NCEP OPERATIONAL OCEAN WAVE FORECAST MODELS

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Abstract

From September 1994 to February 2000, the NOAA/WAM was an operational global ocean wave forecast model at National Centers for Environment Protection (NCEP). Its wave forecasts were consistently accurate and satisfactory, compared with buoy data, satellite data, and the model data from the Fleet Numerical Meteorology and Oceanography Center (FNMOC) and European Centre for Medium-range Weather Forecasts (ECMWF). The model wave forecasts for storm events were also satisfactory. We also applied the model to China Sea. It predicted waves quite well, including the waves generated by the typhoons in August and September 1997. In March 2000, NCEP completed its implementation of an IBM RS/6000-SP computer. Since then, the NOAA WAVEWATCH-III (NWW3) model has replaced the NOAA/WAM as NCEP operational model and, consequently, the NOAA/WAM has become obsolete, because of its anachronistic computer code and its coarse spatial and spectral resolutions, among others. The NWW3 computer code utilizes the Massively Parallel Processing (MPP) structure of the new computer and is very efficient for model computation. The NWW3 wave forecasts showed an improvement over the NOAA/WAM. Currently, we are still continuing evaluating the NWW3.

Introduction

Sea-state prediction is of considerable interest to marine communities, forecasters, scientists, and engineers. Because it provides sea-state warnings and advisories for adjacent waters and ocean areas, primarily for the protection of life and property, it has become an important marine service in many countries. There are many sea-state parameters used in marine forecast, and wind wave is one of the essentials because it is the most commonly encountered in ocean and coastal waters and has a significant impact on human activity. Obviously, to have a good marine service requires an accurate prediction of wind waves.

An operational ocean wave forecast model is required to base on state-of-the-art ocean wave physics. It is also required to be efficient in model computation, in order to have the forecasts timely reach the users. During last five decades, wind wave prediction has improved significantly from the empirical SMB scheme (Shore Protection Manual 1984) to the spectral model based on the radiative transport equation (SWAMP Group 1985, Komen, et.al. 1994). A spectral model generally includes the physical processes for wave propagation and source functions. The latter includes the wave generation function S_i that is the wave energy generated from atmosphere, the wave dissipation function S_d that is the wave energy dissipated through wave breaking and friction, and the nonlinear wave interaction function S_n that is the wave energy transfer among the spectral components. A spectral model is usually classified as the first, second, and third generation (1G, 2G, and 3G) wave mode. Roughly speaking, The 1G and 2G models impose a wave growth limitation on S_i, but the 3G model does not do so. The 1G model neglects S_n, the 2G model uses an over-simplified S_n, and the 3G model employs a parameterized wave interaction function for S_n. The NOAA/WAM and the NWW3 are the 3G model. Currently, the 3G models are considered the most advanced wind wave model and are used not only for marine forecast and engineering practice, but also for researches involving wind wave evolution.

The NOAA/WAM

The NOAA/WAM in essence is the Cycle-4 WAM (The WAMDI Group 1988, Komen, et.al. 1994). It is modified to accommodate an ever-changing ice edge and to assimilate buoy and satellite data. In both cases the successive correction scheme for data assimilation is employed. In this scheme at each computational time step and at each observation location, the significant wave height H_s is replaced by the observed data, and the wave spectrum is reconstructed by assuming the same proportional energy distribution of the spectral components of the replaced one.

The model is also modified to fix the streaking problem that may occur under a low wind situation when excess spurious wave energy propagates along longitude or latitude. This is because the model does not implement diffraction or the 'directional bin size' effect to provide mechanism for laterally spreading energy in wave propagation. WAM uses the upwind numerical scheme for wave propagation that more or less like the back ray tracing scheme, which generates numerical diffusion and causes energy spreading laterally for the waves propagating in the direction other than longitude and latitude. To avoid the streaking problem, the NOAA/WAM simply uses three lateral grid points (instead of one point in WAM) to provide laterally numerical diffusion for the waves propagating along longitude and latitude. The weighing factors used for the three grid points are 0.92 for the middle point and 0.04 for each side point. The NOAA/WAM was applied to the global ocean and China Sea.

Global Ocean

From September 1994 to February 2000, the NOAA/WAM was implemented as NCEP operational global wave model (Chen 1995). The model was run twice daily at the 0000 and 1200 UTC forecast cycles to produce global ocean wave spectra for a 12-h (hour) hindcast and a 72-h forecast. Figure 1 shows an example of the H_s contour output. The lowest sigma layer winds from the NCEP analysis and aviation (AVN) winds were adjusted to the winds at 10-meter height above the mean sea surface by assuming a logarithmic profile. These adjusted winds were the only driving force for the model wave hindcast and forecast. Analysis winds from the previous 12 hours at 3-h intervals were used for a 12-h wave hindcast and the AVN winds at 3-h intervals out to 72 hours for a 72-h wave forecast. The model grid domain covers the global ocean from 67.5°S to 77.5°N and from 0°E to 360°E with 2.5° grid resolution in longitude and latitude. The wave spectrum is discretized into 12 directions and 25 frequencies; the directions begin with 0° at the north and measure clockwise with 30° resolution, and the frequencies begin with the lowest frequency at $0.04177h_z$ and have each following frequency increased by 0.1 times the frequency: i.e. $f_{n+1} = 1.1f_n$, where f_n denotes the n-th frequency. The numerical time step is 20 minutes.

The NOAA/WAM global waves have been extensively evaluated for many years by comparing with buoy data, ERS-1 and ERS-2 altimeter data, and model data from FNMOC and ECMWF. The comparison includes wave statistics and several storm events (Chen 1995). In short, the NOAA/WAM waves were adequately accurate and satisfactory. Recently, during the period from September 1998 to March 1999, the NOAA/WAM waves were compared with buoy data. The H_s statistics show that the biases are about 0.05, 0.20, 0.30, and 0.40 m respectively for 00, 24, 48, and 72-h forecast, and their root mean squared errors about 0.35, 0.55, 0.75, and 0.85 m respectively.

China Sea

The model setup for China Sea is no different than the global ocean model, except the follows. The model has a coarse grid domain and a nested fine grid domain. The coarse grid domain covers geographical area from 1°N to 41°N and from 99°E to 142°E as shown in Figure 2, with 0.5° grid resolution in longitude and latitude. The nested fine grid domain covers the surrounding area of Taiwan from 18°N to 30°N and from 115°E to 127°E, with 0.25° grid resolution in longitude and latitude. Since 1997, the coarse grid model has been run in a parallel mode as requested. Data from two Japanese buoys at Buoy 22001 and 21004 are available for comparison study. During the period from July to September, the H_s comparison is shown in Figures 3 and 4. It indicates that H_s prediction is adequately accurate and satisfactory except the 08/07/97-typhoon event. Note that the bad model H_s prediction in the 08/07/97-typhoon event is actually due to the bad wind field input. On the other hand, during Typhoon Winnie on 08/18/97 near Buoy 22001, the wind field is well predicted and the model H_s predicts 11.0 m, accurately compared with the buoy data 11.1 m. This indicates that an accurate wind field input and a fine spatial resolution are pre-requisites to an accurate wind wave prediction.

The NWW3

In March 2000, NCEP completed its implementation of an IBM-RS/6000-SP computer. Since then, the NOAA WAVEWATCH III (NWW3) model has replaced the NOAA/WAM as NCEP operational model, and the NOAA/WAM has declared obsolete, because of its anachronistic code to the new computer and its coarse spatial and spectral resolutions, among others. The NWW3 model is developed at NCEP (Tolman 1999). The model is also a 3G model, but differs in many respects from the NOAA/WAM. It accounts for wave energy dispersion within a discrete spectral bin by adding diffusion terms to the propagation equation (Booij and Holthuijsen 1987). It uses Chalikov and Belevich (1993) formulation for wave generation and Tolman and Chalikov (1996) formulation for wave dissipation. It employs a third order finite difference method with a split-mode scheme and total variance diminishing limiter to solve wave propagation. Its computer code is fully optimized to utilize the Massively Parallel Processing (MPP) structure of the new IBM-RS/6000-SP computer to make the model computation much more efficient. It uses a finer spatial resolution (1.25° x 1.00° longitude/latitude grid instead of 2.5° x 2.5°), a slightly larger geographical domain in north-south extension (78°N - 78°S rather than 77.5°N - 67.5°S), and a finer directional resolution (24 directions in place of 12).

Before being implemented as an operational model, the NWW3 has been extensively evaluated by Tolman. Typical comparisons of H_s for the NWW3 and the NOAA/WAM are illustrated at the website, **http://polar.wwb.noaa.gov/waves**, where we also post updated forecast of ocean waves and ocean surface winds. Currently, we are still continuing evaluating the NWW3 as an operational model.

Conclusion Remarks

At NCEP, we have made systematic effort to test and develop wave models based on prediction accuracy, computational efficiency and sound wave dynamics and to employ them to produce operational forecasts. The NWW3 and NOAA/WAM predict waves quite well and are considered to be the best wind wave models on the shelf. Although the physical grounds and formulations are very similar, the NWW3 and NOAA/WAM computer codes and structures are tremendously different. The NOAA/WAM was retired last March, because of its anachronistic code to the new MPP computer, among others. Computer with high speed and large memory is always a pre-requisite for forecast now a day. With the new computer, we are able to setup the model with finer spatial and spectral resolutions, and we are also preparing to extend forecasts from 3 days to 5 or 7 days. Unfortunately, the new computer is still too slow and too less number of CPU to exactly compute the nonlinear wave-wave transfer S_n in time for forecast. Accuracy of wave model prediction depends much on the accuracy of wind field input. NCEP analysis and AVN winds are satisfactory and useful, but occasionally they might go astray, particularly in the event of hurricane or typhoon. Observed wave data from buoy and satellite provide a realistic source for wave model verification. H_s data may be relatively abundant, but directional frequency spectral data are very scarce, and, up to now, not much have been done to verify model spectra. Currently, we are continuing evaluating the NWW3.

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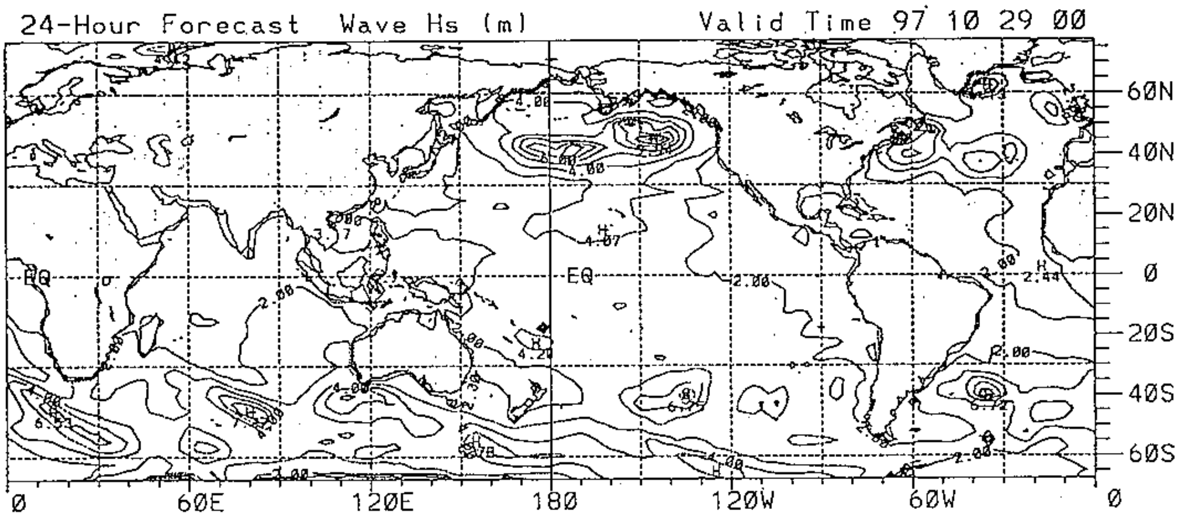

Figure 1. Contours of significant wave heights in the global ocean

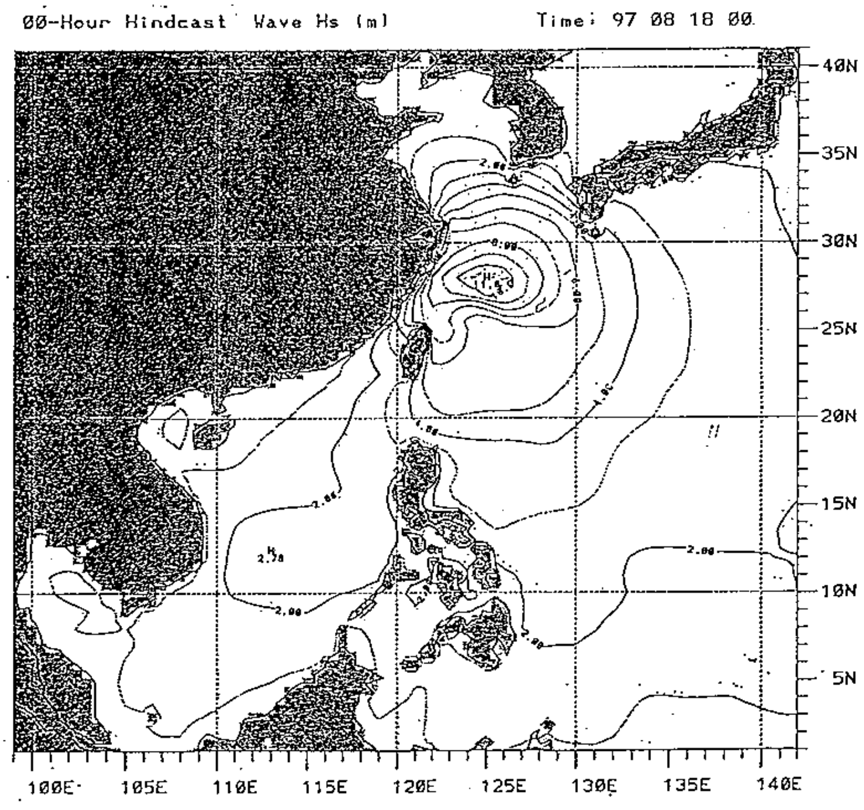

Figure 2. Contours of significant wave heights in China Sea

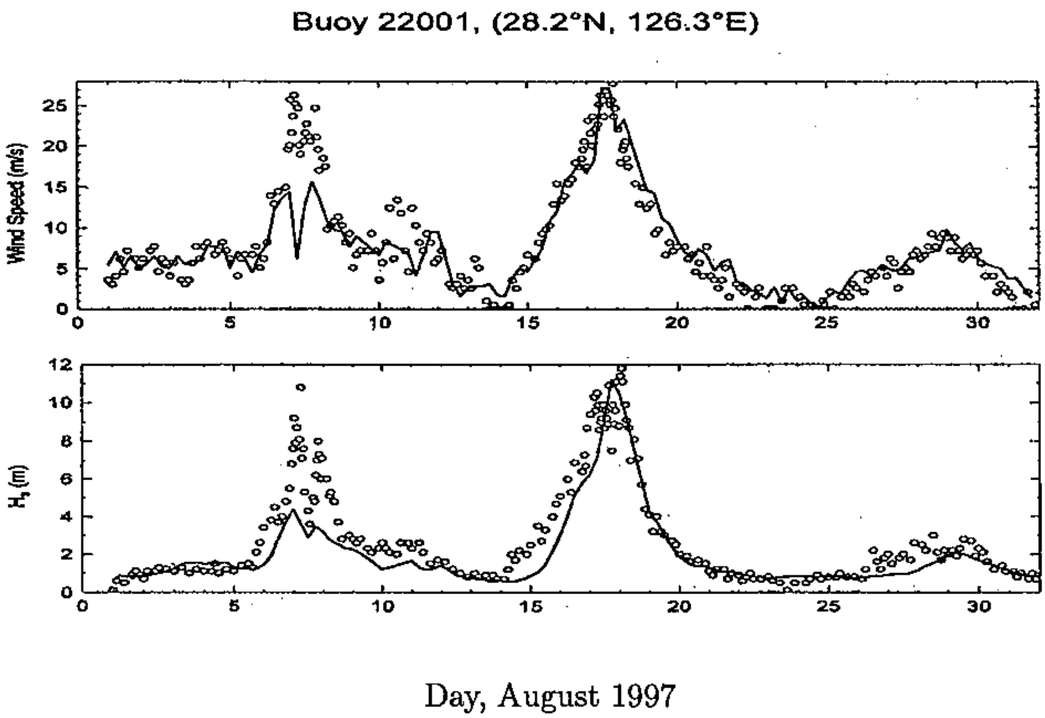

Figure 3. 08/97 Model vs Buoy Data: — Model, o o o Buoy.

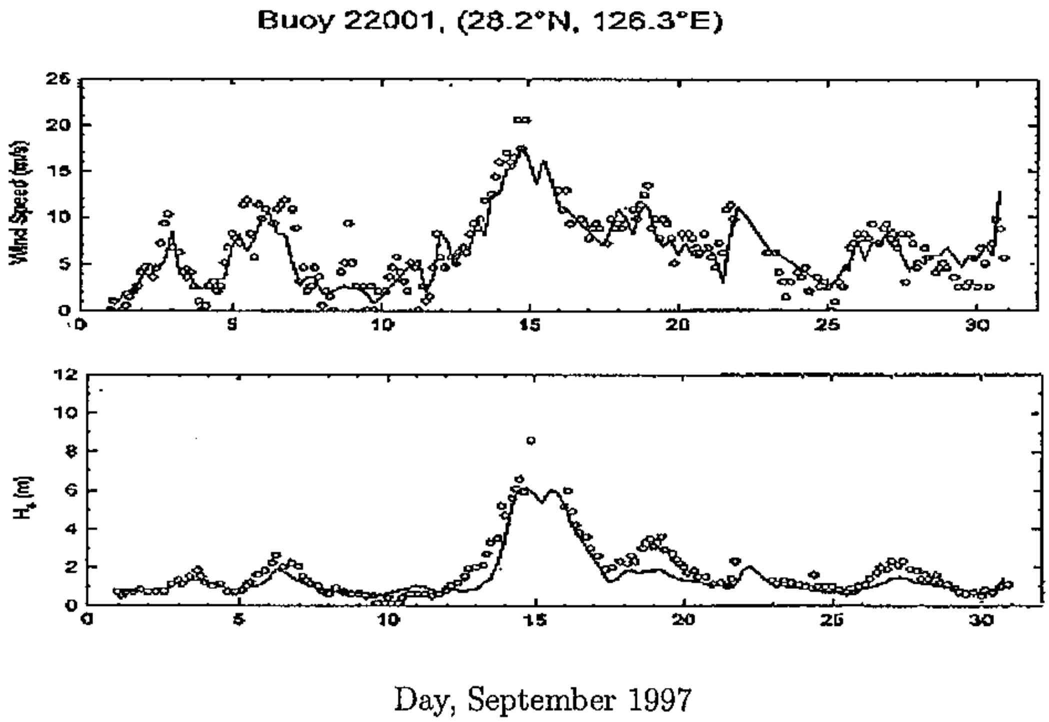

Figure 4. 09/97 Model vs Buoy Data: — Model, o o o Buoy.