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Addendum to "Effects of sea roughness and atmospheric stability on wind wave growth"

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1. Introduction

Myrhaug and Slaattelid (2002) (hereafter referred to as MS) considered the effects of sea surface roughness and atmospheric stability on the wind wave growth using the logarithmic boundary layer profile including a stability function, combined with some commonly used sea surface roughness formulations. Since no consistent sea surface roughness formulations existed in the literature at that time, MS chose to demonstrate how the results varied by using two roughness formulas having significantly different behaviour. MS used the Toba et al. (1990) formula where the roughness increases as the wave age increases, and the Smith et al. (1992) formula where the roughness decreases as the wave age increases (see Table 2, MS). The wave age independent Charnock (1955) formula was used as a reference. Since then an expression for the sea surface roughness has been provided by Volkov (2001). The purpose of this note is to use the Volkov (2001) roughness formula and to present similar results as in MS. Volkov concludes that simple power law formulas like that proposed by e.g. Toba et al. and Smith et al. for the dependency of roughness with wave age are not adequate. At present state of knowledge he suggests the model given by

$$\begin{aligned} z_0^* &= 0.03x\exp(-0.14x) \text{ for } 0.35 < x < 35 \\ z_0^* &= 0.008 \text{ for } 35 \leq x \end{aligned} \tag{1}$$

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where $z_0^* = gz_0/u_*^2$ is the dimensionless roughness, and x $= c_p/u_*$ is the wave age. Moreover, g is the acceleration of gravity, z_0 is the sea surface roughness length, u_* is the friction velocity equal to the square root of the vertical flux of horizontal momentum at the surface, and c_p is the phase speed associated with wind waves with peak frequency σ_p. Eq. (1) is obtained as a reasonable fit to existing data (see Fig. 10.6, Volkov (2001)). The non-dimensional roughness has a maximum value at c_p/u_* around 10 (see Fig. 1.15, Jones et al. (2001)), and for $c_p/u_* > 35$, corresponding to light wind over swell, the sea surface becomes smooth with a non-dimensional roughness near 0.01. So, essentially Eq. (1) behaves as the Toba et al. roughness for very young waves and as the Smith et al. roughness for fully developed waves. Volkov's expression seems to be a reasonable compromise between simplicity and accuracy based on the present state of knowledge. Further background and details are given in Volkov (2001) and Jones et al. (2001).

2. Results and discussion

Firstly, used as a reference case in MS, some results for neutral stability will be given.

Fig. 1 shows the non-dimensional total energy for neutral stability ε_n versus the wave age $c_p/U_{10} = gT_p/2\pi U_{10}$ according to Toba et al., Donelan et al. (1993) and Volkov. One should note that Fig. 1 excluding the Volkov results is the same as Fig. 1 in MS. Here $T_p = 2\pi/\sigma_p$ is the peak period, and U_{10} is the mean wind velocity at the 10 m elevation. The non-dimensional total wave energy is defined as

$$\varepsilon = \frac{g^2 E}{U_{10}^4};\ E = \frac{H_s^2}{16} \tag{2}$$

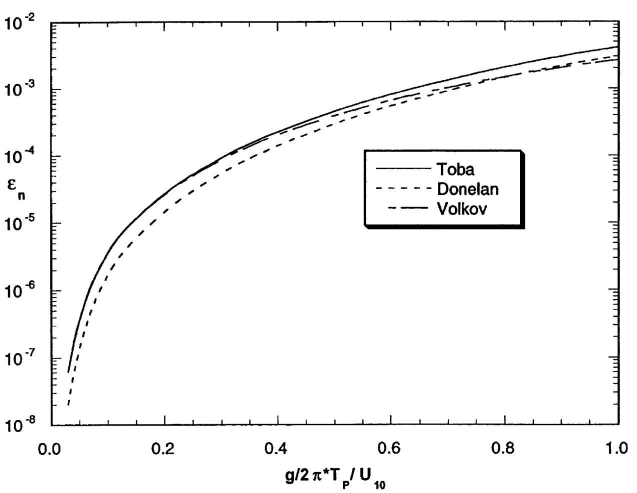

Fig. 1. Non-dimensional total energy for neutral flow versus wave age according to Toba et al. (1990); Donelan et al. (1993) and Volkov (2001).

where E is the wave energy, and H_s is the significant wave height taken as

$$H_s = 0.058 g^{1/2} u_*^2 \left(\frac{T_p}{u_*} \right)^{3/2} \tag{3}$$

Now u_* is determined from Eq. (6) in MS for neutral stability using the z_0-formulas according to Toba et al., Donelan et al. (see Eq. (11), MS) and Volkov. More specifically, Eq. (2) takes the form in Eq. (13) in MS for the models of Toba et al. and Volkov; Eq. (2) takes the form in Eq. (14) in MS for the Donelan et al. model, which is stability invariant. More details are given in MS. One should note that according to the Donelan et al. z_0-formula, z_0 decreases as the wave age increases, as Volkov's formula does for higher wave ages. From Fig. 1 it appears that ε_n, and thus H_s, increase as the wave age increases, similar to the behavior of the Toba et al. and Donelan et al. models. For young waves the Volkov model gives very similar results as the Toba et al. results, while it approaches the Donelan et al. results as the wave age increases, and it becomes slightly lower than the Donelan et al. results for fully developed waves.

Fig. 2 shows the deviation of non-dimensional total wave energy from the results for neutral stability $\xi = (\varepsilon - \varepsilon_n)/\varepsilon_n$ versus the stability z_{10}/L for different wave ages c_p/U_{10}. ξ represents the wind wave growth relative to neutral stability, $z_{10} = 10$m, and L is the Monin-Obukhov length. More specifically, ξ takes the form in Eq. (15) in MS, and the results in Fig. 2 are obtained by using the Volkov roughness formula in Eq. (1) for $0.35 < c_p/u_* < 35$. For a given wave age the results are qualitatively the same as those given in Figs. 3 and 4 in MS representing the Toba et al. and Smith et al. roughness formulas, respectively. However, for a given stability the results are qualitatively the same as those for the Toba et al. formula for both unstable

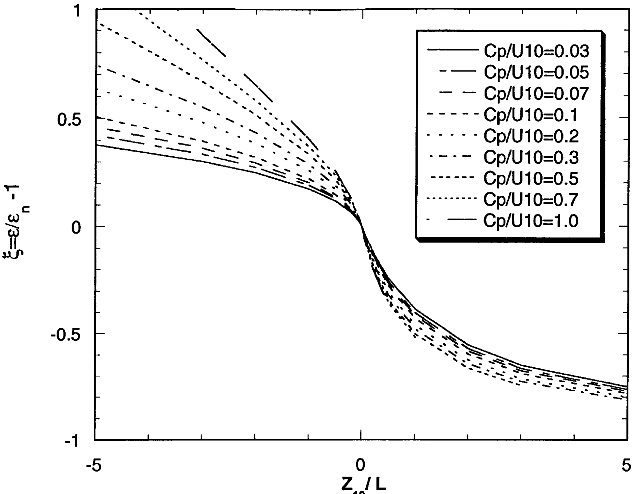

Fig. 2. Deviation of non-dimensional energy from neutral stability versus stability and wave age according to Eq. (15) in MS using Volkov's (2001) roughness parameter for $0.35 < c_p/u_* < 35$.

($z_{10}/L < 0$) and stable ($z_{10}/L > 0$) conditions. Apriori these results appear to be inconsistent with the behavior of Volkov's roughness formula in Eq. (1), since it follows the Toba et al. formula for very young waves and the Smith et al. formula for fully developed waves. However, there is no reason to believe that the results are not correct. It should be noted that the drag coefficient C_D as well as the neutral drag coefficient C_{Dn} both have a behavior consistent with the Volkov roughness formula (see Eqs. (7) and (8), MS). The expression for ξ in Eq. (15) in MS contains the ratio C_D/C_{Dn}, and the result is as shown in Fig. 2. Moreover, as noted in MS, it is observed that the wave growth dependence on the stability is generally an order of magnitude larger than the dependence on the wave age.

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