The effects of swell and wave steepness on wave growth and depth-induced wave breaking

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INTRODUCTION

Several authors have inferred from wave observations in the laboratory that the presence of swell may significantly reduce or enhance the growth of wind sea, depending on the direction of the swell relative to the wind (Donelan, 1987; Mitsuyasu and Yoshida, 1989). These two observed and opposite effects of swell may have operational importance, as they are not accounted for in third-generation wave models such as WAM (WAMDI, 1988) or SWAN (which is based on the WAM formulations; Booij et al., 1999).

Depth-induced breaking of waves (surf breaking) is usually modeled with a random-bore model. The Battjes and Janssen (1978) model, which is used in SWAN, tends to overestimate the dissipation with the default value for the maximum wave height –to-depth ratio of 0.73. Moreover, the nominal fraction of breakers in this model is considerably higher than observed, at least for steep bottom slopes.

SWELL

Komen et al. (1984) suggested that dissipation due to whitecapping scales with the overall steepness of the waves. This suggestion has been implemented in the WAM model and the SWAN model. It implies that when swell is added to a pure wind sea (and therefore the overall steepness decreases), the net growth of the wind sea increases sharply. This is in remarkable disagreement with the laboratory observations of Donelan (1987), as illustrated in Fig. 1. We speculated earlier (Holthuijsen et al., 2000) that decoupling low-frequency steepness from high-frequency steepness and adding a straining effect at the crests of the swell would result in more realistic results. That indeed, correctly reduces the growth in the presence of swell but it has the same effect for an opposing swell where the effect should be the inverse. In the present study, we follow the suggestion of Mitsuyasu (1997) that, at the crest of an opposing swell, the orbital motion reduces the propagation speed of the wind waves. This would enhance the exposure (residence time) of the wind sea to the wind. In the troughs of the swell, the opposite would be the case but to a lesser extent. For a following swell the inverse would be the case. This suggestion was implemented in SWAN (in addition to decoupling the low-frequency steepness from the high-frequency steepness) and the results show that this indeed enhances growth in the presence of an opposing swell and reduces growth in the presence of a following swell. The results are also quantitatively in good agreement with the experiments of Donelan (1987) and Mitsuyasu and Yoshida (1989) as shown in Fig. 2.

WAVE STEEPNESS

The random-bore model of Battjes and Janssen (1978) is usually applied with a Rayleigh distribution for the wave heights that is clipped at some maximum wave height obtained from a fixed depth-to-wave height ratio. Observations show that a full Rayleigh distribution is a better approximation. The results obtained with the correspondingly adapted Battjes-Janssen model (Baldock et al., 1998) in SWAN are compared with observations in the field (Petten, the Netherlands; DUCK'94, Vincent and Smith, 2000) and in a laboratory (Baldock et al., 1998). On gentle, to fairly steep bottom slopes (in the field; in the laboratory with 1:80 and 1:30 bottom slopes) the model shows only marginal improvements. However, on steep bottom slopes (1:10), both the fraction of breakers and the significant wave height are significantly better estimated (error in fraction of breakers of order 100% reduces to about 10%; error in significant wave of 10-20% reduces to 5-10%).

Replacing the fixed depth-to-wave height ratio with a ratio that depends on the local wave steepness (in analogy with the suggestion of Battjes and Stive, 1985 to use the deep-water steepness) improves the estimates of the significant wave heights significantly. A comparison with the same observations shows an improvement from an underestimation of 5-30% to a nearly bias-free error of 5-10% in the field and an error of less than 5% in the laboratory cases (including the case with 1:10 bottom slope).

TESTBED

The version of SWAN with the new codes will be applied to the ONR test bed that includes several dozen field cases and laboratory cases (Ris et al., 2002). The resulting scores will be presented.

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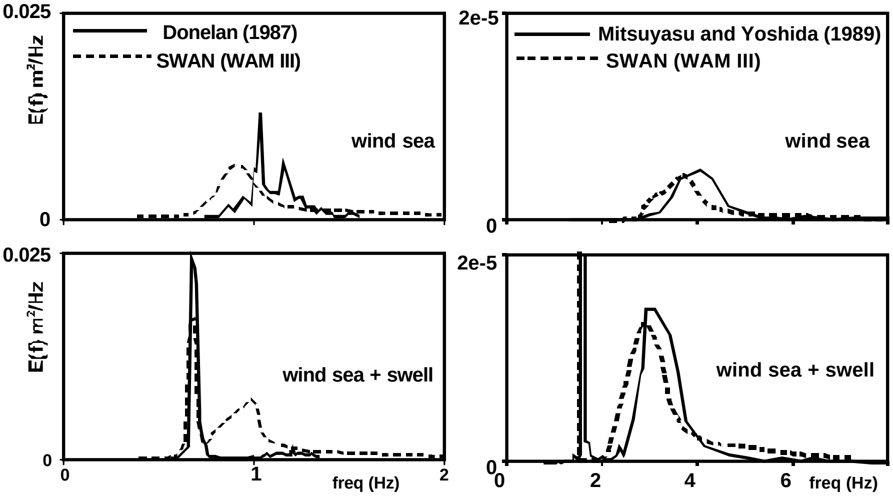

Fig. 1 The observations of Donelan (1987) and of Mitsuyasu and Yoshida (1989) and the results of the WAM III model. Upper panels = wind sea generated in a wind flume without swell. Lower panels = wind sea generated by wind in the presence of mechanically generated swell, left = following swell, right = opposing swell. In the observations, the wind sea is suppressed by the following swell (lower left panel) and enhanced by the opposing swell (lower right panel). WAM III performs poorly for the following swell but it performs well for the opposing swell.

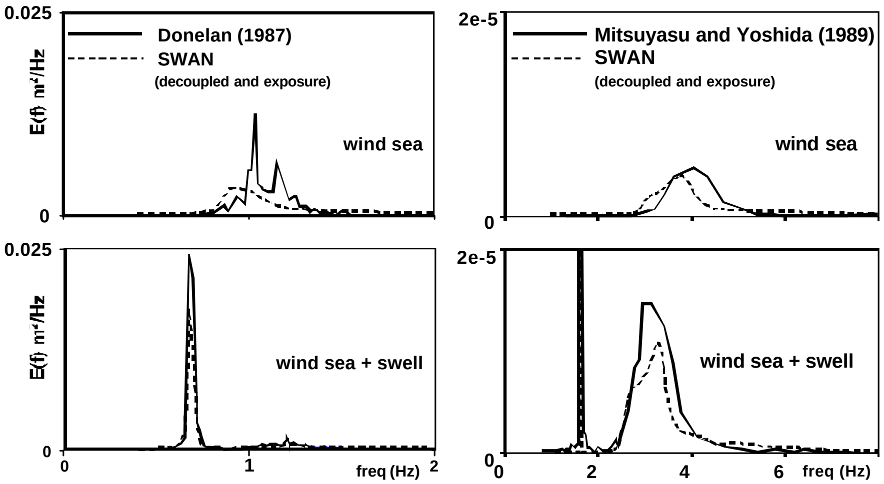

Fig. 2 The observations of Donelan (1987) and of Mitsuyasu and Yoshida (1989) and the results of decoupling the low-frequency steepness from the high-frequency steepness and of adding the exposure hypothesis in SWAN. Upper panels = wind sea generated in a wind flume without swell. Lower panels = wind sea generated by wind in the presence of mechanically generated swell, left = following swell, right = opposing swell. SWAN performs well for both the following and opposing swell.