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COMPARISON OF PERIODIC AND OTHER CHARACTERISTICS OF GEOMAGNETIC AND METEOROLOGICAL ROCKET DATA

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16. Abstract

The purpose of this study is to compare the temporal variations in stratospheric winds and temperatures with the geomagnetic field elements. From a periodic analysis of the geomagnetic field elements, based on data from 1960-1972, the amplitude and phase of the quasibiennial, annual, and semiannual waves are given for stations from 1°S to 89°N. These results are then compared with corresponding waves reported in rocketsonde wind and temperature data, 30 to 60 km. The annual waves are found to be coupled as a result of the annual variation in the dynamo effect of the wind in the lower ionosphere. The semiannual waves are also found to be coupled and three possible causes for the extra-tropical stratospheric semiannual wind wave are discussed.

Time variance spectra for the interval from 4 days to 44 days in both zonal winds and horizontal geomagnetic field intensity are compared for years when major midwinter warmings occur and years when only minor warmings occur. The noted differences are suggested to arise from upward propagating planetary waves which are absorbed or refracted in varying amounts depending on the prevailing circulation.

Lastly, a superposed epoch study reveals a statistically significant correlation between stratospheric temperature and k_p fifteen hours earlier. The possible reason for this peak is discussed, but a similar relationship with respect to the solar sector structure could not be found.

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TABLE OF CONTENTS

TABLE OF CONTENTS

(Cont'd)

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

Coupling between the atmospheric circulation and the earth's magnetic field is strongly suggested by the evidence presented in the literature. This evidence covers a wide spectrum of space and time scales, is usually in the form of correlations, and has been given for all levels of the atmosphere. For example, Flohn (1952) showed that the meteorological equator (the ITCZ) is more nearly parallel to the geomagnetic than to the geographic equator and that the polar vortex at 200 mb is more nearly centered on the geomagnetic than on the geographic pole. King (1974) has shown that the isolines of total ozone are similar to the isolines of magnetic field strength; and Belmont, at al. (1974b), showed that the contours of the amplitude of the semiannual wave in zonal wind at 50 km are more nearly congruent with the geomagnetic, rather than geographic, coordinate system. The mechanisms which give rise to these correlations are not yet fully understood.

It should be determined whether the atmosphere or the geomagnetic field, or neither, is the independent variable responsible for correlations such as the above. If the geomagnetic field is the independent variable for a given relationship, then meteorologists ought to include that relationship in their studies. For example, a high latitude source of NO produced by cosmic rays, which enter the atmosphere at latitudes determined by their interaction with the geomagnetic field, is now being included in studies of the ozone budget (Crutzen, et al., 1975). On the other hand, if the atmosphere is found to be the independent variable for a given relationship, then such knowledge may be useful to space scientists, but meteorologists need not consider that geomagnetic relationship in studies of the atmospheric circulation.

The purpose of the present study is to find relationships between stratospheric parameters, 30-60 km, and geomagnetic field parameters. The mid- and upper-stratosphere may respond dramatically to geophysical events (e.g., Zadvernyuk, 1973), and by studying relationships at high altitudes it may be possible to more readily identify some coupling mechanisms between the atmosphere and geomagnetic field. Hopefully, this could help explain which are the independent variables for some of the known relationships between geomagnetic and meteorological data. The method used here will be to compare temporal variations of wind and temperature at rocketsonde stations (MRN data) with time variations of the vertical (Z) and horizontal (H) geomagnetic field intensity at a nearby geomagnetic observatory.

The frequency range of time variations which can be studied is limited only by the time distribution of MRN data, as the geomagnetic data are taken hourly in a (usually) continuous sample. The MRN data are sufficiently plentiful to define variations longer than a month, so a major portion of the study deals with periodic analysis, the quasi-biennial oscillation, and the first three harmonics of the annual wave. On time scales of a season or less, midwinter sudden stratospheric warmings are the most spectacular events. While the MRN data are too sparse to perform case studies of individual warmings, it is possible to stratify all years according to whether or not a major warming occurred. This procedure has been used to study differences of the variance spectra in MRN and geomagnetic data during years when major warmings occurred compared with the other years. Finally, results are given for a superposed epoch study of the changes in stratospheric temperature over a few hours time at Fort Churchill using solar sector boundary crossing dates as the key events.

II. DATA

Meteorological rocket (MRN) data 1960-72 were obtained from the World Data Center, Asheville. Station locations and the nearest geomagnetic observatories are given in Table 1. Further details concerning the MRN data and results of periodic analysis of wind and temperature have been given in Belmont, et al. (1974a), and Nastrom and Belmont (1975).

Daily mean values of the geomagnetic field elements for years corresponding to the MRN data were obtained from the World Data Center, Boulder.

Observatories used in this study are listed in Table 2. Generally, geomagnetic data prior to 1960 were not used in order to make the periods of record of the MRN and geomagnetic data as compatible as possible. Also, the analysis was limited to observatories near a MRN station (see Table 1). At most observatories the field elements given are declination (D), horizontal (H), and vertical (Z) field intensity. At the Canadian stations indicated in Table 2 they were reported as X, Y, and Z; but daily values were converted to D, H, and Z prior to further processing. The observatory at San Juan was moved at the end of 1964, and it was necessary to adjust the base line of 1960-1964 data to be consistent with 1965-1972 data. Also, the observatory at Honolulu was moved during 1960, so data for 1960 were not used there.

III. RESULTS

A. PERIODIC ANALYSIS OF GEOMAGNETIC FIELD ELEMENTS

1. Procedure

Significant peaks at 12 and 6 months are present in the H and Z spectra (Currie, 1966), and resolving them as discrete lines provides the possibility of studying their phases as well as amplitudes. However, secular trends are often very large in the H and Z data, and failure to remove them prior to periodic analysis can lead to inconclusive results (Chapman and Bartels, 1940, Chapter 16; Currie, 1966). Inspection of plots of our time series for 1960-1972 (not shown here; see Chapman and Bartels, 1940, p. 132) indicated that a parabola can be used to effectively remove the secular trend. This technique is more desirable than other filters because no data are lost at each end of the time series. Although a parabolic trend line does interact with the approximately 11 year cycle found in H and Z, numerical tests made using synthetic time series show that the error in amplitude and phase of the 11 year cycle, and shorter periods, is less than 4% after removing a parabolic trend from a time series 13 years long.

Time series of mean daily H and Z values are characterized by a relatively steady background which may be dramatically interrupted during a geomagnetic disturbance. The effect of geomagnetic storms, which last for only hours or days, could be thought of as a very large amplitude high-frequency variation which occurs more during some years than during others. As the purpose here is to study the month-to-month changes of the background geomagnetic field, it is desirable to remove the aliasing of monthly data caused by the irregular occurrence of geomagnetic storms. One method to achieve this is to use only non-disturbed days when computing monthly means. This method has the drawback that disturbed days can be identified only on a subjective basis. If the disturbed days form only a small part of total daily values in a month, however, then an objective and nearly as effective method is to use monthly medians rather than monthly means. Periodic analyses were made using both monthly median and monthly mean data. The resulting amplitudes and phases differed significantly between the two analyses with the monthly median amplitudes always smaller (e.g., 5.3 versus 8.8 gammas for the amplitude of the annual wave in H at College). Moreover, the corresponding statistical error estimates were always smaller in the case of monthly median data, indicating less interannual variability of the periodic waves when monthly medians are used. Thus, the following analyses are based on time series of monthly median values of H and Z. (Note that monthly mean MRN data were used here, as previously, because the range of those fluctuations is relatively much smaller.)

Monthly data of both the MRN and geomagnetic parameters were analyzed with the joint periodic regression technique of Belmont, et al., 1974a. The technique can be used to analyze a time series of irregularly spaced data points, weighting the months by number of observations, even if zero, and to simultaneously determine an estimate of the statistical error of the amplitude and phase of each frequency included. Further, frequencies analyzed need not be integral divisions of the period of record. Frequencies included in the present analyses are the long-term mean, 11 year cycle (geomagnetic data only), quasi-biennial oscillation (29 months), and the first four harmonics of the annual wave.

The statistical errors given in Table 2, which provide confidence estimates for the results, are not the same as RMS deviations. However, they resemble RMS deviations because the coherence of the data from cycle to cycle is the most important consideration in computing them; in fact, regression of the errors in Table 2 (SE) for the annual and semiannual waves with RMS deviations determined from harmonic analysis of yearly data showed that SE = 0.38 RMS. The regression coefficient is small for several reasons: because the frequencies included in the SE analysis are not orthogonal over the data, they can interfere with each other to give a better fit (smaller residuals) to the complete time series than can the orthogonal components of harmonic analysis. Also, as SE weights each point of the time series by the number of observations, it allows occasional erratic points based on few observations to be largely disregarded.

2. Annual Wave

Estimates of the amplitude and phase, with errors, of the QBO, annual, and semiannual waves in H and Z are given in Table 2. Results for the annual wave in H and Z are plotted in Figure 1 as functions of geomagnetic latitude. Lines estimating the latitudinal variation in the figure have been fitted by eye. These results are similar to the corresponding values given by Currie (1966), but have much less scatter, particularly at mid-latitudes. As noted by Currie, the scatter of his results may arise from differing periods of record at the various stations he used; for example, the interannual variations of the annual waves in H at Tucson and Sitka (Figure 2) are so large that averaging a given number of arbitrary years will clearly lead to widely varying mean values. In anticipation of the discussion in Section B, a large part of the interannual variations in Figure 2 is due to the well-known solar cycle influence on E region ionization. Note that both stations are at the right extreme in 1963 and the left extreme in 1969 (1963 was near sun spot minimum and 1969 near sun spot maximum). Returning to Figure 1, the sharp increase of amplitude of the annual waves in H and Z at high latitudes has been noted by Currie (1966) whose data extended to 80^{o}N (geomagnetic latitude). The decrease of amplitude in H and continued rise in Z as the pole is approached does not seem to have been reported previously, although Langel and Brown (1974) have noted that the largest seasonal variations of ΔZ are near the pole.

The phase of the annual wave in H is fairly uniform at all latitudes, with the annual maximum occurring in June (Figure 1a). The phase of Z, on the other hand, undergoes an abrupt shift of 180^{o} near 65^{o}N. Equatorward of 65^{o}N the average phases of Z and H are quite similar.

3. Semiannual Wave

Amplitudes and phases of the semiannual variations in H and Z are plotted in Figure 3. The present amplitude results are generally smaller than those given by Currie (1966). In this case, the difference may again be due to differing periods of record, or it may be due to our use of monthly median data which reduces the occasionally severe impact of magnetic storms which occur on a predominantly semiannual rhythm. It should be borne in mind that the present results are for the mean semiannual wave over about one sunspot cycle. [Chapman and Bartels (1940) have shown that the semiannual amplitude varies with the sunspot cycle.] From 70^{o} to 80^{o} magnetic latitude, the decline of amplitude in H and the increase in Z are in accord with Currie's (1966) results which extend to Godhavn (80^{o}N). As the pole is approached from 80^{o}N the amplitudes of both H and Z increase, although the large statistical errors associated with the H values make that analysis less reliable.

The phase of the semiannual variation in H is fairly steady up to about 70^{o}N, with a 180^{o} shift near 75^{o}N indicated by all three stations north of 80^{o}N. The phase of Z is less steady, but indicates a systematic shift with latitude such that the phase of the pole and the equator are about 180^{o} different.

4. Quasi-Biennial Oscillation (QBO)

Before discussing the periodic analysis results for the QBO in H and Z, it should be pointed out that there have been several conflicting reports regarding the existence of a quasi-biennial line in the geomagnetic spectrum. Hope (1963) reported that the QBO in K_p had been isolated, but Currie (1966) could not find it in the spectra of H or Z and suggested that these results were based on faulty numerical filtering procedures. Fraser-Smith (1972) presented the spectrum of the A_p index and concluded that no QBO exists, but Currie (1973) has analyzed H and Z data from 49 observatories and now concludes that there is a line near 2.15 years.

Nearly all periodic waves in geophysical data show variations from cycle to cycle, but usually the amplitude and phase converge on mean values if enough cycles are averaged. Statistical tests can be used to determine if enough cycles of a periodic wave have been used to estimate the mean wave with confidence (Chapman and Bartels, 1940). As the quasi-biennial oscillation is not truly periodic, but has variable amplitude, phase, and period from cycle to cycle (e.g., see Figure 4), there is no assurance that a mean wave can be rigorously defined in a usual statistical sense. Thus, the mean QBO can only be defined for the years of record analyzed by each writer, with the understanding that the QBO for different years of record will probably not have the same amplitude or phase. For this reason, the latitudinal variation of the QBO values in Table 2 is erratic and inconclusive unless stations with the most complete and most nearly identical years of record are considered. Therefore, only those stations with over 110 months of data have been used in order to obtain the most reliable estimates of the latitudinal variation of the QBO. (The average period of the QBO during these years was 29 months.) In Figure 5, the average QBO amplitude is near 2γ for both elements, although Resolute (83°N) indicates an increase of H's amplitude as the pole is approached. The individual phase dates, relative to 1 January 1960, have fairly uniform latitudinal variation except for Z at College and H at Resolute.

B. COMPARISON OF GEOMAGNETIC AND METEOROLOGICAL PERIODIC WAVES

The present objective is to determine possible relations of geomagnetic to meteorological variables by comparing periodic properties of geomagnetic and MRN data. Identifying those periodic frequencies which show a close relationship can allow effort to be focused on them, with the remainder of the variance discarded as being unrelated and therefore of no immediate interest.

1. Procedure

Waves of the same period whose relative phase lags show broad patterns of spatial continuity are sometimes found to be related, and charts of the relative phase lags between MRN and geomagnetic periodic variations will be presented below. However, as all periodic components of the two data sets may have large year -to-year variability in amplitude and phase (for example, the annual wave in H in Figure 2), it is desirable to first examine the year-to-year relationship of each frequency to determine if "average" phase lag values are representative. The coherence square (COH2) statistic of cross spectral analysis provides an objective measure of how uniformly the amplitudes and phases within each frequency band vary with time at a given location, and has been used here to decide which frequencies of MRN and geomagnetic data are synchronous. Cross-spectral analyses of horizontal and vertical components of the geomagnetic field versus the temperature and wind at nearby rocket stations were made using monthly data at five stations with the most complete periods of record (Table 3), yet well distributed in latitude, and with a maximum lag of twelve months. Prior statistical significance of each COH2 value was tested by the method of Julian (1975). No values in the frequency band centered at 24 months (near the QBO frequency), nor more values than expected by chance for frequencies higher than $2\pi/6$ months, passed the 5% confidence level. COH2 values for frequency bands centered at biennial, annual, semiannual, and terannual periods are given in Table 3; those which exceed the 5%, 1%, and 0.1% confidence levels are marked.

There is apparently closest coupling for the annual and semiannual variations of zonal wind with H at mid-latitudes and with Z at lower latitudes. The annual temperature variation, especially at 30 km, also is significantly coupled with geomagnetic variations. Semiannual variations of temperature and all terannual variations exceed the 5% confidence limit no more often than expected by chance. These results indicate that only the annual, and some semiannual, variations in MRN and geomagnetic data exhibit significantly synchronous year to year changes; therefore, only those waves will be considered further.

There are two techniques for determining relative phase lags: first, relative phase lag can be found during cross-spectral analysis. Second, the phases determined by periodic analyses can be subtracted. The latter method has the advantage that a measure of confidence can be derived by combining the statistical phase errors determined during periodic analysis. This was done by the root-sum-square technique. It was found that all phase lags associated with a COH2 in Table 3 which exceeded the 1% confidence limit were within the limits of statistical error of the phase lags determined by subtracting periodic analysis results. Therefore, values presented below are based on periodic analysis results.

2. Relative Phase Lags

Relative phase lags for the annual and semiannual waves between MRN and geomagnetic data are presented in Figure 6 as functions of height and latitude. For each station pair listed in Table 1a, the relative phase lag of each frequency for each parameter was determined by subtracting the phase of the geomagnetic wave from the meteorological wave, at 4 km height intervals from 28-64 km. The resulting phase lag values were plotted at the geographic latitude of the MRN station. Contours were drawn for phase lags = ± 30, ± 150 degrees to indicate areas of nearly in or nearly out of phase. The relative uncertainty of each value, estimated by the root-sum-square of the individual phase errors, and the spatial patterns of phase given in Figures 1 and 3, and in Belmont, et al. (1974a), and Nastrom and Belmont (1975), were taken into account while drawing the contours.

In Figure 6, U-H are out of phase throughout the mid-latitudes for both the annual and semiannual waves. U-Z are out of phase from about 10°N - 40°N for the annual wave, with small in phase areas at high latitudes. The phase lags of U-Z for the semiannual wave are near 180° in the upper tropical stratosphere and nearly in phase at high latitudes. The annual waves in T-H are out of phase above 55 km near 20°N, and in phase north of a line from 28 km, 10°N to 64 km, 60°N. The annual waves in T-Z appear out of phase in the upper low-latitude stratosphere and at highest latitudes, and are in phase near 30-50°N. Clearly, the phase lags presented in Figure 6 have broad spatial continuity. Together with the large COH2 values these results suggest that physical coupling between the MRN and geomagnetic periodic variations may exist. Possible mechanisms which could produce coupling will be discussed next.

3. Discussion

a. Annual Wave

It must be noted here that the annual variation in geomagnetic data is not yet fully understood, although several writers have discussed it. Vestine (1954) suggested it could be a seasonal effect induced by air motions in the ionosphere. Currie (1966) concurred with Vestine and offered qualitative arguments from the scanty data then available, and later (Currie, 1974) strengthened the theory by arguing the annual wave could not arise from modulation of the S_q current system but must be a DC effect.

(1) Suggested Mechanism: Due to the differing ion and electron Hall conductivities, zonal wind in the lower ionosphere produces a ring current along the wind which induces a magnetic field in the meridional

plane. This induced magnetic field affects the geomagnetic field in proportion to the wind speed, and the effect decreases with distance. The maximum effect on the N-S component of the geomagnetic field will be directly below and above the wind jet where the induced field is coincident with the geomagnetic H field. Similarly, there is a maximum effect on the Z component to the north and south of the zonal wind jet with a minimum directly below and above it.

At high latitudes (Fig. 1), the maximum amplitude of the annual wave in both H and Z occurs. It apparently has not yet been explained in the literature. The cause of the high latitude maximum could be the annual variation in ionization density, which is a function of solar elevation angle, and winds in the lower ionosphere or of magnetospheric origin; but there is insufficient data to verify either hypothesis at this time.

At mid- and low-latitudes, however, sufficient data are now available to crudely estimate the magnitude of the annual effect of ionospheric winds on geomagnetism and thereby perhaps bring future research efforts on this issue into focus. Here the annual variation in wind is the major factor as there is only a small seasonal change in electron density. The annual variation in zonal winds in the lower ionosphere has maximum amplitudes of about 30 m/s from 20-50° latitude near 110 km with phase dates near mid-May (Groves, 1972). Ionized gas is dragged eastward during the half year centered about May, and westward during the half year centered about November, producing an annual variation in the geomagnetic field intensity. To estimate the magnitude of this effect, the current sheet approximation is applied using a width of 500 km (after Bates, 1975), depth of 15 km, uniform charge density of $5 \times 10^{4}\,cm^{-3}$, at an altitude of 110 km. A wind variation of (30 m/s) cos (wt+ϕ) yields a field variation of (3.28 gammas) cos (wt+ϕ). Of course this estimate could easily be changed by a factor of two or more, but the amplitude is certainly of the proper order of magnitude for the mid-latitude annual wave in geomagnetism (Fig. 1). Also, the charge density varies, particularly with solar zenith angle; this could account winds (mid-May) and the geomagnetic variation (mid-June). Since the annual amplitude in the zonal wind above 100 km has a maximum near 50°N it should create a maximum in the annual amplitude of H near 50°N and a minimum in Z near 50°N, as found in Figure 1.

Conventional heat sources (e.g., radiative heating) are adequate to account for the annual wind waves in the stratosphere (Leovy, 1964) and lower thermosphere (Volland and Mayr, 1972). The MRN individual data has high coherence with the geomagnetic data at the annual frequency because the variations in annual wave between the thermospheric and stratospheric wind are apparently also coherent. (The fact that the annual wave in the stratosphere is out of phase with that in the thermosphere has no bearing on their coherence.) The point here is that a seemingly intriguing relation between two parameters may arise from a mutual association with a third parameter through normally accepted processes; in this case the third parameter is the annual wave in thermospheric circulation. Hence, the present results do not suggest any geomagnetic influence on the atmospheric circulation.

These results should be useful to those trying to understand apparent correlations between atmospheric and geomagnetic processes, and to those concerned with the description of the earth's magnetic field and its variations. The annual dynamo concept presented above could be incorporated into models of the geomagnetic field and thereby help overcome the problems of interpretation discussed by Alldredge and Stearns (1974).

As the above calculation, based on constant ion density, does not pertain to the large, high latitude annual waves in geomagnetism, it is not inconsistent that relatively low COH2 values for the annual frequency are found in Table 3 at Greely and Churchill. Values of COH2 in Table 3 at mid- and low-latitude stations are less than 1.0 for reasons besides instrument error and incomplete sampling. Solar cycle influence on charge density in the ionosphere, causing a solar cycle in the annual wave in geomagnetism but not in that in stratospheric wind, may be the most important additional reason. However, upward propagating planetary and gravity waves, which may affect the stratosphere and ionosphere much differently, could also be important. Although recent theories suggest that planetary waves will be absorbed, reflected, refracted and radiatively damped in the stratosphere and mesosphere, there is a large body of evidence which suggests they do exist in the lower thermosphere (e.g., Lysenko, et al., 1974; Deland and Friedman, 1972; Graznik, et al., 1975). The possible role of gravity waves in the upper atmosphere is also poorly understood (Muller and Kingsley, 1974). It seems unlikely that these uncertainties will be cleared up until detailed wind measurements from the surface to the lower thermosphere are studied. A preliminary effort has been made by Manson, et al. (1975), but conclusive results are not yet available.

(2) Applicability to Correlation Studies: During an early phase of the present study the linear correlation coefficients between the monthly means of MRN and geomagnetic data were computed. Those results, given in Table 4a, have a high level of statistical significance. It is now realized that the correlation coefficients are large because the annual waves in MRN and geomagnetic data are coupled and, except at low latitudes, the annual wave is generally larger than any other periodic component in the MRN data. Thus, one would expect the linear correlation between zonal winds and geomagnetic data to decrease significantly if the annual waves were removed from both data sets. To test this hypothesis, the linear correlation coefficients were recomputed between the monthly residuals after the annual waves had been subtracted. The results of this test, given in Table 4b, show that in nearly all cases the correlation ceases to be significant when the annual wave is removed. The correlation remains significant at Hawaii because the semiannual wave in zonal wind is nearly as large as the annual.

Application of this point to other reported correlations may help explain them. For example, King (1975) has reported that the longitudinal variations at 60^{o}N of the average 500 mb height for January and the geomagnetic intensity shifted 25^{o} in longitude have a correlation coefficient of -0.963. Longitudinal variations in the circulation of the mid-stratosphere reveal a standing wave up to at least 10 mb; in the meridional component the predominant standing wavenumber is two (van Loon, et al., 1972; Figure 72). Lysenko, et.al. (1972), and Glass, et al. (1975), have offered evidence that standing waves also exist in the circulation of the lower thermosphere. If the predominant wavenumber of wind speed, ion density, or a combination of them in the lower thermosphere in January is two, then the resulting current will induce a wavenumber two pattern in the longitudinal variations of the geomagnetic field intensity. The high correlation found by King may therefore reflect a very mundane relationship, as long proposed by Wulf (1945), rather than any solar-terrestrial effect. A similar principle could apply regarding the relationship between spatial variations of tropospheric temperature, humidity, and surface pressure and the geomagnetic field intensity reported by King (1974).

b. Semiannual Wave

The results in Table 3 and Figure 6 suggest that the semi-annual waves in MRN zonal wind and geomagnetism are also closely coupled. For the zonal wind in Table 3, significant COH2 values are found for the semiannual variation at nearly the same station-levels as for the annual variation. A dynamo mechanism might be suggested, as Groves (1972) shows that there are large semiannual wind variations near 115 km. However, Volland and Mayr (1972) found that most of the latitudinally varying part of the semiannual wind wave in the lower thermosphere is due to corpuscular heating. They suggest (Mayr and Volland, 1971) that this heating is related to the semiannual occurrence of magnetic storms, which Chapman and Bartels (1940) have argued is due to earth-sun geometry and thus is independent of meteorological influence. Therefore, the close coupling of the semiannual waves seen in Table 3 and Figure 6 may be explained independently of the dynamo mechanism of the annual wave.

More insight regarding the cause for this coupling of the semiannual waves in geomagnetic and MRN data might be possible if the cause of the semiannual wave in zonal wind were known. Possible causes for the tropical semiannual wind wave have been discussed by Dickinson (1975), but the extra tropical semiannual wave has not yet been explained. As processes which show more symmetry in one coordinate system than another may be driven by mechanisms peculiar to that coordinate system, tests of the relative symmetry of the semiannual wind wave in geomagnetic and geographic coordinates were made. These tests, described below, were generally inconclusive. Finally, three possible causes of the extratropical semiannual wind wave are discussed. None can yet be accepted, and it is suggested that more research is needed before a conclusion can be reached.

(1) <u>Further Tests for Coupling with the Geomagnetic Field</u>: In order to test the relative symmetry of the semiannual wind wave in geomagnetic compared with geographic coordinates the relative phase lags of Figure 6b and 6d have been plotted in geomagnetic coordinates in Figure 7. In either case, the change of coordinates makes little difference, although for U-Z the contours become smoother in geomagnetic coordinates.

Belmont, et al. (1974b), compared the symmetry of the amplitude of the semiannual wind wave at 50 km on maps in the geographic and geomagnetic coordinate systems and found the symmetry slightly greater in geomagnetic coordinates. Even greater symmetry may be found by plotting the amplitude at each station at that level where the closest relationship is found. The height of the level at each station was selected as that height where the magnitude of the product of the two semiannual waves' amplitudes and the cosine of their phase lag ($a_2 \cdot b_2 \cdot \cos\Delta\emptyset$) is maximum.

Note that this parameter, which is an approximation of the co-spectrum in the case of large COH2, will be relatively small if either amplitude is small or if the phases are near quadrature. The height of this surface is shown by the dotted line in Figure 6b. Contours of the amplitude of the semiannual wind wave at the heights thus selected are shown in Figure 8, and appear to show little, if any, enhanced symmetry in either coordinate system compared with the results of Belmont, et al. (1974b). Clearly, these tests for increased symmetry do not suggest preference for either coordinate system.

(2) Possible Mechanisms: Three hypotheses can be advanced to account for the extratropical stratospheric semiannual wave in zonal wind. Before discussing them, however, it should be pointed out that Gregory, et al. (1975b), have noted that the phases of the annual wind waves in the stratosphere and upper mesosphere are reversed. Cole and Kantor (1974) have noted a similar relationship with regard to the annual waves in temperature at stratospheric and mesospheric levels. Both papers suggest that the semiannual waves in the lower mesosphere at extratropical latitudes result from the overlapping of the annual waves. This descriptive account of the lower mesospheric semiannual wave is useful, but does not by itself explain the semiannual wave. For example, early descriptions of the tropical semiannual wind wave in the upper stratosphere viewed it as the result of alternating intrusions of winter hemisphere westerlies into the summer hemisphere (Webb, 1966). While that does occur, it does not explain the tropical semiannual wave, and efforts to do so have invoked a wide variety of mechanisms, e.g., ozone heating, the diurnal tide, planetary waves, Kelvin waves, and semidiurnal tides. Hopefully, the discussion below will help stimulate other research efforts to explain the extratropical semiannual wind wave.

The first forcing mechanism for the extratropical semiannual wind wave to be considered here is upward propagating planetary waves. If these waves interact with the background flow on a semiannual basis they could induce a semiannual component in the background wind speed.

In an effort to determine if the amount of absorption of planetary waves varies with season, the variance spectrum of filtered time series of zonal and meridional winds have been determined at eight MRN stations on a seasonal basis. Details of procedure and complete results are given in the Appendix. As noted in the Appendix, maximum power usually occurs between $2\pi/10$ and $2\pi/20$ days, so for brevity only the results at $2\pi/11$ days will be presented below. However, the graphs for the total variance and for the results at $2\pi/6.3$ days (not shown) are similar.

Planetary waves propagating vertically in a hydrostatic atmosphere with no dissipation increase their spectral density (i.e., power) exponentially with height. Further, if attenuation of the waves occurs, the slope of the power will be proportional to the amount of attenuation. Spectral density for the frequency band centered at $2\pi/11$ days is presented as a function of height in Figure 9 for six MRN stations. Although the power at a given level changes with season, sometimes dramatically, the slope of the curves does not change much with season except at Kennedy. There is a large difference at Kennedy between the slope during spring and autumn from that during the solstitial seasons. During winter unexplained absorption occurs above 45 km at both Kennedy and Pt. Mugu. These results support the hypothesis of Belmont, et al. (1974b) that planetary wave absorption is responsible for the secondary amplitude maximum of the semiannual wave found near 30°N. They do not, however, suggest that the semiannual wave at other latitudes arises directly from seasonal absorption of planetary waves.

The second proposed mechanism is influence on the ozone field by particle precipitation. This mechanism was proposed by Belmont, et al. (1974b), but cannot yet be directly tested due to a dearth of high level ozone data. However, it should be noted that Heath (1974) has found evidence for a non-photochemical source of high latitude ozone creation which he attributes to incident charged particles; and recent modeling efforts by Crutzen, et al. (1975), have shown that incident charged particles can dramatically influence the ozone field. Also, Golyshev, et al. (1974), found that the amplitude of the semiannual wind wave near the stratopause exhibits a solar cycle modulation. To illustrate this, yearly values of several solar and geophysical parameters are presented in Table 5. A station-year is not included in the table unless data for all twelve months are available, and temperature data were thus too irregular to include in the table. Note that the values of the sunspot number and of the semiannual amplitudes have relative maxima in 1969 in all cases. Further, note that the annual wave in zonal wind is a relative minimum in 1969 at all stations except at Barking Sands. While this table suffers from the short period of record available, it does support and extend the results of Golyshev, et al. (1974).

Solar cycle modulation of the periodic variations in stratospheric zonal wind, as seen in Table 5, is consistent with the hypothesis that particle precipitation during magnetic storms influences the ozone and hence thermal and wind fields. If stratospheric semiannual wind variations are related to the occurrence of magnetic storms through the ozone field, then their amplitude should be largest during active sun years (as found in Table 5) as the semiannual component in magnetic storm frequency is largest during active sun years. Solar cycle modulation of the annual wind wave is not easily conjectured, but the well-known solar cycles in total yearly magnetic storms and yearly solar flare occurrence may prove responsible, especially in view of the results of Crutzen, et al. (1975), regarding particle precipitation and ozone concentration.

The third possible mechanism is IR radiation generated in the lower thermosphere during magnetic storms and absorbed by CO_2 at 30-40 km. During magnetic storms the amount of IR radiated by the lower thermosphere is increased by several orders of magnitude, and Gordiyets, et al. (1972), have suggested that it causes heating of CO_2 at 30-40 km and H_2O at 7-12 km. This mechanism has appeal because 30-40 km is the region where maximum amplitudes of the semiannual wave in observed temperatures occur

(Nastrom and Belmont, 1975), and the semiannual component in the occurrence of magnetic storms would produce the proper phase and periodicity. Large amounts of radiative energy are possible for brief periods during severe geomagnetic disturbances, but following Volland and Mayr (1972), the long period form of this heat input (averaged over space and time) should take the same form as the variation in magnetic energy, which is given by

$$U_1^2 \sim \overline{U}^2 \; [1\text{-}0.2 \; \cos(W_{sa}t)],$$

where $\overline{U}$ is a yearly mean magnetic energy, dependent on solar activity, W_{sa} is the semiannual frequency, and t is time. This implies that the amount of energy deposited by IR radiation is $E_{IR} \sim \overline{E}_{IR}[1\text{-}0.2 \cos(W_{sa}t)]$, where $\overline{E}_{IR}$ is a yearly mean value. Alternatively, because layer mean temperature and energy are directly related, $T_{IR} \sim \overline{T}_{IR} \; [1\text{-}0.2 \cos(W_{sa}t)]$. This latter relation says that the IR should contribute five times as much to the mean temperature as it does to the semiannual component of temperature. However, in order to produce a zonal wind oscillation of 20 m/s the latitudinal variation of the corresponding temperature oscillation must be near 5°K (Groves, 1972), which implies a contribution to the average temperature of 25°K. As dynamic models of the stratosphere have encountered no evidence of such a large unconventional heat source (Leovy, 1964), it seems highly unlikely that IR radiation from the lower thermosphere is an important forcing mechanism for the stratospheric semiannual zonal wind wave.

c. QBO

Coupling between the QBO's in MRN and geomagnetic data may exist despite the lack of statistical significance of the COH2 values in Table 3. Even in the tropical stratosphere, where the QBO is the dominant oscillation, the QBO is not regular in amplitude or period from cycle to cycle nor between levels during the same cycle (Wallace, 1973). Thus, the small

COH2 values may be misleading in this case. Moreover, the QBO in thermospheric zonal winds found by Sprenger, et al. (1975), suggests that the geomagnetic QBO may result from a dynamo mechanism, parallel to the annual wave. Although the present theory explaining the well-known tropical stratospheric QBO appears successful (Dickinson, 1975) it is dependent on waves and processes unique to the tropics and thus cannot be invoked to explain an extra tropical thermospheric QBO. Similarily, any explanation for the thermospheric QBO cannot be based on processes unique to the thermosphere because the large negative correlation between the multi-year variations in Z at Honolulu with the 56 km zonal wind at Barking Sands (Fig. 4) suggests the oscillation is not unique to thermospheric (dynamo) altitudes. Until the altitude and latitude progression of the QBO throughout the upper atmosphere is better known, no conclusion regarding the present results seems warranted.

C. SPECTRAL CHANGES DURING SUDDEN WARMINGS

In the stratosphere, rapid changes in the number, amplitude and phase of planetary waves are the major events during winter. These changes are sometimes associated with "sudden warmings" and it seems of interest to study the changes in MRN and geomagnetic parameters during these disturbances. For this purpose, all years have been catagorized as either major sudden warming years (SW) or as other years (MSW). A sudden warming is defined to occur when there is a "reversal of the polar circulation at 10 mb. (30 km) or below". During 1961-72, SW were in 1962-63, 1965-66, 1967-68, 1969-70, and 1970-71, according to a list by Finger.

Several different methods could be used to study the changes of parameters during SW. For example, as planetary wave activity and other events associated with a SW are global in nature (Quiroz, et al., 1975), spatial wavenumber analysis of global data may be used to detect changes in the planetary wave patterns. However, the MRN and geomagnetic data are not sufficiently distributed geographically to permit detailed spatial analysis. Superposed epoch studies are often useful for single station analysis, but in the case of sudden warmings it is difficult to meaningfully define a key-date. Indeed, the criteria used for defining the occurrence of a SW are admittedly arbitrary. Thus, the approach used here is to perform power spectrum analysis of single station data and to compare the spectra of SW years with those of MSW years.

The available wind observations (Hook, 1972; Gregory and Manson, 1976) indicate that the circulation of the lower thermosphere is disturbed during a SW. Winds in the ionosphere can act as electric currents and can thereby produce variations in the geomagnetic field. Of course, processes unique to the magnetosphere can also produce variations in the geomagnetic field; but if a geomagnetic spectral feature can be assoiated with a meteorological process, it may be reasonable to assume that it arises from that meteorological process. Thus, studying spectral changes in the geomagnetic field between SW and MSW years may help better understand the thermosphere. Spectral analysis results for the zonal winds and for the horizontal field intensity are presented first, with a brief discussion of noteworthy features. A comparison of the two sets of results follows and a possible interpretation is suggested.

1. Stratospheric Zonal Winds

Spectra for the zonal winds at 40 km at Fort Greely and White Sands are given in Figures 10-11 for autumn through spring. These stations were chosen because they have the most complete data at high- and mid-latitudes, respectively. In Figures 10-13, K is wavenumber, solid lines are for SW spectra, and dashed lines are for MSW spectra. In autumn and winter there is more energy at Fort Greely (Fig. 10) during SW years if the peaks near K = 8 are momentarily disregarded. The high frequency peaks will be discussed later. At White Sands (Fig. 11), however, largest energy occurs during MSW years at K = 6 to 9 in autumn and K = 2 to 6 in winter. In spring the high frequency energy is significantly larger at both stations during MSW years. Chi-squared confidence limits have been entered at noteworthly wavenumbers in the figures to indicate the probability that the differences arise from chance. These results for autumn and winter support Matsuno's (1971) suggestions that there is enhanced upward flux of wave energy at high latitudes (e.g., Greely) during SW years, but during MSW years the waves are refracted toward lower latitudes (e.g., WSMR) resulting in more energy there during MSW years.

2. Horizontal Field Intensity

Time spectra of the variations in H at College and Tucson are given in Figures 12 and 13. Spectra for several observatories were computed. As College and Tucson demonstrate the salient features noted and are near the MRN stations used above, only they are presented here. The spectral differences between SW and MSW years noted below are probably due to meteorological influences, and not to solar induced effects. Hauska, et al. (1973), found that over all years 1932-1969 the magnitude of geomagnetic variations in the time range 4 to 40 days varies primarily with the approximately 11-year cycle. During the period 1961-1972, SW years defined above are well distributed over a solar cycle.

In general, at both stations, there is either little difference between SW and MSW years or the spectral values are greater during MSW years. During autumn, the largest differences are at low wavenumbers (K=1-3 at CO and K=1-6 at TU), while in spring differences are found at intermediate and high wavenumbers (K=4-5 at CO and K=3-11 at TU). During MSW autumn at College, a significant (1% level) peak is found at K=9; less significant peaks at K=10 are found there during winter and spring.

3. Discussion

The following chart summarizes which years have the significantly greater spectral values and the wavenumbers at which they occur:

	AUT	WIN	SPR
Greely	SW(3-5)	SW(5)	MSW(3-11)
CO	MSW(1-3)	MSW(1,5-6)	None
WSMR	MSW(6-11)	None	MSW(6-9)
TU	MSW(1-6)	None	MSW(3-11)

From the above chart and Figures 10-13 two points should be noted. First, the only time the spectral values are significantly higher during SW years is at Greely during autumn and winter. The first point was noted to be consistent with the theory of wave propagation and refraction. Second, significant spectral peaks near K=9 are found only at Greely and College during autumn and winter of MSW years and at Greely during autumn of SW years. The second point may also be explained by planetary waves as will be suggested next.

Planetary waves occur in the troposphere every year. As they propagate upward, they may be refracted toward lower latitudes or they may continue propagating upward, depending on the vertical and horizontal curvature of the flow profile (Simmons, 1974). As waves travel upward they decay; the rate of decay depends on the prevailing circulation. It is now hypothesized that waves of period near 4 to 5 days (K=8-11) are upward propagating at high latitudes during all years. If during MSW years they do not suffer severe attenuation then they may continue all the way to the lower ionosphere resulting in spectral peaks near K=9 at Greely (40 km winds) and College (lower ionospheric winds). During SW years the prevailing circulation may cause large attenuation or total absorption; thus, during SW years the peak near K=9 at Greely in autumn is smaller than during MSW years, and a corresponding peak is not found in winter at Greely nor in autumn or winter at College.

The above arguments, although sketchy and heuristic, are consistent with present knowledge. Lacking from present knowledge, however, is an adequate climatology of circulation differences during SW and MSW years, especially in the upper stratosphere.

D. CORRELATION OF MRN TEMPERATURES WITH K_p AND THE SOLAR SECTOR STRUCTURE

Numerous authors have suggested that the middle atmosphere may be heated following geomagnetic disturbances (e.g., Gordiyets, et al., 1973). A desirable method of testing this hypothesis would be a superposed epoch study using a magnetic storm parameter as the keydate. However, as the MRN data are too scanty to permit that study, the alternative procedure of finding lagged correlations of K_p with respect to the MRN temperature observations was used. The linear correlation coefficients between K_p and the layer mean temperature, 40 - 50 km, at Fort Churchill are given in Figure 14. All temperature soundings, 1960-1972, which had data through the entire layer were used in this study. Values of K_p, obtained from the World Data Center, Boulder, are reported for three-hourly periods; thus, the correlation coefficient was determined at three-hourly intervals as the temperatures were lagged with respect to the K_p values. In Figure 14, negative lag means that the K_p value was measured before the temperature value. The relative maximum correlations are found at lag zero and at lag -15 hours; although both peaks are statistically significant at only the 5% level (if all data are assumed independent), these results are complementary to those found by others.

Ramakrishna and Seshamani (1973) report a statistically significant correlation between the layer mean temperature (from grenade data) at Churchill, 60-89 km, and K_p. The peak correlation occurs when temperature is lagged 15 hours, and the largest correlation coefficients are found when the mean temperature is for the entire layer rather than just the upper portion of the layer. They report this correlation is significant at the 0.1% level. The largest regression coefficients, a measure of the relative magnitude of the effect, are found when only the upper portion of the altitude layer is used; and they suggest this may indicate a larger heating effect at highest altitudes. However, it also may be due to cancellation resulting from opposite effects in different portions of the entire layer. Results given by Zadvernyuk (1973) indicate that the critical layers of the atmosphere may respond differently to magnetic disturbances; e.g., following a magnetic storm there may be heating at the mesopause but cooling at the stratopause.

Several possible mechanisms could be suggested to account for the correlations discussed above: e.g., corpuscular heating, enhanced IR radiative exchange, etc. However, the correlation could also arise from a meteorological influence on K_p in a manner similar to that suggested by Hines (1973). Therefore, if correlation studies such as the above are to be taken as indicators of a geophysical process important to the lower atmosphere, they must be based on unambiguous parameters so that cause and effect can be clearly discerned.

The previous studies are inconclusive with respect to solar-terrestrial effects. Wilcox (1975) has already related K_p to solar sectors. The real question is whether temperature can be related to solar sector structure. To examine this, a superposed epoch study of the 40 - 50 km layer mean temperatures with solar sector boundary crossings used as key dates is desirable.

However, well defined solar sector boundaries sweep past the Earth at irregular intervals, about every week on the average, and the joint distribution of them with the intermittent MRN observations is not adequate for a superposed epoch study. Thus, it is possible to present in Figure 15 the sign of the temperature change at 40 km between closely spaced consecutive MRN observations at Churchill as a function of time, relative to a solar sector boundary crossing and K_p. The magnitudes of the temperature changes are not shown, but they are random. Solar sector boundary crossing dates were taken from the list in Shapley, et al. (1975). There are 21 temperature rises and 28 temperature falls on the chart, and they seem to be evenly distributed on both sides of the boundary. From this small sample it appears that the temperature trend shows no preference relative to the passage of a solar sector boundary. In summary, either the purported T-K_p relationship is due to some factor other than mutual coupling with solar sector structure, or a much larger sample would be required to establish reliably such a relationship.

IV. SUMMARY

Periodic analysis results of the horizontal and vertical field intensity show that maximum amplitudes of semiannual and annual waves are at high latitudes. It is suggested the high latitude maxima of the annual waves arise from annual waves in ionization density and thermospheric zonal wind speed. At mid- and low-latitudes the annual wave in zonal wind speed in the lower thermosphere (the dynamo region), which is driven by solar heating, accounts for most of the geomagnetic annual wave.

Annual variations in geomagnetic and MRN data are closely coupled. In view of the above cause of the geomagnetic annual wave, coupling between the circulations of the stratosphere and lower thermosphere can explain the geomagnetic-MRN coupling; thus, the present results for the annual wave are not evidence of any geomagnetic influence on the lower atmosphere. Other apparent correlations of the lower atmosphere and geomagnetic field may arise from a similar dynamo action in the thermosphere caused by coupling of the thermosphere with the lower atmosphere.

Semiannual variations in geomagnetic and stratospheric zonal wind data are also closely coupled. As the semiannual wave in thermospheric zonal wind is driven primarily by auroral heating, the cause of this coupling is not clear. It would be helpful if the cause of the stratosphereic semiannual wind wave were known, so three possible causes were discussed. Planetary wave absorption seems to be a direct cause only near 30^{o}N, and heating by IR from the lower thermosphere during magnetic storms is energetically unlikely. Possible modulation of the ozone (and hence thermal and wind fields) by particle precipitation during geomagnetic storms has not yet been verified by observations. Amplitudes of the annual and semiannual waves in stratospheric zonal wind may be modulated with the solar cycle as they generally have extreme values concurrent with extreme values of the sunspot number. This result for the annual wave is believed reasonable as the yearly number of proton solar flares varies with the solar cycle and solar flares can dramatically affect the ozone field. If particle precipitation during geomagnetic storms also influences the ozone field, then this result for the semiannual wave could also be explained as the semiannual variation in geomagnetic activity varies with the solar cycle.

Power spectrum analysis of zonal wind variations shows that at high latitudes there is significantly more wave energy in the upper stratosphere during years when major sudden warmings (SW) occur, but at mid-latitudes largest wave energy is found during years when major sudden warmings do not occur (MSW). This could be explained by wave refraction which occurs in varying degree each year depending on the profile of the background flow; however, a climatology of background flows during SW and MSW years is apparently not available. If geomagnetic variations reflect wind activity in the lower thermosphere then the noted differences between SW and MSW years at mid- and high-latitudes seem consistent with recent theories of planetary wave propagation. The present results suggest that the planetary wave absorption peculiar to SW years occurs in the upper stratosphere, far below the region where direct geomagnetic effects are significant, and thus any direct geomagnetic "trigger" for sudden warmings seems unlikely.

Although the correlation between stratospheric temperature and K_p appears statistically significant and is complimentary to the results of others, cause and effect cannot be discerned. If correlation studies are to be used as evidence of a solar-terrestrial effect, they must be based on parameters of strictly solar origin such as the solar sector structure.

APPENDIX

Organized wave activity in the upper stratosphere has been studied with MRN data by several writers, most recently by Hirota (1975). The latter used only those MRN stations which had at least 30 observations during a given season, subjectively interpolated the data to daily values by analyzing height-time sections for each station, and computed the frequency content of the interpolated data by power spectral analysis. Hirota's method is very effective for analyzing a single season's data; however, the present objective is to prepare a climatology of the power spectra of MRN data, and a less restrictive, objective approach is desirable. Rocket data have historically been taken on an irregular often sporadic basis, and there are instances of many observations at a given station over a time span of a few weeks with relatively sparse data before and after that period. A climatological analysis method should take advantage of those intermittent periods of dense data. The lag-weighted autovariance function method described below is suited for this purpose, and has been used to estimate seasonal power spectra of MRN wind components, 30-60 km. This method was also used to analyze the power spectra of geomagnetic variations reported in Section III-C of the text. Although a complete description of this method can be found in Dartt and Hovland (1974), a basic outline of it and the variations used here will be given.

A. BASIC DATA HANDLING AND TECHNIQUE

At each 2 km level, 30 - 62 km, multiple rocket ascents over a two-day period were averaged together and counted as one datum in the time series. Due to the poor distribution of MRN observations, many data points represent only one observation and many are missing; but a surprisingly large number (for example, 20% at Churchill) of data points do represent multiple observations. Interpolation was not used for missing data. The time series thus obtained at each station and level were then high-pass filtered by convolution with a discrete, symmetric series of Gaussian weights. To account for missing observations, the weights under the filter were normalized at each data point such that their sum was always equal to 1.0. The ideal frequency response of this filter is shown in Figure A-1; however, due to missing observations, the actual frequency response is slightly less sharp than shown in the figure.

If an observation is far removed in time from other elements of the time series the filtering process will be ineffective as the datum is then filtered, essentially, with only itself. To preclude this, it was required that there be at least five other data points under the filter (out of a possible 30) and that the sum of the weights before normalization be at least 0.25. These latter conditions resulted in discarding about 10% of the data.

Autovariances up to lag 11 were computed for each individual season, 1961-1972. Three-month seasons were used at all stations with winter defined as December through February. The autovariances and the number of data pairs at each lag and each season were then stored for future use. Seasonal autovariances for all years of record were computed by combining individual seasonal values according to:

$$\overline{R(\tau)} = \frac{\Sigma\, R(\tau)N(\tau)}{\Sigma\, N(\tau)}$$

where $R(\tau)$ is the autovariance and $N(\tau)$ is the number of data pairs available at lag τ for a given season. With this procedure seasonal autovariances can be computed for the entire period of record, or for just selected years (e.g., years of major sudden warmings). Autovariances thus obtained were Hanned; estimates of the power spectra were obtained by taking the cosine transform of the Hanned autovariances. Finally, the computed values, V, were normalized:

$$\hat{S} = V\ [2\ \mathrm{MAX}\ \Delta T/2\pi]$$

where, in this case, MAX is 11 and ΔT is 2 days; and $\hat{S}$ is the normalized value.

The percentage relative error of each spectral estimate was computed by determining the variance of Hanned spectral estimates according to the formulation of Eddy (1968). The effective number of degrees of freedom required for that calculation were determined with the method of Mitchell (1963). It must be noted that these errors reflect how well each spectrum conforms to a particular statistical model and are only as realistic as that model. Further, they do not account for suspected error sources such as aliasing. Aliasing, or spectral folding, results from sampling at a frequency lower than twice that of the natural variability; this problem is discussed in detail by Lumley and Panofsky (1964). If the true spectrum is a "red-noise" spectrum, as frequency decreases energy increases, then aliasing will tend to make the estimated spectrum flat, i.e., with equal energy at all frequencies. As discussed below, this problem may be more serious for the meridional wind than for the zonal wind.

B. TABLES OF SPECTRAL ESTIMATES

Eight MRN stations have adequate data to provide meaningful estimates of the variance spectrum for the wind components. Temperature observations are less plentiful than wind observations and did not provide useful results. Tables associated with this appendix give climatological spectral estimates for the wind components for each season. The values in the tables have been smoothed with height by a three point binomial filter. As the effect of missing observations on the frequency response of the high pass filter is difficult to estimate, no attempt to restore the spectra has been made; but it appears that the energy in the first frequency (centered at $2\pi/44$ days) is reduced more than the 55% predicted by the theoretical frequency response of the filter.

The relative reliability of the spectrum at each height is indicated by the number of lagged data pairs and the percentage relative error estimates. The distribution of MRN observations is such that N(1) $\approx$ .... N(11) $\approx$ 1/2 N(0), so only N(1) is given in the interest of brevity. Also, the percentage relative errors are nearly linear with wavenumber; thus, errors at intermediate frequencies can be estimated by linear interpolation of the values given for K=1 and K=11.

In spectral analysis there is always a trade-off between resolution and reliability of the spectrum. By averaging adjacent bands a more reliable spectrum may be obtained, but a corresponding loss of resolution results. The most reliable parameter is thus the total variance of the filtered data, which is included in the tables. From experience, the best indicator of the reliability of the total variance is the number of lagged data pairs, and when N(1) is less than about 60 the variance should be disregarded.

In the tables, "VAR" is the total variance of the filtered data, "N" is the number of data pairs at lag one, and "P.R.E." is the percent relative error for bands one and eleven.

C. DISCUSSION

During the Northern Hemisphere summer, the power of zonal wind spectra at a given level generally decreases with increasing K at mid-latitude stations (Kennedy through Wallops) and at Ascension. Zonal wind spectra at Greely, Churchill, and Barking Sands, and meridional wind spectra at all stations, are generally very flat at a given height but have large gradients with height. Although this strongly suggests that aliasing may be a serious problem at the latter stations, Dartt and Hovland (1974) report that summer spectra in the lower stratosphere (30 mb), determined from relatively complete time series of twice daily radiosonde data, are also very flat, especially for the meridional wind. It is therefore likely that aliasing by periods longer than diurnal is not serious in the present results. Note that it is impossible to comment on possible aliasing by periods shorter than diurnal.

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(a)

(b)

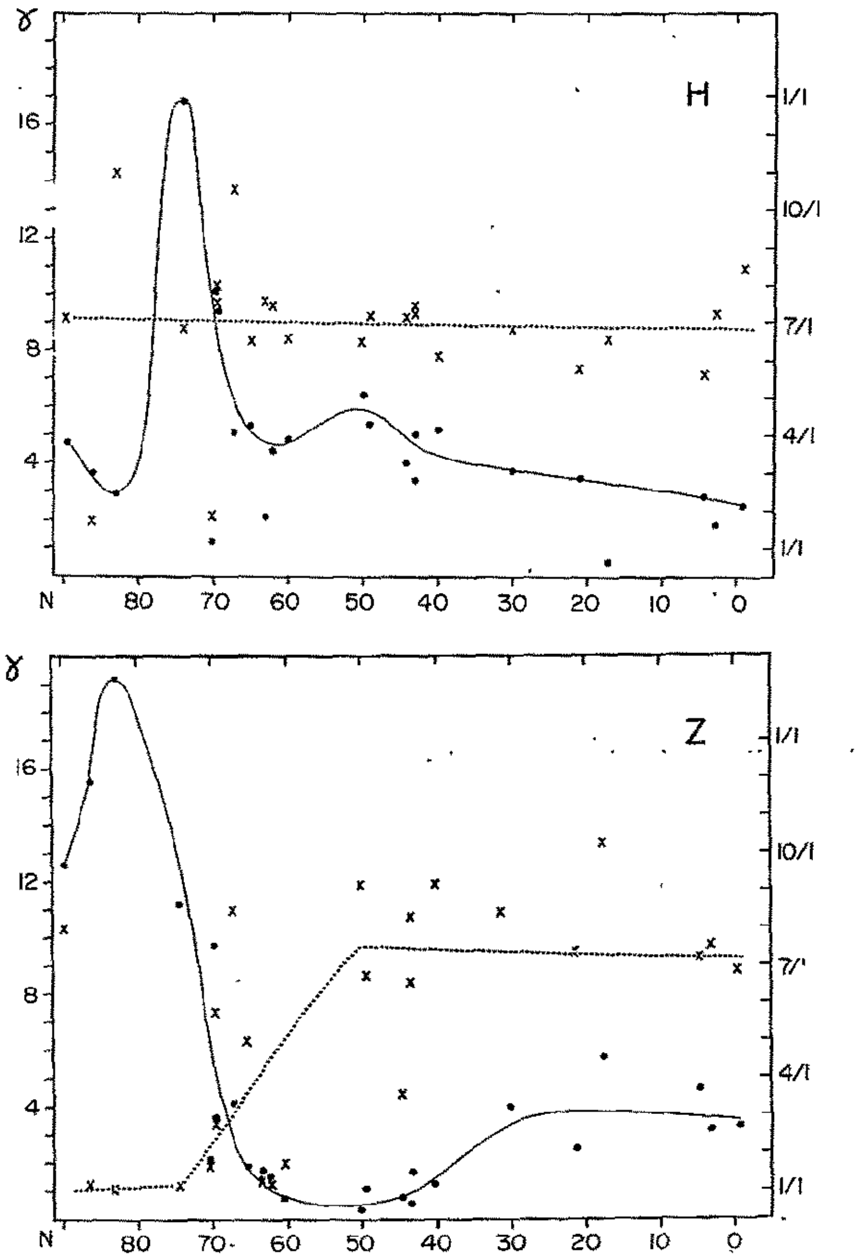


Figure 1. Annual wave in (a) horizontal, (b) vertical field intensity. Dots are amplitudes and crosses are phases of stations in Table 2, plotted at geomagnetic latitude. Lines estimating the latitudinal variation of amplitude (solid) and phase (dotted) have been fitted by eye.

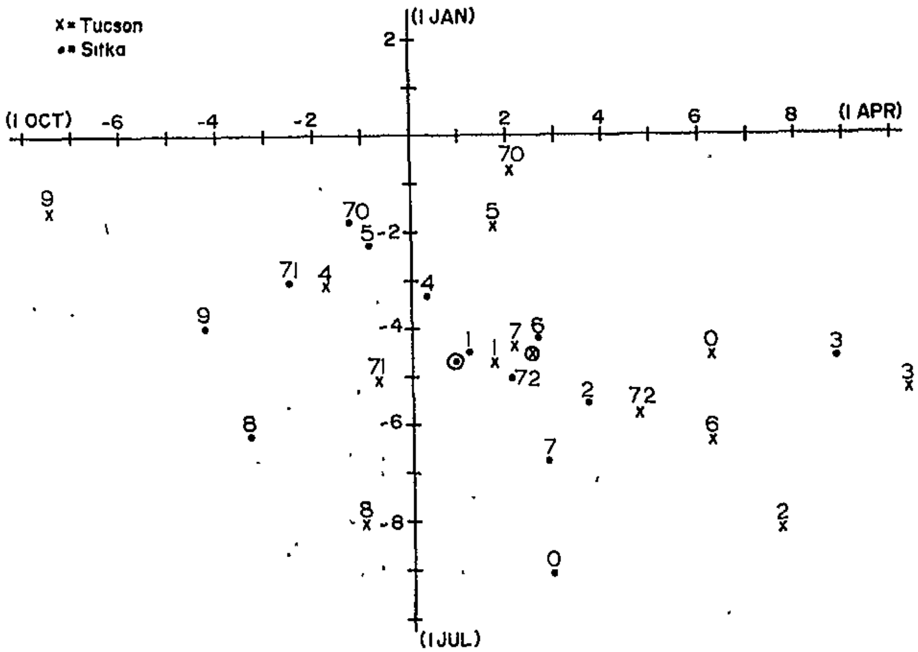


Figure 2. Harmonic dial of the amplitude and phase of the annual wave for each year, 1960-1972, at Sitka and Tucson. The average values for all years are circled. The small number above each point is the year that the point represents (i.e., 3 is for 1963). Axes are labeled in gammas.

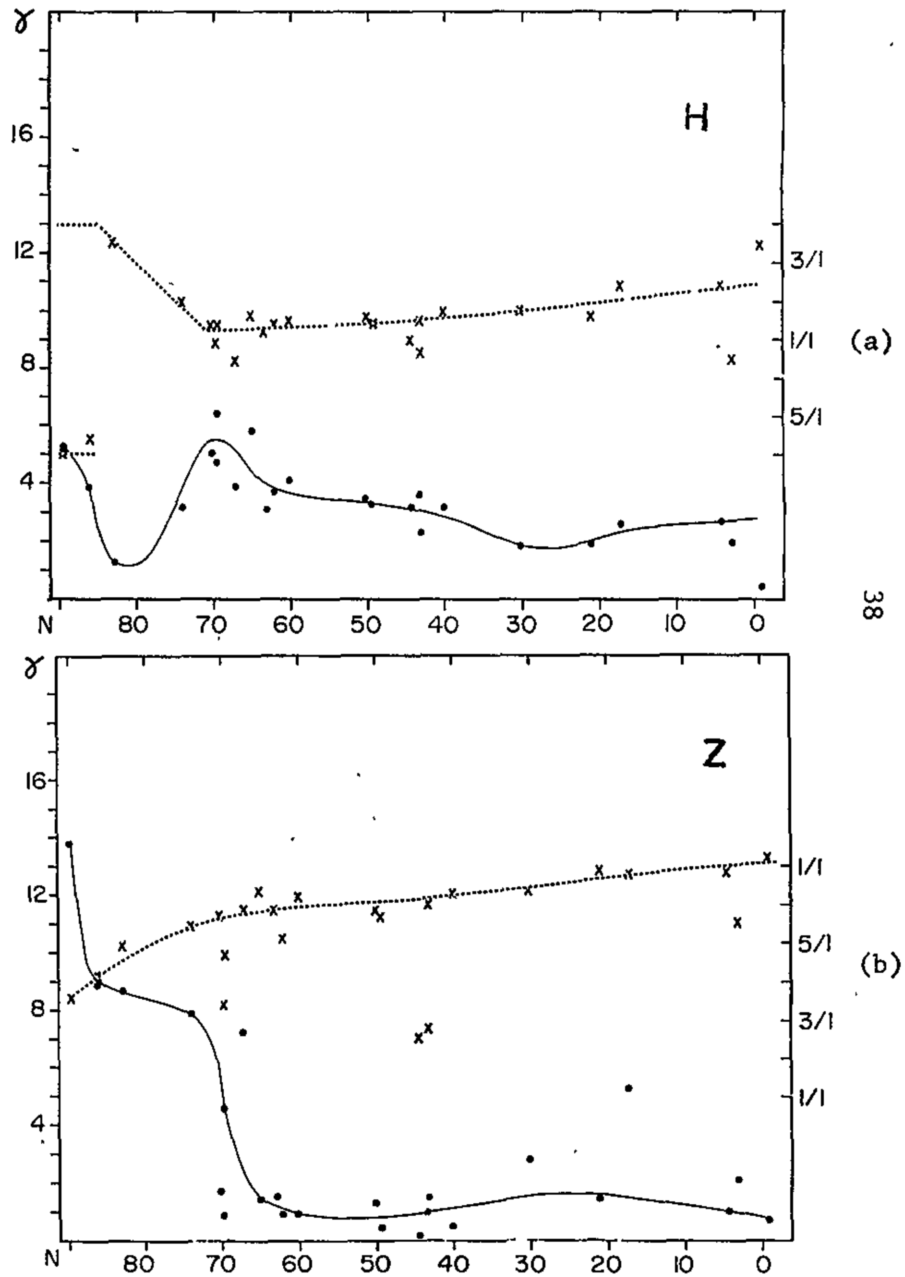


Figure 3. As in Figure 1 except for the semi-annual wave.

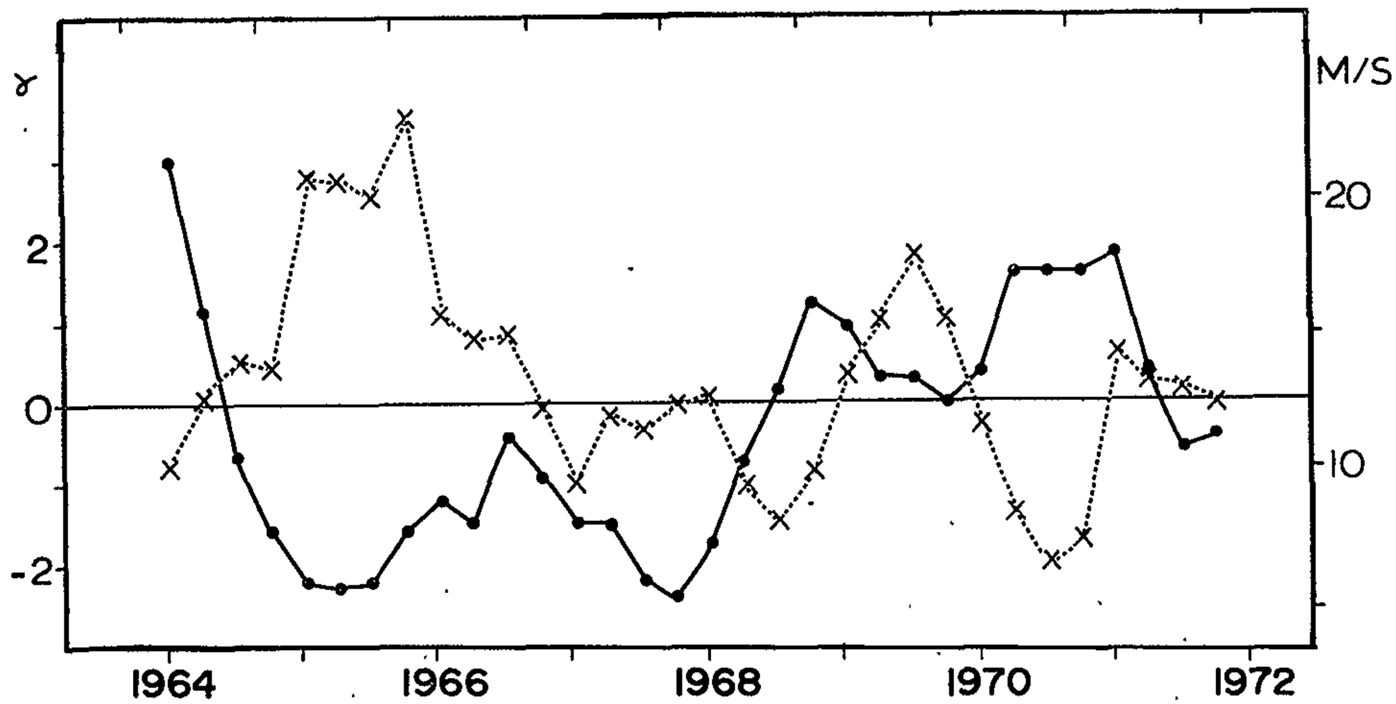


Figure 4. Twelve-month running mean values of Z (solid line) at Honolulu relative to the parabolic secular trend line, and twelve-month running mean values of zonal wind at 56 km at Barking Sands (dotted line). Tick marks on abcissa are for 1 July; every third month is plotted.

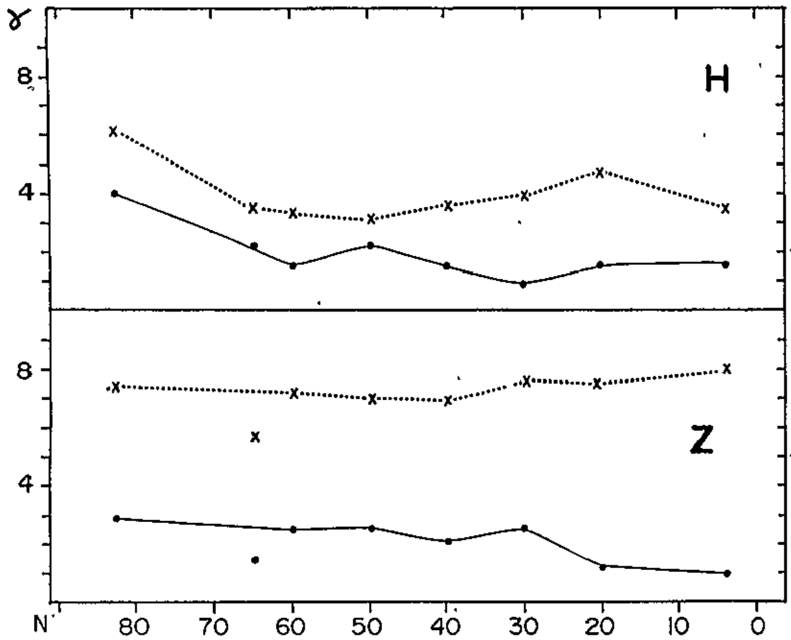


Figure 5. As in Figure 1 except for the QBO. Ø scale is months relative to 1 January 1960.

Figures 6a-6f. Height-latitude sections of relative phase lags of MRN and geomagnetic periodic waves in geographic coordinates for station pairs in Table 1. In dotted areas phase lag is within 30° of zero; in shaded regions it is within 30° of 180°. (a) annual wave, U and H (b) semiannual wave, U and H, the dashed line is explained in the text (c) annual wave, U and Z (d) semiannual wave, U and Z (e) annual wave, T and H (f) annual wave, T and Z.

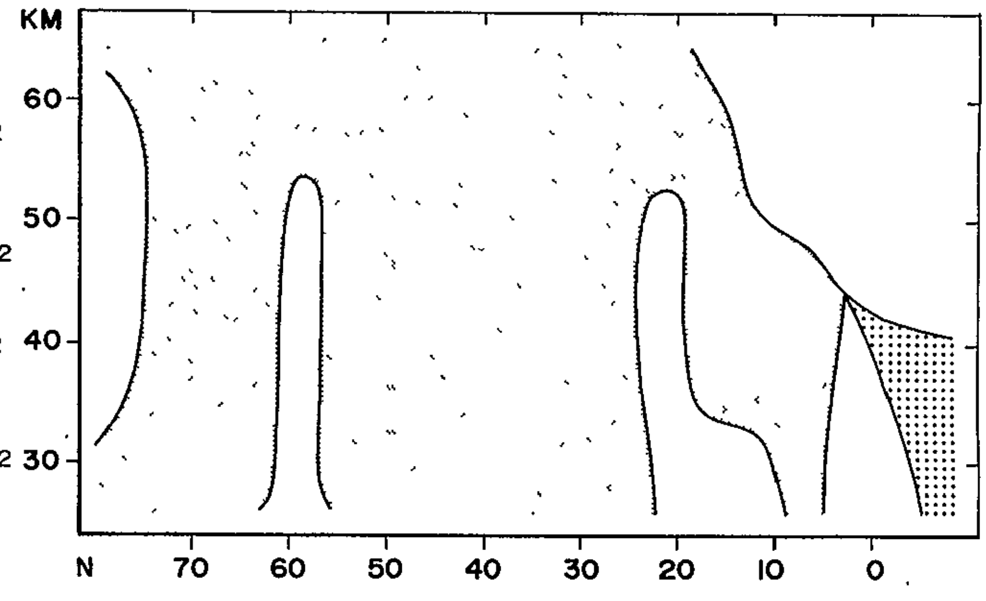


Figure 6a.

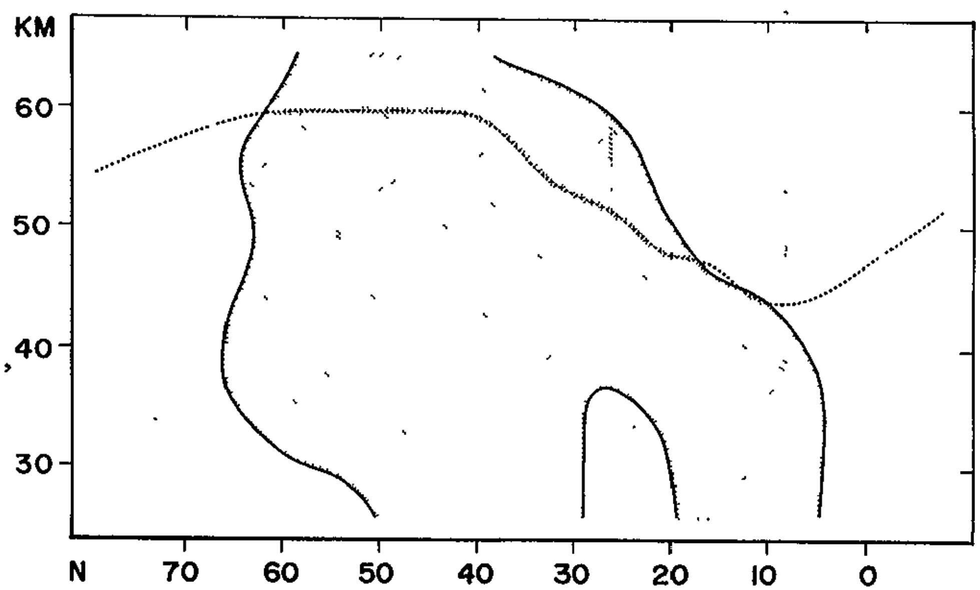


Figure 6b.

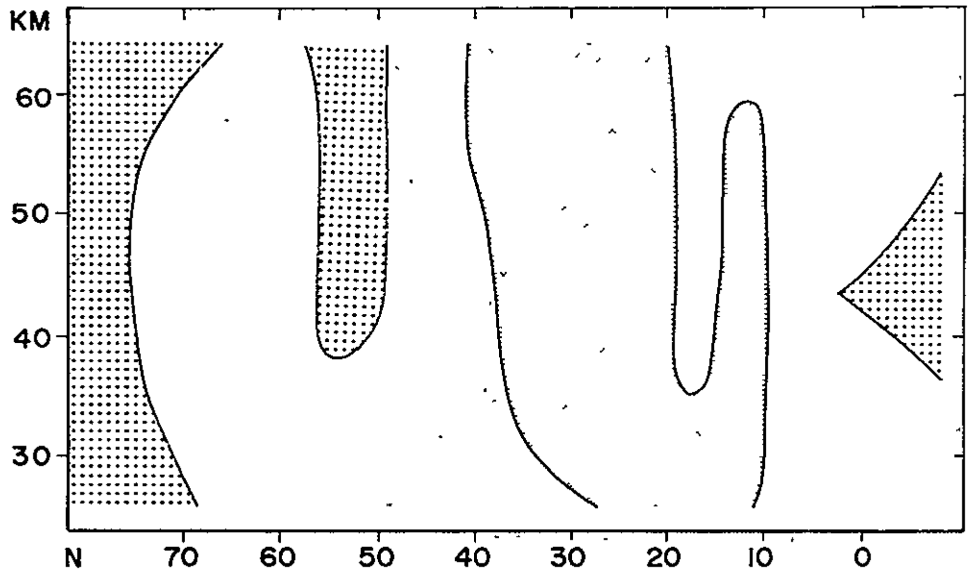


Figure 6c.

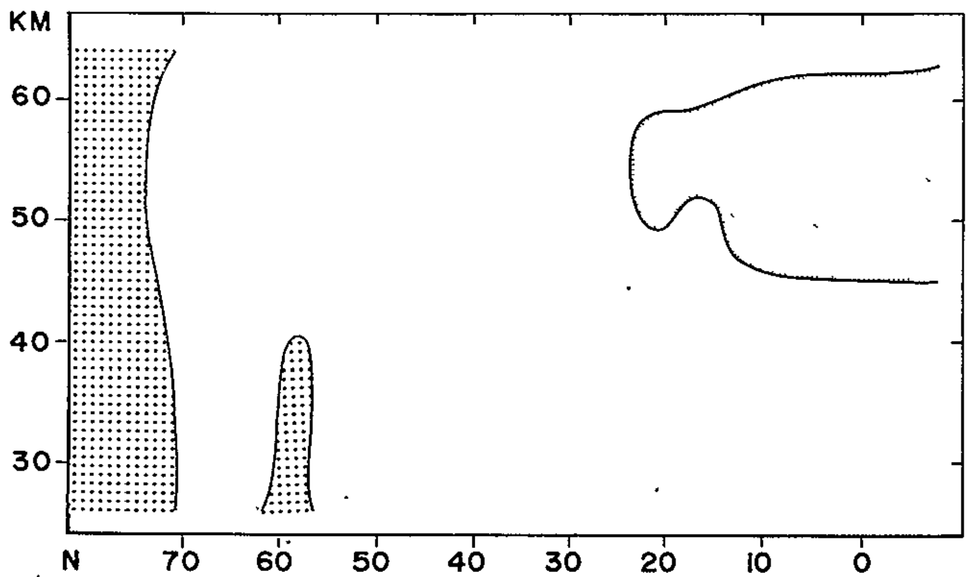


Figure 6d.

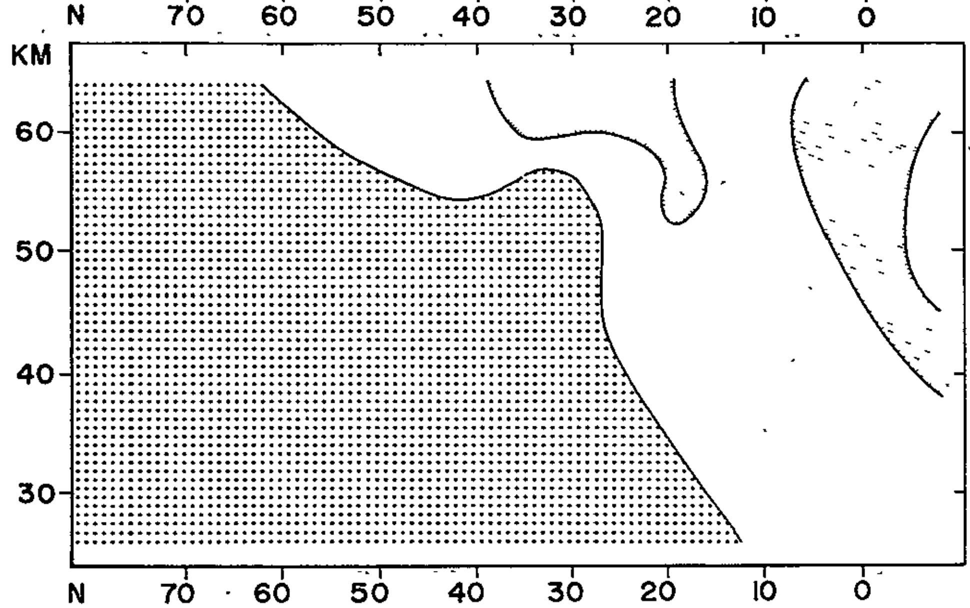


Figure 6e.

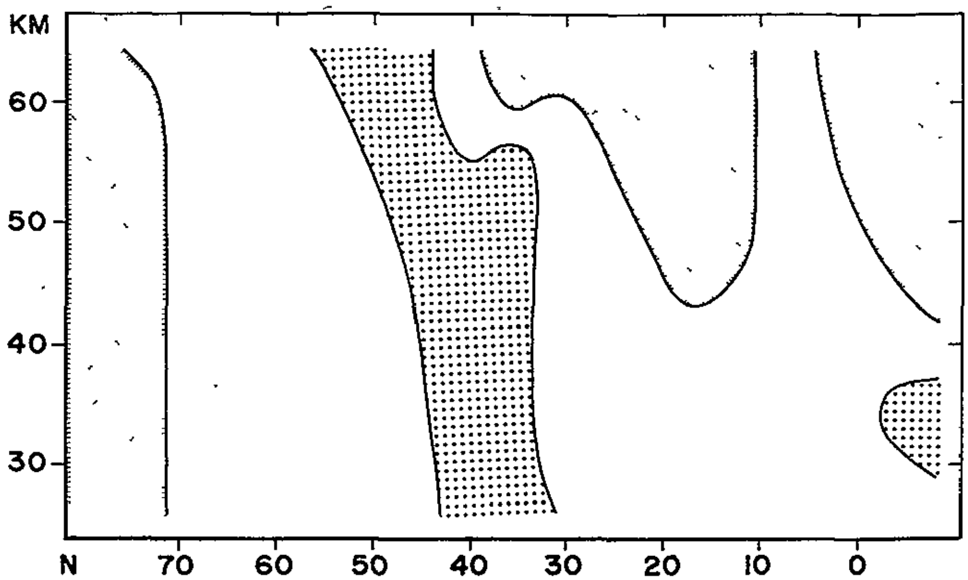
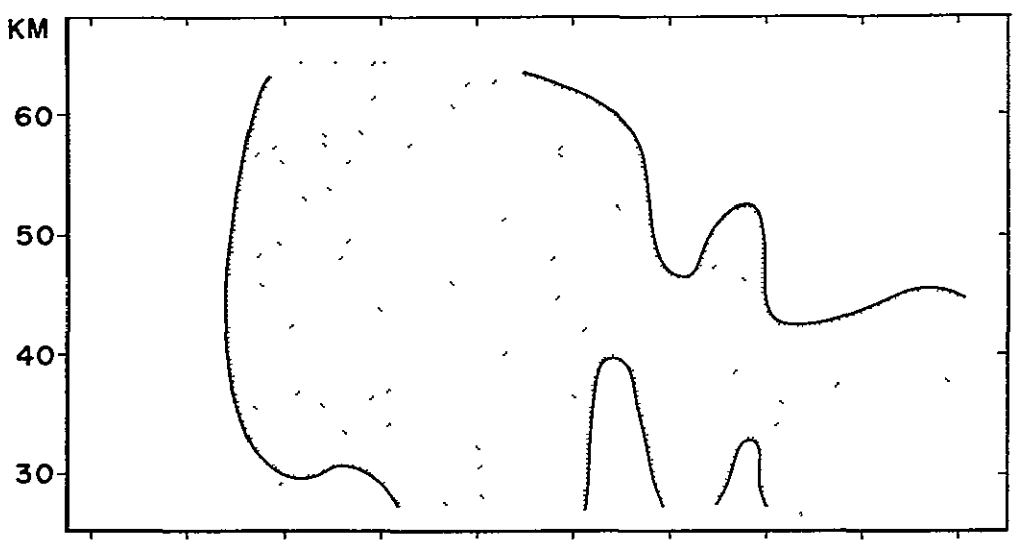
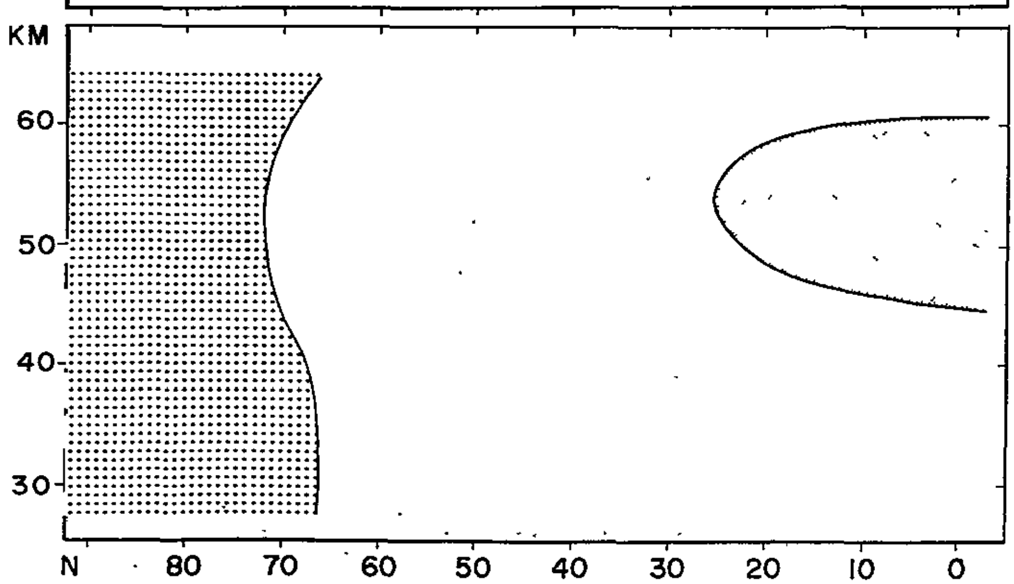


Figure 6f.

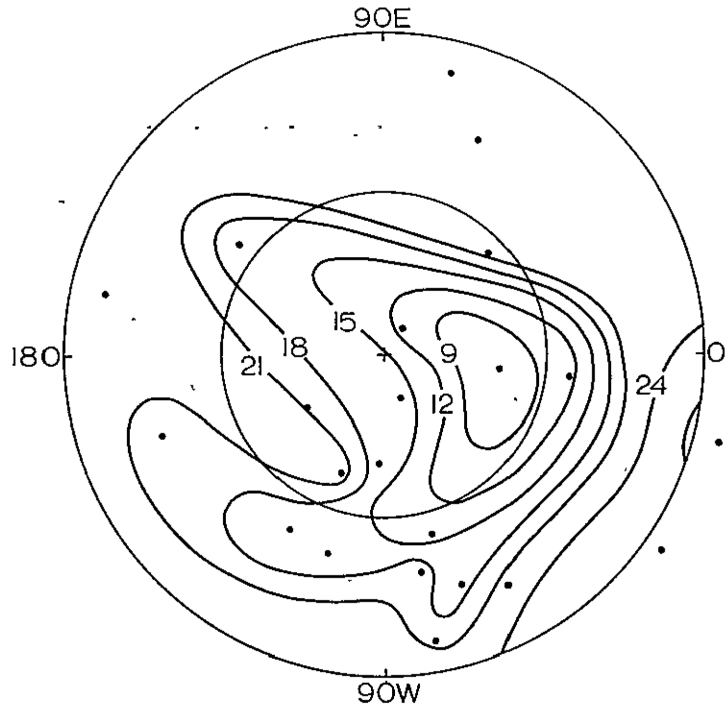


(a)

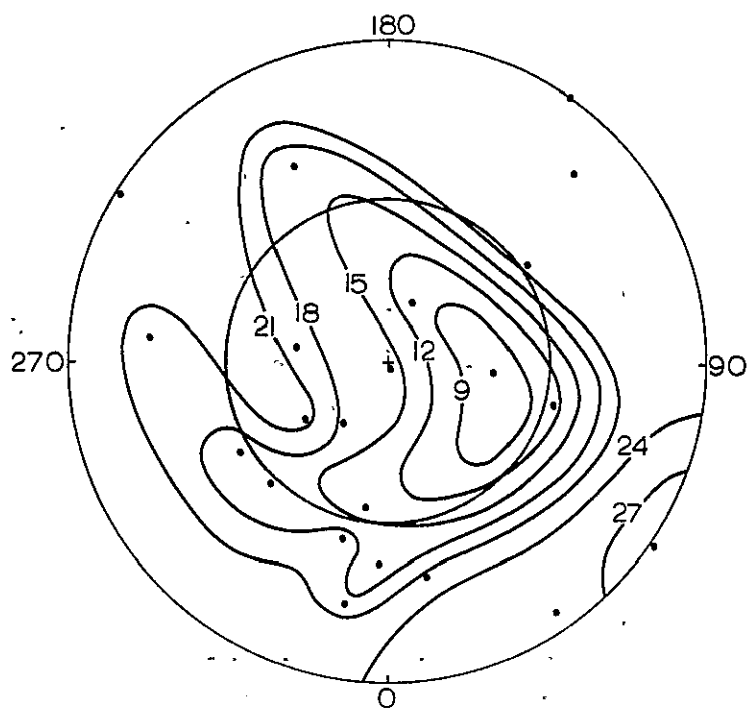


(b)

Figure 7. As in Figure 6 except geomagnetic latitude. (a) semiannual wave, U and H; (b) semiannual wave, U and Z.



(a)



(b)

Figures 8a and 8b. The amplitude (m s^{-1}) of the semiannual wave in zonal wind at the altitude indicated by the dashed line in Figure 6(b) or Table 1. Dots are MRN station locations. (a) geographic coordinates; (b) geomagnetic coordinates.

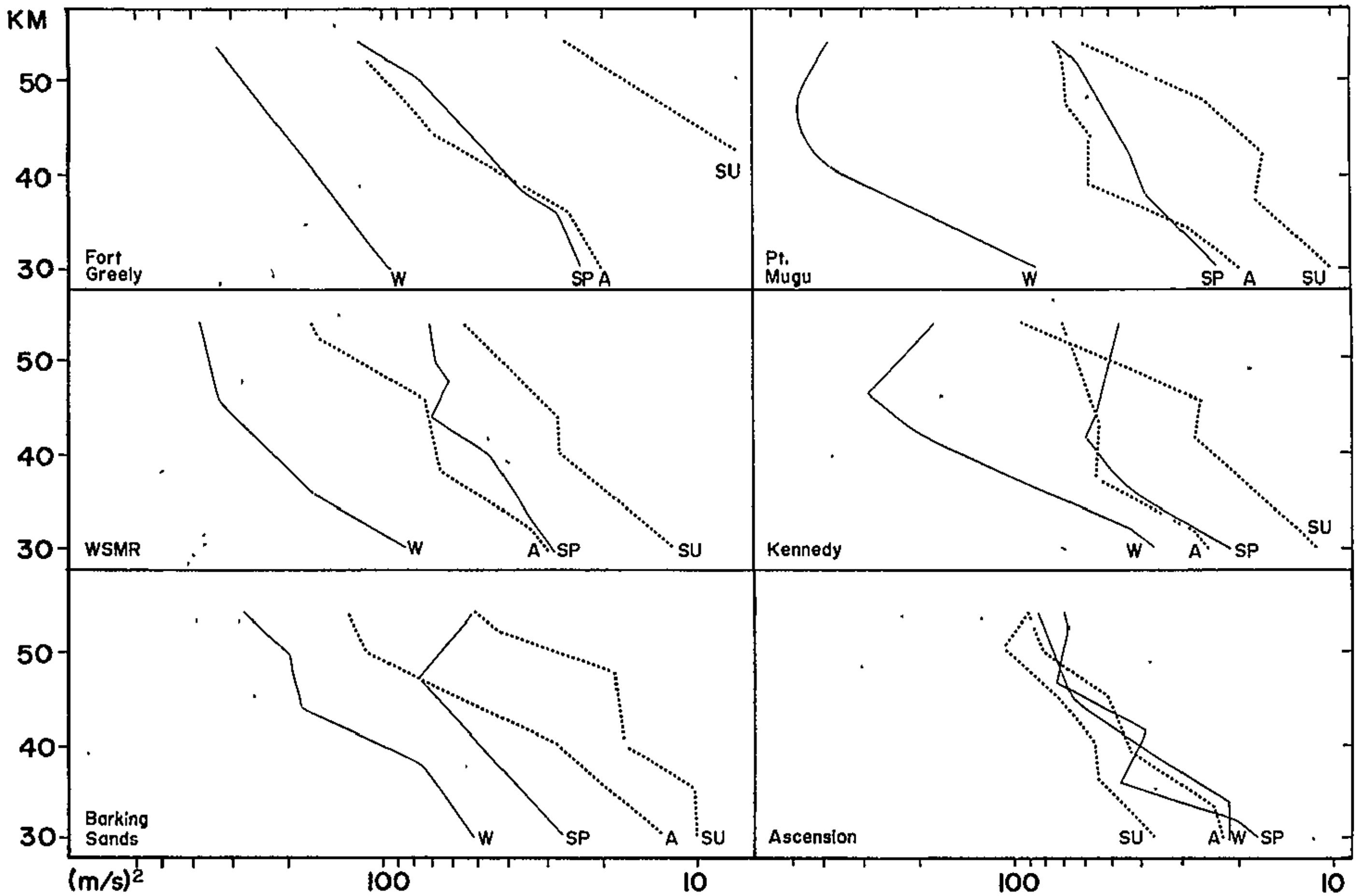


Figure 9. Power spectral density in zonal wind as a function of height for the band centered at 2π/11 days, by season.

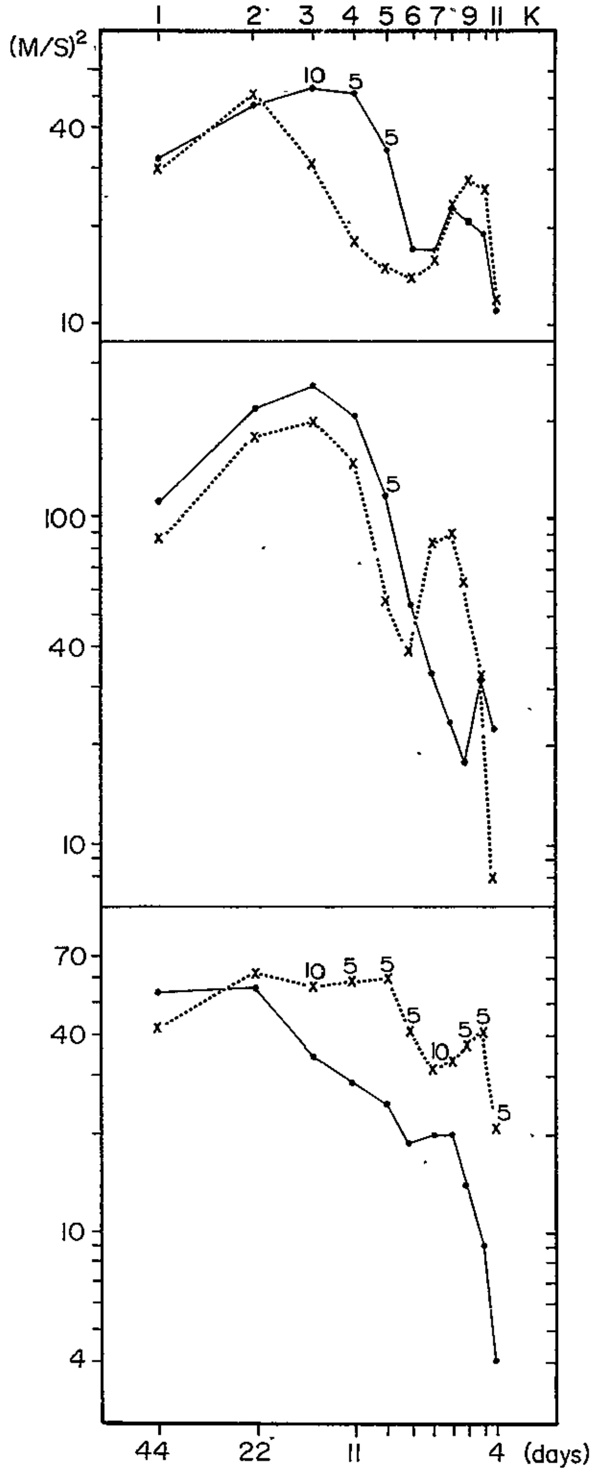


Figure 10. Power spectrum of zonal wind variations at 40 km at Fort Greely. Solid line is for SW years, dotted line is for MSW years, as defined in the text. Statistical significance level of the difference between the two spectra is indicated for continuum values.
(a) autumn (b) winter (c) spring.

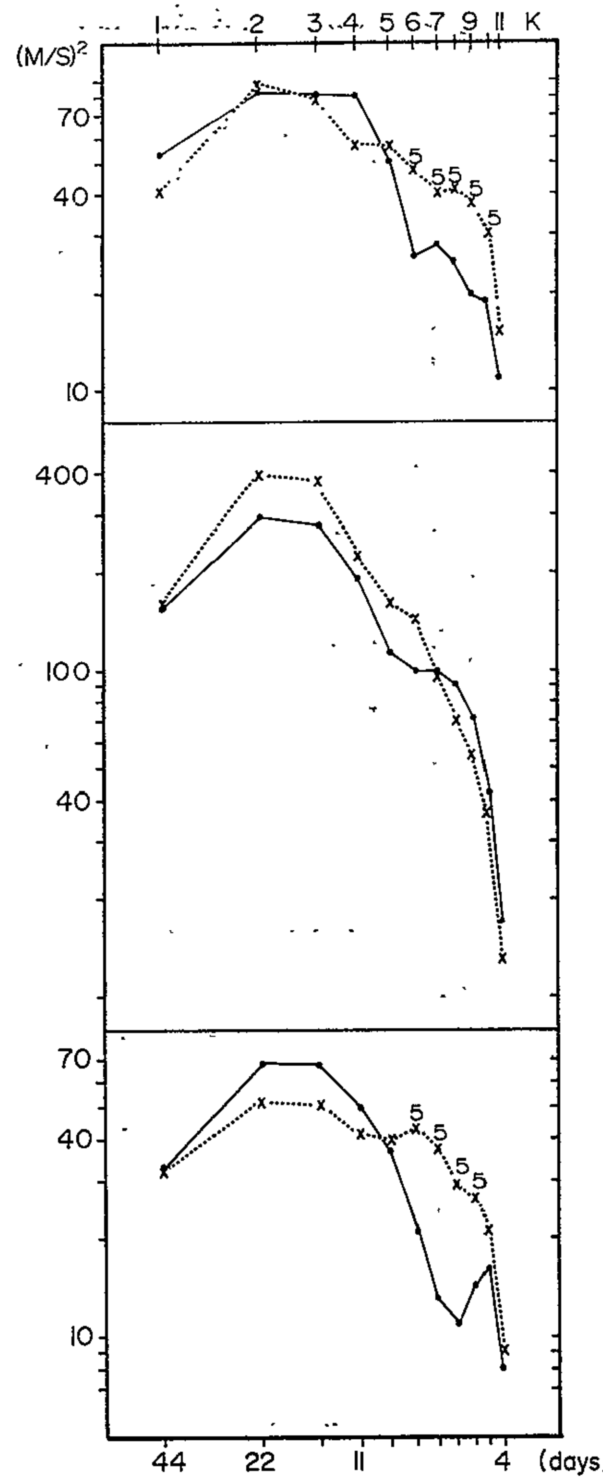


Figure 11. As in Figure 10 except at White Sands.

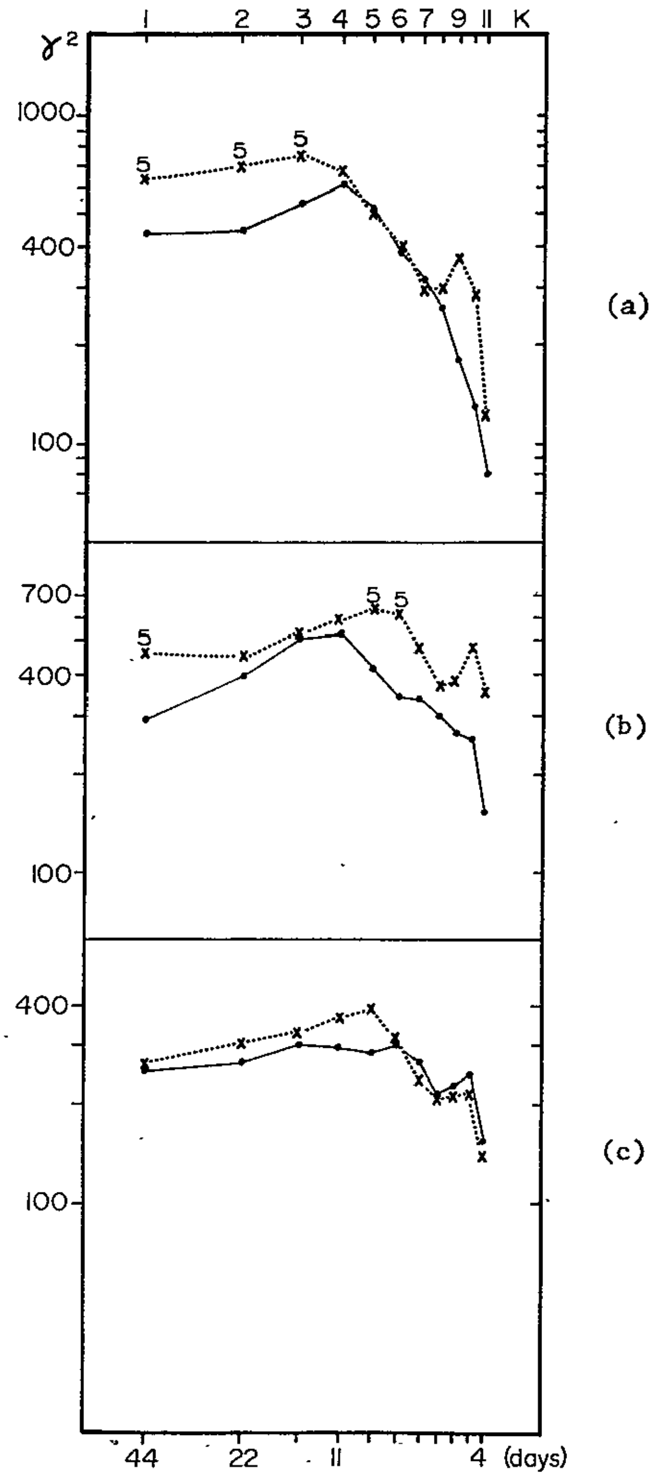


Figure 12. As in Figure 10 except for the horizontal field intensity at College.

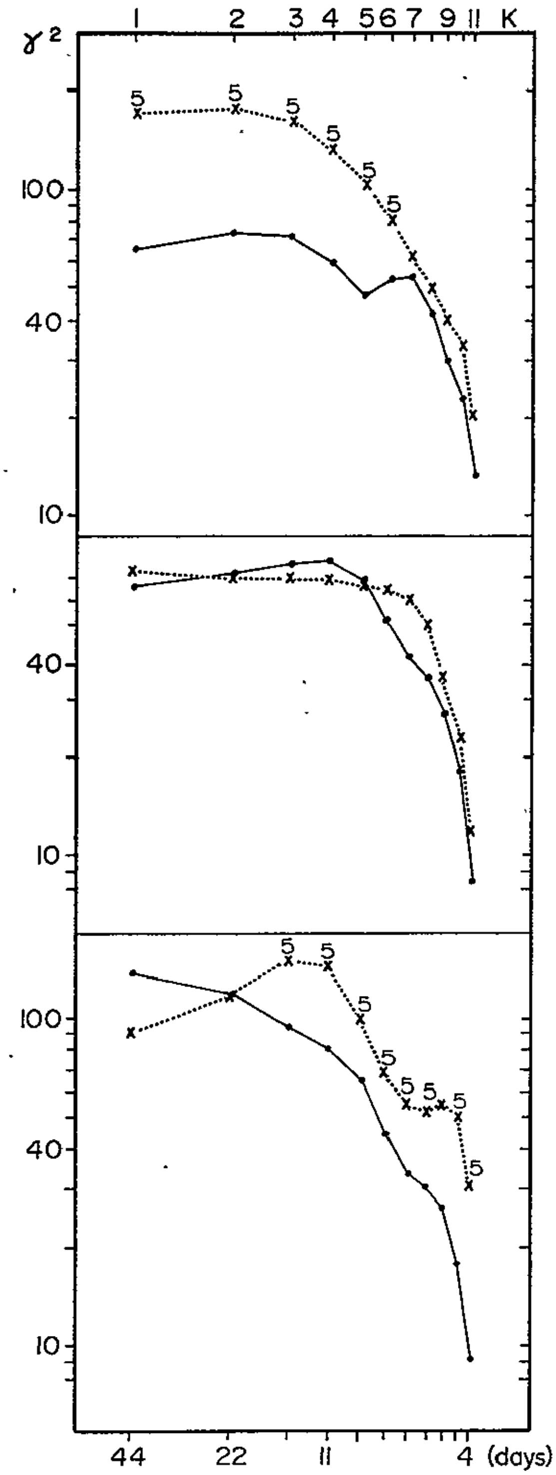


Figure 13. As in Figure 10 except for the horizontal field intensity at Tucson.

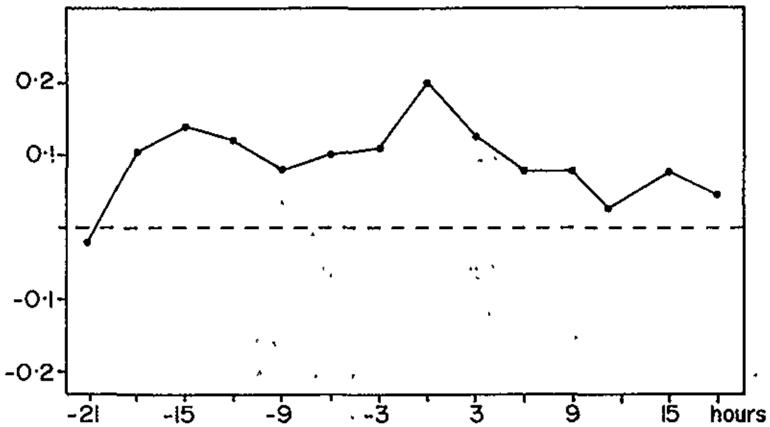


Figure 14. Linear correlation coefficient between layer mean temperature, 40-50 km, at Fort Churchill and K_p as a function of the lag of temperature.

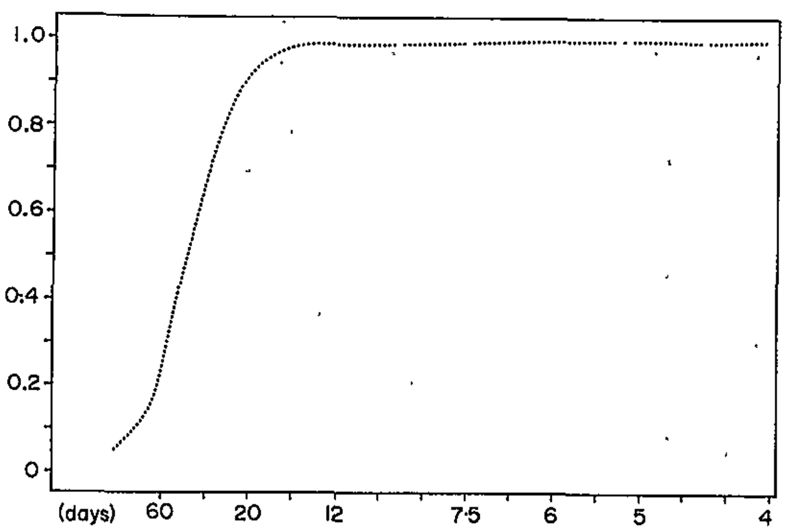


Figure A-1. Theoretical frequency response of the numerical filter described in the Appendix.

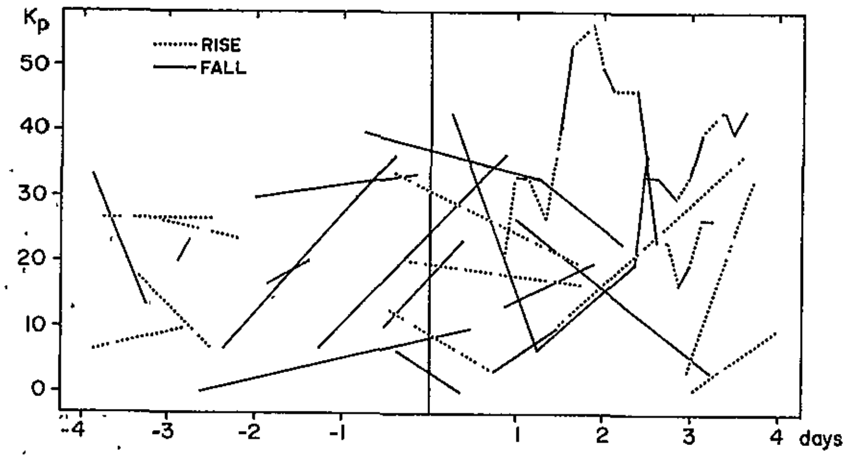


Figure 15. Trend of the temperature at 40 km at Fort Churchill between closely spaced ascents made near a solar sector boundary crossing. End points of each line segment are plotted at the time relative to boundary crossing and at the corresponding value of K_p.

Table 1. List of meteorological rocket stations.

STATION	LAT.* (GEOGRAPHIC)	LONG.* (GEOGRAPHIC)	LAT.* (GEOMAGNETIC)	LONG. (GEOMAGNETIC)	NUMBER OF OBS. AT 50 KM (WIND)	NUMBER OF OBS. AT 50 KM (TEMP.)	NEAREST GEOMAGNETIC OBSERVATORY	SYMBOL
a. Stations used in Figures 6-8.								
THULE	77	69	88	10	335	296	RESOLUTE	RB
FORT GREELY	64	146	64	261	1011	563	COLLEGE	CO
CHURCHILL	59	94	68	324	991	884	CHURCHILL	FC
PRIMROSE LAKE	55	110	62	305	316	312	SITKA	SI
WALLOPS	38	75	48	351	1351	674	FREDRICKSBURG	FR
POINT MUGU	34	119	41	302	1971	1226	BOULDER	BD
WHITE SANDS	32	106	42	317	2481	988	TUCSON	TU
KENNEDY	28	81	38	347	1916	1142	DALLAS	DS
BARKING SANDS	22	160	21	265	1372	898	HONOLULU	HO
ANTIGUA	17	62	28	10	466	371	SAN JUAN	SJ
SHERMAN	9	80	20	350	631	422	FUQUENE	FQ
KWAJALEIN	9	-168	1	238	318	305	GUAM	GU
ASCENSION	-8	14	-1	55	1196	937	HUANCAYO	HU
b. Stations used only in Figure 8.								
HEISS ISLAND	81	-58	72	156	156 (56 KM)			
WEST GEIRNISH	57	7	60	84	124 (56 KM)			
VOLGOGRAD	49	-44	43	125	87 (52 KM)			
RYORI	39	-142	29	207	32 (48 KM)			
ARENOSILLO	37	7	41	76	80 (54 KM)			
SONMIANI	25	-67	16	137	54 (50 KM)			
GRAND TURK	21	71	32	357	170 (50 KM)			
THUMBA	9	-77	0	146	145 (50 KM)			
NATAL	-6	35	5	34	131 (46 KM)			

* Minus is south or east.

TABLE 2. Periodic analysis results of the geomagnetic field elements. Amplitudes are in tenths of gammas and phases are in degrees. Statistical errors are in parentheses.

	GEO-MAGNETIC		NUMBER OF MONTHS		H						Z					
					QBO		ANNUAL		SEMIANNUAL		QBO		ANNUAL		SEMIANNUAL	
	LAT	LON	H	Z	AMP	PHASE	AMP	PHASE	AMP	PHASE	AMP	PHASE	AMP	PHASE	AMP	PHASE
THULE	89	358	34	34	46(25)	-78(44)	47(17)	-177(23)	53(17)	-175(20)	190(69)	-102(36)	126(42)	-151(20)	138(40)	151(18)
ALERT	86	168	77	77	46(16)	106(22)	36(15)	21(27)	39(15)	-154(25)	15(24)	84(9)	156(23)	4(8)	89(22)	-173(15)
RESOLUTE	83	168	115	115	40(5)	159(7)	29(5)	-62(10)	13(5)	153(23)	29(13)	-118(30)	192(14)	1(4)	87(13)	-125(9)
BAKER LAKE	74	315	101	101	89(13)	-15(9)	169(14)	174(5)	32(13)	55(27)	109(20)	134(11)	112(20)	2(11)	79(20)	-94(15)
LIERVOGUR	70	71	87	81	1(13)	-122(95)	12(14)	27(23)	50(4)	20(15)	18(14)	-7(14)	21(14)	23(11)	17(4)	-80(14)
CHURCHILL	69	323	69	69	86(14)	79(8)	102(12)	-151(6)	47(11)	-8(14)	28(12)	81(26)	97(11)	54(7)	9(8)	141(73)
BARROW	69	241	95	94	29(9)	-107(17)	94(8)	-167(5)	64(8)	21(7)	16(6)	150(25)	36(6)	142(10)	46(6)	-141(8)
GREAT WHALE RIV	67	347	64	64	139(16)	30(7)	51(5)	-74(19)	39(15)	-33(25)	40(9)	-43(13)	41(8)	-135(12)	73(9)	-66(7)
COLLEGE	65	257	156	156	22(5)	-43(15)	53(6)	164(6)	58(6)	38(5)	15(3)	112(13)	19(3)	119(10)	14(3)	-40(14)
LERWICK	63	89	20	20	24(10)	81(17)	21(16)	-164(26)	31(5)	10(10)	13(16)	87(20)	17(4)	7(12)	15(3)	-68(12)
MEANOOK	62	301	68	68	7(4)	30(39)	44(4)	-168(5)	37(4)	25(6)	14(4)	-35(15)	15(4)	6(14)	9(3)	-115(25)
SITKA	60	275	156	156	15(4)	-49(15)	48(4)	168(4)	41(4)	30(5)	25(4)	-137(5)	7(2)	21(21)	9(2)	-49(16)
FREDRICKSBURG	50	350	156	156	22(5)	-70(15)	64(5)	163(5)	34(5)	37(9)	26(5)	-148(13)	3(4)	-115(86)	13(5)	-69(25)
BOULDER	49	317	72	72	19(5)	-11(17)	54(5)	-174(6)	33(5)	27(9)	17(3)	-140(12)	12(3)	172(16)	4(3)	-80(61)
STEPANORKA	44	111	32	32	9(8)	143(70)	40(9)	-175(14)	32(9)	-2(16)	47(6)	104(9)	8(5)	78(55)	2(4)	93(87)
CASTLE ROCK	43	299	33	33	19(6)	-88(19)	34(6)	-170(11)	36(6)	-18(10)	9(3)	101(19)	6(3)	-141(33)	15(3)	108(11)
DALLAS	43	328	99	99	15(5)	-94(20)	51(5)	-168(5)	23(5)	29(12)	28(3)	-96(6)	17(3)	167(10)	10(3)	-62(18)
TUCSON	40	312	156	153	15(4)	-39(18)	53(4)	152(5)	32(4)	44(8)	21(3)	-158(8)	13(3)	-114(4)	5(3)	-43(44)
SAN JUAN	30	3	156	156	9(6)	-7(69)	38(4)	175(7)	18(4)	43(14)	26(4)	-108(9)	40(7)	-138(10)	28(7)	-37(15)
HONOLULU	21	266	144	144	15(4)	49(15)	35(4)	143(6)	19(4)	37(12)	12(2)	-116(9)	25(2)	-169(4)	14(2)	-7(8)
FUQUENE	17	355	49	38	8(5)	126(42)	5(4)	167(66)	26(6)	85(12)	81(18)	52(13)	57(16)	-83(37)	53(26)	-14(28)
GUAM	4	213	154	147	15(4)	-45(18)	29(4)	138(9)	27(4)	84(10)	10(3)	-75(16)	46(3)	-174(4)	11(3)	-9(15)
MUNTINLUPA	3	190	60	60	84(7)	50(5)	18(7)	-172(23)	20(7)	-31(21)	19(4)	-48(13)	32(4)	-162(7)	22(4)	-88(11)
HUANCAYO	-1	354	51	44	38(6)	69(10)	24(6)	-138(16)	4(4)	149(77)	4(3)	-13(58)	33(3)	176(6)	7(3)	13(38)
TOOLANGI	-47	221	57	0	3(5)	136(90)	46(7)	24(8)	34(7)	50(11)	-	-	-	-	-	-
ARGENTINE IS.	-54	3	96	96	10(3)	52(22)	36(3)	32(5)	33(3)	50(6)	10(3)	13(18)	26(3)	20(7)	21(3)	65(8)
KERGUELEN	-57	128	55	0	24(6)	-19(16)	26(6)	2(14)	34(6)	17(11)	-	-	-	-	-	-
BYRD	-71	336	91	90	38(37)	62(5)	115(35)	95(19)	15(25)	-100(89)	21(21)	61(5)	73(19)	72(16)	64(19)	2(19)

Table 3. Coherence-squared statistics between MRN and geomagnetic monthly data, and number of data pairs at lag one month. Station symbols as in Table 1.

	30 KM					48 KM					56 KM				
STATION	CO	FC	FR	TU	HO	CO	FC	FR	TU	HO	CO	FC	FR	TU	HO
N(T)	95	65	100	134	87	86	65	89	130	85	77	65	74	114	77
N(U)	114	66	144	148	115	110	66	144	147	117	102	61	131	146	110
a. H-T	.12	.50	.23	.50*	.12	.21	.54	.15	.19	.02	.16	.56	.16	.20	.08
Z-T	.05	.51	.06	.18	.46	.14	.55	.12	.05	.08	.09	.55	.09	.10	.31
H-U	.16	.32	.48*	.52*	.27	.20	.59	.51*	.49*	.27	.15	.53	.48*	.51*	.28
Z-U	.03	.37	.00	.13	.53	.02	.53	.00	.15	.57*	.02	.55	.00	.16	.56*
b. H-T	.39	.28	.05	.11	.13	.19	.18	.12	.05	.18	.11	.10	.16	.11	.14
Z-T	.18	.05	.19	.17	.34	.32	.18	.17	.03	.08	.05	.05	.36	.13	.02
H-U	.05	.42	.42	.40	.09	.20	.29	.39	.50*	.22	.21	.23	.40	.57*	.27
Z-U	.15	.25	.17	.07	.48	.16	.03	.07	.04	.53	.20	.10	.02	.03	.66*
c. H-T	.19	.38	.20	.00	.02	.27	.22	.05	.17	.08	.07	.14	.07	.13	.02
Z-T	.01	.03	.03	.00	.17	.04	.03	.03	.17	.02	.03	.05	.15	.08	.06
H-U	.01	.04	.03	.12	.31	.01	.09	.03	.07	.05	.02	.03	.02	.07	.09
Z-U	.20	.23	.02	.01	.02	.02	.13	.03	.04	.11	.01	.04	.06	.10	.24
d. H-T	.02	.28	.11	.20	.06	.06	.36	.02	.18	.01	.14	.24	.01	.13	.20
Z-T	.22	.36	.03	.07	.07	.13	.45	.05	.10	.08	.01	.38	.08	.10	.14
H-U	.05	.12	.08	.13	.16	.08	.32	.09	.11	.03	.06	.37	.09	.10	.04
Z-U	.05	.38	.02	.03	.07	.02	.35	.00	.03	.27	.01	.41	.01	.03	.15

CODE: a. Annual Wave
b. Semiannual Wave
c. Terannual Wave
d. Quasi-biennial Wave

STATISTICAL SIGNIFICANCE INDICATORS: * Value exceeds 0.1% confidence level.
= Value exceeds 1% confidence level.
_ Value exceeds 5% confidence level.

Station codes are given in Table 1.

"H-T" = Comparison of horizontal component of the geomagnetic field strength with temperature at specified level from nearest rocket observation.

Table 4a. Linear correlation coefficients of monthly values of MRN and geomagnetic data. Those which meet the 1% significance level are asterisked, 5% level are underlined.

PARAMETERS	(LEVEL)	CO	FC	FR	TU	HO
T-H	30	.083	.491*	$\underline{.223}$	.280*	-.138
	48	.121	.485*	.014	.247*	-.070
	56	.145	.363*	-.127	.161	.071
U-H	30	$\underline{-.188}$	-.354*	-.313*	-.218*	$\underline{-.211}$
	48	-.277*	-.488*	-.350*	-.320*	-.265*
	56	-.338*	-.466*	-.343*	-.351*	$\underline{-.222}$
T-Z	30	$\underline{.230}$	$\underline{-.280}$	.117	-.026	.293*
	48	$\underline{.253}$	$\underline{-.301}$	.089	$\underline{-.181}$	-.143
	56	.118	$\underline{-.309}$	-.164	$\underline{-.246}$	-.303*
U-Z	30	-.020	$\underline{.286}$	.064	-.110	-.282*
	48	-.026	$\underline{.284}$	.047	-.103	-.490*
	56	.010	$\underline{.303}$	.051	-.094	-.504*

Table 4b. Same as above except the annual waves were first subtracted from the data. Note the lack of significant correlation here compared with above.

PARAMETERS	(LEVEL)	CO	FC	FR	TU	HO
T-H	30	-.114	.174	.111	.099	$\underline{-.227}$
	48	-.195	.136	.034	.165	-.044
	56	-.024	.006	-.090	$\underline{.195}$	.173
U-H	30	.013	-.033	-.077	-.038	-.077
	48	-.149	-.226	-.083	-.105	-.051
	56	-.190	-.200	-.020	-.109	.053
T-Z	30	.169	-.002	.132	-.024	.008
	48	.154	-.048	.111	-.167	-.102
	56	-.027	-.151	-.015	-.184	-.172
U-Z	30	.095	.101	.116	-.026	$\underline{-.189}$
	48	.083	.086	.020	-.063	$\underline{-.203}$
	56	.113	.157	-.014	-.082	-.196

TABLE 5. Yearly values of solar and geophysical parameters. Some relative maxima are underlined; for annual wave relative minima are underlined.

YEARS	61	62	63	64	65	66	67	68	69	70	71
SUN SPOT NO.	54	38	28	10	15	47	94	106	<u>106</u>	105	67
10.7 cm FLUX	104	84	80	72	76	103	143	149	151	<u>156</u>	113
<u>SEMIANNUAL AMPLITUDES</u>											
SITKA (H)	4.7	4.3	4.0	3.2	2.3	4.1	2.7	3.7	<u>6.9</u>	5.5	4.1
FREDRICKSBURG (H)	2.9	3.9	5.0	4.1	1.6	4.5	2.8	1.9	<u>6.9</u>	5.5	3.4
TUCSON (H)	3.3	3.1	4.4	4.0	2.3	4.5	4.8	2.6	<u>6.1</u>	4.5	2.6
GREELY (U - 48KM)					9.2	9.2	12.8	19.5	<u>21.5</u>	11.9	
WALLOPS (U - 48KM)	23.7		24.0		9.9	16.8	8.5	8.7	<u>18.4</u>	16.4	8.0
MUGU (U - 48KM)		16.4	14.8		10.0	4.4	11.5	13.5	<u>20.0</u>	17.4	10.5
WSMR (U - 48KM)	11.0	19.5	15.5	15.1	8.0	8.8	11.6	13.4	<u>24.6</u>	18.8	11.3
BARKING SANDS (U - 48KM)					19.3			23.9	<u>26.5</u>	25.0	23.5
<u>ANNUAL AMPLITUDES</u>											
GREELY (U - 48KM)					21.3	25.5	32.9	27.1	<u>13.2</u>	28.6	
WALLOPS (U - 48KM)	49.8		43.0		74.5	60.0	57.6	61.5	<u>59.1</u>	65.8	61.9
MUGU (U - 48KM)		53.9	46.0		63.6	60.4	49.1	51.8	<u>46.8</u>	55.6	53.4
WHITE SANDS (U - 48KM)	54.4	50.3	46.0	58.3	63.8	56.7	48.0	49.0	<u>43.5</u>	48.4	52.4
BARKING SANDS (U - 48KM)					42.4			36.1	37.6	<u>27.9</u>	38.2

(a) SEASON= WINTER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.
60	80	303	534	406	236	283	377	397	305	237	118	497	3	159330
	60	301	454	335	243	329	401	375	272	203	104	443	11	135135
	59	341	411	281	237	314	362	336	234	157	81	367	30	102102
	119	435	500	316	203	207	243	268	206	139	71	397	61	64 64
	165	485	516	319	185	149	165	193	159	119	61	356	102	24 24
50	184	420	402	275	182	122	137	155	118	84	40	316	115	23 23
	168	326	287	225	164	92	109	126	87	52	22	223	123	23 23
	145	280	259	212	152	81	85	94	68	43	18	193	130	22 22
	130	272	285	227	139	71	74	81	62	48	24	219	133	22 22
	116	242	273	214	109	49	62	69	55	46	24	184	138	22 22
40	99	197	226	176	86	46	61	59	42	31	15	140	144	22 22
	92	182	195	140	78	60	66	52	37	26	9	137	145	22 22
	88	176	177	119	77	70	70	49	39	33	12	129	145	21 21
	85	166	164	116	83	72	67	45	34	33	14	132	143	22 22
	88	166	153	106	79	65	52	35	27	27	12	116	145	21 21
30	92	169	147	95	73	59	43	30	25	23	10	105	146	22 22
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)			

SEASON= SPRING
POWER (M2/SEC2)

												VAR	N	P.R.E.
	11	26	51	58	55	42	48	71	74	90	58	61	11	135135
	4	41	66	69	68	55	53	74	83	96	59	94	34	96 96
	11	70	99	97	88	69	66	85	92	92	50	117	73	51 51
	24	84	118	116	92	69	73	87	84	74	38	132	111	21 21
	34	81	102	100	82	66	66	71	67	60	30	105	139	21 21
	38	70	75	76	75	67	59	59	57	46	21	91	153	20 20
	35	55	58	67	72	65	57	59	54	42	20	82	164	20 20
	35	48	50	62	68	60	55	59	52	44	23	81	172	20 20
	41	54	49	55	58	50	48	51	43	39	21	76	182	19 19
	49	61	49	48	47	36	36	37	31	30	16	62	188	19 19
	50	59	44	42	40	30	26	28	25	23	11	57	189	19 19
	48	53	37	35	33	24	22	26	26	20	9	48	192	19 19
	46	51	33	28	25	17	18	25	26	20	8	45	192	19 19
	45	52	34	26	22	16	17	21	23	20	8	41	194	19 19
	43	51	33	25	21	16	15	16	18	17	8	43	201	19 19
	42	50	32	23	20	16	13	13	16	15	7	30	204	19 19
PERIOD	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)			

SEASON= SUMMER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.
60	6	30	32	31	33	37	50	65	66	54	25	60	23	105105
	6	28	34	35	39	40	44	53	54	43	19	60	75	49 49
	5	22	32	35	37	35	32	34	32	26	12	41	115	23 23
	3	17	26	26	26	25	24	23	21	22	12	27	134	22 22
	2	15	23	21	19	21	21	19	20	22	12	29	142	22 22
50	1	12	20	17	14	16	17	17	18	16	9	21	145	22 22
	2	9	14	12	11	11	12	12	13	13	6	16	147	22 22
	1	7	10	10	10	11	11	10	10	10	5	11	151	22 22
	1	5	9	9	10	11	11	10	9	8	4	14	152	22 22
	1	4	7	8	8	8	9	9	7	6	4	9	155	22 22
40	1	4	5	5	5	5	5	5	4	5	3	6	158	21 99
	1	4	4	4	4	4	4	3	3	4	2	4	158	22 22
	1	3	5	5	5	4	4	3	3	3	2	6	156	22 22
	1	3	4	4	4	3	3	3	3	3	2	3	154	22 22
	1	2	3	3	3	3	3	3	3	3	2	4	154	22 22
30	1	2	3	3	3	2	2	3	3	3	2	3	154	22 22
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)			

SEASON= AUTUMN
POWER (M2/SEC2)

												VAR	N	P.R.E.
	10	105	194	177	119	91	55	14	34	51	21	137	1	162162
	8	98	157	135	98	83	63	32	52	80	42	97	13	122122
	1	81	106	82	79	83	81	70	75	101	61	126	47	82 82
	4	67	94	85	103	109	98	94	81	103	71	105	77	47126
	6	65	107	111	120	117	105	94	69	98	75	174	97	28130
	17	61	100	108	94	86	93	77	47	58	41	91	113	21 86
	28	58	76	80	62	53	63	56	39	35	18	88	120	23 23
	27	56	68	69	50	37	40	41	35	34	19	58	123	23 23
	24	50	64	69	49	33	35	35	27	26	15	68	129	22 22
	24	47	52	52	38	27	29	30	25	24	14	48	133	22 22
	31	49	43	37	25	15	16	23	24	21	11	43	135	22 22
	33	48	39	32	21	9	9	16	18	16	8	36	137	22 22
	29	[illegible]	32	26	18	9	10	15	15	11	5	29	140	22 22
	27	36	27	23	17	11	12	15	13	9	3	29	144	21 21
	25	33	24	21	17	11	11	13	11	8	3	26	145	22 22
	24	30	21	20	16	11	10	11	10	7	3	21	145	21 21
PERIOD	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)			

(b) SEASON= WINTER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.
60	111	358	291	167	176	192	147	131	140	69	6	310	3	170453
	52	272	265	170	154	189	186	174	187	140	50	185	10	138138
	25	225	264	211	186	226	236	217	229	209	97	335	26	107107
	90	291	308	259	253	251	206	184	202	192	95	325	55	71 71
	127	333	352	277	253	233	173	155	183	166	75	328	94	30 30
50	129	345	385	283	213	196	163	151	182	147	54	343	106	24 24
	147	364	408	288	172	140	127	128	153	118	39	267	109	23 23
	194	414	430	289	153	114	110	107	117	82	22	315	117	23 23
	208	424	410	260	140	119	118	106	113	81	24	273	124	23 23
	187	384	354	228	150	140	130	108	115	92	34	293	129	22 22
40	167	338	309	216	158	139	124	92	84	62	20	245	137	22 22
	143	292	274	200	141	113	102	72	50	24	3	200	138	22 22
	112	239	230	176	128	96	85	62	37	15	1	167	137	22 22
	87	182	174	139	110	86	74	52	31	19	7	141	139	22 22
	70	136	127	105	85	69	60	41	25	19	8	101	144	22 22
30	63	119	110	93	74	59	50	33	21	16	7	84	146	22 22
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)			

SEASON= SPRING
POWER (M2/SEC2)

												VAR	N	P.R.E.
	7	31	36	40	43	44	37	31	43	52	27	54	11	135135
	7	32	47	53	46	40	38	37	45	63	38	55	34	96 96
	10	41	73	85	64	46	50	52	62	96	62	87	73	51 51
	12	48	86	100	80	69	70	66	85	124	75	133	110	21 21
	13	49	76	81	76	83	77	64	83	114	67	107	139	21 21
	18	49	60	56	62	75	66	52	65	84	48	95	153	20 20
	21	42	45	45	49	57	52	43	48	63	37	63	164	20 20
	25	40	39	40	43	46	48	41	38	51	33	64	172	20 20
	31	51	46	38	38	42	47	39	30	37	24	62	183	19 19
	35	61	52	35	31	38	45	35	24	24	14	56	189	19 19
	36	64	54	34	29	34	38	29	20	20	11	54	189	19 19
	37	63	51	34	32	30	25	20	16	19	12	49	192	19 19
	36	57	43	29	32	27	19	17	16	18	11	43	192	19 19
	33	49	35	24	26	24	20	20	16	16	10	41	194	19 19
	28	40	28	20	20	22	22	19	13	13	8	32	201	19 19
	25	35	24	18	18	21	22	18	12	12	7	29	203	19 19
PERIOD	44	22	14.7	11	8/8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)			

SEASON= SUMMER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.
60	4	22	38	36	32	34	46	57	49	39	20	45	23	103191
	3	18	30	28	27	32	43	51	45	38	19	57	75	49 49
	0	15	21	19	21	27	31	32	30	27	13	23	115	23 23
	0	13	21	19	20	21	19	17	16	15	7	27	134	22 22
	0	10	17	18	16	16	17	15	13	12	6	17	142	22 22
50	0	7	13	15	14	14	14	11	10	11	6	17	145	22 22
	0	5	10	13	12	12	11	8	8	9	5	13	147	22 22
	0	3	6	9	9	9	9	7	6	7	4	8	151	22 22
	0	2	4	7	8	7	8	7	6	6	3	9	152	22 22
	0	2	4	6	7	6	6	5	5	4	2	5	155	22 22
40	0	2	4	5	6	5	4	4	4	3	2	6	158	22 22
	0	2	3	3	4	5	5	4	4	4	2	4	158	22 22
	0	2	3	2	3	5	5	4	4	3	2	5	156	22 22
	0	2	3	3	3	4	4	3	3	3	1	4	154	22 22
	0	2	3	3	3	2	2	2	2	2	1	2	154	22 22
30	0	2	3	3	2	2	2	1	1	1	1	2	154	21103
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)			

SEASON= AUTUMN
POWER (M2/SEC2)

												VAR	N	P.R.E.
	11	60	53	46	88	136	100	28	49	118	77	72	1	156344
	4	70	79	94	122	125	90	54	83	143	89	141	13	121121
	7	95	126	160	158	111	86	81	95	131	82	173	48	81 81
	16	99	144	177	156	115	99	78	76	93	53	139	77	49 49
	20	91	134	172	153	127	112	76	80	98	52	166	96	29 29
	35	98	130	169	145	115	103	68	63	87	53	153	112	25130
	55	101	126	159	115	71	65	47	43	63	40	128	120	23 23
	70	100	106	126	80	35	32	34	41	46	25	96	122	23 23
	78	102	85	84	54	26	25	34	37	30	15	83	128	22 22
	80	103	76	57	30	18	26	35	31	26	15	72	133	22 22
	79	100	73	48	18	7	17	28	29	35	24	66	135	18 33
	77	94	70	50	21	6	9	21	28	43	31	67	137	18 34
	74	89	66	50	27	15	13	18	25	42	31	66	139	19 28
	72	86	61	45	27	21	16	17	23	37	27	67	143	18 28
	63	75	53	39	24	21	15	15	22	31	20	55	145	22 22
	57	67	48	36	22	19	15	15	22	27	17	47	144	22 22
PERIOD	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)			

Table A-1. Analysis of the high frequency variability of the wind at Greely; (a) Zonal, (b) Meridional.

(a)

SEASON= WINTER
POWER (M2/SEC2)

KM	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	VAR	N	P.R.E.
60	285	549	454	324	356	326	222	203	259	309	175	504	29	111111
	288	545	437	345	417	380	249	205	223	247	142	493	44	94 94
	302	585	456	354	448	426	285	225	199	202	125	511	51	81 81
	313	665	536	338	378	406	299	230	199	230	155	553	66	62 62
	312	686	570	336	316	376	301	192	164	216	143	522	90	35 35
50	303	634	527	340	296	328	282	157	118	161	97	459	107	23 23
	256	527	457	346	316	304	249	134	88	113	63	407	113	23 23
	196	410	392	343	324	286	209	115	77	73	33	355	119	23 23
	166	333	334	322	296	229	161	101	68	40	8	287	122	23 23
	143	267	268	286	265	183	123	86	63	30	1	249	124	23 23
40	112	203	209	243	233	152	95	72	57	32	5	198	124	23 23
	89	162	171	206	198	126	78	59	45	35	17	166	123	23 23
	80	151	159	175	163	109	72	49	30	35	24	150	124	23 23
	78	155	163	155	133	94	64	39	20	31	24	134	124	23 23
	77	156	170	148	114	78	51	28	13	26	23	130	124	22 22
30	75	154	171	146	108	72	44	23	9	24	22	114	125	22 22

PER. 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= SPRING
POWER (M2/SEC2)

KM	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	VAR	N	P.R.E.
60	2	25	59	88	78	64	65	62	64	68	37	90	19	118218
	3	31	54	85	86	70	58	49	57	62	32	79	34	103103
	17	48	56	78	87	71	53	43	47	45	20	79	44	87 87
	34	58	61	74	73	55	47	52	51	34	12	81	61	67 67
	41	47	57	81	70	38	32	49	54	34	11	75	74	51 51
50	41	45	63	91	67	27	23	46	53	30	8	69	90	34 34
	43	58	81	97	59	17	22	50	54	29	8	78	97	28 28
	44	68	91	95	51	12	21	49	51	30	11	78	98	26 26
	45	71	86	81	42	11	19	44	47	31	12	71	99	25 25
	43	64	71	66	39	16	22	42	44	28	10	67	99	25 25
40	40	54	53	52	34	17	25	41	39	26	11	57	99	25 25
	39	47	38	36	23	12	27	43	38	29	15	49	99	25 25
	37	40	26	28	21	13	29	41	35	32	18	48	99	25 25
	35	34	22	27	24	16	24	29	27	31	18	43	99	25 25
	36	36	22	27	24	14	18	19	18	21	12	35	99	25 25
30	38	39	24	27	24	14	16	17	13	14	8	34	99	25 25

PERIOD 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= SUMMER
POWER (M2/SEC2)

KM	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	VAR	N	P.R.E.
60	14	16	4	27	58	33	12	35	47	30	10	45	8	134212
	9	17	13	26	42	28	18	35	42	30	12	36	15	127127
	1	20	26	27	28	23	23	29	30	28	15	35	22	110110
	4	19	26	23	24	24	24	24	24	27	16	32	37	91 91
	5	12	21	18	18	22	24	22	20	22	12	25	50	77 77
50	2	10	20	21	19	20	19	16	15	12	6	20	60	66 66
	0	10	19	23	19	16	14	12	12	10	5	20	67	59 59
	1	10	17	18	14	11	11	11	10	11	6	17	71	54 54
	1	9	13	12	9	10	11	9	7	8	6	12	74	51 51
	0	5	9	9	8	9	11	10	7	6	4	11	76	45103
40	1	3	6	7	6	6	8	8	7	5	3	8	77	48 48
	2	5	5	4	4	5	5	5	4	4	2	5	77	48 48
	2	6	5	4	4	5	6	6	4	3	2	6	77	47139
	2	6	5	4	3	5	6	6	5	4	2	7	77	48 48
	1	5	5	4	4	5	5	5	5	4	2	5	77	48 48
30	1	4	4	4	4	5	5	4	5	4	2	6	77	48 48

PER. 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= AUTUMN
POWER (M2/SEC2)

KM	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	VAR	N	P.R.E.
60	83	128	108	154	136	69	83	142	187	163	68	162	40	95 95
	68	119	112	160	143	75	90	157	202	189	89	215	57	74 74
	52	127	139	164	138	73	87	147	179	187	100	206	68	60 60
	57	156	166	162	131	72	64	90	108	125	71	161	80	46 46
	66	171	166	152	131	87	54	42	59	88	56	150	91	34 34
50	75	183	159	120	102	86	52	23	46	89	58	141	99	25114
	78	182	150	87	57	61	42	18	48	84	51	125	103	24124
	68	155	134	77	39	39	36	27	42	51	27	91	105	24 24
	57	132	117	75	46	36	32	34	36	22	7	83	106	24 24
	53	115	96	62	48	36	22	22	29	22	9	77	108	24 24
40	50	97	73	46	39	30	15	11	22	25	12	53	109	24 24
	48	86	58	38	39	29	14	11	20	22	9	55	109	24 24
	42	78	52	35	44	36	15	13	21	18	6	50	110	24 24
	39	76	52	31	42	36	12	13	25	21	8	50	111	24 24
	36	74	51	25	35	31	9	11	28	28	11	51	111	24 24
30	33	70	48	22	30	28	8	10	28	29	13	40	112	23 23

PERIOD 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

(b)

SEASON= WINTER
POWER (M2/SEC2)

KM	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	VAR	N	P.R.E.
60	2	223	359	340	305	282	221	172	220	184	50	280	29	111111
	4	236	373	395	375	319	256	196	194	156	47	376	44	94 94
	14	220	347	430	435	358	292	210	161	126	43	389	51	81 81
	26	204	321	381	370	351	317	211	150	117	40	315	66	62 62
	38	219	327	326	281	306	336	251	149	93	32	375	89	36 36
50	47	204	281	274	231	226	275	256	145	69	27	261	104	24 24
	69	201	239	231	205	171	198	211	122	55	30	250	108	23 23
	87	216	234	201	177	154	161	163	101	56	32	220	113	23 23
	91	219	235	183	159	151	130	111	90	70	34	211	114	23 23
	103	237	243	175	147	145	105	73	78	69	29	199	115	23 23
40	116	254	243	158	125	120	90	77	81	58	21	193	117	23 23
	123	260	248	152	106	99	83	89	89	55	18	185	118	23 23
	122	269	274	167	97	90	74	73	78	48	14	197	119	23 23
	114	270	275	160	90	87	70	56	61	41	10	170	122	23 23
	105	265	255	133	84	83	59	46	60	47	13	168	122	23 23
30	101	265	248	122	81	77	46	40	65	54	16	149	122	23 23

PER. 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= SPRING
POWER (M2/SEC2)

KM	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	VAR	N	P.R.E.
60	7	65	70	36	36	41	60	78	56	33	15	76	19	142453
	10	58	60	36	33	40	56	63	46	33	17	62	34	103103
	10	45	49	39	38	45	50	49	43	41	23	52	44	87 87
	6	40	53	49	48	46	40	48	54	53	29	74	61	63141
	6	42	59	56	48	36	34	46	52	53	29	58	74	51 51
50	10	48	60	57	46	34	36	46	47	42	20	65	90	34 34
	20	62	69	59	43	29	31	41	46	31	9	59	97	28 28
	23	70	84	70	43	24	25	34	39	23	3	62	98	26 26
	16	72	102	86	45	22	24	34	36	18	2	62	99	25 25
	10	75	116	94	42	15	20	33	34	18	4	69	99	25 25
40	6	72	119	95	39	11	14	27	28	17	6	56	98	26 26
	4	72	121	93	34	8	12	29	33	18	4	58	98	26 26
	1	73	126	91	31	7	12	37	45	20	1	62	99	25 25
	0	67	119	85	28	7	11	36	45	18	0	60	99	23105
	1	54	100	74	27	9	8	26	36	19	3	47	99	25 25
30	1	45	87	69	28	12	8	21	31	21	6	43	99	25 25

PERIOD 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= SUMMER
POWER (M2/SEC2)

KM	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	VAR	N	P.R.E.
60	13	35	46	29	41	53	39	34	37	31	14	54	8	144144
	9	32	41	30	37	37	26	32	36	29	14	39	15	135374
	6	22	33	32	30	21	15	23	27	24	13	31	22	110110
	7	12	28	31	23	19	18	17	18	21	12	25	37	91 91
	6	8	24	27	18	16	20	20	20	21	11	24	50	77 77
50	3	9	20	22	16	14	18	19	20	22	12	25	61	65 65
	2	8	17	19	14	12	13	14	15	17	9	17	67	59 59
	2	6	14	16	14	10	10	12	11	10	6	13	71	54 54
	2	5	12	15	13	9	8	11	10	8	5	12	74	49128
	2	4	10	12	11	8	6	8	8	7	4	11	76	49153
40	1	3	8	8	7	6	5	5	5	6	3	6	77	48 48
	1	3	7	8	7	6	5	3	4	4	2	6	77	51181
	1	4	7	9	8	7	5	3	3	3	1	7	77	48 48
	0	4	6	7	7	6	5	3	2	2	1	6	77	49157
	0	2	4	5	5	5	5	3	2	2	1	4	77	48 48
30	0	1	3	4	4	4	4	3	3	3	1	3	77	48 48

PER. 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= AUTUMN
POWER (M2/SEC2)

KM	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	VAR	N	P.R.E.
60	20	189	234	139	138	171	149	114	81	77	46	249	40	97256
	14	146	201	128	112	143	123	94	80	71	37	131	57	74 74
	5	101	172	127	91	105	84	73	89	75	30	134	68	60 60
	8	108	182	144	96	89	75	83	108	89	32	137	79	47 47
	16	114	174	146	102	84	80	91	110	83	24	162	91	34 34
50	23	110	143	119	98	87	76	70	76	56	15	115	99	26 26
	31	108	117	84	70	72	68	48	40	34	12	97	103	24 24
	36	95	98	70	48	45	51	39	30	26	10	75	105	24 24
	31	77	79	62	43	33	34	29	26	21	9	62	106	24 24
	27	72	70	50	35	28	27	25	25	24	13	52	108	24127
40	29	76	70	42	28	24	26	26	26	29	17	56	109	24 24
	30	77	68	41	29	25	27	27	27	28	15	56	109	24 24
	31	67	59	40	32	31	30	23	22	24	13	54	110	24 24
	28	54	48	37	32	34	30	18	16	22	13	46	111	24 24
	21	45	43	34	30	31	27	16	15	20	11	41	111	24 24
30	17	43	44	34	29	30	25	14	14	19	10	37	112	23 23

PERIOD 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

Table A-2. Analysis of the high frequency variability of the wind at Churchill. (a) Zonal, (b) Meridional.

(a)

SEASON= WINTER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.
60	44	117	255	327	305	210	143	271	382	133	61	265	5	146146
	65	202	322	315	255	190	131	239	352	155	25	346	14	124124
	85	306	401	292	172	152	104	154	245	152	24	298	28	104104
	87	316	373	263	146	139	97	92	142	120	46	233	42	87 87
	105	335	336	238	166	160	119	92	123	119	55	248	51	76 76
50	149	385	330	217	179	185	143	105	134	132	57	297	60	65 65
	170	381	317	223	199	208	156	96	130	140	61	286	71	54 54
	142	328	320	280	252	244	161	83	115	123	50	305	76	48 48
	122	305	329	311	244	266	153	73	98	87	32	292	78	46 46
	115	305	321	294	295	282	146	44	49	64	40	277	78	46 46
40	101	280	296	262	280	277	131	16	7	53	54	253	78	46 46
	95	256	267	219	223	210	89	13	9	49	51	203	78	46 46
	101	253	234	165	147	128	52	24	31	55	46	174	77	47 47
	105	247	208	117	90	79	49	31	42	59	41	147	75	50 50
	95	216	176	90	59	54	36	30	39	53	36	128	74	51 51
30	86	194	158	81	48	44	32	27	35	49	33	95	72	53 53
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

SEASON= SPRING
POWER (M2/SEC2)

											VAR	N	P.R.E.
	9	32	88	112	85	38	5	0	38	89	58	84	3	143143
	2	37	76	89	68	34	15	20	48	75	43	64	21	113113
	8	51	69	64	56	43	36	47	55	50	24	66	39	88 88
	16	62	70	58	60	56	45	48	44	31	15	83	65	59 59
	25	61	57	43	47	44	35	37	33	24	12	50	87	35 35
	33	63	50	35	36	28	25	31	31	27	14	54	96	26 26
	40	69	52	38	37	27	22	24	25	28	15	54	103	21 21
	44	74	58	46	43	29	21	18	19	25	15	54	107	22 22
	47	79	68	57	48	29	19	19	18	25	17	64	108	21 21
	45	76	72	61	47	28	17	18	19	25	17	64	108	21 21
	40	69	67	56	41	25	13	14	18	20	13	55	107	21 21
	34	64	62	49	35	20	10	10	14	17	9	44	106	21 21
	28	59	59	45	31	19	11	9	10	13	8	43	105	22 22
	25	54	57	41	24	16	12	10	10	11	7	38	105	22 22
	22	46	48	35	18	10	10	11	10	11	7	33	105	22 22
	20	41	42	32	16	8	10	11	10	11	6	26	103	22 22
PERIOD	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

SEASON= SUMMER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.
60	21	15	59	80	85	87	71	53	47	46	24	70	4	144144
	14	29	76	90	82	74	62	60	63	57	29	79	19	116116
	6	60	106	100	69	46	44	67	85	70	31	103	43	84 84
	11	83	118	102	63	34	33	52	66	54	21	86	71	54 54
	22	85	117	105	69	38	31	27	21	17	7	79	87	36 36
50	14	60	89	85	60	36	29	21	10	9	6	58	100	22 22
	1	25	43	46	40	30	27	26	23	28	17	38	109	21 21
	6	10	21	27	27	25	25	24	30	33	18	33	114	21 21
	7	6	15	19	20	20	22	24	28	23	11	25	117	21 21
	4	3	12	14	14	15	17	21	19	15	7	15	119	21 21
40	3	4	12	13	11	12	13	14	13	11	6	14	120	20 20
	2	6	12	12	9	10	11	11	10	9	5	14	122	20 20
	1	5	9	10	10	8	8	8	7	7	4	9	122	20 20
	1	4	7	5	10	7	6	6	5	6	4	9	120	20 20
	1	4	7	8	8	6	6	5	4	6	4	7	120	20 20
30	1	4	7	7	6	5	6	5	4	5	3	6	119	20 20
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

SEASON= AUTUMN
POWER (M2/SEC2)

											VAR	N	P.R.E.
	44	72	101	121	86	79	98	65	38	17	2	99	1	154154
	37	69	97	111	84	82	100	68	30	13	3	109	13	123242
	25	62	89	87	72	77	83	60	28	21	15	82	27	107253
	21	56	75	70	60	62	57	45	37	35	20	80	45	83 83
	24	50	59	59	54	48	42	41	39	30	14	63	63	62 62
	26	51	59	54	48	37	29	34	31	20	9	55	78	46 46
	24	57	69	58	44	32	26	26	20	13	6	54	87	36 36
	21	56	67	55	40	31	28	24	15	9	4	51	91	32 32
	21	55	62	52	39	31	29	21	14	11	4	43	93	30 30
	25	61	65	59	46	34	27	18	15	11	2	55	93	29 29
	28	64	68	63	50	33	25	18	17	10	0	53	91	31 31
	31	69	72	65	50	30	23	19	15	6	2	53	91	31 31
	32	74	74	68	56	35	26	18	10	2	4	56	91	31 31
	29	75	73	63	57	38	28	16	7	1	5	56	90	32 32
	26	69	65	53	49	31	23	12	3	1	4	47	88	35 35
	24	63	59	47	43	26	18	10	2	2	4	33	88	35 35
PERIOD	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

(b)

SEASON= WINTER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.
60	5	79	88	57	105	200	187	73	8	27	7	115	5	230*15
	15	89	112	80	92	153	141	60	16	13	11	89	14	124272
	32	117	158	104	73	114	109	56	48	68	39	145	28	104104
	29	139	172	108	87	131	118	60	47	71	44	142	42	87 87
	22	132	151	126	137	150	114	67	56	59	30	135	50	77 77
50	9	120	140	139	163	164	122	90	83	66	28	167	58	68 68
	9	118	135	120	129	143	123	92	77	67	34	147	68	57 57
	17	107	119	95	97	122	113	73	48	47	27	112	73	52 52
	17	88	95	81	97	121	101	55	27	26	17	105	75	50 50
	13	66	68	71	94	98	72	45	23	19	13	79	73	52 52
40	11	50	52	63	81	68	42	33	23	14	9	58	72	53 53
	8	44	49	52	62	54	33	25	20	14	8	50	72	53 53
	6	38	46	45	45	41	31	25	20	16	9	45	72	53 53
	5	32	40	40	38	31	22	21	21	17	8	37	68	57 57
	6	29	34	28	27	24	14	14	19	18	9	31	68	57 57
30	7	28	30	20	19	21	12	11	16	19	11	22	67	59 59
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

SEASON= SPRING
POWER (M2/SEC2)

											VAR	N	P.R.E.
	11	19	44	52	36	33	51	57	48	42	22	50	3	137256
	11	17	41	49	39	34	44	51	46	42	23	57	21	113113
	8	16	38	46	41	33	32	38	37	34	19	41	39	88 88
	4	19	36	40	38	33	29	30	27	24	13	39	65	59 59
	0	24	36	31	31	33	28	26	23	20	11	38	87	35 35
	2	24	37	31	25	25	23	21	18	17	10	30	96	26 26
	2	21	36	35	24	17	17	18	18	18	10	29	103	21 21
	4	21	30	30	22	14	14	18	21	23	12	30	107	22 22
	4	19	24	26	25	17	12	18	23	25	14	25	108	21 21
	4	18	26	32	32	21	11	15	20	23	14	34	108	21 21
	3	16	26	32	29	18	11	13	17	20	12	28	107	21 21
	1	12	20	24	22	15	10	13	15	15	8	20	106	21 21
	0	10	16	20	20	15	10	10	12	11	5	18	105	22 22
	0	10	15	18	18	13	8	8	9	8	4	14	105	22 22
	0	9	13	15	15	12	8	8	8	5	2	13	105	22 22
	1	7	12	15	15	12	7	8	7	3	0	10	103	22 22
PERIOD	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

SEASON= SUMMER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.
60	11	25	59	53	38	45	35	30	73	74	24	67	4	142314
	6	30	55	43	32	38	30	27	55	60	25	56	19	116116
	1	27	38	28	27	32	28	24	28	39	24	35	43	88228
	3	16	25	25	27	34	36	27	19	25	18	35	71	54 54
	6	11	23	28	29	32	35	28	17	15	10	31	87	36 36
50	6	8	19	25	29	26	24	22	16	13	7	24	100	22 22
	5	8	17	18	20	20	18	17	16	17	10	22	109	21 21
	3	6	13	12	12	16	17	16	14	16	10	16	114	21 21
	2	5	9	9	10	14	16	14	11	12	7	15	117	21 21
	2	4	7	7	8	11	11	9	8	9	5	9	119	21 21
40	2	4	6	6	7	8	8	7	8	9	5	8	120	20 20
	2	3	7	8	8	7	6	7	8	8	4	9	122	20 20
	2	3	6	7	7	5	5	6	6	7	4	6	122	20 20
	1	2	4	5	5	5	4	4	4	5	3	5	120	20 20
	1	1	3	4	5	4	3	3	3	3	2	4	120	20 20
30	1	1	3	4	4	3	3	3	3	3	1	2	119	20 20
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

SEASON= AUTUMN
POWER (M2/SEC2)

											VAR	N	P.R.E.
	7	31	17	6	29	45	41	31	21	30	23	41	1	156398
	10	43	27	13	31	40	33	27	25	30	18	37	13	127127
	12	57	40	19	30	34	25	30	41	37	16	47	27	106106
	7	53	46	27	30	32	29	36	46	46	23	54	44	84196
	4	41	48	41	37	33	31	29	32	40	24	50	62	63 63
	6	31	44	47	39	34	31	22	24	27	13	45	78	46 46
	5	26	39	45	38	33	29	23	22	18	7	37	87	36 36
	5	26	35	39	34	28	25	23	20	15	8	39	91	32 32
	7	28	33	32	31	27	21	17	14	10	5	27	93	30 30
	5	27	32	30	31	29	20	12	9	6	2	31	93	29 29
	3	22	26	24	27	26	18	10	7	5	2	21	91	31 31
	3	19	22	18	20	20	15	10	7	6	3	19	91	31 31
	3	19	26	22	17	15	11	8	6	4	2	18	91	31 31
	2	19	32	29	18	12	9	7	5	1	0	19	90	32 32
	0	15	28	26	16	11	8	8	6	2	0	17	88	35 35
	1	13	24	22	13	9	8	8	7	3	1	11	88	35 35
PERIOD	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

Table A-3. Analysis of the high frequency variability of the wind at Wallops. (a) Zonal, (b) Meridional.

(a)

SEASON= WINTER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.
60	163	393	346	275	337	343	217	127	154	133	41	384	9	125125
	151	426	433	316	310	291	187	122	128	104	35	332	48	78 78
	132	472	554	367	270	235	167	120	91	66	28	369	90	32 32
	126	498	602	382	254	231	189	129	85	70	32	344	124	20 20
	138	556	663	410	274	255	217	144	97	97	48	409	147	20 20
50	171	656	752	458	321	291	230	147	96	102	55	474	160	19 19
	214	727	801	484	345	293	211	129	71	70	40	494	170	19 19
	237	708	767	480	334	261	179	111	43	25	17	454	174	19 19
	236	616	674	461	309	211	139	94	29	2	2	396	176	19 19
	221	507	566	421	266	157	105	84	32	7	5	338	177	19 19
40	201	411	455	350	207	107	85	89	47	1	5	281	177	19 19
	176	325	346	273	156	71	67	88	62	19	1	230	179	19 19
	143	253	262	206	119	55	50	69	61	31	8	182	179	19 19
	107	191	195	148	89	48	38	47	46	27	7	139	178	19 19
	76	137	136	102	67	40	28	30	30	19	5	89	178	19 19
30	63	114	110	84	58	36	24	24	23	15	4	72	178	19 19
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

SEASON= SPRING
POWER (M2/SEC2)

												VAR	N	P.R.E.
	7	40	81	107	96	65	40	41	41	29	13	80	7	133133
	11	47	84	101	82	56	41	39	40	40	22	78	42	83 83
	21	60	85	89	66	42	36	34	41	52	29	83	103	21 21
	25	63	77	76	60	36	29	32	40	44	22	73	154	18 18
	24	55	65	63	55	36	26	27	31	29	12	58	207	17 17
	24	50	58	57	52	36	23	22	24	20	8	53	232	17 17
	27	51	57	55	47	32	21	19	21	19	8	51	241	17 17
	31	53	54	50	40	26	19	18	20	19	9	49	245	17 17
	35	56	52	45	35	23	17	16	16	17	9	45	246	17 17
	40	61	54	43	33	22	16	14	13	13	7	46	248	17 17
	43	62	52	41	31	20	15	13	12	11	6	46	250	17 17
	40	56	47	38	29	17	14	14	11	9	5	41	250	17 17
	32	47	41	34	25	16	15	15	10	9	6	37	250	17 17
	24	38	35	28	20	14	14	12	8	10	7	30	250	17 17
	19	32	30	24	17	11	10	8	6	9	6	24	250	17 17
	18	30	29	23	16	10	8	7	5	8	6	22	250	17 17
PERIOD	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

SEASON= SUMMER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.
60	0	83	109	69	75	116	124	93	73	65	31	142	24	109109
	3	59	82	66	75	95	94	78	68	63	31	91	53	70 70
	3	31	51	63	74	66	56	57	57	49	23	66	119	19 19
	2	25	43	59	67	56	48	51	50	39	17	64	196	18 18
	3	19	33	47	53	48	44	44	42	39	20	60	232	17 17
50	2	14	23	32	37	35	31	30	32	33	17	37	253	17 17
	1	10	17	25	27	23	19	21	27	26	12	27	263	16 16
	0	8	15	22	23	18	16	14	22	21	10	25	267	16 16
	0	8	14	18	19	16	16	18	17	15	7	20	268	16 16
	0	7	13	16	16	14	14	14	13	11	5	18	268	16 16
40	0	6	13	17	15	11	11	11	10	9	5	13	269	16 16
	0	6	13	17	15	12	11	11	10	9	5	17	268	16 16
	1	6	12	16	14	12	12	11	9	7	3	13	266	16 16
	2	6	10	14	13	10	10	10	8	6	3	12	265	16 16
	2	6	8	11	11	9	9	9	7	6	3	11	263	16 16
30	2	5	8	10	10	8	9	8	6	6	3	9	261	16 16
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

SEASON= AUTUMN
POWER (M2/SEC2)

												VAR	N	P.R.E.
	54	110	110	103	67	32	45	66	79	95	57	136	15	120120
	45	99	104	94	65	37	43	63	74	81	46	97	45	80 80
	30	80	93	82	64	49	45	61	68	62	33	98	99	22 22
	24	72	84	73	62	54	47	54	55	50	28	84	148	19 19
	28	76	86	68	54	47	41	42	40	39	24	75	170	19 19
	34	86	93	68	46	39	36	36	34	34	20	74	185	18 18
	42	91	93	68	44	33	32	33	32	29	16	76	200	18 18
	45	89	86	63	40	26	25	28	28	25	13	67	205	18 18
	[illegible]	84	75	57	37	20	18	21	22	21	12	57	207	18 18
	5	84	74	58	36	16	14	17	17	20	13	57	208	18 18
	55	90	78	58	33	14	13	16	15	17	11	60	208	18 18
	54	89	72	48	27	14	12	15	14	12	8	55	208	18 18
	48	77	58	36	23	15	13	15	12	8	6	43	207	18 18
	40	65	46	27	21	18	14	14	9	6	4	39	207	18 18
	33	53	37	22	18	15	12	11	8	5	3	32	208	18 18
	29	46	33	19	15	12	10	9	8	5	2	23	207	18 18
PERIOD	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

(b)

SEASON= WINTER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.
60	16	161	213	211	208	177	140	79	28	41	33	199	9	125261
	27	160	193	163	160	152	126	73	33	44	31	163	47	79 79
	44	155	157	103	102	113	99	62	39	41	22	121	88	35 35
	49	145	137	95	96	99	88	64	42	31	14	119	119	21 21
	43	133	133	107	110	103	91	70	45	33	16	123	140	20 20
50	41	127	133	114	111	98	90	72	46	42	25	131	152	20 20
	40	120	132	112	93	75	79	69	44	47	29	119	162	19 19
	38	108	126	111	81	58	65	55	37	46	29	104	164	19 19
	35	89	103	99	75	51	54	43	30	40	25	98	167	19 19
	28	66	73	76	62	44	43	34	25	28	16	64	167	20 20
40	19	47	55	59	51	39	34	26	21	20	10	54	167	19 19
	12	33	43	47	41	33	28	21	19	19	10	43	168	19 19
	9	23	31	34	28	24	22	19	18	17	8	32	166	19 19
	6	18	23	24	20	19	18	16	16	13	6	25	165	19 19
	4	13	18	17	17	18	15	10	10	10	4	19	164	20 20
30	2	11	16	15	16	19	15	8	7	8	4	14	166	19 19
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

SEASON= SPRING
POWER (M2/SEC2)

												VAR	N	P.R.E.
	16	31	63	58	63	62	48	40	44	64	41	65	7	139348
	12	29	55	54	62	64	52	41	40	49	30	72	42	84194
	5	25	44	45	50	52	46	36	29	29	17	47	103	21 21
	1	21	38	38	34	32	32	29	22	23	15	38	154	18 18
	2	20	34	33	28	24	25	27	23	24	14	35	207	17 17
	5	23	32	29	25	23	22	24	24	23	12	35	232	17 17
	7	23	31	26	24	22	19	20	21	19	9	30	241	17 17
	8	24	30	25	22	20	16	15	16	16	8	27	245	17 17
	8	23	29	24	20	18	15	14	14	13	7	27	246	17 17
	7	20	25	21	18	15	13	14	14	12	6	23	248	17 17
	6	17	20	18	16	13	11	11	13	12	6	19	250	17 17
	6	15	17	16	14	11	10	10	12	11	5	19	250	17 17
	6	13	14	13	12	10	9	9	10	8	3	13	250	17 17
	4	10	11	11	10	9	9	8	8	6	3	12	250	17 17
	2	6	9	9	8	8	8	7	7	6	3	10	250	17 17
	1	5	8	8	8	7	7	6	6	6	4	8	250	17 17
PERIOD	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

SEASON= SUMMER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.
60	10	55	49	40	55	51	41	41	38	36	20	63	24	109109
	8	40	37	37	51	48	40	39	36	35	21	58	53	70160
	4	21	26	33	40	38	33	29	25	30	20	39	119	19 19
	2	16	23	27	26	26	26	22	19	23	15	30	196	18 18
	2	14	20	21	20	19	21	21	20	18	9	26	232	17 17
50	1	11	19	20	18	16	17	17	17	16	8	21	253	17 17
	1	10	17	18	15	14	14	14	14	15	8	20	263	16 16
	1	10	15	14	12	11	11	12	13	12	6	16	267	16 16
	1	8	12	10	8	9	10	11	11	10	5	13	268	16 16
	1	6	9	7	7	9	10	10	9	8	4	11	268	16 16
40	0	4	6	6	6	8	9	9	8	6	3	8	269	16 16
	0	3	6	6	6	7	8	8	7	6	3	9	268	16 16
	0	3	5	5	5	6	6	6	5	5	2	6	266	16 16
	0	2	4	4	4	5	4	4	4	4	2	4	265	16 16
	0	2	4	4	3	3	3	3	3	3	2	4	263	16 16
30	0	2	4	4	3	3	3	3	3	3	2	3	261	16 16
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

SEASON= AUTUMN
POWER (M2/SEC2)

												VAR	N	P.R.E.
	24	68	83	75	57	59	67	63	75	75	34	110	15	120120
	23	67	78	69	54	49	50	48	63	69	32	82	45	80 80
	17	59	69	60	50	37	28	30	50	58	27	66	99	22 22
	11	49	63	53	44	34	24	28	43	47	22	59	148	19 19
	9	42	54	45	39	32	25	28	35	37	18	50	170	19 19
	9	37	44	36	36	31	24	27	31	27	13	45	185	18 18
	8	33	36	31	34	28	21	25	25	18	7	36	199	18 18
	7	30	34	29	29	23	16	20	20	14	6	31	205	18 18
	7	29	34	27	22	17	12	14	17	15	7	27	207	18 18
	6	25	32	26	18	13	10	12	16	15	7	25	208	18 18
	5	20	28	22	15	12	10	12	15	13	5	22	208	18 18
	4	17	22	17	13	12	10	12	12	10	5	18	208	18 18
	4	15	17	13	11	11	9	9	9	9	5	15	207	18 18
	3	11	13	11	10	9	7	6	7	7	4	12	207	18 18
	1	6	9	10	9	8	7	6	5	6	3	9	208	18 18
	1	4	7	9	8	8	7	6	5	5	3	7	207	18 18
PERIOD	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

Table A-4. Analysis of the high frequency variability of the wind at Pt. Mugu. (a) Zonal, (b) Meridional.

(a)

SEASON= WINTER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.	
60	102	369	464	348	251	289	302	171	99	115	60	322	90	31	31
	92	368	479	366	263	296	308	183	113	117	57	407	126	20	20
	97	372	482	383	273	283	285	178	132	131	57	359	154	19	19
	118	384	468	373	267	262	254	152	120	132	60	385	171	19	19
	127	399	465	393	252	246	233	139	99	113	59	335	182	18	18
50	141	423	477	345	239	217	192	128	101	107	56	349	190	18	18
	156	431	475	344	235	195	158	118	110	111	59	340	195	18	18
	163	404	428	320	227	178	142	115	105	107	61	329	198	18	18
	170	380	382	283	201	159	131	103	84	82	48	283	202	18	18
	173	364	356	240	164	141	117	87	67	55	29	263	205	18	18
40	159	339	326	205	134	118	99	81	65	40	16	224	209	18	18
	139	293	290	185	117	94	74	68	62	36	11	199	213	18	18
	120	245	250	166	100	71	51	49	50	33	11	167	215	18	18
	98	192	199	135	78	52	38	34	34	27	10	130	213	18	18
	76	142	145	99	56	35	28	27	25	20	8	94	212	18	18
30	65	117	119	83	46	26	22	25	23	17	6	65	214	18	18
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)				

SEASON= SPRING
POWER (M2/SEC2)

											VAR	N	P.R.E.	
26	98	117	99	80	58	57	97	126	110	51	150	140	19	92
29	88	106	92	69	50	50	72	98	103	54	109	180	18	18
33	74	86	78	57	46	45	42	58	86	53	91	209	18	18
35	68	73	70	61	53	46	35	39	63	42	83	233	17	17
34	64	68	69	67	56	41	29	31	49	33	77	251	17	17
31	61	68	67	65	52	36	27	30	49	33	73	260	17	17
31	63	68	61	54	46	39	31	32	47	29	73	268	17	17
30	64	70	63	53	47	44	36	34	36	18	67	271	17	17
31	65	74	69	59	49	41	31	28	26	11	76	273	17	17
33	63	68	59	51	42	32	24	22	20	10	58	274	16	16
33	59	58	45	38	32	26	21	20	18	9	52	276	16	16
30	57	55	40	33	29	24	19	19	17	8	46	281	16	16
26	52	52	39	31	27	22	18	18	16	7	46	284	16	16
20	41	42	36	30	24	19	17	17	15	7	38	286	16	16
16	32	34	31	26	19	15	14	13	12	6	31	287	16	16
15	31	33	29	23	16	13	12	11	10	5	26	287	16	16
PERIOD 44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)				

SEASON= SUMMER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.	
60	2	65	112	122	104	95	93	94	107	85	31	150	137	19	19
	6	66	102	102	92	89	87	91	99	75	28	105	188	17	17
	9	57	82	74	70	79	80	85	85	68	31	110	229	17	17
	7	38	59	56	54	66	74	75	69	64	35	81	253	17	17
	5	27	40	42	42	55	66	64	53	50	28	65	268	16	16
50	3	22	34	38	39	45	54	52	41	38	22	55	279	16	16
	2	19	32	37	37	36	40	39	32	29	16	43	286	16	16
	3	18	29	33	33	30	31	32	29	24	12	37	288	16	16
	2	16	25	28	28	25	24	29	29	24	11	35	290	16	16
	3	17	25	28	29	24	19	23	26	22	10	28	294	16	16
40	3	17	24	28	31	26	19	19	20	18	9	35	300	16	16
	2	12	18	22	24	20	17	15	15	14	7	21	303	16	16
	1	7	13	17	15	13	14	13	11	11	6	15	304	16	16
	0	6	13	16	13	11	13	12	11	10	5	17	303	16	16
	1	6	12	14	12	10	10	9	9	8	4	12	302	16	16
30	1	6	11	12	10	8	7	7	7	7	3	10	304	16	16
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)				

SEASON= AUTUMN
POWER (M2/SEC2)

											VAR	N	P.R.E.	
14	114	155	157	171	149	114	116	97	78	45	168	127	19	19
15	106	149	153	160	138	107	112	100	82	45	170	180	18	18
20	104	152	156	146	117	94	107	108	90	45	146	213	18	18
30	117	168	164	140	109	91	107	112	96	47	181	227	17	17
35	120	172	152	114	98	93	97	93	85	45	162	238	17	17
38	110	150	119	75	77	84	75	61	56	32	123	252	17	17
43	96	112	86	58	64	67	57	45	39	22	92	264	17	17
[illegible]	89	91	72	53	55	55	48	42	37	19	87	267	16	16
44	87	85	69	54	51	49	43	37	31	16	81	271	16	16
[illegible]	82	78	69	58	49	44	39	31	24	12	75	275	16	16
46	84	79	68	52	37	34	33	29	25	13	72	278	16	16
48	92	84	63	40	25	22	25	28	27	14	69	277	16	16
44	[illegible]	76	54	33	20	16	20	26	24	11	59	277	16	16
36	65	58	42	29	20	17	19	21	19	9	47	277	16	16
29	51	43	33	25	18	17	17	17	17	10	39	277	16	16
27	46	38	29	22	16	15	15	15	17	10	33	278	16	16
PERIOD 44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)				

(b)

SEASON= WINTER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.	
60	1	107	158	162	156	132	115	117	115	114	61	168	90	31	31
	11	118	170	167	152	122	98	101	107	99	49	176	126	20	20
	29	131	167	151	130	100	71	81	100	90	44	146	150	19	19
	43	138	148	125	107	79	61	76	95	98	53	146	165	19	19
	44	137	146	129	108	74	65	74	82	85	47	138	177	19	19
50	42	133	151	138	110	77	71	76	77	68	32	136	185	18	18
	44	129	148	135	106	77	71	73	74	59	24	138	189	18	18
	37	109	130	122	96	73	68	64	60	48	20	117	192	18	18
	28	90	111	99	77	61	60	56	48	41	21	94	193	18	18
	25	78	90	74	61	50	49	48	42	39	21	84	195	18	18
40	21	58	64	56	53	43	35	33	33	34	19	62	200	18	18
	14	40	50	51	48	36	25	22	26	28	14	46	205	18	18
	8	30	44	47	40	32	23	21	23	23	12	45	209	18	18
	5	22	33	35	30	26	22	20	19	20	11	34	208	18	18
	5	16	23	23	21	20	17	13	12	15	10	23	205	18	18
30	6	15	19	18	16	17	15	10	8	12	8	17	208	18	18
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)				

SEASON= SPRING
POWER (M2/SEC2)

											VAR	N	P.R.E.	
2	31	58	66	63	70	77	78	75	63	30	95	140	19	19
1	29	51	57	55	63	70	71	70	66	34	76	180	18	18
0	26	42	43	44	51	57	57	59	62	33	68	209	18	18
2	23	36	36	38	44	45	45	46	44	23	52	233	17	17
6	22	29	30	33	40	40	37	37	38	21	41	251	17	17
6	21	27	29	33	40	38	34	36	42	25	51	260,	17	17
6	22	30	33	37	40	35	29	32	39	23	44	268	17	17
6	22	32	36	36	36	32	27	29	33	19	45	271	17	17
5	21	32	34	32	30	29	27	27	26	14	39	273	17	17
.5	20	29	28	26	27	26	24	20	17	8	32	274	16	16
6	19	25	23	22	23	23	19	15	12	6	26	276	16	16
6	16	19	20	20	20	19	15	12	12	6	23	281	16	16
6	13	15	16	16	16	16	13	12	13	7	19	284	16	16
5	12	13	13	12	12	14	13	12	12	7	18	286	16	16
3	10	12	11	9	10	12	10	9	10	6	13	287	16	16
2	8	11	10	9	10	10	8	6	8	5	11	287	16	16
PERIOD 44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)				

SEASON= SUMMER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.	
60	1	41	65	76	76	69	61	52	61	67	33	88	137	19	19
	1	39	65	72	66	58	55	50	56	62	31	79	188	17	17
	0	33	59	65	55	48	51	48	46	50	26	63	229	17	17
	0	26	47	54	53	52	50	44	39	38	20	64	253	17	17
	1	22	37	39	43	47	42	38	36	32	16	46	268	16	16
50	2	21	31	29	30	36	35	33	33	28	13	41	279	16	16
	3	19	30	27	25	29	30	28	27	24	11	36	286	16	16
	2	16	26	26	24	23	22	22	22	20	10	30	288	16	16
	2	12	18	22	22	18	17	19	19	17	8	24	290	16	16
	2	8	13	16	17	15	14	16	18	16	7	19	294	16	16
40	1	7	11	13	14	13	12	12	14	14	7	16	299	16	16
	1	7	10	11	12	12	11	9	10	11	5	13	303	16	16
	1	6	9	9	9	10	9	9	9	9	5	12	304	16	16
	0	4	7	8	8	8	8	8	8	8	4	9	303	16	16
	0	3	6	7	7	7	7	7	7	6	3	8	302	16	16
30	0	3	6	7	7	7	7	7	6	6	3	8	304	16	16
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)				

SEASON= AUTUMN
POWER (M2/SEC2)

											VAR	N	P.R.E.	
3	48	79	92	94	84	78	81	72	77	49	115	127	19	19
1	44	71	88	91	80	73	73	69	74	44	94	179	18	18
8	45	62	77	83	74	63	57	59	61	33	92	213	18	18
11	51	65	63	66	65	52	44	44	41	21	70	226	17	17
12	53	65	56	55	54	43	36	36	30	13	60	234	17	17
9	49	64	58	56	50	38	33	35	29	11	62	249	17	17
7	44	61	57	53	49	37	30	31	26	11	57	261	17	17
8	40	52	48	47	44	34	29	29	25	11	50	264	16	16
6	34	44	42	43	38	28	26	26	24	13	47	271	16	16
4	32	41	37	38	32	21	20	18	17	10	35	275	15	67
5	29	36	31	31	25	15	15	14	11	6	31	278	16	16
5	23	26	23	23	18	12	14	15	12	6	23	277	16	16
5	18	22	19	18	13	12	15	15	11	5	21	276	16	16
3	15	20	18	16	12	11	14	13	9	4	19	277	16	16
2	11	15	16	16	12	10	11	10	9	5	16	276	16	16
1	9	13	14	15	12	9	9	9	9	5	12	277	16	16
PERIOD 44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)				

Table A-5. Analysis of the high frequency variability of the wind at White Sands. (a) Zonal, (b) Meridional.

(a)

SEASON= WINTER
POWER (M2/SEC2)

KM	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)	VAR	N	P.R.F.
60	181	354	278	236	205	118	100	119	84	7	20	243	12	120120
	171	336	268	210	185	112	92	108	87	29	3	231	58	66 66
	161	308	245	175	163	111	87	96	85	56	20	207	107	21 21
	155	292	241	177	165	116	93	102	85	66	31	223	147	19 19
	146	286	257	197	173	113	89	102	86	67	32	226	179	19 19
50	139	281	277	226	188	111	81	92	79	53	21	216	200	18 18
	128	265	290	266	207	108	80	92	73	40	12	231	215	18 18
	114	242	281	269	200	96	80	95	70	35	10	219	227	18 18
	111	231	256	236	173	84	71	81	60	29	6	189	231	18 18
	120	231	228	192	141	75	62	59	43	21	2	174	231	18 18
40	124	224	197	147	105	61	51	41	27	16	4	143	232	18 18
	114	207	168	107	74	47	39	26	16	16	8	120	233	18 18
	97	177	137	77	56	41	31	19	12	15	9	95	233	18 18
	76	135	101	57	45	37	28	18	14	15	8	79	230	18 18
	54	93	69	42	37	33	25	17	14	14	7	56	225	18 18
30	43	74	56	36	34	31	23	16	13	13	7	43	221	18 18

PER. 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= SPRING
POWER (M2/SEC2)

	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)	VAR	N	P.R.F.
	14	78	111	89	60	50	48	50	60	76	45	98	8	124124
	16	77	100	77	61	57	48	45	54	65	37	93	62	62 62
	20	71	78	57	55	60	45	34	42	47	24	74	115	21 21
	26	68	66	46	45	48	35	25	33	33	15	58	165	19 19
	32	71	68	49	41	35	24	22	29	25	10	59	191	19 19
	35	72	72	52	38	28	19	20	25	24	11	56	204	19 19
	37	71	70	52	35	23	18	20	22	24	14	55	214	18 18
	36	65	65	52	37	25	21	21	20	20	12	54	220	18 18
	30	55	59	55	44	29	22	21	17	16	9	51	227	18 18
	22	44	55	59	47	27	18	18	16	14	7	47	232	18 18
	17	40	54	56	42	22	13	15	16	14	7	42	234	18 18
	17	41	52	50	36	20	13	13	14	14	7	38	232	18 14
	20	42	47	44	35	21	14	13	12	13	8	40	229	18 18
	20	36	35	34	30	21	14	12	11	12	7	35	228	18 18
	15	25	24	24	23	17	11	9	10	11	6	23	226	18 18
	11	20	21	21	19	15	10	8	9	9	5	19	224	18 18

PERIOD 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= SUMMER
POWER (M2/SEC2)

KM	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)	VAR	N	P.R.F.
60	23	32	86	112	99	97	122	119	87	76	44	115	18	109204
	11	45	89	105	94	97	120	113	79	63	35	120	68	54 54
	1	50	93	100	78	77	101	101	76	55	25	106	136	20 20
	6	51	91	96	67	56	76	84	75	70	37	93	179	19 19
	13	53	74	74	60	52	59	61	59	72	45	106	199	19 19
50	10	33	44	47	44	40	42	44	43	48	28	45	213	18 18
	4	17	27	33	30	27	30	35	35	31	15	41	224	18 18
	3	14	23	26	24	24	27	28	27	26	14	33	231	18 18
	3	15	23	25	25	26	27	24	21	20	11	26	235	18 18
	4	18	26	27	29	30	30	26	21	17	8	39	237	18 18
40	4	16	23	24	25	27	28	24	19	17	9	29	238	18 18
	2	12	18	20	20	20	20	18	16	18	10	23	238	18 18
	2	9	15	19	20	17	15	14	13	15	9	20	238	18 18
	1	7	12	18	20	16	14	14	12	12	7	18	237	18 18
	1	6	10	14	15	14	14	13	12	10	5	18	233	18 18
30	1	6	9	11	12	13	14	12	11	10	5	11	229	18 18

PER. 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= AUTUMN
POWER (M2/SEC2)

	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)	VAR	N	P.R.E.
	34	115	97	73	67	35	34	102	122	63	17	122	24	109244
	41	120	101	68	63	42	34	78	92	55	21	89	58	66156
	44	116	102	66	62	51	41	58	62	48	24	100	94	28 28
	40	101	96	70	61	48	45	58	59	49	25	92	125	20 20
	41	91	92	68	53	42	39	46	47	44	24	86	156	20 20
	42	85	87	64	49	41	33	33	31	30	18	71	177	19 19
	42	76	78	62	46	35	27	27	26	21	11	67	184	19 19
	39	46	70	57	37	27	24	24	24	20	9	55	191	19 19
	3	62	69	53	31	24	25	22	20	19	10	52	200	19 19
	34	62	72	54	30	27	26	18	14	16	9	55	206	18 18
	33	57	67	56	32	25	23	18	14	12	6	46	211	18 18
	32	51	59	55	34	22	17	17	15	10	4	48	214	18 18
	28	[illegible]	49	47	31	17	12	14	13	10	5	39	213	19 19
	19	36	40	35	24	13	10	12	12	12	7	31	213	19 19
	11	26	32	27	18	11	9	11	11	12	7	24	212	19 19
	9	24	30	24	16	10	9	10	10	10	6	20	210	19 19

PERIOD 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

(b)

SEASON= WINTER
POWER (M2/SEC2)

KM	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)	VAR	N	P.R.E.
60	6	82	126	130	125	115	92	71	63	45	17	109	12	120120
	1	75	129	139	129	111	87	77	68	41	14	134	58	66 66
	5	67	124	131	113	89	70	71	67	43	16	106	105	21 21
	4	63	101	98	80	65	54	58	62	52	23	90	145	19 19
	15	63	81	74	63	54	49	55	57	47	22	82	177	19 19
50	22	66	74	63	53	51	47	46	46	39	19	70	198	18 18
	22	67	74	56	47	49	47	42	41	35	16	73	193	19 19
	21	68	76	55	45	47	45	41	36	26	11	61	225	18 18
	20	66	71	55	50	46	39	37	33	23	9	69	230	18 18
	17	54	57	51	49	38	30	32	33	25	10	53	228	18 18
40	16	45	48	44	41	29	22	24	27	25	11	47	229	18 18
	13	37	40	35	34	28	20	19	20	21	11	39	230	18 18
	9	27	30	27	30	27	20	17	16	16	9	32	230	18 18
	8	23	25	21	23	23	18	14	12	10	5	25	229	18 18
	8	21	22	18	17	17	14	10	8	7	3	19	222	18 18
30	9	20	21	17	15	15	12	9	7	6	3	18	218	18 18

PER. 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= SPRING
POWER (M2/SEC2)

	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)	VAR	N	P.R.E.
	2	26	30	37	49	39	26	27	37	45	25	49	8	124124
	0	25	32	35	42	37	30	34	37	36	19	46	62	60132
	0	25	37	32	29	29	31	34	31	23	11	38	115	21 21
	3	27	37	30	23	23	24	24	23	19	8	32	165	19 19
	4	22	30	27	23	22	21	21	22	18	7	31	191	19 19
	3	18	25	24	21	19	20	22	24	22	11	27	204	19 19
	3	20	28	24	19	16	18	22	23	26	15	31	186	19 19
	3	22	33	26	19	19	21	20	18	22	13	29	220	18 18
	6	26	34	26	21	22	22	18	14	15	9	32	227	18 18
	9	26	31	23	19	19	18	17	15	14	8	27	232	18 18
	8	22	27	22	19	17	15	15	15	14	7	25	234	18 18
	6	19	26	22	19	18	14	13	14	13	6	24	232	18 18
	4	15	23	21	18	16	14	13	14	11	5	23	229	18 18
	2	10	15	16	15	13	12	11	11	9	4	16	228	18 18
	1	8	11	11	10	10	10	9	8	7	4	12	226	18 18
	1	7	11	9	7	8	9	7	6	6	3	8	224	18 18

PERIOD 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= SUMMER
POWER (M2/SEC2)

KM	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)	VAR	N	P.R.E.
60	3	43	65	75	73	74	81	80	74	66	33	108	18	112112
	1	42	58	63	63	65	70	69	64	60	31	75	68	54 54
	5	37	50	51	53	54	50	48	49	50	26	67	136	20 20
	4	29	43	47	49	47	41	41	41	37	17	55	177	19 19
	2	21	34	40	41	39	38	40	39	29	13	45	196	19 19
50	1	16	31	37	35	33	32	33	35	29	13	42	212	18 18
	2	18	32	34	29	27	28	29	31	26	12	37	195	19 19
	2	15	27	28	23	24	27	29	26	20	10	33	231	18 18
	2	10	17	22	23	23	24	24	20	16	8	26	235	18 18
	1	7	11	16	19	19	17	16	14	14	8	20	236	18 18
40	1	7	10	12	14	14	13	12	12	13	7	14	237	18 18
	1	6	10	12	13	14	12	10	10	11	6	17	237	18 18
	1	6	9	10	10	10	9	8	8	9	5	11	237	18 18
	1	5	8	8	7	7	6	6	7	8	4	9	236	18 18
	1	4	7	7	6	6	6	5	6	8	4	9	231	18 18
30	0	3	6	6	6	6	5	5	6	7	4	6	227	18 18

PER. 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= AUTUMN
POWER (M2/SEC2)

	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4 (DAYS)	VAR	N	P.R.E.
	16	46	36	47	69	58	36	34	32	33	21	77	24	109109
	12	38	35	45	55	46	37	35	31	30	18	42	58	67 67
	8	33	38	40	35	32	41	44	36	30	15	51	94	28 28
	8	38	43	36	28	31	43	45	40	33	16	51	125	20 20
	8	37	43	34	32	37	38	31	30	32	17	46	155	20 20
	8	34	43	37	37	40	34	23	23	28	15	47	176	19 19
	8	32	43	38	33	33	27	22	23	25	13	41	159	20 20
	8	30	40	34	27	25	22	23	26	25	13	38	188	19 19
	7	24	34	31	24	20	20	23	27	24	12	36	199	19 19
	7	21	29	30	24	17	15	18	22	21	10	26	205	18 18
	8	21	27	30	26	18	14	15	18	17	8	30	210	18 18
	8	20	24	26	22	17	15	15	17	15	7	27	214	18 18
	4	14	19	18	14	12	13	14	16	14	7	19	212	19 19
	2	10	14	15	12	10	10	12	12	11	5	15	212	19 19
	2	8	12	12	10	9	10	10	9	9	4	13	212	19 19
	1	7	11	10	9	9	10	9	9	8	4	10	210	19 19

PERIOD 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

Table A-6. Analysis of the high frequency variability of the wind at Kennedy. (a) Zonal, (b) Meridional.

(a)

SEASON= WINTER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.
60	14	251	364	280	272	254	167	129	83	102	84	282	7	139311
	8	261	335	266	279	240	155	139	103	119	91	260	21	114280
	44	261	295	271	304	235	147	123	94	134	103	299	60	66 66
	64	236	255	268	309	241	150	82	47	110	91	261	85	39 39
	59	197	205	225	277	235	156	74	39	89	69	218	100	23 23
50	45	171	183	197	243	233	180	96	65	100	62	217	111	23 23
	57	190	197	194	220	219	182	101	74	104	60	231	115	23 23
	93	239	224	196	194	172	145	88	63	89	53	218	116	23 23
	122	272	238	178	146	113	106	83	62	73	43	211	117	22 22
	123	266	229	141	93	73	79	76	68	67	35	177	118	22 22
40	112	233	196	102	56	49	58	68	71	61	27	149	119	22 22
	94	188	152	76	43	36	40	55	66	53	21	118	117	23 23
	70	139	113	65	42	29	28	39	51	43	16	88	116	23 23
	51	107	94	63	43	27	21	27	37	31	11	70	116	23 23
	43	94	84	56	42	28	15	16	26	21	6	62	116	23 23
30	40	89	78	51	40	30	13	10	20	17	5	49	116	23 23
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

SEASON= SPRING
POWER (M2/SEC2)

												VAR	N	P.R.E.
	15	66	85	62	49	49	49	65	66	40	13	79	7	139139
	18	68	82	61	52	49	41	53	59	41	15	78	25	103103
	22	61	69	54	54	47	34	42	48	37	15	68	80	44 44
	21	49	56	52	53	42	31	38	41	31	12	59	119	22 22
	18	45	58	58	52	36	23	27	33	30	14	56	140	22 22
	20	48	66	65	51	31	17	20	26	29	16	54	146	22 22
	23	50	68	71	51	29	17	18	21	27	17	58	150	22 22
	23	43	62	71	50	30	23	20	18	23	15	54	152	21 21
	19	32	49	62	48	33	26	21	16	17	11	50	156	21 21
	16	26	37	50	44	32	24	19	13	11	7	37	160	21 21
	14	24	33	43	40	30	22	16	10	8	5	34	162	21 21
	11	23	33	41	36	27	21	15	9	8	5	33	161	21 21
	11	23	32	38	31	21	18	13	8	7	4	29	161	21 21
	11	23	29	34	26	16	14	11	7	5	2	25	161	21 21
	11	22	26	29	23	13	11	9	6	4	2	22	160	21 21
	9	21	25	26	21	11	9	7	5	4	2	17	160	21 21
PERIOD	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

SEASON= SUMMER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.
60	35	40	83	100	165	179	126	93	81	71	36	127	15	129324
	25	39	78	86	129	154	119	85	76	73	38	130	35	91 91
	8	33	62	62	70	90	82	65	63	63	33	81	96	26 26
	1	23	44	50	43	39	40	41	43	44	24	50	136	21 21
	3	17	33	42	36	28	28	27	25	29	19	40	159	17 62
50	4	14	24	28	29	29	27	24	20	20	12	32	168	19 19
	4	13	18	20	23	25	24	21	18	17	9	27	187	19 19
	4	12	16	18	19	20	19	18	16	13	7	21	190	19 19
	3	10	15	17	18	18	18	19	16	12	6	21	193	19 19
	2	10	15	17	17	16	18	19	15	13	7	21	194	19 19
40	3	10	15	17	16	14	15	15	12	11	7	20	195	19 19
	7	8	13	14	13	12	11	9	8	9	5	14	194	19 19
	1	6	10	11	10	9	8	7	6	7	5	10	189	20 20
	0	5	9	10	10	8	7	6	6	7	4	10	181	20 20
	0	4	8	10	10	8	7	6	5	5	3	9	173	20 20
30	0	4	8	10	9	8	8	6	5	5	2	8	170	20 20
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4.	4	(DAYS)		

SEASON= AUTUMN
POWER (M2/SEC2)

												VAR	N	P.R.E.
	31	143	157	93	58	64	69	65	73	69	32	117	11	154513
	29	145	167	101	59	57	57	60	73	65	27	121	47	79 79
	18	128	171	116	73	57	39	44	64	53	18	108	87	36 36
	12	106	161	126	86	60	27	27	46	38	11	97	118	22 22
	18	100	156	126	78	50	21	18	35	27	7	90	135	21 21
	21	97	144	111	60	35	17	14	24	23	10	80	150	20 20
	20	84	116	82	41	24	16	14	19	24	14	64	159	20 20
	17	65	84	59	29	18	17	16	18	22	13	47	161	20 20
	14	50	61	44	24	17	18	16	16	20	12	41	163	20 20
	13	37	42	33	21	16	16	15	15	19	12	33	166	20 20
	11	28	31	26	17	12	12	13	14	17	10	25	165	20 20
	9	24	29	24	17	12	11	12	12	13	7	24	166	20 20
	7	23	29	21	15	13	12	11	10	10	5	22	166	20 20
	5	21	27	18	13	13	12	11	8	8	5	20	166	20 20
	4	16	21	14	11	11	11	10	8	8	5	16	165	19 87
	3	13	18	13	10	10	9	9	8	9	5	13	165	20 20
PERIOD	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

(b)

SEASON= WINTER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.
60	9	95	138	67	27	35	41	65	93	85	38	84	7	144366
	4	87	123	72	39	43	58	85	99	74	28	101	21	109109
	7	70	94	73	52	57	81	106	100	60	21	104	59	68179
	10	52	71	64	49	53	69	89	83	58	27	93	84	40 40
	5	37	58	59	48	44	49	63	60	49	27	61	98	26 26
50	3	29	51	60	53	45	49	56	45	35	19	65	108	23 23
	7	31	50	59	50	42	47	49	39	31	16	59	111	23 23
	11	38	52	55	42	34	38	37	36	37	20	54	111	23 23
	13	42	50	47	37	30	29	30	37	43	23	56	113	23 23
	11	37	39	33	30	30	29	32	37	36	18	46	116	23 23
40	7	29	32	27	25	26	28	31	30	22	10	37	117	23 23
	6	23	29	27	20	17	20	24	23	16	7	28	116	23 23
	5	18	22	21	16	14	16	19	20	15	7	23	114	23 23
	4	13	14	14	15	16	17	17	16	14	7	21	112	23 23
	2	10	12	11	12	15	14	11	10	9	5	14	113	23 23
30	1	9	12	10	10	12	11	8	7	6	3	10	113	23 23
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

SEASON= SPRING
POWER (M2/SEC2)

												VAR	N	P.R.E.
	17	24	40	48	59	57	50	45	49	48	22	64	7	137306
	12	21	41	48	49	43	42	40	42	42	20	50	25	103103
	2	21	39	41	32	29	34	32	29	30	16	41	79	45 45
	3	23	33	30	26	28	28	23	21	23	13	34	119	22 22
	4	21	31	31	28	25	19	15	17	21	12	30	140	22 22
	3	18	31	34	28	21	16	14	14	15	8	29	146	22 22
	4	16	27	30	25	17	15	14	12	11	5	24	150	22 22
	5	14	20	24	21	16	14	15	14	10	5	20	152	21 21
	4	13	17	19	19	16	15	16	15	10	4	22	156	21 21
	3	11	16	16	16	14	14	14	13	10	4	18	160	21 21
	2	9	13	15	14	12	10	11	11	9	4	15	162	21 21
	1	7	10	12	13	10	8	9	10	8	3	13	161	21 21
	1	6	8	9	10	8	8	9	9	8	3	10	160	21 21
	1	4	7	9	8	6	7	8	8	7	3	10	161	21 21
	1	4	7	8	6	5	6	7	5	5	2	7	160	21 21
	1	4	7	7	5	5	6	6	4	3	2	6	160	21 21
PERIOD	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

SEASON= SUMMER
POWER (M2/SEC2)

KM												VAR	N	P.R.E.
60	15	17	53	64	53	36	28	50	66	72	42	61	15	125125
	11	19	47	56	51	39	32	46	60	72	44	67	35	88163
	3	22	37	44	42	36	34	38	47	59	35	55	96	26 26
	2	22	32	35	31	30	31	28	30	34	19	38	135	21 21
	2	18	26	27	28	28	26	22	19	21	12	31	158	20 20
50	0	12	17	21	25	25	24	21	17	17	10	26	168	19 19
	1	8	13	16	20	21	22	20	16	15	8	22	187	19 19
	1	8	12	13	14	16	16	15	15	14	7	17	190	19 19
	1	9	12	11	12	12	10	11	12	14	7	16	193	19 19
	0	6	10	10	11	10	9	9	9	11	6	12	194	19 19
40	0	5	9	9	9	9	9	8	7	7	4	10	195	19 19
	0	5	8	8	7	7	8	7	7	6	3	9	194	19 19
	0	3	6	6	6	6	6	6	6	5	2	7	189	20 20
	0	2	4	5	5	5	5	5	5	4	2	5	181	20 20
	0	2	4	4	4	4	4	4	3	3	2	4	173	20 20
30	0	2	4	5	4	3	3	3	3	2	1	3	170	20 20
PER.	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

SEASON= AUTUMN
POWER (M2/SEC2)

												VAR	N	P.R.E.
	7	20	36	33	29	35	36	36	46	59	35	48	11	124124
	5	24	37	31	28	36	35	34	47	65	39	50	47	79 79
	0	28	36	30	28	36	36	33	47	63	36	55	87	36 36
	3	27	34	33	31	31	31	34	42	45	24	44	118	22 22
	4	27	38	38	31	24	24	32	35	31	15	41	135	21 21
	4	25	36	35	27	20	19	26	29	25	12	38	150	20 20
	4	23	30	25	20	16	15	19	21	19	10	26	159	20 20
	3	20	28	22	17	13	12	15	16	15	8	22	161	18 82
	2	18	26	23	18	12	12	16	16	12	5	24	163	20 20
	1	15	23	21	15	10	10	15	17	12	4	20	166	20 20
	2	12	18	16	12	8	8	14	17	11	4	17	165	20 20
	1	9	13	13	11	8	8	12	15	10	3	14	166	20 20
	0	6	11	12	10	8	8	10	11	9	4	12	166	20 20
	1	5	9	10	9	8	7	7	8	8	4	10	166	20 20
	1	3	6	7	7	6	6	6	7	7	3	8	165	20 20
	1	2	5	6	6	5	5	5	6	6	3	5	165	20 20
PERIOD	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	(DAYS)		

Table A-7. Analysis of the high frequency variability of the wind at Hawaii. (a) Zonal, (b) Meridional.

(a)

SEASON= WINTER
POWER (M2/SEC2)

KM	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	VAR	N	P.R.E.
60	30	79	92	84	77	64	56	73	72	62	33	95	13	122127
	31	78	89	77	71	62	65	91	84	75	44	110	58	66150
	31	76	94	74	64	65	83	111	95	85	52	121	114	20 89
	32	73	100	81	59	70	101	115	90	72	39	122	149	22 22
	34	65	89	82	59	71	107	111	77	55	28	112	160	21 21
50	31	58	78	78	64	66	86	90	71	53	25	102	166	21 21
	27	59	76	70	56	51	56	67	72	63	29	86	167	21 21
	20	58	79	66	46	41	43	52	66	71	37	85	168	21 21
	10	43	71	61	42	42	40	36	48	60	32	73	169	21 21
	7	32	50	46	41	47	41	29	32	38	20	46	169	21 21
40	8	31	41	36	38	45	37	26	25	28	15	52	170	21 21
	7	27	37	32	31	34	30	23	22	23	13	35	171	21 21
	5	19	26	25	25	26	26	25	21	19	11	34	171	21 21
	2	13	20	21	22	21	22	23	19	15	8	23	170	21 21
	0	11	21	21	19	17	17	17	14	12	6	21	170	21 21
30	0	11	21	21	18	16	16	14	13	12	6	19	170	21 21

PER. 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= SPRING
POWER (M2/SEC2)

44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	VAR	N	P.R.E.
24	104	133	63	15	16	15	15	14	21	16	59	20	116253
17	97	134	68	16	17	20	21	15	22	17	63	52	79231
11	92	134	73	21	20	28	27	16	20	16	64	116	20 89
16	97	130	71	27	23	28	26	15	15	11	64	145	22111
22	98	121	68	31	23	25	24	17	13	7	63	162	20 89
22	89	112	69	33	24	24	22	16	13	8	60	167	21 21
17	75	105	73	34	23	24	20	14	15	10	58	168	21 21
15	63	92	68	33	22	24	22	17	18	10	54	168	21 21
14	52	74	54	27	21	22	22	19	17	9	50	170	21 21
9	40	57	40	21	18	18	19	18	16	8	33	170	19 85
6	29	44	36	23	17	17	19	17	16	8	33	169	21 21
5	23	41	44	29	16	15	16	16	15	7	31	170	21 21
4	21	40	46	31	15	12	13	14	13	6	33	170	21 21
3	18	30	33	24	16	15	14	14	12	6	24	170	21 21
3	13	20	20	17	16	17	17	13	10	6	22	170	21 21
2	11	17	17	15	15	16	16	12	10	5	16	171	21 21

PERIOD 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= SUMMER
POWER (M2/SEC2)

KM	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	VAR	N	P.R.E.
60	29	91	111	115	92	54	35	31	46	51	22	86	15	119119
	33	94	114	112	89	55	37	35	50	53	24	104	60	64 64
	39	91	104	98	82	58	40	42	54	52	24	100	124	22 22
	41	77	88	90	77	57	42	44	53	48	22	87	150	22 22
	39	72	92	102	81	54	38	37	47	49	25	92	159	21 21
50	38	77	102	107	86	56	33	27	37	48	28	92	165	21 21
	37	78	98	96	84	61	36	27	33	42	25	89	170	21 21
	34	75	88	79	76	61	38	30	33	39	23	85	172	21 21
	33	74	81	67	67	56	33	26	27	33	20	72	173	21 21
	30	68	72	61	65	52	29	24	22	22	13	67	176	21 21
40	25	55	59	56	59	46	31	27	21	17	9	56	177	21 21
	22	46	54	56	49	34	26	23	20	19	9	52	178	21 21
	19	41	52	54	40	22	14	15	18	19	9	45	180	21 21
	14	34	46	46	32	15	10	11	14	15	8	31	181	21 21
	9	25	37	40	26	12	11	12	10	11	6	32	181	21 21
30	6	20	32	36	24	11	12	12	9	10	6	17	181	21 21

PER. 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= AUTUMN
POWER (M2/SEC2)

44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	VAR	N	P.R.E.
4	35	60	59	61	60	48	37	41	67	47	69	8	129129
8	53	78	68	58	58	49	34	38	66	46	74	48	77 77
27	90	116	87	63	61	51	34	38	60	39	97	110	22 22
36	112	137	93	67	64	49	33	36	46	27	111	150	21 21
36	109	130	85	60	55	40	30	32	33	18	80	173	20 20
34	100	116	79	58	49	37	34	34	31	15	88	184	20 20
29	87	99	69	57	47	35	33	35	32	16	80	189	20 20
21	66	75	54	47	41	30	27	28	29	15	59	189	20 20
15	49	59	46	41	35	27	23	22	23	13	48	190	20 20
13	43	53	46	41	33	25	21	18	19	11	45	190	20 20
11	37	47	44	42	34	27	20	14	17	11	44	190	20 20
8	26	35	38	39	34	28	20	13	17	11	37	190	20 20
5	17	24	30	32	27	25	22	17	18	11	33	190	20 20
3	15	23	25	23	21	24	23	18	16	9	27	190	20 20
3	15	24	23	17	16	20	20	15	14	8	24	189	20 20
3	14	24	22	15	14	17	17	15	14	8	20	189	20 20

PERIOD 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

(b)

SEASON= WINTER
POWER (M2/SEC2)

KM	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	VAR	N	P.R.E.
60	8	38	81	93	83	62	55	66	62	39	13	96	13	122122
	5	38	79	85	72	55	46	49	48	39	18	66	57	69 69
	2	39	79	72	54	47	37	34	37	42	23	63	114	23 23
	3	35	69	58	45	45	40	42	43	41	21	66	149	20 91
	0	28	50	41	36	42	45	45	37	28	13	49	160	21 21
50	3	27	41	32	26	35	39	34	24	17	8	41	166	21 21
	4	25	39	29	20	25	27	21	18	14	7	30	166	21 21
	3	18	29	25	17	19	20	17	17	19	10	26	167	21 21
	1	11	18	20	18	19	18	15	16	22	14	26	167	21 21
	2	9	12	14	17	18	16	13	13	17	11	18	169	21 21
40	1	8	12	13	14	15	14	12	11	13	8	16	169	21 21
	0	7	13	14	12	11	11	11	11	12	7	15	168	21 21
	0	5	11	13	11	10	10	10	10	9	4	12	169	21 21
	0	4	9	13	12	10	9	9	9	8	3	13	170	21 21
	0	4	7	9	10	9	7	7	8	8	4	10	170	21 21
30	0	4	7	7	7	7	6	6	8	8	4	7	168	21 21

PER. 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= SPRING
POWER (M2/SEC2)

44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	VAR	N	P.R.E.
3	28	33	31	31	34	40	34	29	31	15	49	20	117117
3	23	31	30	27	28	34	30	28	29	14	37	52	73 73
4	16	26	26	20	20	24	24	25	26	13	32	116	23 23
4	14	20	19	18	20	20	18	20	23	12	25	145	22 22
3	11	15	17	20	22	18	15	18	20	11	23	162	21 21
2	8	14	20	22	20	16	14	18	20	11	24	167	21 21
2	8	14	20	19	15	12	13	17	19	11	20	168	21 21
3	10	14	17	17	13	12	14	17	17	10	20	168	21 21
3	11	13	14	15	13	12	14	16	14	7	18	170	21 21
3	9	12	13	14	14	13	12	12	11	6	16	170	21 21
1	7	11	13	14	14	13	11	10	10	6	16	169	21 21
1	6	10	12	11	11	11	9	9	9	5	13	170	21 21
1	5	8	9	9	10	9	7	8	8	4	10	170	21 21
1	5	8	8	8	8	7	6	7	7	4	9	170	21 21
1	5	7	7	7	7	6	6	6	6	3	9	170	21 21
1	4	6	6	7	7	6	6	5	5	3	6	171	21 21

PERIOD 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= SUMMER
POWER (M2/SEC2)

KM	44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	VAR	N	P.R.E.
60	3	61	85	68	65	83	75	48	36	38	22	92	15	119119
	4	48	72	68	61	65	60	43	33	32	17	70	60	64 64
	6	31	47	54	47	38	39	37	29	22	10	47	124	22 22
	6	23	30	34	32	26	29	31	25	20	10	36	150	22 22
	4	17	22	26	27	24	23	26	26	24	12	30	159	21 21
50	2	14	21	26	29	25	22	25	28	27	13	32	165	21 21
	2	15	23	27	29	26	23	24	25	23	11	34	170	21 21
	4	18	24	24	24	21	19	18	18	17	8	27	172	21 21
	4	17	22	20	18	15	15	17	16	13	6	20	173	21 21
	3	15	20	17	14	12	15	20	19	14	7	23	175	21 21
40	3	13	16	16	13	11	14	19	17	15	7	20	177	21 21
	2	9	13	15	13	11	13	14	13	13	7	17	178	21 21
	2	6	10	12	11	10	10	10	9	11	6	13	180	21 21
	1	5	8	9	9	9	9	9	9	9	5	10	181	21 21
	1	5	7	8	8	8	8	9	9	9	5	11	181	21 21
30	1	4	7	7	7	7	7	8	9	9	5	9	181	21 21

PER. 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

SEASON= AUTUMN
POWER (M2/SEC2)

44	22	14.7	11	8.8	7.3	6.3	5.5	4.9	4.4	4	VAR	N	P.R.E.
0	31	53	60	53	45	30	32	53	57	29	66	8	133316
1	24	42	48	44	40	30	31	47	52	26	56	47	78 78
0	16	27	30	29	30	28	29	35	36	18	34	109	22 22
2	15	23	24	22	22	22	24	28	26	12	30	150	21 21
4	17	24	22	20	19	18	20	24	23	11	28	173	20 20
5	20	25	22	19	18	17	18	21	19	9	26	184	20 20
6	19	24	23	19	17	17	19	20	18	8	28	189	22119
4	15	20	21	19	16	16	18	19	18	8	24	189	20 20
1	9	14	17	17	17	17	17	18	17	9	20	190	20 20
0	8	13	14	16	19	19	16	16	17	9	20	189	20 20
0	8	13	15	16	19	19	17	17	16	8	22	189	20 20
0	8	13	14	14	16	16	16	16	13	6	18	189	20 20
1	7	11	11	11	11	12	13	13	12	6	14	188	20 20
1	6	9	10	9	9	10	11	11	11	6	12	188	20 20
0	5	10	10	8	8	9	10	9	9	5	12	188	20 20
0	5	9	10	8	8	9	9	8	8	4	9	188	20 20

PERIOD 44 22 14.7 11 8.8 7.3 6.3 5.5 4.9 4.4 4 (DAYS)

Table A-8. Analysis of the high frequency variability of the wind at Ascension.