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POWER DENSITY SPECTRUM OF SURFACE WIND SPEED ON PALMYRA ISLAND

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ABSTRACT

Power spectra covering a frequency range of 0.002 to 100 cycles/hr of scalar surface-wind speed at Palmyra Island during the period of the Line Island Experiment of 1967 are presented. The distribution of eddy kinetic energy in the medium- and high-frequency range is similar to that at the middle latitudes. In general, the spectrum followed the minus five-thirds power law.

1. INTRODUCTION

The analysis of spectra of time series have found many applications in meteorology. Notable among these is the work of Van der Hoven (1957), who found that near the earth's surface a) the most important factor which influences the fluctuation in wind speed is the synoptic scale pressure systems; b) another significant contribution of eddy energy to the total spectrum comes from micrometeorological turbulence; and c) there is little eddy kinetic energy in the mesoscale range. His findings were based on analysis of power spectra of horizontal wind speed recorded at 91- to 125-m levels with aerovane speed recorders at Brookhaven, N.Y., over a large frequency range (0.007 to 900 cycles/hr). In the present work, the author has constructed the power spectra of surface wind speed with a frequency range of 0.002 to 200 cycles/hr at Palmyra Island in order to evaluate the contributions of the various scale disturbances to the total spectrum in the tropical Pacific area. These data were obtained as a part of the Line Islands Experiment (LIE), one of the field programs of the Tropical Meteorology Experiment (TROMEX), which was conducted during March and April 1967. A series of observations, which included continuous surface wind direction and speed, were taken on Palmyra (5.8° N., 162.2° W.), Fanning (3.9° N., 159.3° W.), and Christmas (1.9° N., 157.3° W.) Islands.

2. DATA

The surface wind-speed data used in this study were obtained by two different types of instruments. One was a modified AN/GMQ–12 anemometer of the three-cup generator type. Wind speed and direction were recorded on an analog record sheet at a chart speed of 12 in. hr^{-1}. The second type of instrument was a MRI 1072 anemometer of the three-cup counter type, which recorded wind direction and accumulated run-of-wind.

The data that were obtained by MRI anemometers were read out for every 1 hr run-of-wind and converted to mean hourly wind speed at the University of Hawaii. The analog wind-speed record from the AN/GMQ–12 anemometer was digitized to obtain an average wind speed for time intervals of 4 sec, 20 sec, and 1 min (table 1).

The MRI and AN/GMQ–12 anemometers were exposed at 6 and 40 ft above the ground, respectively, at the causeway site of Palmyra Island (fig. 1). The site was established in the center of the causeway, which is oriented almost north-south. Vegetation was removed for a distance of 200 ft centered at the site to minimize any effect on north-south direction. As a result, this site afforded unrestricted off-lagoon exposure for all winds except due north or due south. The site was adjacent to the deep water portion of the east lagoon, with no upstream restrictions for about three-quarters of a mile. Ground elevation was 6 ft above mean sea level.

In order to establish any possible island effects, a data sample from another site was used for comparison. Those data were obtained by MRI anemometer from 1200 LST on March 16 through 1400 LST on Apr. 19, 1967, at Barren Island site (fig. 1) at 6 ft above ground. This site was established to approximate an open-ocean exposure as closely as possible. Shrubbery was negligible near the site and exposure was unrestricted except for north winds. The elevation was 6 ft above mean sea level. (See Zipser and Taylor 1968 for further details.)

TABLE 1.—*List of data*

Observing site	Anemometer	Height	Periods covered	Time interval	Remark
Causeway	MRI	6 ft	1500 LST, 3/14/67 to 1200 LST, 5/1/67	1 hr	
	GMQ	40 ft	1105 LST, 4/10/67 to 1600 LST, 4/18/67	1 min	
	GMQ–12	40 ft	1105 LST, 4/10/67 to 1600 LST, 4/18/67	1 min	
	GMQ–12	40 ft	0000 LST, 4/10/67 to 2400 LST, 4/10/67	20 sec	
	GMQ–12	40 ft	0730 LST, 4/17/67 to 0830 LST, 4/17/67	4 sec	Clear sky
	GMQ–12	40 ft	1400 LST, 4/9/67 to 1430 LST, 4/9/67	4 sec	ITCZ passage
Barren Island	MRI	6 ft	1200 LST, 3/16/67 to 1400 LST, 4/19/67	1 hr	
Army site	MRI	6 ft	0200 LST, 3/1/67 to 0800 LST, 4/19/67	1 hr	

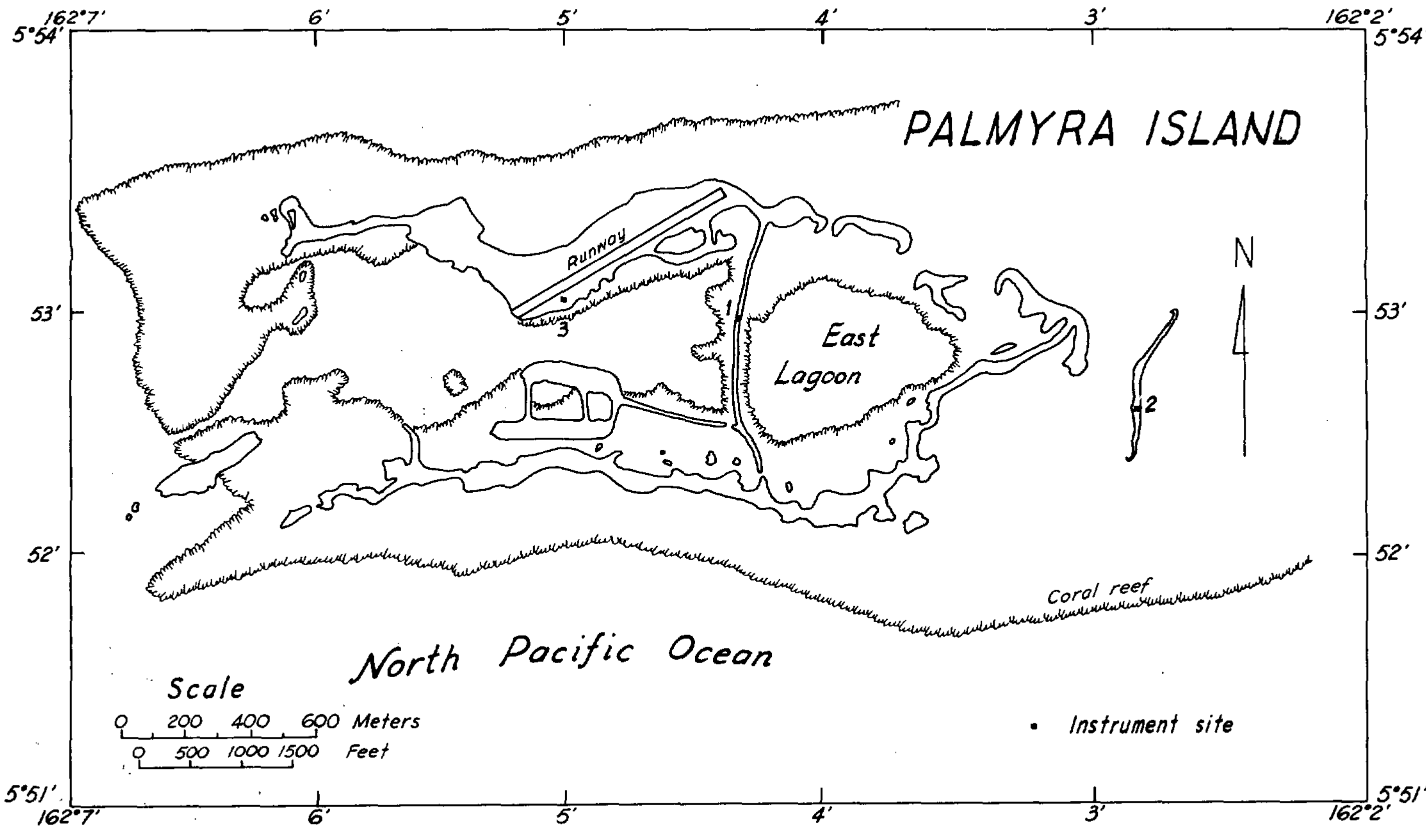

FIGURE 1.—Observation sites at Palmyra Island; 1) causeway site, 2) Barren Island site, 3) Army site.

3. ANALYSIS

The method of spectral analysis used here is derived from the covariance and Fourier transform of time series data. This method has been thoroughly discussed by Blackman and Tukey (1958), Muller (1966), and Griffith et al. (1956) for meteorological application and will not be described in this paper. For further information on spectral analysis, the reader is referred to articles by Panofsky and Brier (1958), Munk et al. (1959), Chiu (1967), and Brumbach (1968).

The data used to construct the wide frequency-range power density spectrum were taken by the MRI anemometer from 1500 LST on March 14 through 1200 LST on May 1, 1967 (for the frequency range 0.001–0.5 cycles/hr) and by the AN/GMQ–12 anemometer from 1105 LST on April 10 through 1600 LST on Apr. 18, 1967 (for the frequency range 0.042–225.2 cycles/hr).

Two special short-data samples, which were obtained by the AN/GMQ–12 anemometer at the causeway site, were used to study the effect of different weather conditions at the high-frequency range of the spectrum. The first sample was taken from 1400 LST through 1430 LST on Apr. 9, 1967. During the day of the ITCZ passage, cloud cover was 100 percent from 1000 LST through midnight; hourly rainfall at 1300, 1400, 1500, and 1600 LST was 5, 30, 51, and 20 mm, respectively. The other data sample was recorded from 0730 through 0830 LST on Apr. 17, 1967, by the AN/GMQ–12 anemometer at the same site under clear skies.

4. POWER SPECTRA OF SURFACE WIND SPEED

Figure 2 is a plot of the power density spectrum of wind speed at 6 ft above ground recorded by the MRI anemometer at the causeway site. Frequency is depicted along the abscissa on a logarithmic scale with units in cycles per hour. Power density multiplied by frequency in m^2/sec^2 is depicted along the ordinate.

In order to establish any possible island effects on the data obtained at the causeway site, two samples of data that were recorded at Barren Island and Army sites were analyzed in the same fashion and plotted on figure 2. The power spectra of the data from the causeway site and from the Barren Island site were in quite close agreement, while the power spectrum of the data from the Army site appeared to be greatly influenced by the site environment: namely, the energy in the low-frequency range was spread to the higher frequency range, and the thermal diurnal oscillation was strongly reflected. Thus, it seems reasonable to conclude that the data recorded at the causeway contained no significant site effects.

Wind-speed data recorded by the GMQ–12 anemometer at the causeway site 40 ft above ground were analyzed and plotted on figure 3 together with the spectrum from the MRI anemometer shown on figure 2. In figure 3 the major spectral peak at the low-frequency end of the spectrum occurs at a period of 96–144 hr (4–6 days), which is slightly longer than the period of the "easterly wave" model. Another small spectral peak was found with a period of 36 hr. Because this peak was statistically only marginally significant, its reality is questionable. However, it is interesting to note that a similar peak appeared in the Barren Island data (fig. 2). An analysis of a longer period of data confirming the reality of this peak might reveal the scale of certain types of activity or system which significantly influences the wind field at this area.

It is interesting to note that there was no significant peak appearing at either diurnal or semidiurnal periods in causeway data or in the Barren Island data. A sample of hourly surface-pressure data which were recorded at Palmyra during the same time period was analyzed and plotted (fig. 4). The analysis of these data showed significant diurnal and semidiurnal oscillations. A review of the observations of the height of sea level during the period of Feb. 19 through Mar. 16, 1967, at Palmyra (Wyrtki 1967) revealed that the average tidal period was about 12 hr and average sea-level variation was about 60 cm. Because the water channel between the east lagoon (windward side) and the open ocean is quite narrow, the lagoon water-level fluctuations might have a certain phase lag and the variation of water level might be as large as 60 cm. However a low, lagoon water level should affect the wind speed recorded by anemometer in two ways: 1) it would increase the height, relative to the water level of the anemometer, and tend to increase the wind speed; and 2) it would tend to increase the water surface temperature (shallower water layer being heated more by solar radiation), to increase the vertical momentum flux of the low-level air, and to decrease the wind speed. It is possible in this case that these two effects compensated each other, and the resultant effect on the wind-speed record was nearly negligible. Since the magnitude of the diurnal variation of wind speed caused by the pressure diurnal oscillation is quite small, a 2-mo period of data may be too short to detect any diurnal variation.

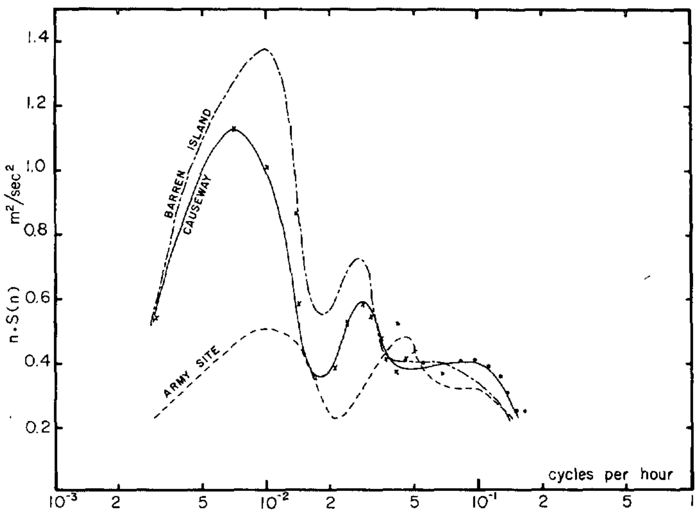

FIGURE 2.—Power spectra of surface wind speed recorded by MRI anemometer. The solid line is for causeway data, the dot-dashed line for Barren Island data, and the dashed line for Army site data.

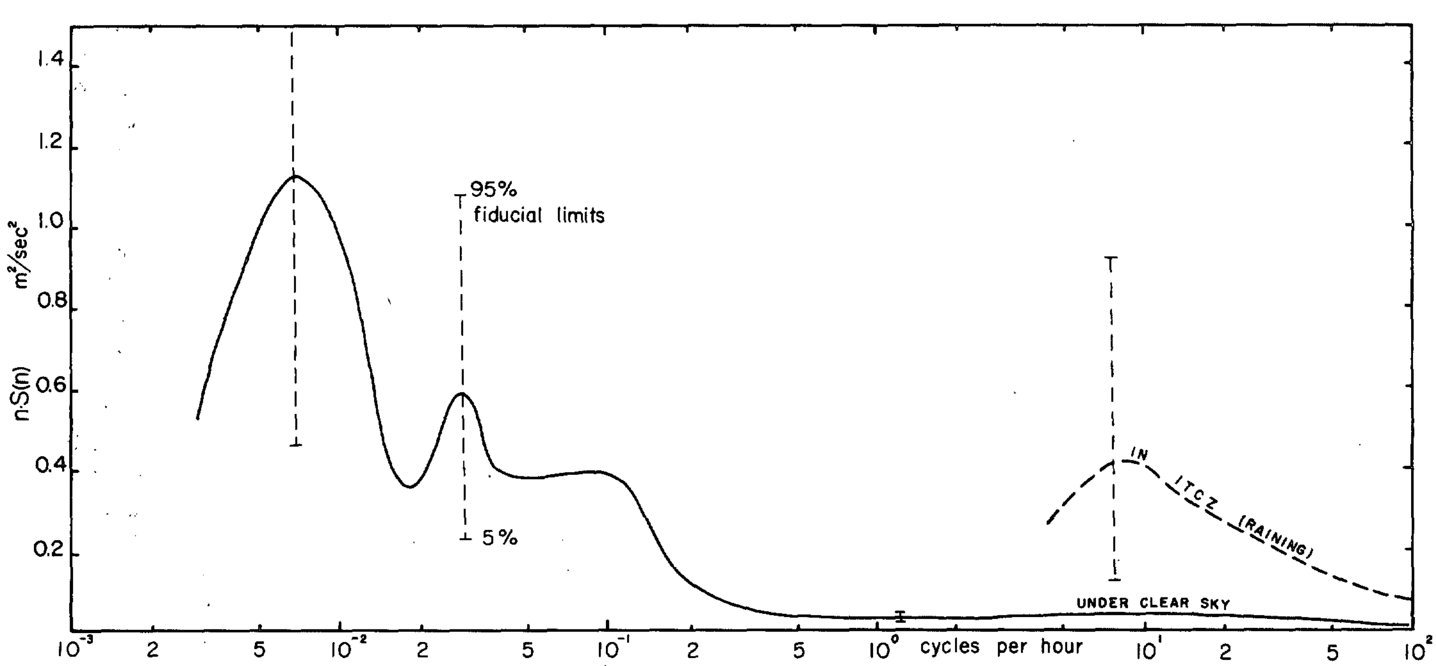

FIGURE 3.—Power spectra of surface wind speed at the causeway, Palmyra Island. The dashed line was based on data from a short period of precipitation during an ITCZ passage.

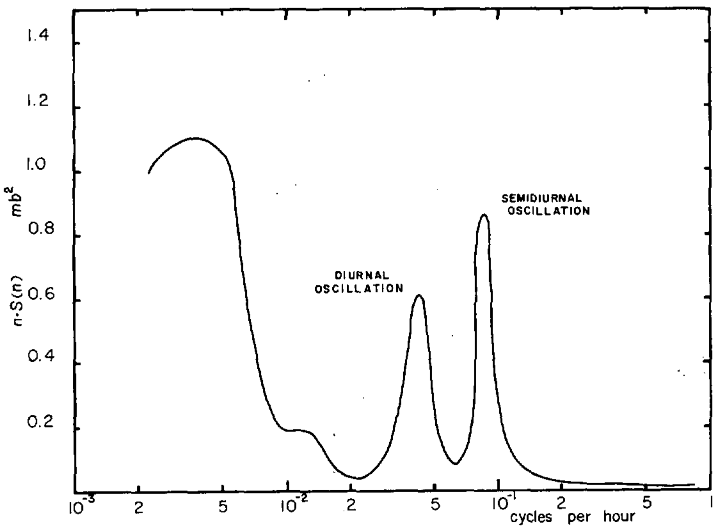

FIGURE 4.—Power spectrum of surface pressure at Palmyra Island.

The remainder of the spectrum of the wind speed was quite smooth, the spectral density decreased steadily from the low-frequency end to the high-frequency end.

A small sample of wind-speed data obtained during a period of precipitation at the passage of the ITCZ was analyzed. The result is indicated on figure 3 as a dashed curve. Similarly, the result of the analysis of another small sample of data obtained under an essentially clear-sky condition is indicated in figure 3 as a solid curve. A comparison of these curves shows that the ITCZ contained a large amount of eddy kinetic energy in the high-frequency range. In other words, its "eddy kinetic energy level" was higher. Because of the small data sample, more information concerning this ITCZ in the low-frequency range could not be deduced. Van der Hoven (1957) obtained a similar spectral peak in the high-frequency range in an analysis of a short period of wind data (60 min) taken in a hurricane.

The data of figure 3 have been replotted in figure 5 in which the ordinate is variance per frequency (m^2/sec^2) (cycles/hr)$^{-1}$ on a logarithmic scale. Two line segments (long-dashed lines labeled (1) and (2)) best fit the calculated data.

Almost all of the data followed the minus five-thirds power law, which states that eddy kinetic energy cascades from the lower frequency scale to the higher frequency scale. Line (2), of the data in an ITCZ, showed that it contained a significantly larger amount of eddy kinetic energy than that simply cascading from the lower frequency disturbance. This extra eddy kinetic energy was transformed by the system ITCZ from other types of energy (such as latent heat, etc.) and was injected into the turbulence. The eddy kinetic energy level of the turbulence rose by these energy injections until cascading took place again. For comparison, Van der Hoven's (1957) spectrum has been plotted in figure 5.

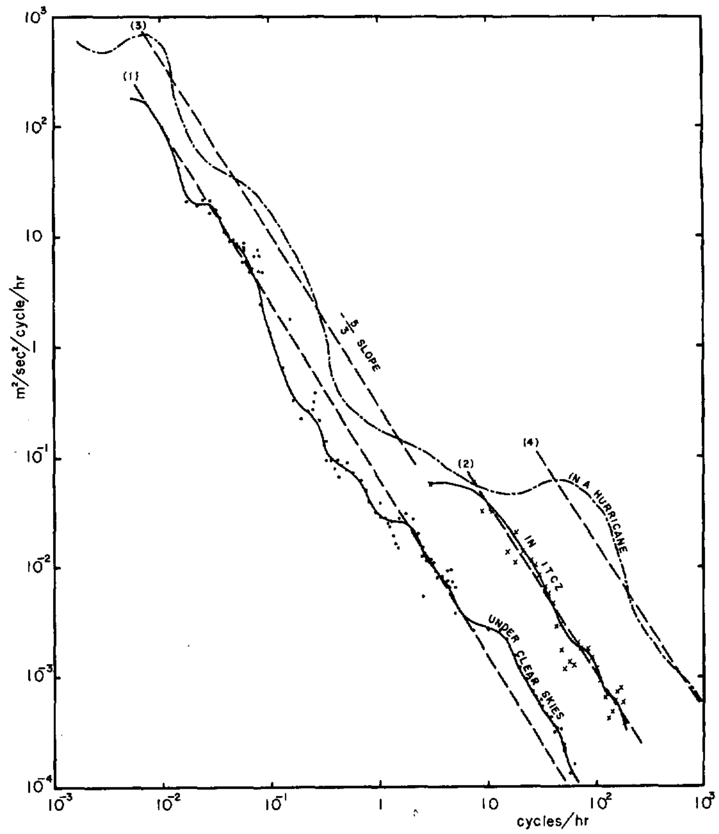

FIGURE 5.—Power spectrum of surface wind speed at the causeway, Palmyra Island (solid line), and Brookhaven, N.Y. (dot-dashed line). The ordinate is variance per frequency (m^2/sec^2) (cycles/hr)$^{-1}$, the abscissa is frequency (cycles/hr), and both are plotted on a logarithmic scale. Long dashed lines are slope lines.

Because of the limitation imposed by the length of the period of the data obtained in an ITCZ (30 min) or that used in Van der Hoven's study (1957) obtained during a hurricane (60 min), larger scale eddy kinetic energy transformations could not be detected. Neither of these sets of data revealed at which frequency range the extra energy was transferred to the eddy kinetic energy form, but only that both were on a higher eddy kinetic energy level. In order to resolve this question, data over a long period, including a period before the system (ITCZ, hurricane, etc.) approached until the influence of the system completely disappeared and the atmosphere returned to an undisturbed condition, are necessary.

The scale range and the amount of eddy kinetic energy that was transferred from another type of energy by various atmospheric systems were not studied in detail. Because of the limitations of the LIE data, the detail of the low-frequency portion of the spectrum (beyond about 10 days) could not be investigated. Most of the remaining problems are still being investigated.

5. SUMMARY AND CONCLUSIONS

During the Line Islands Experiment:

a) In general, the distribution of eddy kinetic energy in the medium- and high-frequency range in the Tropics was quite similar to that at the middle latitudes. For the low-frequency range, beyond about 10 days, it could not be investigated by those data.

b) Atmospheric turbulence followed the minus five-thirds power law. Large-scale eddy kinetic energy cascaded to small-scale eddy kinetic energy in accordance with the minus five-thirds power law.

c) Various atmospheric systems, such as a hurricane, the ITCZ, etc. might have transferred other types of energy into the eddy kinetic energy of a certain frequency range and injected it into the turbulence of the atmosphere.

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