

Numerics in wind wave models ¹

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Abstract

Numerical aspects of wind wave models are reviewed and discussed. The paper focusses on three main aspects: (i) Model resolution. (ii) Source terms integration. (iii) Numerical propagation schemes. Arguments for increasing spectral resolution rather than spatial resolution are presented. Alternatives for increasing spatial resolution are discussed. The discussion of source term integration schemes mostly focusses on the use of limiters. The discussion of propagation schemes mostly focusses on the so-called garden sprinkler effect, and its remedies.

1. Introduction

Almost a decade ago, a systematic assessment was made of sources of numerical errors in wave models (Tolman 1992). With several years of additional experience, it is now an appropriate time to revisit the issues raised in this paper.

The state-of-the-art in ocean wave modelling is now represented by the so-called third-generation wave models. Such models are based on a random-phase, spectral description of the ocean surface. The basic conservation equation used in such models is

$$\frac{DA}{Dt} = S \quad , \quad (1)$$

where A represents a wave action or energy spectrum, and S represents sources and sinks. In a third-generation model, a form of Eq. (1) is solved by directly parameterizing all processes involved, without assuming spectral shapes. The first such model was the WAM model (WAMDIG 1988, Komen et al. 1994). This model has been widely used for over a decade. More recently, the WAVEWATCH (Tolman 1991, 1999; Tolman and Chalikov 1996) and SWAN (Booij et al. 1999, Ris et al. 1999) models have become popular.

Typically, the spectrum A and source term S in Eq. (1) are described as a function of wave frequency f and direction θ , or as a function of the wavenumber k and direction θ . The exact equation and the parameters spanning spectral space differ from model to model, but are for the most part not relevant in the present context. An exception is the potential loss of spectral resolution in shallow water for a spectrum defined on k , as is discussed in detail in Tolman and Booij (1998). The actual parameterizations of the source terms S are also not expected to be important in the present discussion. Although details of source terms may differ drastically between models,

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their balance should be similar for models to give good results. This in principle implies that general numerical considerations can be expected to be valid for arbitrary models.

Tolman (1992) first addressed wave growth in homogeneous conditions, to assess the impact of numerical choices on the integration of source terms. Secondly, pure propagation tests and fetch-limited growth tests were performed to assess the impact of (errors in) propagation schemes on wave model results. Finally, all was brought together in some realistic test cases from the SWADE experiment (Weller et al., 1991).

Several years of experience with operational wave modelling at NCEP, including many interactions with the Weather Service Field Offices (WFO), have identified some additional points of interest. The original tests in Tolman (1992) do not focus well on swell propagation issues. Swell prediction is of major interest for the WFO's, particularly in the Pacific Ocean. Furthermore, it has become increasingly clear that requirements for a wave model as a research tool, or as an operational tool, are different, and in some ways conflicting. Also, the introduction of new super-computer paradigms, particularly that of parallel computing, have an impact on details of the model (e.g., Tolman 2001a). Parallel computing considerations, however, focus on general model designs rather than numerics, and will therefore not be addressed here.

In the present paper, several numerical issues will be discussed and revisited. We will first consider model resolution in general. Secondly, source term integration is addressed. Finally, wave propagation, particularly swell dispersion will be addressed.

2. Model resolution

For large-scale, deep ocean wind-wave models, the wave spectrum is typically discretized using 24 directions (15° resolution), and about 25 frequencies with a logarithmic distribution and a 10% increment in frequencies ($f_{i+1} = 1.1f_i$, where i is the discrete grid counter in frequency space). Spatial resolutions range from the order of 1° in longitude and latitude to about 0.25° for operational models, and as small $1/12^\circ$ or of the order of 10 km for regional operational and research applications. The trend over the last decade has been to increase the spatial resolution, while leaving the spectral resolution largely unchanged. There does not seem to have been much discussion on the appropriateness of this trend.

The need for additional spatial resolution is well known. To optimally use the information contents of the wind field, the wave model resolution should be comparable to the resolution of the driving wind field. This appears to have been the driving force behind increasing spatial model resolutions in the near past. Furthermore, increased spatial resolution makes it possible to realistically resolve more island chains. The importance of the latter is illustrated in, for instance, Bidlot et al. 1997 or Tolman et al. 2001.

As mentioned above, spectral resolutions have largely been left unchanged over the last decade. Most arguments about required spectral resolution focus on wave growth (e.g., Tolman 1992). Furthermore, the Discrete Interaction Approximation (DIA) to nonlinear interactions (Hasselmann et al. 1985), which still is the cornerstone of present operational state-of-the-art wave models, has been more or less developed for presently common spectral resolutions. Attempts to drastically increase spectral resolutions appear to result in the introduction of notable noise in the resulting spectra. Whereas this behavior has been mentioned by several sources, it has not yet been documented adequately (to the knowledge of the present author).