Technical Memorandum EDS BOMAP-17

BOMEX WIND SPECTRA DERIVED FROM THE BOUNDARY LAYER INSTRUMENT PACKAGE (BLIP)

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Abstract. Spectral analysis of wind time-series data obtained with the Boundary Layer Instrument Package (BLIP) during the Barbados Oceanographic and Meteorological Experiment (BOMEX) in 1969 shows the spectra to be contaminated by ship and balloon motion only at the very high frequencies (0.11 to 0.07 Hz). Spectra for undisturbed weather show the existence of weak eddies with wavelengths centered near 300 m, while those for disturbed conditions indicate energetic two-dimensional eddies with wavelengths of up to several hundred meters.

1. INTRODUCTION

One of the objectives of the Barbados Oceanographic and Meteorological Experiment (BOMEX), held in the summer of 1969, was to gather information about the marine tropical planetary boundary layer. Since the experiment was to take place on the open sea, standard instrumentation and techniques could not be used. The need for specially designed instrumentation gave birth to the Boundary Layer Instrument Package (BLIP), which was developed for BOMEX by the University of Wisconsin.

The BLIP is a modified radiosonde that was launched by a tethered balloon during the first three BOMEX observation periods from the four corner ships in the array (fig. 1a), and from the *Oceanographer* and *Mt. Mitchell* during the fourth observation period (fig. 1b). It consists of a three-cup anemometer mounted on an A-frame that acts as a wind vane, with temperature, humidity, and pressure sensors contained in a package attached to the bottom of the frame. A detailed description of the instrumentation has been given by Almazan (1972).

The data obtained by the BLIP are likely to be contaminated by ship movement, balloon motion, and the interaction between the balloon and the tether line. The purpose of this study is to separate the effects of such motions from meteorological scales of motion using spectral analysis of BLIP data for both undisturbed and disturbed weather conditions.

2. WIND SPECTRA

Wind speed and direction, temperature, and wet-bulb temperature were sampled by the BLIP at a rate of three samples per second. From these raw data, 1-s averages were formed, edited, and archived on magnetic tape as described in NOAA Technical Report EDS 12, "BOMEX Permanent Archive: Description of Data" (CEDDA, 1975, pp. 118-175).

The spectra presented here were calculated using the fast Fourier transform technique (Cooley and Tukey, 1965) in a computer program written by D. T. Acheson of CEDDA. Missing data points were flagged and filled in by linear interpolation. The criteria used in selecting the data for spectral analysis were, for undisturbed conditions, to reject a flight if more than 3 percent of the data were missing, and, for disturbed conditions, do so if 10 percent of the data were missing.

The spectral values shown in figures 2 to 5 are bandwidth averaged for logarithmically spaced frequency bands. Thus, at the lower frequencies, the values contain too few estimates to be statistically significant, and at the very lowest, only one or two estimates. Since it was assumed for this analysis that the spectral values were not significant if they contained less than 10 estimates, the values in figures 2 and 3 were considered significant only for frequencies greater than 4.0×10^{-2} Hz and in figure 5 only for frequencies greater than 5.0×10^{-3} Hz. The composite spectra in figure 4 were considered significant throughout the entire range.

2.1 Undisturbed Conditions

No cloud clusters, waves, or depressions passed through the BOMEX array (fig. 1a) during the early part of Period III, June 22 to 26, 1969. Data from this undisturbed period provided an opportunity for studying the effects of balloon and ship motions.

2.1.1 Spectra of Wind Speed and Direction

Spectra of wind speed and direction were formed from a relatively small sample (2,048 points) of 1-sps data from a BLIP flight on June 22, 1969. For this flight, the instrument package was held at a nominal height of 300 m. The spectrum of wind speed shows a small peak at 0.11 Hz and that of wind direction a broad peak centered near 0.07 Hz (figs. 2a and b). These frequencies correspond to a period of 9 and 14 s, respectively, and are close to the normal periods of ship motion. As reported by Almazan (1972), fixed-tower tests with the BLIP show no peaks in the speed spectrum, but do show a peak for direction in the frequency range of 0.15 to 0.3 Hz that is ascribed to oscillations characteristic of the instrument package itself. Thus, although this instrument frequency peak may contribute to the high-frequency end of the broad spectral peak in wind direction shown in figure 2b, it is not the whole cause. Ship motion also plays a role.

Similar peaks in the spectrum of wind speed have been identified with ship roll and pitch by Berman (1974) using tethered-balloon data from the GATE (GARP Atlantic Tropical Experiment) International Sea Trials, and have been attributed by Thompson (1972) to ship motion and "noise" based on data from a completely different balloon system. According to Thompson, the influence of ship motion will be stronger the closer the balloon is tethered to the ship. Note that in figure 3a, showing wind speed during the BLIP ascent on the June 22 flight, the frequency peak is much larger than the same peak in figure 2a. This increase may be partly the result of the fact that the balloon is closer to the ship during ascent. In the case of the spectrum of wind direction, shown in figure 3b, the peak remains broad but tends to center at a higher frequency than at the 300-m level. Here, a relative increase in the oscillation of the instrument itself is implied in the greater variance of direction in the frequency range of 0.15 to 0.3 Hz. However, it seems fairly certain that the peak in the speed spectrum and part of the peak in the direction spectrum can be ascribed to ship pitch and roll.

Other ship motions may also exert an influence. The BOMEX ships were required to keep on station during each of the observation periods. To do so, they had to operate in alternating modes, consisting of 2 to 3 hr of drifting and 30 min of steaming. These motions could have two effects on the spectra derived from the BLIP. The relatively abrupt change from the drifting to the steaming mode could cause brief high-frequency oscillations of the balloon, and the 30 min of steaming, separated by longer periods of drifting, could induce low-frequency noise in the spectra.

Spectra of wind speed and direction (not shown here) were calculated for a BLIP flight lasting a little over 4.5 hr. This flight contained two 30-min periods of steaming, one near the beginning and the other near the end of the sounding. Based on ship navigation logs, the steaming speed was approximately 1 m/s and the mean wind speed as measured by the BLIP was about 11 m/s. A second set of spectra was then calculated for the same time series corrected for ship motion. Virtually no difference between the spectra was found, which leads to the tentative conclusion that the steaming mode has no significant effect on the spectra of wind speed for time periods ranging from several seconds to a few hours. The conclusion is tentative because the drifting and steaming velocities are only approximate (N. Delver, personal communication), and corrections for ship motion were applied to the BOMEX ship operations data only for days on which the ship speed is a small fraction of the measured mean wind speed (NOAA Technical Report EDS 12, "BOMEX Permanent Archive: Description of Data," CEDDA, 1975, pp. 17-23). It is possible that for larger ratios of ship to mean wind speed the ship maneuvers may influence the BLIP spectra.

2.1.2 Composite Spectra

Time series of wind speed and direction were transformed into time series of wind components parallel (U) and perpendicular (V) to the mean wind for eight BLIP flights launched from the Oceanographer during undisturbed conditions. Each sounding covered approximately 4.5 hr. The means and variances of U and the variances of V are listed in table 1. The mean of V is, by definition, zero. To cut down on computation time in the spectral analysis of these flights, 4-s averages were formed, which, in effect, low-pass filtered the data. The U and V spectra for these flights (not shown here) did not indicate any strong peaks except for those associated with ship pitch and roll. They did show some tendency toward weak, broad spectral

Table 1.--Means and variances of wind components for undisturbed conditions, Oceanographer

BOMEX Observation Period	BLIP flight No.	Beginning date and time (1969)	(GMT)	U component $\overline{U}$ (m/s)	σ_u^2 $(m/s)^2$	V Component σ_v^2 $(m/s)^2$
III	3	June 22	0507	11.01	0.55	1.45
"	6	June 23	0303	8.97	0.54	1.62
"	9	June 24	1526	5.58	0.85	0.80
"	10A	June 25	0234	7.09	0.77	0.85
"	10B	June 25	0708	7.21	0.54	0.69
"	11	June 25	1526	7.07	0.70	0.44
"	12	June 26	0244	6.63	0.95	0.79
"	15	June 27	0502	10.39	0.68	0.24

peaks at the lower frequencies, but it was difficult to judge whether these peaks were peculiar to a particular BLIP flight or an indication of some typical scale of motion in the undisturbed subcloud layer. For further investigation, raw spectral estimates, without bandwidth averaging, were obtained for U and V for each flight and combined into composite spectra. This was done by replacing the natural frequency associated with each spectral analysis estimate, f, by a nondimensional frequency, N, using the expression

$$N = \frac{fz}{u_i} ,$$

where z is the height of the BLIP (nominally 300 m), and u_i is the mean wind speed for each of i flights.

These estimates were then grouped into logarithmically spaced frequency bands, averaged, and plotted against nondimensional frequency. The resulting composite spectra for the U and V wind components are shown in figures 4a and b. The high-frequency spectral peaks in both U and V seen in these figures are the result of ship pitch and roll and correspond to the peaks in figures 2 and 3. The high spectral values at the lowest nondimensional frequencies indicate that, although the eight time series that went into the composite were randomly distributed with respect to time of day, some long-term trends were not averaged out. Both wind components also show broad spectral peaks centered around a nondimensional frequency of N = 1, corresponding to a period of approximately 40 s. The existence of these peaks implies that eddies between 250 and 450 m in size are present during undisturbed conditions, given an overall mean speed of 8 m/s. Similar low-magnitude broad spectral peaks in wind speed have been found by Echternacht and Garstang (1975) based on data gathered on the island of Barbados, and by Donelan and Miyake (1972), who used aircraft data collected at several heights ranging from 18 to 500 m. In a study of aircraft data obtained at heights ranging from 18 to 142 m, Grossman and Bean (1973) also found eddies with similar wavelengths in the BOMEX area. Pond et al. (1973), on the other hand, from measurements made at the 8-m level aboard the Navy Floating Laboratory Platform (FLIP), give evidence of much longer wavelengths.

2.2 Disturbed Conditions

Days on which disturbances passed the island of Barbados during BOMEX have been identified by Frank (1971) from satellite data. A total of 55 BLIP flights that occurred on such days during Periods II, III (fig. 1a) and IV (fig. 1b) were selected for this study. As noted earlier, the criterion used in the selection for undisturbed conditions was to reject a flight if more than 3 percent of the data were missing. Because more than 3 percent of the data were missing in a large number of flights during disturbed conditions, the time series chosen were shortened from 4.5 to 2.5 hr and flights with 10 percent of missing data were accepted. This selection process left 27 out of the 55 flights for spectral analysis. Missing data were filled in by linear interpolation, and spectra of wind speed and direction were formed. Averaging for composite spectra was not done for these flights. The means and variances of the two variables are listed in table 2, which shows no systematic variation of σ_s^2 with $\overline{s}$, but some tendency of σ_θ^2 to decrease with increasing mean wind speed.

The spectra of wind speed for 13 flights show sharp peaks in the frequency range of 3.977×10^{-3} to 1.031×10^{-2} Hz, clearly indicating disturbed conditions (table 3). The spectra for the remaining flights resembled those for undisturbed conditions. Since the method used in identifying disturbed days is not a precise one, however, it is entirely possible that these BLIP flights were actually made before or after a disturbance had passed the ship. Significant spectral peaks in wind direction, all at lower frequencies than the peaks in wind speed, are apparent in only 4 flights (table 3), and are therefore probably not indicative of any characteristic scales of motion associated with disturbed weather conditions.

3. SUMMARY REMARKS

The analysis presented here shows that the wind speed and direction measurements obtained with the BLIP during BOMEX are affected by ship motion at the very highest frequencies (0.11 to 0.07 Hz). These frequencies correspond to periods of 9 to 14 s, and are the only ones influenced by ship motion for periods ranging from 8 s to several hours. During undisturbed weather, there is evidence of weak atmospheric motion, with periods centered around 40 s. During disturbed conditions, the wind-speed spectra show strong peaks with periods ranging from about 40 to 200 s, suggesting the existence of rather energetic eddies with wavelengths of several hundred meters. Whether these eddies are associated with downdrafts resulting from enhanced convection as suggested by Garstang and Betts (1973), or with plumes or "bubbles" rising from the sea surface during disturbed weather is difficult to determine from the limited data used in this study.

Table 2.--BLIP flights during disturbed conditions

Ship	BOMEX Observation Period	BLIP flight No.	Beginning date and time (1969)	(GMT)	Speed		Direction	
					$\overline{S}$ (m/s)	σ_s^2 $(m/s)^2$	$\overline{\theta}$ (deg)	σ_θ^2 $(deg)^2$
Mt. Mitchell	II	06	June 2	0103	8.12	0.66	93.33	9.99
"	"	07	June 2	1432	9.18	0.49	87.41	10.50
"	"	08	June 2	2144	7.93	0.51	100.54	9.71
Oceanographer	"	22A	June 7	2144	7.73	0.31	66.38	21.09
"	"	22B	June 8	0406	6.76	0.24	57.39	59.08
"	"	23A	June 8	0843	7.09	0.21	65.29	26.94
"	"	23B	June 8	1531	6.29	0.27	64.44	30.36
Rainier	III	01	June 22	1430	9.68	0.64	95.06	12.10
Discoverer	"	03	June 28	0058	9.62	1.26	81.83	25.95
"	"	04	June 28	0657	10.09	1.64	115.92	-----
"	"	07	June 29	0745	10.20	0.65	87.77	38.89
Mt. Mitchell	"	25	July 2	0749	6.05	0.36	67.46	6.00
"	IV	04	July 13	1437	5.97	1.01	108.35	31.18
"	"	05	July 14	0020	4.19	0.87	143.91	34.50
"	"	06	July 15	0802	4.61	0.42	55.46	9.19
"	"	17	July 21	0742	8.07	0.34	75.71	17.50
"	"	18	July 21	1407	7.67	0.59	58.16	-----
"	"	25	July 26	1830	5.61	0.61	98.98	46.01
"	"	26	July 26	0021	6.95	0.67	94.24	18.24
Oceanographer	"	05	July 13	1829	3.21	1.67	96.05	58.90
"	"	06A	July 13	2243	2.74	0.65	40.33	-----
"	"	06B	July 14	0101	3.90	2.56	51.37	-----
"	"	14A	July 17	1057	4.30	0.16	192.58	78.84
"	"	14B	July 17	1541	3.97	0.29	192.50	83.73
"	"	16	July 17	2152	3.58	0.40	127.44	89.49
"	"	20	July 19	0943	4.04	0.86	244.85	24.95
"	"	30	July 22	0420	3.90	0.84	55.15	-----

Table 3.--Spectral peaks during disturbed conditions

Ship	BOMEX Observation Period	BLIP flight No.	Wind speed: Frequency (Hz)	Wind speed: Period (s)	Wind speed: Wavelength (m)	Wind direction: Frequency (Hz)	Wind direction: Period (s)	Wind direction: Wavelength (m)
Mt. Mitchell	II	08	1.661×10^{-2} to 2.675×10^{-2}	60 to 37	476 to 293	--	--	--
Oceanographer	"	22B	3.977×10^{-3} to 2.675×10^{-2}	251 to 37	1,697 to 250	--	--	--
"	"	23A	1.031×10^{-2} to 1.661×10^{-2}	97 to 60	687 to 524	--	--	--
"	"	23B	5.047×10^{-3} to 2.675×10^{-2}	198 to 37	1,245 to 233	--	--	--
Discoverer	III	07	2.675×10^{-2} to 3.395×10^{-2}	37 to 29	377 to 29	--	--	--
Mt. Mitchell	IV	06	8.128×10^{-3} to 1.661×10^{-2}	123 to 60	567 to 277	--	--	--
"	"	17	--	--	--	6.405×10^{-3} to 1.031×10^{-2}	156 to 97	1,259 to 784
"	"	25	--	--	--	8.128×10^{-3} to 1.661×10^{-2}	123 to 60	690 to 337
Oceanographer	"	06A	1.031×10^{-2} to 2.108×10^{-2}	96 to 47	263 to 129	--	--	--
"	"	06B	1.309×10^{-2} to 1.661×10^{-2}	76 to 60	297 to 234	-- --	-- --	-- --
"	"	14A	1.031×10^{-2} to 2.675×10^{-2}	96 to 37	417 to 160	2.469×10^{-3} to 3.977×10^{-3}	405 to 251	1,742 to 1,081
"	"	14B	8.128×10^{-3} to 2.108×10^{-2}	123 to 47	488 to 188	5.047×10^{-3}	198	787
"	"	16	1.031×10^{-2} to 1.661×10^{-2}	97 to 215	347	--	--	--
"	"	20	1.031×10^{-2} to 2.108×10^{-2}	97 to 47	392 to 192	1.946×10^{-3} to 5.047×10^{-3}	514 to 198	2,077 to 800
"	"	30	8.128×10^{-3} to 1.661×10^{-2}	123 to 60	480 to 234	--	--	--

The peaks in the wind-speed spectra give evidence of meteorological scales of motion characteristic of disturbed weather in the tropical subcloud layer, and the lack of energy in the spectra of wind direction indicate that the eddies typical of disturbed conditions are two-dimensional. The weaker peaks in the composite spectra for undisturbed conditions center at a nondimensional frequency near N = 1 for both the U and V component. From a mean wind speed of 8 m/s, a mean eddy size of about 300 m can be inferred. Thus, the eddies during undisturbed weather are, in general, not as large as the largest eddies during disturbed conditions. The V component is, in essence, equivalent to wind direction, and the peak in the spectrum of this component is equivalent to a peak in the spectrum of wind direction. The presence of such a peak for undisturbed but not for disturbed conditions bears out the difference in eddy structure in the two cases.

An analysis of temperature and humidity based on the BLIP data was also attempted, but the results were ambiguous. The total variance in both temperature and humidity, calculated from the dry- and wet-bulb temperatures, was very small, and therefore no meaningful spectra could be formed.

REFERENCES

Almazan, J.A., "The BOMEX Boundary Layer Instrument Package," Second Symposium on Meteorological Observations and Instrumentation, March 27-30, 1972, American Meteorological Society, Boston, Mass., 1972, pp. 138-144.

Berman, E.A., "Observations of Convective Scale Turbulence Over the Tropical Ocean," Ph.D. Thesis, University of Wisconsin, Madison, Wis., 1974, 92 pp.

CEDDA, "BOMEX Permanent Archive: Description of Data," NOAA Technical Report EDS 12, Center for Experiment Design and Data Analysis, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Washington, D.C., 1975, 327 pp.

Cooley, J.W., and J.W. Tukey, "An Algorithm for the Machine Calculation of Complex Fourier Series, Mathematics of Computation, Vol. 19, pp. 297-301.

Donelan, M., and Miyake, "Spectra and Fluxes in the Boundary Layer of the Trade-Wind Zone," Journal of the Atmospheric Sciences, Vol. 30, No. 3, 1973, pp. 444-464.

Echternacht, K.L., and M. Garstang, "Changes in the Structure of the Tropical Subcloud Layer From the Undisturbed to Disturbed States," Submitted to Monthly Weather Review, 1975.

Frank, N.L., "Atlantic Tropical Systems in 1969," Monthly Weather Review, Vol. 98, No. 4, 1970, pp. 307-314.

Garstang, M., and A.K. Betts, "A Review of the Tropical Boundary Layer and Cumulus Convection: Structure, Parameterization, and Modeling," Bulletin of the American Meteorological Society, Vol. 55, No. 10, 1974, pp. 1195-1205.

Grossman, R.L., and B.Q. Bean, "An Aircraft Investigation of Turbulence in the Lower Layers of the Marine Boundary Layer," NOAA Technical Report ERL 291-WMPO 4, Environmental Research Laboratories, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Boulder, Colo., 1973, 166 pp.

Pond, S., G.T. Phelps, T. E. Paquin, G. McBean, and R.W. Stewart, "Measurements of the Turbulent Fluxes of Momentum, Moisture, and Sensible Heat Over the Ocean," Journal of the Atmospheric Sciences, Vol. 28, No. 6, 1971, pp. 901-917.

Thompson, N., "Turbulence Measurements Over the Sea by a Tethered-Balloon Technique," Quarterly Journal of the Royal Meteorological Society, Vol. 98, pp. 745-762.

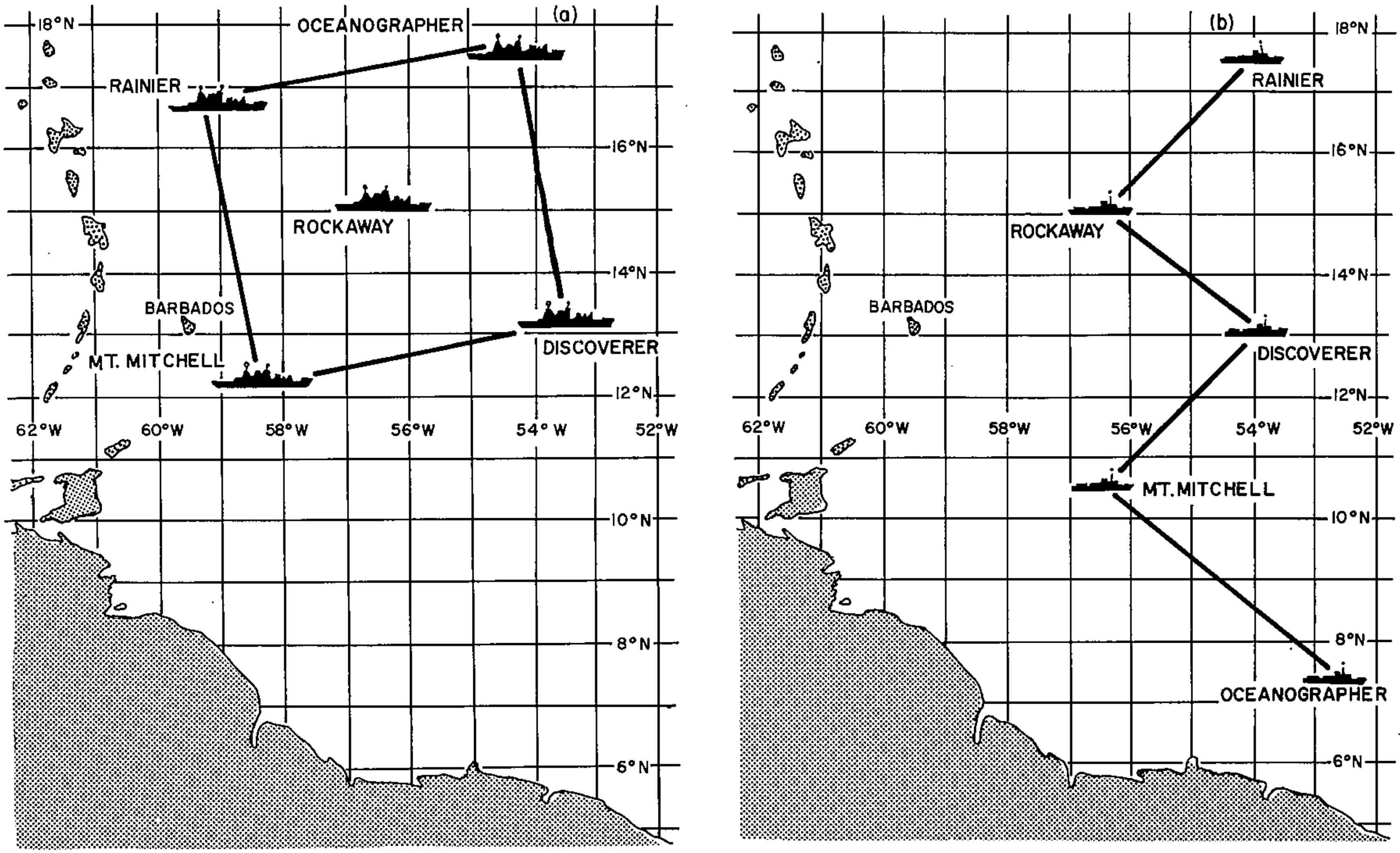
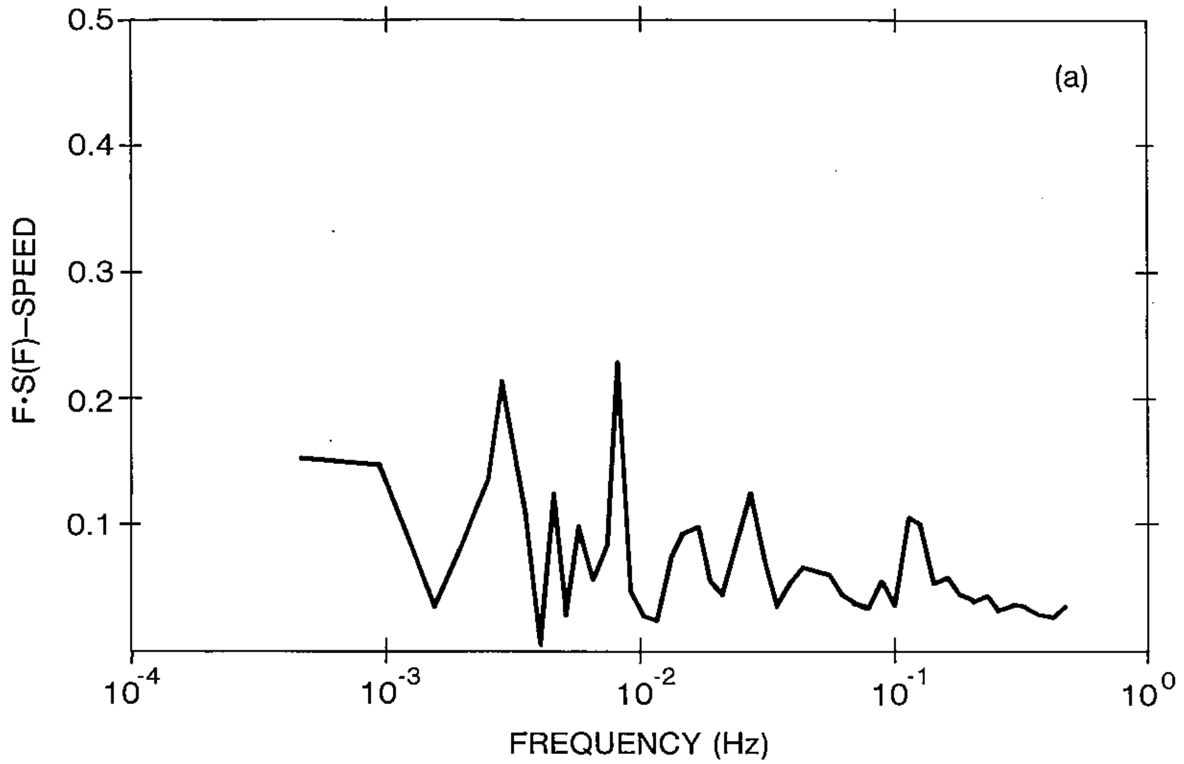


Figure 1.--BOMEX ship array: (a) Periods I, II, and III (May 3 to July 2, 1969); (b) Period IV (July 11 to 28, 1969).



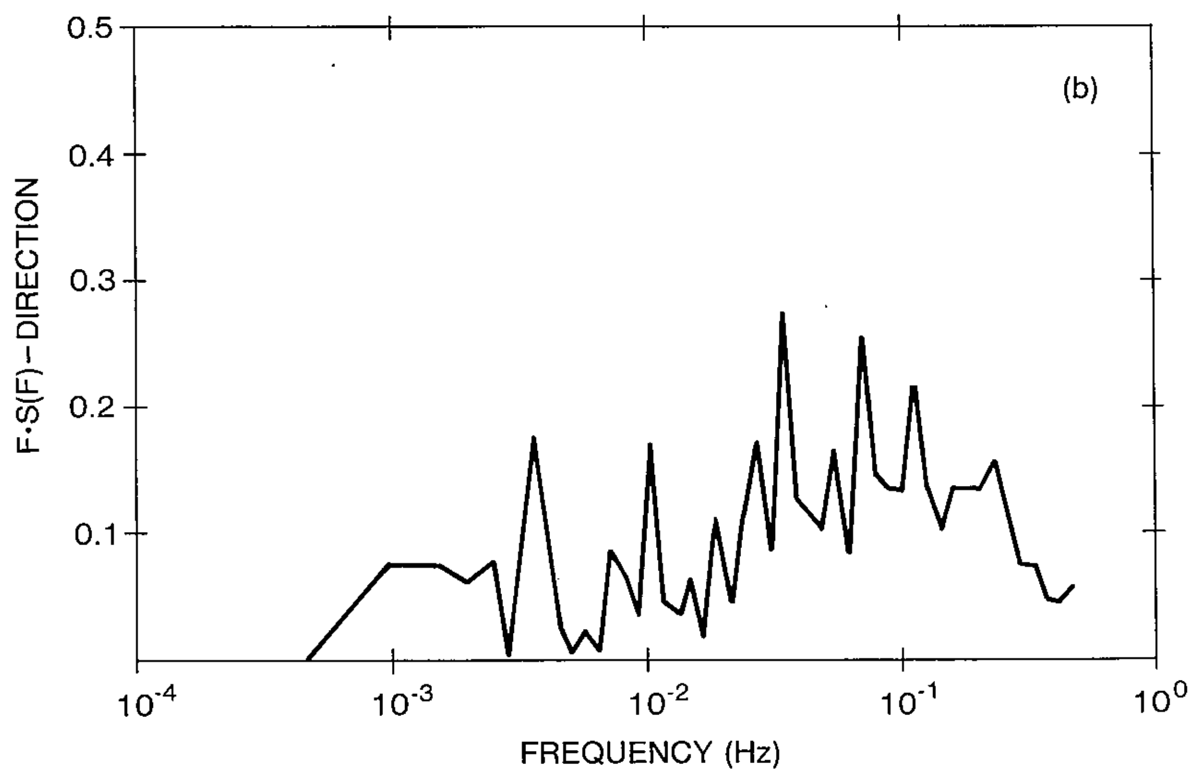


Figure 2.--Spectra for the Oceanographer, *0030 GMT, June 22, level flight: (a) wind speed; (b) wind direction.*

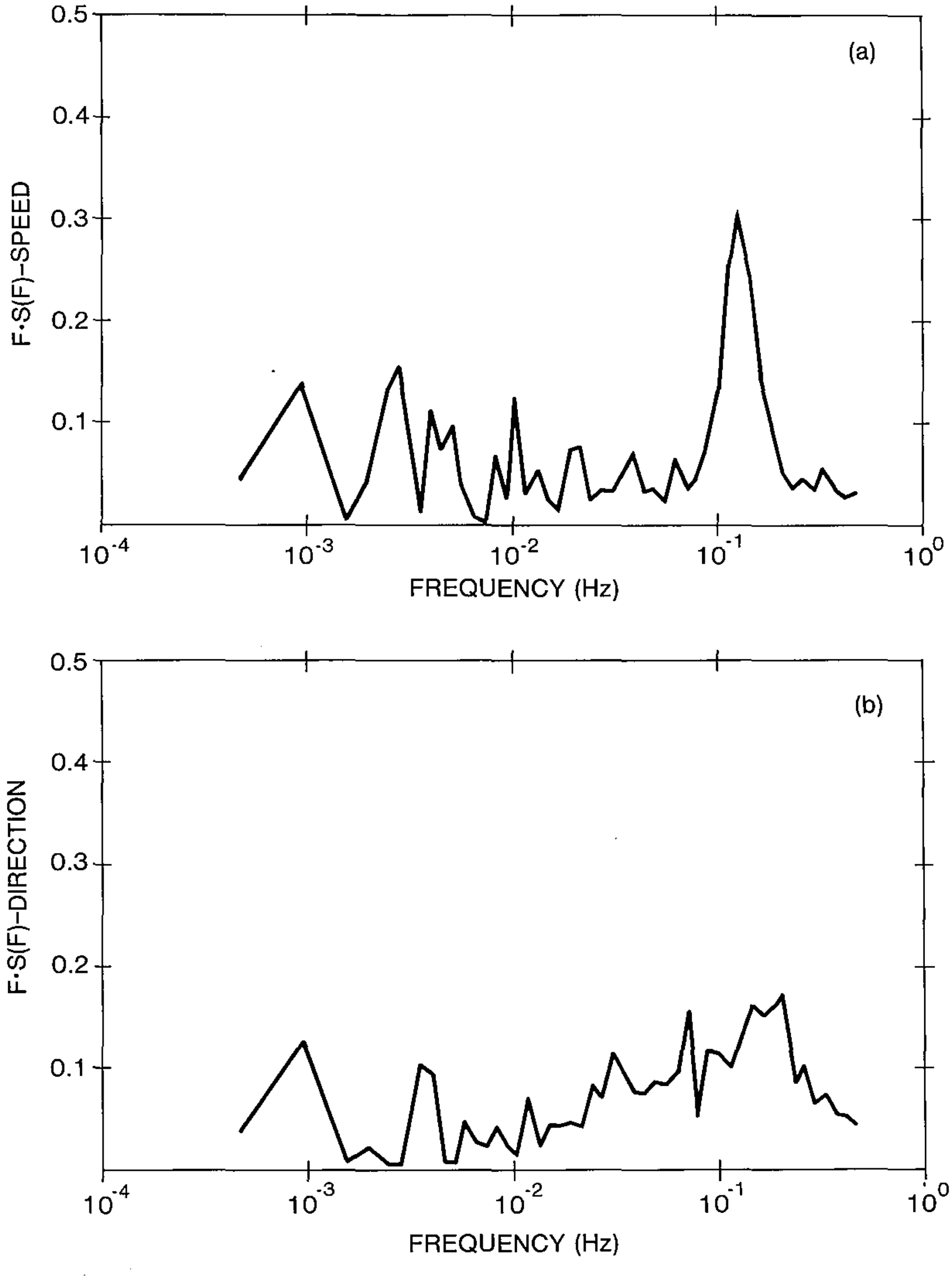


Figure 3.--Spectra for the Oceanographer, *0010 GMT, June 22, BLIP ascent: (a) wind speed; (b) wind direction.*

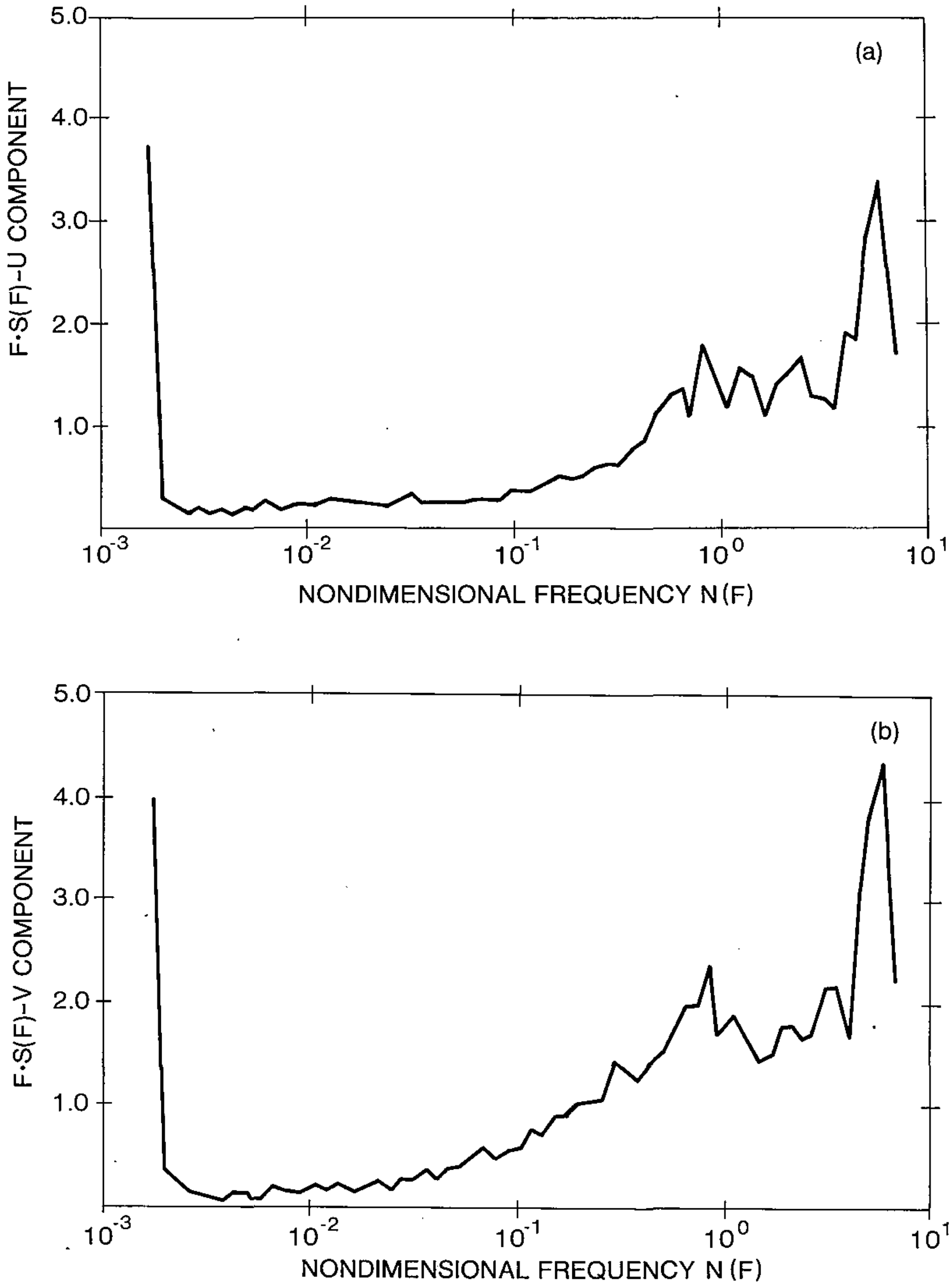


Figure 4.--Composite spectra for undisturbed conditions: (a) U and (b) V vs. nondimensional frequency.

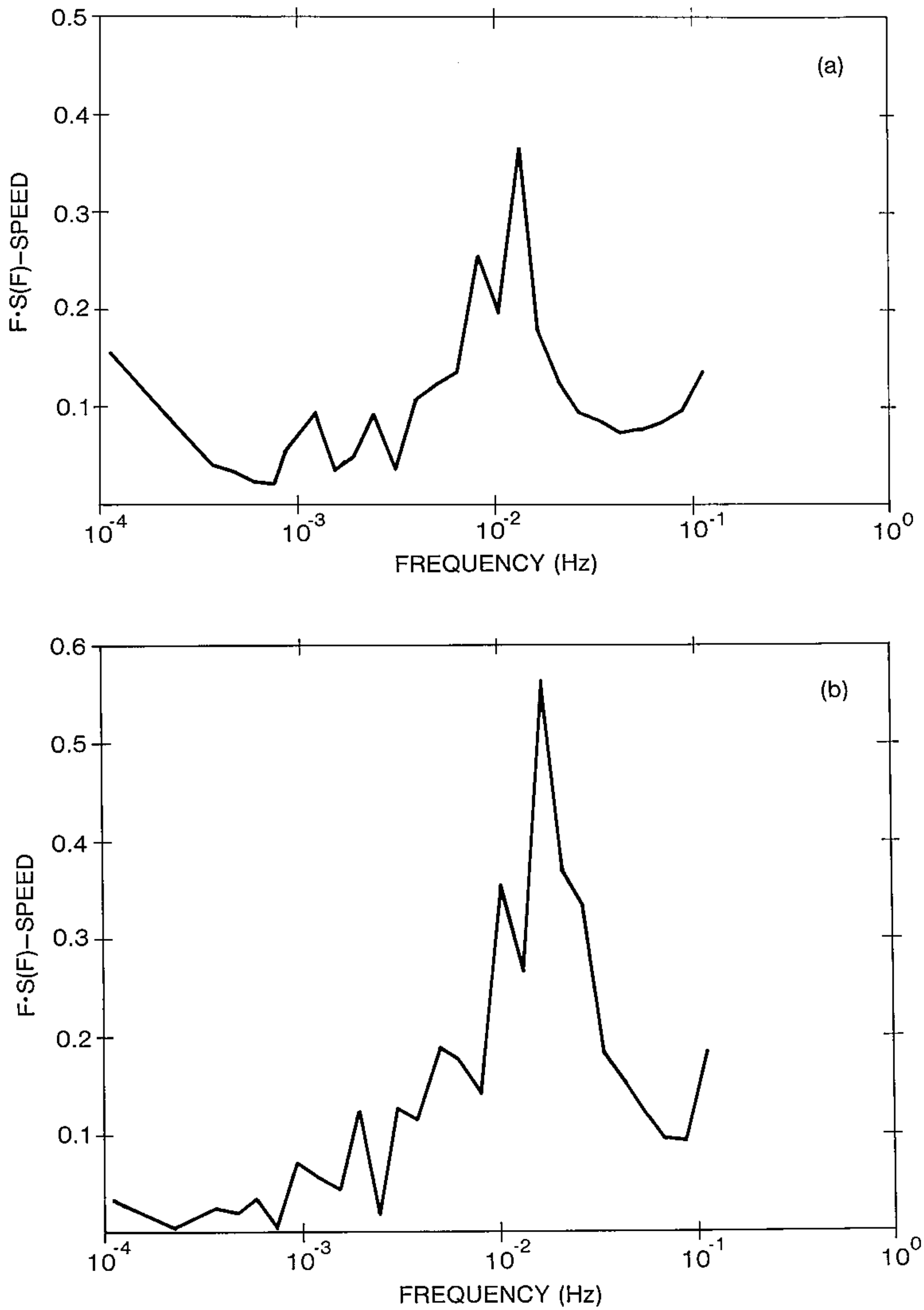


Figure 5.--Wind-speed spectra for disturbed conditions: (a) Mt. Mitchell, *0800 GMT, July 14; (b)* Discoverer, *0750 GMT, June 29.*

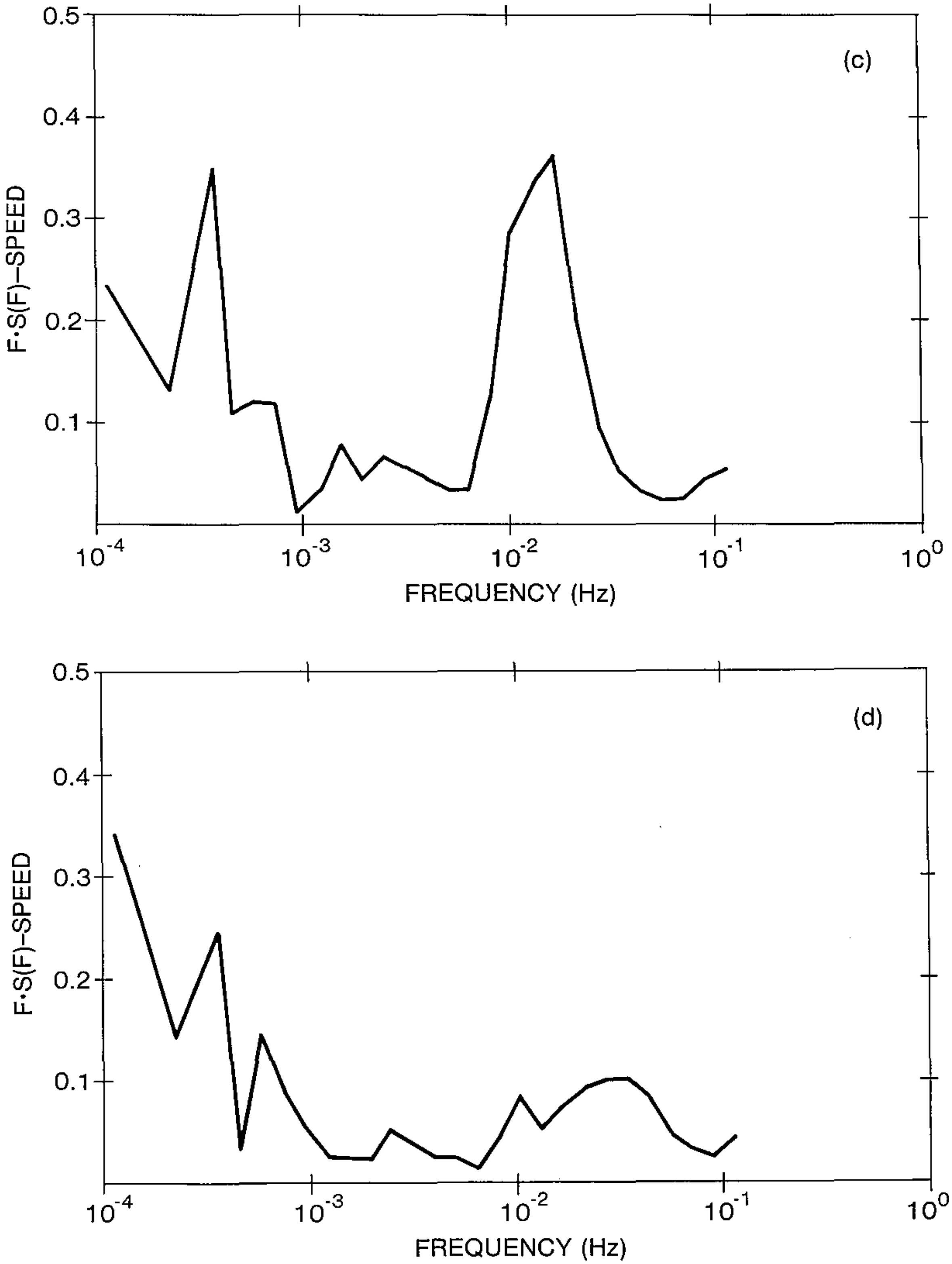


Figure 5 (cont'd).--Wind-speed spectra for disturbed conditions, Oceanographer: *(c) 0420 GMT, July 21; (d) 1100 GMT, July 18.*