

Fig. 4 The observations and the results of the SWAN model with high-frequency whitecapping decoupled from low-frequency wave steepness and with the exposure effect included.

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#### IMPROVING PROPAGATION IN OCEAN WAVE MODELS <sup>1</sup>

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**Abstract** Intermediate results of ongoing research at NCEP to improve the accuracy and economics of wave propagation in large-scale wind wave models are presented. The main attention is focussed on new solutions for the so-called Garden Sprinkler Effect. Also briefly discussed are the need for higher spectral resolution and plans to deal with unresolved islands by sub-grid treatment rather than by increasing spatial resolution.

#### INTRODUCTION

Ocean wind wave models generally solve some form of the spectral energy balance equation

$$\frac{\partial E}{\partial t} + \nabla \cdot cE = S, \quad (1)$$

where  $E$  represents the spectrum,  $c$  the advection velocities in both spectral and physical spaces, and  $S$  describes non-conservative processes. The second term on the left represents effects of propagation. In the deep ocean, effects of propagation are, from a physical perspective, simple to describe; wave energy propagates along great circles subject to dispersion in all spaces. Both propagation and dispersion are inherently linear. From a numerical perspective, however, wave propagation in the deep ocean poses major problems. In arbitrary order, the three major problems are:

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- Selection of the numerical scheme. The scheme has to be accurate for propagation, while being positive definite (no generation of negative energy) and free of notable spurious solutions (i.e. 'wiggles'). Note that selecting a scheme with the above properties will generally also avoid most numerical problems for shallow water propagation with strong refraction (not discussed in the present paper).
- Alleviation of the so-called 'Garden Sprinkler Effect' (GSE). This subject will be discussed in detail in the following section.
- Determining and/or attaining required resolutions.

In the present paper these issues will be discussed in the context of the ocean wave model WAVEWATCH III (Tolman and Chalikov 1996, Tolman 1999), which is now the operational forecast model at NCEP. New concepts as discussed here are implemented in, and illustrated with the present experimental version of this model. New methods are also tentatively targeted for inclusion in the next public release of this model.

Although development of adequate propagation schemes is far from trivial, this problem for wave models is shared with many other fields in numerical engineering. Rather than reinventing the wheel, it makes much more sense to adopt experience from other fields from either text books like Fletcher (1988), or from comprehensive comparisons of existing schemes like Falconer and Calhoun (1993). Using such an approach, Tolman (1995) selected the third-order accurate ULTIMATE QUICKEST scheme of Leonard (1979, 1991) for use in WAVEWATCH III. Although there is always room for incremental improvement in accuracy and/or economy, this scheme at present seems satisfactory. Therefore, there appears to be no urgent need to systematically investigate numerical schemes. The present paper will therefore focus on the GSE and resolution problems in the following two sections.

#### GARDEN SPRINKLER EFFECT

When some form of Eq. (1) is solved in a computer model, physical and spectral space are discretized. From a historical perspective describing the spectral space with the spectral frequency  $f$  and direction  $\theta$ , models like WAVEWATCH III generally use a logarithmic discretization of  $f$ ,

$$f_{i+1} = \gamma f_i \quad (2)$$

where  $i$  is the discrete grid counter. Directions are generally discretized uniformly. Typical resolutions in operational models are  $\gamma = 1.10$  and  $\Delta\theta = 15^\circ$ . When performing spatial propagation, discrete spectral components ( $f_i, \theta_j$ ) are propagated with the group velocity vector  $c_g$  corresponding to the average frequency and direction of the spectral bin ( $f_i, \theta_j$ ). Thus instead of generating continuous dispersion of swell fields, discrete swell fields are propagated in discrete directions

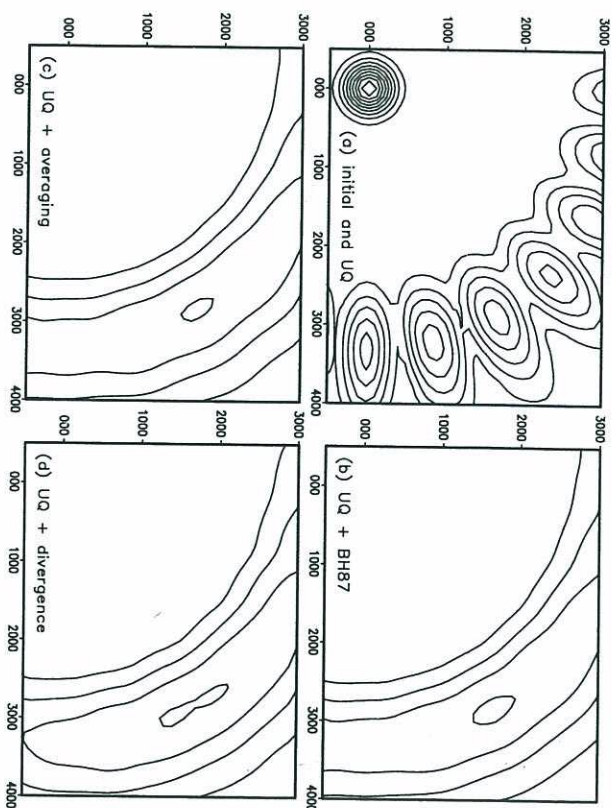


Fig. 1: GSE test adopted from Booij and Holthuijsen (1987) (BH87). See text for details. Axes in km. Contour levels at 0.25 m for initial conditions and 0.10 m otherwise.

and with discrete speeds at intervals  $\Delta\theta$  and  $(\gamma - 1)f$ , respectively. The corresponding spurious disintegration of continuous swell fields is known as the Garden Sprinkler Effect (GSE).

The GSE is illustrated in Fig. 1 using a test case loosely based on the test case of Booij and Holthuijsen (1987, henceforth denoted as BH87). In an area of  $4500 \times 3500$  km, discretized with increments of 100 km, an initial swell field is placed 500 km from the lower and left sides. The initial maximum wave height  $H_s = 2.5$  m. The wave height distribution is Gaussian in physical space with a spread of 150 km. The mean spectral direction is  $30^\circ$  (Cartesian) with a directional distribution of the type  $\cos^2$ . The peak frequency is 0.1 Hz, and the frequency spectrum is of Gaussian shape with a spread of 0.005 Hz. The spectral discretization is defined by  $\gamma = 1.10$  and  $\Delta\theta = 15^\circ$ . Fig. 1 shows initial conditions (panel a), and results after 5 days of propagation for several numerical approaches. Fig. 1a shows the results of the ULTIMATE QUICKEST (UQ) scheme, clearly displaying the GSE. The exact solution without the GSE is not shown here, but is close to Fig. 1d.