MEMORANDUM
RESEARCH DEPARTMENT

To: Jean Bidlot and Saleh Abdalla

From: Peter Janssen

Date: September 24, 2004

Subject: A suggestion for a slightly different wave dissipation formulation

Abstract

Presently the dissipation source function is formulated in terms of a mean steepness parameter s that is based on the product of significant wave height and the square of the f^{-1} moment. This choice of mean steepness emphasizes the low-frequency contributions. In particular, in the presence of low-frequency swell the mean steepness is to a considerable extent determined by swell. This is not the intention. In this note the consequences of a different choice of mean steepness, based on the first wavenumber moment, are briefly discussed. This choice of steepness parameter gives more emphasis on the high-frequencies and results in a more realistic interaction between windsea and swell.

1 Introduction.

In the ECWAM model wave dissipation due to white capping, S_{ds}, is modelled in the manner suggested by Hasselmann (1974).

Introduce the mean frequency $\langle\omega\rangle$ by means of the inverse mean frequency,

$$\langle\omega\rangle = \int d\vec{k}\ F(\vec{k}) / \int d\vec{k}\ F(\vec{k})/\omega \tag{1}$$

with F the wavenumber spectrum, and a similar relation for the mean wavenumber $\langle k\rangle$,

$$\sqrt{\langle k\rangle} = \int d\vec{k}\ F(\vec{k}) / \int d\vec{k}\ F(\vec{k})/\sqrt{k}. \tag{2}$$

Hasselmann (1974) suggested the following dissipation source function

$$S_{ds} = -\gamma_d F, \tag{3}$$

with

$$\gamma_d = \beta \langle \omega \rangle \; s^{2m} \; \left[(1-a)\frac{k}{\langle k \rangle} + a \left(\frac{k}{\langle k \rangle} \right)^2 + \; ... \right], \tag{4}$$

where

$$s^2 = \langle k \rangle^2 m_0 \tag{5}$$

Here, β, a and m are constants which still need to be determined. It is remarked that in the original work of Hasselmann (1974) the second term in the square bracket is absent. The reason for this is that Hasselmann assumed a large separation between the length scale of the waves and the white caps, giving a power 1 for the wavenumber in the dissipation term. For the high-frequency part of the wave spectrum, however, such a large gap between waves and white caps may not exist, therefore allowing the possibility of a different dependence of dissipation on wavenumber.

The first rationale attempt to determine the unknown coefficients in the dissipation source function was reported by Komen et al (1984). These authors started from the empirical expression for wind input of Snyder et al (1981), which was adapted to accomodate friction velocity scaling, whilst the exact form of Hasselmann's nonlinear transfer was taken. For a constant wind speed, the energy balance equation was integrated until stationary conditions were reached, and the unknown coefficients m and β were chosen in such a way that the equilibrium spectrum resembled the Pierson-Moskovitz (1964) spectrum as closely as possible (Note that in their work a was put to zero from the outset). The power m was found to be equal to 2 while the coefficient β was of the order of 3.

Later, Janssen introduced a wind input source function based on Miles theory, which resulted in much higher inputs at higher frequencies. Consequently, the dissipation source function required some adaptation, in particular at higher frequencies. He fixed m to 2 and he found, using the DIA approximation to the nonlinear transfer, optimal results for $a = 0.5$ and $\beta = 4.5$.

The choice of the definition of mean steepness requires some discussion, however. By choosing an inverse moment there is too much emphasis on the low-frequency part of the spectrum, which in particular in cases of windsea- swell interaction may give rise to non-desirable evolution of the wave spectrum. In this note we choose a steepness parameter s which is based on the first wavenumber moment. Hence, we redefine the mean wave number as

$$\langle k \rangle = \int d\vec{k} \; kF(\vec{k}) / \int d\vec{k} \; F(\vec{k}). \tag{6}$$

and we use this new definition in the expression for the mean square steepnes given in Eq. (5).

Another point of concern is the choice of the prognostic frequency range. Since July 1999 the ECWAM model uses as definition of prognostic range range all those frequencies f with

$$f \leq 2.5 f_{mean}, \tag{7}$$

with $f_{mean} = \langle\omega\rangle/(2\pi)$, replacing the previous definition of WAMcy4, where the upper frequency was given by $\max(2.5f_{mean}, 4f_{PM})$ (with f_{PM} the Pierson-Moskovitz frequency). This change had a favourable impact on relations such as the mean square slope versus wind speed while, compared to ERS-2 Altimeter wave height data, the first-guess wave height error reduced by 5%. However, in light wind conditions in the presence of low-frequency swells, it is very likely that no windsea is generated. Although this is a relatively minor problem, it will effect verification statistics for the mean period (as pointed out Kumar et al (2003) and by Oceanor near the coast of India). Therefore, it would be desirable to introduce a larger prognostic frequency range to capture windseas in light wind situations. However, this should be done in such a way that relations such as mean square slope and Charnock parameter versus wind speed do not suffer. In the present note we will revert to the WAMcy4 definition of the prognostic range, hence all frequencies are treated dynamically that satisfy the inequality

$$f \leq f_{max}, \ f_{max} = \max(2.5 f_{mean}, 4 f_{PM}) \tag{8}$$

A tuning exercize was performed in such a way that the duration limited growth curve for significant wave height and the time evolution of the Charnock parameter resembled as much as possible the corresponding results of the reference model (which is essentially

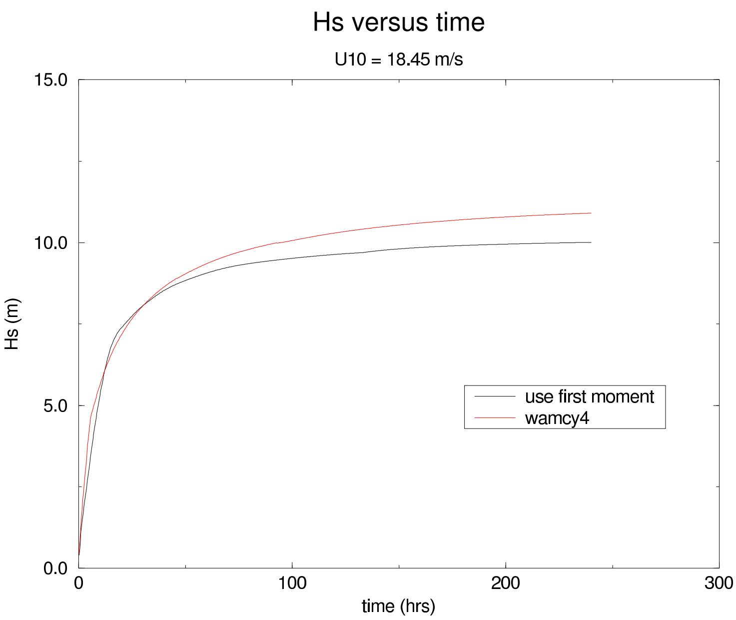

Figure 1: Time evolution of significant wave height over a 10-day period. The wind speed is 18.45 m/s. The new setup shows more definite signs of saturation.

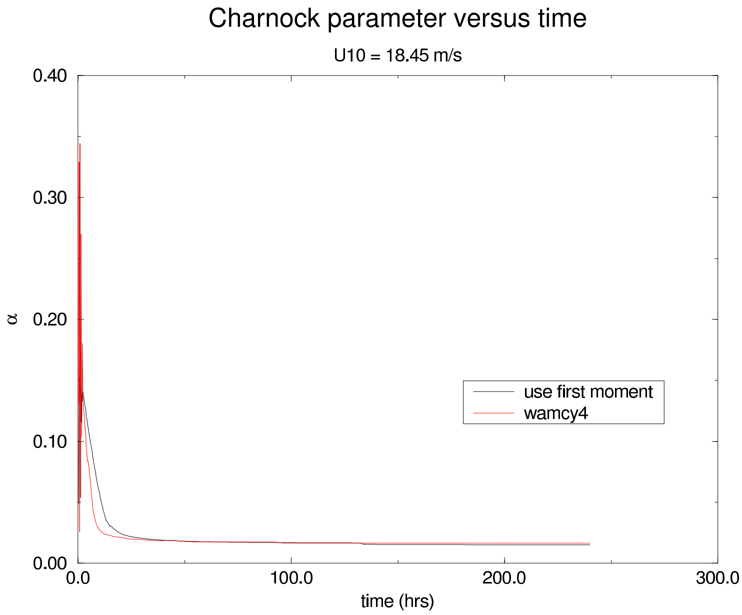

Figure 2: Time evolution of Charnock parameter over a 10-day period. The wind speed is 18.45 m/s. The parameter α has been chosen in such a way that for large times there is agreement between new set up and reference run.

WAM cy4, but using Eq. (7)). As a result it was found that

$$\beta = 1.15,\ a = 0.5,\ \text{and}\ \alpha = 0.0095 \tag{9}$$

where α, which is a constant that controls the asymptotic value of the Charnock parameter, was only changed by 5%.

Finally, we found that for light winds the Hersbach-Janssen limiter to the wave growth was too liberal and we reduced it by a factor of 0.4.

2 Results.

In Fig.1 we compare wave height evolution for the new model with the reference run over a 10-day period. Windspeed was 18.45 m/s. The resemblence is satisfactory, but it cannot be perfect for the following two reasons: 1) for short times the growth limiter is more effective in the new model configuration resulting in less fast growth, and, because of the new steepness definition 2) the new set up shows more definite signs of saturation for long times. For large winds the saturation in wave height only plays a role for very large duration, hence it is not expected that extreme sea states are effected by this change. This may be a different story for light wind cases where saturation already occurs during one day.

In Fig.2 we display the time evolution of the Charnock parameter. The parameter α has been chosen in such a way that for large times there is agreement between new set up and reference run. The larger values of the Charnock parameter in the reference run at initial time are caused by the too liberal limiter on wave growth.

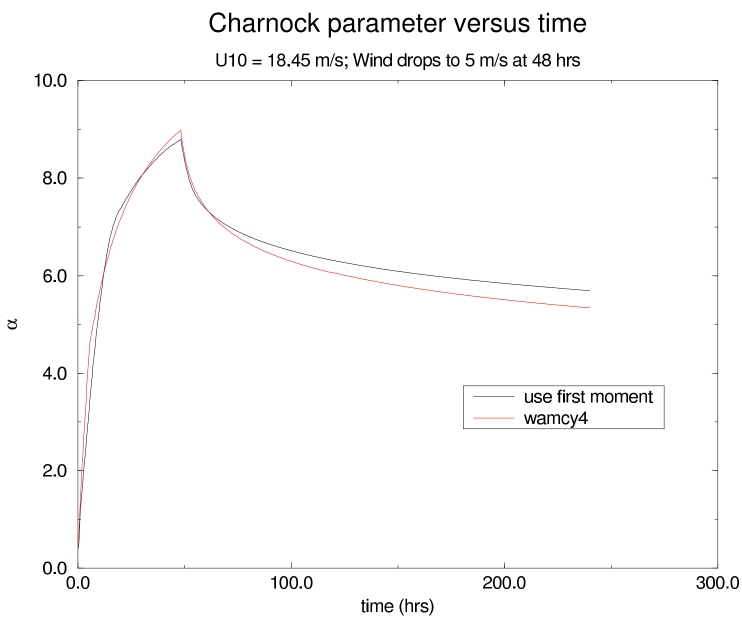

Figure 3: Time evolution of significant wave height over a 10-day period. Initially the wind speed is 18.45 m/s, and after 48 hrs it drops to 5 m/s.

The next experiment I did was to compare the decay of swell. Thus I run the models for 2 days with a constant wind of 18.45 m/s, after which the windspeed dropped to 5 m/s while the wind direction turned by 90 deg. Results for significant wave height are shown in Fig.3. Decay time scales in the new setup are slightly longer because the dissipation source function is a more sensitive function of the sea state.

The final set of experiments were performed with the aim to investigate the impact of the presence of low-frequency swell on the growth of windsea. To that end we the swell spectrum was a Pierson-Moskovitz spectrum with a peak frequency of 0.0588 and a Phillips parameter α_p 0f 0.00012. The swell propagated in the wind direction. For a windspeed of 8.45 m/s we show in Fig.4 what happens according to the old model configuration.

With the definition of prognostic range given in Eq. (7) no windsea is generated, while with a wider frequency range (i.e. Eq. (7)) windsea is generated but after a few hours the windsea in the presence of swell is larger than in the absence of swell. This was not the intention of the original WAM development. The reason for the too large windsea in the presence of swell is in the definition of the mean square slope. In the old setup the mean wave number according to Eq. (2) is used, which gives a considerable emphasis on the low frequencies. In the new setup we use Eq. (6) and results for the interaction of windsea and swell are shown in Fig. 5. The new setup now gives a satisfactory qualitative behaviour of the interaction of windsea and swell.

This also follows from the time evolution of the frequency spectrum as shown in Fig. 6

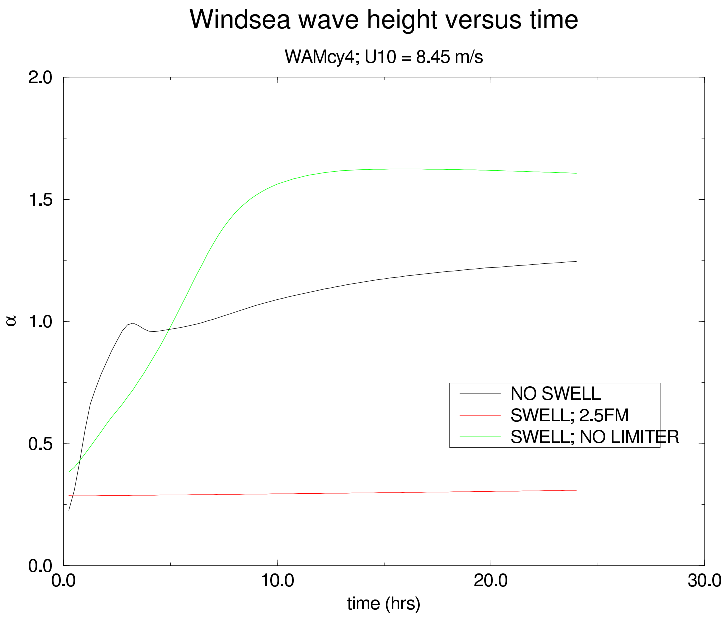

Figure 4: Time evolution of windsea wave height in the presence of swell. over a one-day period. The wind speed is 8.45 m/s. The default setup does not give any growth of windsea.

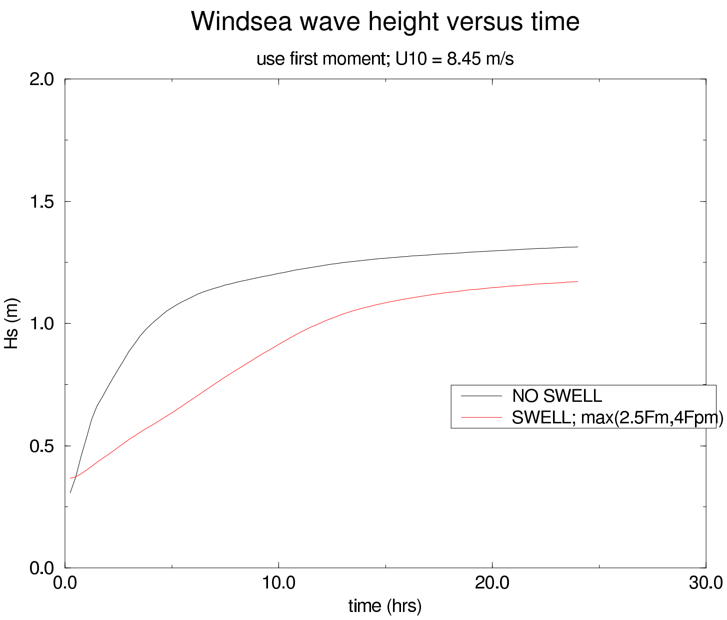

Figure 5: Time evolution of windsea wave height in the presence of swell. over a one-day period. The wind speed is 8.45 m/s. The new setup gives a qualitative correct growth of windsea.

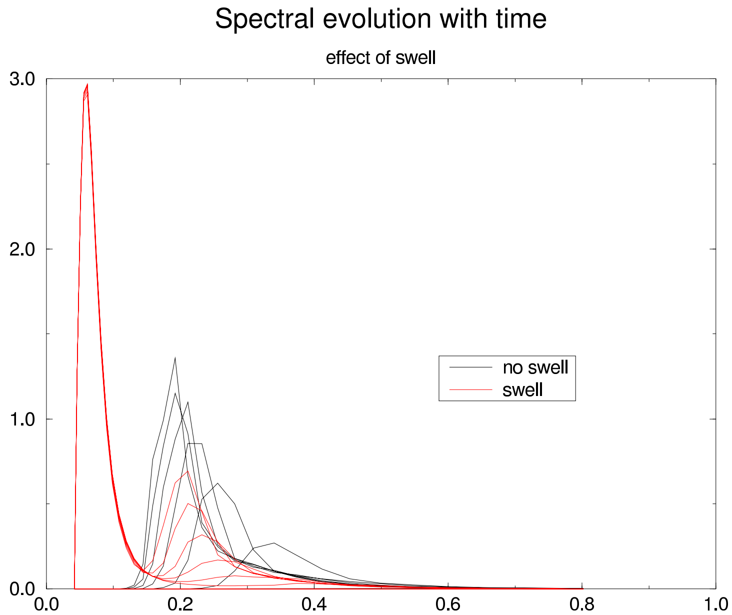

Figure 6: Time evolution of frequency spectra, shown every 2 hrs, in case low frequency swell is present. The wind speed is 18.45 m/s. Results are shown for the new setup, and for reference spectral evolution for pure windsea is shown as well.

3 Conclusions.

We have presented arguments why the present model configuration is not beahving in a satisfactory manner for the case of the interaction of windsea and swell. Using a definition of mean square slope that puts more emphasis on the high frequencies, seems to alleviate the problem.

Further experimentation is required to determine whether the new version of windsea-swell interaction is also quantitatively correct.

References