Spectrum of Long-Period Fluctuations of Surface Wind at Marcus Island

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ABSTRACT

Spectra of the surface wind at Marcus Island (24°N, 154°E) in the subtropical Pacific area were constructed over a wide frequency range from 10^{-8} to 5×10^{-5} Hz (periods from 6 h to about three years). The major kinetic energy peak is found at a period of about 6 days. Besides this peak, for the lower frequency range the significant peak is found at a period of 14–22 days. The latter peak is not found in the spectra at other places in the middle latitudes reported before and is significant in the warm season. This means that equatorial planetary-scale waves exert influence on the surface wind at this island. The diurnal and semidiurnal peaks are small but clearly found. The daily variation of the surface wind may be due to the diurnal and semidiurnal tidal waves of atmospheric pressure. Small peaks are found in some cases at or near the inertial period. Rotary spectra are calculated and also shown.

1. Introduction

Since the work of Van der Hoven (1957), many studies of the spectrum of long-period wind fluctuations near the surface have been published. Ishizaki *et al.* (1968) attempted the same analysis as that by Van der Hoven for the surface wind at Shionomisaki (Japan). Oort and Taylor (1969) made a spectrum analysis of the surface wind at six stations in the northeastern United States. These results show the characteristics of the spectrum of the surface wind at the middle latitudes. Hwang (1970) made a spectrum analysis of the surface wind at Palmyra Island in the tropical Pacific area. Byshev and Ivanov (1969) analyzed the spectrum of the surface wind at the north and south Atlantic. They suggest that the nature of the spectrum varies with latitude.

In the present work, the author has constructed spectra of the surface wind at Marcus Island (24°18′N, 153°58′E) over a frequency range from 10^{-8} to 5×10^{-5} Hz (periods from 6 h to about three years). Marcus Island (Minamitori-Shima in Japanese) is of coral and the surface is flat. The coastline forms an approximate equilateral triangle ~2 km on a side. As a result it is considered that the surface wind at this island is not seriously affected by topography. The purpose of this study is to investigate spectral characteristics of surface wind fluctuations at the subtropical Pacific area and to compare the results with those at other sites.

2. Data and analysis

The surface wind data used in this study were obtained at the Minamitori-Shima Meteorological Observatory which is affiliated with the Japan Meteorological Agency (JMA). The elevation of this site is 8 m above mean sea level. The routine wind observations were taken at 3 h intervals with each value representing a 10 min average at 13 m above the ground. The wind sensor has been changed from the three-cup type anemometer to the aerovane type one in 1976, but the wind observations and the maintenance of instruments have been performed according to Japan Meteorological Agency standard regulations. The wind data compiled on magnetic tapes by JMA became recently available and were used in this study. Time series of wind speed and direction were transformed to the east-west (u) and north-south (v) components.

The method of spectrum analysis used here was derived from Blackman and Tukey (1958). To obtain a spectral estimate over a wide range of frequencies, different portions of the spectrum were estimated separately by using different averages and pieced together afterward (Griffith *et al.*, 1956). The reason why we employ this procedure is that if we choose the large maximum number of lags to get high resolution at low frequencies, we get more resolution at high frequencies than would actually be needed and the statistical confidence of each spectral density estimate decreases.

In addition to the spectra for the u and v components, the rotary spectra were also calculated in the present study. Rotary spectrum analysis (Gonella, 1972; Mooers, 1973; O'Brien and Pillsbury, 1974) is a relatively new technique which has come to be used in meteorology.

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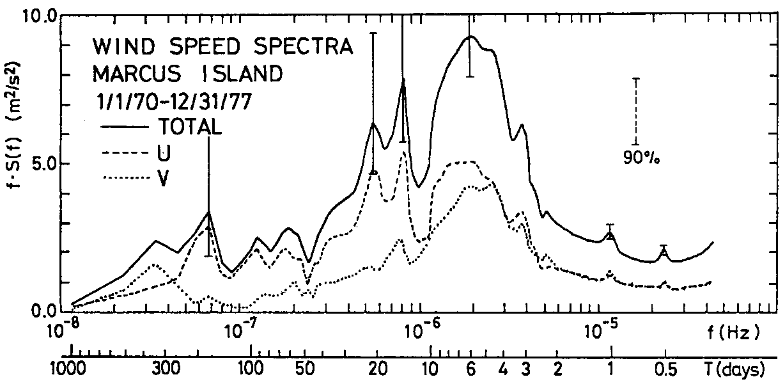

FIG. 1. Composite spectra for the surface wind at Marcus Island.

3. Spectra of the surface wind at Marcus Island

A preliminary analysis of the spectrum of the scalar wind speed at this island has been made by Mori (1977). Further analysis was made for the u and v components.

The spectrum analysis was made by using eight years of the data (from 1 January 1970 to 31 December 1977). Spectra were estimated by using 3 h, 1-day, 4-day and 16-day averages and then these spectra were pieced together. The composite spectra for the u and v components are shown in Fig. 1. The total spectrum is the sum of the u and v spectra and is also shown in this figure. The abscissa is frequency on a logarithmic scale with units in hertz. Spectral density multiplied by frequency ($m^2 s^{-2}$) is depicted along the ordinate. In this paper all spectra were plotted on the same coordinate as above. The 90% confidence limit, which is different for each subsection, is indicated in the figure at the peak. The total spectrum shows the two major energy peaks at periods of about 6 days and 14–22 days. The latter peak consists of the two peaks at periods of 14 days and 22 days. These two peaks are found in the u spectrum, but the peak at a period of 22 days is not found in the v spectrum. However, the separation of these two peaks does not approach the 90% confidence level.

For the longer period range, the total spectrum shows the peaks at periods of two, three and six months and one year. The annual peak is found only in the v spectrum and other peaks are found mainly in the u spectrum. However, except for the annual peak in the v spectrum and the semiannual peak in the u spectrum, other peaks in these spectra do not approach the 90% confidence level.

The spectral density for the u component agrees with that for the v component at periods less than 5 days, but is larger at the longer periods except for a period of one year.

The rotary spectra corresponding to Fig. 1 are shown in Fig. 2. The spectral density for the clockwise component is larger than that for the counterclockwise component at periods of ½–40 days. The difference in magnitude is large at periods of 2–8 days. This means that wind fluctuations in this range of periods show clockwise rotation caused by the cyclones and anticyclones passing north of this island as shown in Fig. 3. The semiannual fluctuations show clockwise rotation and annual fluctuations show counterclockwise rotation, but the reason for this can not be explained.

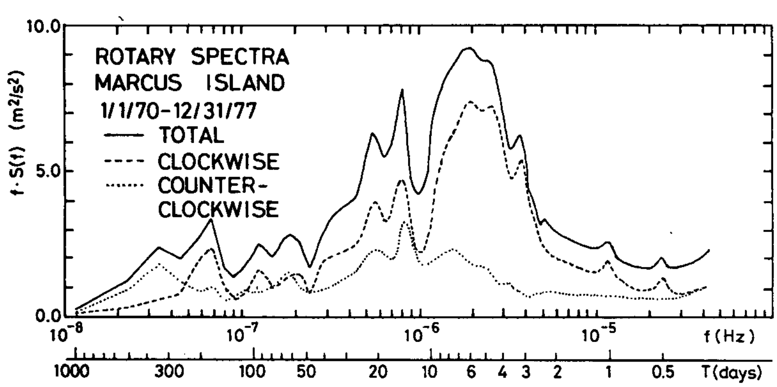

FIG. 2. Composite rotary spectra for the surface wind at Marcus Island.

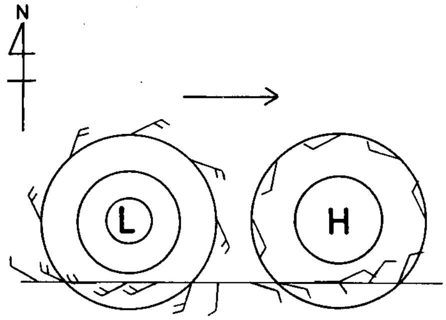

FIG. 3. Schematic pressure patterns and the associated wind field.

The diurnal and semidiurnal peaks in the total spectrum (Fig. 1) are small but statistically significant at the 90% confidence level. These fluctuations show clockwise rotation. The 8-year mean u and v components as a function of the local time (JST) are calculated and the mean daily wind vector variation is shown in Fig. 4. The observation site at Marcus Island is shown in this figure. The directions of the additional wind vectors during daytime and nighttime are opposite to what would be expected if land and sea breezes occur at this site. The characteristics of the daily wind variation seem to relate not to the thermal effect of the island body, but to the diurnal and semidiurnal tidal waves of atmospheric pressure (Roll, 1965).

In order to investigate the seasonal change of spectra, we calculated the spectra for different times of a year using 420 days of data (from 1 December 1975 to 23 January 1977). The reason for selecting this period was that the broad 1-day peak was found in the spectrum for the year 1976 (not shown), and that it was of interest to investigate whether the peak at the inertial period (1.2 days for this latitude) was included in that broad peak. We calculated the spectrum for the first 90 days and then shifted to 30 days and again calculated the spectrum and so on. For all spectral estimates, the averaging time was 3 h, the sampling duration 90 days and the maximum number of lags 128. The 12 total and rotary spectra are shown in Fig. 5. The total spectra show that in the cold season the major kinetic energy peak occurs at a period of 4–6 days, but in the warm season no significant peaks are seen at this period. In the warm season the main factor contributing to the kinetic energy is wind fluctuations at periods > 6 days.

The spectral density for the counterclockwise component is small and changes little with the season. On the other hand, the spectral density for the clockwise component changes with season and is large in the cold season with the peak at a period of 4–6 days. This means that the cyclones and anticyclones which pass far north of this island exert strong influence on the surface wind of this island in the cold season.

The diurnal peaks are found in both the cold and warm seasons in the total spectra. The diurnal and semidiurnal peaks are found only in the rotary spectrum for the clockwise component. Small peaks are found at or near the inertial frequency in the winter season (November–April) of 1976. These peaks are found only in the rotary spectrum for the clockwise component as expected (e.g., Haltiner and Martin, 1957). The statistical significance of these peaks is low, but in December when no significant diurnal peak exists the inertial peak approaches the 90% confidence level as shown in Fig. 5. This means that the wind fluctuations with the inertial period occur under some conditions at this site. Halpern (1974) showed a small peak in the kinetic energy spectra at the inertial period for the summertime wind off the Oregon coast. It is of interest to note that no peak is found at the inertial period for the summertime wind at Marcus Island. Burt *et al.* (1974) also showed a small peak at slightly subinertial frequency in the rotary spectrum for the clockwise component for the surface wind at the North Atlantic Ocean. For the spectral range at periods < ½ day, significant peaks are found at a period of 8 h in the total spectra during the period from August to October at the 90% confidence level. The wind fluctuations at the 8 h period are found mainly for the u component (not shown) and show counterclockwise rotation. It is of interest that these peaks are in the so-called spectral gap. However,

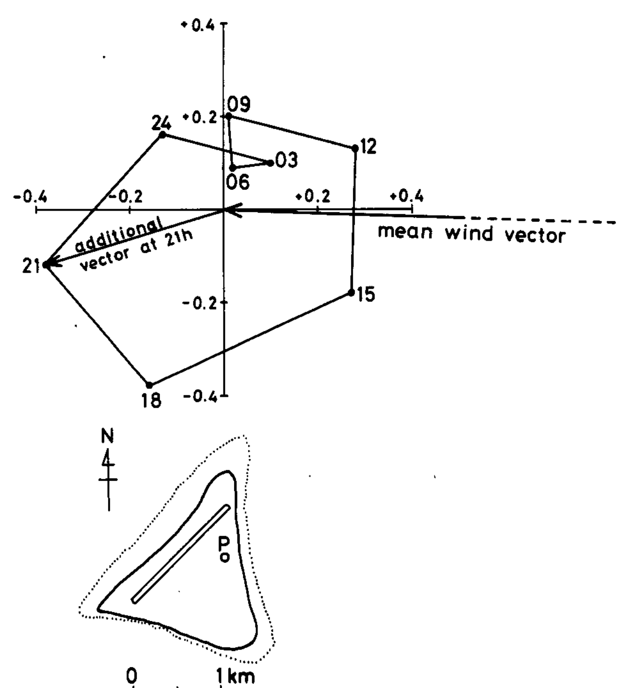

FIG. 4. Daily variation of mean wind vectors at Marcus Island. The diagram of additional wind vectors is shown. Mean wind vector: 93°, 2.9 m s^{-1}. Numbers denote hours in local time (JST). The observation site (P) is shown in the figure.

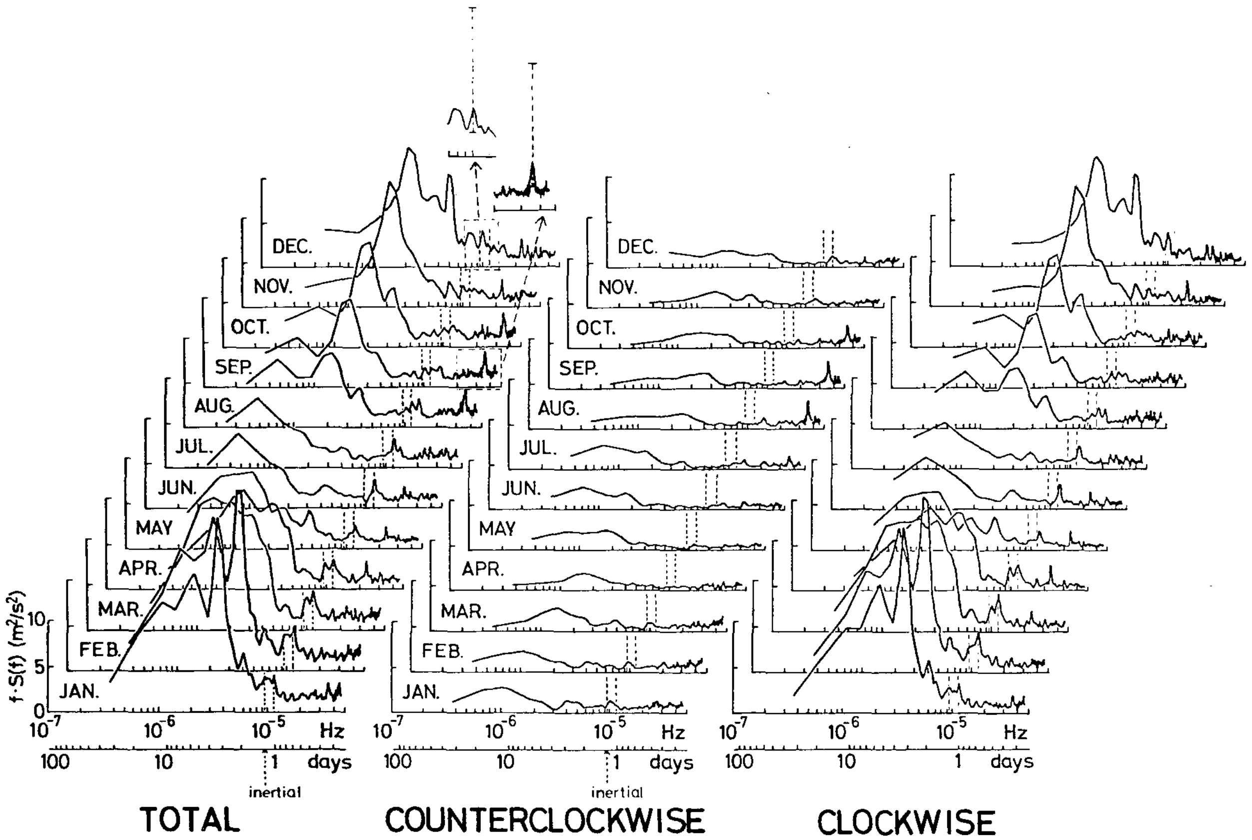

FIG. 5. Total and rotary spectra for the surface wind at Marcus Island estimated for each time of the year of 1976. The month labelled in the figure means the center of the sampling duration of 90 days. The 90% confidence limits are indicated at two peaks in the total spectra.

further investigations are required to clarify to what phenomena these peaks relate.

It is of interest to compare the present results with the spectra at other sites. The results obtained by Van der Hoven (1957), Oort and Taylor (1969), Ishizaki *et al.* (1968), Mori (1975) and Hwang (1970) are redrafted and shown in Fig. 6. Except for the result by Mori (1975), other spectra were mentioned in the first section. Mori (1975) made a spectrum analysis of the surface wind at Shionomisaki using the data of the period longer than those used by Ishizaki *et al.* (1968). The 90% confidence limit is indicated in the figure at the peak.

The peak at a period of about 4–6 days is found in all the spectra. However, the energy peak at a period of 4–6 days in the equatorial region is caused by the easterly waves and other waves. It is interesting to note that the peak at a period of 14–22 days in the spectrum at Marcus Island is not found in the mid-latitude spectra. In Hwang's analysis the spectrum at periods beyond 10 days was not investigated, but spectral studies of tropospheric wave disturbances at this period in the western Pacific have been performed and a detailed review has been presented by Wallace (1971). Yanai and Murakami (1970a,b) have found a 10–15 day period wave and a 15–25 day period wave in the tropical troposphere. The peak at a period of 14–22 days at Marcus Island is found in the warm season as shown in Fig. 5. It is considered that this means upper wind fluctuations at periods beyond 10 days at the equatorial Pacific area exert influence on the surface wind at Marcus Island in the warm season.

The diurnal peak is clearly found in the spectra at Caribou in Maine and Shionomisaki, but not in the spectrum at Brookhaven. Ishizaki *et al.* (1968) and Oort and Taylor (1969) suggested that this was mainly due to the difference in elevation above ground level at which the observations were taken. The significant diurnal peak is not found in the spectra at Marcus Island and Palmyra Island. The winds at these islands show the characteristics of the surface wind over the ocean.

4. Conclusions

Spectra of the surface wind at Marcus Island in the subtropical Pacific area were constructed over a wide frequency range from 10^{-8} to 5×10^{-5} Hz (periods from 6 h to about three years). The

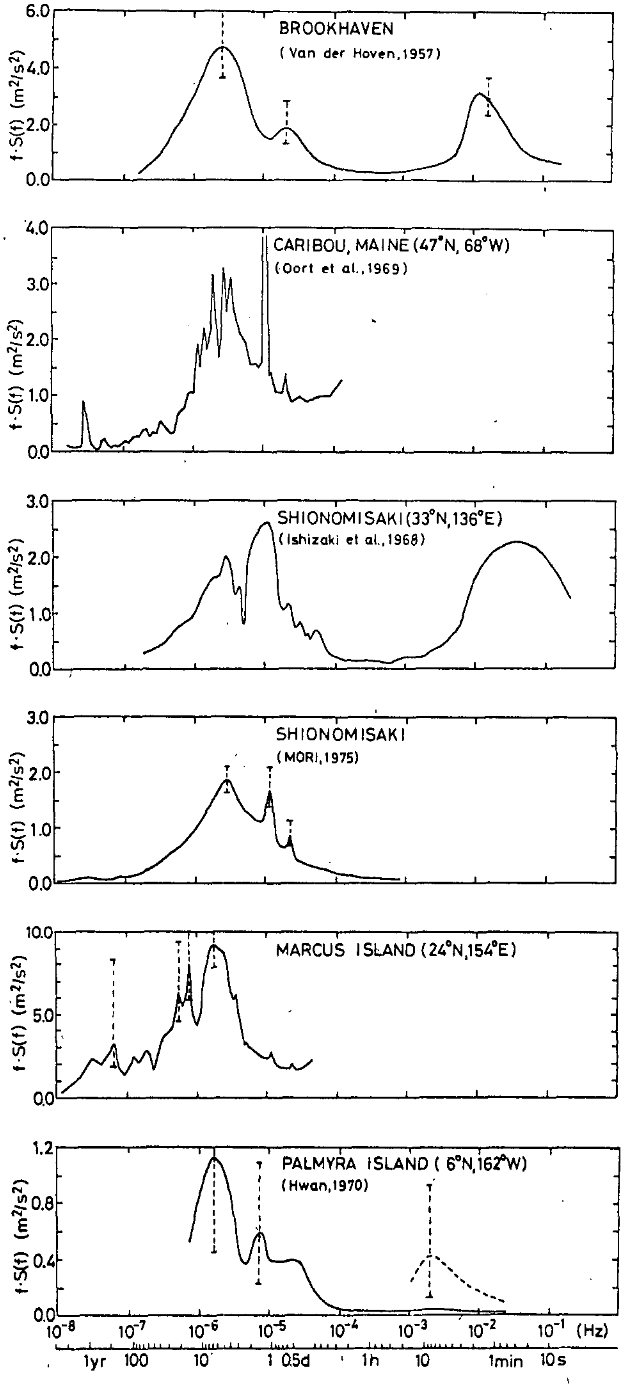

FIG. 6. Comparison of the spectra of the surface wind at sites of various latitudes. The 90% confidence limit is indicated in the figure at the peak.

major kinetic energy peak is found at a period of about 6 days. In addition to this peak, for the lower frequency range the significant peak is found at a period of 14–22 days. This peak is not found in the spectra at the middle latitudes reported before. This means that equatorial planetary-scale waves exert influence on the surface wind at this isla[illegible] warm season.

The magnitude of the spectral density for t[illegible] component agrees with that for the v compone[illegible] at periods $\leqslant$ 5 days, but is larger at longer periods, except for a period of one year. The rotary spectra show that the spectral density for the clockwise component is larger than that for the counterclockwise component at periods of 2–70 days.

Both the diurnal and semidiurnal peaks are small but clearly found in the total spectrum and are significant in the rotary spectrum for the clockwise component. The daily variation of the surface wind may be due to the diurnal and semidiurnal tidal waves of atmospheric pressure. Though the statistical significance is marginal, kinetic energy peaks at or near the inertial period are found in some cases. These peaks are significant in the rotary spectrum for the clockwise component. This may mean that the wind fluctuations with the inertial period occur under some conditions at this site.

For the longer period range, kinetic energy peaks occur at a period of six months for the u component and at a period of one year for the v component.

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