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LOCAL AND REGIONAL SCALE WAVE MODELS*

by

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ABSTRACT

The development of regional and local scale ocean wave forecast models at the National Meteorological Center (NMC) is discussed. Some results from a second generation shallow water spectral wave forecast model implemented on the Gulf of Mexico and a local wave forecast model developed for the entrance of the Columbia River using ray tracing technique are presented.

I. Introduction:

The methods employed to forecast ocean waves were originally based on empirical techniques developed by Sverdrup and Munk and subsequently modified by others (see Hubert, 1964 for a review). These methods provide information on significant wave heights due to swell and local wind sea. Even though these empirical techniques are still being used to forecast (and hindcast) waves for special situations both at NMC and elsewhere around the world, it has become clear that further advances in our understanding of wave processes (such as growth, propagation, dissipation, and non-linear energy transport) and our ability to improve the wave forecasts requires a different approach. The state of wave forecasting has now gone through significant advances with the recognition that in reality the sea surface can, and should, only be described as a random superposition of several wave components. Hence only the statistical properties of the motion should be viewed as either observationally significant or theoretically predictable. This concept led to the introduction of the wave spectrum and the formulation of the time-dependent spectral wave energy balance equation. In its simplest form, the growth (or decay) of the spectral wave energy density $F(f, \theta)$ - f is the frequency and θ is the direction- at any point is determined by the advection of energy by the group velocity, energy input from the winds at the ocean surface, dissipation of energy due to various sources, and non-linear interactions between the wave components (for example, see Phillips, 1980, for a review of wave dynamics). In this approach, the significant wave height is simply proportional to the square root of the energy over all frequencies and directions.

Parallel with the theoretical development of the spectral wave forecasting techniques, the demands for spectral wave information also have been increasing for various applications. However the forecasting of waves using the spectral method in its most general form requires considerable computational resources. The most time consuming part of the spectral energy equation is the calculation of the non-linear wave interactions (which redistribute the energy among the various frequencies and thereby determine the spectral shape but do not change the total energy under the spectrum). Hence a hierarchy of spectral

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wave forecast models has evolved to optimize the computer time. These models are commonly referred to as the first, second, and third generation models– 1G, 2G, and 3G. In the 1G models, the non-linear terms are completely suppressed, in the 2G models they are calculated by approximate (parameterized) representations, and in the 3G models an attempt is made to calculate them more exactly (see the SWAMP group report, 1985).

The NMC routinely provides ocean wave guidance forecasts on global, regional, and local scales to the weather service forecast offices with marine responsibilities. For the purposes of this article, a regional scale is defined as one that spans a limited area (less than global) and a local scale is considered to be one that is applied to a specific site. Even though there are still a few forecasts issued for selected locations by NMC using the empirical techniques, a systematic effort has been initiated to replace all forecasts based on spectral approach. A 2G deep water global model has been operational for over three years and a regional shallow water 2G model has become operational over the Gulf of Mexico in the last year. The regional model is now being modified to cover the Gulf of Alaska and the continental shelves along the east and west coasts of the U.S. At the same time, efforts are underway to develop site specific forecasts using ray tracing techniques to bring the wave spectrum from either the global or a regional model to selected locations. This article presents a brief review of the techniques developed to provide the guidance for the regional and local areas.

II. Regional Scale Model:

Even though the operational global wave models of NOAA (NOW) and the U.S. Navy (GSOWM) have grid points along the continental shelves and the gulfs adjacent to the U.S coast line at which forecasts are available, these forecasts are not capable of representing the true wave conditions over these areas for reasons mentioned below. These global scale wave models are deep water models with coarse horizontal resolution to economize the computer time. The large grid spacing precludes a reasonable resolution of the geometry of the region– such as the presence of any islands and barriers– and mesoscale features of the ocean surface winds. Since most regional models are likely to be in coastal areas or gulfs, the water depth in the region would range from shallow to intermediate values. Refraction and shoaling by bathymetry, as well as diffraction around islands and structures, may be substantial. Dissipation of wave energy by bottom friction also becomes important in shallow water. This process depends on the details of the wave induced flow in the bottom boundary layer and the composition of the bottom material, and is not an easy process to represent accurately. In regions dominated by strong oceanic currents, complicated wave–current interactions result in significant modifications of the wave spectrum. In a regional domain, mesoscale variations in the wind field play an important role in determining the sea state. All of these factors are absent in a global scale model and these, also, are the factors that contribute to the errors in wave forecasts in any regional model. Another complication in regional modeling is having to prescribe the deep ocean wave conditions along open boundaries across which wave trains propagate into the domain of interest; thus making any regional model susceptible to boundary errors which are normally obtained from a larger (global) scale model.

(a) Model description–

In order to isolate the performance characteristics of the regional model by itself, the model developed at NMC for regional applications was first implemented on the Gulf of Mexico because, for all practical purposes, it is a closed basin with very little wave energy transfer between the Gulf and the open ocean. This model is essentially based on the one developed by Golding (1983) for operational use by the British Meteorological Office. The model solves the energy balance equation: