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THE PHYSICAL CONSEQUENCES OF WAVE BREAKING IN DEEP WATER

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MANAGEMENT PERSPECTIVE

The breaking of waves at the surface of natural water bodies has important effects on many physical processes. Among these are: interfacial gas transfer, enhancement of wind stress, mixing of surface pollutants, changes in optical emissivity and microwave reflectivity, formation of bubble clouds and the generation of sound, dissipation of surface waves. These processes are themselves an integral part of the general problem of monitoring and predicting the short and long term evolution of the coupled ocean-atmosphere system, i.e., weather and climate prediction.

This review paper outlines the current understanding of wave breaking in deep water and its physical consequences. In addition, it points out the areas where future research efforts are most likely to be fruitful.

SOMMAIRE À L'INTENTION DE LA DIRECTION

Le déferlement des vagues à la surface de plans d'eau naturels a des effets importants sur de nombreux processus physiques, entre autres, le transfert des gaz à l'interface, l'augmentation de la tension due au vent, le mélange de polluants de surface, les modifications de l'émissivité optique et de la réflectivité des micro-ondes, la formation de nuages de bulles et la production de son, la dissipation des vagues de surface. Ces processus font eux-mêmes partie intégrante des problèmes généraux de surveillance et de prévision de l'évolution à court et à long terme du système couplé océan-atmosphère, c'est-à-dire des prévisions météorologiques et climatiques.

Ce document offre un survol des connaissances actuelles du déferlement des vagues en eau profonde et ses conséquences physiques. De plus, il signale les domaines où les efforts de recherche futurs sont les plus susceptibles d'être fructueux.

Summary
The evolving technology of remote sensing and the increasing interest in the distribution of anthropogenic gases have, in recent years, focused attention on the ocean surface. In particular, the complex process of wave breaking has a wide range of consequences for remote sensing, momentum, heat and mass transfer and oceanic acoustics. In this paper we consider some of the more important effects of wave breaking that have recently been subjected to intensive observational scrutiny. These include: changes in microwave reflectivity; stress and gas transfer enhancement; formation of bubble clouds and sound generation; dissipation of surface waves.

RÉSUMÉ

La technique en plein essor de la télédétection et l'intérêt croissant pour la répartition des gaz de source anthropique ont, au cours des dernières années, mis l'accent sur la surface des océans. Notamment, le processus complexe du déferlement des vagues comporte une vaste gamme d'effets au niveau de la télédétection, du transfert de mouvement, de chaleur et de masse et des propriétés acoustiques de l'océan. Dans le présent document, nous étudions certains des effets les plus importants du déferlement des vagues qui ont fait dernièrement l'objet d'une observation rigoureuse et intensive. Ces effets comprennent des modifications de la réflectivité des micro-ondes, l'augmentation des tensions et du transfert des gaz, la formation de nuages de bulles et la production de son; la dissipation des vagues de surface.

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The Physical Consequences of Wave Breaking in Deep Water

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Introduction

It is well recognized that at moderate and high winds the sea surface is aerodynamically rough. What is less certain is the relative contribution of various scales (wavelengths) to the roughness. The success of Charnock's formula in describing the roughness length in open ocean conditions suggests that the small waves (several times the peak wavenumber) are the principal stress receptors. This indeed appears to be so when the sea state is well-developed (wave age ~ 1). Underdeveloped waves, on the other hand, produce relatively high drag coefficients and these appear to be related to the relative speed of the peak waves with respect to the wind speed (Kitaigorodskii, 1970; Donelan, 1990). In fact, at short fetch, the waves at the spectral peak are strongly forced and a significant part of the total momentum transfer is absorbed by the waves near the peak (Figure 1).

In fully rough flow the momentum transfer across the interface is due to form drag, i.e., differential pressure on upwind versus downwind slopes. All the momentum transferred in this way enters the wave field initially, but only a fraction remains as wave momentum — at full development the fraction is identically zero. Deductions from fetch-limited

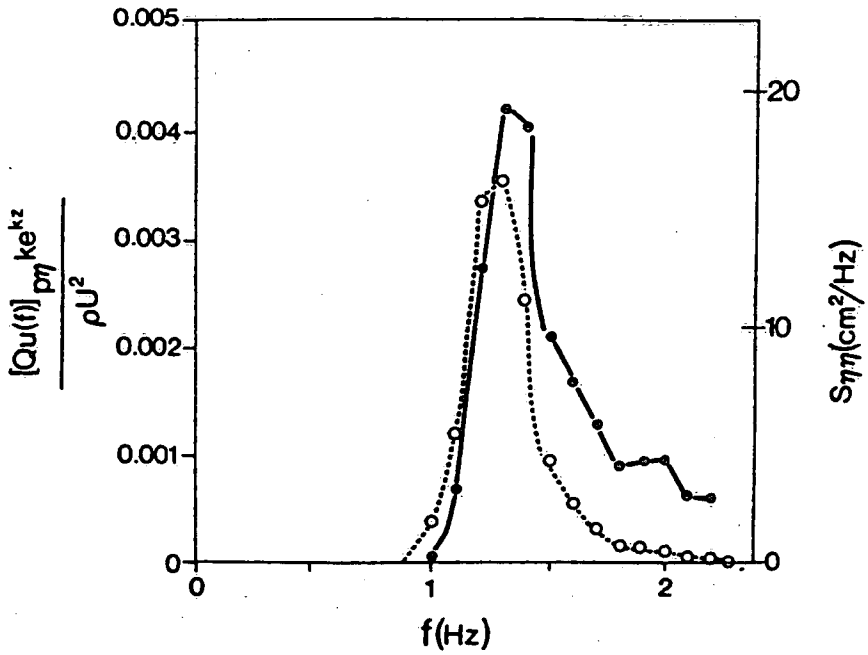

Fig. 1. A laboratory wave spectrum $S_{\eta\eta}(f)$ (broken line) and associated pressure-elevation quadrature spectrum (solid line). The quadrature spectrum has been adjusted by the exponential decay to yield the momentum transfer to the waves. Further normalization by ρU^2 yields the spectrum of contributions to the drag coefficient.

growth curves suggest that developing waves retain about 5 % of the total momentum flux (Hasselmann et al., 1973). Direct measurements of differential growth and surface stress (Donelan, 1978) show that as much as 25 % may be retained by the waves at very short fetch, in laboratory tanks, but 0 to 8 % is more typical of field conditions (Figure 2) and the atmospheric stability has a pronounced influence on it. Presumably, the effect of stability is to alter the wavenumber distribution of waves contributing to the stress transfer. The larger turbulent scales associated with unstable conditions may bias the transfer distribution toward longer waves. Since the short waves are believed to be quasi-saturated, any momentum transferred to them is quickly handed over to currents via enhanced breaking.

Are the short waves in the equilibrium range, indeed, nearly saturated and is the limiting process correctly identified as wave-breaking? These seem to be unresolved issues although a good deal of recent work has attempted to clarify the spectral balance above the peak (Kitaigorodskii, 1983; Phillips, 1985; Donelan and Pierson, 1987; Banner, 1990c). Figure 3 shows two frequency spectra obtained in very different winds (1.2 m/s and 17.4 m/s). In the former case the dominant waves are recent swell and, while the

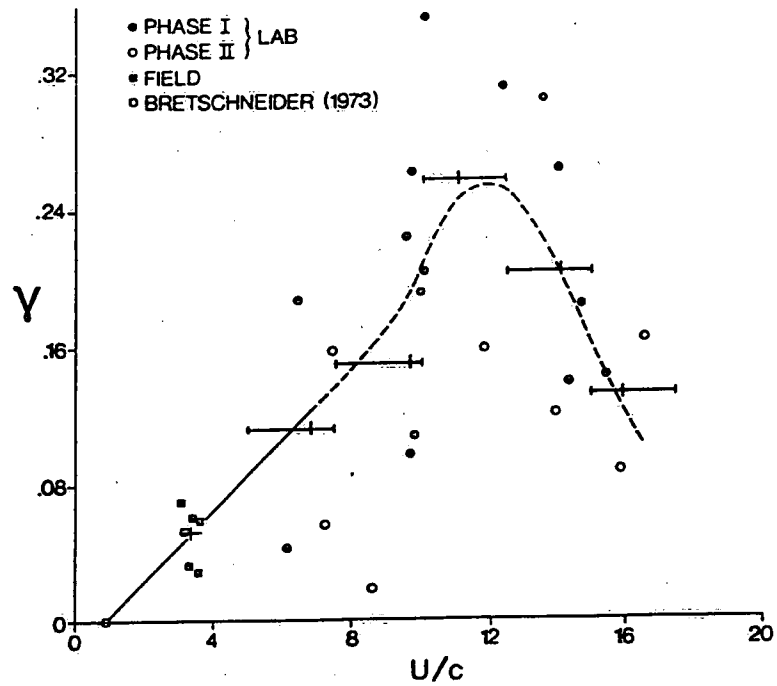

Fig. 2. The fraction of wind momentum retained by waves Υ versus the inverse wave age U/c. For the laboratory data the larger crosses indicate the averages of the data assembled in groups of width 2.5 in U/c. The vertical bar indicates the average value of U/c in the group. The cross representing the field data has been placed at the value of Υ corresponding to neutral atmospheric stability. The point of full development ($U/c = 0.83$, $\Upsilon = 0$) according to Bretschneider (1973) provides another estimate of Υ. The straight line (solid) at lower values of U/c provides convenient access to Υ for wave prediction purposes. The extension of the line to higher values of U/c (dashed) serves only to illustrate the trend in Υ.

wind is well above the minimum for sustaining short wave growth (Kahma and Donelan, 1987), it is very light indeed and it is difficult to believe that the same limiting process maintains the same shape of the high frequency spectra, i.e., ω^{-4}. The ratio of spectral levels is roughly the same as the square root of the wind speed ratio. At high wind speeds there is little doubt that wave breaking is the principal limiting process.

Despite the widespread occurrence of wave breaking in the ocean, our present knowledge of this process is incomplete. However, existing studies indicate that it appears to contribute significantly to basic geophysical air-sea interfacial transfer processes including momentum, mass and heat transfers, as well as in related areas such as underwater ambient noise generation and microwave backscatter from the sea surface. This contribution provides a brief overview of present knowledge, highlighting areas where further research is needed in order to refine our present physical understanding and predictive modelling capabilities.

Breaking Types

Wave breaking is a familiar feature of the wind-driven sea surface, occurring most visibly

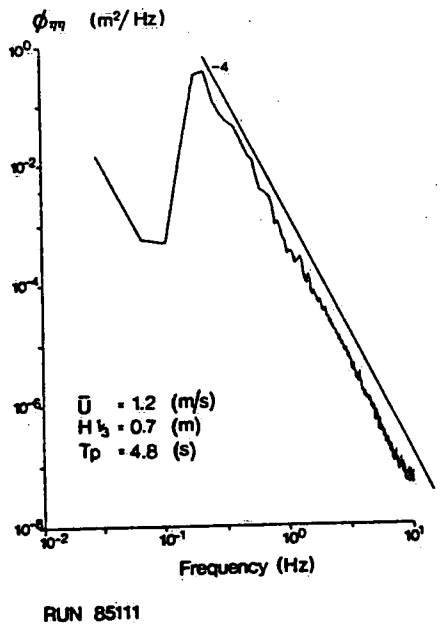

Fig. 3 a. The spectrum of surface elevation for the case of recent swell. The −4 power law fitted to Fig. 3 b is also shown here.

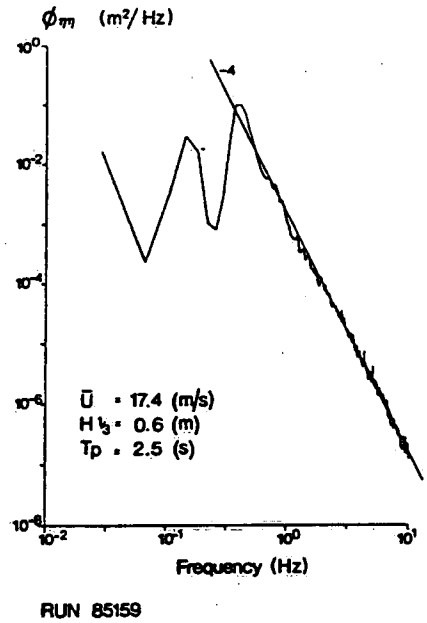

Fig. 3 b. The spectrum of surface elevation for the strongly wind-generated case. Above the peak, the spectrum conforms to a −4 power law (Donelan et al, 1985).

in the form of whitecaps of various scales. It also occurs on a more widespread basis as *microscale* breaking, but in this form it is less conspicuous because of its lack of air entrainment and smaller scale, involving wavelengths less than about 30 cm. The most prevalent form of deep water wave breaking occurs as spilling breakers, where the breaking crest water surges gradually forward to spill down the forward face of the breaker. The more violent form known as the plunging breaker, though more typical of shallow water breaking, can also be observed. This form is characterised by the breaking crest water jetting forward, and engulfing a pocket of air as it collapses on to the forward face of the breaker.

Momentum and energy transfer

Enhanced Wind Input

Several authors have reported significant influence of wave breaking on the interfacial stress at the onset of breaking. Using a quasi-steady breaking wave realization, Banner and Melville (1976) identified the presence of locally separated flows in the air flow associated with wave breaking, and noted a consequent significant enhancement of the local wind stress. The association of strong air flow separation effects with breaking

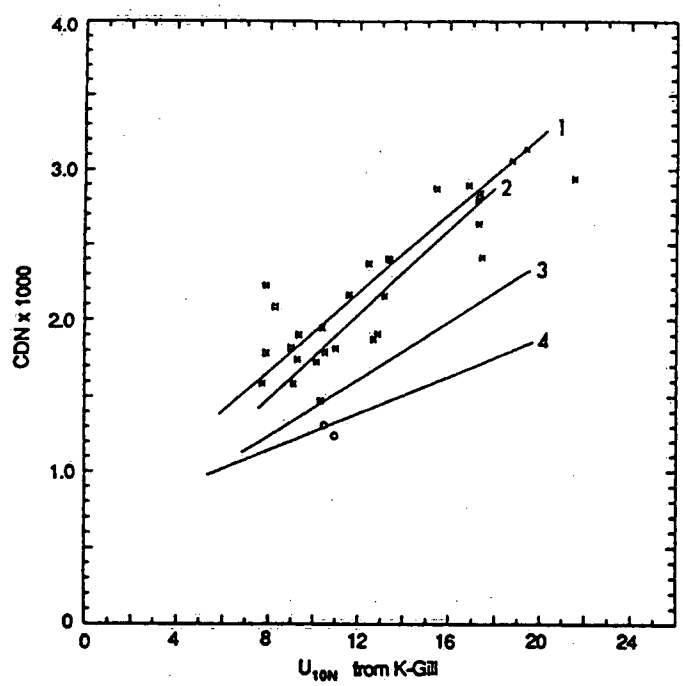

Fig. 4. Neutral drag coefficient, CDN, vs. ten-meter height wind speed for HEXMAX data. Asterisks indicate measurements in slightly unstable conditions, small circles for slightly stable conditions.
Line 1 is best fit to data, Line 2 from Donelan (1982), Line 3 from Geernaert, et al. (1986), Line 4 from Smith (1980) represents open ocean conditions. From De Cosmo et al. (1988).

wind waves was explored in greater depth in detailed flow visualisation studies over propagating wind waves by Kawai (1981, 1982). Strong local enhancements in the wind stress were also found. However, investigations seeking to identify relative contributions to the stress enhancement as normal or tangential have produced somewhat conflicting results. Detailed hydrogen bubble observations in the immediately underlying water by Okuda *et al.* (1977), Okuda (1982) suggest that strong wave-coherent tangential stresses dominate, peaking on the windward face of the wave form. However, measuring near-surface pressure distributions, Banner (1990a) reported a near-doubling of the wind stress when comparing incipient and actively breaking wind-driven waves, with (separation-induced) phase shifts in the wave-coherent pressure producing wave drag increases of about the same size as the total stress enhancement, indicating a lesser influence of enhanced tangential stress. Therefore basic questions still remain on the relative importance of normal and tangential stresses in the actual mechanism of enhanced momentum flux from the wind associated with breaking wind waves.

Such local considerations are germane to the heightened recent interest in the sea state dependence of the wind stress, or equivalently, in the aerodynamic drag coefficient C_d of the sea surface. The trends of recent observational studies shown in Figure 4 indicate

a significant sea state dependence in the wind stress [e.g. Donelan (1982), Geernaert, Katsaros and Richter (1986), Smith and Anderson (1988), DeCosmo, Katsaros and Lind (1988)]. These findings are of basic importance in the parameterisation of C_d, a primary parameter in modelling wind waves, ocean circulation, as well as weather and climate prediction, where C_d parameterisations in current use contain *no* sea state dependence.

Theoretical models to account for these observed trends have been proposed [e.g. Janssen (1989), Toba *et al.* (1990), Banner (1990b), Plant (1991)]. However, both observationally and theoretically, there is still a lack of consensus on this problem. The model proposed by Toba *et al.* (1990) predicts that C_d increases with wave age, while most other model studies predict the opposite trend. On the one hand there is a notable lack of wind stress and wave data for strong winds and long fetches: the wind stress is difficult to measure reliably, as are the desired complementary wave measurements (e.g. directional wave spectra, breaking wave probabilities). On the other hand, the proposed spectral models are very sensitive to the form of the wave spectrum and its assumed variation with wave development. Model studies suggest that although the momentum flux to the energetic wind wave components is locally large, the contribution to the wind stress from wave drag is significantly greater from the much larger spectral range embracing wind wave components shorter than about one tenth of the dominant wavelength. It appears that a reliable improvement in the C_d parameterisation will require considerable further research effort, and will need to investigate closely the contributions from the short wind wave scales, including microscale breaking waves.

Breaking influence on spectral transfers

Modulation of very short wind waves by longer waves is an important mechanism influencing the microwave backscattering process from the sea surface, and underlies the data interpretation from a potentially very useful class of active microwave remote sensing sea state and marine meteorological instruments. In this context, an intriguing feature of a wind wave field concerns its modulation by an underlying large scale wave field propagating in the wind direction. In laboratory studies, it has been found by a number of investigators that the short wave spectrum attenuates markedly as the modulating wave steepens [e.g. Mitsuyasu (1966), Phillips and Banner (1974), Donelan (1987)]. Phillips and Banner (1974) attempted to explain this effect on the basis of enhanced breaking due to enhanced wind drift layer influence, but the influence of this mechanism was questioned by Wright (1976). Donelan (1987) observed that the input source term was largely unaffected by the influence of the modulation and suggested that modification

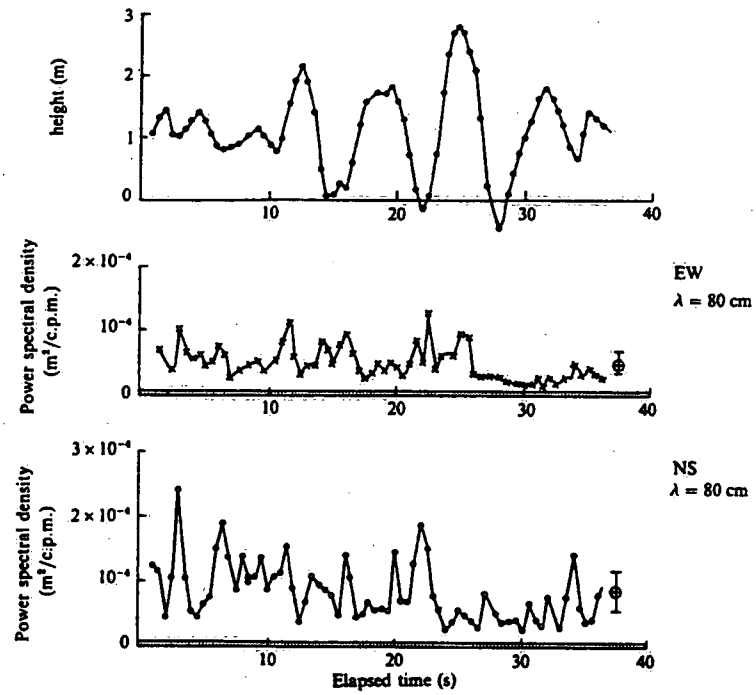

Fig. 5. Time series of power spectral density of wavenumber components during an interval embracing a whitecapping event, uncorrected for noise. Wavelength = 0.80 m. Experiment 2. Water height is with respect to an arbitrary origin. Noise levels are shown for each wavenumber component as a shaded band. 95% confidence limits about the mean level are shown at the right.

of the nonlinear wave-wave interactions was responsible for the observed behaviour. Also, Longuet-Higgins (1987) proposed a two-scale model which considered randomness in both long and short waves and examined the effects of breaking of the short waves under conditions where the short waves were re-generated by the wind. His predictions were in qualitative agreement with the observations. With its potential to elucidate short wave modulation in a continuous spectrum, further research effort is needed to understand the underlying physical mechanisms in such two-scale problems. When the large scale wind wave is itself involved in breaking, it produces a marked local attenuation of the entire short wind wave spectrum in its wake [Banner *et al.* (1989), Figure 5]. This highly nonlinear behaviour has potentially important implications for air-sea interaction and remote sensing and warrants further study, particularly for strong wind forcing conditions with extensive whitecapping.

Momentum flux to currents

Duncan (1981), (1983) studied quasi-steady wave breaking associated with a towed subsurface hydrofoil. He reported a series of interesting geometrical and dynamical relations for these quasi-steady breakers, including the useful result that the stress per unit width of breaking crest was about $0.06c^4/g$, where c is the phase speed, indicating the effect

of wave scale. As part of a very detailed laboratory study of *transient* breaking, Rapp and Melville (1990) reported systematic results for the breaking-induced momentum flux to the underlying flow due to wave *packets* involved in varying degrees of wave breaking embracing incipient, spilling and plunging breaking. Their results showed somewhat lower mean breaking wave stress levels than the quasi-steady breaking wave stress levels reported by Duncan. Similar investigations involving near-monochromatic wave *trains* have provided very useful quantitative information on the very interesting three-dimensional instability properties associated with the approach to breaking [e.g. Su and Green (1986)] and significant frequency downshifting which occurs following breaking [e.g. Lake and Yuen (1978)]. Studies exploring these nonlinear aspects are continuing, both theoretically and observationally [e.g. Trulsen and Dysthe (1990)] .

The application of the results of such laboratory studies of the hydrodynamic consequences of breaking waves to broader wind wave spectral situations has not yet been widespread. However, applying these laboratory findings in conjunction with spectral breaking distributions can provide useful guidance in the field: Phillips (1985) invoked Duncan's findings as a basis for modeling the spectral wave energy dissipation rate and the spectral momentum flux from the wave field to the underlying currents.

Kinetic energy dissipation due to wave breaking

The important role of the turbulent kinetic energy distribution in the dynamics of the upper ocean has led to numerous attempts to measure and parameterize it in terms of air-sea interaction variables. Most results are expressed in wall layer coordinates and, although the scatter of data points is usually about an order of magnitude, agreement with the wall layer value $\varepsilon = \frac{u_*^3}{\kappa z}$ is generally claimed (Jones, 1985; Soloviev et al., 1988). Some near surface measurements in Lake Ontario (Kitaigorodskii et al., 1983) show dissipation rates that are 2 or 3 orders of magnitude above $\frac{u_*^3}{\kappa z}$. New measurements of such high dissipation rates are to be reported at this conference (Drennan et al., 1991). It is shown that these high dissipation rates occur near the surface in breaking wave conditions and are entirely consistent with the expected energy transfer to a wide range of steep waves at and above the spectral peak.

Heat and mass transfer

Of obvious geophysical importance, the parameterisation of mass and heat transfer across the air-sea interface has attracted considerable interest. Despite the intrinsic difficulties of measuring transfer rates within very thin conduction sublayers adjacent

to the interface, recent investigators have made substantial progress in identifying wind-wave influences on these processes. In an authoritative recent paper, Jähne *et al.* (1987) review the status of the field and present detailed measurements that improve our knowledge on the underlying role of the wave field. They report that the mass transfer rates are enhanced by the wave field, closely tracking the mean squared wave slope of the whole wave spectrum, rather than just the capillary waves previously thought to be dominant. Interestingly, the photographs [Figures 6 and 7] of the wave field shown in their paper reveal the presence of microscale breaking, even at the low wind speed of 2.7 m/s. Thus while this was not noted explicitly by Jähne *et al.* in their discussion,

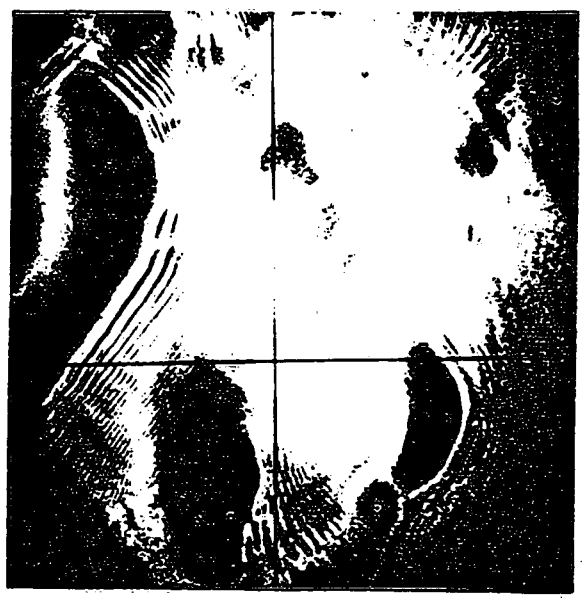

Fig. 6. Photograph of wind waves at 21 m fetch in the large IMST wind/wave facility at 2.7 m/s wind speed. The sector shown is 40 cm times 40 cm.

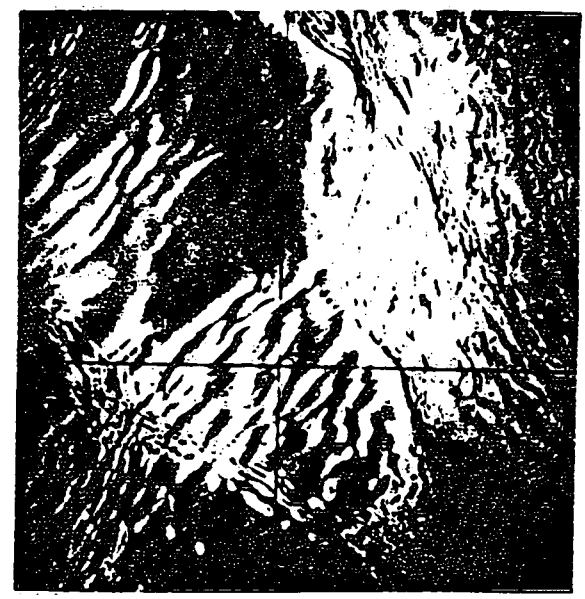

Fig. 7. Photograph of the wind waves at 21 m fetch in the large IMST facility at 8.1 m/s wind speed. See below for detailed explanation.

N.B.: The pictures have been taken using a special slope visualization technique indicating the slope in different colours or a gray scale. The picture shown is a black and white copy of a color slide, so that the dark parts correspond to upwind slopes, the light parts to small slopes, and the medium gray colors to downwind slopes. The wind is blowing from the left to the right. After Jähne et al. (1987).

it suggests the importance of wave breaking on interfacial scalar transfers, especially as the spilling zones disrupt the very thin conduction sublayers. In an experiment aimed at isolating the influence of breaking, Banner and Wilkinson (1991) have found that the sensible heat transfer rate is augmented considerably following the onset of breaking. Thus, in a spectral context, the distribution of microscale breaking is likely to be a significant factor in improving estimates of scalar interfacial fluxes. The importance of microscale breaking in controlling the transfer of heat and mass has added impetus to the search for the wavenumber spectrum of capillary-gravity waves and its wind sensitivity. Kahma and Donelan (1987) investigated the growth rates of initial wavelets and found that a (10 m) wind speed of 0.7 m/s ($u_* \sim 2$ cm/s) is sufficient to begin the

growth process and that both shear flow instability (Valenzuela, 1976; Kawai, 1979 and van Gastel et al., 1985) and resonance with advected pressure fluctuations (Phillips, 1957) could be effective.

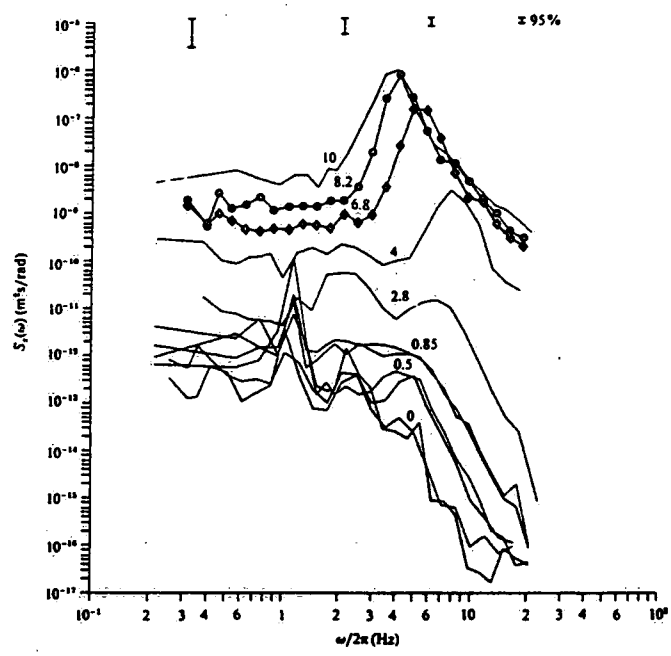

Fig. 8. The evolution of the frequency spectrum with wind speed (indicated on the figure). The spectra at 0, 0.5, 0.85 and 2.8 m/s wind speed are composites derived from surface displacement spectra and transformed slope spectra. From Kahma and Donelan (1988).

The development of the spectrum at various wind speeds and fixed fetch (4.3 m) is shown in Figure 8. The first waves to grow ($\sim$ 5 Hz) exhibit strong wind sensitivity at high winds and quickly approach saturation at wind speeds in excess of 4 m/s. Kahma and Donelan (1988) suggest that the approach to saturation depends on available fetch and, indeed, the slope measurements of Jähne and Riemer (1990) at much longer fetch (90 m) show that the 5 Hz waves are already nearly saturated at 2.7 m/s (Figure 9). Their wavenumber spectra (Figure 10) demonstrate that although the downwind slopes tend to saturation above 12 m/s, continued growth at off-wind angles extend the range of wind sensitivity of the overall mean-square slope. This wind sensitivity of the small waves and their connection with microscale-breaking helps to explain the observed strong wind dependence of mass transfer velocity of liquid phase limited compounds across the air-water interface (Liss, 1973).

Water vapour, on the other hand, is gas phase limited and no particularly dramatic increase of the evaporation coefficient (Dalton number, C_E) is expected when microscale breaking intensifies. Field measurements of C_E show the usual geophysical and sam-

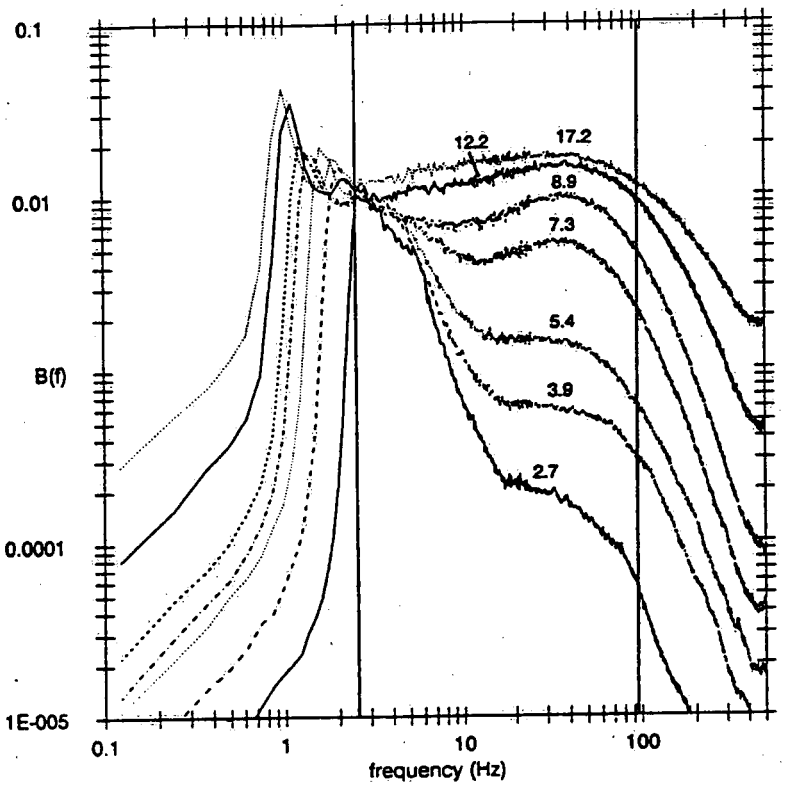

Fig. 9. Wave frequency spectra weighted by f^5 measured at several wind speeds and about 90 m fetch with the laser slope gauge. The vertical lines mark the approximate range contained in the wave number spectra shown in Fig. 10. The curves are labelled with wind speed U_{10} in m/s. From Jähne and Riemer (1990).

pling variability, but are, in general, quite insensitive to wind speed. The breaking of large waves and the production of spray in the boundary layer might be expected to cause a substantial increase in C_E at high winds ($> 12m/s$, say). Indeed, in a comprehensive treatment of the subject, Bortkovskii (1987) suggests that spray evaporation will double C_E between 9 and 18 m/s. There is no evidence for this in the data. The recent experiment to investigate the Humidity Exchange over the Sea (HEXOS, Smith and Anderson, 1988, and DeCosmo et al., 1988) extended C_E values to 18 m/s and found no appreciable increase. The study of heat and mass transfer at the air-sea interface and the effects of water temperature, slicks and wave breaking is being approached with all the modern tools required to examine the properties of short waves, the breaking characteristics of all waves and the turbulence near the interface. There is much to be learned here and the rewards, in terms of improved modeling of the energy balance of the ocean atmosphere system, are substantial.

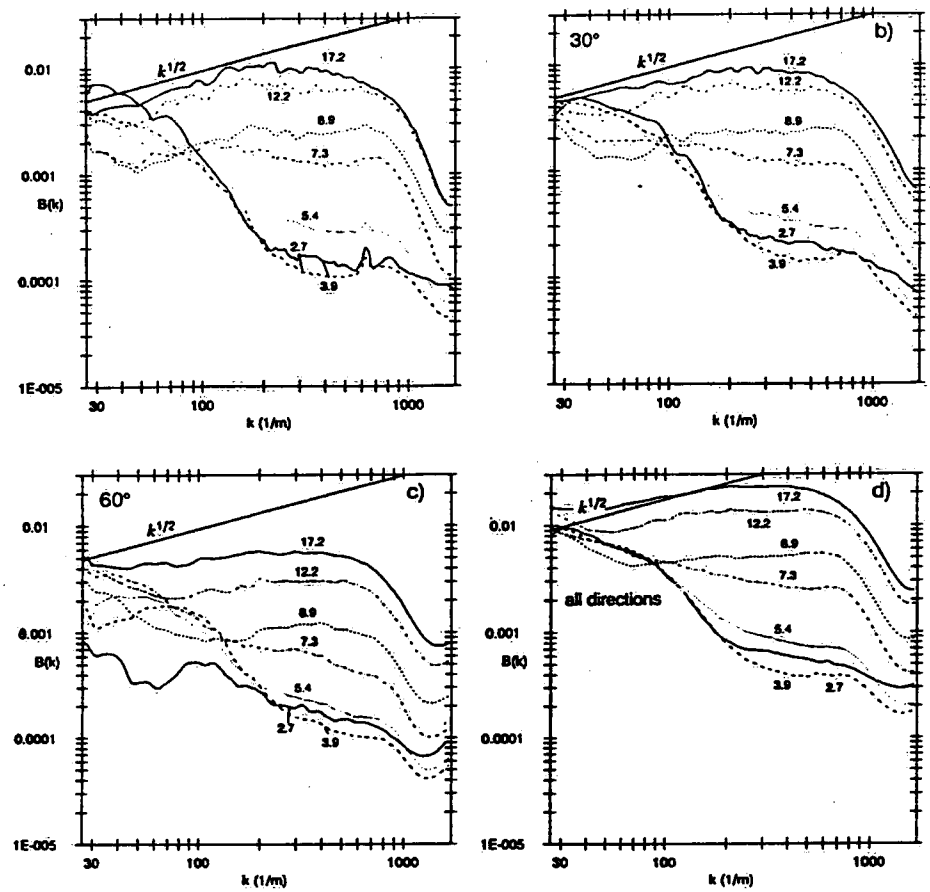

Fig. 10. Wave number spectra weighted by k^4 in different directions: (a) along-wind ($\pm 5°$); (b) $30 \pm 5°$; (c) $60 \pm 5°$; (d) unidirectional spectra integrated over all angles; wind speeds (U_{10} in ms^{-1}) as indicated. From Jähne and Riemer (1990).

Allied processes

Microwave reflectivity

Techniques utilising active microwave backscatter from the sea surface have been investigated intensively for satellite remote sensing of fundamental ocean surface variables, such as ocean currents, sea state and wind stress. Reliable interpretation of the microwave returns requires a detailed understanding of the backscattering mechanisms. Wave tank investigations have established that Bragg backscatter plays a major role in the backscattering process but in the field context, where a broader wave spectrum often modulates the short wave components responsible for the backscatter, additional mechanisms may be operative. Microwave return signals are often characterised by intermittent spikey signatures, known as sea spikes. In particular, associated with steep waves and the onset of breaking, it has been demonstrated that specular and wedge scattering may occur [e.g. Kwoh *et al.* (1988)], while Banner and Fooks (1985) found the breaking regions of short gravity waves to be a significant source of strong microwave reflections, owing to the concentration of very short wave energy there, plausibly arising

from the instability of the intense shear layer formed by the spilling water. It is likely that these regions enhance the local Bragg backscatter, but the detailed backscattering mechanism was not resolved conclusively. Strong microwave returns from breaking waves in the field have been documented by Chaudhry and Moore (1984), Keller *et al.* (1986) and Jessup *et al.* (1990). These studies illustrate the intrinsic difficulties in deciding the threshold for the presence of spikes. Phillips (1988) investigated theoretically the relative contributions to the radar backscatter cross section from Bragg and sea spike returns, on the basis of his revised equilibrium range model [Phillips (1985)]. The choice of fixed threshold level as in Phillips (1988) and Jessup *et al.* (1990) detects spikes associated with larger-scale breaking waves, but misses contributions from smaller-scale breaking waves and thereby underestimates non-Bragg contributions. Nevertheless, the fractional sea spike power contribution reported by Jessup *et al.* (1990) was significant, particularly for HH polarisation. However, Plant and Keller (1990) argued that the dominant process is Bragg scattering via Doppler spectral broadening of the return signal rather than amplitude characteristics, and concluded that model calculations based on Bragg scattering were generally very close to the observations. Further research in this area is required to resolve the importance of sea spike contributions to the return signal, requiring an improved knowledge of the wavenumber spectrum for the very short wind wave components for checking the proportionality with the radar return power spectrum.

Bubble clouds

The entrainment of air in the wave breaking process produces a distinct visual signature and also alters the microwave emissivity and reflectivity in characteristic ways, many of which are exploited by downward looking electromagnetic remote sensing methods. The submerged bubbles alter the optical and acoustic properties of the near surface layer and various possibilities for upward looking remote sensing are being actively explored. A wide spectrum of air bubbles is entrained in a typical whitecap and the smallest of these remain to mark the passage of a breaker long after the surface, viewed from above, retains no further memory of it. These "bubble clouds" are significant acoustic scatterers, and may reveal various dispersive properties of the turbulence and trace the organized motions in the surface layers. The collection of papers in the first two NATO symposia on surface sound [Kerman (1988), (1991)] explore various aspects of bubble clouds including their effect on gas transfer and noise generation.

Underwater ambient noise generation

The physics of ambient noise generation by sea surface sources has received much attention in recent years, with whitecapping identified as a primary contributor. There is now a growing literature on both observations and models investigating the detailed mechanisms associated with sound generation by breaking waves. A major goal in this research is the prediction of the influence of wave breaking on the underwater ambient noise spectrum. While it has long been appreciated that noise generation is associated with the air bubbles in whitecaps, the bubble motions actually contributing significantly to noise generation had not been resolved observationally. Banner and Cato (1988) investigated the detailed configurations of bubbles in the spilling zones which were involved in active noise generation, and concluded that the process was dominated by noise bursts from only a subset of the bubbles present. The predominant noise bursts arose when bubbles relaxed after air was entrained at the toe of the breaker, when bubbles coalesced and when they collided impulsively. Interestingly, bursting bubbles at the surface were not a strong noise source, nor were most of the bubbles present, which were convected passively in the spilling zone. More recent related work by Pumphrey and Ffowcs Williams (1990) correlated bubble size with underwater noise bursts, and concluded that the lowest order bubble oscillation mode was dominant. Further discussion of related studies on breaking wave influence on noise generation are given in the recent symposium volumes [Kerman (1988, 1991)], with more recent contributions described in this symposium.

Conclusions

Wave breaking is a highly nonlinear aspect of ocean wave dynamics with a significant impact on the evolution of the wave spectrum as well as on fundamental transfers of momentum, energy and scalar quantities across the air-sea interface. It also enhances radar reflectivity of the sea surface and ambient underwater noise generation. A more complete understanding of the underlying physics of this conspicuous but incompletely understood process is required to improve the reliability of predictions from ocean wave, general circulation and climatological models.

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