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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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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°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° near 65°N. Equatorward of 65°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° to 80° 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°N). As the pole is approached from 80°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°N, with a 180° shift near 75°N indicated by all three stations north of 80°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° 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 <u>mean</u> 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 2π/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^{o} 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+0) yields a field variation of (3.28 gammas) cos (wt+0). 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°N of the average 500 mb height for January and the geomagnetic intensity shifted 25° 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 semiannual 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 2π/10 and 2π/20 days, so for brevity only the results at 2π/11 days will be presented below. However, the graphs for the total variance and for the results at 2π/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 2π/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^{o}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

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

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 $E_{IR} \sim \overline{E}_{IR}[1-0.2\, \cos(W_{sa}t)]$, where $\overline{E}_{IR}$ is a yearly mean value. Alternatively, because layer mean temperature and energy are directly related, $T_{IR} \sim \overline{T}_{IR}\, [1-0.2\, \cos(W_{sa}t)]$. 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 noteworthy 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 $N(1) \approx \ldots\ldots N(11) \approx 1/2\ N(0)$, 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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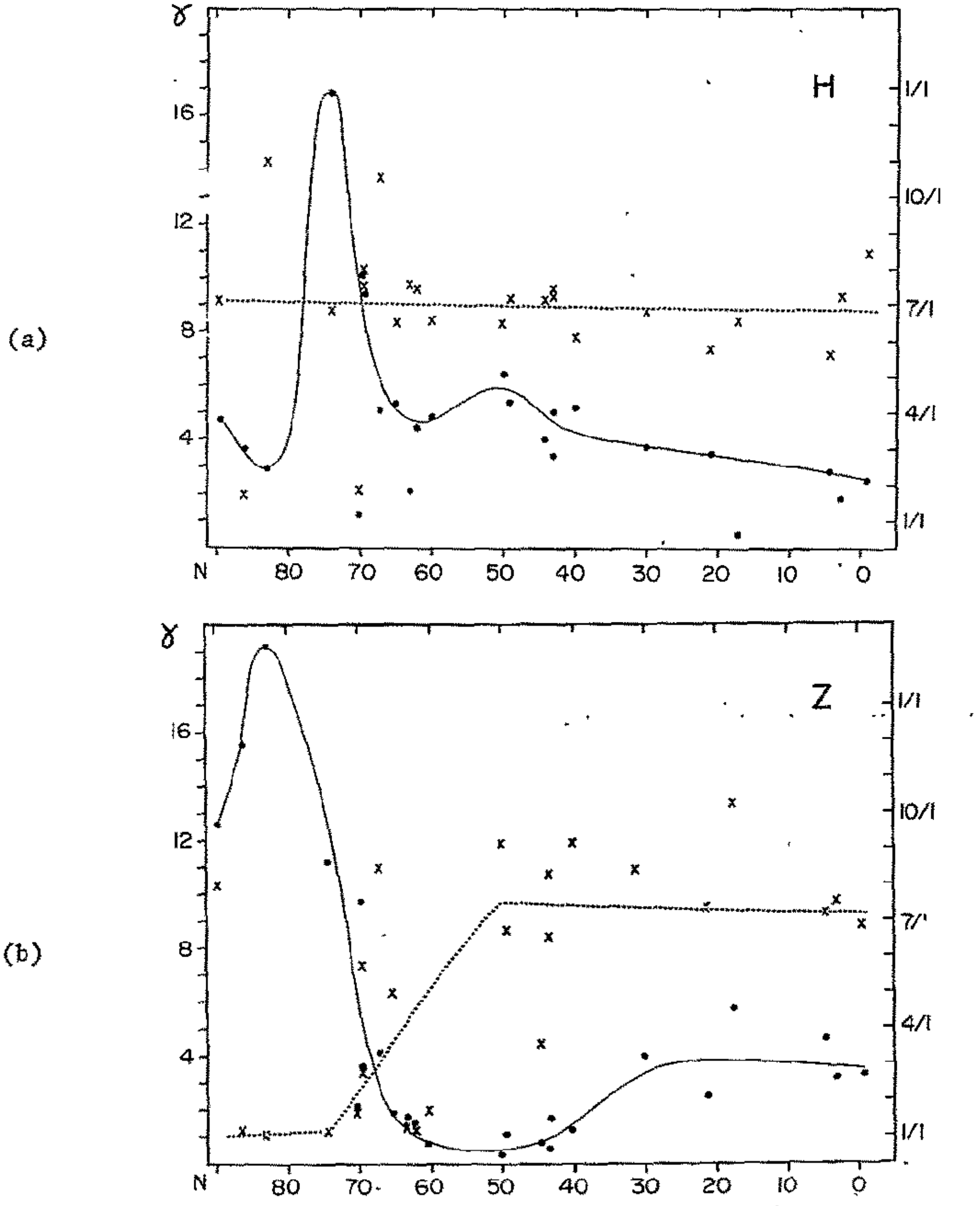


Figure 1. Annual wave in (a) horizontal, (b) vertical field intensity. Dots are amplitudes and crosses are phases of stations in Table 2, plotted at geomagnetic latitude. Lines estimating the latitudinal variation of amplitude (solid) and phase (dotted) have been fitted by eye.

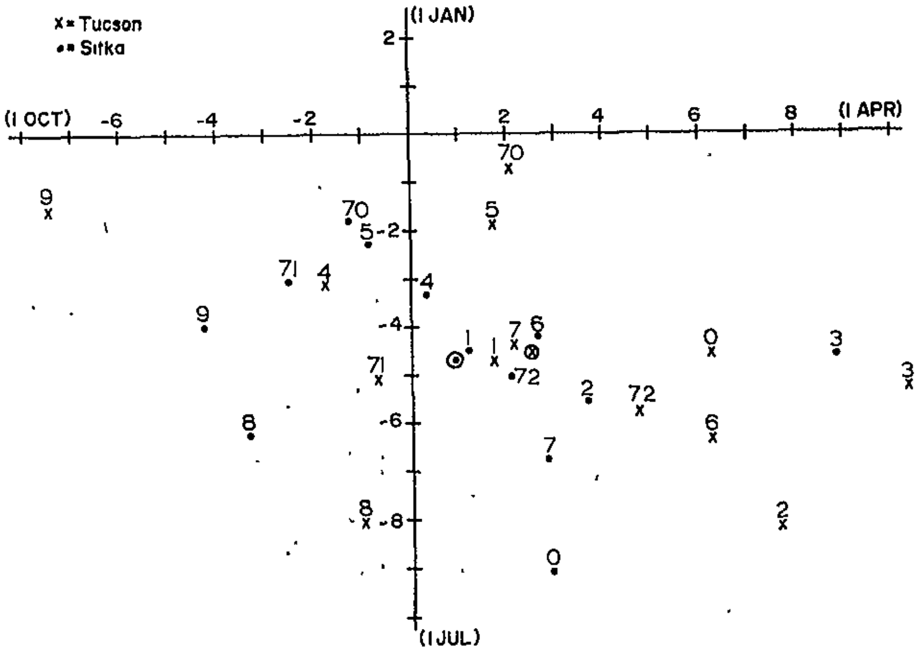


Figure 2. Harmonic dial of the amplitude and phase of the annual wave for each year, 1960-1972, at Sitka and Tucson. The average values for all years are circled. The small number above each point is the year that the point represents (i.e., 3 is for 1963). Axes are labeled in gammas.

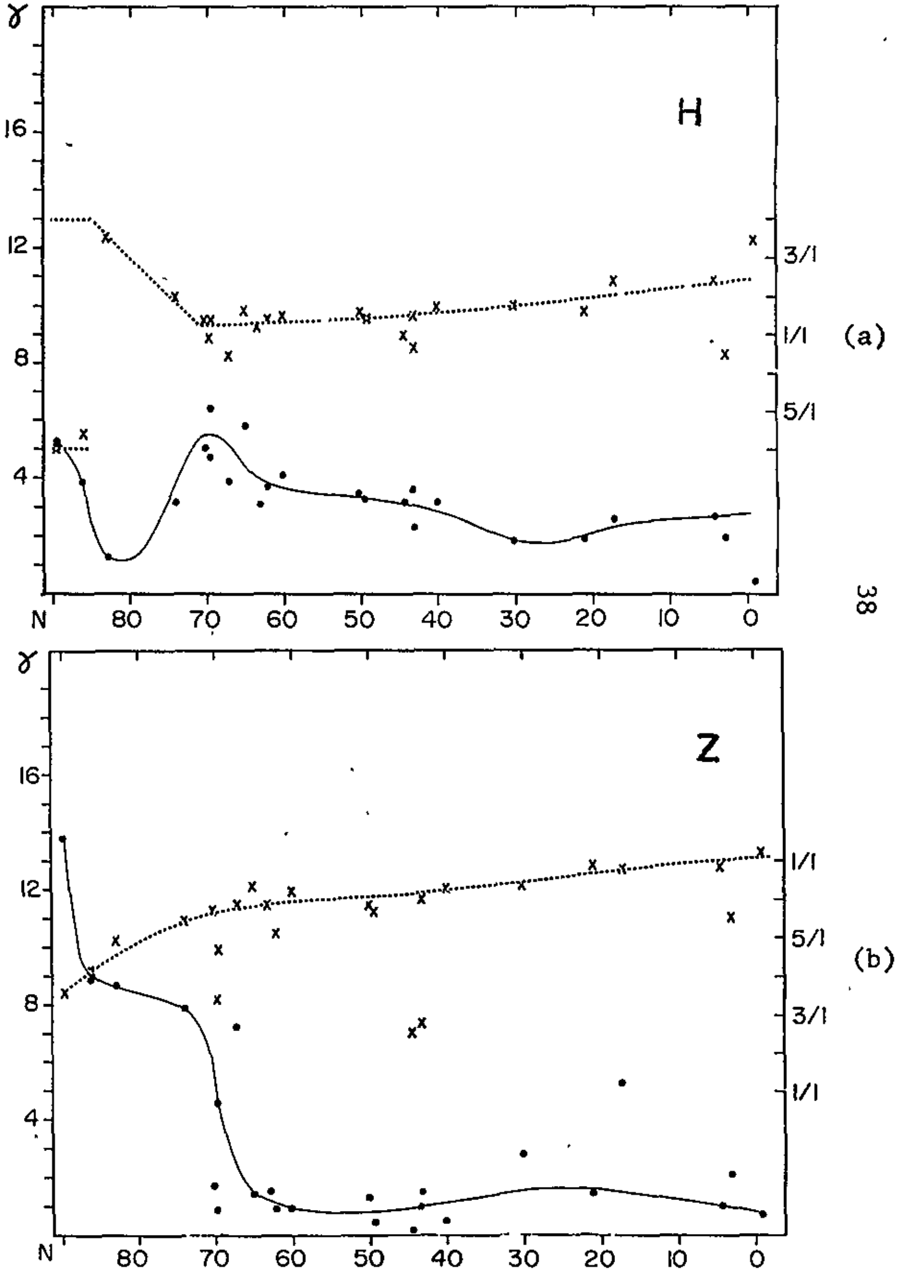


Figure 3. As in Figure 1 except for the semi-annual wave.

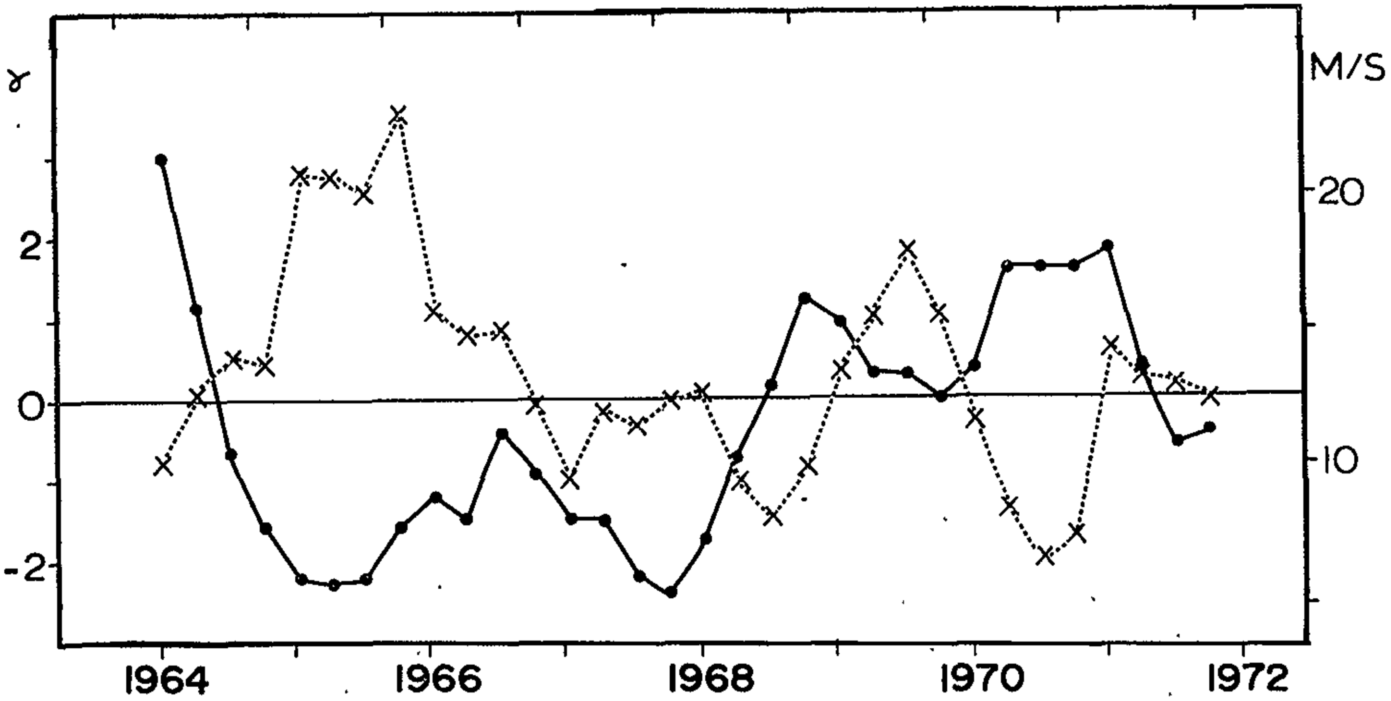


Figure 4. Twelve-month running mean values of Z (solid line) at Honolulu relative to the parabolic secular trend line, and twelve-month running mean values of zonal wind at 56 km at Barking Sands (dotted line). Tick marks on abcissa are for 1 July; every third month is plotted.

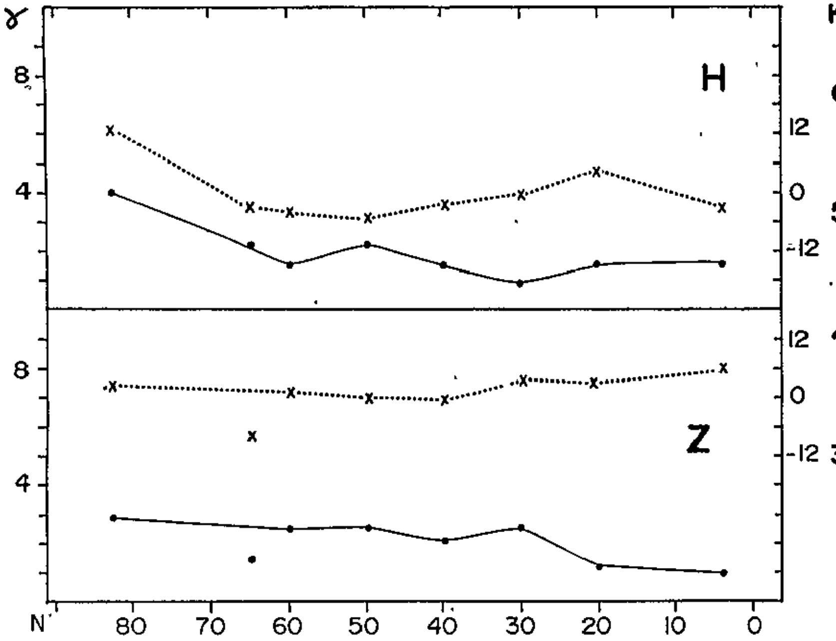


Figure 5. As in Figure 1 except for the QBO. 0 scale is months relative to 1 January 1960.

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.

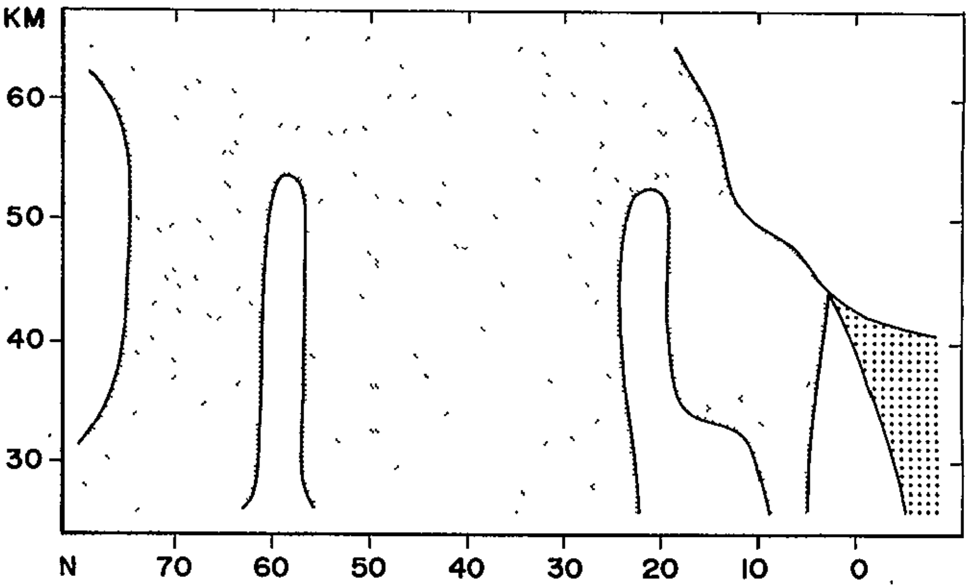


Figure 6a.

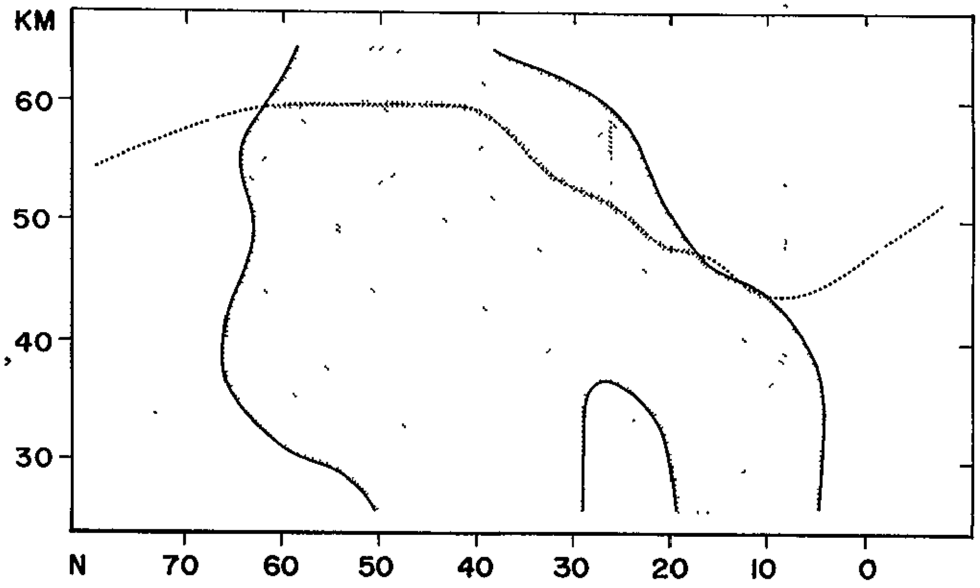


Figure 6b.

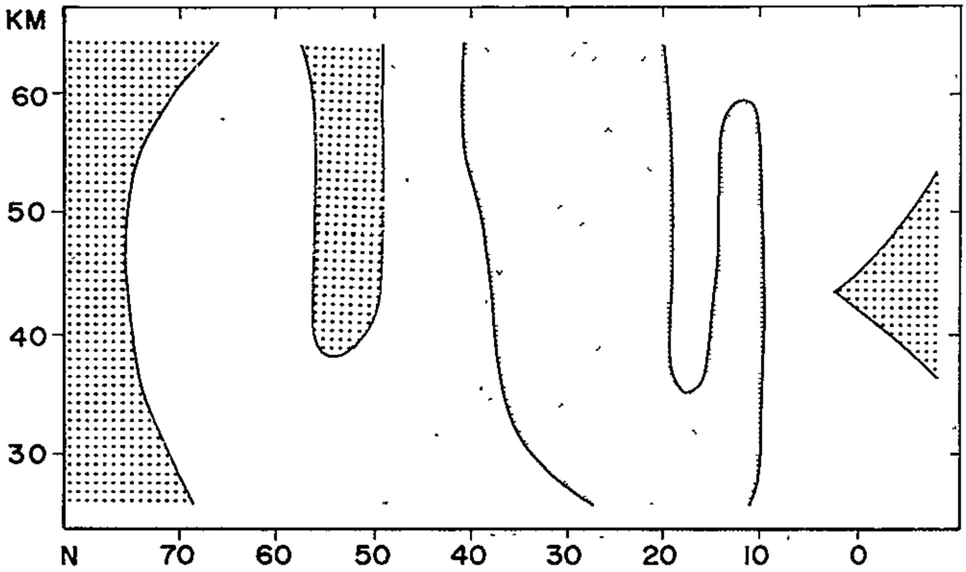


Figure 6c.

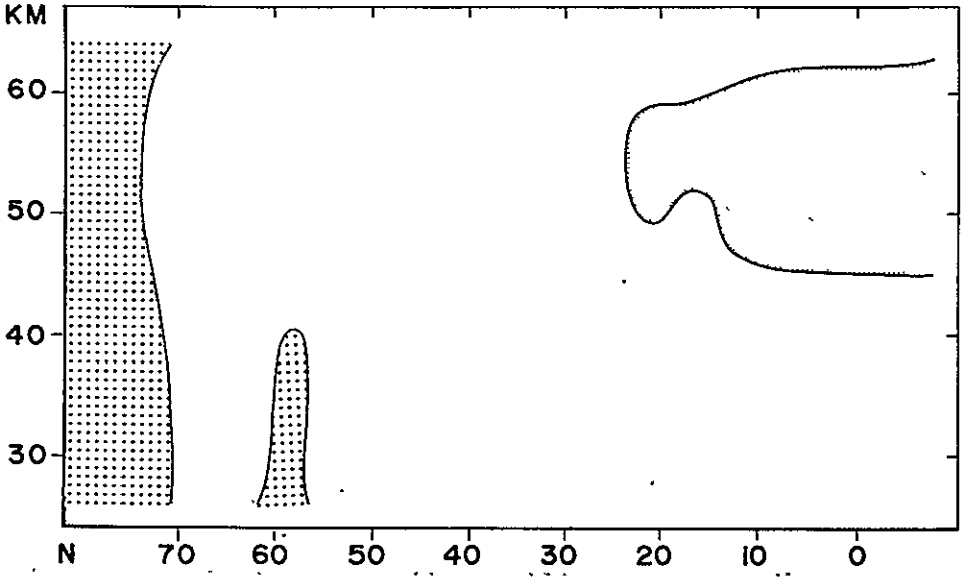


Figure 6d.

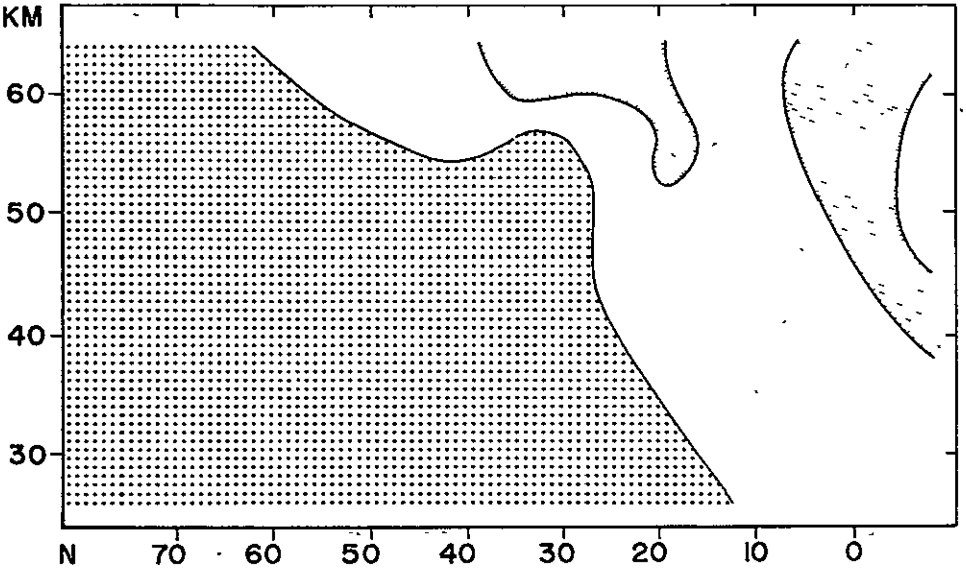


Figure 6e.

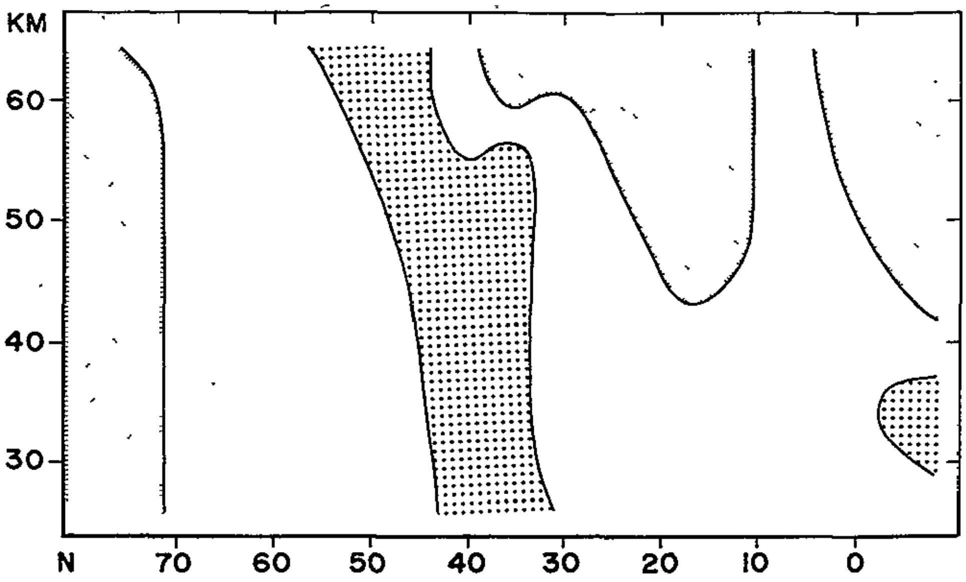


Figure 6f.

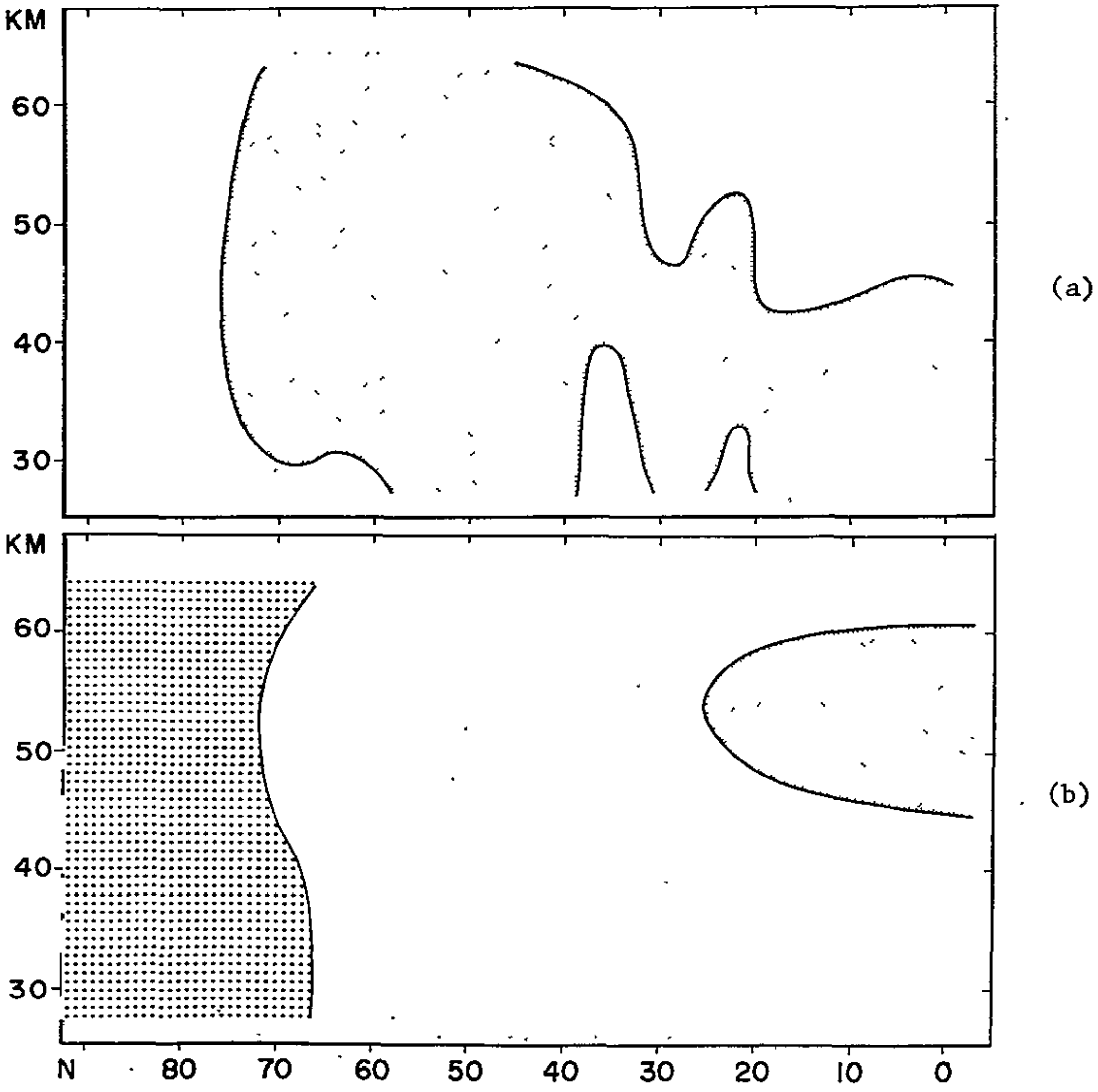
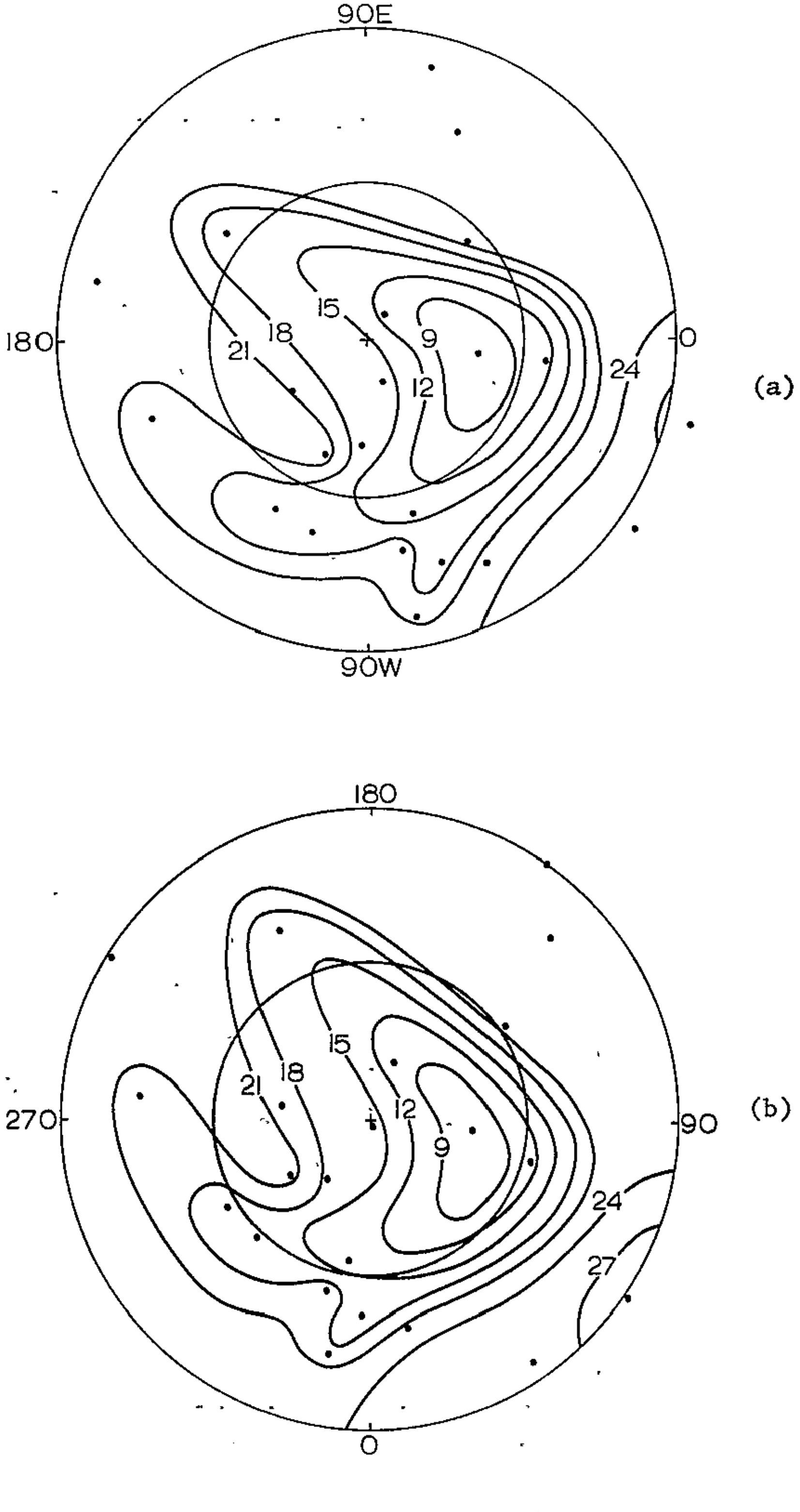


Figure 7. As in Figure 6 except geomagnetic latitude. (a) semiannual wave, U and H; (b) semiannual wave, U and Z.



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.

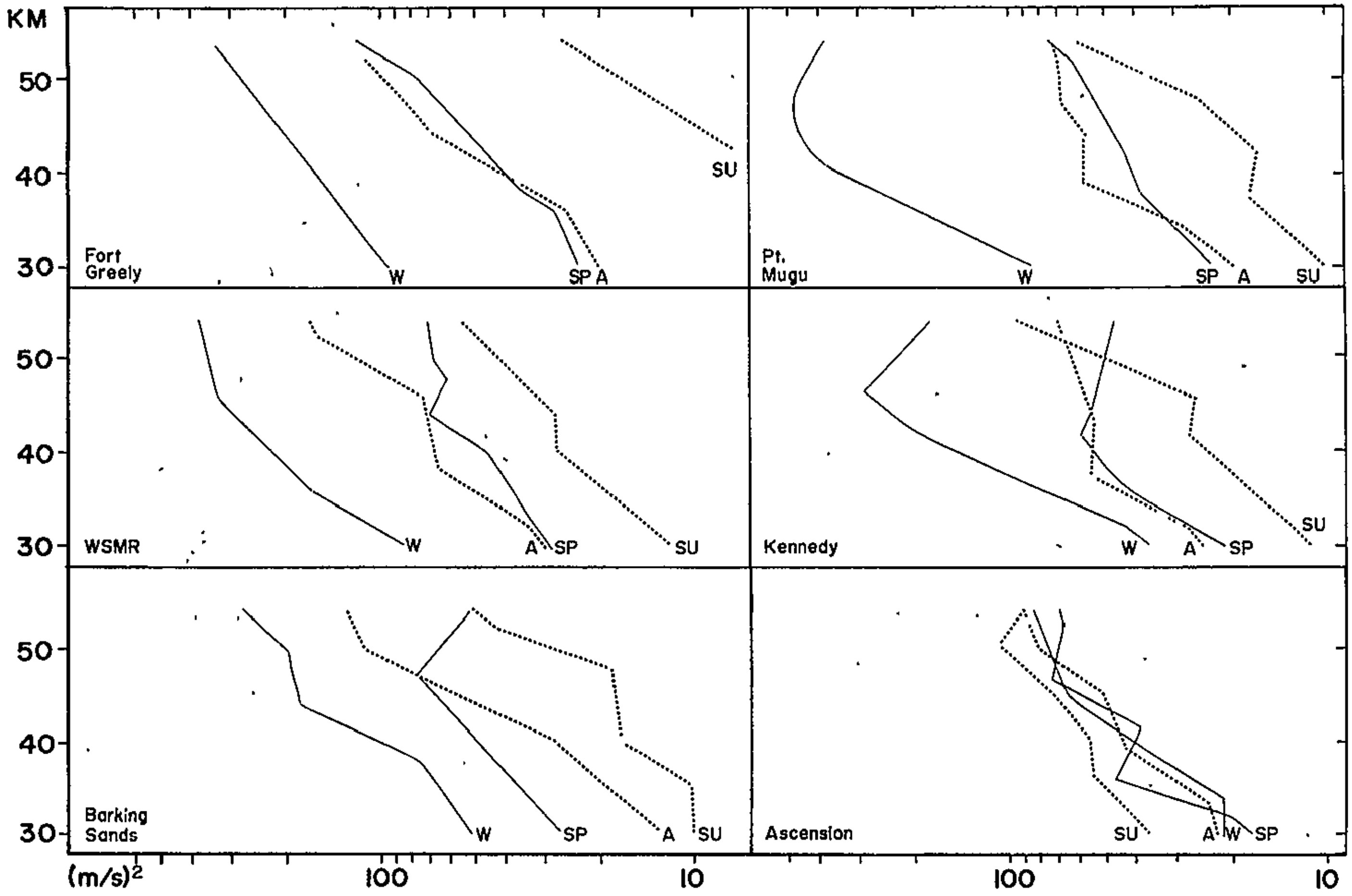


Figure 9. Power spectral density in zonal wind as a function of height for the band centered at 2π/11 days, by season.

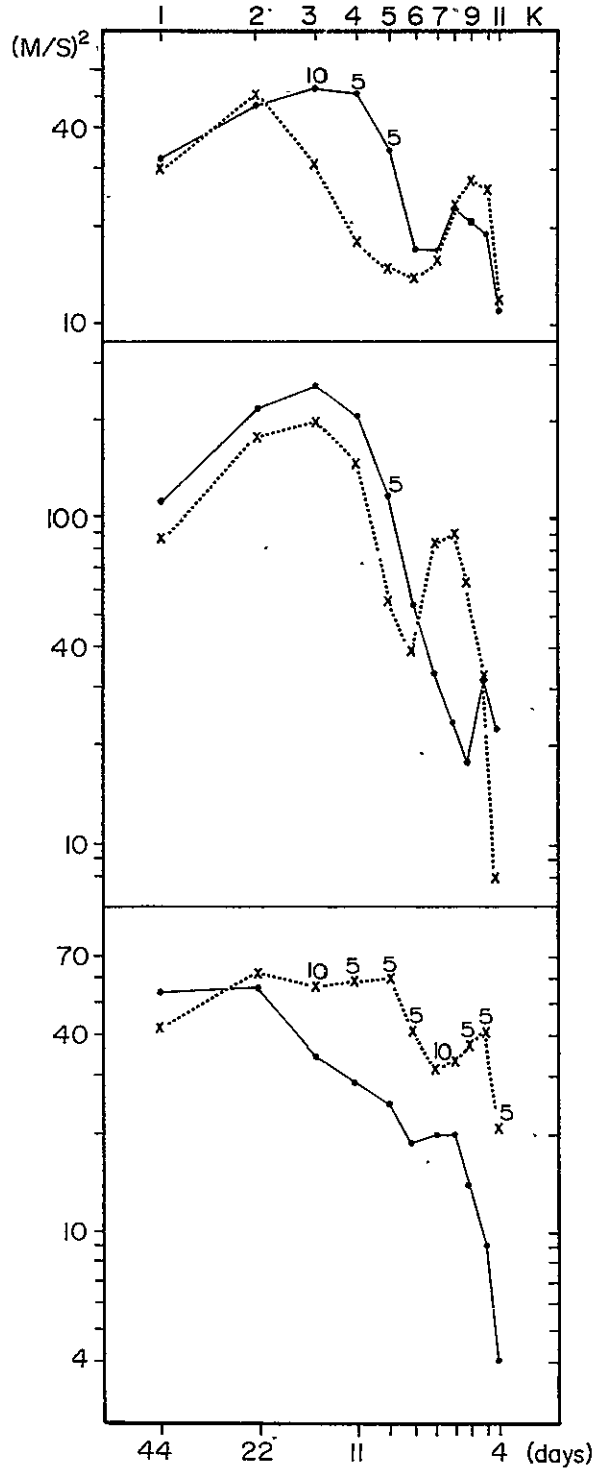


Figure 10. Power spectrum of zonal wind variations at 40 km at Fort Greely. Solid line is for SW years, dotted line is for MSW years, as defined in the text. Statistical significance level of the difference between the two spectra is indicated for continuum values.
(a) autumn (b) winter (c) spring.

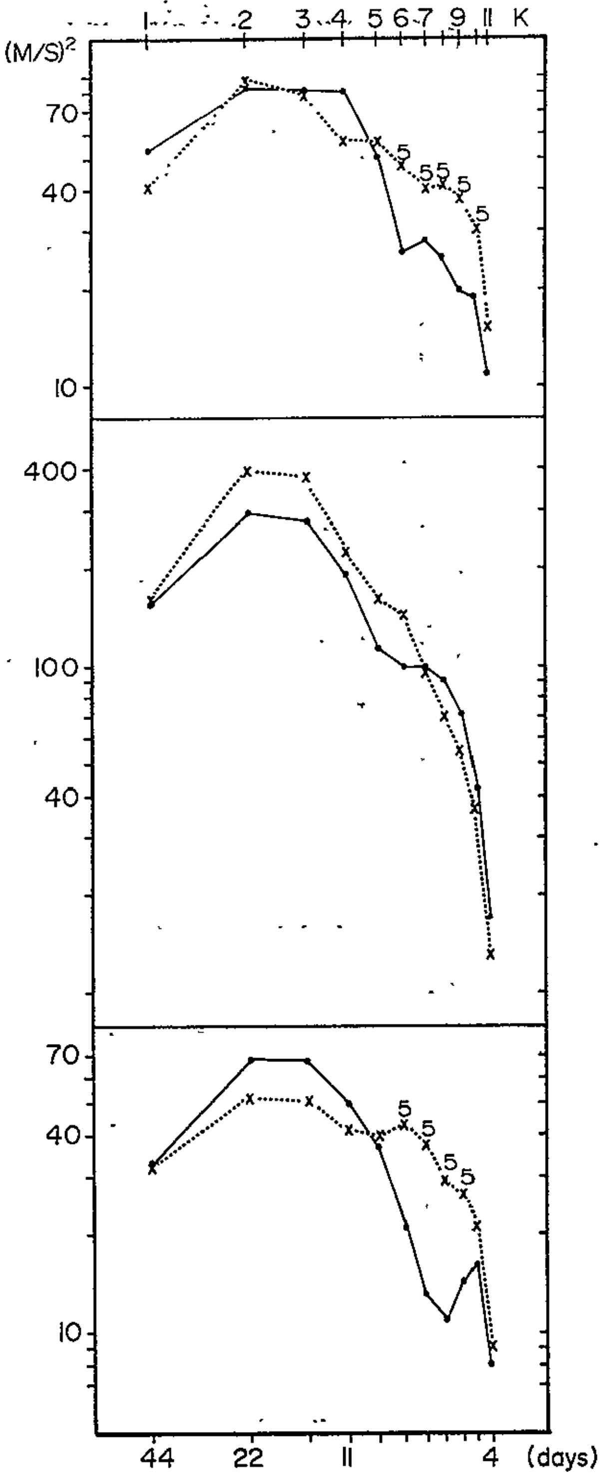


Figure 11. As in Figure 10 except at White Sands.

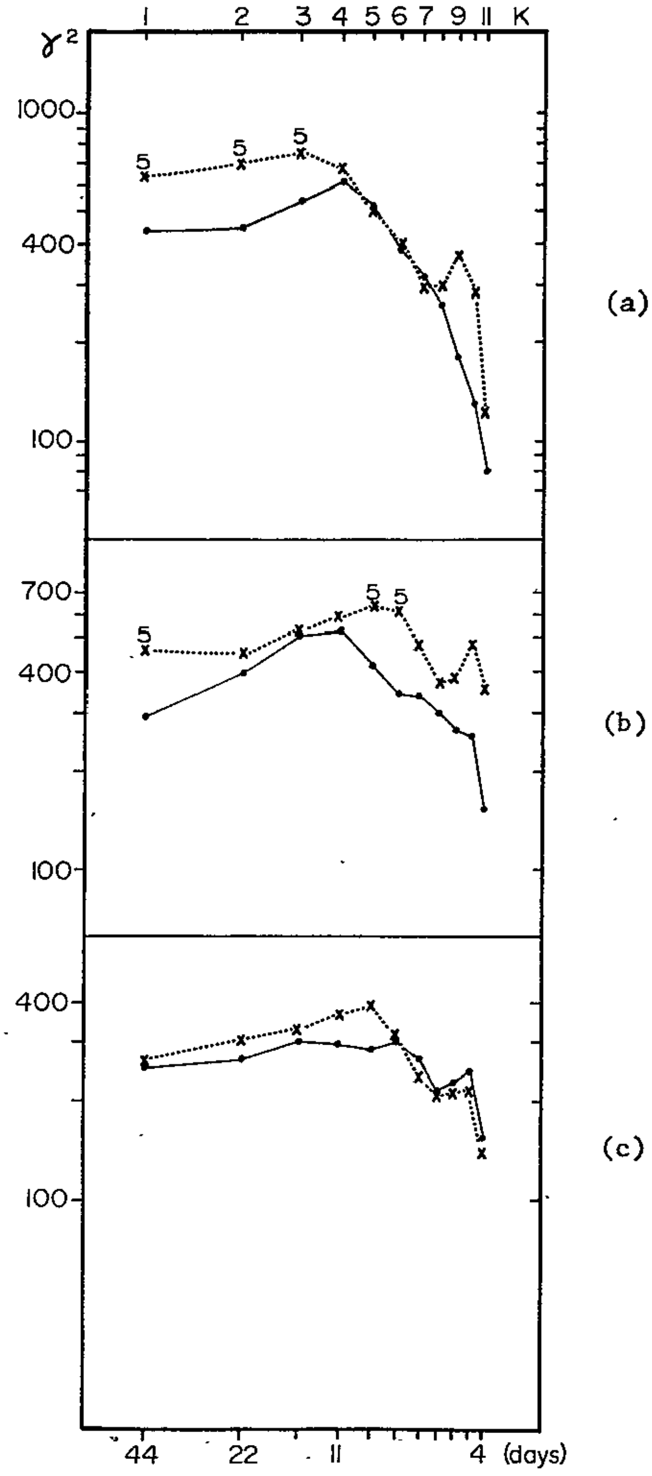


Figure 12. As in Figure 10 except for the horizontal field intensity at College.

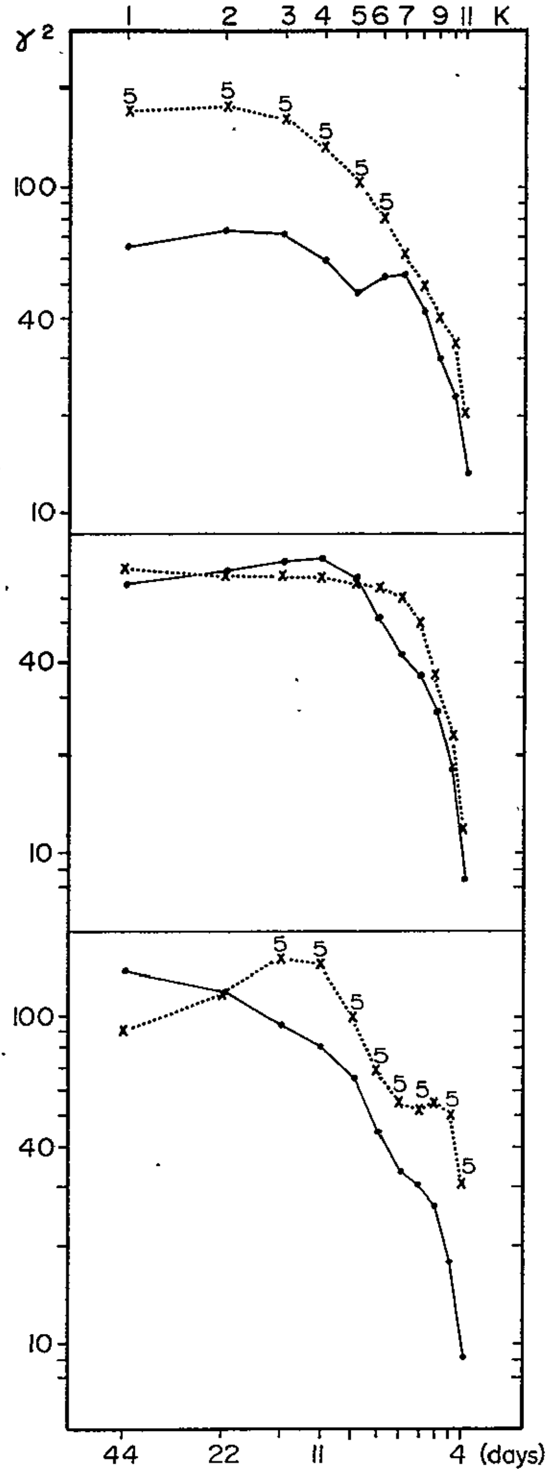


Figure 13. As in Figure 10 except for the horizontal field intensity at Tucson.

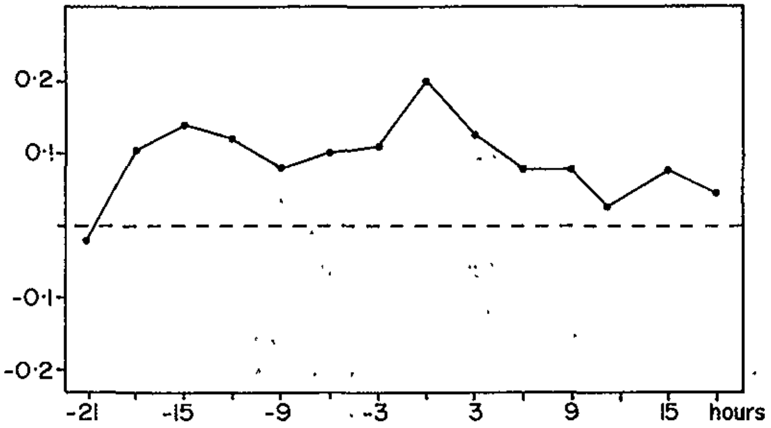


Figure 14. Linear correlation coefficient between layer mean temperature, 40-50 km, at Fort Churchill and K_p as a function of the lag of temperature.

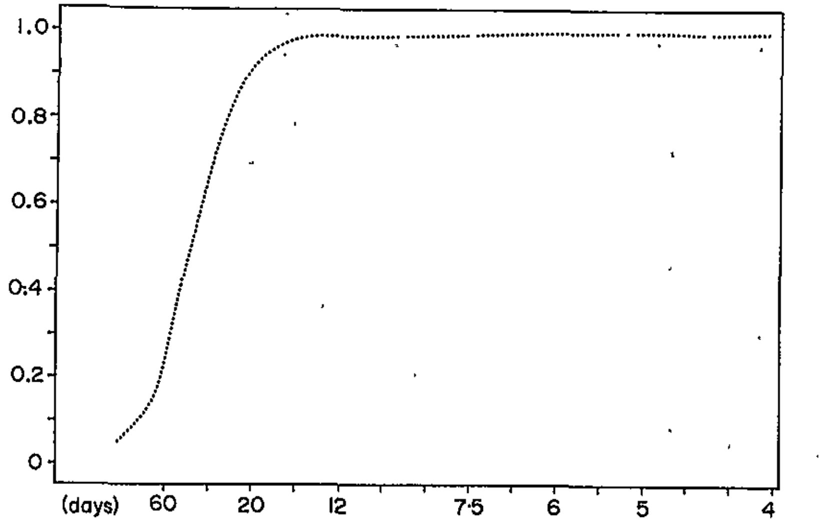


Figure A-1. Theoretical frequency response of the numerical filter described in the Appendix.

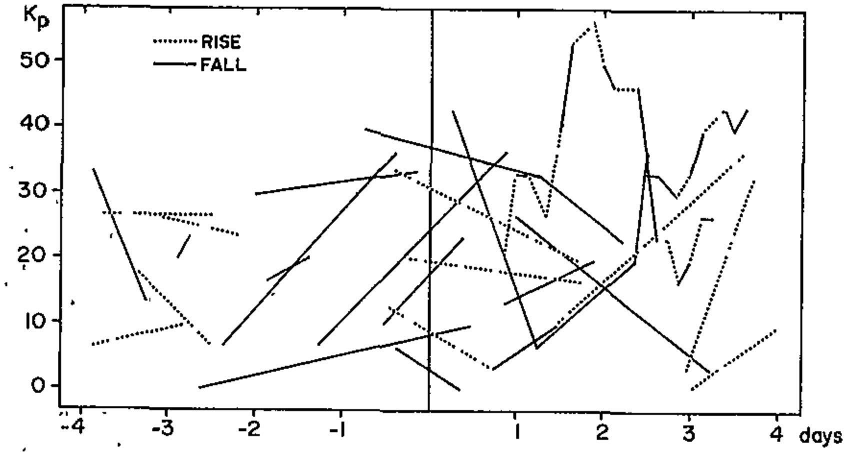


Figure 15. Trend of the temperature at 40 km at Fort Churchill between closely spaced ascents made near a solar sector boundary crossing. End points of each line segment are plotted at the time relative to boundary crossing and at the corresponding value of K_p.

Table 1. List of meteorological rocket stations.

STATION	LAT.*	LONG.*	LAT.*	LONG.	NUMBER OF OBS. AT 50 KM		NEAREST GEOMAGNETIC OBSERVATORY	SYMBOL
	(GEOGRAPHIC)		(GEOMAGNETIC)		(WIND)	(TEMP.)		
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*	.223	.280*	-.138
	48	.121	.485*	.014	.247*	-.070
	56	.145	.363*	-.127	.161	.071
U-H	30	-.188	-.354*	-.313*	-.218*	-.211
	48	-.277*	-.488*	-.350*	-.320*	-.265*
	56	-.338*	-.466*	-.343*	-.351*	-.222
T-Z	30	.230	-.280	.117	-.026	.293*
	48	.253	-.301	.089	-.181	-.143
	56	.118	-.309	-.164	-.246	-.303*
U-Z	30	-.020	.286	.064	-.110	-.282*
	48	-.026	.284	.047	-.103	-.490*
	56	.010	.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.

T-H	30	-.114	.174	.111	.099	-.227
	48	-.195	.136	.034	.165	-.044
	56	-.024	.006	-.090	.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	-.189
	48	.083	.086	.020	-.063	-.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	106	105	67
10.7 cm FLUX	104	84	80	72	76	103	143	149	151	156	113
SEMIANNUAL AMPLITUDES											
SITKA (H)	4.7	4.3	4.0	3.2	2.3	4.1	2.7	3.7	6.9	5.5	4.1
FREDRICKSBURG (H)	2.9	3.9	5.0	4.1	1.6	4.5	2.8	1.9	6.9	5.5	3.4
TUCSON (H)	3.3	3.1	4.4	4.0	2.3	4.5	4.8	2.6	6.1	4.5	2.6
GREELY (U - 48KM)					9.2	9.2	12.8	19.5	21.5	11.9	
WALLOPS (U - 48KM)	23.7		24.0		9.9	16.8	8.5	8.7	18.4	16.4	8.0
MUGU (U - 48KM)		16.4	14.8		10.0	4.4	11.5	13.5	20.0	17.4	10.5
WSMR (U - 48KM)	11.0	19.5	15.5	15.1	8.0	8.8	11.6	13.4	24.6	18.8	11.3
BARKING SANDS (U - 48KM)					19.3			23.9	26.5	25.0	23.5
ANNUAL AMPLITUDES											
GREELY (U - 48KM)					21.3	25.5	32.9	27.1	13.2	28.6	
WALLOPS (U - 48KM)	49.8		43.0		74.5	60.0	57.6	61.5	59.1	65.8	61.9
MUGU (U - 48KM)		53.9	46.0		63.6	60.4	49.1	51.8	46.8	55.6	53.4
WHITE SANDS (U - 48KM)	54.4	50.3	46.0	58.3	63.8	56.7	48.0	49.0	43.5	48.4	52.4
BARKING SANDS (U - 48KM)					42.4			36.1	37.6	27.9	38.2

(a)

```
SEASON= WINTER
POWER (M2/SEC2)                                          VAR   N P.R.E.

KM *
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
   * 110 435 500 316 203 207 243 264 206 139  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 *  90 197 226 176  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 13513-
   *   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)                                          VAR   N P.R.E.

KM *
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  14  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   4   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)                                          VAR   N P.R.E.

KM *
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)                                          VAR   N P.R.E.

KM *
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)                                     VAR   N  P.R.E.

KM *
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 * 303 634 527 340 296 328 282 157 119 161  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)                                     VAR   N  P.R.E.

   *
   *   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
   *  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  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
   *  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)                                     VAR   N  P.R.E.

KM *
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)                                     VAR   N  P.R.E.

   *
   *  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
   *  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  17    83 106  24 24
   *  53 115  96  62  48  36  22  22  29  22   9    77 108  24 24
   *  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
   *  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)                                     VAR   N  P.R.E.

KM *
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)                                     VAR   N  P.R.E.

   *
   *   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
   *  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
   *   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
   *   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)                                     VAR   N  P.R.E.

KM *
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)                                     VAR   N  P.R.E.

   *
   *  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
   *  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
   *  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
   *  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)                                         VAR   N  P.R.E.

KM *
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
   * 104 335 336 238 166 160 119  92 123 119  55   248  51  76 76
50 * 149 385 330 217 179 185 143 105 134 132  57   297  60  65 65
   * 170 381 317 223 199 204 156  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)                                         VAR   N  P.R.E.

KM *
60 *  21  15  59  80  85  87  71  53  47  46  24    70   4 144144
   *  18  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  29  43  45  40  30  27  25  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  26  28  23  11    25 117  21 21
   *   6   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   9  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)                                         VAR   N  P.R.E.

KM *
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)                                         VAR   N  P.R.E.

KM *
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)                                          VAR   N  P.R.E.

KM *
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)                                          VAR   N  P.R.E.

KM *
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  34  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   9  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)
                                                         VAR   N  P.R.E.
KM *
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)
                                                         VAR   N  P.R.E.
KM *
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)                                              VAR   N  P.R.E.

KM *
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
   * 127 399 465 353 252 246 233 139  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)                                              VAR   N  P.R.E.

KM *
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
   *  45  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
   *  4[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  44  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)                                              VAR   N  P.R.E.

KM *
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)                                              VAR   N  P.R.E.

KM *
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)                                  VAR   N  P.R.E.

KM *
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)                                  VAR   N  P.R.E.

   *
   *   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 18
   *   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)                                  VAR   N  P.R.E.

KM *
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  19  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)                                  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  56  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  45  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)                                  VAR   N  P.R.E.

KM *
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)                                  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)                                  VAR   N  P.R.E.

KM *
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)                                  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)                                         VAR   N P.R.E.

KM *
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)                                         VAR   N P.R.E.

KM *
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  48  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)                                         VAR   N P.R.E.

KM *
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)                                         VAR   N P.R.E.

KM *
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)                                           VAR   N  P.R.E.

KM *
60 *   30  79  92  84  77  64  56  73  72  62  33     95  13 122122
   *   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)                                           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)                                           VAR   N  P.R.E.

KM *
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)                                           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)                                           VAR   N  P.R.E.

KM *
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)                                           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)                                           VAR   N  P.R.E.

KM *
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)                                           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.