SEASONAL VARIATIONS
OF
TROPICAL WIND SPECTRA

VOLUME I: Basic Statistical Parameters

D. G. Dartt
D. N. Hovland

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Abstract

Synoptic wind spectra and horizontal and vertical cross spectra have been computed for time series from tropical stations during the interval 1964-1970. Spectral properties have been determined both for individual seasons and for seasons based on consolidated years for the 850, 500, 200, 70 and 30 mb levels. In this report, the method of spectral computations is described along with techniques that can be used for analyzing the variability of spectral properties as a function of the number of missing observations within a season. The report is intended to be a guide for the user of the spectral parameters which have been provided on two magnetic tapes. The format of the magnetic tapes is described along with samples of spectra and cross spectra of zonal and meridional winds for consolidated seasons. These samples indicate some of the primary regional characteristics of spectral properties of wind in tabular form.

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SEASONAL VARIATIONS OF TROPICAL WIND SPECTRA

VOLUME II: Basic Statistical Parameters

I. OBJECTIVE

This report presents some basic synoptic scale wind spectra and cross spectra for selected tropical regions where several consecutive years of rawinsonde data are available among neighboring stations. The spectral statistics are for zonal and meridional components at 850, 500, 200, 70 and 30 mb. The parameters are computed for individual and consolidated seasons during the interval September 1963 through December 1970. Spectra for consolidated seasons are provided in tabulated form, while all of the results including covariances are given on magnetic tapes. An inventory of the statistical data on the tapes is provided in this report along with a detailed description of the numerical computation procedures. Possible methods of interpreting the confidence of the statistics as a function of the number of data are also discussed.

The basic spectral data are being used to study time and space variations of spectral properties on a global basis and to relate the variability of these parameters to other properties of the seasonal mean flow. This investigation is giving rise to a companion report entitled "Seasonal Variations of Tropical Wind Spectra; Volume III: Analysis."

II. DISCUSSION OF STATISTICAL PARAMETERS

Briefly, power spectra and cross spectra (coherence and phase) are computed from the respective autovariance and covariance functions of time series of winds that have been prefiltered to isolate synoptic waves with periods of one to twenty-five days. The autovariances and covariances were determined from incomplete series of rawinsonde data with no interpolation of missing values. Spectral properties are therefore determined from incomplete data; however, the procedure requires that measurements occur at regular observation times. The technique is not applicable to the determination of spectral properties of observations collected at random times. A detailed discussion of the computations is given below.

A. Quality of Data

All data are 12-hourly and 24-hourly rawinsonde winds obtained from Tape Deck 5801 (NWRF) at the National Weather Records Center, Asheville, North Carolina. These data are assimilated from normal international communication channels and no detailed quality control measures are employed in their conversion to TD-5801. A preliminary examination of several years of wind values revealed a few obvious errors in data transcription. These values were eliminated from the resulting time series. The observations contain the normal tracking errors and hydrostatic errors associated with the rawinsonde; there are also observational biases in the stratosphere favoring a warm tropopause and weak vertical shear of the horizontal wind.

B. Prefiltering

To isolate the synoptic variability from the seasonal variation, the time series were first prefiltered using a filter whose frequency response is shown in Figure 1. The filter, $W(j\Delta t)$, is similar to those used by Maruyama (1968) and Wallace (1971) and is given in equation (1):

$$W(j\Delta t) = \{\Delta t / \sigma \sqrt{2\pi}\} \exp \{-[j\Delta t]^2 / 2\sigma^2\} \quad (1)$$

$$j = 0, \pm 1, \pm 2, - - - - \pm 50, \Delta t = .5 \text{ days}, \sigma = 9 \text{ days}$$

A filtered wind component, $u'(t)$, is the difference between the observed value, $u(t)$, and the sum of the weighted data beneath the filter during convolution, the latter normalized to account for missing observations (2).

$$u'(t) = u(t) - \frac{\sum_{j=-50}^{+50} W(j\Delta t) u(t-j\Delta t) \delta_{s,m}}{\sum_{j=-50}^{+50} W(j\Delta t) \delta_{s,m}} \quad (2)$$

It is to be noted that (t) is understood to be $m\Delta t$, a time sequence of discrete uniform observation times, $m = 0; 1, 2, - - - M$. The delta function, $\delta_{s,m}$, is used to represent the distribution of observations (s) over the interval of uniform time, $m\Delta t$. For a particular m , if an observation is present $\delta_{s,m} = 1$; if the observation is missing $\delta_{s,m} = 0$. Missing observations in the filtered time series were not interpolated.

Immediately prior to the actual filtering, the data beneath the filter envelope (101 values) were examined for time consistency, with values greater than four standard deviations from the mean being discarded and hence interpreted as missing data. This helped eliminate the errors in data transmission mentioned previously.

C. Covariances for Individual Seasons

The filtered wind component time series of seven years duration is subdivided into 28 segments corresponding to three month seasons (Winter 1964 consists of December 1963, January 1964 and February 1964; spring consists of March, April, May, etc.). The autovariance function, $R_i(\tau)$ of each segment, (i) as a function of time lag (τ) is then computed according to (3).

$$R_i(\tau) = \frac{\sum_{t=\tau}^{M\Delta t} u(t)u(t-\tau) \delta_{s,m} \delta_{s,m-\tau} - \left(\sum_{t=\tau}^{M\Delta t} u(t) \delta_{s,m} \right) \left(\sum_{t=\tau}^{M\Delta t} u(t-\tau) \delta_{s,m} \delta_{s,m-\tau} \right)}{\sum_{t=\tau}^{M\Delta t} \delta_{s,m} \delta_{s,m-\tau}} \quad (3)$$

For a missing observation either $\delta_{s,m}$ or $\delta_{s,m-\tau}$ is zero and there is no contribution to the autovariance for that particular time lag. The last term in the numerator of (3) corrects the lagged product for the mean of the lagged and non-lagged time series. The mean varies randomly with time lag (about zero because of prefiltering) because of the distribution of missing observations.

Sim8

Similarly, $g'(t)$ may be substituted for $u'(t)$ in (3) for the formula for the negative lag covariance between $g'(t)$ and $u'(t-\tau)$. The positive lag covariance is found by substituting $g'(t-\tau)$ for $u'(t-\tau)$. Equation (3) is used to compute all individual seasonal autovariances and covariances on the output tapes. Time lag (τ) varies from 0, .5, 1, ----, 6 days, comprising 13 time lags.

D. Covariances for Consolidated Seasons

Composite seasonal autovariance and covariance functions were also computed by combining the results for the seven individual seasons for years 1964-1970 according to (4).

$$\overline{R(\tau)} = \frac{\sum_{i=1}^7 R_i(\tau) N_i(\tau)}{\sum_{i=1}^7 N_i(\tau)} \quad (4)$$

Here $N_i(\tau)$ is the number of lagged data pairs for each time lag of the seasonal covariance functions. These values are given on the output tapes along with the number of observations for the covariance function of the composite data.

E. Power Spectra

Hanning (5) was applied to the autovariances from (3) and (4) to help produce a smoothed spectrum. ~~The resulting autovariances, $R_i(\tau)$~~

$$\hat{R}_i(\tau) = \frac{1}{2} R_i(\tau) [1 + \cos(\pi\tau/\max)] \quad (5)$$

Max is the number of nonzero time lags, twelve for these results. The resulting autocorrelations, $\hat{R}_i(\tau)$, were then utilized to produce a conventional Hanned power spectrum $\hat{S}_i(\omega_k)$:

$$S_i(\omega_k) = \frac{1}{\max} \left[\hat{R}_i(0) + 2 \sum_{\tau=1}^{\max-1} \hat{R}_i(\tau) \cos(\pi k \tau / \max) + (-1)^k \hat{R}_i(\max) \right] \quad (6)$$

$$k = 0, 1, \dots, \max$$

Here $\omega_k = 2\pi k / 2 \max \Delta t \Delta f$ and the spectral values for $k = 0$ and $k = \max$ should be one-half the value computed by (6).

It is well known that Hanning, as computed by (5), distorts the two neighboring frequencies at both the high and low frequency extremes of the spectrum. For instance, if Hanning is applied as smoothing, in the frequency domain, equation (5) becomes:

$$\begin{aligned} \hat{S}_i(0) &= .50 S_i(0) + .25 S_i(1) \\ \hat{S}_i(1) &= .50 S_i(0) + .50 S_i(1) + .25 S_i(2) \\ \hat{S}_i(k) &= .25 S_i(k-1) + .50 S_i(k) + .25 S_i(k+1) \\ \hat{S}_i(\max-1) &= .25 S_i(\max-2) + .50 S_i(\max-1) + .25 S_i(\max) \\ \hat{S}_i(\max) &= .25 S_i(\max-1) + .50 S_i(\max) \end{aligned} \quad (7)$$

Here $\hat{S}_i(k)$ is the Hanned spectral estimate at $\omega = 2\pi k / 2 \max \Delta t \Delta f$, while $S_i(k)$ is the respective raw spectral estimate resulting from a direct cosine transform of the autocovariance without Hanning. Equation (7) smooths the raw spectrum and conserves its variance, however, $\hat{S}_i(1)$ and $\hat{S}_i(\max-1)$ tend to overestimate the smoothed contribution because the weights total 1.25.

Similarly, $\hat{S}_i(0)$ and $\hat{S}_i(\max)$ are underestimates because their weights total .75.

This effect of Hanning on the end values of the spectrum was quite evident for our results with regard to the diurnal wind variation. With 12-hourly data, the frequency $(2\pi/1) \text{ day}^{-1}$ is the highest spectral frequency which can be resolved. However, because of (7) the diurnal peak was consistently displaced to the neighboring lower frequency. The Hanned spectrum can be improved at low frequencies by subtracting $.25 S_i(0)$ from $\hat{S}_i(1)$ and adding $.25 S_i(0)$ to $\hat{S}_i(0)$. Similarly, at high frequencies $.25 S_i(\max)$ can be subtracted from $\hat{S}_i(\max-1)$ and $.25 S_i(\max)$ added to $\hat{S}_i(\max)$. Thus, the raw spectral values $S_i(0)$ and $S_i(\max)$ were also computed, and the above correction was applied to all power spectra.

Each spectrum contains ~~13 values ranging from a frequency of~~ 0 to $(2\pi/1) \text{ day}^{-1}$. The spectral resolution is accordingly $(2\pi/12) \text{ day}^{-1}$. For the best stations, the spectrum would have been meaningful computed at a higher resolution. However, as our primary purpose was to compare various seasons and stations, we chose the coarse resolution which allowed us to compare results based on quite different distributions of missing data. A discussion of the effect of missing observations on the resolution and accuracy of the spectrum is given in Section ~~IV.~~

For stations with a 24-hourly sampling rate, the autovariance for odd numbered lags (.5, 1.5, - - - days) is zero according to equation (3), and the power spectrum computed from these values exhibits symmetry about

$k=6$, $\{\omega_k = 2\pi(6)/12\} \text{ day}^{-1}$. When this occurs the spectra are folded so that $S(k) = 2S(k)$ in the range $k = 0, 1, 2, \dots, 5$; the spectral values are replaced by zero for the range $k = 7-12$. Also, other stations may have a predominant 24-hourly sampling rate with only a few 12-hourly observations. Autovariance functions based on these values can be quite noisy as even numbered time lags are computed from many more data pairs than odd numbered time lags. Thus, if the number of data pairs for any odd numbered time lag was less than 25% of the number for a time lag of 24 hours, the autovariance of all odd time lags was replaced by zero before the spectrum was computed. The resulting spectrum was folded as before. When comparing spectral values in the range $k = 0, 1, \dots, 5$ for stations with 12~~and 24~~ hourly sampling rates, the latter are generally larger than the former as a consequence of this aliasing. This further should be considered in the interpretation of results. Auto-variances on the tapes have not been altered in the above manner; the possible elimination of odd numbered values only occurs during the spectrum computation. Thus, alternative spectrum computations can be performed from the basic autovariance data supplied on the tapes.

F. Cross Spectra

Seasonal cross spectra of component winds are computed between neighboring stations, and also, vertical cross spectra of winds at neighboring pressure levels are determined for the best regional stations. Forward, $R_F(\tau)$, and backward, $R_B(\tau)$ covariances for individual seasons (3) (or consolidated seasons (4)) are used to determine the even, $R_E(\tau)$, and odd, $R_O(\tau)$,

covariance functions:

$$R_E(\tau) = \frac{1}{2}[R_F(\tau) + R_B(\tau)] \quad (8)$$

$$R_O(\tau) = \frac{1}{2}[R_F(\tau) - R_B(\tau)]$$

For some stations the forward and backward covariances may be based on a predominantly 24-hourly distribution of observations, as were the auto-variances. Thus, if the number of data pairs at an odd numbered time lag was less than 25% of the number for a time lag of zero, the forward and backward covariances at all odd time lags were replaced by zero before the even and odd covariances were computed. The even and odd covariance functions of (8) are Hanned in the same manner as the autovariances (5). The corresponding cosine transform of the even covariance function to produce the cospectrum, $\hat{C}(\omega_k)$, is similar to (66):

$$\hat{C}(\omega_k) = \frac{1}{\max} \left[\hat{R}_E(0) + 2 \sum_{\tau=1}^{\max-1} \hat{R}_E(\tau) \cos(\pi k \tau / \max) + (-1)^k \hat{R}_E(\max) \right] \quad (9)$$

$$k = 0, 1, 2, \dots, \max$$

Again the cospectrum values for $k=0$ and $k=\max$ are one-half the values given by (9). The sine transform of the odd covariance function is used to define the quadrature spectrum, $\hat{Q}(\omega_k)$:

$$\hat{Q}(\omega_k) = \frac{2}{\max} \sum_{\tau=1}^{\max-1} \hat{R}_O(\tau) \sin(\pi k \tau / \max) \quad (10)$$

$$k = 0, 1, 2, \dots, \max$$

The distortion caused by Hanning of the two neighboring frequencies at both the high and low frequency extremes of the cospectrum was corrected in the same manner as the power spectrum. The quadrature spectrum does not need to be corrected because $Q(\omega_k) = 0$ for both $k = 0$ and $k = \max$ (see page 6).

The coherence, $\hat{Coh}_{ij}(\omega_k)$, is defined as:

$$\hat{Coh}_{ij}(\omega_k) = \frac{\hat{C}_{ijj}^2(\omega_k) + \hat{Q}_{ijj}^2(\omega_k)}{\hat{S}_i(\omega_k) \hat{S}_j(\omega_k)} \quad (11)$$

where $\hat{S}_i(\omega_k)$ and $\hat{S}_j(\omega_k)$ are the respective power spectra of the i and j time series. The phase, $\hat{\theta}_{ij}(\omega_k)$ was computed as:

$$\hat{\theta}_{ij}(\omega_k) = \tan^{-1} [\hat{Q}_{ij}(\omega_k) / \hat{C}_{ij}(\omega_k)] \quad (12)$$

Both coherence and phase were computed from 12-hourly autovariance data. In the event that either the covariance between the time series or their autovariances have only 24-hourly values, then the coherence and phase in the frequency range $\{2\pi(7)/12 - 2\pi(12)/12\} \text{ day}^{-1}$ cannot be defined. The corresponding values on the magnetic tapes are then zero.

III. INVENTORY OF RESULTS

Table 1 indicates tropical stations for which spectral and cross spectral parameters have been computed both for individual and consolidated seasons. The period of record of the data begins in September 1963 and

continues through

August 1964

continues through December 1970. Thus, spectral properties were computed for twenty-eight individual seasons. The approach was to compute the entire assortment of parameters for each season independent of the number of missing data. Thus, on the output tapes, AECX and AECT, there is an 880 character BCD record for each season whether there are any data present or not. Appendix i indicates the record format on the accompanying tapes.

Appendix ii indicates the distribution of stations for which power spectra and horizontal cross spectra have been computed. The master station is correlated with each of the slave stations and resulting cross spectral parameters computed. This was done for zonal and meridional wind components at 850, 500, 200, 70 and 30 mb. Tape AECT contains horizontal cross spectra and power spectra for individual seasons. Tape AECX contains vertical cross spectra and power spectra for individual seasons as well as both horizontal and vertical cross spectra and power spectra for consolidated seasons. For the vertical cross spectra the 850 and 200 mb levels are the master levels to which the remaining levels are correlated.

Some samples of statistical parameters for consolidated seasons are shown in Appendix iii (power spectra), iv (horizontal cross spectra) and v (vertical cross spectra). These results are for only those stations where the number of data at 200 mb are greater than 300. These tables summarize characteristic spectral features of the consolidated data for the best stations. The basis of the relative error of the power spectrum in Appendix iii is discussed in the next section.

Table 1. List of Stations on Tapes AECX and AECT

CARIBBEAN STATIONS

WMO NUMBER	LATITUDE	LONGITUDE	STATION NAME
61641	15N	18W	Dakar, Senegal
61902	8S	14W	Ascension Island
72201 ²	25N	82W	Key West, Florida
72202	26N	80W	Miami, Florida
76394	26N	100W	Monterrey, Mexico
76644	21N	90W	Merida, Mexico
78063	27N	78W	Gold Rock Creek, Grand Bahama
78384	19N	81W	Grand Cayman Island
78397	18N	77W	Kingston, Jamaica
78486	18N	70W	Santo Domingo, Dominican Republic
78501	17N	84W	Swan Island
78526	18N	66W	San Juan, Puerto Rico
78806	9N	80W	Balboa, Canal Zone
78967	11N	62W	Chaguaramas
78988	12N	69W	Dr. A. Plesman, Airport, Curacao
80001	13N	82W	San Andres Island

EQUATORIAL STATIONS

WMO NUMBER	LATITUDE	LONGITUDE	STATION NAME
41350	1S	73E	Gan, Maldive Islands
43369	8N	73E	Minicoy, India
43371	8N	77E ³	Trivandrum, India
48455	14N	101E	Bangkok, Thailand
48568	7N	101E	Songkhla, Thailand
48601	5N	100E	Penang, Malaysia
48694	1N	104W	Singapore Airport
63894	7S	39E	Dar es Salaam, Tanzania
64650	4N	19E	Bangui, Central African Republic
64910	4N	10E	Douala, Cameroon
65578	5N	4W	Abidjan, Ivory Coast
66160	9S	13E	Luanda, Portuguese West Africa
91334	7N	152E	Truk, Caroline Islands
91348	1	158	
	9		

Table 1. List of Stations on Tapes AECX and AECT (Cont'd)

WMO NUMBER	LATITUDE	LONGITUDE	STATION NAME
91348	7N	158E	Ponape, Caroline Islands
91366	9N	168E	Kwajalein, Marshall Islands
91376	7N	171E	Majuro, Marshall Islands
91408	7N	134E	Koror, Palau Islands
91413	9N	138E	Yap, Caroline Islands
91517	9S	160E	Honiara, British Solomon Islands
91700	3S	172W	Canton Island, Phoenix Islands
91925	10S	139W	Atuona, Marquesas Islands
94027	7S	147	Lae, New Guinea
94120	12S	131E	Darwin, Australia
96471	6N	116E	Kota Kinabalu, Malaysia
96743	6S	107E	Djakarta, Indonesia
96996	12S	97E	Cocos Island

IV. ACCURACY AND INTERPRETATION OF RESULTS

In this section ~~errors are discussed and the problems of interpreting the~~ statistical parameters as a result of deficiencies in the data. Besides problems in the basic wind data series caused by errors in measurement and transmission, already discussed in IIA, the spectral values may be degraded by poor sampling rate, missing observations, and length of record.

A. Invalidities of Power Spectra, Coherence and Phase

There are some obvious improprieties of spectral values on the output tapes; these are discussed below.

1. Negative Power Spectra

The occurrence of occasional negative values of power spectra at certain frequencies results from ~~an truncated autovariance function whose~~ absolute value does not generally decrease with time lag. This is not a serious problem here, occurring infrequently and with small magnitude with respect to other spectral values. Normally, the use of Hanning conditions the autovariance function so that negative power spectral values do not occur. However, with missing observations, the autovariance function at various lags can be based on quite different distributions of observations, and there is no assurance that a positive-semi-definite autovariance function is computed. It is to be noted that the autovariance function could be constrained to insure the positive-semi-definite condition (Peterson, 1973). However, for our purpose of comparison of spectral properties between seasons and regimes, this would

constitute an assumption on the form of the spectrum and so was not utilized.

2. Coherence Greater Than 1.00:

A similar problem occurs with regard to the coherence between two time series especially when the power spectral values of either time series are almost zero at a particular frequency (equation 11). If the distribution of data pairs as a function of time lag is different for the covariance function and the autovariance functions of the two time series as a result of missing observations, coherences larger than 1.00 may occasionally occur. (Coherence data on the magnetic tapes that are not between 0 and 1.00 are replaced by 9.99.) Thus, it is important that the relative values of the power spectra be considered when interpreting the coherence and phase, i.e., the coherence and phase should be ignored when either or both the power spectra of the individual time series are approximately zero for a particular frequency.

3. Interpreting Phase:

It should also be noted that the accuracy of phase at a particular frequency between two time series is sensitive to the value of coherence. Low values of coherence indicate a lack of significant correlation between the time series at that particular frequency and thus, phase is not very meaningful. As a result, in the sample cross spectra shown in Appendices iv and v, phases are not indicated unless the coherence was equal to or greater than .10, which corresponds to a linear correlation coefficient

of approximately .3. The coherence of both wind components for consolidated seasons is naturally a small parameter, decreasing very rapidly with distance horizontally and vertically from the master location.

4. Interpreting Spectra for Frequencies of 0 and $2\pi \text{ Day}^{-1}$

The use of Hanned autocovariance and covariance introduces smoothing into all spectral parameters (equation 7). This should of course be considered in the interpretation of these values, especially with regard to the extreme high and low frequency components of the spectrum. For instance, at the high frequency extreme, of the power spectrum $2\pi(12)/12 \text{ day}^{-1}$, some of the energy of the periodic diurnal wave is smeared into the neighboring frequency, $2\pi(11)/12 \text{ day}^{-1}$. The data also have been prefiltered to remove the energy of the low frequency components whose periods are more than 25 days (Figure 1). Thus, most of the energy at zero frequency in the spectrum results primarily from that occurring naturally at $2\pi/12 \text{ day}^{-1}$ as a result of the Hanning process.

B. Problems of Sampling

The problem of taking observations at a rate slower than higher frequency components of natural variability is termed aliasing. Properties of the high frequency components are then mixed with those of lower frequency which may result in a misinterpretation of the latter. Eddy, et al. (1968) provides a technical discussion of problems of aliasing of meteorological data. Both the problems of a discrete observation rate, 12- or

24-hourly, and ~~missing observations constitute aliasing.~~ These are discussed individually below.

1. Discrete 12- and 24-Hourly Sampling Rate:

To estimate the properties of synoptic waves, the energy contribution of frequencies greater than $2\pi/\Delta t$ ~~must be minimized.~~ Wallace (1971) indicates a reduction in amplitude of the power spectrum with increasing frequency for tropical winds and concludes that aliasing from high frequencies is not significant for synoptic spectra computed from rawinsonde data. It is to be noted that rawinsonde winds are based on averages through a layer from 2000 to 4000 feet thick (two-minute or four-minute averages, assuming a balloon ascent rate of 1000 feet/minute). This space averaging reduces the magnitude of naturally occurring high frequency wind fluctuations. The best data for objectively evaluating the magnitude of aliasing for the rawinsonde system in the tropics should include winds derived from sequences of ATS photographs. Such winds can have a resolution of twenty minutes in time and perhaps ten nautical miles horizontally. These cloud motion winds used in conjunction with a dense network of conventional data such as produced by the GATE program would constitute an excellent data base for investigating the aliasing problem.

Serious aliasing with multiple spectral folding tends to produce a uniform spectrum not unlike that of random noise. Thus, an alternative approach to evaluate the significance of aliasing is to consider the spectral distribution of energy determined from existing data. If

the spectral energy diminishes rapidly with increasing frequency and this trend is expected to extend to higher frequencies because of physical considerations, then the rate of decrease can be used to estimate the energy contribution of higher frequencies. Table 2 indicates the spectral energy for consolidated seasons in two frequency bands, $0-\pi \text{ day}^{-1}$ and $\pi-2\pi \text{ day}^{-1}$ for Kwajalein, one of the tropical stations with few missing observations. The spectral energy in these bands results from that occurring naturally at these frequencies and also includes the contributions from higher frequencies by aliasing. For instance, for a one sided spectrum the energy in the band $0-\pi \text{ day}^{-1}$ includes energy from the bands $0-\pi$, $3\pi-4\pi$, $4\pi-5\pi$, $7\pi-8\pi$, - - - day^{-1} while that in the band $\pi-2\pi$ includes contributions from $\pi-2\pi$, $2\pi-3\pi$, $5\pi-6\pi$, $6\pi-7\pi$ - - - day^{-1} . For spectra that decrease with increasing frequency, the percentage decrease from $0-\pi$ to $\pi-2\pi \text{ day}^{-1}$ is thus smaller than would occur for a non-aliased spectrum. Thus, if a model such as $S(k) = \frac{AS(k-1)}{(k-1)^2}$ is used to extend the spectrum to higher frequencies, the parameter A determined from the aliased spectrum will tend to overestimate the contribution of higher frequencies and serve as a worst case for estimating aliasing within the limitations of the model.

Using this approach, Table 2 indicates that aliasing should not be a problem in the troposphere. At stratospheric levels aliasing, however, becomes significant for the meridional component at 70 and 30 mb. In particular, at 30 mb aliasing of the meridional component may be so large as to invalidate all results. These criteria are

Table 2. Spectral Energy in the Frequency Bands $0-\pi$ and $\pi-2\pi$ day⁻¹ at Kwajalein for Consolidated Seasons. The numbers in parenthesis are for the band $\pi-2\pi$ day⁻¹.

mb	ZONAL COMPONENT				MERIDIONAL COMPONENT			
30	14.2(5.4)	11.1(4.8)	8.8(4.8)	11.2(4.4)	5.7(4.6)	5.4(4.2)	4.4(4.3)	5.4(5.0)
70	19.9(5.6)	14.5(3.5)	11.7(4.5)	12.4(3.2)	7.3(3.7)	6.2(4.2)	5.2(3.4)	5.0(3.8)
200	31.9(4.6)	35.5(4.9)	38.7(3.8)	46.1(4.9)	23.3(4.0)	30.9(5.5)	27.4(4.6)	37.9(4.1)
500	24.9(2.0)	17.1(1.7)	10.9(2.2)	17.8(1.9)	12.8(2.3)	9.5(1.8)	7.2(2.0)	9.2(2.1)
850	7.4(1.8)	7.6(1.3)	8.7(1.4)	12.7(2.0)	5.1(1.9)	4.4(1.6)	4.3(1.6)	8.7(1.8)
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn

based on an assumed modeled form of the true spectrum that is somewhat characteristic of dissipative physical processes. If the spectral energy increases with increasing frequency, then aliasing is probably an insurmountable a posteriori problem with regard to interpretation of results. Another danger is if a natural spectral gap occurs near the frequency of spectrum folding. A decrease in spectral energy is observed with increasing frequency, however, the spectrum is badly aliased.

Table 2 may also be used to help validate the consequences of a 24-hourly observation rate on the spectrum computed for some tropical stations.

In these cases the folded spectrum from $0 - \pi \text{ day}^{-1}$ contains the additional energy from $\pi - 2\pi \text{ day}^{-1}$. As a result, detailed spectra based on 24-hourly data in the stratosphere (70 and 30 mb) would be highly questionable for both wind components. Aliasing would also have some effect at lower levels, particularly 850 mb, and should be considered in the interpretation of results.

The effect of aliasing on the cross spectral parameters is similar to that of the power spectra. The coherence and phase would be based on a mixture of high and low frequency energy components arising from the cospectrum and quadrature spectrum as well as from the power spectra of the individual time series. Thus, if the power spectral values are declared invalid because of aliasing, the cross spectral properties should also not be considered.

2. Missing Observations for Individual Seasons

In order to analyze spectral parameters on an individual seasonal basis, objective estimates of error based on the number of 24-hourly or 12-hourly samples within a three month season are required. These criteria are necessary to identify the naturally occurring seasonal variability of the spectra (nonstationarity) from the variability caused by the different distributions of observations associated with individual seasons. To estimate this error, an examination of spectral variability was made as a function of increasing degradation of actual, complete time series. The resulting rms spectral variation was analyzed as a function of the number of missing observations, the total energy (variance) of the time series, and the spectral values, themselves.

a. Spectral Variability Resulting from Random Missing Observations

Briefly, a given complete time series of evenly spaced values was randomly sampled using the computer algorithm for generating random numbers. A series with 10% randomly missing data was produced; the spectrum of this ~~series was~~ determined from the estimated autocovariance function and saved internally. This procedure was repeated ten times with spectra for ten distinctive distributions of 10% missing data being produced. The rms departure of these estimates from the spectrum of complete data was then computed for each frequency band (k). These rms deviations, k , were then normalized with respect to the variance of the original time series, σ^2 .

The above technique was repeated for series containing 20, 30, 40, 50, 60 and 70% missing observations. Also, the ratio of spectral energy to white noise energy, $\hat{S}(\omega_k)/\bar{S}$, was computed for each frequency band of the complete series. This ratio is an indicator of the relative ~~energy~~ of the spectrum at a particular frequency. The white noise energy, $\bar{S}$, is the variance of the time series, σ^2 , divided by the number of complete frequency bands in the spectrum, $\max = 12$. Figure 2 indicates the normalized ~~variability of spectral values, σ_k^2/σ^2 , as a~~ function of the ratio, $\hat{S}(\omega_k)/\bar{S}$, and the percentage of missing observations. The rms variation, σ_k , for a spectral value may be estimated from the number of missing observations, the ~~spectral~~ value itself, $\hat{S}(\omega_k)$, and the variance of the time series, σ^2 . Figure 2 was based on

the spectral variability of several series of actual wind data for San Juan from 850 to 200 mb. Several fictitious series consisting of combinations of sinusoidal waves and random numbers indicated a similar relationship. The diagram can only be used for evaluating Hanned seasonal spectra with a resolution of $2\pi/12$ days⁻¹ based on times series with two observations per day. If either the length of time series, or the spectral bandwidth is changed, the magnitude of the curves in Figure 2 will be inversely changed, but their shape appears unaltered.

b. Cross Spectral Variability Resulting from Random Missing Observations

The respective rms variation of coherence and phase, σ_{coh} and σ_{θ} , as a function of the simulated joint distribution of missing observations in both series was determined in the same manner used to estimate the spectral variability.

The ratios $\hat{S}(\omega_k)/\bar{S}$ were determined for frequency bands in both time series. For a given frequency band, the rms variation of coherence and phase seemed most sensitive to the smallest ratio, $\{\hat{S}(\omega_k)/\bar{S}\}_{\text{min}}$ of either series. Figure 3 indicates the largest value of $\{\hat{S}(\omega_k)/\bar{S}\}$ minimum that was detected among the various frequency bands of test cross spectra for fixed coherence and phase accuracy criteria as a function of the joint distribution of missing data for both time series.

To use 3a and 3b to estimate confidence, incoherence and

phase for a given frequency band, the spectral values, $\hat{S}(\omega_k)$, and variances, σ^2 , of both series are required. The ratios, $\hat{S}(\omega_k)/\bar{S}$, are determined for each series and the smallest is $\{\hat{S}(\omega_k)/\bar{S}\}$ minimum. If this value is larger than the value indicated on the diagram for the joint distribution of missing observations being considered, the specified accuracy criteria is satisfied.

As for the case of spectral variability, Figure 3 can only be used for Hanned seasonal cross spectra with a bandwidth resolution of $2\pi/12$ days⁻¹. The results appeared nearly independent for various time series analyzed in this manner.

C. Statistical Variability

There are various statistical tests and confidence limits that can be applied to the computed parameters, all of which are based on the number of effective degrees of freedom in the data. It is important to realize that because of persistence in the wind component time series, the number of effective degrees of freedom can be considerably less than the number of data points minus the number of constraints. Mitchell (1963) indicates the number of effective degrees of freedom for correlations (covariances) to be

$$N^* = N \left[\frac{1 - \rho_x(1) \rho_y(1)}{1 + \rho_x(1) \rho_y(1)} \right] \quad (15)$$

for time series with persistence. Here $\rho_x(1)$ and $\rho_y(1)$ are autocorrelations indicating the persistence for time series x and time series y. These values

are best estimated by fitting the expression

$$\rho(1) = \rho(\tau)^{1/\tau} \quad (16)$$

from actual autocorrelation data, $\rho(\tau)$ for each time series. The corresponding expression for the number of effective degrees of freedom for autocorrelations can be obtained from (15) by assuming $\rho_x(1) = \rho_y(1) = \rho(1)$. The resulting computed degrees of freedom can be used in place of the number of data points in the formulas for the variance of statistical parameters (Eddy, 1968):

$$\text{Var} \{ R_{xy}(\tau) \} = \frac{2\sigma_x^{22} \sigma_y^2}{N} \left[\frac{1 + \rho_x(1) \rho_y(1)}{1 - \rho_x(1) \rho_y(1)} \right] \quad (17)$$

$$\text{Var} \{ R_{xx}(\tau) \} = \frac{2\sigma_x^4}{N} \left[\frac{1 + \rho_x^2(1)}{1 - \rho_x^2(1)} \right] \quad (18)$$

$R_{xy}(\tau)$ and $R_{xx}(\tau)$ are the respective covariances and autocorrelations for a time series at a given time lag (τ) while σ_{xx}^{22} and σ_{yy}^{22} are estimates of population variance computed from the sample. For time series with missing observations, N may also be regarded as a function of time lag. The corresponding expression for the variance of a Hanned spectral estimate from a time series with persistence is given by:

$$\text{Var} \{ \hat{S}_i(\omega_k) \} = \frac{2 \bar{S}_i^2(\omega_k) \max}{N} \left[\frac{1 + \rho^2(1)}{1 - \rho^2(1)} \right] \left[\frac{1 - 2\rho(1) \cos(\omega_k) + \rho^2(1)}{1 - \rho^2(1)} \right] \quad (19)$$

Here $\max$ is the number of spectral bands (122 for these results) and $\bar{S}_i(\omega_k)$ is the expected population value of the Hanned spectrum at frequency ω_k . The computed value $\hat{S}_i(\omega_k)$ from the sample can be used as an estimate of the

expected value. Persistence tends to minimize the significance of high frequencies because of dampening. The last term in parentheses accounts for this decrease in the effective degrees of freedom with an increase in frequency. The relative spectral error, ϵ , can be defined from (19) as

$$\epsilon = \left[\text{Var} \{ \hat{S}_i(\omega_k) \} / \bar{S}_i^2(\omega_k) \right]^{1/2} \quad (20)$$

This expression was used to define the relative errors of the consolidated seasonal spectra in Appendix i.

More general confidence limits may also be derived, as the ratio of the sampled spectral value to population value is a multiple of a Chi-squared variable with N'' effective degrees of freedom:

$$N'' = \frac{N}{\max} \left[\frac{1 - \rho^2(1)}{1 + \rho^2(1)} \right] \left[\frac{1 - \rho^2(1)}{1 - 2\rho(1) \cos \omega + \rho^2(1)} \right] \quad (21)$$

Confidence limits (95% - 5% etc.) can then be found from Chi-squared tables by dividing the respective tabulated values by the number of effective degrees of freedom (N''). For example for $N'' = 30$, the Chi-squared value for 95% confidence limits is 43.77 and for 5% is 18.49. Thus, there is a 95% chance that (the sample spectral value/population spectral value) is less than $43.77/30 = 1.46$. Also there is a 5% chance that this ratio is less than $18.49/30 = .62$. The population value is usually estimated from a spectral model such as a second order Markoff process with persistence $\rho(1)$. A comparison of observed and model statistics with regard to the confidence

limits can be used to accept or reject the model hypotheses.

Panofsky and Briand (1958) indicate a comparable formula for indicating the confidence limits for the coherence.

$$\beta = \left[1 - \rho^{1/(N''-1)} \right]^{\frac{1}{2}} \quad (22)$$

Here, the probability level ρ is expressed in decimal form as .05, .10, etc., and β is the upper limit of coherence corresponding to the respective probability level. Accuracy in phase depends on the absolute values of coherence, of cospectrum and quadrature spectrum as well as the variability of the parameters. Because the coherence is generally small, no objective criteria for rms phase variations was described.

D. Physical Versus Statistical Interpretation

The choice of criteria formulated in sections B2 and C for validating the spectral parameters as a function of the number of data depends on the particular application. The rms variability resulting from random missing observations derived in B2 is useful for qualifying a physical diagnostic interpretation of individual seasonal parameters. In this case, differences in spectral properties of synoptic waves for individual seasons can be compared and also studied with respect to other atmospheric variables within the limits of variability imposed by the missing data. In contrast, the statistical criteria of C can be used to test the computed parameters with respect to hypothetical models and to provide confidence limits for consolidated seasons. In the latter case, the variability of seasonal

climatic spectral parameters can be ~~formulated in terms of the number of~~ independent samples. Julian (1971) gives an informative discussion on the use and ~~mis~~use of statistical confidence limits for the time spectrum of meteorological parameters.

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Figure 1. Gaussian filter response function

Figure 2. Normalized variation of spectral estimates $(\sigma_k/\sigma^2)m^{-1}\text{sec}$ as a function of percent complete data and $\hat{S}(u_k)/\bar{S}$ ratio, based on seasonal records, sampled twice daily, and a Hanned spectrum with a resolution of $2\pi/12 \text{ day}^{-1}$.

Figure 3. As a function of the joint distribution of missing observations in two time series, the largest $\hat{S}(\omega_k)/\hat{S}_{\min}$ ratio is indicated (a) for which the rms variation of coherence equals 0.2; (b) for which the rms variation of phase angle equals $22\frac{1}{2}^\circ$. Both diagrams can be used only for seasonal records, sampled twice daily, and for Hanned spectra with a resolution of $2\pi/12 \text{ days}^{-1}$.

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Appendix i
Appendix i: Magnetic Tape Format

880 Character Record Tape Format

<u>FIELD</u>	<u>CHARACTERS</u>	<u>FORMAT</u>	<u>DESCRIPTION</u>
1	1-6	I6	Master station number (WMO); see Table 1.
2	7-9	I3	Master station level (1-12); see Note A.
3	10-15	I6	Slave station number (WMO); see Table 1.
4	16-18	I3	Slave station level (1-12); see Note A.
5	19-20	I2	Season; see Note B.
6.	21-25	I5	Year (1964, 1965, . . .)
7	26-30	I5	Length of period; see Note C.
8-20	31-108	13F6.1	Autovariances for series 1 at 13 lags (m^2/sec^2); see Note D.
21-33	109-186	13F6.1	Autovariances for series 2 at 13 lags (m^2/sec^2).
34-46	187-264	13F6.1	Positive lag covariances at 13 lags (m^2/sec^2).
47-59	265-342	13F6.1	Negative lag covariances at 13 lags (m^2/sec^2).
60	343-345	3X	Three blanks
61-73	346-410	13I5	Number of data pairs in autovariances for series 1 at 13 lags.
74-86	411-475	13I5	Number of data pairs in autovariances for series 2 at 13 lags.
87-99	476-540	13I5	Number of data pairs in positive lag covariances at 13 lags.
100-112	541-605	13I5	Number of data pairs in negative lag covariances at 13 lags.
113	606	1X	One blank
114-126	607-684	13F6.1	Spectral values for series 1 at 13 frequencies (m^2/sec^2) $\div (\pi/12)$
127-139	685-762	13F6.1	Spectral values for series 2 at 13 frequencies (m^2/sec^2) $\div (\pi/12)$
140-152	763-814	13F4.2	Coherence <u>squared</u>
153	815	1X	One blank
154-166	816-880	13F5.0	Phase (degrees)

NOTES A, B, C, D

NOTE A: Following is a list of all levels appearing on the tapes.

LEVEL NUMBER	MILLIBAR LEVEL	PARAMETER
1	1000	u
2	850	u
3	500	u
4	200	u
5	70	u
6	30	u
7	1000	v
8	850	v
9	500	v
10	200	v
11	70	v
12	30	v

NOTE B: Seasons; 1 = Winter
 2 = Spring
 3 = Summer
 4 = Autumn

NOTE C: The length of the period is the number of observations when none are missing.

NOTE D: Values that are invalid or undefined have all digits set to 9, e.g., 9999.9.

Appendix ii: Statistical Parameters on Tapes AECT and AECX

TAPE AECT

Files 1-6 contain individual seasonal horizontal cross-spectra for Caribbean stations, 1964-1970.

Files 7-15 contain individual seasonal horizontal cross-spectra for equatorial stations, 1964-1970. File 15 has data only for years 1967-1970.

FILE	NUMBER OF RECORDS	MASTER	SLAVE 1	SLAVE 2	SLAVE 3	SLAVE 4	SLAVE 5
1	840	80001	78806	78988	78967		
2	840	78967	80001	78806	78988		
3	840	72202	78063	76394	72201		
4	1400	78526	78501	78486	78397	78384	76644
5	1400	78501	78526	78486	78397	78384	76644
6	280	61641	61902				
7	560	43371	43369	41350			
8	560	91408	91700	91413			
9	560	48568	48694	48601			
10	560	48568	48455	96471			
11	840	91366	91376	91348	91334		
12	840	91348	91376	91366	91334		
13	280	63894	66160				
14	560	64910	65578	64650			
15	800	91517	96996	96743	94120	94027	91925

TAPE AECX

Files 1-6 contain consolidated seasonal horizontal cross-spectra for Caribbean stations.

Files 7-15 contain consolidated seasonal horizontal cross-spectra for equatorial stations.

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Appendix ii (Cont'd)

Files 16-29 contain consolidated seasonal vertical cross-spectra for 14 stations.

Files 30-43 contain individual seasonal vertical cross-spectra for 14 stations.

FILE	NUMBER OF RECORDS	MASTER	SLAVE 1	SLAVE 2	SLAVE 3	SLAVE 4	SLAVE 5
1	120	80001	78806	78988	78967		
2	120	78967	80001	78806	78988		
3	120	72202	78063	76394	72201		
4	200	78526	78501	78486	78397	78384	76644
5	200	78501	78526	78486	78397	78384	76644
6	40	61641	61902				
7	80	43371	43369	41350			
8	80	91408	91700	91413			
9	80	48568	48694	48601			
10	80	48568	48455	96471			
11	120	91366	91376	91348	91334		
12	120	91348	91376	91366	91334		
13	40	63894	66160				
14	80	64910	65578	64650			
15	200	91517	96996	96743	94120	94027	91925
16	64	91517					
17	64	91408					
18	64	91366					
19	64	91348					
20	64	64910					
21	64	63894					
22	64	48568					
23	64	43371					
24	64	80001					
25	64	78967					
26	64	78967					
27	64	78967					
28	64	78967					
29	64	78967					
30	64	78967					
31	64	78967					
32	64	78967					
33	64	78967					
34	64	78967					
35	64	78967					
36	64	78967					
37	64	78967					
38	64	78967					
39	64	78967					
40	64	78967					
41	64	78967					
42	64	78967					
43	64	78967					

Appendix ii (Cont'd)Appendix ii (Cont'd)

FILE	NUMBER OF RECORDS	MASTER	SLAVE 1	SLAVE 2	SLAVE 3	SLAVE 4	SLAVE 5
26	64	78526					
27	64	78501					
28	64	72202					
29	64	61641					
30	256	91517					
31	448	91408					
32	448	91366					
33	448	91348					
34	448	64910					
35	448	63894					
36	448	48568					
37	448	43371					
38	448	80001					
39	448	78967					
40	448	78526					
41	448	78501					
42	448	72202					
43	448	61641					

WIND COMPONENT SPECTRA (M/SEC)2 X (6/PI) DAYS													FOR STATION 61902	AUTUMN
ZONAL WINDS														
30 MB	2.2	4.1	4.9	4.2	2.9	2.2	1.8	1.2	1.0	.9	1.2	2.4	1.6	
70 MB	3.4	6.2	6.4	4.6	2.7	1.7	1.2	.9	.9	1.0	.9	.3	.7	
200 MB	29.4	34.7	20.3	6.7	4.2	3.4	3.1	2.3	2.0	1.9	.9	.9	2.2	
500 MB	6.0	9.2	6.9	2.8	1.3	.7	.4	.5	.4	.4	.5	.5	.9	
850 MB	3.2	5.9	5.6	3.0	1.3	.7	.6	.6	.5	.3	.4	.0	.5	
PERCENTAGE RELATIVE ERROR														
30 MB	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	
70 MB	11.	11.	12.	13.	14.	15.	16.	17.	18.	18.	19.	19.	19.	
200 MB	10.	11.	14.	17.	21.	24.	28.	30.	33.	35.	36.	37.	38.	
500 MB	10.	11.	14.	17.	20.	24.	27.	30.	32.	34.	36.	37.	37.	
850 MB	10.	11.	12.	14.	16.	19.	20.	21.	23.	24.	25.	26.	26.	
MERIDIONAL WINDS														
30 MB	.2	1.1	2.0	2.8	2.7	2.0	1.9	2.0	1.9	1.5	1.3	1.3	1.0	
70 MB	.4	1.4	3.2	4.0	2.6	1.5	1.1	.9	.9	1.0	1.0	1.0	.8	
200 MB	18.6	26.7	21.5	10.4	5.2	2.8	1.4	1.3	1.1	1.1	2.4	2.2	3.2	
500 MB	1.7	3.6	4.2	2.9	1.7	1.0	.6	.6	.5	.4	.5	.5	.7	
850 MB	.7	1.9	2.9	2.8	1.8	.8	.5	.4	.4	.5	.4	.2	.4	
PERCENTAGE RELATIVE ERROR														
30 MB	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	
70 MB	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	
200 MB	10.	11.	13.	16.	19.	22.	25.	28.	30.	32.	33.	34.	34.	
500 MB	11.	11.	12.	13.	14.	15.	16.	17.	18.	19.	19.	20.	20.	
850 MB	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	
PERIOD(DAYS)	12.0	6.0	4.0	3.0	2.4	2.0	1.7	1.5	1.3	1.2	1.1	1.0		

Appendix iii(a) - Autumn wind spectra for Ascension Is. (8°S, 14°W).

WIND COMPONENT SPECTRA (M/SEC)2 X (6/PI) DAYS FOR STATION 78967 AUTUMN													
ZONAL WINDS													
30 MB	2.7	4.6	4.2	2.5	2.2	2.1	1.5	1.1	1.8	2.1	1.4	1.3	1.2
70 MB	2.9	4.3	4.2	3.3	2.1	1.5	1.8	1.8	1.5	1.2	1.3	.9	1.0
200 MB	21.8	31.6	20.8	6.9	3.8	2.9	2.5	1.9	1.5	2.0	2.8	2.7	3.2
500 MB	3.7	6.5	6.2	3.3	1.4	.7	.6	.7	.6	.3	.4	.4	.8
850 MB	3.0	4.5	3.5	1.7	.9	.6	.6	.6	.6	.4	.2	.0	.4
PERCENTAGE RELATIVE ERROR													
30 MB	15.	15.	15.	16.	17.	18.	19.	20.	21.	21.	22.	22.	22.
70 MB	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.
200 MB	12.	13.	16.	20.	23.	27.	31.	34.	37.	39.	41.	42.	42.
500 MB	11.	12.	14.	16.	18.	21.	23.	25.	27.	29.	30.	30.	30.
850 MB	11.	12.	13.	15.	17.	20.	22.	24.	25.	27.	28.	28.	29.
MERIDIONAL WINDS													
30 MB	.3	1.1	1.8	1.8	1.6	1.6	1.5	1.5	1.2	.9	.9	.7	.7
70 MB	.5	1.4	2.1	2.1	1.7	1.6	1.2	.9	1.1	1.4	1.3	1.5	.9
200 MB	13.1	19.2	14.2	8.5	6.0	2.5	1.2	1.1	1.0	2.1	4.1	2.8	2.7
500 MB	1.3	2.8	3.2	2.6	1.9	1.2	.9	.6	.4	.3	.4	.5	.6
850 MB	1.4	3.2	3.1	2.0	1.4	.9	.8	.7	.5	.4	.5	.5	.5
PERCENTAGE RELATIVE ERROR													
30 MB	17.	17.	17.	17.	17.	17.	17.	17.	17.	17.	17.	17.	17.
70 MB	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.
200 MB	12.	13.	15.	18.	21.	24.	26.	29.	31.	33.	34.	35.	35.
500 MB	15.	15.	15.	15.	15.	15.	15.	15.	15.	15.	15.	15.	15.
850 MB	12.	13.	13.	14.	15.	16.	17.	18.	19.	20.	20.	21.	21.
PERIOD(DAYS)	12.0	6.0	4.0	3.0	2.4	2.0	1.7	1.5	1.3	1.2	1.1	1.0	1.0

Appendix iii(b) - Autumn wind spectra for Trinidad (11°N, 62°W).

WIND COMPONENT SPECTRA (M/SEC)2 X (6/PI) DAYS													FOR STATION 80001		AUTUMN	
ZONAL WINDS																
30 MB	3.8	7.3	6.4	4.9	3.7	3.9	5.1	4.5	3.4	3.0	3.3	3.1	2.1			
70 MB	2.5	4.2	3.1	2.1	2.1	1.5	1.3	1.6	1.7	1.8	2.4	3.2	1.9			
200 MB	13.1	16.1	11.0	5.3	3.9	3.3	2.8	2.9	3.4	3.4	3.1	2.0	2.5			
500 MB	6.8	10.3	8.1	4.1	2.4	1.5	1.3	1.1	1.0	1.0	1.0	.3	1.0			
850 MB	5.4	6.8	5.0	2.1	.9	.8	.7	.7	.5	.5	.6	.6	.9			
PERCENTAGE RELATIVE ERROR																
30 MB	17.	17.	17.	17.	17.	17.	17.	17.	17.	17.	17.	17.	17.			
70 MB	12.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	21.	21.			
200 MB	10.	10.	11.	12.	14.	15.	17.	19.	19.	20.	21.	22.	22.			
500 MB	9.	9.	10.	12.	14.	16.	17.	19.	20.	21.	22.	22.	23.			
850 MB	9.	9.	11.	13.	15.	18.	20.	22.	24.	25.	26.	27.	27.			
MERIDIONAL WINDS																
30 MB	5.7	5.3	3.1	1.7	2.2	2.8	2.2	1.5	1.6	1.5	1.4	.4	.5			
70 MB	.4	1.2	1.4	1.4	1.4	1.2	1.1	1.1	1.3	1.4	1.4	1.4	.8			
200 MB	6.7	12.0	11.3	7.6	5.3	4.1	4.0	3.7	3.3	3.8	3.9	3.2	2.7			
500 MB	1.9	3.4	3.8	2.9	2.1	1.7	1.4	1.3	1.1	1.1	1.0	1.2	1.0			
850 MB	2.0	3.4	2.8	1.5	1.0	.9	.9	.9	.8	.7	.6	.5	.6			
PERCENTAGE RELATIVE ERROR																
30 MB	13.	14.	16.	18.	21.	24.	27.	29.	31.	33.	35.	35.	36.			
70 MB	15.	15.	15.	15.	15.	15.	15.	15.	15.	15.	15.	15.	15.			
200 MB	10.	11.	11.	12.	12.	13.	14.	15.	15.	16.	16.	16.	16.			
500 MB	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.			
850 MB	19.	10.	10.	11.	12.	13.	14.	15.	15.	16.	16.	17.	17.			
PERIOD(DAYS)	12.0	6.0	4.0	3.0	2.4	2.0	1.7	1.5	1.3	1.2	1.1	1.0				

Appendix iii(c) - Autumn wind spectra for San Andreas (13°N, 82°W).

WIND COMPONENT SPECTRA (M/SEC)2 X (6/PI) DAYS								FOR STATION 41350				AUTUMN	
ZONAL WINDS													
30 MB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70 MB	-1.0	8.5	12.8	12.0	16.3	17.6	7.5	0.0	0.0	0.0	0.0	0.0	0.0
200 MB	19.7	26.7	22.6	18.0	15.7	12.2	5.5	0.0	0.0	0.0	0.0	0.0	0.0
500 MB	5.3	9.4	7.9	3.6	1.8	2.6	1.7	0.0	0.0	0.0	0.0	0.0	0.0
850 MB	5.4	7.3	4.9	2.6	2.2	2.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0
PERCENTAGE RELATIVE ERROR													
30 MB	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
70 MB	23.	23.	23.	23.	23.	23.	23.	0.	0.	0.	0.	0.	0.
200 MB	14.	15.	17.	20.	22.	23.	24.	0.	0.	0.	0.	0.	0.
500 MB	12.	14.	18.	22.	26.	28.	29.	0.	0.	0.	0.	0.	0.
850 MB	11.	13.	18.	22.	26.	29.	29.	0.	0.	0.	0.	0.	0.
MERIDIONAL WINDS													
30 MB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70 MB	2.1	5.0	7.2	6.3	5.1	8.2	5.5	0.0	0.0	0.0	0.0	0.0	0.0
200 MB	5.4	9.7	11.9	10.1	6.8	4.9	2.3	0.0	0.0	0.0	0.0	0.0	0.0
500 MB	1.7	6.1	7.0	4.2	2.0	1.8	1.1	0.0	0.0	0.0	0.0	0.0	0.0
850 MB	3.1	6.1	5.4	2.9	1.7	1.5	.8	0.0	0.0	0.0	0.0	0.0	0.0
PERCENTAGE RELATIVE ERROR													
30 MB	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
70 MB	23.	23.	23.	23.	23.	23.	23.	0.	0.	0.	0.	0.	0.
200 MB	14.	15.	17.	19.	20.	21.	22.	0.	0.	0.	0.	0.	0.
500 MB	12.	13.	16.	19.	21.	23.	24.	0.	0.	0.	0.	0.	0.
850 MB	11.	13.	16.	20.	23.	25.	26.	0.	0.	0.	0.	0.	0.
PERIOD(DAYS)	12.0	6.0	4.0	3.0	2.4	2.0	1.7	1.5	1.3	1.2	1.1	1.0	1.0

Appendix iii(d) - Autumn wind spectra for Gan (1°S, 73°E).

WIND COMPONENT SPECTRA (M/SEC)2 X (6/PI) DAYS								FOR STATION 43371 - AUTUMN					
ZONAL WINDS													
30 MB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70 MB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
200 MB	9.5	13.4	10.9	9.0	7.0	4.1	2.4	3.6	4.4	4.0	4.0	5.7	4.0
500 MB	8.5	11.1	8.0	4.2	3.3	2.6	1.9	1.3	.9	1.0	.9	.5	1.2
850 MB	5.6	5.8	3.7	1.8	1.1	.9	1.1	1.2	.9	.9	1.1	.8	.9
PERCENTAGE RELATIVE ERROR													
30 MB	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
70 MB	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
200 MB	14.	15.	16.	17.	18.	20.	21.	23.	24.	25.	26.	27.	27.
500 MB	12.	13.	14.	16.	18.	20.	22.	24.	25.	27.	28.	28.	28.
850 MB	11.	12.	14.	16.	19.	22.	24.	27.	29.	30.	31.	32.	32.
MERIDIONAL WINDS													
30 MB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70 MB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
200 MB	2.3	3.8	5.7	5.1	3.4	2.8	2.6	2.3	2.5	3.0	3.0	1.9	1.8
500 MB	1.2	2.6	2.9	2.1	1.7	1.5	1.1	1.0	.8	.7	1.0	1.2	.9
850 MB	1.1	2.5	2.6	1.6	.9	.5	.5	.6	.7	.6	.6	.6	.6
PERCENTAGE RELATIVE ERROR													
30 MB	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
70 MB	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
200 MB	18.	18.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	18.
500 MB	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.
850 MB	12.	13.	13.	14.	15.	17.	18.	19.	20.	21.	22.	22.	22.
PERIOD(DAYS)		12.0	6.0	4.0	3.0	2.4	2.0	1.7	1.5	1.3	1.2	1.1	1.0

Appendix iii(e) - Autumn wind spectra for Trivandrum (8°N, 77°E).

WIND COMPONENT SPECTRA (M/SEC)2 X (6/PI) DAYS								FOR STATION 48568				AUTUMN	
ZONAL WINDS													
30 MB	3.5	10.6	10.0	9.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70 MB	1.5	4.8	5.9	4.8	3.6	2.8	2.9	3.2	2.8	2.6	2.8	1.1	1.4
200 MB	10.7	13.8	9.9	5.3	3.8	3.9	4.2	4.5	4.5	3.9	2.9	2.2	2.3
500 MB	7.4	9.4	6.6	3.0	1.9	1.8	1.8	1.5	1.3	1.1	1.1	.9	1.3
850 MB	8.4	9.3	6.4	3.0	1.7	1.4	1.3	1.2	.9	.8	1.0	1.0	1.4
PERCENTAGE RELATIVE ERROR													
30 MB	20.	24.	33.	45.	0.	0.	0.	0.	0.	0.	0.	0.	0.
70 MB	21.	21.	21.	21.	21.	21.	21.	21.	21.	21.	21.	21.	21.
200 MB	11.	11.	12.	12.	13.	14.	15.	16.	17.	18.	18.	19.	19.
500 MB	9.	10.	11.	13.	15.	17.	19.	20.	22.	23.	24.	24.	25.
850 MB	9.	10.	11.	13.	16.	18.	20.	22.	24.	26.	27.	27.	27.
MERIDIONAL WINDS													
30 MB	-1.0	.4	1.4	1.6	2.0	3.1	3.0	1.4	.7	1.4	1.7	1.8	1.0
70 MB	-.2	1.3	2.0	2.1	2.3	2.2	1.7	1.0	.9	1.3	1.7	1.1	.9
200 MB	3.1	4.6	5.2	5.1	5.3	5.1	4.2	3.6	3.3	3.2	3.5	3.6	2.6
500 MB	2.0	3.9	4.2	3.1	2.3	1.6	1.0	.9	.9	1.0	.9	.5	.9
850 MB	1.3	2.9	2.7	1.5	1.0	1.0	.8	.7	.6	.8	.9	.8	.7
PERCENTAGE RELATIVE ERROR													
30 MB	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.
70 MB	21.	21.	21.	21.	21.	21.	21.	21.	21.	21.	21.	21.	21.
200 MB	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.
500 MB	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.
850 MB	10.	10.	11.	11.	12.	13.	14.	15.	16.	16.	17.	17.	17.
PERIOD(DAYS)		12.0	6.0	4.0	3.0	2.4	2.0	1.7	1.5	1.3	1.2	1.1	1.0

Appendix iii(f) - Autumn wind spectra for Songkhla (7°N, 101°E).

WIND COMPONENT SPECTRA (M/SEC)2 X (6/PI) DAYS								FOR STATION 48694				AUTUMN	
ZONAL WINDS													
30 MB	3.6	12.2	12.6	12.2	12.5	9.8	4.0	0.0	0.0	0.0	0.0	0.0	0.0
70 MB	6.6	16.6	16.8	15.3	15.7	16.2	9.1	0.0	0.0	0.0	0.0	0.0	0.0
200 MB	9.2	14.0	11.9	7.6	6.8	6.1	2.7	0.0	0.0	0.0	0.0	0.0	0.0
500 MB	4.5	7.3	6.1	3.3	2.0	1.2	.4	0.0	0.0	0.0	0.0	0.0	0.0
850 MB	3.2	4.9	4.0	2.4	1.7	1.1	.4	0.0	0.0	0.0	0.0	0.0	0.0
PERCENTAGE RELATIVE ERROR													
30 MB	21.	21.	21.	21.	21.	21.	21.	0.	0.	0.	0.	0.	0.
70 MB	15.	15.	15.	15.	15.	15.	15.	0.	0.	0.	0.	0.	0.
200 MB	10.	11.	13.	15.	17.	18.	18.	0.	0.	0.	0.	0.	0.
500 MB	9.	11.	15.	19.	23.	25.	26.	0.	0.	0.	0.	0.	0.
850 MB	8.	10.	13.	16.	19.	21.	21.	0.	0.	0.	0.	0.	0.
MERIDIONAL WINDS													
30 MB	.2	3.2	6.5	8.2	6.3	3.3	1.2	0.0	0.0	0.0	0.0	0.0	0.0
70 MB	1.3	2.8	4.6	5.3	3.7	2.8	1.5	0.0	0.0	0.0	0.0	0.0	0.0
200 MB	3.0	5.8	7.5	6.5	4.4	3.7	1.9	0.0	0.0	0.0	0.0	0.0	0.0
500 MB	1.2	2.7	3.2	2.7	1.7	1.0	.4	0.0	0.0	0.0	0.0	0.0	0.0
850 MB	2.5	4.7	4.2	2.2	1.2	.9	.4	0.0	0.0	0.0	0.0	0.0	0.0
PERCENTAGE RELATIVE ERROR													
30 MB	21.	21.	21.	21.	21.	21.	21.	0.	0.	0.	0.	0.	0.
70 MB	15.	15.	15.	15.	15.	15.	15.	0.	0.	0.	0.	0.	0.
200 MB	13.	13.	13.	13.	13.	13.	13.	0.	0.	0.	0.	0.	0.
500 MB	10.	10.	12.	13.	15.	16.	16.	0.	0.	0.	0.	0.	0.
950 MB	8.	10.	13.	17.	20.	22.	23.	0.	0.	0.	0.	0.	0.
PERIOD(DAYS)	12.0	6.0	4.0	3.0	2.4	2.0	1.7	1.5	1.3	1.2	1.1	1.0	

Appendix iii(g) - Autumn wind spectra for Singapore (1°N, 104°W).

WIND COMPONENT SPECTRA (M/SEC)2 X (6/PI) DAYS								FOR STATION. 65579				AUTUMN	
ZONAL WINDS													
30 MB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70 MB	2.0	9.9	12.0	9.5	10.4	12.1	6.1	0.0	0.0	0.0	0.0	0.0	0.0
200 MB	16.6	24.0	18.7	10.8	9.4	9.3	4.6	0.0	0.0	0.0	0.0	0.0	0.0
500 MB	2.5	4.9	5.1	3.4	2.3	1.9	.9	0.0	0.0	0.0	0.0	0.0	0.0
850 MB	1.5	2.8	3.2	2.6	2.0	1.7	.9	0.0	0.0	0.0	0.0	0.0	0.0
PERCENTAGE RELATIVE ERROR													
30 MB	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
70 MB	16.	16.	16.	16.	16.	16.	16.	0.	0.	0.	0.	0.	0.
200 MB	9.	10.	12.	15.	17.	18.	18.	0.	0.	0.	0.	0.	0.
500 MB	9.	10.	11.	13.	15.	16.	16.	0.	0.	0.	0.	0.	0.
950 MB	11.	11.	11.	11.	11.	11.	11.	0.	0.	0.	0.	0.	0.
MERIDIONAL WINDS													
30 MB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70 MB	1.2	6.4	10.9	11.4	9.6	9.7	5.4	0.0	0.0	0.0	0.0	0.0	0.0
200 MB	9.4	13.0	13.0	11.5	9.5	9.1	4.0	0.0	0.0	0.0	0.0	0.0	0.0
500 MB	1.0	2.9	4.0	3.5	2.5	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
850 MB	.8	2.3	3.5	3.4	2.6	2.3	1.2	0.0	0.0	0.0	0.0	0.0	0.0
PERCENTAGE RELATIVE ERROR													
30 MB	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
70 MB	16.	16.	16.	16.	16.	16.	16.	0.	0.	0.	0.	0.	0.
200 MB	12.	12.	12.	12.	12.	12.	12.	0.	0.	0.	0.	0.	0.
500 MB	11.	11.	11.	11.	11.	11.	11.	0.	0.	0.	0.	0.	0.
850 MB	11.	11.	11.	11.	11.	11.	11.	0.	0.	0.	0.	0.	0.
PERIOD(DAYS)	12.0	6.0	4.0	3.0	2.4	2.0	1.7	1.5	1.3	1.2	1.1	1.0	1.0

Appendix iii(h) - Autumn wind spectra for Abidjan (5°N, 4°W).

WIND COMPONENT SPECTRA (M/SEC) 2 X (6/PI) DAYS								FOR STATION 66160				AUTUMN	
ZONAL WINDS													
30 MB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70 MB	11.6	15.3	19.1	20.5	19.2	13.4	5.1	0.0	0.0	0.0	0.0	0.0	0.0
200 MB	22.9	32.5	33.3	24.1	11.4	5.6	3.0	0.0	0.0	0.0	0.0	0.0	0.0
500 MB	10.0	13.0	10.2	7.2	6.0	5.2	2.6	0.0	0.0	0.0	0.0	0.0	0.0
850 MB	1.9	3.0	3.0	2.2	1.9	2.1	1.1	0.0	0.0	0.0	0.0	0.0	0.0
PERCENTAGE RELATIVE ERROR													
30 MB	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
70 MB	23.	23.	23.	23.	23.	23.	23.	0.	0.	0.	0.	0.	0.
200 MB	12.	14.	19.	24.	28.	30.	31.	0.	0.	0.	0.	0.	0.
500 MB	12.	13.	15.	18.	21.	22.	23.	0.	0.	0.	0.	0.	0.
850 MB	14.	14.	14.	14.	14.	14.	14.	0.	0.	0.	0.	0.	0.
MERIDIONAL WINDS													
30 MB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70 MB	6.4	22.9	33.7	22.9	11.7	23.3	17.7	0.0	0.0	0.0	0.0	0.0	0.0
200 MB	4.1	11.8	18.4	15.6	12.7	15.4	8.6	0.0	0.0	0.0	0.0	0.0	0.0
500 MB	1.9	4.9	5.8	5.2	5.2	5.1	2.5	0.0	0.0	0.0	0.0	0.0	0.0
850 MB	1.0	2.5	3.5	3.5	2.8	2.5	1.4	0.0	0.0	0.0	0.0	0.0	0.0
PERCENTAGE RELATIVE ERROR													
30 MB	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
70 MB	23.	23.	23.	23.	23.	23.	23.	0.	0.	0.	0.	0.	0.
200 MB	16.	16.	16.	16.	16.	16.	16.	0.	0.	0.	0.	0.	0.
500 MB	15.	15.	15.	15.	15.	15.	15.	0.	0.	0.	0.	0.	0.
850 MB	14.	14.	14.	14.	14.	14.	14.	0.	0.	0.	0.	0.	0.
PERIOD(DAYS)		12.0	6.0	4.0	3.0	2.4	2.0	1.7	1.5	1.3	1.2	1.1	1.0

Appendix iii(i) - Autumn wind spectra for Luanda (9°S, 13°E).

WIND COMPONENT SPECTRA (M/SEC)2 X (6/PI) DAYS													FOR STATION 91366		AUTUMN	
ZONAL WINDS																
30 MB	1.9	3.6	3.7	3.2	3.4	3.1	2.6	2.3	1.6	.9	1.1	1.3	1.3			
70 MB	3.2	5.1	4.4	3.5	3.3	2.5	1.7	1.2	1.1	1.2	1.1	.6	.8			
200 MB	21.1	28.5	20.6	8.5	4.2	2.9	2.2	2.1	2.1	1.9	1.7	-.4	2.2			
500 MB	6.3	9.8	8.3	4.3	2.2	1.7	1.4	.9	.7	.6	.6	.1	.9			
850 MB	4.6	7.5	6.0	3.0	1.6	.8	.7	.7	.8	.7	.6	.3	.7			
PERCENTAGE RELATIVE ERROR																
30 MB	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.			
70 MB	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.			
200 MB	8.	9.	10.	12.	14.	17.	19.	20.	22.	23.	24.	25.	25.			
500 MB	8.	9.	10.	11.	13.	14.	16.	17.	19.	20.	20.	21.	21.			
850 MB	8.	9.	10.	11.	13.	15.	17.	18.	20.	21.	22.	22.	22.			
MERIDIONAL WINDS																
30 MB	.5	1.4	1.8	1.7	1.7	1.7	1.5	1.5	1.6	1.6	1.6	2.0	1.2			
70 MB	.2	.9	1.3	1.8	2.0	1.8	1.7	1.6	1.6	1.5	1.2	.7	.6			
200 MB	11.9	18.6	17.3	11.5	6.6	3.5	2.9	2.5	1.7	1.2	1.0	-.4	1.7			
500 MB	1.2	2.8	4.1	3.9	2.7	1.7	1.2	.8	.7	.8	.7	.4	.7			
950 MB	.8	2.4	4.2	4.5	2.5	1.1	1.0	.8	.6	.5	.6	.3	.6			
PERCENTAGE RELATIVE ERROR																
30 MB	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.			
70 MB	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.			
200 MB	9.	9.	10.	11.	12.	13.	14.	16.	17.	17.	19.	19.	18.			
500 MB	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.			
850 MB	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.			
PERIOD(DAYS)	12.0	6.0	4.0	3.0	2.4	2.0	1.7	1.5	1.3	1.2	1.1	1.0	1.0			

Appendix iii(j) - Autumn wind spectra for Kwajalein (9°N, 168°E).

WIND COMPONENT SPECTRA (M/SEC) 2 X (6/PI) DAYS													FOR STATION 91408		AUTUMN	
ZONAL WINDS																
30 MB	1.8	4.3	5.0	4.5	4.0	3.3	3.0	2.7	2.7	2.7	2.4	1.9	1.7			
70 MB	2.6	6.6	6.3	4.0	3.2	2.5	1.8	1.6	1.4	1.0	1.0	1.2	1.3			
200 MB	9.4	12.5	12.6	8.8	5.3	4.1	4.0	3.4	3.0	3.0	2.5	1.2	2.5			
500 MB	11.9	17.5	14.0	5.9	2.4	1.9	1.6	1.1	.9	.8	.6	.8	1.2			
850 MB	17.6	19.5	11.8	4.0	1.9	1.2	.9	.7	.7	.5	.3	1.3	1.0			
PERCENTAGE RELATIVE ERROR																
30 MB	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.			
70 MB	11.	11.	12.	12.	13.	13.	14.	15.	16.	16.	16.	17.	17.			
200 MB	10.	11.	11.	12.	12.	13.	14.	15.	16.	16.	17.	17.	17.			
500 MB	9.	9.	11.	13.	16.	18.	20.	23.	24.	26.	27.	27.	29.			
850 MB	8.	10.	12.	16.	20.	23.	26.	29.	32.	34.	35.	36.	36.			
MERIDIONAL WINDS																
30 MB	.5	1.4	2.1	2.3	2.2	2.3	1.8	1.2	1.0	1.2	1.5	1.4	.9			
70 MB	.1	.6	1.1	1.6	1.9	1.7	1.3	1.1	.9	1.0	1.3	2.3	1.2			
200 MB	7.4	15.0	15.7	10.6	7.1	5.2	3.8	3.8	4.2	4.0	3.7	2.6	3.1			
500 MB	2.0	5.7	7.5	5.6	3.4	2.2	1.5	1.2	1.4	1.6	1.4	.5	1.0			
850 MB	2.0	5.7	6.7	3.9	1.7	1.3	1.1	1.0	.9	.5	.4	.2	.8			
PERCENTAGE RELATIVE ERROR																
30 MB	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.			
70 MB	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.			
200 MB	10.	11.	11.	12.	12.	13.	14.	15.	15.	16.	16.	16.	16.			
500 MB	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.			
850 MB	9.	10.	10.	11.	12.	13.	14.	15.	15.	16.	16.	17.	17.			
PERIOD(DAYS)	12.0	6.0	4.0	3.0	2.4	2.0	1.7	1.5	1.3	1.2	1.1	1.0				

Appendix iii(k) - Autumn wind spectra for Koror (7°N, 134°E).

WIND COMPONENT SPECTRA (M/SEC)2 X (6/PI) DAYS								FOR STATION 91700				AUTUMN	
ZONAL WINDS													
30 MB	6.8	10.7	10.8	7.7	4.9	5.6	3.7	0.0	0.0	0.0	0.0	0.0	0.0
70 MB	8.2	10.5	7.9	5.2	4.5	4.4	2.4	0.0	0.0	0.0	0.0	0.0	0.0
200 MB	15.6	29.5	13.9	5.9	4.0	2.9	2.2	2.2	2.1	1.3	-3.6	-3.8	-7
500 MB	7.8	9.0	6.7	3.5	1.7	1.0	.8	.6	.7	.9	1.3	.3	1.0
850 MB	3.6	4.7	3.4	1.8	1.2	.9	.7	.7	.7	1.0	1.9	2.9	1.6
PERCENTAGE RELATIVE ERROR													
30 MB	14.	14.	16.	18.	20.	21.	21.	0.	0.	0.	0.	0.	0.
70 MB	12.	13.	15.	18.	21.	22.	23.	0.	0.	0.	0.	0.	0.
200 MB	15.	16.	18.	21.	25.	29.	32.	35.	38.	40.	42.	43.	43.
500 MB	15.	16.	18.	22.	26.	30.	34.	37.	40.	43.	45.	46.	46.
850 MB	15.	16.	18.	21.	24.	27.	31.	33.	36.	38.	39.	40.	41.
MERIDIONAL WINDS													
30 MB	1.3	2.7	4.1	5.1	5.9	4.8	1.9	0.0	0.0	0.0	0.0	0.0	0.0
70 MB	6.3	5.0	5.2	4.9	3.4	2.9	1.4	0.0	0.0	0.0	0.0	0.0	0.0
200 MB	8.3	9.6	10.3	8.1	4.3	2.6	2.1	1.5	1.4	1.6	2.0	1.1	1.9
500 MB	2.0	5.4	7.7	6.0	2.4	.9	1.0	.9	.2	.3	1.8	1.6	1.3
850 MB	.9	1.8	3.1	2.9	1.6	.8	.7	.6	.5	.8	1.2	1.0	.8
PERCENTAGE RELATIVE ERROR													
30 MB	16.	16.	16.	16.	16.	16.	16.	0.	0.	0.	0.	0.	0.
70 MB	11.	15.	23.	30.	36.	39.	41.	0.	0.	0.	0.	0.	0.
200 MB	16.	16.	17.	19.	21.	23.	25.	26.	28.	29.	30.	31.	31.
500 MB	15.	16.	17.	19.	21.	23.	25.	27.	28.	30.	31.	31.	32.
850 MB	17.	17.	17.	18.	19.	20.	21.	22.	23.	24.	25.	25.	25.
PERIOD(DAYS)	12.0	6.0	4.0	3.0	2.4	2.0	1.7	1.5	1.3	1.2	1.1	1.0	

Appendix iii(1) - Autumn wind spectra for Canton Is. (3°S, 172°W).

Number of Data Pairs for a Time Lag of 1 Day

	TRUK (152° E)	PONAPE (158° E)	KWAJALEIN (168° E)	MAJURO (171° E)
Winter	686	665	670	582
Spring	780	701	827	611
Summer	816	764	843	667
Autumn	807	735	817	678

Zonal Component for Period of 12 Days

Winter	.08	.31 (17)	.50 (-4)
Spring	.25 ((28))	.35 (9)	.60 (-16)
Summer	.15 (31)	.35 (14)	.70 (-13)
Autumn	.14 (50)	.48 (18)	.68 (-26)

Meridional Component for Period of 12 Days

Winter	.08	.20 (39)	.57 (-17)
Spring	.04	.24 (63)	.41 (-14)
Summer	.02	.17 (62)	.32 (-36)
Autumn	.06	.26 ((69))	.58 (-31)

Zonal Component for Period of 4 Days

Winter	.01	.06	.28 (-15)
Spring	.02	.06	.13 ((-20))
Summer	.01	.19 (32)	.36 (-24)
Autumn	.01	.18 (33)	.46 (-32)

Meridional Component for Period of 4 Days

Winter	.00	.05	.21 ((-38))
Spring	.00	.10 (84)	.19 ((-17))
Summer	.07	.24 (78)	.57 ((-233))
Autumn	.07	.16 (93)	.62 ((-445))

Appendix iv(a) - Horizontal coherence and phase angle (degrees) in the Pacific, 8° N, at 850 am, Kwajalein is the master station to which other stations are correlated.

Number of Data Pairs for Time Lag of 1 Day

	TRUK (152°E)	PONAPE (158°E)	KWAJALEIN (168°E)	MAJURO (171°E)
Winter	605	501	587	446
Spring	599	508	703	442
Summer	612	541	758	480
Autumn	637	516	710	493

Zonal Component for Period of 12 Days

Winter	.19 (12)	.32 (10)	.75 (1)
Spring	.18 (-7)	.39 (-4)	.78 (3)
Summer	.13 (19)	.39 (9)	.83 (-6)
Autumn	.14 (14)	.34 (16)	.70 (-6)

Meridional Component for Period of 12 Days

Winter	.07	.36 (21)	.60 (-5)
Spring	.14 (17)	.42 (2)	.57 (-2)
Summer	.17 (101)	.35 (45)	.66 (-22)
Autumn	.07	.29 (52)	.70 (-26)

Zonal Component for Period of 4 Days

Winter	.01	.03	.26 (-2)
Spring	.00	.20 (-35)	.46 (9)
Summer	.03	.09	.34 (-8)
Autumn	.05	.17 (76)	.31 (-13)

Meridional Component for Period of 4 Days

Winter	.08	.20 (75)	.42 (-16)
Spring	.00	.13 (-20)	.46 (20)
Summer	.11 (112)	.26 ((56))	.48 (-27)
Autumn	.04	.24 (68)	.49 (-27)

Appendix iv(b) - Horizontal coherence and phase angle (degrees) in the Pacific, 8°N, at 200 mb.

Number of Data Pairs for Time Lag of 1 Day

	SAN ANDREAS	BALBOA (82°W)	(80°W)	CURACAO (69°W)	TRINIDAD (62°W)
Winter	550	589		390	376
Spring	775	783		338	400
Summer	760	806		454	496
Autumn	690	789		418	371

Zonal Component for Period of 12 Days

Winter	.37 (-23)	.28 (-13)	.04
Spring	.21 (-34)	.21 (-7)	.01
Summer	.25 (-34)	.07	.00
Autumn	.25 (-13)	.19 (-57)	.09

Meridional Component for Period of 12 Days

Winter	.31 (5)	.06	.00
Spring	.36 (-3)	.01	.01
Summer	.31 (-27)	.14 (-139)	.07
Autumn	.13 (-15)	.04	.02

Zonal Component for Period of 4 Days

Winter	.21 (12)	.11 (50)	.01
Spring	.05	.04	.00
Summer	.12 (-73)	.16 (-97)	.05
Autumn	.07 (-22)	.18 (-67)	.05

Meridional Component for Period of 4 Days

Winter	.15 (9)	.10	.00
Spring	.20 (15)	.01	.01
Summer	.16 (-40)	.04	.01
Autumn	.26 (-41)	.00	.01

Appendix iv(c) - Horizontal coherence and phase angle (degrees) in the southern Caribbean, 11°N, at 850 mb. San Andreas is the master station to which other stations are correlated.

Number of Data Pairs for Time Lag of 1 Day

	SAN BALBOA (80°W) ANDREAS (82°W)		CURACAO (69°W)	TRINIDAD (62°W)
Winter	461	527	330	321
Spring Spring	658	718	300	323
Summer	672	711	400	433
Autumn	539	767	347	282

Zonal Component for Period of 12 Days

Winter	.34 (-5)	.21 (3)	.05
Spring	.34 (6)	.12 (7)	.01
Summer	.46 (-16)	.08	.03
Autumn	.45 (-27)	.12 (-29)	.07

Meridional Component for Period of 12 Days

Winter	.43 (-9)	.09	.05
Spring	.56 (-6)	.05	.08
Summer	.45 (-9)	.20 (-153)	.01
Autumn	.47 (-24)	.10 (-104)	.11

Zonal Component for Period of 4 Days

Winter	.09	.03	.02
Spring	.18 (1)	.03	.08
Summer	.17 ((-144))	.01	.00
Autumn	.19 (-24)	.02	.04

Meridional Component for Period of 4 Days

Winter	.18 ((-8))	.02	.01
Spring	.27 (7)	.14 (-31)	.01
Summer	.45 (-17)	.15 (-148)	.04
Autumn	.30 (-34)	.04	.03

Appendix iv(d) - Horizontal coherence and phase angle (degrees) in the southern Caribbean, 11°N, at 200 mb.

Number of Data Pairs for Time Lag of 1 Day

	MERIDA (90°W)	SWAN (84°W)	GRAND CAYMAN (81°W)	KINGSTON (77°W)	SANTA DOMINGO (70°W)	SAN JUAN (66°W)
Winter	544	951	667	566	350	949
Spring	582	940	676	530	292	1013
Summer	637	1015	737	628	394	1052
Autumn	600	1024	794	641	476	1043

Zonal Component for Period of 12 Days

Winter	.48 (-17)	.12 (-1)	.72 (-1)	.27 (1)	.46 (7)	.12 (10)
Spring	.41 (-11)	.06 (-1)	.66 (-1)	.23 (3)	.22 (-1)	.06
Summer	.40 (37)	.16 (17)	.56 (17)	.20 (-24)	.04	.03
Autumn	.20 (7)	.09 (-5)	.59 (-5)	.20 (-26)	.09	.09

Meridional Component for Period of 12 Days

Winter	.61 (-30)	.18 (1)	.78 (1)	.18 (1)	.01	.03
Spring	.48 (-24)	.04 (2)	.64 (2)	.07	.07	.08
Summer	.15 (39)	.12 (-25)	.32 (-25)	.06 (-76)	.16 (-149)	.08
Autumn	.07	.17 (-9)	.57 (-9)	.03	.06	.07

Zonal Component for Period of 4 Days

Winter	.30 (-12)	.18 (7)	.38 (7)	.06 (1)	.13 (68)	.05
Spring	.20 (-15)	.11 (7)	.31 (7)	.06	.06	.00
Summer	.04	.16 (0)	.26 (0)	.14 (-96)	.02	.02
Autumn	.06	.17 (0)	.37 (0)	.10 (-36)	.01	.00

Meridional Component for Period of 4 Days

Winter	.58 (-51)	.12 (8)	.72 (8)	.29 (29)	.03 (89)	.10 (111)
Spring	.32 (-42)	.10 (15)	.50 (15)	.05 (16)	.10 (95)	.02
Summer	.25 (75)	.12 (-51)	.42 (-51)	.29 (-115)	.12 (-178)	.07
Autumn	.04	.13 (-15)	.43 (-15)	.00	.01	.03

Appendix iv(e) - Horizontal coherence and phase angle (degrees) in the central Caribbean, 17°N, at 850 mb. Swan is the master station to which other stations are correlated.

Number of Data Pairs for Time Lag of 1 Day

	MERIDA (90°W)	SWAN (84°W)	GRAND CAYMAN (81°W)	KINGSTON (77°W)	SANTA DOMINGO (70°W)	SAN JUAN (66°W)
Winter	201	846	341	344	200	780
Spring	300	832	401	404	174	858
Summer	406	876	584	487	223	863
Autumn	371	890	578	452	284	898

Zonal Component for Period of 12 Days

Winter	.49 (9)	.80 (5)	.64 (0)	.27 (6)	.22 (18)
Spring	.38 (24)	.79 (52)	.58 (12)	.22	.10 (26)
Summer	.10 (47)	.50 (-2)	.38 (-20)	.08	.11 (-62)
Autumn	.23 (12)	.78 (8)	.41 (2)	.13	.03

Meridional Component for Period of 12 Days

Winter	.45 (24)	.71 (-6)	.47 (-4)	.16	.00
Spring	.66 (4)	.81 (8)	.10 (6)	.02	.19 (-177)
Summer	.20 (61)	.57 (-16)	.18 (-68)	.10	.08 (-160)
Autumn	.33 (28)	.68 (-11)	.19 (-37)	.08	.15 (-154)

Zonal Component for Period of 4 Days

Winter	.02	.32 (23)	.11 (17)	.04	.04
Spring	.22 (-40)	.33 (10)	.37 (22)	.04	.05
Summer	.01	.24 (0)	.19 (-35)	.03	.00
Autumn	.03	.25 (12)	.13 (-16)	.03	.00

Meridional Component for Period of 4 Days

Winter	.12	.56 (9)	.44 (32)	.18	.05
Spring	.27 (-19)	.59 (33)	.25 (62)	.09	.09
Summer	.30 (76)	.73 (-33)	.36 (-101)	.16	.08
Autumn	.13 (65)	.30 (-11)	.11 (-88)	.00	.01

Appendix iv(f) - Horizontal coherence and phase angle (degrees) in the central Caribbean, 17°N, at 200 mb.

Station	Winter	Spring	Summer	Autumn	N(1 day)
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850 - 500 mb zonal component for a period of 12 days

Dakar	.15 (-9)	.14 (-6)	.07	.25 (-4)	679
Miami	.44 (18)	.56 (18)	.53 (3)	.61 (8)	1014
San Juan	.31 (19)	.24 (1)	.10 (1)	.51 (-9)	943
Swan	.42 (-2)	.25 (6)	.41 (-10)	.36 (-15)	948
San Andreas	.17 (6)	.12 (-29)	.28 (-9)	.41 (-7)	554
Curacao	.11 (4)	.03	.10 (-44)	.11 (26)	367
Kwajalein	.13 (-26)	.08	.13 (2)	.32 (-3)	654
Ponape	.17 (-8)	.15 (0)	.08	.31 (-6)	621
Koror	.23 (-30)	.20 (-14)	.44 (0)	.58 (-4)	600
Songkhla	.05	.02	.27 (7)	.28 (-10)	541
Trivandrum	.10 (-19)	.11 (31)	.33 (-20)	.42 (-22)	248

850 - 500 mb meridional component for a period of 12 days

Dakar	.13 (45)	.12 (18)	.09	.18 (23)
Miami	.44 (28)	.33 (27)	.32 (2)	.39 (12)
San Juan	.12 (22)	.19 (19)	.06	.24 (-9)
Swan	.11 (15)	.11 (31)	.14 (11)	.25 (-3)
San Andreas	.05	.02	.12 (24)	.19 (-2)
Curacao	.02	.10 (-46)	.01	.18 (35)
Kwajalein	.15 (-1)	.10 (-11)	.17 (26)	.19 (8)
Ponape	.14 (-16)	.18 (-14)	.05	.09
Koror	.26 (-29)	.22 (-14)	.27 (-24)	.42 (-20)
Songkhla	.08	.10 (-3)	.10 (-17)	.12 (-11)
Trivandrum	.10 (-7)	.22 (-15)	.02	.17 (-39)

850 - 200 mb zonal component for a period of 12 days

Miami	.19 (25)	.16 (42)	.01	.05	886
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850 - 200 mb meridional component for a period of 12 days 886

Kwajalein	.10 (-99)	.05	.13 (-132)	.16 (-110)	587
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Appendix v(a)le. 29. Vertical coherence and phase angle (degrees) between 850 - 500 mb and 850 - 200 mb for low latitude stations for the frequency $2\pi / 12$ day.

<u>Station</u>	<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Autumn</u>	<u>N(1 day)</u>
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850 - 500 mb zonal component for a period of 4 days

Dakar	.02	.00	.10 (15)	.05	679
Miami	<u>.32</u> (19)	<u>.45</u> (12)	.22 (-1)	<u>.32</u> (10)	1014
San Juan	<u>.12</u> (29)	<u>.07</u>	.18 (24)	<u>.19</u> (-3)	943
Swan	.13 (27)	.08	.22 (7)	.13 (17)	948
San Andreas	.09	.01	.10 (17)	.22 (9)	554
Curacao	.02	.00	.08	.05	367
Kwajalein	.03	.03	.09	.04	654
Ponape	.02	.01	.09	.17 (39)	621
Koror	.01	.09	.16 (-21)	.16 (-20)	600
Songkhla	.00	.01	.09	.04	541
Trivandrum	.17 (18)	.01	.08	.08	248

850 - 500 mb meridional component for a period of 4 days

Dakar	.09	.03	.21 (9)	.23 (-2)
Miami	<u>.40</u> (39)	<u>.30</u> (37)	.18 (-2)	<u>.29</u> (22)
San Juan	<u>.10</u> (31)	<u>.07</u>	<u>.26</u> (-41)	<u>.17</u> (12)
Swan	.12 (55)	.04	.14 (-14)	.16 (-2)
San Andreas	.04	.03	.12 (23)	.14 (0)
Curacao	.07	.04	.04	.07
Kwajalein	.04	.03	.10 (31)	<u>.28</u> (26)
Ponape	.02	.06	.14 (35)	.20 (4)
Koror	.19 (-20)	.10 (-5)	<u>.30</u> (-31)	<u>.25</u> (-20)
Songkhla	.02	.01	.08	.12 (12)
Trivandrum	.02	.01	.15 (20)	.01

850 - 200 mb meridional component for a period of 4 days

Kwajalein	.01	.01	.14 (-90)	.06	587
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Appendix IV(b). - Vertical coherence and phase angle (degrees)
 between 850 - 500 mb and 850 - 200 mb at
 low latitude stations for the frequency
 $2\pi/4$ day⁻¹.

<u>Station</u>	<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Autumn</u>	<u>N(1 day)</u>
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200 - 500 mb zonal component for a period of 12 days

Dakar	.18 (2)	.17 (-10)	.01	.19 (18)	594
Miami	.50 (-5)	.47 (-12)	.19 (-10)	.24 (-2)	886
San Juan	.41 (-7)	.40 (-1)	.13 (25)	.37 (8)	863
Swan	.45 (-7)	.42 (-6)	.07	.27 (31)	832
San Andreas	.09	.12 (-7)	.03	.11 (24)	461
Kwajalein	.17 (22)	.10 (-8)	.09	.11 (15)	587
Ponape	.11 (6)	.06	.06	.07	501

200 - 500 mb meridional component for a period of 12 days

Dakar	.21 (-19)	.15 (15)	.01	.17 (-2)
Miami	.41 (-22)	.50 (-5)	.15 (8)	.36 (3)
San Juan	.37 (-4)	.38 (-19)	.15 (8)	.15 (18)
Swan	.27 (-22)	.25 (-4)	.01	.07
San Andreas	.03	.05	.03	.05
Kwajalein	.06	.04	.02	.02
Ponape	.05	.11 (27)	.03	.09

200 - 70 mb zonal component for a period of 12 days

Miami	.49 (10)	.32 (14)	.08	.23 (-17)	530
San Juan	.31 (17)	.27 (15)	.02	.20 (-15)	538
Swan	.16 (12)	.20 (14)	.03	.12 (11)	616
San Andreas	.14 (-4)	.06	.06	.05	308
Kwajalein	.04	.04	.03	.01	374

200 - 70 mb meridional component for a period of 12 days

Miami	.46 (6)	.31 (-6)	.11 (-72)	.36 (-1)
San Juan	.25 (-12)	.07	.05	.02
Swan	.10 (-24)	.13 (-19)	.00	.06
San Andreas	.05	.00	.01	.03
Kwajalein	.00	.01	.00	.00

Appendix (c) 0.

Vertical coherence and phase angles (degrees)
between 200 - 500 mb and 200 - 70 mb for low
latitude stations for the frequency $2\pi/12$ day⁻¹.

<u>Station</u>	<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Autumn</u>	<u>N(1 day)</u>
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200 - 500 mb zonal component for a period of 4 days

Dakar	.05	.10 (-43)	.01	.01	594
Miami	.15 (-14)	.16 (-31)	.09	.24 (-22)	886
San Juan	.20 (3)	.11 (-15)	.09	.04	863
Swan	.09	.08	.01	.03	832
San Andreas	.02	.03	.01	.01	461
Kwajalein	.02	.04	.04	.02	587
Ponape	.01	.01	.08	.11 (-18)	501

200 - 500 mb meridional component for a period of 4 days

Dakar	.07	.02	.03	.03
Miami	.28 (-22)	.24 (-2)	.09	.15 (-19)
San Juan	.15 (8)	.09	.23 (9)	.07
Swan	.03	.02	.22 (27)	.03
San Andreas	.02	.04	.03	.01
Kwajalein	.01	.00	.03	.02
Ponape	.03	.00	.05	.01

200 - 70 mb zonal component for a period of 4 days

Miami	.09	.12 (25)	.01	.11 (10)	530
San Juan	.11 (35)	.09	.00	.05	538
Swan	.01	.02	.00	.03	616
San Andreas	.07	.02	.00	.00	308
Kwajalein	.00	.03	.02	.02	374

200 - 70 mb meridional component for a period of 4 days

Miami	.16 (20)	.13 (26)	.01	.07
San Juan	.09	.03	.05	.02
Swan	.03	.01	.05	.00
San Andreas	.03	.04	.02	.00
Kwajalein	.00	.02	.01	.01

Appendix v(d) -- Vertical coherence and phase angles (degrees)
 between 200 - 500 mb and 200 - 70 mb for low
 latitude stations for the frequency $2\pi/4 \text{ day}^{-1}$.