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SURFACE GRAVITY WAVES AND AMBIENT MICROSEISMIC NOISE

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The research described below was led by post-doctoral scholar Dr T.H.C. Herbers, in collaboration with R.T. Guza.

EXPERIMENT

A coherent array of 24 pressure transducers was deployed on the sea bed in 13 m depth, approximately 2 km from shore, at Duck, North Carolina (Fig. 1). The objective of this experiment was to examine the generation of low frequency (0.005-0.05 Hz) and high frequency (0.25-1.0 Hz) pressure fluctuations on the sea floor through nonlinear interactions of sea and swell. The pressure transducers were carefully positioned by divers (distances between the sensors are accurate within 1 %), and buried about 10 cm within the sandy sea bed to reduce flow noise. The sample frequency is 4 Hz. Data was collected nearly continuously between 3 September and 1 December 1990. During this period, a 170 minutes long data run was acquired every 3 hours. The 10 minutes gaps between the data runs were necessary to transfer the data from a personal computer to a SUN Sparcstation 1. Occasionally the data collection was interrupted for a few hours for dive inspections and maintenance of the array. Between 1 December 1990 and 1 June 1991, a 170 minutes long data run was collected every 6 hours by the staff of the Army Corps of Engineers Field Research Facility in Duck NC.

There were a number of instrument failures, but most of the failed sensors and cables were rapidly replaced by divers on the site. Two instruments that failed during the experiment could not be replaced. Sensor P12 (Fig. 1) was buried about 2 m below the sea bed during a severe Nor'easter on 26 October and the degraded (attenuated) pressure data from this instrument collected after 26 October is not useful. After the Scripps divers left the site on 15 November, sensor P14 (Fig. 1) failed on 23 January 1991 and was not replaced. All instruments were recovered in early June, 1991.

OBSERVATIONS

The sea floor pressure measurements collected in 13 m depth are unique in terms of the array aperture, number of sensors deployed, sensor placement accuracy, the wide range of wave conditions encountered and the available environmental data (extensive bathymetry and wind data were collected by the Army Corps of Engineers Field Research Facility). Fig. 2 shows the root-mean-square pressure fluctuations in the frequency ranges: 0.005-0.05 Hz, 0.05-0.35 Hz, and 0.35-0.7 Hz, at 1.5 hour intervals between 1 October and 5 December. The observed spectra and root-mean-square values illustrate the strong variability of both low frequency (0.005-0.05 Hz, i.e. frequencies lower than sea and swell) and high frequency (0.35-0.70 Hz, about double the frequencies of locally generated seas) pressure fluctuations. The energy at both low and high frequencies varies by several orders of magnitude and appears to be strongly coupled to the energy at sea and swell frequencies.

Estimates of average wave numbers and directions (computed for the entire data set) show that the observed low frequency pressure fluctuations are predominantly edge waves (gravity waves trapped at the coastline; e.g. Ursell, 1952, Proc. Roy. Soc. Lon., A214, 79-97) travelling in the alongshore direction. During storm events (e.g. the Nor'easter on 26 October, 1990) and during the arrival of energetic swell (e.g. Hurricane Lilly on 12 October, 1990), low frequency forced waves, excited by nonlinear wave-wave interactions (e.g. Longuet-Higgins and Stewart, 1962, J. Fluid Mech.,13, 481-504) were observed. Bispectra (also computed for the entire data set) confirm the theoretically expected phase-coupling between these low frequency forced waves and the dominant wave groups. Only on a few occasions a net flux of seaward propagating (leaky) low frequency energy is observed. The dependence of the relative contributions of edge, forced and leaky waves to low frequency pressure, on the energy and directional properties of sea and swell is discussed in Elgar et al (in press) and Herbers et al (submitted; a list of the publications supported by this grant is appended).

Observed wave numbers of pressure fluctuations in the frequency range 0.05-0.30 Hz are generally within a few percent of the linear dispersion relation, showing that this frequency range is dominated by free surface gravity waves. However, when the surface wave spectrum is energetic (for example during the Hurricane on 12 October and the Nor'easter on 26 October; Figs. 2), significant deviations from the dispersion relation are observed at frequencies ranging from about 0.14 to 0.30 Hz. Bispectra confirm that the observed longer wavelength pressure fluctuations are the theoretically expected phase-coupled second and higher harmonics of the dominant surface waves (0.07-0.15 Hz).

The sea floor pressure data generally show a rather sharp transition between free wave dominance at frequencies below 0.30 Hz and forced wave dominance at frequencies above 0.35 Hz. The high frequency forced wave dominance is evident in an abrupt change in slope in the frequency spectrum (Figs. 3a), large deviations from the dispersion relation and relatively high bispectral levels. This transition is due to the strong attenuation of relatively short wavelength free high frequency surface gravity waves. At frequencies higher than 0.35 Hz, free wave spectra are attenuated by more than five orders of magnitude at the sea floor. Only relatively long wavelength forced waves, excited by nonlinear interactions between nearly directionally opposing free waves of about the same frequency reach the sea floor at these high frequencies (e.g. Longuet-Higgins, 1950, Phil. Trans. Roy. Soc. Lon., A243, 1-35). On numerous occasions, a sudden sharp increase in high frequency forced wave energy was observed at the sea floor, in response to nearly directionally opposing seas generated by a sudden veering in wind direction. An example of this phenomenon is shown in Fig. 3. On 19 October the wind veered from South-East to North, causing a a bimodal surface wave directional spectrum with nearly opposing 0.15 Hz and 0.25 Hz seas (Fig. 3b). The growth of the new 0.25 Hz sea peak coincides with the growth of the sum frequency (0.4 Hz) forced wave peak (Fig. 3a). Herbers and Guza (1992, submitted) show that the observed forced wave energy levels, wavelengths and propagation directions agree well with predictions based on the general weakly nonlinear theory of Hasselmann (1962, J. Fluid Mech., 12, 481-500) and the observed free wave directional spectra. The dependence of the high frequency pressure variability on changes in local wind direction is also examined using the longterm observations.

A dramatic increase in high frequency (about 0.3-0.5 Hz) forced wave energy was also observed during the Nor'easter (October 26, Figs. 2, 3). Bispectra show that in this case the nonlinear interactions between the energetic 0.1 Hz spectral peak and less energetic higher frequency seas (0.2-0.3 Hz) travelling in a different direction contribute significantly to the observed forced high frequency pressure fluctuations. Thus, double sea frequency pressure fluctuations are associated with directionally broad spectra, which can occur both with and without veering winds (Herbers and Guza, submitted).

Publications Acknowledging Support from this Contract

Herbers, T. H. C., and R. T. Guza, Wind-wave nonlinearity observed at the sea floor, Part II: Wavenumbers and thirdDorder statistics, J. Phys. Oceanogr., 22(5), 489-504 1992.

Elgar, S., T. H. C. Herbers, M. Okihiro, J. Oltman-Shay, and R. T. Guza. Observations of infragravity waves, J. Geophys. Res., in press.

Herbers, T. H. C., R. L. Lowe, and R. T. Guza. Field observations of orbital velocities and pressure in weakly nonlinear surface gravity waves, J. Fluid Mech., in press.

Herbers, T. H. C., S. E. Elgar, and R. T. Guza. Infragravity-frequency (0.005-0.05 hz) motions on the shelf. Part 1: Local nonlinear forcing by surface waves, submitted to J. Phys. Oceanogr.

Herbers, T. H. C., and R. T. Guza. Nonlinear wave interactions and sea floor pressure, submitted to J. Acoust. Soc. Am.

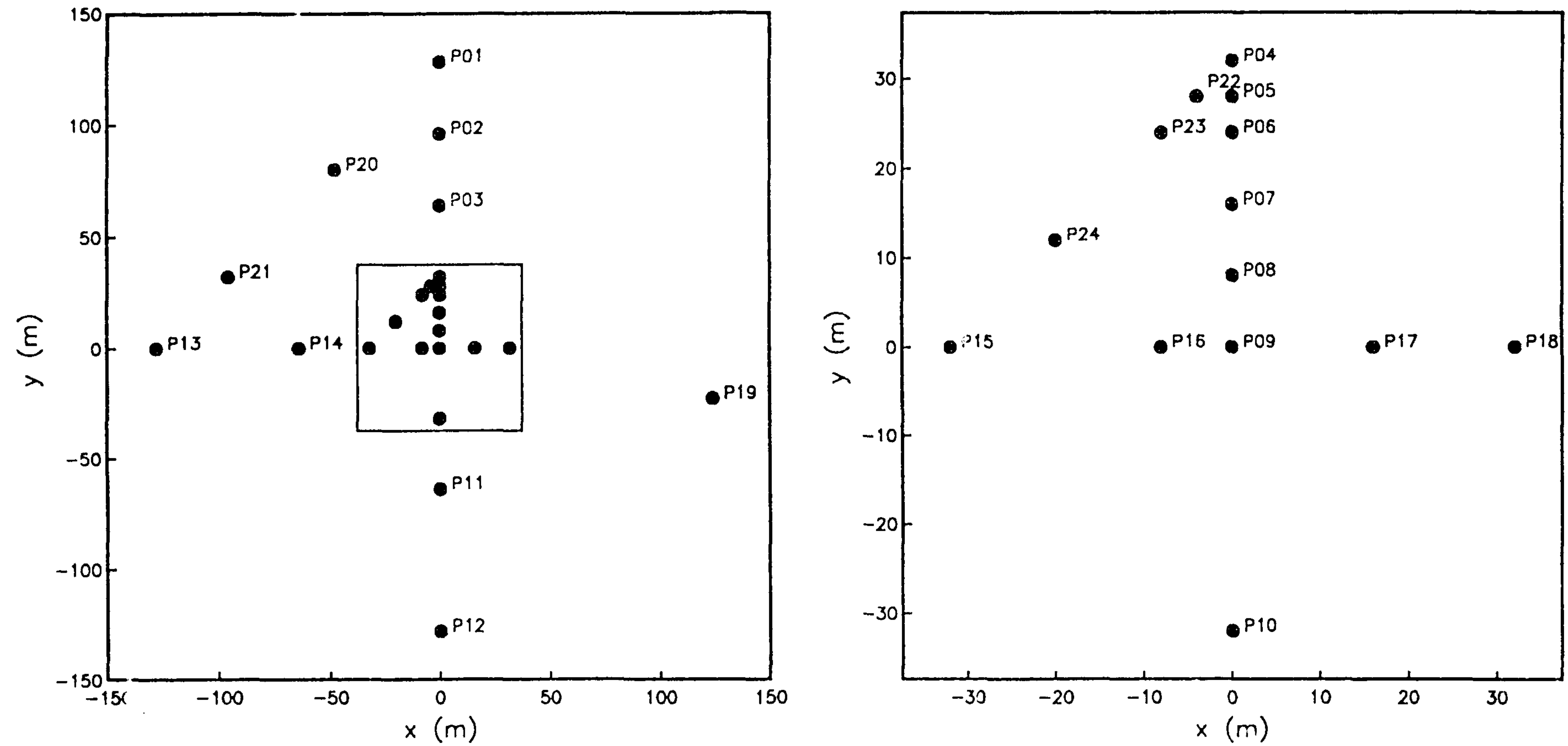


Fig. 1 Geometry of the array of pressure sensors deployed in 13 m depth. The left panel shows the entire 24 element array. The square box with the 14 sensors closest to the array center is enlarged in the right panel. The array center (x=0,y=0) is at approximately 36°11'24.582"N, 75°44'4.400"W and the x-axis points offshore (approximately 70° clockwise from North).

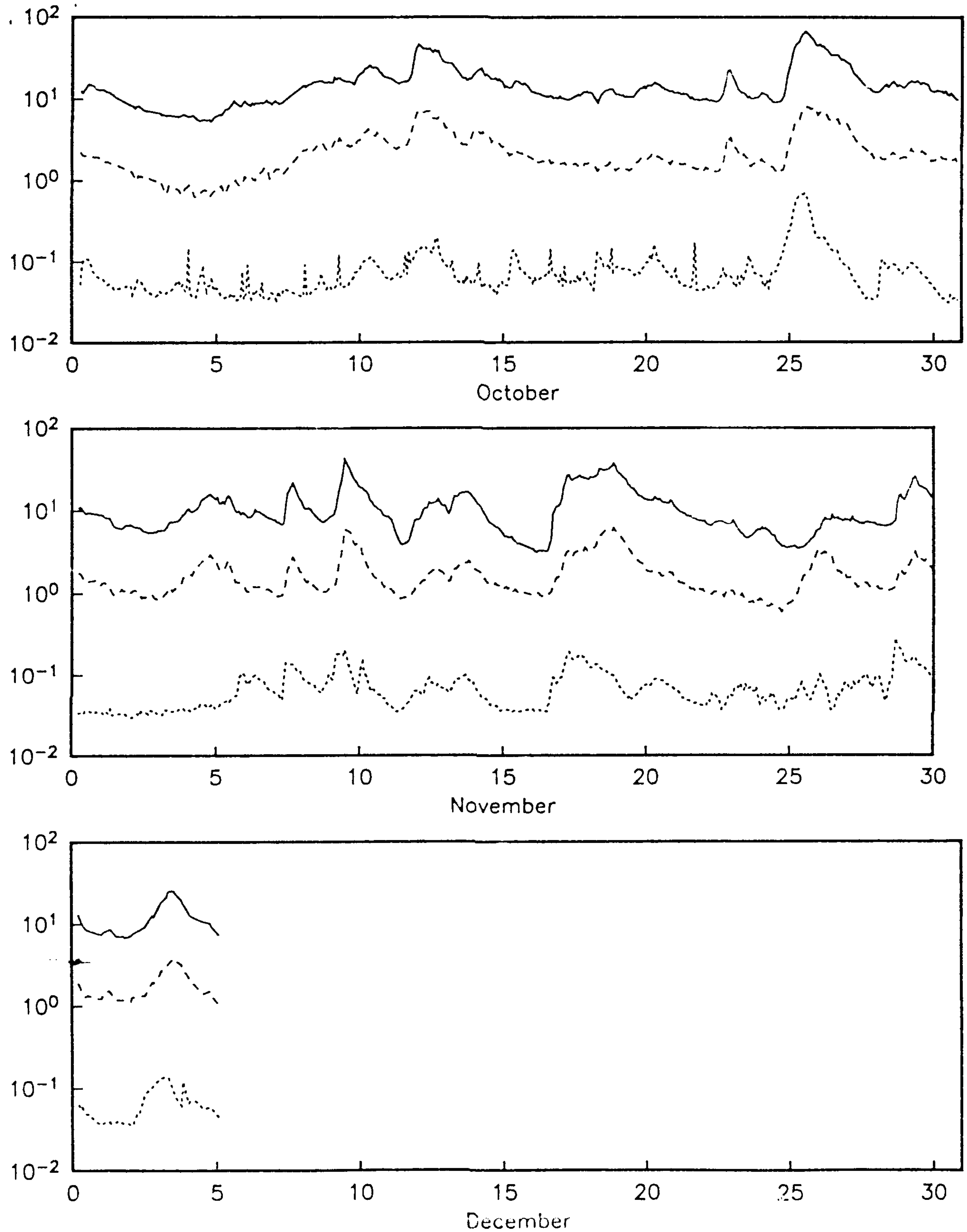
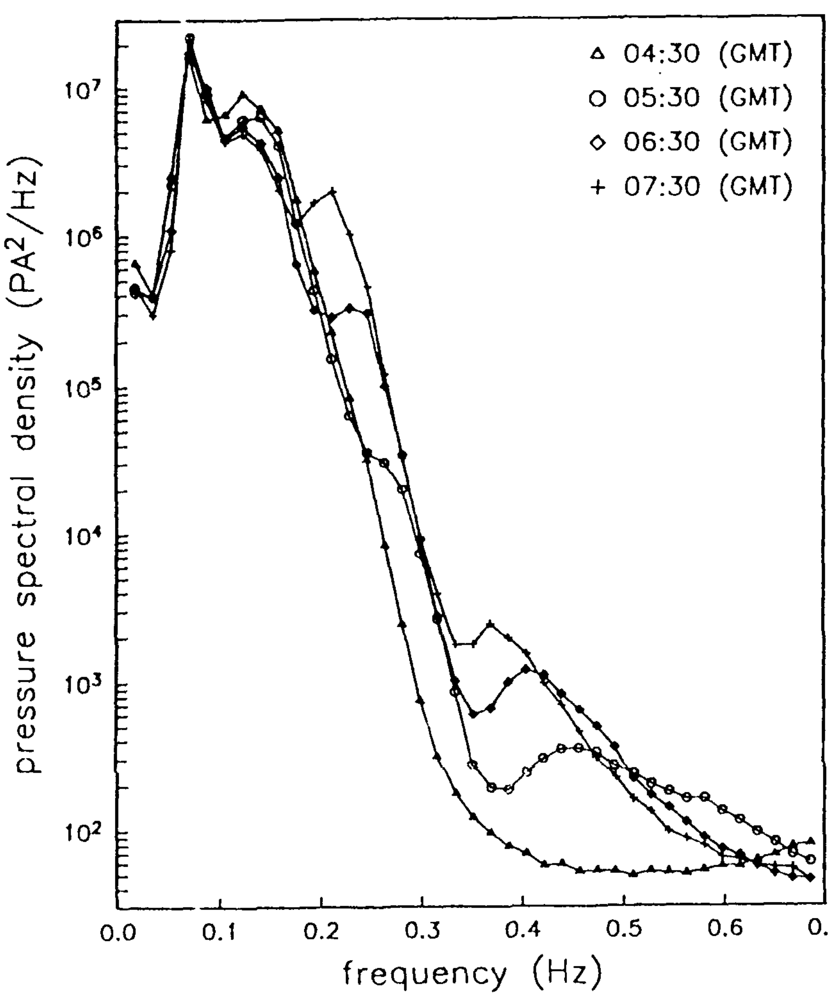


Fig. 2 Observed root-mean-square pressure fluctuations (units PA) in the frequency ranges 0.005-0.05 Hz (dashed), 0.05-0.35 Hz (solid) and 0.35-0.7 Hz (dotted) at 1.5 hour intervals from 1 October through 5 December 1990.



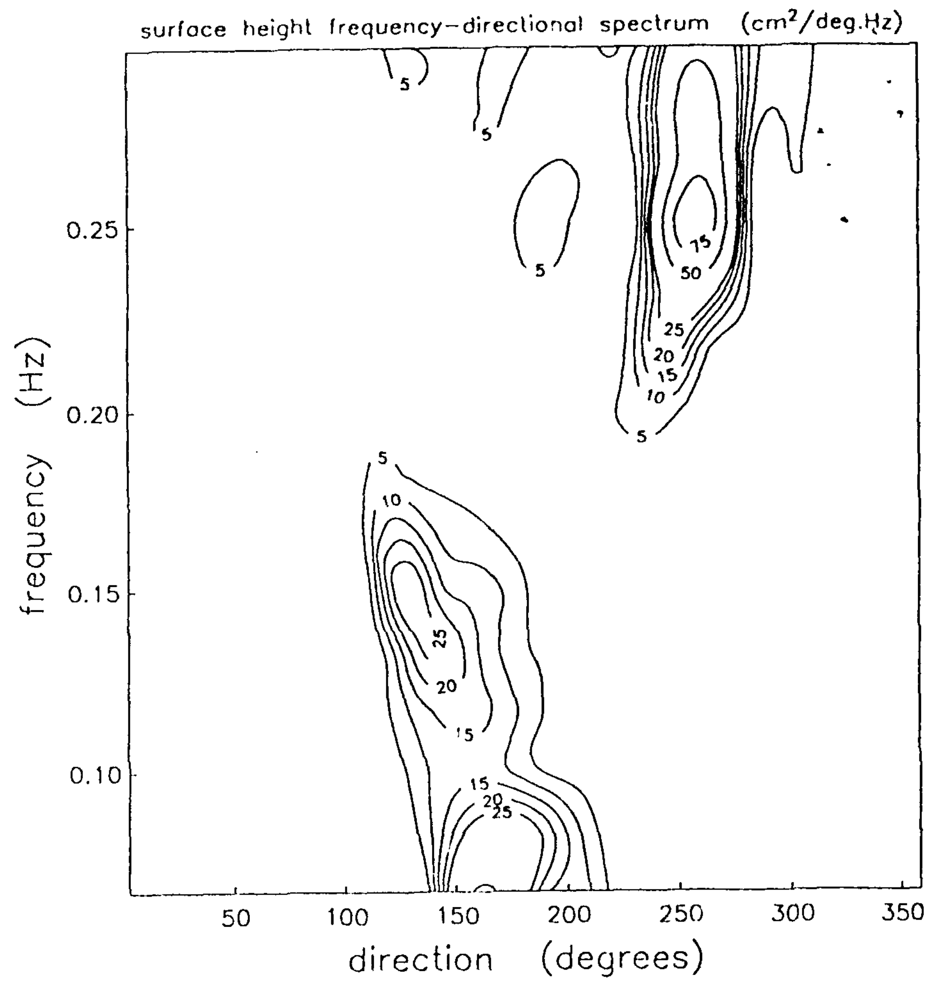


Fig. 3 Panel a) shows the evolution of the bottom pressure frequency spectrum between 04:00 h and 08:00 h (GMT) on 19 October, 1990, when the local wind direction suddenly veered from South-East to North. Panel b) shows an estimate of the surface elevation frequency-directional spectrum at 06:30 h (GMT). The wave propagation direction is measured counter-clockwise from the positive x-axis (Fig. 1; i.e. 250° corresponds to waves arriving from the North).