SI
C
C MO IS NUMERICAL VALUE OF CURRENT MONTH, KDA IS CURRENT DAY.
C
C PREPARED BY C.J. NEUMANN, SPACEFLIGHT METEOROLOGY GROUP, MIAMI, FLA.
C FEBRUARY 1971.  DEPENDENT DATA ARE FROM 1957 THROUGH 1969.
C
      COMMON CNST(5,36)
      DIMENSION MONTH(5)
      DATA MONTH/3HMAY,3HJUN,3HJUL,3HAUG,3HSEP/
      DATA INDEX/1/
C CONSTANTS ARE STORED IN ARRAY ((CNST(I,J),I=1,5),J=1,36) WHERE I IS
C EQUAL TO (MO-4) AND J IS ASSIGNED AS FOLLOWS......
C J=01 THRU J=10---3RD ORDER POLYNOMIAL EVALUATING UV850=F(U8,V8)
C J=11 THRU J=20---3RD ORDER POLYNOMIAL EVALUATING UV500=F(U5,V5)
C J=21 THRU J=24---3RD ORDER POLYNOMIAL EVALUATING RHF=F(RH)
C J=25 THRU J=27---2ND ORDER POLYNOMIAL EVALUATING SIF=F(SI)
C J=28 THRU J=30---2ND ORDER POLYNOMIAL EVALUATING CP=F(DAY)
C J=31 THRU J=36---REGRESSION EQUATION  PROB=F(UV850,UV500,RHF,SIF,CP)
      GO TO(5,18),INDEX
C READ IN 180 CONSTANTS FROM 30 DATA CARDS, SIX TO A CARD
    5 DO 10 KARDS=1,30
   10 READ(5,15)I,K,L,(CNST(I,J),J=K,L)
   15 FORMAT(3X,I1,2I2,6E12.7)
      INDEX=2
C BYPASS IF MONTH IS EARLIER THAN MAY OR AFTER SEPTEMBER.
   18 IF(MO-5)20,30,30
   20 WRITE(6,25)
   25 FORMAT(34H1SYSTEM NOT IN EFFECT UNTIL 1 MAY.)
      RETURN
   30 IF(MO-10)45,35,35
   35 WRITE(6,40)
   40 FORMAT(41H1SYSTEM NOT IN EFFECT AFTER 30 SEPTEMBER.)
      RETURN
C CONVERT WIND TO U/V COMPONENTS
   45 U8=SIN(DIR8*.0174533+3.14159)*SPD8
      V8=COS(DIR8*.0174533+3.14159)*SPD8
      U5=SIN(DIR5*.0174533+3.14159)*SPD5
      V5=COS(DIR5*.0174533+3.14159)*SPD5
      CALL Q(MO,KDA,U8,V8,U5,V5,RH,SI,UV850,UV500,RHF,SIF,PROB,CP,DAY)
      KTIME=ISTART(U8,V8,DAY,PROB)
```

```
C CONVERT PROBABILITIES TO PERCENT AND ROUND OFF TO INTEGER VALUES.
      N1=UV850*100.+0.5
      N2=UV500*100.+0.5
      N3=RHF*100.+0.5
      N4=SIF*100.+0.5
      N5=PROB*100.+0.5
      N6=CP*100.+0.5
C WRITE RESULTS
      WRITE(6,50)KDA,MONTH(MO-4),N6,N1,N2,N3,N4
   50 FORMAT(1H1,/////,6X,37HAFTERNOON (1000-2200EST) THUNDERSTORM/6X,30
     1HPROBABILITY FOR CAPE KENNEDY, ,I2,1X,A3/7X,24HCLIMATOLOGICAL-----
     2-----,I3,8H PERCENT/7X,24H850MB WINDS ONLY---------,I3,8H PERCENT/7
     3X,24H500MB WINDS ONLY--------,I3,8H PERCENT/7X,24HMEAN RH 800/600M
     4B ONLY--,I3,8H PERCENT/7X,24HSTABILITY INDEX ONLY----,I3,8H PERCEN
     5T)
      IF(N5-5)55,65,65
   55 WRITE(6,60)
   60 FORMAT(1H0,5X,44HCOMBINED PROBABILITY IS LESS THAN 5 PERCENT.)
      GO TO 88
   65 IF(N5-95)80,80,70
   70 WRITE(6,75)
   75 FORMAT(1H0,5X,40HCOMBINED PROBABILITY IS OVER 95 PERCENT.)
      GO TO 88
   80 WRITE(6,85)N5
   85 FORMAT(1H0,5X,24HCOMBINED PROBABILITY IS ,I2,9H PERCENT.)
   88 WRITE(6,89)KTIME
   89 FORMAT(1H0,5X,36HIF AN AFTERNOON THUNDERSTORM OCCURS,/1H ,5X,31HTH
     1E ESTIMATED STARTING TIME IS ,I4,3HEST/1H ,5X,24HPLUS OR MINUS TWO
     2 HOURS.)
      IF(NTEST(U8,V8,1,MO-4))100,100,90
   90 JSPD8=SPD8+0.5
      JDIR8=DIR8+0.5
      WRITE(6,95)JDIR8,JSPD8
   95 FORMAT(1H0,5X,18HTHE 850MB WIND OF ,I3,1H/,I2,9H KNOTS IS/6X,35HBE
     1YOND THE BOUNDS OF THE 99 PERCENT/6X,38HELLIPSE DEFINED BY THE DEP
     1ENDENT DATA.)
  100 IF(NTEST(U5,V5,2,MO-4))115,115,105
  105 JSPD5=SPD5+0.5
      JDIR5=DIR5+0.5
      WRITE(6,110)JDIR5,JSPD5
  110 FORMAT(1H0,5X,18HTHE 500MB WIND OF ,I3,1H/,I2,9H KNOTS IS/6X,35HBE
     1YOND THE BOUNDS OF THE 99 PERCENT/6X,38HELLIPSE DEFINED BY THE DEP
     1ENDENT DATA.)
  115 RETURN
      END
```

```
      SUBROUTINE Q(MO,KDA,U8,V8,U5,V5,RH,SI,UV850,UV500,RHF,SIF,PROB,CP,
     1DAY)
C MO IS CURRENT MONTH, KDA IS CURRENT DAY. U8 IS 850MB U-COMPONENT,
C V8 IS 850MB V-COMPONENT. U5 IS 500MB U-COMPONENT, V5 IS 500MB
C V-COMPONENT, RH IS MEAN RELATIVE HUMIDITY IN LAYER 800/600MBS AND SI
C IS THE SHOWALTER STABILITY INDEX.
C
      COMMON CNST(5,36)
      DIMENSION C(10),SMLRH(5)
      DATA SMLRH/12.0,15.0,22.0,35.0,19.0/
      INDEX=1
      X=U8
      Y=V8
C SET-UP 850MB U/V FUNCTION CONSTANTS FOR CURRENT MONTH.
      DO 10 I=1,10
   10 C(I)=CNST(MO-4,I)
      GO TO 25
   15 INDEX=2
      X=U5
      Y=V5
C SET-UP 500MB U/V FUNCTION CONSTANTS FOR CURRENT MONTH.
      DO 20 I=1,10
   20 C(I)=CNST(MO-4,I+10)
C COMPUTE 850 AND 500MB U/V FUNCTIONS.
   25 FZ=C(1)+C(2)*X+C(3)*Y+C(4)*X*Y+C(5)*X*X+C(6)*Y*Y+C(7)*X*X*X
     1+C(8)*X*X*Y+C(9)*X*Y*Y+C(10)*Y*Y*Y
C MODIFY FZ FOR STRONG EASTERLIES
      FZ=FIXFZ(FZ,INDEX,MO-4,X,Y)
      GO TO(30,35),INDEX
   30 UV850=FZ
      GO TO 15
   35 UV500=FZ
C SET UP HUMIDITY CONSTANTS FOR CURRENT MONTH.
      DO 40 I=1,4
   40 C(I)=CNST(MO-4,I+20)
C SET RHF EQUAL TO 0.01 IF RH IS LOW.
      IF(RH-SMLRH(MO-4))41,42,42
   41 RHF=0.01
      GO TO 44
   42 RHF=C(1)+C(2)*RH+C(3)*RH*RH+C(4)*RH*RH*RH
C SET-UP CONSTANTS FOR STABILITY INDEX FUNCTION.
   44 DO 45 I=1,3
   45 C(I)=CNST(MO-4,I+24)
      SIF=C(1)+C(2)*SI+C(3)*SI*SI
C ASCERTAIN THAT PROBABILITIES ARE WITHIN RANGE 0.01 TO 0.99
      UV850=ADJUST(UV850)
      UV500=ADJUST(UV500)
      RHF=ADJUST(RHF)
      SIF=ADJUST(SIF)
C SET-UP CONSTANTS FOR CLIMATOLOGICAL PROBABILITY FUNCTION.
      DO 50 I=1,3
   50 C(I)=CNST(MO-4,I+27)
      DAY=NBRDA(MO,KDA)
      CP=C(1)+C(2)*DAY+C(3)*DAY*DAY
C SET UP CONSTANTS FOR COMBINED PROBABILITY DETERMINATION.
      DO 55 I=1,6
   55 C(I)=CNST(MO-4,I+30)
      PROB=C(1)+C(2)*UV850+C(3)*UV500+C(4)*RHF+C(5)*SIF+C(6)*CP
      RETURN
      END
```

```
      FUNCTION NTEST(U,V,LEVEL,I)
C THIS FUNCTION DETERMINES WHETHER THE 850 AND 500MB OBSERVED WINDS ARE
C BEYOND THE 99 PERCENTILE RANGE OF THE DEPENDENT DATA.
      DIMENSION CT8(5),ST8(5),A8(5),B8(5),XH8(5),YK8(5)
      DIMENSION CT5(5),ST5(5),A5(5),B5(5),XH5(5),YK5(5)
      DATA CT8/.84897,.89180,.98686,.84989,.83772/
      DATA ST8/.52844,.45243,.16160,.52696,.54610/
      DATA A8/33.79,30.58,25.88,26.77,35.78/
      DATA B8/24.06,21.78,18.58,19.26,24.93/
      DATA XH8/-0.120,1.902,2.146,0.061,-2.573/
      DATA YK8/ 0.596,3.257,4.941,4.359, 1.887/
      DATA CT5/.82511,.98741,.97630,.83962,.83772/
      DATA ST5/.56497,.15816,.21644,.54317,.46020/
      DATA A5 /45.06,33.46,28.04,30.72,40.06/
      DATA B5/34.26,25.64,23.18,22.89,27.15/
      DATA XH5/12.336,5.065,2.048,0.995,2.560/
      DATA YK5/-1.539,0.511,1.700,2.202,0.268/
      GO TO(10,20),LEVEL
   10 XPRIME=(U-XH8(I))*CT8(I)+(V-YK8(I))*ST8(I)
      YPRIME=(V-YK8(I))*CT8(I)-(U-XH8(I))*ST8(I)
      SUM=(XPRIME*XPRIME)/(A8(I)*A8(I))+(YPRIME*YPRIME)/(B8(I)*B8(I))
      IF(SUM-1.0)30,30,40
   20 XPRIME=(U-XH5(I))*CT5(I)+(V-YK5(I))*ST5(I)
      YPRIME=(V-YK5(I))*CT5(I)-(U-XH5(I))*ST5(I)
      SUM=(XPRIME*XPRIME)/(A5(I)*A5(I))+(YPRIME*YPRIME)/(B5(I)*B5(I))
      IF(SUM-1.0)30,30,40
C GOES TO 30 IF WIND IS WITHIN OR ON THE 99 PERCENT ELLIPSE
C GOES TO 40 IF WIND IS OUTSIDE 99 PERCENT ELLIPSE
   30 NTEST=0
      RETURN
   40 NTEST=1
      RETURN
      END
```

```
      FUNCTION FIXFZ(FZOLD,INDEX,MOM4,X,Y)
C THIS FUNCTION MAKES SUBJECTIVE CORRECTIONS TO THE 850 AND 500MB WIND
C FUNCTIONS IN THE CASE OF STRONG EASTERLY WINDS.
      GO TO(10,40),INDEX
   10 GO TO(15,20,25,30,35),MOM4
   15 IF(Y+2.0*X+38.9)70,75,75
   20 IF(Y+0.3*X+15.4)70,75,75
   25 IF(-Y+1.6*X+30.4)70,75,75
   30 IF(Y+2.3*X+25.0)70,75,75
   35 GO TO 75
   40 GO TO(45,50,55,60,65),MOM4
   45 IF(Y+0.7*X+22.3)70,75,75
   50 IF(Y+5.0*X+78.9)70,75,75
   55 GO TO 75
   60 IF(Y+4.0*X+59.7)70,75,75
   65 GO TO 75
   70 FIXFZ=0.01
      RETURN
   75 FIXFZ=FZOLD
      RETURN
      END
```

```
      FUNCTION ISTART(V,W,X,Y)
C THIS FUNCTION EVALUATES TSTM STARTING TIME AS A FUNCTION OF THE 850 MB
C WIND COMPONENTS, THE DAY NUMBER AND THE TSTM PROBABILITY
      DIMENSION C(35)
      DATA C        /+.1273831E+2,-.5524785E+2,+.1678743E+2,-.3044658E+1,
     1+.1428297E+0,+.4120300E+0,-.5984368E-1,-.1020633E-2,-.8332961E-3,
     2+.2010301E-5,+.1091247E+1,-.2395890E+0,+.8079287E+0,-.9742853E-2,
     3-.3330773E-2,+.2572378E-4,+.3275030E-2,-.1128065E-5,+.3928772E-4,
     4-.3878205E-3,+.3856991E-1,+.2283849E+0,-.1152510E+1,-.1318092E-2,
     5+.5700343E-2,-.2110866E-6,+.5209711E-2,+.5253384E-4,+.4564636E-5,
     6-.6700146E-3,+.1260419E-1,+.9910755E-2,-.1220748E-3,+.1705095E-3,
     7-.4914740E-4/
      S=C(1)+C(2)*Y+C(3)*Y*Y+C(4)*Y*Y*Y+C(5)*X+C(6)*X*Y+C(7)*X*Y*Y
     1+C(8)*X*X+C(9)*X*X*Y+C(10)*X*X*X+C(11)*W+C(12)*W*Y+C(13)*W*Y*Y
     2+C(14)*W*X+C(15)*W*X*Y+C(16)*W*X*X+C(17)*W*W+C(18)*W*W*Y
     3+C(19)*W*W*X+C(20)*W*W*W+C(21)*V+C(22)*V*Y+C(23)*V*Y*Y+C(24)*V*X
     4+C(25)*V*X*Y+C(26)*V*X*X+C(27)*V*W+C(28)*V*W*Y+C(29)*V*W*X
     5+C(30)*V*W*W+C(31)*V*V+C(32)*V*V*Y+C(33)*V*V*X+C(34)*V*V*W
     6+C(35)*V*V*V
      IF(S.LT.10.0)S=10.0
      IF(S.GT.22.0)S=22.0
C CONVERT S TO CLOCK TIME
      I=S
      B=I
      J=((S-B)*60.)+0.5
      IF(J-60)30,20,20
   20 J=0
      I=I+1
   30 ISTART=I*100+J
      RETURN
      END

      FUNCTION ADJUST(V)
C THIS FUNCTION ADJUSTS PROBABILITIES TO WITHIN ALLOWABLE RANGE
      IF(V)15,15,5
    5 IF(V-0.99)10,10,20
   10 ADJUST=V
      RETURN
   15 ADJUST=0.01
      RETURN
   20 ADJUST=0.99
      RETURN
      END

      FUNCTION NBRDA(MO,KDA)
C THIS FUNCTION COMPUTES THE DAY NUMBER
      DIMENSION MONDA(12)
      DATA MONDA/0,31,59,90,120,151,181,212,243,273,304,334/
      NBRDA=MONDA(MO)+KDA
      RETURN
      END
```

DATA CARD FORMAT FOR ARRAY CNST(5,36)

AS REQUIRED BY PF1970

Column 1 → / Column 80 →

```
MAY10106+.1787416E+0+.1074020E-1+.1365651E-1+.4523660E-3-.1802959E-3+.3397793E-3
MAY10712-.1051838E-4-.3954366E-4+.3376410E-4+.1677435E-5+.1206249E+0+.1080646E-1
MAY11318+.1001964E-1+.2794513E-3-.1012098E-3+.1964561E-3-.1929388E-5-.1095389E-4
MAY11924-.6512555E-5-.1931907E-5+.1037449E+0-.1196854E-1+.4832994E-3-.3570444E-5
MAY12530+.4273235E+0-.7480216E-1+.3056700E-2-.5430778E+0+.6855607E-2-.1053707E-4
MAY13136-.1589528E+0+.5503053E+0+.3738171E+0+.3233246E+0+.5656907E+0+.2053246E-1
JUN20106+.3326784E+0+.2172438E-1+.2162950E-1+.3762057E-3-.6835820E-3+.2579027E-3
JUN20712+.1179004E-5+.1437934E-5-.3373770E-4-.2199710E-4+.2927882E+0+.2638450E-1
JUN21318+.1023307E-1+.3206674E-3+.7055071E-4+.1576005E-3-.3090318E-4-.1422489E-4
JUN21924+.5588606E-5-.9225416E-5+.1350110E+0-.1999291E-1+.8150660E-3-.6342578E-5
JUN22530+.6102192E+0-.8066767E-1+.2403756E-2-.1323037E+0+.1070858E-2+.1208962E-4
JUN23136-.5556250E+0+.6102450E+0+.4851770E+0+.3646010E+0+.3541640E+0+.6391500E+0
JUL30106+.4307867E+0+.4366697E-1+.1055475E-1-.3983282E-4-.3116466E-3-.1888946E-2
JUL30712-.5616631E-4+.7757704E-4-.5417381E-4+.3519052E-4+.4145883E+0+.3166340E-1
JUL31318-.7151265E-3+.5390950E-3+.4251009E-4-.5091109E-4-.2425546E-4+.1581160E-4
JUL31924-.2172134E-4-.1060904E-4-.1029031E+0-.2906759E-2+.4229306E-3-.3308301E-5
JUL32530+.6177575E+0-.6421018E-1+.1310411E-2+.9355280E+0-.3771816E-2+.6918595E-5
JUL33136-.5553775E+0+.6370509E+0+.4154169E+0+.4982033E+0+.4217904E+0+.2361394E+0
AUG40106+.3627524E+0+.3272211E-1+.1085207E-1-.5623188E-4+.1038914E-2-.3726892E-3
AUG40712-.3354727E-4-.1055251E-3-.6772392E-5+.1606764E-4+.3932798E+0+.3119719E-1
AUG41318+.2545731E-2+.1592548E-3+.9662810E-4+.2887853E-4-.3745136E-4-.1717338E-4
AUG41924-.1704165E-4+.4082921E-5+.2562494E+1-.1702073E+0+.3551389E-2-.2161341E-4
AUG42530+.5271789E+0-.3530199E-1-.1094883E-2-.4163536E+0+.1394724E-1-.4493190E-4
AUG43136-.4622971E+0+.6391629E+0+.4061392E+0+.4244231E+0+.5676596E+0+.6062162E-1
SEP50106+.2816768E+0+.1256518E-1+.5804331E-2+.1096534E-3-.2671097E-3+.1469291E-4
SEP50712-.1099520E-4+.2925611E-5+.3228711E-5-.3325703E-5+.2527479E+0+.1084204E-1
SEP51318+.3136786E-2+.1899334E-3-.2175208E-3-.3547892E-4-.5449895E-5-.4427336E-5
SEP51924+.6122512E-5+.5412232E-5+.1736004E+0-.1918291E-1+.6220713E-3-.4414412E-5
SEP52530+.4078606E+0-.6376678E-1+.2571961E-2+.3758034E+1-.2287890E-1+.3598785E-4
SEP53136-.6182956E+0+.5269289E+0+.6065540E+0+.5538999E+0+.4831459E+0+.1294910E+1
```