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REVISED PREDICTION (ESTIMATION) OF CAPE KENNEDY, FLORIDA, WIND SPEED PROFILE

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16. ABSTRACT

The prediction of the wind profile maximum speed at Cape Kennedy, Florida, is made for any selected calendar date. The prediction is based on a normal probability distribution model with 15 years of smoothed input data and is static in the sense that no dynamic principles of persistence or synoptic features are considered. Comparison with similar predictions based on 6 years of data shows the same general pattern, but the variability decreased with the increase of sample size.

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REVISED PREDICTION (ESTIMATION) OF CAPE KENNEDY, FLORIDA, WIND SPEED PROFILE MAXIMA

I. INTRODUCTION

The launching of space vehicles sometimes becomes hazardous because of the wind fields of the atmospheric circulation. Turbulence may be detrimental to the passage of the vehicle. On the other hand, in a macroscopic sense the air flow may be relatively smooth, but the mesoscale environment through which the vehicle flies may contain wind shears between altitude levels that adversely affect the vehicle operations.

This study considers only one small feature of the complex, three dimensional, dynamic vector wind patterns, namely, the static point prediction of the maximum wind speed from the surface through 27 km over Cape Kennedy, Florida on any given calendar date. Direction is ignored. A similar study was prepared (Crutcher and Quinlan, 1964) using 6 years of data. The present work is designed to compare the prediction curves derived from a larger data sample with the curves prepared using the 6 years of data. Support for the project was given to the National Climatic Center (NCC), Environmental Data Service, National Oceanic and Atmospheric Administration, Asheville, North Carolina by the National Aeronautics and Space Administration, Marshall Space Flight Center (MSFC), Huntsville, Alabama.

II. DATA ANALYSIS

The development of prediction techniques requires sets of data which are serially complete. The NCC has prepared for MSFC on a continuing basis a card image tape deck of serially complete wind data for a number of stations. The record for Cape Kennedy contains wind speed and direction in mps at 1 km intervals from the surface through 27 km for the period January 1956 through September 1970. The maximum speed has been extracted from this tape deck for each 0000Z or 0300Z and 1200Z or 1500Z observation at Cape Kennedy for the entire period of record with the exception that February 29 data have been ignored.

Three data sets are defined for this study:

1. The set of 0000Z (0300Z) evening maxima for each period calendar day.
2. The set of 1200Z (1500Z) morning maxima for each period calendar day.
3. The set of daily maxima for each period calendar day irrespective of the time of observation (0000Z or 0300Z and 1200Z or 1500Z combined).

For each calendar day there are 15 morning maxima, 15 evening maxima and 15 daily maxima during January through September, and 14 morning maxima, 14 evening maxima and 14 daily maxima during October, November, and December.

Use of data sets by calendar date prevents contamination of the results from the influence of autocorrelation since wind speeds from one calendar date to the same date one year hence are not correlated. However, from day to day there is autocorrelation. The extent of this autocorrelation and its relationship to the mean speed configuration is not examined here. It is not a problem in this presentation. The 365 subsets comprising the morning, evening or daily data set defined above are therefore independent within themselves but not amongst themselves.

In order to examine departure from normality, the unbiased estimates of the mean, variance, standard deviation, skewness and kurtosis were computed for each subset. Following Cramér (1946), if the sample mean

$$\overline{x} = \frac{1}{N} \sum_i x_i$$

the k-th central sample moment

$$m_k = \frac{1}{N} \sum_i (x_i - \overline{x})^k$$

where N is the total number of observations and x_i is the i-th observation. The sample mean is unbiased, but it is necessary to correct m_k for bias. The unbiased central sample moments, M_k, are

$$M_2 = \frac{N}{N-1} m_2$$

$$M_3 = \frac{N^2}{(N-1)(N-2)} m_3$$

$$M_4 = \frac{N(N^2-2N+3)}{(N-1)(N-2)(N-3)} m_4 - \frac{3N(2N-3)}{(N-1)(N-2)(N-3)} m_2{}^2$$

The unbiased sample variance is M_2, and its square root is the sample standard deviation. The skewness usually is denoted as the square root of β_1,

$$\beta_1^{1/2} = \frac{M_3}{M_2^{3/2}}$$

and the kurtosis

$$\beta_2 = \frac{M_4}{M_2^{2}}$$

The assumption of normality implies that

$$\beta_1^{1/2} = 0$$

and

$$\beta_2 = 3$$

For large samples the skewness and kurtosis are normally distributed. Fisher (1928, 1930) derived the exact relationships for the moments of the distributions, but he points out that convergence to normality as the sample size increases is slow. Snedecor and Cochran (1967) state that the distributions of skewness and kurtosis converge to normality for sample sizes in excess of 150 and 1000, respectively. Tests for departures of a sample distribution from normality on the basis of skewness and kurtosis are therefore unreliable for small samples. Visual inspection of the computed values for each data set, however, indicates that the assumption of normality need not be rejected.

Time plots of the 365 means, variances and standard deviations of each of the three data sets were examined. For a given day, comparison among the three sets indicates close similarity of values of the respective parameters. Sufficient within-day stability is attained so that it is necessary to use only one data set for further analysis. The 0000Z data set was chosen. A lack of stability, however, exists in the between-day variations. This noise is a random component in the time series which results from observer and instrumental error. Smoothing techniques partially eliminate the noise problem.

Panofsky and Brier (1963) discuss several methods of smoothing meteorological data. Harmonic (Fourier) analysis was applied to the 0000Z data sets since wind speeds essentially are periodic over a year. The procedure involves fitting the original data series of 365 discrete points with a finite number of independent sinusoidal functions (harmonics). Since covariances between the independent functions are zero, the sum of the values of all the harmonics at the 365 points will equal the original data series, while the sum of the variances contributed by each harmonic will equal the variance of the original series.

Mathematically, the value x(t) of the data series at point t

$$x(t) = \sum_{t=1}^{N} \frac{x(t)}{N} + \sum_{i=1}^{N/2} [A_i \sin (\frac{2\pi}{P} it) + B_i \cos (\frac{2\pi}{P} it)]$$

where N is the number of data points, i is the harmonic number and P is the fundamental period of oscillation. The coefficients are evaluated from

$$A_i = \begin{cases} \frac{2}{N} \sum_t [x(t)\sin(\frac{2\pi}{P} it)] & 1 \leq i < \frac{N}{2} \\ 0 & i = \frac{N}{2} \end{cases}$$

$$B_i = \begin{cases} \frac{2}{N} \sum_t [x(t)\cos(\frac{2\pi}{P} it)] & 1 \leq i < \frac{N}{2} \\ \frac{1}{N} \sum_t [x(t)\cos(\frac{2\pi}{P} it)] & i = \frac{N}{2} \end{cases}$$

For a given harmonic the terms involving A_i and B_i can be added together such that

$$A_i \sin(\frac{2\pi}{P} it) + B_i \cos(\frac{2\pi}{P} it) = C_i \cos[\frac{2\pi}{P} i(t-t_i)]$$

where

$$C_i = (A_i^2 + B_i^2)^{1/2}$$

and

$$t_i = \frac{P}{2\pi i} \tan^{-1}(\frac{A_i}{B_i}) = \frac{P}{2\pi i} \sin^{-1}(\frac{A_i}{C_i})$$

C_i is the amplitude of the i-th harmonic and t_i is the point at which the i-th harmonic has a maximum value. The variance V_i contributed by the i-th harmonic

$$V_i = \begin{cases} \frac{C_i^2}{2} & 1 \leq i < \frac{N}{2} \\ C_i^2 & i = \frac{N}{2} \end{cases}$$

In this study the 0000Z daily means and the standard deviations of the 0000Z daily means were harmonically analyzed with P = 365 and t varying from 1 to 365. Since data smoothing is the purpose of the analysis, only the first six harmonics were computed. The sum of these six harmonics accounts for .95 of the variance of original series of means and .82 of the variance of the original series of standard deviations. Table 1 summarizes the parameters of the computations. The difference between the smooth curve resulting from the six harmonic sum and the input data curve represents the noise in the data. This difference is not shown.

Table 1. Coefficients, phase and mean of harmonic analyses

Data Set	Harmonic Number	Amplitude (mps)	Time of Maximum (day number)*	Mean of 365 Input Data (mps)
Daily Mean	1	15.69766	36.13114	
	2	2.32495	49.26773	
	3	2.82161	79.46066	
	4	1.19668	31.16127	
	5	1.52883	8.96337	
	6	0.52798	2.35532	35.13644
Daily Standard Deviation	1	6.23563	38.85321	
	2	1.30521	119.08593	
	3	0.18994	39.49409	
	4	0.49745	35.62650	
	5	0.08122	70.93753	
	6	0.85643	37.92681	10.52726

* Day numbers begin with Jan. 1 = 1 and end with Dec. 31 = 365.

III. PREDICTION MODEL

The expected value of the distribution of maximum wind speeds from the surface through 27 km over Cape Kennedy, Florida for a given day is the mean μ_x of the population of wind speeds for the day. Since the value of the population mean is not known, the sample mean $\bar{x}$ is used for the maximum-likelihood estimate of μ_x. The prediction of the chances in 10 that a wind speed will be exceeded is in effect a statement describing the confidence placed in using the sample mean $\bar{x}$ as an estimator of the population mean μ_x.

Assuming that the daily mean wind speeds are normally distributed, the quantity

$$y = \frac{\bar{x}-\mu_x}{\sigma_x/\sqrt{N}}$$

where σ_x is the standard deviation and N is the observation count, is normally distributed with zero mean and unit variance. The cumulative standardized normal probability distribution F(y)

$$F(y) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{y} e^{-y^2/2}\, dy$$

is independent of the true value of the unknown parameter μ_x.

The probability that y is less than or greater than any arbitrary value can be determined from tabulated values of the cumulative standardized normal probability distribution. For example,

$$p(y \leq 1.28) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{1.28} e^{-y^2/2} \, dy = .90$$

and

$$p(y > 1.28) = 1 - p(y < 1.28) = .10$$

Both of these statements mean that in repeated sampling from the same underlying population, nine out of ten values of y will be less than 1.28, and one out of ten values will be greater than 1.28. For prediction purposes,

$$y = \frac{\bar{x} - \mu_x}{\sigma_x / \sqrt{N}} > 1.28$$

or

$$\mu_x < \bar{x} + 1.28 \, (\sigma_x / \sqrt{N})$$

so that the true value μ_x will be less than $\bar{x} + 1.28\,(\sigma_x/\sqrt{N})$ nine out of ten times. The chance of $\bar{x} + 1.28\,(\sigma_x/\sqrt{N})$ being equalled or exceeded is one in ten.

When μ_x is not known, as in the present study, Student's (1925) t distribution is used for prediction. The cumulative Student's t distribution

$$F(t) = \int_{-\infty}^{t} \frac{\left(\frac{N-1}{2}\right)!}{\left(\frac{N-2}{2}\right)!\,\sqrt{\pi N}\,\left(1+\frac{z^2}{N}\right)^{(N+1)/2}}\,dz$$

approaches the standardized normal distribution as N increases without bound. The quantity

$$t = \frac{\bar{x}-\mu_x}{s_{\bar{x}}}$$

where $s_{\bar{x}}$ is the sample standard deviation of the mean values

$$s_{\bar{x}} = \left[\frac{\sum_i (x_i-\bar{x})^2}{N(N-1)}\right]^{1/2}$$

is distributed as Student's t with N-1 degrees of freedom. It involves only the population parameter μ_x and the known sample mean and standard deviation. For prediction purposes,

$$\mu_x < \bar{x} + t s_{\bar{x}}$$

where t is the abscissa value of F(t) corresponding to the desired cumulative probability level for the proper number of degrees of freedom. If, for example, a probability of .90 is chosen and the observation count is 15, the true value μ_X will be less than $\overline{x} + 1.345 s_{\overline{X}}$ nine out of ten times. The chances are one in ten that the value will be greater than $\overline{x} + 1.345 s_{\overline{X}}$.

IV. RESULTS

Table 2 shows the predicted values of wind profile maxima for selected dates at Cape Kennedy, Florida using

$$\overline{x} + t s_{\overline{X}}$$

as the predictor. The values of $\overline{x}$ and $s_{\overline{X}}$ for a given date are the smoothed values resulting from the harmonic analyses. The chances in ten of a predicted wind speed being exceeded are determined by the multiplier t:

Degrees of	Chances in 10 of being exceeded								
Freedom	1	2	3	4	5	6	7	8	9
13	1.350	.870	.538	.259	.000	-.259	-.538	-.870	-1.350
14	1.345	.868	.537	.258	.000	-.258	-.537	-.868	-1.345

Table 2. Smoothed daily means and standard deviations and predicted values of wind profile maxima for selected days

Date	Day Number	Mean (mps)	Standard Deviation (mps)	Chances in 10 for the indicated value (mps) to be exceeded								
				9	8	7	6	5	4	3	2	1
Jan. 4	4	48.03	13.72	30	36	41	44	48	52	55	60	66
	11	49.42	14.16	30	37	42	46	49	53	57	62	68
	18	50.16	14.98	30	37	42	46	50	54	58	63	70
	26	50.47	16.07	29	37	42	46	50	55	59	64	72
Feb. 2	33	50.63	16.78	28	36	42	46	[illegible]	55	60	65	73
	40	50.97	17.00	28	36	42	47	51	55	60	66	74
	47	51.56	16.67	29	37	43	47	52	56	61	66	74
	55	52.37	15.85	31	39	44	48	52	56	61	66	74
Mar. 3	62	52.83	15.11	33	40	45	49	53	57	61	66	73
	69	52.70	14.65	33	40	45	49	53	56	61	65	72
	77	51.52	14.61	32	39	44	48	52	55	59	64	71
	84	49.56	14.90	30	37	42	46	50	53	58	62	70
Apr. 1	91	46.90	15.18	26	34	39	43	47	51	55	60	67
	98	43.80	15.18	23	31	36	40	44	48	52	57	64
	106	40.11	14.65	20	27	32	36	40	44	48	53	60
	113	36.99	13.76	18	25	30	33	37	41	44	49	55
Apr. 30	120	34.10	12.72	17	23	27	31	34	37	41	45	51
	128	31.14	11.63	15	21	25	28	31	34	37	41	47
	135	28.86	10.93	14	19	23	26	29	32	35	38	44
	142	26.88	10.41	13	18	21	24	27	30	32	36	41
May 29	150	25.03	9.75	12	17	20	23	25	28	30	33	38
	157	23.81	8.89	12	16	19	22	24	26	29	32	36
	164	22.97	7.65	13	16	19	21	23	25	27	30	33
	172	22.46	5.93	14	17	19	21	22	24	26	28	30
June 28	179	22.39	4.49	16	18	20	21	22	24	25	26	28
	186	22.61	3.34	18	20	21	22	23	23	24	26	27
	193	23.08	2.99	19	20	21	22	23	24	25	26	27
	201	23.79	3.19	20	21	22	23	24	25	26	27	28
July 27	208	24.43	3.69	19	21	22	23	24	25	26	28	29
	215	24.88	4.15	19	21	23	24	25	26	27	28	30
	223	24.89	4.29	19	21	23	24	25	26	27	29	31
	230	24.28	4.02	19	21	22	23	24	25	26	28	30
Aug. 25	237	23.10	3.59	18	20	21	22	23	24	25	26	28
	244	21.56	3.35	17	19	20	21	22	22	23	24	26
	252	19.93	3.68	15	17	18	19	20	21	22	23	25
	259	19.21	4.64	13	15	17	18	19	20	22	23	25
Sept. 23	266	19.65	6.07	11	14	16	18	20	21	23	25	28
	274	21.83	7.88	11	15	18	20	22	24	26	29	32
	281	25.02	9.21	13	17	20	23	25	27	30	33	37
	288	28.87	10.10	15	20	23	26	29	31	34	38	43
Oct. 23	296	33.17	10.61	19	24	27	30	33	36	39	42	47
	303	36.14	10.85	21	27	30	33	36	39	42	46	51
	310	38.01	11.17	23	28	32	35	38	41	44	48	53
	318	38.87	11.83	23	29	33	36	39	42	45	49	55
Nov. 21	325	38.98	12.63	22	28	32	36	39	42	46	50	56
	332	39.09	13.43	21	27	32	36	39	43	46	51	57
	339	39.72	13.99	21	28	32	36	40	43	47	52	59
	347	41.34	14.17	22	29	34	38	41	45	49	54	60
Dec. 20	354	43.42	13.99	25	31	36	40	43	47	51	56	62
	361	45.72	13.73	27	34	38	42	46	49	53	58	64
	4	48.03	13.72	30	36	41	44	48	52	55	60	66

Note that 14 degrees of freedom are used for January 1 through September 30 and 13 degrees of freedom are used for October 1 through December 31 since the period of record examined is January 1, 1956 through September 30, 1970.

The information given in Table 2 is also presented in graphic form on Figure 1. Comparison with the earlier analysis based on 1956-1961 data (Figure 2) shows considerable smoothing with the increased sample. The large day to day variability in the curves for the shorter period of record is a reflection of the unusually high wind speeds encountered during the late 1950's.
Increasing the data sample to 15 years of record has the effect of reducing the influence of the extreme maximum winds.

The profile maxima wind speeds observed in 1971 are also shown on Figures 1 and 2. If the model is a good predictor, about 37 observations in a year should fall above the 1 chance in 10 curve and about 37 should fall below the 9 chance in 10 curve. Using 1971 data as a test, the 1956-61 set of curves provides a better fit than the 1956-70 curves. It appears that wind speeds in 1971 are similar to those in the late 1950's, i.e., they are unusually high, especially in the summer. It is important to keep in mind, however, that the test data are autocorrelated whereas the model is not. Thus, once a regime of high wind speeds starts, it will tend to continue until another weather pattern starts operating.

Some similarities exist between the curves derived from 6 years of data and the ones using 15 years of data. Most noticeable are the

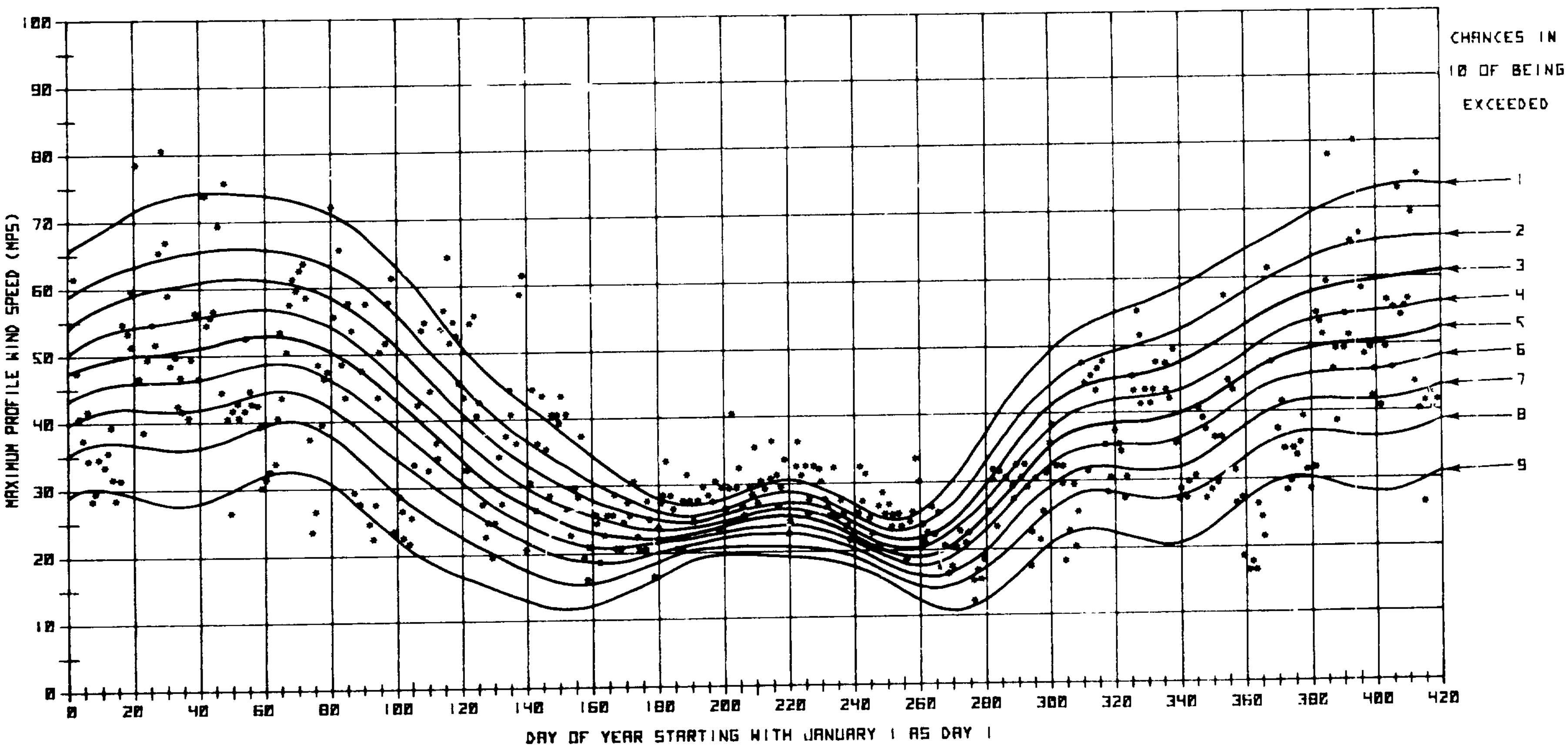

FIG 1 CAPE KENNEDY, FLA , PROFILE WIND SPEED MAXIMA SHOWING THE CHANCES IN 10 FOR A MAXIMUM SPEED TO BE EXCEEDED BASED ON PERIOD 1956-70
OBSERVED WIND SPEEDS FOR 1971 ARE INDICATED BY *

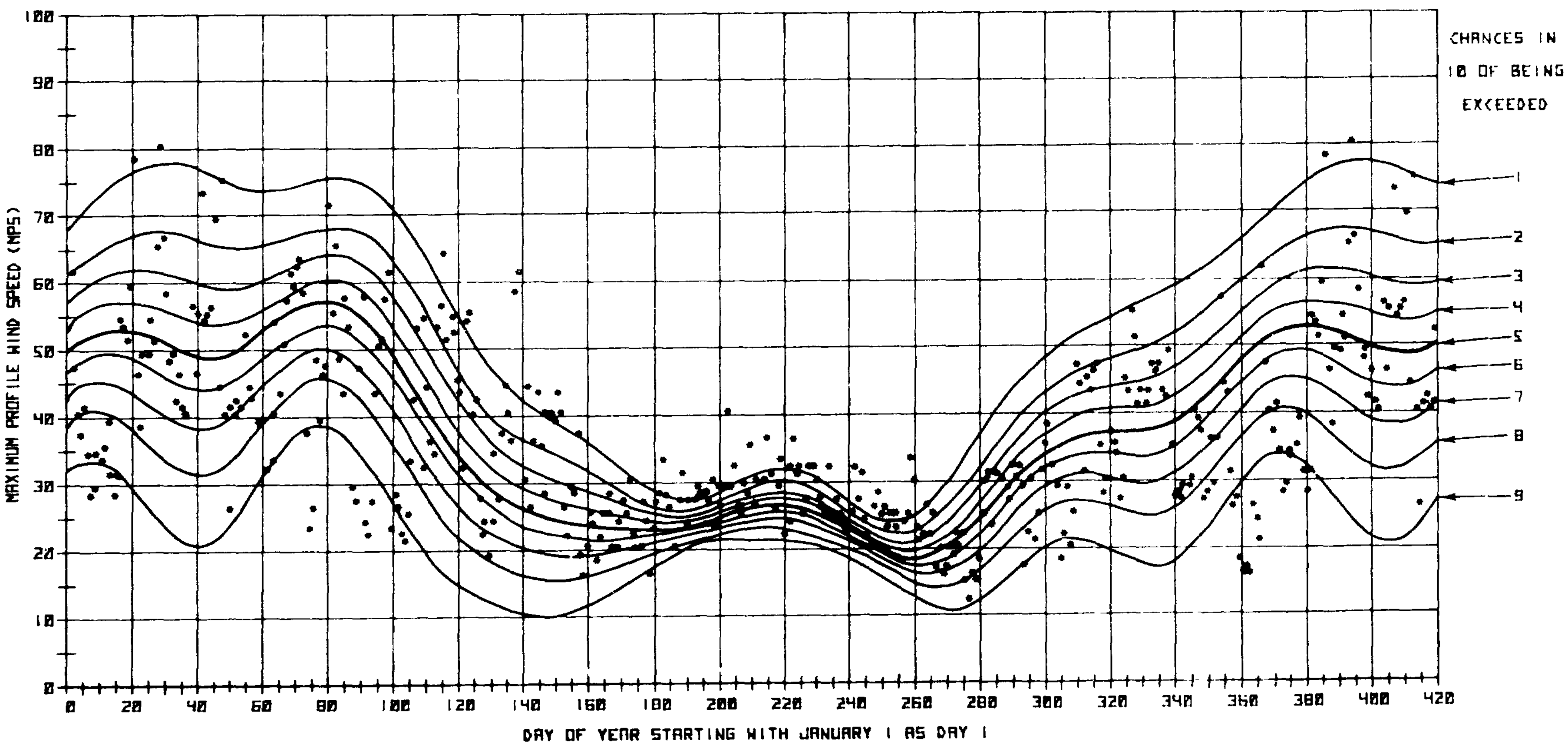

FIG 2 CAPE KENNEDY, FLA., PROFILE WIND SPEED MAXIMA SHOWING THE CHANCES IN 10 FOR A MAXIMUM SPEED TO BE EXCEEDED BASED ON PERIOD 1956-61
OBSERVED WIND SPEEDS FOR 1971 ARE INDICATED BY *

double minima during the summer season. The profile maximum wind speed is lowest at the end of June and also at the end of August. A summertime peak occurs at the end of July. The highest wind speeds are found in March with a secondary peak occurring in January. It seems apparent that cyclic phenomena other than that with an annual period are operating in the climatic regime over Cape Kennedy.

It is also interesting to note that the variability of the winds is greater in the winter than in the summer months. The coefficient of variability (the sample standard deviation expressed as a percentage of the sample mean) is approximately 30% in winter compared to 15% in summer. The precision of a forecast is therefore greater during the warmer months when the wind speeds are low. Unfortunately, design engineers are often concerned with the high wind speeds that occur during the colder months when the forecast is not as precise.

V. CONCLUSIONS

Prediction of the wind profile maximum speed at Cape Kennedy, Florida has been made for any selected calendar date. The prediction is based on a normal probability distribution model with 15 years of smoothed data as input. Comparison with similar predictions based on 6 years of data shows the same pattern, but the variability decreases as the sample size increases. Confidence in the prediction based on 15 years of data is therefore greater than the confidence that can be placed in the results of the earlier study. Based on the 1971 test data, sufficient statistical stability still has not been obtained. It is recommended that the study be repeated when an additional 7 years of data become available.

The model presented is static in the sense that no dynamic principles of persistence or synoptic features are considered. Improvement in the prediction scheme could probably be made if such features as climatic cycles, trends and persistence are included. Analysis of these features is reserved for future study.

VI. ACKNOWLEDGMENTS

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