WAVE TRANSFORMATION NEAR A QUASI-1D COAST

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ABSTRACT

Two sets of observations of wave transformation near two quasi one-dimensional coasts, from deep water (22 m) to shallow water (0.5 m) have been simulated with the third-generation spectral wave model SWAN. The first set of observations contains wind waves that are generated by a local storm off the North Sea coast of the Netherlands. The second set contains a mix of swell and local wind waves at the Pacific coast of Japan. Repeated computations without triad wave-wave interactions show that the inclusion of this process in the model is essential. A f ²-dependency of the depth-induced dissipation (rather than the conventional frequency independence in SWAN), causes too much energy dissipation in the high frequencies, shifting the mean frequency to too low values.

INTRODUCTION

As waves approach a gently sloping coast, both the significant wave height and the mean wave period are reduced. The former is mostly due to depth-induced breaking. The latter can be ascribed to a transfer of energy from lower frequencies to higher frequencies (triad wave-wave interactions; e.g. Beji and Battjes, 1994) which is often evident from the generation of a secondary high-frequency peak in the observed spectra. To properly describe and understand such evolution, field observations and models that take into account the relevant physical processes are required. In the present study, observations of such waves approaching two, quasi-1D coasts (one in the Netherlands and one in Japan) are modelled with a third-generation spectral wave model. The computational results are compared with observations.

THE OBSERVATIONS

The waves that are considered in this study have been observed off the beach near the town of Petten in the Netherlands (waves from the southern North Sea; courtesy Ministry

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The bathymetry and observation locations off the Petten coast.





of Transport, Public Works and Water Management, the Netherlands) and off the beach at the Kashimanada coast in Japan (waves from the Pacific Ocean; courtesy Hazaki Oceanographical Research Facility, Port and Harbour Research Institute, Japan; Nakamura and Katoh, 1992). In both cases the coast is rather straight with two sand bars (Figs. 1 and 2).

The observations are made from deep water to the shore, along a line normal to the beach over a distance of about 8.3 km in the Petten case (from 22.0 m to 4.2 m water depth). The data set from Kashima overlaps this range on the shallow water with the observations starting at about 300 m from shore, from 5.4 m to 0.5 m water depth. Several



triad wave-wave interactions.

techniques were used to measure the waves along these transects: buoys (directional and omni-directional), wave gauges and a pressure transducer (Petten) and ultra-sonic wave gauges (Kashima). From the Petten data set, a storm situation is selected with a uni-modal, deep-water spectrum (characteristic for a local storm in a sheltered sea). It has been described by Eldeberky et al. (1997). From the Kashima data set a situation is available with a bi-modal, deep-water spectrum (characteristic for the mix of wind sea and swell along an open oceanic coast). It has been described by Beji and Nadaoka (1998). In the Petten case, the wind speed was 18.6 m/s, the deep-water significant wave height was 4.61 m and the mean wave period was 8.4 s (peak period 10.0 s). In this case the (uni-modal) spectrum shows qualitatively the above described characteristic behaviour as the waves propagate along the transect. In the measurements the significant wave height reduces to 3.07 m at the shallowest station. Remarkably the observed significant wave height-to-depth ratio remains well above the value of 0.4 which is often used in engineering practice. The mean wave period reduces to about 6.4 s while the peak period remains constant. In the Kashima case, the wind is ignored, the deep-water significant wave height was 1.68 m and the mean wave period was 5.7 s (peak period 14.9 s). Here the observed wave height reduces to 0.32 m at the shallowest station (0.5 m water depth so that the observed ratio of significant wave height-to-depth ratio equals 0.64). The evolution of the observed spectra and of the significant wave height H_s and the mean wave period \overline{T} defined as $H_s = 4\sqrt{m_0}$ and $\overline{T} = 2\pi (m_1/m_0)^{-1}$ where $m_n = \int \int \sigma^n E(\sigma, \theta) d\sigma d\theta$, are given in Figs. 3 through 6.





THE WAVE MODEL

The wave model is a discrete spectral model which is based on the action balance equation of random, short-crested waves (the SWAN wave model; e.g. Booij et al., 1996). It is a discrete spectral model based on the action balance equation which for Cartesian coordinates is

$$\frac{\partial}{\partial t}N + \frac{\partial}{\partial x}c_xN + \frac{\partial}{\partial y}c_yN + \frac{\partial}{\partial \sigma}c_oN + \frac{\partial}{\partial \theta}c_{\theta}N = \frac{S}{\sigma}$$
(1)

in which $N(\sigma, \theta, x, y, t)$ is the action density as a function of intrinsic frequency σ , direction θ , horizontal coordinates x and y and time t. The first term in the left-hand side of this equation represents the local rate of change of action density in time, the second and third term represent propagation of action in geographical space (with propagation velocities in x- and y-space, c_x and c_y respectively). The fourth term represents shifting of the intrinsic frequency due to variations in depths and currents (with propagation velocity in σ -space, c_{σ}). The fifth term represents depth- and current-induced refraction (with propagation velocity in θ -space, c_{θ}). The source terms are taken from the WAM model (WAM Cycle 3; WAMDI, 1988: exponential growth by wind, quadruplet wave-wave interactions, whitecapping and bottom friction). They are supplemented with a spectral version of the dissipation model for depth-induced breaking of Battjes and Janssen (1978)and a discrete interaction approximation for the triad wave-wave interactions (Eldeberky 1996). It was verified that the processes of depth-induced wave breaking and



triad wave-wave interactions dominate the evolution of the waves in the present study. The formulations of these processes is therefore briefly addressed here.

Laboratory observations (e.g., Battjes and Beji, 1992; Vincent et al. 1994; Arcilla et al., 1994 and Eldeberky and Battjes, 1996) have shown that the shape of initially uni-modal spectra propagating across simple (barred) beach profiles, is fairly insensitive to depth-induced breaking. This has led Eldeberky and Battjes (1995) to formulate a spectral version of the bore model of Battjes and Janssen (1978) which conserves the spectral shape. Expanding their expression to include directions, the expression that is used in SWAN is:

$$S_{ds,br}(\sigma,\theta) = -\frac{D_{tot}}{E_{tot}}E(\sigma,\theta)$$
(2)

in which E_{tot} is the total wave energy and D_{tot} is the rate of dissipation of the total energy due to wave breaking according to Battjes and Janssen (1978). The value of D_{tot} depends critically on the breaking parameter $\gamma = H_{max}/d$ (in which H_{max} is the maximum possible individual wave height in the local water depth d). The value in the SWAN computations is $\gamma = 0.73$ (the mean value of the data set of Battjes and Stive, 1985).

A first attempt to describe triad wave-wave interactions in terms of a spectral energy source term was made by Abreu et al. (1992). However, their expression is restricted to non-dispersive shallow water waves and is therefore not suitable in many practical applications of wind waves. The breakthrough in the development came with the work of Eldeberky and Battjes (1995) who transformed the amplitude part of the Boussinesq model of Madsen and Sørensen (1993) into an energy density formulation and who parameterized the biphase of the waves on the basis of laboratory observations (Battjes and Beji, 1992; Arcilla et al., 1994). A discrete triad approximation (DTA) for co-linear waves was



The observed and computed spectra for the Kashima case.

subsequently obtained by considering only the dominant self-self interactions. Their model has been verified with flume observations of long-crested, random waves breaking over a submerged bar (Beji and Battjes, 1993) and over a barred beach (Arcilla et al., 1994). The model appeared to be fairly successful in describing the essential features of the energy transfer from the primary peak of the spectrum to the super harmonics. The slightly different version of Eldeberky (1996) is used in SWAN (the lumped triad approximation).

COMPUTATIONS AND RESULTS

The Petten case has been computed as a two-dimensional case (although the coast is fairly straight) with the two-dimensional spectrum at deep-water taken from the observations (a directional buoy at station 1, Figs.1 and 5). The Kashima case has been computed as a one-dimensional case (see Beji and Nadaoka, 1998) with the twodimensional, deep-water spectrum constructed from the observed one-dimensional spectrum with the assumption that the mean wave direction is normal to the shore and that the directional spreading is relatively narrow for the swell part of the spectrum ($\sigma_{\rm e} = 5^{\circ}$ for f < 0.1 Hz) and typical for wind sea for the higher frequencies ($\sigma_{\rm p} = 30^{\circ}$ for f > 0.1 Hz). For both cases the model results in terms of the significant wave height and the mean wave period are shown in Figs. 3 and 4, respectively. The agreement with the observations is fairly good with a slightly better model performance in the Petten case than in the Kashima case: the rms-error in the significant wave height and mean wave period are about 7 % and 5 % of the deep water values respectively in the Petten case, versus 7 % and 16 % in the Kashima case. The difference in performance is also illustrated with the computed spectra in Fig. 5 and 6 where it is obvious that the amount of energy at the peak frequency for the shallowest stations is slightly better predicted in the Petten case.



wave-wave interactions, compared with measured data (compare with Fig. 5).

DISCUSSION

As noted above, the computations were carried out with triad wave-wave interactions active. To illustrate the effect of these triad wave-wave interactions, the computations have been repeated without these interactions. The results in terms of significant wave height and mean wave period are shown in Figs. 3 and 4 and in terms of the spectra in Figs. 7 and 8. It is evident that the significant wave height is only marginally affected but that the mean wave period is greatly affected, especially in the shallowest region. The inclusion of these interactions also gives a much better agreement with the observations of the spectra (notably near the low-frequency peak).

In the above computations, the spectral distribution of the depth-induced wave breaking is proportional to the energy density and independent of frequency. This is based on observations of initially unimodal spectra. However, Mase and Kirby (1992, supported by Elgar et al., 1997) found a f²-dependency in many observations, although Chen et al. (1997) inferred from observations and simulations with a Boussinesq model that the high-frequency (i.e. above the lowest peak frequency) levels in the spectra are insensitive to such frequency dependency. This is due the approximate compensation of the increased dissipation at high frequencies by increased nonlinear energy transfer (but they did find the frequency dependency to be relevant in time domain). To investigate this for the Kashima case, the computations have been repeated for this case with such f²-dependency (F = 0 in the notation of Chen et al., 1997). The results are shown in Figs. 9 and 10. The significant wave height is only marginally affected but the mean wave period is significantly affected in the shallowest region. The spectra at stations 4 and 5 show that this



 $\sigma_{\theta} = 30^{\circ}$ for f > 0.1 Hz), compared with measured data (compare with Fig. 6).

is due the overestimation of the amount of energy at the lower frequencies.

Separate computations with individual processes of generation, dissipation and wavewave interactions de-activated show the relatively minor importance of wind generation, bottom friction, whitecapping and quadruplet wave-wave interactions and the dominant effect of depth-induced wave breaking and triad wave-wave interactions.

CONCLUSIONS

The observed evolutions of a uni-modal spectrum and of a bi-modal spectrum, approaching a gently sloping, barred coast of a shelf sea (North Sea) and an oceanic coast (Pacific Ocean) respectively have been numerically simulated with the third-generation SWAN wave model. The agreement between the observed and computed evolution, both in terms of integral wave parameters and spectra is rather good. Repeated computations without triad wave-wave interactions show that the inclusion of this process in the model is essential. A f²-dependency of the depth-induced dissipation (rather than the conventional frequency independence in SWAN), causes too much energy dissipation in the high frequencies, shifting the mean frequency to too low values.



Fig. 9 The observed and computed significant wave height and mean wave period for the Kashima case, with and without f²-dependency of depth-induced breaking (F=0).



Fig. 10 The computed spectra for the Kashima case with and without f^2 -dependency of depth-induced breaking (F=0).

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