THE FLORIDA STATE UNIVERSITY

COLLEGE OF ARTS AND SCIENCES

STATISTICS OF WIND SPEED OVER THE OCEANS

by

EDGAR G. PAVIA-LOPEZ

A Thesis submitted to the
Department of Meteorology
in partial fulfillment of the
requirements for the degree of
Master of Science

Approved:

Professor Directing Thesis

December 1985

December, 1985

Abstract

The probability distribution of wind speed data over the world's oceans is studied using a two parameter Weibull distribution. The parameters are estimated following a linearized least-squares approach. The seasonal and latitudinal variation are described. A bootstrap statistical stability criterion is developed to select the appropriate method to estimate the Weibull parameters A and C. The method with the most stable estimate of parameters gives acceptable goodness-of-fit values. The Kolmogorov-Smirnov test also shows that the distribution adequately fits the data.

The seasonal and latitudinal variations are presented using Hovmöller diagrams of the Weibull parameters. In general, these diagrams showed a seasonal change in fair agreement with other independent estimates of wind speed statistics. The results are more reliable in the Northern Hemisphere because more adequate data are available. The uneven geographical distribution, and the scarcity of data at high latitudes and the Southern Hemisphere, do not permit precise determination of Weibull statistics and remain unsolved problems.

PARENTIBVS CARIS PIVS FILIVS

To my mother.
To the memory of my father.

iii

ACKNOWLEDGEMENTS

This work was supported by the National Science Foundation Grants OCE 8119052 and OCE 8415986.

I wish to express my gratitude to my major professor Dr. J. J. O'Brien. His guidance and encouragement throughout the last two years made possible for me to finish my studies at FSU. I thank Dr. D. W. Stuart, Dr. S. Stage and Dr. J. Ahlquist for serving in my M.S. committee. Sincere appreciation is extended to my collegues of the Mesoscale Air-Sea Interaction Group for their criticisms and suggestions for this thesis. Especially I would like to thank Dr. Benoit Cushman-Roisin for suggesting the approach used to estimate the Weibull parameters. The help provided by Jim Merritt with computer programming is highly appreciated. Also, I wish to thank Rita Kuyper for typing the different versions of this thesis, and Ricky Chapman for reviewing part of the early draft.

Finally, I would like to thank Manuel Lopez and Alejandro Pares for all their help during my studies at FSU, and the rest of my friends at the Departments of Meteorology and Oceanography of FSU for making my stay in Tallahassee a most enjoyable one.

TABLE OF CONTENTS

	Page
ABSTRACT	ii
DEDICATION	iii
ACKNOWLEDGEMENTS	iv
TABLE OF CONTENTS	v
LIST OF TABLES	vi
LIST OF FIGURES	vii
1. INTRODUCTION	1
a. THE WIND SPEED DATA	4
2. THE STATISTICAL METHOD	8
a. THE WEIBULL DISTRIBUTION	8
b. ESTIMATION OF THE PARAMETERS	12
3. DISCUSSION OF THE CLIMATOLOGICAL RESULTS	18
4. CONCLUSIONS	29
REFERENCES	31
APPENDIX	33

LIST OF TABLES

		PAGE
Table I.	Summary of the average number of data used at each bin per month.	7
Table II.	Results of the bootstrap statistic stability test.	17
Table A1.	The value of the Weibull parameters: A [m s^{-1}] and C. January 1983.	34
Table A2.	Same as Table A1, but for February 1983.	35
Table A3.	Same as Table A1, but for March 1983.	36
Table A4.	Same as Table A1, but for April 1983.	37
Table A5.	Same as Table A1, but for May 1983.	38
Table A6.	Same as Table A1, but for June 1983.	39
Table A7.	Same as Table A1, but for July 1983.	40
Table A8.	Same as Table A1, but for August 1983.	41
Table A9.	Same as Table A1, but for September 1983.	42
Table A10.	Same as Table A1, but for October 1983.	43
Table A11.	Same as Table A1, but for November 1983.	44
Table A12.	Same as Table A1, but for December 1983.	45

LIST OF FIGURES

		PAGE
Figure 1.	Locations where wind speed observations were reported during January 1983.	6
Figure 2.	The shape of the pdf for different values of the Weibull parameter C.	9
Figure 3.	The points used to fit the Weibull distribution. Note that in Method I the points are evenly spaced in the ordinate axis. In Method II the points are evenly spaced in the abscissa axis.	15
Figure 4.	Hovmöller diagram of the Weibull parameter A for the Atlantic Ocean. Note that 3 months are repeated at both ends of the ordinate axis.	20
Figure 5.	Hovmöller diagram of the Weibull parameter C for the Atlantic Ocean. M = Maximun, m = minimun.	21
Figure 6.	Hovmöller diagram of the Weibull parameter A for the Eastern Pacific Ocean.	22
Figure 7.	Hovmöller diagram of the Weibull parameter C for the Eastern Pacific Ocean.	23
Figure 7. Hovmöller diagram of the Weibull parameter C for the Eastern Pacific Ocean. 23

Figure 8. Hovmöller diagram of the Weibull parameter A for the Western Pacific Ocean. 25

Figure 9. Hovmöller diagram of the Weibull parameter C for the Western Pacific Ocean. 26

Figure 10. Hovmöller diagram of the Weibull parameter A for the Indian Ocean. 27

Figure 11. Hovmöller diagram of the Weibull parameter C for the Indian Ocean. 28

1. Introduction

The importance of the distribution of wind speed over the ocean has been recognized since people first ventured onto the sea. The wind force was of primary interest in the days of sailing ships, as sails were set according to it. Thus in the early nineteenth century, Beaufort proposed a scale of wind force based on the amount of canvas that a full-rigged frigate could carry (Höflich, 1984). Later, the numbers in the Beaufort scale were related to the effect of the wind on the sea surface. Beaufort estimates of the wind have been taken by ships for many years over all oceans. More recently these estimates are being replaced by measurements of wind speed; i.e. observations using an anemometer. This does not necessarily mean a better estimate, since the ship itself disturbs the wind field (Höflich, 1984).

These ship observations have been used for climatological studies (e.g. Hellerman and Rosenstein, 1983) and to compose climatological charts of wind speed over the oceans (e.g. Gorshkov, 1974a, 1974b; van Loon, 1984).

In recent years a great deal of effort has been devoted to the effect of winds on the ocean. An excellent bibliography of works on this subject has been compiled by Witte (1984). The general

effect of winds on the ocean. An excellent bibliography of works on this subject has been compiled by Witte (1984). The general

consensus is that often adequate data are not available. Thus the use of satellites to measure winds represents the most possible solution to the wind data problem.

After a series of wind speed observations has been taken we can present the results as a histogram; i.e., as a plot of wind speed against relative frequency. Theoretically if the wind speed intervals are made smaller and smaller, the histogram becomes the probability density function (pdf). With a continuous function as an expression for the histogram we can obtain other statistical quantities analytically; i.e., the moments of a pdf. A practical way to obtain a pdf is by fitting a curve to the histogram. In the case of wind speed a Gaussian or Rayleigh distribution curve does not always give good results. A better idea is to use a Weibull distribution (see Gumbel, 1958). This is a more general model in which the Gaussian and Rayleigh distributions are just special cases. The advantages of the two-parameter Weibull model have been pointed out by Justus et al. (1976) and Justus et al. (1978). Other three-parameter Weibull models have also been suggested (Stewart and Essenwanger, 1978; and Takle and Brown, 1978); but for the purpose of this study they were not considered.

The first Atlas of wind using the Weibull distribution was done for Denmark by Petersen et al. (1981). This Atlas is especially suited for wind power assessment. Also, Stewart and Essenwanger (1978) estimated the Weibull parameters for 45 land stations

suited for wind power assessment. Also, Stewart and Essenwanger (1978) estimated the Weibull parameters for 45 land stations

throughout the Northern Hemisphere. However, as pointed out by Jensen *et al.* (1984), the variation of the Weibull parameters with latitude has not been investigated.

The purpose of this paper is to estimate the Weibull parameters for the wind speed data over the world's oceans and discuss their seasonal and latitudinal variation.

There are several methods to estimate the Weibull parameters. A review of different procedures and a measure of their efficiency is given by Conradsen *et at.* (1984). We first tried a non linear least squares approach and an iterative minimization procedure. The iterative method did not improve significantly our results. In some cases we found convergence problems and therefore this procedure was not used. We propose a new criterion in the selection of a method to estimate the Weibull parameters. This criterion uses a bootstrap technique (See Efron, 1982) to estimate the variance of the parameters. We then define the statistical stability of a method as inversely proportional to the variance of the parameters.

In section 2 we review the Weibull statistics and describe the selection procedure of the method used to estimate the Weibull parameters.

In section 3 we discuss the latitudinal and seasonal variation of the parameters.

In the last section we discuss the conclusions of this investigation.

In the last section we discuss the conclusions of this investigation.

a. The wind speed data

In this study we consider the wind speed observations made by ships all over the world during 1983. We obtained the original data set from the NOAA National Climate Center and it was stored by month on magnetic tape. These monthly files consist of thousands of observations unevenly distributed geographically. Fig. 1 shows the locations where observations were reported during a typical month. The high density along commercial routes and at low and middle latitudes in the Northern Hemisphere is a notable feature in all months. Observations over land constitute erroneous reports of position; they are less than one percent and are typical of errors in this data set.

We sorted the data into 90° longitude by 5° latitude bins. The world is roughly divided in four oceans: Indian Ocean, from 30°E to 120°E; Western Pacific Ocean, from 120°E to 150°W; Eastern Pacific Ocean, from 150°W to 60°W and Atlantic Ocean, from 60°W to 30°E. Due to the sparse data samples at high latitudes we restricted our study from 50°S to 60°N (Indian Ocean from 50°S to 25°N). We excluded all values above 40 m s^{-1} (not many) and the observations in excess of 1500 in each bin. We considered 1500 observations to be a representative sample. A bigger array is not computationally

1500 in each bin. We considered 1500 observations to be a
representative sample. A bigger array is not computationally

convenient, especially for the sorting routine. A summary of the average number of data used at each bin is given in Table I. The numbers in this summary also include the reports of calm conditions; i.e., all wind speed values between 0 and 40 ms^{-1}.

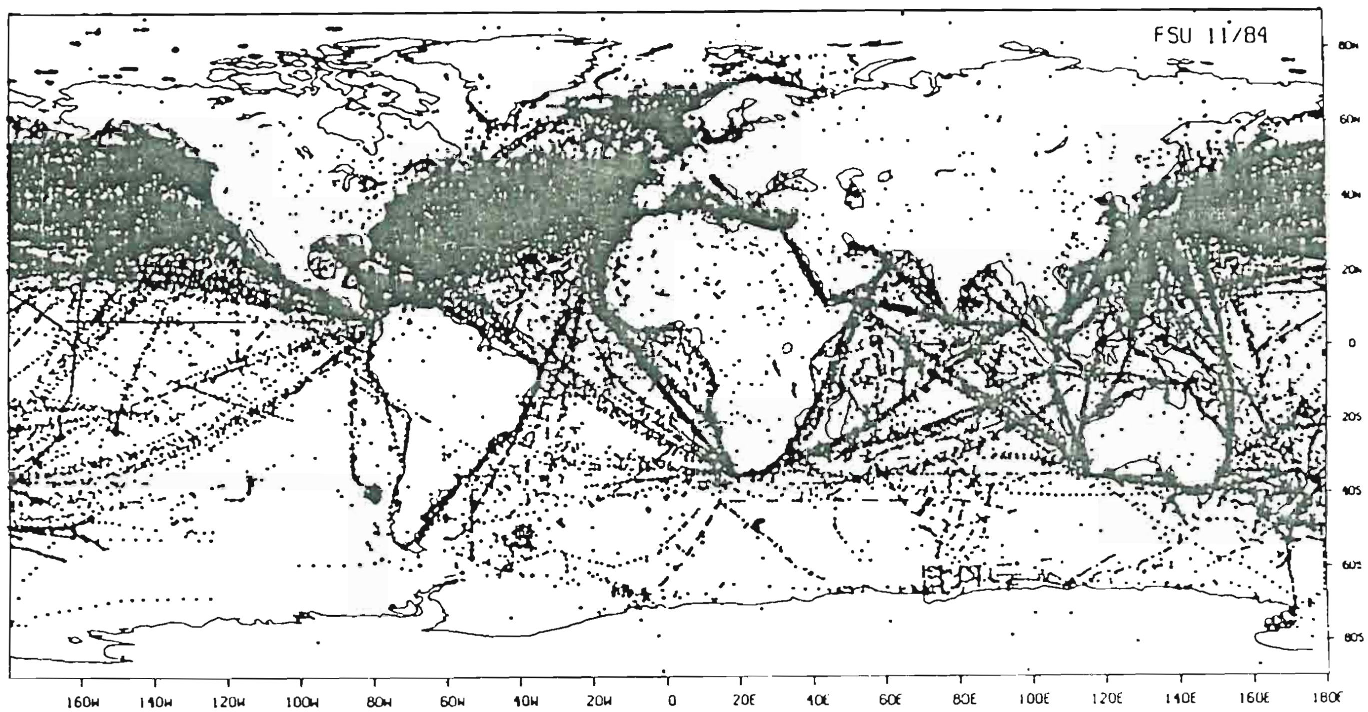

Figure 1.- Locations where wind speed observations were reported during January 1983.

Table I. Average number of data used at each bin per month.

	Indian O. 30°E-120°E		W. Pacific O. 120°E - 150°W		E. Pacific O. 150°W-60°W		Atlantic O. 60°W-30°E	
	N	S	N	S	N	S	N	S
0°-5°	866	444	422	234	252	166	1126	390
5°-10°	1500	498	548	375	529	360	862	432
10°-15°	1500	465	548	637	252	264	686	424
15°-20°	1438	555	827	424	1500	300	813	679
20°-25°	1066	647	1166	404	1500	132	1487	593
25°-30°	-	652	1500	321	1500	110	1484	527
30°-35°	-	514	1500	529	1500	75	1500	892
35°-40°	-	346	1500	1143	1500	227	1500	675
40°-45°	-	97	1500	385	1500	237	1500	434
45°-50°	-	65	1500	230	1500	121	1500	180
50°-55°	-	-	1500	-	1500	-	1500	-
55°-60°	-	-	875	-	1260	-	1500	-

2. The Statistical Method

a. The Weibull distribution

The Weibull pdf of a random variable V, with parameters A and C, is expressed mathematically as

$$f(V;\ A,\ C) = (C/A)\ (V/A)^{C-1}\ \exp\left(-(V/A)^{C}\right) \qquad (1)$$

where

$$V \geq 0,\ A>0,\ C>0.$$

In this case V [ms^{-1}] is wind speed, A [ms^{-1}] is a scaling parameter and C is a dimensionless shape parameter. For $C<1$ the function decreases monotonically, $C=1$ gives an exponential distribution with mean value A. For $C>1$ the function has a maximum away from the origin, $C=2$ is the Rayleigh distribution (Hennessey, 1977) and $C=3.6$ yields an approximation to a Gaussian distribution (Fig. 2). The cumulative distribution function (cdf) is obtained by integrating (1):

$$F(V;\ A,\ C) = 1 - \exp\left(-(V/A)^{C}\right). \qquad (2)$$

Other statistical quantities are given in terms of the parameters; i.e., the mean value:

$$\overline{V} = A\ \Gamma(1 + 1/C), \qquad (3)$$

variance:

$$\sigma^2 = A^2\left(\Gamma(1 + 2/C) - \Gamma^2(1 + 1/C)\right), \qquad (4)$$

variance:

$$\sigma^2 = A^2\left(\Gamma(1 + 2/C) - \Gamma^2(1 + 1/C)\right), \qquad (4)$$

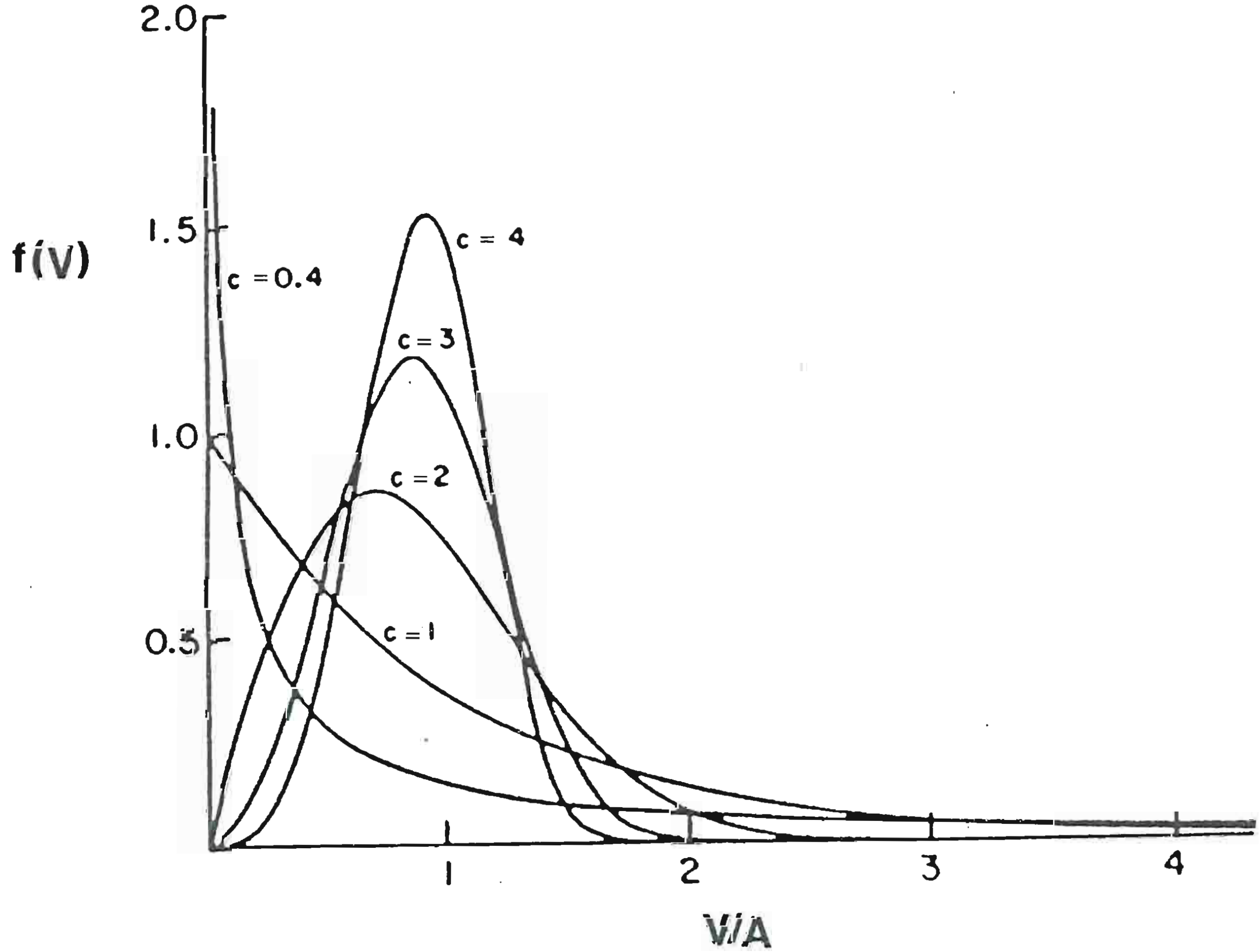

Figure 2.- The shape of the pdf for different values of the Weibull parameter C.

mean nth power:

$$\overline{V^n} = A^n \, \Gamma(1 + n/C), \tag{5}$$

modal value:

$$M_0 = A((C - 1)/C)^{1/C}, \tag{6}$$

median:

$$M_1 = A(\ln 2)^{1/C} \tag{7}$$

and skewness:

$$\gamma = [\Gamma(1 + 3/C) - 3\Gamma(1 + 1/C)\,\Gamma(1 + 2/C) + 2\Gamma^3(1 + 1/C)]/[\Gamma(1 + 2/C) - \Gamma^2(1 + 1/C)]^{3/2} \tag{8}$$

where $\Gamma(x)$ is the gamma function defined by:

$$\Gamma(x) = \int_0^\infty t^{x-1} \exp(-t)\,dt. \tag{9}$$

Tables of gamma functions for $1 \leqslant x \leqslant 2$ and recurrence formulas are given by Abramowitz and Stegun (1970).

A special property of the Weibull distribution is that if V is Weibull distributed then V raised to the power m is also Weibull distributed with shape parameter C/m and scale parameter A^m. This property is important since we could apply a power transformation to non-Gaussian data by selecting

$$m = C/3.6,$$

and now V^m will have an approximate Gaussian distribution. This approach has been used by Brown et al. (1984).

and now V^m will have an approximate Gaussian distribution. This
approach has been used by Brown et al. (1984).

It is important to note that the pdf of wind speed in an isotropic situation would have a shape parameter C = 2 (Hennessey, 1977), i.e., a Rayleigh distribution. This is the distribution of the magnitude of a two-dimensional vector with independent components when each follows a Gaussian distribution with zero mean and variance $A^2/2$. In many meteorological situations, such as in the trades, certain wind directions are preferred and thus, the value of C is often different from, but close to two. Therefore $C \neq 2$ is a measure of the departure of V from isotropic conditions.

Also note that for a fixed A, C=2 will produce a minimum mean value, because the gamma function reaches a minimum at $\Gamma(1.5)$.

b. Estimation of the parameters.

There are several methods to estimate the Weibull parameters A and C. A comparison of different methods is given by Justus et al. (1978); a more comprehensive review of Weibull statistics has recently appeared (Conradsen et al., 1984).

In our case we follow a least-squares approach. In order to obtain a linear problem we take twice the logarithm of (2) and then minimize an expression of the form:

$$\sum_{j=1}^{K} \varepsilon^2 = \sum_{j=1}^{K} \left[\ln(A^{-C}) + C \ln V_j - b_j\right]^2, \qquad (10)$$

where K is the number of points we use to fit the curve. Using (2) we can determine that

$$b_j = \ln(-\ln[1 - F(V_j)]). \qquad (11)$$

Note that this approach actually fits the cdf to the ogive which is analogous to fitting the pdf to the histogram. Estimations of the goodness-of-fit given by this procedure show highly acceptable values; previous estimations of the goodness-of-fit in similar cases have also shown good results (e.g., Justus et al., 1976).

We also consider the stability of the method to estimate the Weibull parameters, simply because different methods give different results. A stable method is one which yields minimum variance-unbiased parameters. We are particularly concerned with the results. A stable method is one which yields minimum variance-unbiased parameters. We are particularly concerned with the fact that two different methods can give different values for the

Weibull parameters and still adequately fit the data. A measure of stability can be obtained by means of a bootstrap technique similar to the one described by Diaconis and Efron (1983). We use a representative set (S) of wind speed data to implement the bootstrap stability method. From S we randomly select M bootstrap sample subsets (X_i; i = 1, 2, ..., M) and estimate A_i and C_i. Each bootstrap sample subset consists of an N-data random sample drawn independently with replacement and with equal probability. The stability of the Weibull method is inversely proportional to the variance of A_i and C_i [$\sigma^2(A)$ and $\sigma^2(C)$]. We may also calculate the average goodness-of-fit:

$$\overline{\Delta\varepsilon} = 1/M \sum_{i=1}^{M} \Delta\varepsilon_i ,$$

where $\Delta\varepsilon_i$ is the individual goodness-of-fit given by A_i and C_i for the subset X_i, and which numerical value is given by:

$$\Delta\varepsilon_i = 1 - \left(1/K \sum_{j=1}^{K} \varepsilon_j^2\right)$$

The efficiency of the method is defined as the ratio between the average goodness-of-fit and the variance of the parameters. The higher the ratio means the better efficiency and the better the method.

In this case S consists of 3000 wind speed observations randomly selected from a high density region. The number M of bootstrap samples is 10000 and their size N is 200 individual wind speed values. The idea behind the bootstrap technique is that
bootstrap samples is 10000 and their size N is 200 individual wind speed values. The idea behind the bootstrap technique is that
it is preferable that these numbers M and N be as large as possible.

Three preliminary tests of this technique did not show a significant difference for bigger M and N ($2x10^6 < MxN < 1x10^7$); but the results were different for smaller M and N ($MxN = 1x10^5$).

This bootstrap method to determine the best procedure is important, since we are interested in the seasonal variation of the Weibull parameters; because the emphasis is put in the determination of the value of A and C and their variability. We do not expect a large seasonal or latitudinal variation in the parameters, thus we should try to estimate them as accurately as possible.

We first tested two Weibull least-squares methods for stability. Method I uses the wind speed values between 10% classes in the ogive; i.e., $F(V_j) = j/10$ for V_j between classes jth and (j+1)th. Then (11) becomes:

$$b_j = \ln(-\ln[1 - j/10]),\ j = 1, 2, \ldots, K=9.$$

Method II uses fixed values for V_j, e.g. $V_j = j \cdot x$ [ms^{-1}] (j = 1, 2, ..., K). Therefore $F(V_j) = n_j/N$, where n_j is the number of outcomes up to V_j; i.e., the number of wind speed values between $V_o = 0$ and V_j, and N is the size of X_i. Now (11) becomes:

$$b_j = \ln(-\ln[1 - n_j/N]),\ j = 1, 2, \ldots, K.$$

Method II is similar to the procedure for grouped data given by Conradsen <u>et al.</u> (1984). The difference between the two methods is that in Method I $F(V_j)$ is uniformly spaced and V_j is variably spaced, in Method II $V_{j+1} - V_j$ is constant and $F(V_j)$ vary. (See Fig. 3).
spaced, in Method II $V_{j+1} - V_j$ is constant and $F(V_j)$ vary. (See Fig. 3).

The bootstrap results showed greater stability for Method II. This suggests that the parameters depend greatly on the highest

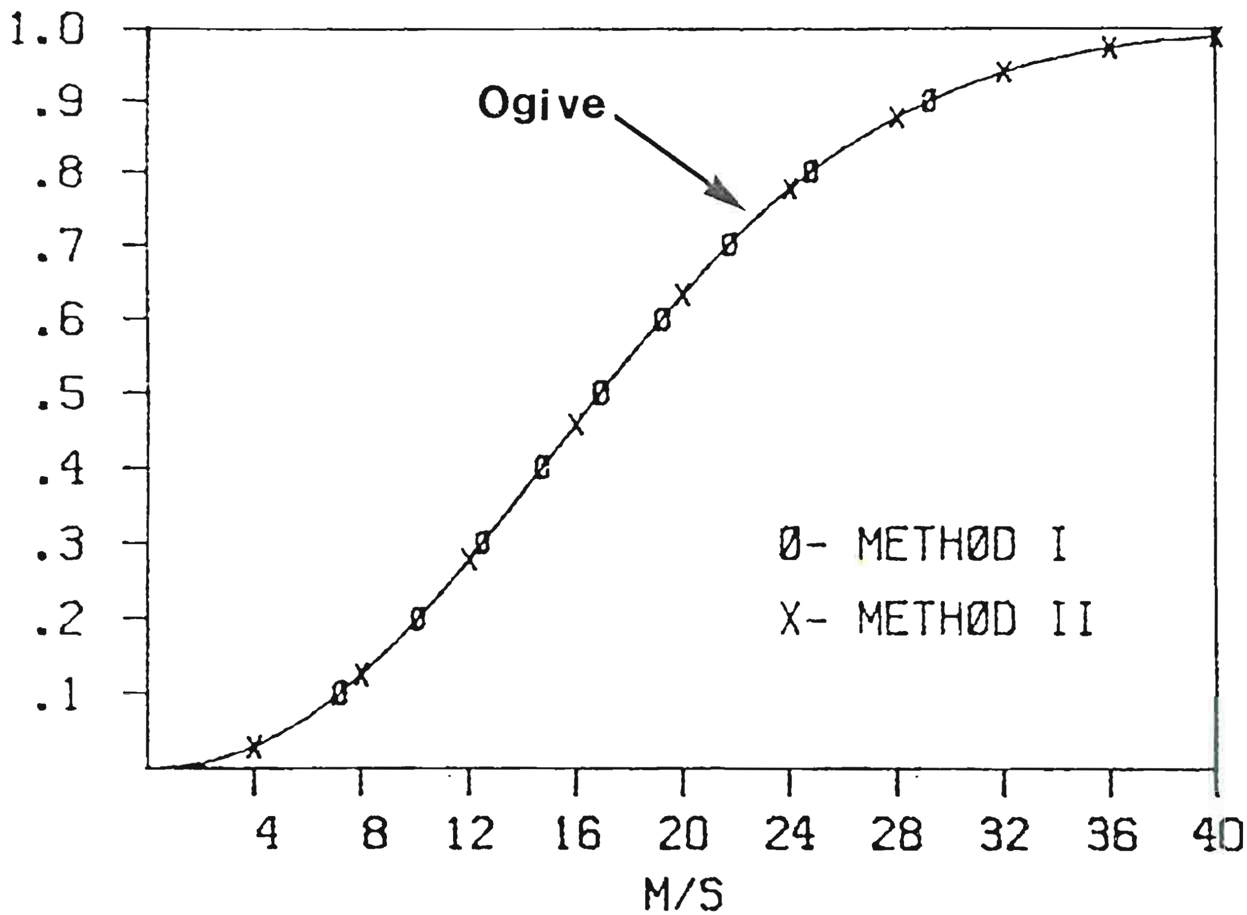

Figure 3.- The points used to fit the Weibull distribution. Note that in Method I the points are evenly spaced in the ordinate axis; in Method II the points are evenly spaced in the abscissa axis.

values. However Method I gave slightly better goodness-of-fit estimations. The advantage of Method I is that all nine points it uses are within the lowest 90% of the data (where Method II normally uses only six or seven points). The disadvantage of Method I is that it can not consider any data in the highest 10% of the sample (Method II considers at least one estimate).

These results suggest a third method. In Method III we use the first 95% of the data in the ogive. The highest value of this sub-sample is used to make 10 groups; i.e. $V_j = j \cdot (V_M/10)$, j = 1, 2, ..., K = 10, where V_M is the speed at the 95% point. $F(V_j)$ is then calculated as in the second case. Method III uses both: variable V_j and variable $F(V_j)$, and can be regarded as a combination of the two previous methods. Method III gave the best bootstrap results; i.e. better stability which means smaller standard deviations and higher efficiency, and therefore was chosen to perform the calculations on the global wind speed data (see Table II). However the Kolmogorov-Smirnov test (see Ostle, 1963) showed that any of the three methods adequately fits the data. The same statistical test in a previous case also gave similar results (Justus et al., 1976) for wind speed data over land.

The data included $0 \leq V \leq 40$ ms^{-1}. We decided to include the reports of calm conditions in the estimation of the parameters. We considered these low wind speed data to be representative of each sample. The effect of the calms on the Weibull distribution has
considered these low wind speed data to be representative of each sample. The effect of the calms on the Weibull distribution has
been discussed by Conradsen et al. (1984) and Takle and Brown (1978).

Table II. Results of the bootstrap statistical stability test

	Method I	Method II	Method III
$\sigma^2(A)$	2.56	1.96	1.21
$\sigma^2(C)$	3.24×10^{-2}	2.59×10^{-2}	2.52×10^{-2}
$\overline{\Delta\varepsilon}$	.9927	.9921	.9925
$E_{ff}(A)$	.39	.51	.82
$E_{ff}(C)$	31	38	39
Efficiency $E_{ff}(A,C)$	12.1	19.4	32.0

Note: $E_{ff}(A) = \overline{\Delta\varepsilon}/\sigma^2(A)$, $E_{ff}(C) = \overline{\Delta\varepsilon}/\sigma^2(C)$

and $E_{ff}(A,C) = E_{ff}(A) \times E_{ff}(C)$.

3. Discussion of the Climatological Results

The results are presented using Hovmöller diagrams (HD) of A and C (Figs. 4-11). These diagrams have a notable general feature. Both parameters clearly show seasonal changes; from high values during the winter to low values during the summer, in both Southern and Northern Hemispheres. Particular details of this variation are discussed separately for each ocean.

A very complete discussion of the climates of the oceans can be found in van Loon (1984). The climatic features of the wind speed over the oceans are well described and the reader is referred to that work for particular details.

There are no climatological studies of Weibull parameters over the ocean. However, Jensen et al. (1984) give expected values of the shape parameter. For the Arctic and near the Equator, $C \sim 1$; for temperate latitudes, $C \sim 2$; for persistent wind zones, $C \sim 3$; and in general $1.5<C<2.5$.

For most values of C found in this study ($1<C<2.5$) A is close to the mean value, and the frequency distribution is positive skewed. Low values of $C(\leq 1)$ reflect a high percentage of calms or light winds. A preliminary test without including the zero values did not yield any $C \leq 1$. $1<C<2$ means that the wind speed values are wide spread. $C=2$ is the isotropic condition, and $C>2$ reflects the
did not yield any $C \leq 1$. $1<C<2$ means that the wind speed values are wide spread. $C=2$ is the isotropic condition, and $C>2$ reflects the

existance of a preferential direction.

The Atlantic Ocean's HD of A (Fig. 4) shows winter maxima in January at 55°N and in September at 30°S. Minima are found at 45°N in July and 40°S in November. The Equator shows low values around the year. The North Atlantic's latitudinal variation shows a marked positive gradient, except above the 20°N maximum during the summer and the winter maximum; i.e., A increases towards higher latitudes almost everywhere. The South Atlantic's latitudinal variation is not so well organized. This may be due to the smaller number of data available for the calculations. The associated HD of C (Fig. 5) shows a winter maximum at 40°N in February. At 30°S there is a high value in October, this is seen as a late winter maximum. Minima are found at 45°N in June and 40°S in November. The latitudinal variation does not seem to have an established pattern.

The Eastern Pacific Ocean's HD of A (Fig. 6) shows winter maxima in January at 45°N and in July at 50°S. Minima are found at 35°N in July and at 15°S in November. The latitudinal variation in the north is somehow similar to the North Atlantic's but shifted 15° southward; i.e. the lowest values are found around 15°S. In this case a similar increase towards higher latitudes is also found from 15°S southward. The associated HD of C (Fig. 7) shows a winter maximum at 50°N in February and a winter maximum at 45°S in September. There is also a summer maximum at 15°S. Low values are

found at 35°N in May and 15°S in November (C=0.49). The latter
September. There is also a summer maximum at 15°S. Low values are

found at 35°N in May and 15°S in November (C=0.49). The latter should be seen carefully since for C~1/2 the mean value is about 2A.

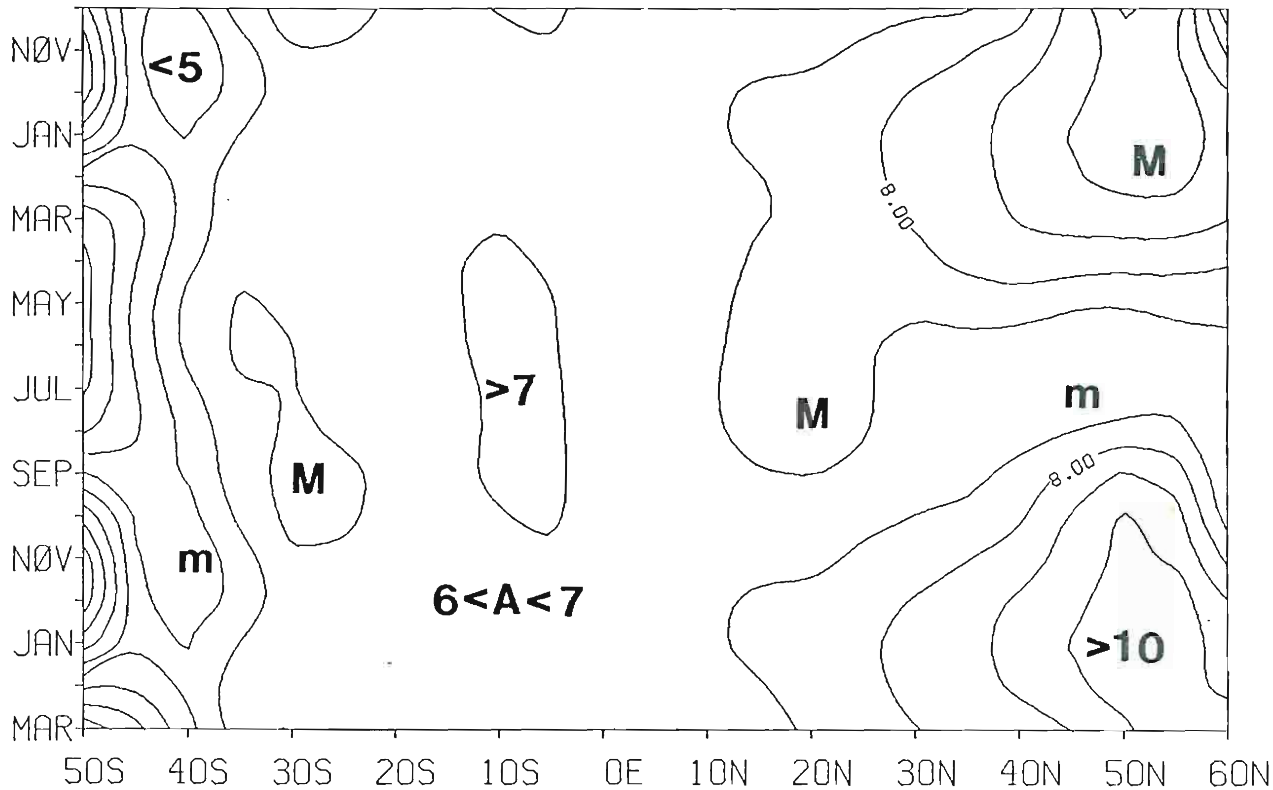

Figure 4.- Hovmöller diagram of the Weibull parameter A for the Atlantic Ocean. Note that 3 months are repeated at both ends of the ordinate axis.

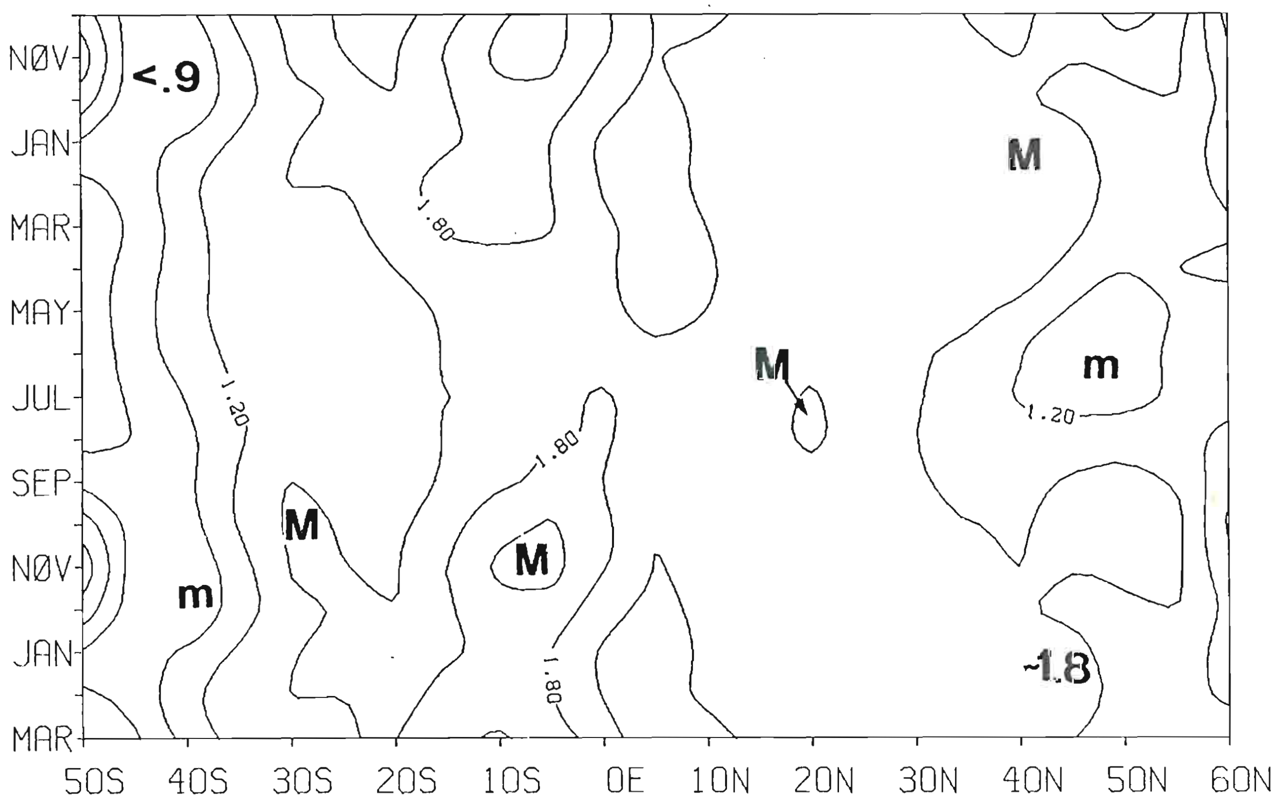

Figure 5.- Hovmöller diagram of the Weibull parameter C for the Atlantic Ocean. M = Maximum, m = minimum.

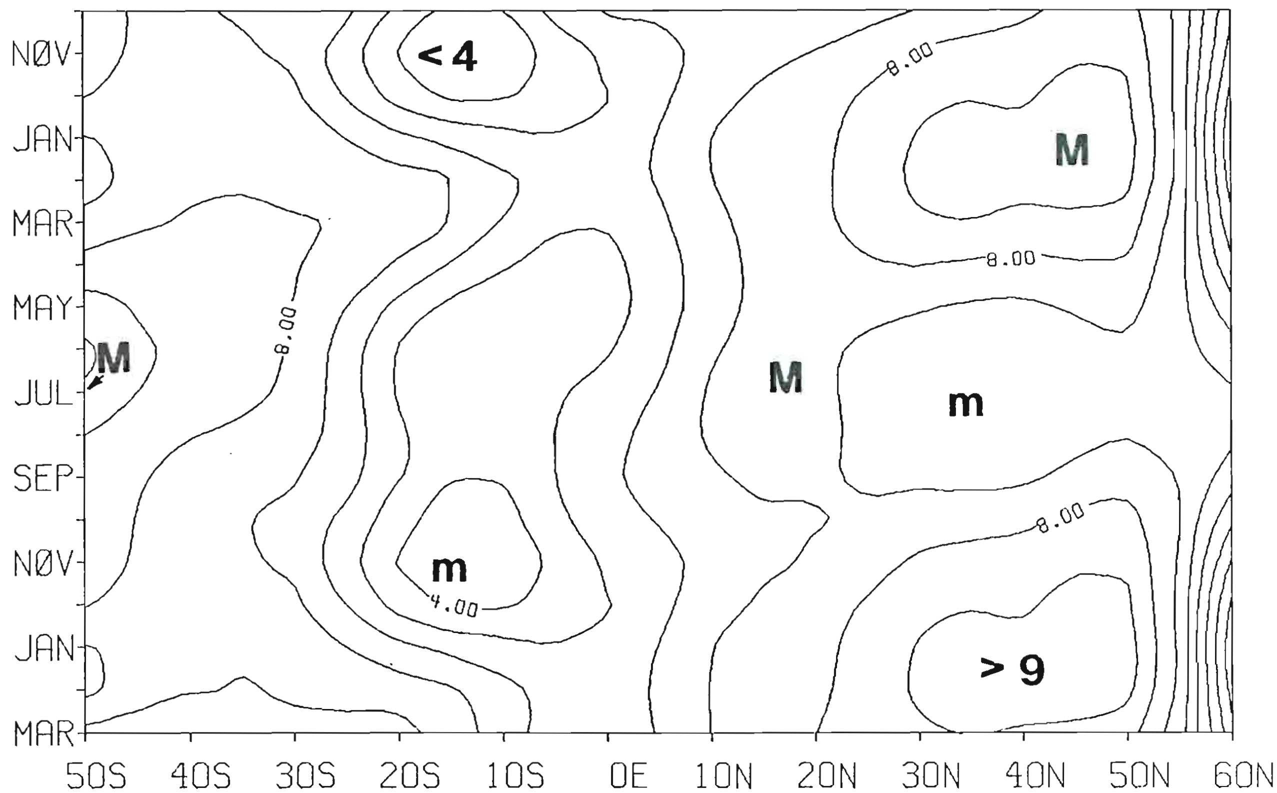

Figure 6.- Hovmöller diagram of the Weibull parameter A for the Eastern Pacific Ocean.

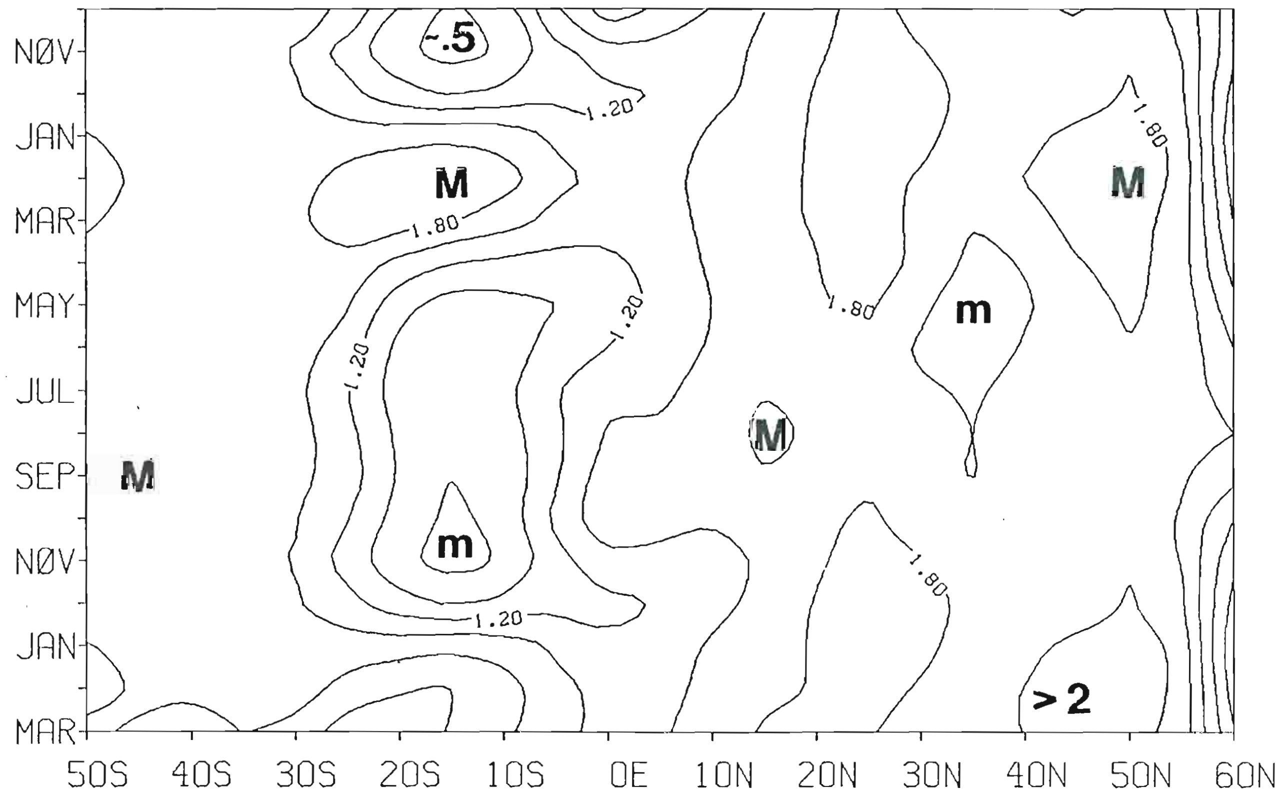

Figure 7.- Hovmöller diagram of the Weibull parameter C for the Eastern Pacific Ocean.

The Eastern Pacific shows little seasonal variation above 55°N.

The Western Pacific Ocean HD of A (Fig. 8) shows a winter maximum in February at 35°N. A maximum is shown in May at 45°S. Minima are found at 35°N in July and at 10°S in November. The latitudinal variation is similar to the Eastern Pacific's but instead of having the lowest values around 15°S, these are around 10°S in February and 5°S in August. The associated HD of C (Fig. 9) shows winter maxima in March at 35°N and in July at 30°S. A summer minimum is found in August at 40°N. A minimum is found in November at 10°S. In this case the pattern of maximum and minimum values is very complicated. The Western Pacific seasonal variation above 55°N is even smaller than in the Eastern Pacific.

The Indian Ocean HD of A (Fig. 10) shows maxima in December and July at 10°N and at 15°S in July. The Equator shows low values around the year. The associated HD of C (Fig. 11) shows roughly low values at the Equator with little increase towards higher latitudes. Maxima are found at 25°N in December and at 15°S in July. The absence of a minimum during the summer may be due to monsoonal effects.

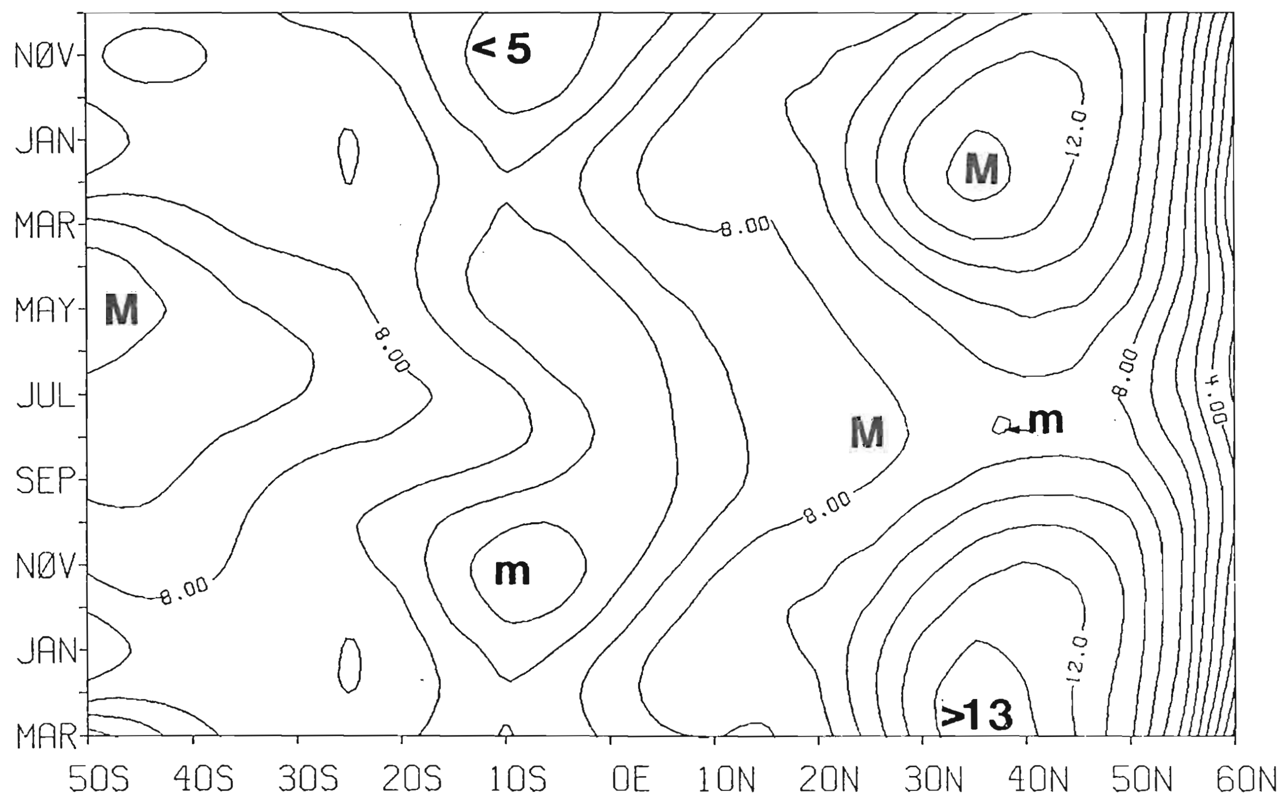

Figure 8.- Hovmöller diagram of the Weibull parameter A for the Western Pacific Ocean.

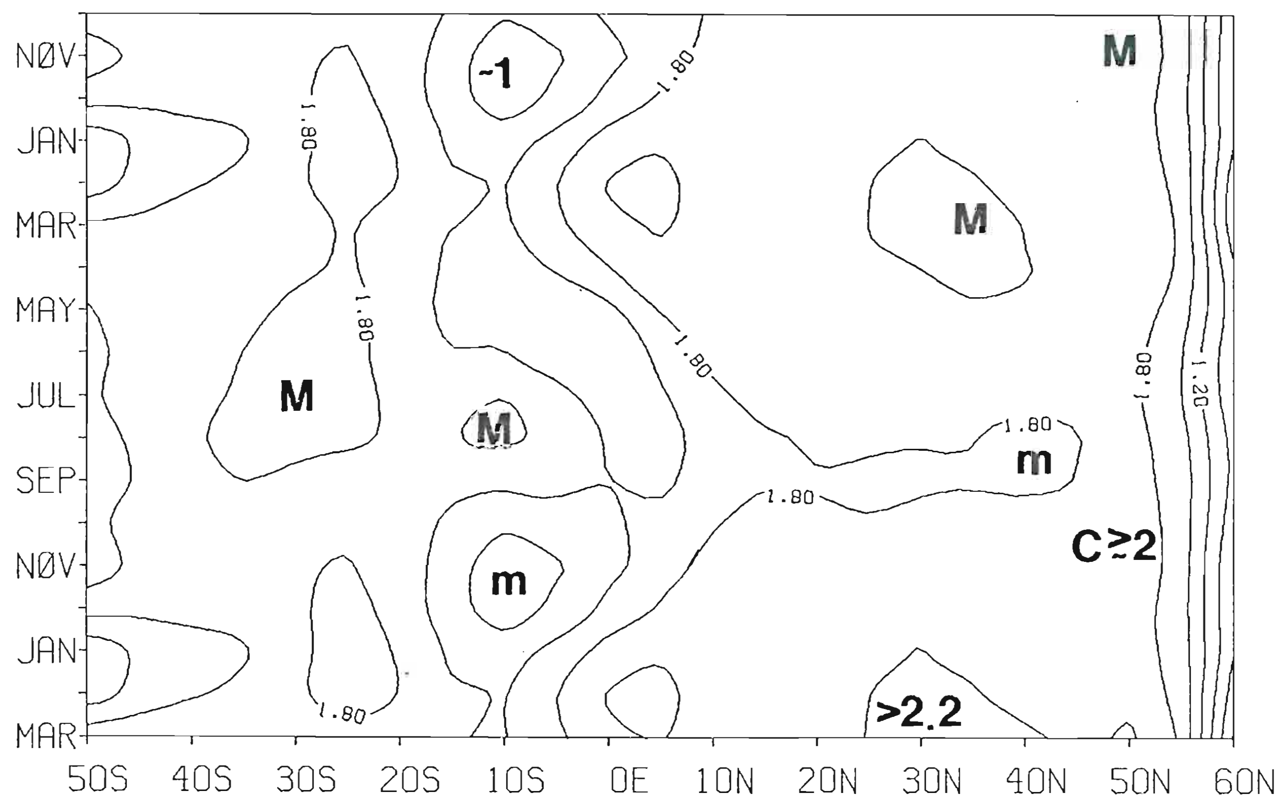

Figure 9.- Hovmöller diagram of the Weibull parameter C for the Western Pacific Ocean.

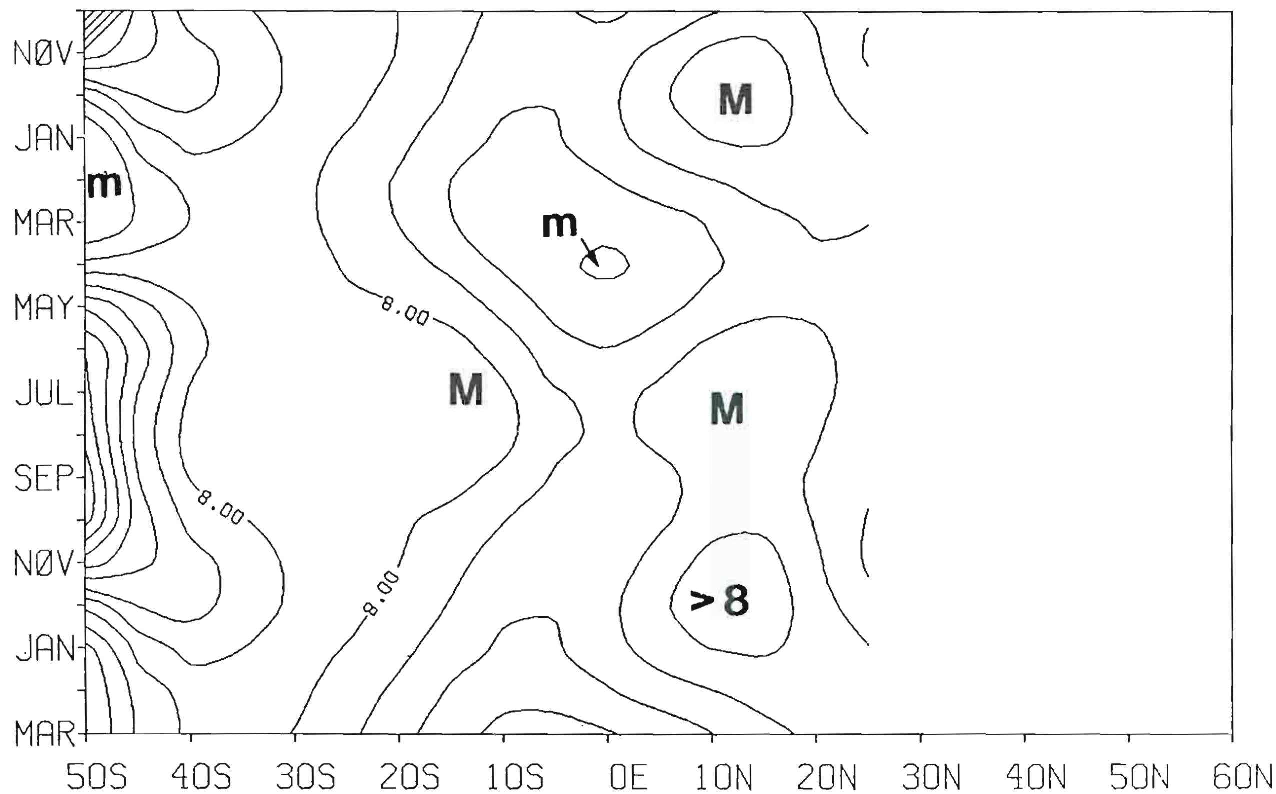

Figure 10.- Hovmöller diagram of the Weibull parameter A for the Indian Ocean.

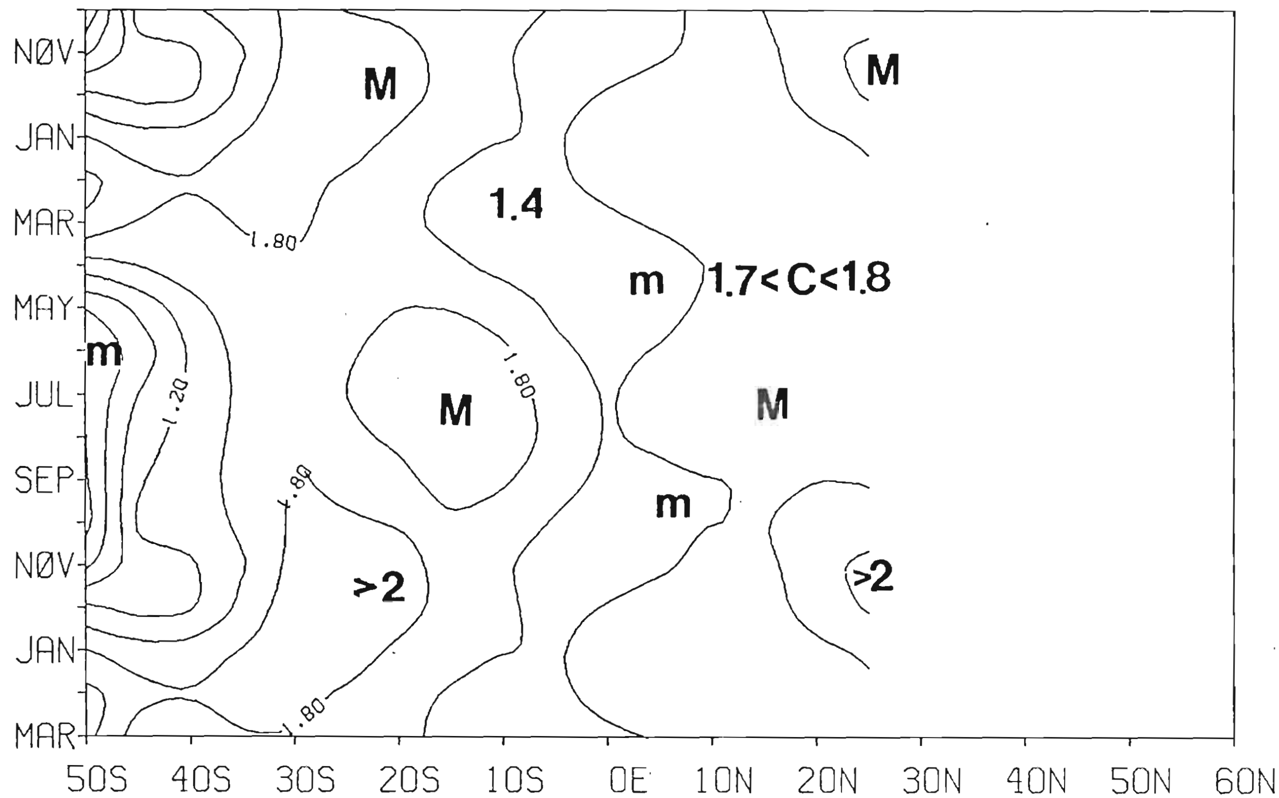

Figure 11.- Hovmöller diagram of the Weibull parameter C for the Indian Ocean.

4. Conclusions

Wind speed data over the World's oceans have been studied using a Weibull model. The two-parameter Weibull distribution adequately fits the data.

The bootstrap statistical stability test provided excellent criteria in the process of selecting the method to estimate the Weibull parameters. The least-squares approach was found to be very flexible for this test. In this sense, the chosen method resulted by combining two procedures: one stable procedure and one that gave better goodness-of-fit results. The bootstrap results also showed that the parameters greatly depend on the highest wind speed values. These values usually have low relative frequencies, and their effect on the goodness-of-fit estimates is minimum.

In general the results agree well with other independent statistics of wind speed. The seasonal and latitudinal variation in the Northern Hemisphere is closely related to the transition from winter to summer. The Southern Hemisphere has a less regular pattern. Although some climatological features are recognized, the results may have been affected by the scarcity of the data.

The main goals of this study have been achieved. This work provides insight on the seasonal and latitudinal variation of the Weibull parameters. However, questions can still be raised about

provides insight on the seasonal and latitudinal variation of the Weibull parameters. However, questions can still be raised about

the representativity of the available data. The uneven geographical distribution of the observations and the uncertainty of the percentage of calms remain unsolved problems.

REFERENCES

Abramowitz, M., and I. A. Stegun, 1970: Handbook of Mathematical Functions. Dover publications, 1045 pp.

Brown, B. G., R. W. Katz and A. H. Murphy, 1984: Time series models to simulate and forecast wind speed and wind power. J. Clim. and App. Met., 23, 1184-1195.

Conradsen, K., L. B. Nielsen and L. P. Prahm, 1984: Review of Weibull statistics for estimation of wind speed distributions. J. Clim. and App. Met., 23, 1173-1183.

Diaconis, P., and B. Efron, 1983: Computer-intensive methods in statistics. Sci. Amer., 248, 116-130.

Efron, B., 1982: The Jacknife, the bootstrap and other Resampling Plans. SIAM Monogr., No. 38, 92 pp.

Gorshov, S. G., editor, 1974a: World Ocean Atlas, Vol. 1 Pacific Ocean. Pergamon Press. 302 pp.

______, editor, 1974b: World Ocean Atlas, Vol. 2 Atlantic and Indian Ocean. Pergamon Press. 306 pp.

Gumbel, E. J., 1958: Statistics of extremes. Columbia University Press. 375 pp.

Hellerman, S., and M. Rosenstein, 1983: Normal monthly wind stress over the World Ocean with error estimates. J. Phys. Oceanogr., 13, 1093-1104.

Hennessey, J. P., Jr., 1977: Some aspects of wind power statistics. J. App., Met., 16, 63-70.

Höflich O., 1984: Climate of the South Atlantic. In Climates of the Oceans. [Edited by H. van Loon]. World Survey of Climatology, 15, Elsevier Science Publishers. 1-192.

Jensen, N. O., E. L. Petersen and I. Troen, 1984: Extrapolation of mean wind statistics with special regard to wind energy applications. World Meteorological Organization, WMO/TD-No 15, WCP-86. 85 pp.

Jensen, N. O., E. L. Petersen and I. Troen, 1984: Extrapolation of mean wind statistics with special regard to wind energy applications. World Meteorological Organization, WMO/TD-No 15, WCP-86. 85 pp.

Justus, C. G., W. R. Hargraves, A. Mikhail and D. Graber, 1978: Methods for estimating wind speed frequency distribution. J. App. Met., 17, 350-353.

_____, _____, and A. Yalcin, 1976: Nationwide Assessment of potential output from wind-powered generators. J. App. Met., 15, 673-678.

Ostle, B., 1963: Statistics in Research. The Iowa State University Press. 585 pp.

Petersen, E. L., I. Troen, S. Frandsen and Klaus Hedegaard, 1981: Wind Atlas for Denmark. Riso National Laboratory. 229 pp.

Stewart, D. A., and O. M. Essenwanger, 1978: Frequency distribution of wind speed near the surface. J. App. Met., 17, 1633-1642.

Takle, E. S., and J. M. Brown, 1978: Note on the use of Weibull statistics to characterize wind-speed data. J. App. Met., 17, 556-559.

van Loon, H., editor, 1984: Climates of the Oceans. World Survey of Climatology, 15. Elsevier Science Publishers. 716 pp.

Witte, J. M., 1984: Winds over water: a bibliography. Nova University/NYIT Press. 177 pp.

APPENDIX

List of Symbols

A — Weibull parameter which approximates mean wind speed.

b_j — Linearized Weibull ogive.

C — Weibull parameter which determines the shape of the pdf.

f — Probability density function (pdf).

F — Cumulative distribution function (cdf).

K — Number of points used in the pdf estimation.

m — A power transformation to rescale Weibull distribution.

M — Total number of tests used in bootstrap method.

M_0 — Modal value.

M_1 — Median.

N — Number of individual data in random bootstrap sample.

S — Representative set of wind speed data.

V — Wind speed.

V_M — Highest value in the 95% sub-sample of the subset X.

X_i — Bootstrap sample subset.

γ — Skewness.

Γ — Gamma function.

$\Delta\varepsilon$ — Goodness-of-fit.

ε — Residual in Eq. (10).

$\Delta\varepsilon$ — Goodness-of-fit.

ε — Residual in Eq. (10).

σ^2 — Variance.

Table A1. The value of the Weibull parameters: A [m s^{-1}] and C. January 1983.

	Indian O. 30°E-120°E				W. Pacific O. 120°E - 150°W				E. Pacific O. 150°W-60°W				Atlantic O. 60°W-30°E			
	N		S		N		S		N		S		N		S	
	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
0°-5°	7.1	1.6	5.4	1.4	8.1	2.1	6.2	1.6	4.9	1.2	5.9	1.7	4.6	1.2	6.2	2.0
5°-10°	9.1	2.0	6.0	1.6	9.8	2.2	6.0	1.4	7.4	1.5	8.5	2.4	5.9	1.2	6.0	1.8
10°-15°	8.1	1.7	6.2	1.6	9.4	2.1	6.5	1.5	9.1	1.8	7.2	2.2	7.3	1.5	5.7	1.8
15°-20°	8.0	1.5	7.9	1.8	9.0	1.9	8.4	1.7	7.3	1.7	6.7	1.9	7.5	1.5	6.6	1.7
20°-25°	9.3	1.9	7.4	1.9	8.2	1.9	8.6	2.1	7.7	1.8	6.7	1.6	7.9	1.8	6.3	1.6
25°-30°			9.1	1.9	11.	2.2	7.6	1.8	7.4	2.0	8.7	1.6	8.4	1.8	7.5	1.5
30°-35°			9.0	2.0	13.	2.2	4.6	0.9	8.8	2.0	9.6	1.6	8.2	1.7	6.3	1.2
35°-40°			8.0	1.9	14.	1.9	7.4	1.3	8.6	1.3	7.8	1.9	7.2	1.5	6.5	1.3
40°-45°			8.8	2.0	13.	1.8	7.5	1.2	8.7	2.2	7.9	1.6	9.1	1.8	5.0	0.8
45°-50°			11.	1.6	11.	1.8	1.9	0.4	8.8	2.0	7.3	1.8	11.	2.0	9.1	0.8
50°-55°					11.	2.2			13.	2.4			8.8	0.8		
55°-60°					10.	1.9			11.	2.3			17.	2.0		

Table A2. The value of the Weibull parameters: A [m s^{-1}] and C. February 1983.

	Indian O. 30°E-120°E N		Indian O. 30°E-120°E S		W. Pacific O. 120°E - 150°W N		W. Pacific O. 120°E - 150°W S		E. Pacific O. 150°W-60°W N		E. Pacific O. 150°W-60°W S		Atlantic O. 60°W-30°E N		Atlantic O. 60°W-30°E S	
	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
0°-5°	6.0	1.6	5.3	1.5	7.9	2.4	7.6	1.9	5.0	1.4	4.4	1.4	5.5	1.3	6.9	1.9
5°-10°	6.4	1.8	4.7	1.3	9.6	2.1	5.2	1.3	5.4	1.3	6.8	1.9	6.7	1.4	7.0	1.9
10°-15°	6.9	1.9	5.6	1.4	8.4	2.1	6.6	1.5	7.1	1.5	7.8	2.1	6.8	1.8	5.8	1.9
15°-20°	6.0	1.6	6.6	1.4	6.6	1.6	9.9	2.0	7.0	1.6	8.1	2.1	6.6	1.7	6.9	1.7
20°-25°	8.9	1.7	7.5	1.8	7.5	1.8	8.5	2.0	7.3	1.9	7.9	1.8	6.0	1.3	5.9	1.4
25°-30°			8.6	2.0	11.	2.1	7.1	1.8	8.3	1.9	7.9	1.5	8.4	1.8	7.7	1.7
30°-35°			9.2	1.9	14.	2.3	7.3	1.6	11.	2.0	6.4	1.5	9.2	1.9	8.0	1.7
35°-40°			8.1	1.7	15.	2.2	7.3	1.6	11.	1.1	7.6	1.7	7.9	1.6	5.6	1.1
40°-45°			9.7	2.0	12.	1.9	7.4	1.2	10.	1.9	6.9	1.4	9.9	1.9	2.6	0.6
45°-50°			12.	2.4	10.	1.7	7.6	1.0	8.8	1.9	4.4	0.8	12.	2.1	3.9	0.5
50°-55°			1.5			1.9			11.	1.9			8.0	0.9		
55°-60°			8.1			2.2			8.8	2.2			11.	1.5		

Table A3. The value of the Weibull parameters: A [m s^{-1}] and C. March 1983.

	Indian O. 30°E-120°E				W. Pacific O. 120°E - 150°W				E. Pacific O. 150°W-60°W				Atlantic O. 60°W-30°E			
	N		S		N		S		N		S		N		S	
	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
0°-5°	4.9	1.4	4.5	1.4	7.3	2.3	6.3	1.6	5.1	1.4	4.9	1.4	6.2	1.6	6.4	2.1
5°-10°	5.2	1.5	4.3	1.2	8.3	2.0	5.2	1.4	5.6	1.4	6.3	2.0	5.0	1.1	7.7	2.3
10°-15°	5.9	1.5	5.0	1.4	8.3	2.1	6.0	1.5	7.6	1.6	7.6	2.0	6.4	1.5	7.4	1.9
15°-20°	6.5	1.5	6.9	1.6	7.5	1.7	7.8	1.6	7.9	2.0	9.6	2.3	6.9	1.6	8.2	2.1
20°-25°	8.0	1.6	7.0	1.8	7.5	1.9	8.3	1.8	7.9	1.7	7.8	2.5	6.9	1.6	6.0	1.0
25°-30°			8.2	1.8	9.8	2.2	7.7	1.7	7.9	1.8	7.7	1.7	7.5	1.6	7.7	1.3
30°-35°			8.5	1.9	13.	2.3	6.5	1.5	9.7	1.9	8.6	1.7	8.6	1.7	7.5	1.5
35°-40°			9.1	1.7	15.	2.4	8.5	1.8	8.6	1.1	9.0	2.1	7.6	1.4	5.2	1.1
40°-45°			8.0	1.4	13.	2.3	9.8	1.7	9.5	2.2	8.5	2.0	8.9	1.7	1.3	0.4
45°-50°			12.	2.2	11.	1.7	10.	1.7	8.0	1.8	8.3	1.7	8.4	1.6	1.3	0.3
50°-55°					9.9	2.3			9.4	1.9			9.6	1.1		
55°-60°					10.	2.2			8.4	2.0			11.	1.4		

Table A4. The value of the Weibull parameters: A [m s^{-1}] and C. April 1983.

	Indian O. 30°E-120°E				W. Pacific O. 120°E - 150°W				E. Pacific O. 150°W-60°W				Atlantic O. 60°W-30°E			
	N		S		N		S		N		S		N		S	
	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
0°-5°	3.8	1.2	4.9	1.3	6.1	1.9	4.9	1.6	3.6	0.9	4.9	1.1	7.4	1.6	6.9	1.2
5°-10°	4.0	1.3	5.6	1.3	8.4	2.1	4.0	1.2	4.9	1.3	4.4	0.8	4.9	1.3	7.1	1.3
10°-15°	5.4	1.6	6.4	1.4	8.2	2.2	5.8	1.3	6.8	1.4	6.7	1.2	6.7	1.5	6.7	1.6
15°-20°	6.0	1.6	8.9	1.6	7.3	1.9	7.4	1.8	7.4	1.9	6.5	1.0	7.5	1.6	5.8	1.6
20°-25°	7.3	1.6	8.6	1.7	7.9	2.0	7.3	1.9	7.0	1.4	9.5	1.7	8.0	1.7	4.7	1.6
25°-30°			8.9	1.9	8.6	2.2	7.2	1.7	8.7	2.3	8.3	1.5	7.2	1.6	7.5	1.4
30°-35°			7.5	1.7	9.2	2.1	8.4	1.7	8.3	2.0	8.3	1.5	8.1	1.8	6.8	1.5
35°-40°			10.	1.8	9.9	2.1	9.7	1.6	8.4	1.1	7.7	1.4	8.4	1.6	6.2	1.2
40°-45°			11.	2.0	10.	2.2	8.9	1.5	6.4	1.3	9.0	1.5	10.	2.0	5.3	1.4
45°-50°			11.	1.4	11.	1.8	10.	1.8	7.4	1.8	8.4	1.6	9.4	1.5	1.9	1.6
50°-55°					10.	2.3			9.2	2.1			7.9	1.1		
55°-60°					8.7	2.0			7.4	1.8			8.5	1.3		

Table A5. The value of the Weibull parameters: A [m s^{-1}] and C. May 1983.

	Indian O. 30°E-120°E				W. Pacific O. 120°E - 150°W				E. Pacific O. 150°W-60°W				Atlantic O. 60°W-30°E			
	N		S		N		S		N		S		N		S	
	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
0°-5°	4.2	1.2	5.3	1.5	4.6	1.1	3.5	1.1	3.4	0.9	3.8	0.9	5.7	1.5	8.1	2.0
5°-10°	5.4	1.3	7.0	1.7	7.6	2.0	5.1	1.5	4.9	1.4	2.7	0.5	4.8	1.2	8.2	1.4
10°-15°	6.1	1.5	8.9	1.9	7.7	2.1	5.2	1.1	7.5	1.4	5.2	0.8	6.8	1.4	7.1	1.8
15°-20°	6.8	1.7	8.7	2.0	7.0	1.9	9.0	1.8	7.2	1.8	3.3	0.6	8.5	1.8	6.4	1.4
20°-25°	6.5	1.6	7.2	1.6	8.2	2.1	9.6	2.1	7.5	1.6	8.1	2.0	8.6	2.0	5.7	1.4
25°-30°			8.0	1.7	7.9	1.9	8.6	1.8	7.9	2.2	7.4	1.9	7.2	1.7	7.7	1.5
30°-35°			9.4	1.6	8.3	1.8	8.7	1.7	6.5	1.5	8.0	1.8	6.6	1.6	7.1	1.2
35°-40°			9.3	1.5	9.7	2.1	10.	1.6	6.2	1.0	8.9	1.6	7.3	1.6	7.9	1.3
40°-45°			3.4	0.5	10.	2.3	12.	1.6	6.6	1.7	8.3	1.5	8.7	1.5	4.6	0.6
45°-50°			2.0	0.4	10.	1.8	11.	1.6	7.2	1.6	8.5	1.7	5.8	0.9	1.7	0.4
50°-55°					9.5	2.2			8.3	1.8			6.8	1.1		
55°-60°					6.4	1.7			7.3	1.9			6.9	1.2		

Table A6. The value of the Weibull parameters: A [m s^{-1}] and C.
June 1983

	Indian O. 30°E-120°E				W. Pacific O. 120°E - 150°W				E. Pacific O. 150°W-60°W				Atlantic O. 60°W-30°E			
	N		S		N		S		N		S		N		S	
	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
0°-5°	5.2	1.3	5.8	1.5	3.0	0.8	4.2	1.1	4.5	1.1	4.9	0.9	5.9	1.5	7.4	1.9
5°-10°	7.5	1.6	8.1	2.0	5.8	1.6	7.5	1.7	5.4	1.4	4.5	0.7	6.2	1.6	7.0	1.5
10°-15°	8.6	1.9	8.2	1.9	7.2	2.0	6.7	1.2	7.2	1.3	3.0	0.6	6.6	1.6	6.9	1.6
15°-20°	8.2	1.8	7.8	1.8	7.2	2.1	7.2	1.7	8.1	2.0	3.2	0.6	7.2	1.7	6.3	1.2
20°-25°	7.7	1.8	6.8	1.6	8.7	2.3	8.5	2.0	7.2	1.5	7.1	1.7	7.4	1.5	6.4	1.3
25°-30°			8.4	1.7	7.4	1.8	10.	1.9	5.8	1.9	9.2	1.6	6.3	1.5	6.4	1.1
30°-35°			8.9	1.8	8.6	1.9	9.1	1.8	5.8	1.1	9.0	1.7	6.3	1.5	8.9	1.5
35°-40°			10.	1.4	9.9	2.1	10.	1.9	6.9	1.0	8.6	1.5	6.1	1.4	7.8	1.2
40°-45°			1.5	0.4	10.	2.0	8.9	1.7	5.3	1.8	9.2	1.8	7.3	1.3	4.7	0.7
45°-50°			1.4	0.2	8.9	1.6	11.	2.1	5.7	1.4	12.	1.5	4.1	0.8	1.2	0.4
50°-55°					8.8	2.2			7.3	2.0			5.3	1.0		
55°-60					6.0	1.7			6.3	2.0			7.6	1.4		

Table A7. The value of the Weibull parameters: A [m s^{-1}] and C July 1983.

	Indian O. 30°E-120°E				W. Pacific O. 120°E - 150°W				E. Pacific O. 150°W-60°W				Atlantic O. 60°W-30°E			
	N		S		N		S		N		S		N		S	
	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
0°-5°	5.9	1.4	6.4	1.5	4.5	1.1	7.0	1.9	4.9	1.4	6.6	1.7	7.1	2.1	7.6	1.9
5°-10°	7.4	1.6	9.3	2.1	6.0	1.6	9.0	1.9	4.8	1.5	3.4	0.7	6.4	1.7	7.5	1.1
10°-15°	8.4	1.8	11.	2.3	7.1	1.7	8.4	1.8	8.6	1.5	3.6	0.5	6.2	1.4	6.9	1.7
15°-20°	8.0	1.8	11.	2.2	7.3	1.9	8.3	1.7	8.7	2.0	3.1	0.5	8.0	1.8	6.5	1.5
20°-25°	6.9	1.7	9.0	1.8	8.2	2.2	8.6	1.8	7.5	1.6	7.0	1.0	9.3	2.1	5.3	0.9
25°-30°			9.0	1.7	7.0	2.0	9.9	2.0	6.1	1.7	8.4	1.5	7.2	1.8	8.6	1.8
30°-35°			9.7	1.6	7.8	1.9	9.5	1.8	6.5	1.9	8.5	1.7	5.8	1.6	7.0	1.0
35°-40°			6.9	1.1	8.1	2.0	9.7	1.6	5.9	1.2	7.6	1.3	5.9	1.4	6.6	0.9
40°-45°			8.9	1.1	8.6	1.9	7.3	1.4	5.0	2.0	8.9	1.8	5.2	0.9	3.8	0.6
45°-50°			4.8	0.5	8.4	1.7	8.4	1.6	7.0	1.5	10.	1.7	4.9	1.0	1.9	0.4
50°-55°					8.0	2.1			7.2	1.8			4.8	0.9		
55°-60°					6.1	1.4			5.7	1.5			7.1	1.3		

Table A8. The value of the Weibull parameters: A [m s^{-1}] and C. August 1983.

	Indian O. 30°E-120°E				W. Pacific O. 120°E - 150°W				E. Pacific O. 150°W-60°W				Atlantic O. 60°W-30°E			
	N		S		N		S		N		S		N		S	
	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
0°-5°	6.4	1.4	7.5	1.6	5.3	1.5	7.1	1.8	7.1	1.9	5.1	0.9	6.3	1.7	7.7	2.1
5°-10°	7.9	1.6	9.2	2.4	5.1	1.3	9.0	2.2	4.5	1.3	3.1	0.6	7.0	1.7	5.9	1.2
10°-15°	9.3	1.7	9.2	2.1	7.0	1.6	8.6	1.8	8.3	1.6	5.8	6.9	6.6	1.6	7.4	1.9
15°-20°	8.9	1.8	7.3	1.6	8.1	1.7	8.7	1.9	8.2	2.2	3.7	0.7	7.5	1.7	6.3	1.2
20°-25°	7.2	1.6	7.2	1.6	8.8	1.9	8.4	2.0	7.6	1.7	8.3	1.7	9.0	2.0	6.8	1.3
25°-30°			8.8	1.8	8.1	1.9	8.2	1.7	5.7	1.5	8.2	1.8	7.1	1.7	7.6	1.6
30°-35°			11.	1.8	8.1	1.8	9.1	2.1	6.3	1.8	7.9	1.9	6.3	1.4	5.9	1.1
35°-40°			8.9	1.1	7.4	1.8	9.6	1.9	6.0	1.2	8.2	1.7	7.1	1.4	5.0	0.8
40°-45°			11.	1.5	7.1	1.6	8.0	1.4	5.2	1.8	8.5	1.7	7.2	1.2	2.3	0.5
45°-50°					7.9	1.6	9.6	2.2	6.8	1.4	8.0	1.4	7.1	1.6	1.8	0.4
50°-55°					8.9	2.2			6.8	1.8			5.7	1.1		
55°-60°					7.6	1.9			6.7	1.7			6.9	1.3		

Table A9. The value of the Weibull parameters: A [m s^{-1}] and C. September 1983.

	Indian O. 30°E-120°E				W. Pacific O. 120°E - 150°W				E. Pacific O. 150°W-60°W				Atlantic O. 60°W-30°E			
	N		S		N		S		N		S		N		S	
	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
0°-5°	5.6	1.5	6.4	1.4	5.3	1.4	6.5	1.8	7.7	2.1	4.4	.8	6.6	1.7	8.1	2.0
5°-10°	6.5	1.4	8.7	2.0	5.3	1.4	7.1	1.5	5.2	1.5	2.6	.5	5.4	1.6	6.9	1.4
10°-15°	6.4	1.3	9.5	1.9	5.8	1.5	6.6	1.4	7.7	1.6	4.8	.5	6.9	1.4	7.8	1.7
15°-20°	6.3	1.5	8.3	1.7	6.2	1.7	7.2	1.7	8.4	2.1	4.4	.6	7.2	1.7	6.4	1.1
20°-25°	6.7	1.6	7.4	1.6	6.8	1.7	6.9	1.6	6.8	1.6	7.8	1.4	7.2	1.8	6.8	1.4
25°-30°			9.3	2.0	6.5	1.6	7.0	1.8	7.6	1.9	6.9	1.6	5.8	1.6	8.3	1.7
30°-35°			9.3	1.6	8.4	1.6	8.4	1.8	7.1	1.5	6.2	1.2	6.8	1.6	8.3	1.3
35°-40°			6.8	0.9	9.8	1.7	10.	1.9	6.9	1.2	7.9	1.7	5.7	1.4	5.7	0.8
40°-45°			8.4	1.6	9.6	1.7	11.	1.7	5.2	1.9	8.1	1.7	6.7	1.4	3.2	0.6
45°-50°			2.0	0.5	8.6	1.5	10.	2.1	7.3	1.5	8.6	1.7	9.3	1.6	4.7	0.7
50°-55°					9.1	2.2			8.1	1.8			11.	1.7		
55°-60					9.4	1.7			7.3	1.4			11.	1.5		

Table A10. The value of the Weibull parameters: A [m s^{-1}] and C. October 1983.

	Indian O. 30°E-120°E				W. Pacific O. 120°E - 150°W				E. Pacific O. 150°W-60°W				Atlantic O. 60°W-30°E			
	N		S		N		S		N		S		N		S	
	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
0°-5°	5.1	1.3	6.2	1.5	5.4	1.6	4.5	1.3	7.0	2.4	6.3	1.4	6.7	1.8	8.4	2.5
5°-10°	6.3	1.4	6.5	1.6	4.9	1.6	4.2	1.1	5.2	1.6	7.3	0.5	4.4	1.3	6.8	2.1
10°-15°	6.7	1.6	7.7	1.8	6.8	1.7	5.3	1.4	6.6	1.4	3.5	0.5	6.1	1.4	6.4	1.6
15°-20°	8.1	1.5	8.2	1.7	9.1	2.4	6.6	1.9	6.2	1.5	3.6	0.6	6.3	1.6	6.3	1.2
20°-25°	7.6	1.3	8.2	1.8	8.6	1.8	6.7	1.8	6.2	1.5	8.3	1.8	6.4	1.7	7.5	1.5
25°-30°			8.8	1.9	7.5	1.7	6.8	1.6	6.5	2.3	6.3	1.5	6.4	1.5	8.6	1.8
30°-35°			8.5	1.9	8.9	2.1	6.9	1.5	7.0	1.6	6.6	1.7	7.5	1.8	7.2	1.3
35°-40°			5.1	0.9	10.	1.7	8.5	1.6	7.7	1.2	7.4	1.6	6.3	1.4	3.9	0.7
40°-45°			11.	2.2	11.	2.2	8.3	1.6	7.2	2.1	7.3	1.7	7.2	1.4	1.7	0.4
45°-50°					11.	1.7	7.2	1.7	8.7	1.7	8.8	1.5	8.2	1.6	8.4	1.4
50°-55°					11.	2.3			8.8	1.8			12.	2.0		
55°-60°					11.	1.8			9.2	1.5			14.	2.1		

Table A.11. The value of the Weibull parameters: A [m s^{-1}] and C. November 1983.

	Indian O. 30°E-120°E				W. Pacific O. 120°E - 150°W				E. Pacific O. 150°W-60°W				Atlantic O. 60°W-30°E			
	N		S		N		S		N		S		N		S	
	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
0°-5°	5.9	1.4	5.5	1.4	4.7	1.2	4.2	1.2	5.7	1.2	5.8	1.4	7.7	2.0	7.6	2.5
5°-10°	7.3	1.3	5.5	1.3	6.3	1.6	2.3	0.7	5.3	1.5	0.4	0.3	4.5	1.3	6.0	2.2
10°-15°	9.7	1.5	7.7	1.9	8.4	2.0	4.8	1.4	6.0	1.2	2.5	0.5	6.8	1.6	6.9	2.3
15°-20°	11.	1.8	8.6	1.9	9.8	2.1	6.7	1.8	7.0	1.8	2.7	0.6	7.0	1.7	5.6	1.1
20°-25°	7.4	1.3	8.2	2.0	8.5	1.8	7.1	1.7	6.4	1.5	1.4	0.4	4.9	1.2	7.3	1.6
25°-30°			9.0	2.0	8.9	1.9	8.3	2.0	7.9	2.1	8.7	1.7	6.9	1.5	8.2	1.7
30°-35°			7.4	1.3	12.	2.2	7.6	1.7	7.8	1.7	7.5	1.7	9.1	1.8	5.7	1.0
35°-40°			5.4	0.9	12.	1.8	9.0	1.8	9.6	1.6	6.4	1.5	7.0	1.5	2.4	0.6
40°-45°			9.1	1.8	13.	2.4	9.4	1.6	8.7	2.0	7.4	1.6	9.0	1.7	1.1	0.4
45°-50°			0.9	0.3	12.	1.7	8.8	2.1	10.	1.7	9.8	1.5	9.0	1.5	10.	2.0
50°-55°					11.	2.5			10.	1.9			10.	1.7		
55°-60°					9.4	1.9			10.	1.8			9.8	1.7		

Table A12. The value of the Weibull parameters: A [m s^{-1}] and C. December 1983.

	Indian O. 30°E-120°E				W. Pacific O. 120°E - 150°W				E. Pacific O. 150°W-60°W				Atlantic O. 60°W-30°E			
	N		S		N		S		N		S		N		S	
	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
0°-5°	6.5	1.5	5.8	1.5	4.8	1.5	4.4	1.2	2.2	0.6	4.6	1.2	6.6	1.4	7.1	2.4
5°-10°	8.5	1.7	5.5	1.4	7.3	1.8	2.1	0.6	4.6	1.2	0.7	0.4	4.9	1.1	5.9	1.8
10°-15°	10.	1.8	7.2	1.9	9.6	2.1	4.1	1.0	7.3	1.2	0.9	0.3	8.6	1.9	5.6	1.9
15°-20°	9.5	1.6	8.1	1.7	10.	2.1	9.4	2.0	7.1	1.6	4.0	0.8	8.4	1.9	4.4	1.0
20°-25°	8.5	1.5	9.0	2.4	7.6	1.7	9.1	2.0	7.8	1.7	6.3	1.5	6.6	1.7	6.6	1.6
25°-30°			8.6	2.2	9.1	1.8	7.4	1.7	8.7	2.5	8.5	1.8	7.9	1.7	7.5	1.7
30°-35°			7.4	1.6	11.	2.1	7.9	1.7	9.5	1.8	7.8	1.3	8.9	1.7	4.6	0.8
35°-40°			3.2	0.6	12.	1.8	8.1	1.8	11.	2.0	6.5	1.5	8.3	1.5	1.5	0.4
40°-45°			0.4	0.3	13.	2.3	9.2	1.6	6.2	0.9	7.0	1.5	11.	1.3	0.1	0.1
45°-50°			13.	1.6	13.	1.8	9.3	2.0	9.0	1.2	7.9	1.6	10.	1.3	10.	1.4
50°-55°					11.	2.0			9.0	1.8			8.0	0.9		
55°-60°					9.8	1.8			7.1	1.7			13.	1.9		