FOURTH CONFERENCE METEOROLOGY AND OCEANOGRAPHY OF THE COASTAL ZONE

FEBRUARY 3-5, 1988 ANAHEIM, CALIF.

SPONSORED BY

American Meteorological Society

Front Cover: Figure depicts streamlines of most frequent September, 1980 wind directions, south-central California. Used by permission, from "South Central Coast Cooperative Aerometric Monitoring Program (SCCCAMP)" by Walter F. Dabberdt and William Viezee. Published in BAMS, Vol. 68, No. 9, Sept. 1987.

The manuscripts reproduced in this collection of extended abstracts are unrefereed papers presented at the Fourth Conference on Meteorology and Oceanography of the Coastal Zone; their appearance in this collection does not constitute formal publication.

AMERICAN METEOROLOGICAL SOCIETY
45 Beacon St., Boston, Mass. 02108 U.S.A.

2.2

EVALUATION OF WAVE FORECASTS FOR THE GULF OF MEXICO*

Yung Y. Chao

National Meteorological Center, NWS, NOAA
Washington D. C.

1. INTRODUCTION

Presently, there are three operational wave models routinely forecasting wave conditions in the Gulf of Mexico. One of them is the Fleet Numerical Oceanography Center's GSOWM which provides 72-hour wave forecasts at 12 hour intervals and at a resolution 2.5 degree grids (Zambresky, 1987). The other two models are the NOAA Ocean Wave (NOW) and the Techniques Development Laboratory (TDL) models. The NOW model (Chin,1985) is a discrete spectral wave model whose mesh size is 2.5 degree in latitude and longitude extending from 70S to 75N. The model computes 72-hour forecasts at 3 hour intervals. Boundary layer wind fields to drive the model are computed from the 1000 mb wind fields of the NMC global atmospheric spectral model. Corrections are made for height above the sea surface and stability using the air-sea temperature difference. The TDL model is a singular wave model based on regression equations for calculating the significant wave height and period (Pore and Richardson, 1973). It provides 48-hour forecasts at 12 hour intervals. The grid size of the model is approximately 250 km. The input winds are obtained from the NMC Limited-Area Fine-Mesh (LFM) wind model.

Questions concerning the adequacy of using these model outputs as a guidance for realistic forecasts of wave conditions in the Gulf have been raised by concerned marine forecasters. The relative levels of forecasting performance of these models have not been systematically verified against observed data. The problem becomes quite acute when the forecast results of these models for an identical location and time are significantly different. The major shortcoming of the TDL model stems from its pure empiricism; there is no physics involved in the formulation of prediction equations. It is difficult to improve this type of model. The NOW model and the GSOWM, on the other hand, are built upon a theoretical base even though they do not include all known wave dynamics. They are, however, designed to predict the general wave patterns of the global-scale ocean. The output of these models cannot be accurate enough to describe small-scale, regional wave phenomena. Furthermore, all three models only predict waves in deep water. Waves near the coastal areas, where most human activities are concentrated, cannot be predicted by either of these models. The effects of bottom conditions on wave growth, transformation and dissipation are excluded from their model formulations.

As part of the continuing effort to improve and extend NMC wave forecasting capability over the coastal areas of the United States, a new regional spectral ocean wave model applicable for both deep and shallow waters of the Gulf of Mexico, NROWM1, has been placed in an experimental operational evaluation mode. The purpose of this article is to present the result of comparisons between measured deep water wave data and concurrent wave forecasts provided by the aforementioned four models. An evaluation of the performance of the new model in shallow water areas will be presented in a separate paper.

2. THE REGIONAL OCEAN WAVE MODEL

The NOW and TDL models as well as GSOWM have been briefly described above. Detailed information concerning the NROWM1 will appear in a separate paper. However, for completeness, some information relevant to the present article are described below.

The NROWM1, is an adaptation of the model developed by Duffy and Atlas (1984) to the Gulf of Mexico. The essential governing equations and computational procedures follow the model described by Golding (1983). The model solves the energy balance equation of the form

$$[[[[\partial E/\partial t = -\nabla.(VE)] - \partial\{(V.\nabla\theta)E\}/\partial\theta] + I + D] + N]$$

where E is the spectral density of the wave field, V the group velocity and θ is the wave direction, and where I represents energy input from winds, D ener-

---

* OPC Contribution No.20

gy loss due to whitecapping and bottom effects and N the redistribution of energy within the wave spectrum due to conservative nonlinear wave-wave interactions. The equation is solved in four stages in the following order: propagation, refraction, growth and dissipation and, nonlinear interaction.

In computing wave propagation, Golding used a modified Lax-Wendroff integration scheme, while Duffy and Atlas use a two-step, third-order accurate staggered grid scheme which minimizes numerical dissipation and dispersion (Takacs, 1984). The wave refraction effect in shoaling water of varying depth is computed using a centered difference scheme instead of the conventional "forward" or "backward" ray tracing technique. The growth of waves is determined according to conventional linear and exponential terms representing, respectively, an excitation by turbulence fluctuation in the surface wind and the coupling of existing waves with mean shear flow in the marine boundary layer. The wave energy dissipation in deep water due to whitecapping is determined according to a formulation involving the entire spectrum as described in a paper by Hasselmann (1974). In shallow water, in addition to the calculation of bottom friction loss of wave energy formulated by Collins(1972), a computation of energy loss due to bottom percolation proposed by Shemdin et al. (1980) is included.

The nonlinear wave-wave energy transfer is considered in a parameterized and empirical manner. Firstly, a wind-sea spectrum is defined as that part of a spectrum that is: (1) above 0.8 of the peak frequency and (2) within 90 degrees of direction of propagation and the wind direction. This wind-sea spectrum is then forced to conform to a modified JONSWAP (Joint North Sea Waves Project) spectrum based on the assumption that nonlinear interactions will always act to bring the wind-sea spectrum back to the modified JONSWAP-shape spectrum. This modified JONSWAP spectrum incorporates the saturation range in water of arbitrary depth suggested by Thornton(1977) with the original JONSWAP spectrum (Hasselmann et al., 1973). The peak frequency is determined through an iterative procedure involving empirical equations.

At present, the model has twenty frequency bands ranging from 0.04 to 0.42 Hz and twelve direction bands. The Gulf of Mexico is assumed to be an enclosed ocean basin. Thus incoming waves from the Yucatan Straight and the Straight of Florida are ignored. The grid mesh is 37x27 with a grid interval of 53 km. The model has been running daily on the NMC Cyber 205 generating the significant wave height field and the directional wave spectra at three hour intervals out to 48 hours. The required wind input at a height of 10 meters above the sea surface is derived from the 1000 mb winds of the NMC Regional Analysis and Forecasting System (Hoke, 1984). A modified two layers boundary model described by Cardone (1969) incorporates stability effects due to air-sea temperature difference. The wind field forecast is made at six hour intervals.

3. COMPARISON OF MODEL FORECASTS WITH MEASUREMENTS

Wave data are acquired from buoy measurements in the Gulf of Mexico operated by NOAA Data Buoy Center. The NDBC 42001 is located at about the center of the Gulf (25.9N, 89.7W), midway between NDBC 42002 (26.0N, 93.5W) and NDBC 42003 (26.0N, 85.9W). The wave data analyzer (WDA) wave measurement system mounted aboard a buoy, consisting of an axial linear accelerometer, provides spectral estimates with a resolution of .01 Hz and degrees of freedom of 30. The frequency bands range from 0.01 up to a cut-off frequency of 0.39 Hz. Thus the upper and lower bounds of the 90% confidence interval are, respectively, 1.622 and 0.685 of the estimated value. These and other data such as wind speeds and directions were encoded and relayed to NMC via the Geostationary Operational Environmental Satellite (GOES). The archived data of both forecasts and measurements are available since March 1987 except measured data at NDBC 42003. The wave gauge at NDBC 42003 did not restart operation until the middle of April 1987.

The statistical error analysis is performed for the significant wave height forecasts of each model interpolated to the buoy locations at forecast hours : +12 Z, +24 Z, +36 Z and +48 Z using the concurrent buoy measurements as common validation standard. The analysis consists of the mean square error (MSE) as well as its systematic and unsystematic proportions of magnitudes (MSE_s and MSE_u), and the average relative error represented by the index of agreement (IOA). Following Willmott (1982), these indices take the form

$$MSE=N^{-1}\sum(P_i-O_i)^2$$

$$MSE_s=N^{-1}\sum(\hat{P}_i-O_i)^2$$

$$MSE_u=N^{-1}\sum(P_i-\hat{P}_i)^2$$

$$IOA=1-[\sum(P_i-O_i)^2/\sum(|P_i'|+|O_i'|)^2],\quad 0\leq IOA\leq 1$$

where N is the number of data points and, $\hat{P}_i = a + bO_i$, in which a and b are the intercept and slope of the least squares regression, respectively, and where $P_i' = P_i-\underline{O}$ and $O_i' = O_i-\underline{O}$, with $\underline{O}$ being the mean of the observed variable (O) and P, the model-predicted variable.

The MSE or its square root (RMSE) summarizes the mean difference in the units of P and O. The MSE comprises two parts, i.e., $MSE = MSE_s + MSE_u$. For a good model, the systematic difference, from the model should approaches zero while the unsystematic difference approach MSE. The IOA descriptively measures the accuracy of the model and is a useful measure for cross-comparisons of models.

Figure 1 shows the monthly variation of the IOA of each model at the projection hour +12Z at the location NDBC Buoy 42001 for March 1987 to August 1987. Similar patterns were found at +24z, +36z and +48z data and at all three buoy locations. There are insignificant differences on the patterns of the variation of IOA due to differences in locations and forecast hours(at least up to +48z). Therefore values of the IOA at the three buoy locations and of the four forecast hours are averaged. The resulting mean values of IOA for each model as a function of the month are showing in Figure 2. The NROWM1 is shown to have the highest IOA values among the four, while the NOW model, the lowest. The TDL model and the GSOWM are in between and have comparable measures. It is of interest to note that the performance of all four models deteriorate in the summer months of July and August 1987. During these two months measured significant wave heights are quite low and rarely exceed one meter.

Table 1 summarizes the over-all performance of each model in terms of IOA, RMSE and $RMSE_s$/RMSE based on the entire sets of data covering the months from March 1987 through August 1987.

Table 1

Model	IOA	RMSE (m)	$RMSE_s$/RMSE
NOW	.63	.64	.81
GSOWM	.74	.53	.72
TDL	.70	.55	.68
NROWM1	.79	.50	.52

As shown in the table, the NROWM1 scores the highest IOA values and lowest RMSE and $RMSE_s$ values for the study period of time.

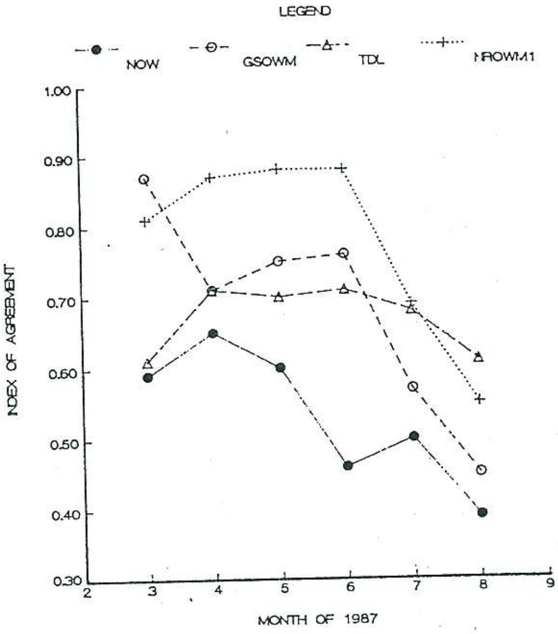

Fig. 1 Monthly index of agreement for the significant wave height of +12z at NDBC 42001.

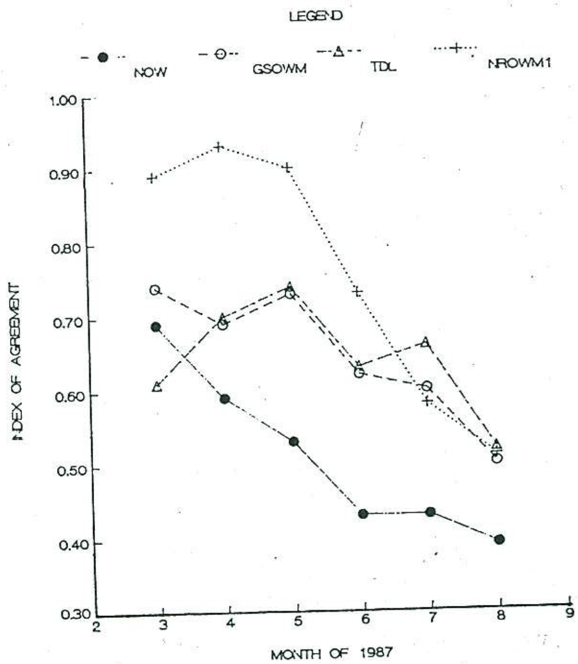

Fig. 2 Mean monthly index of agreement for the significant wave height of +12z, +24z, +36z and +48z, and NDBC 42001, 42002 and 42003.

The sources of systematic error contained in the NROWM1 can result from the wave model and/or wind model. Table 2 gives the variation of the monthly mean of the IOA and RMSE of the model wind speed and $RMSE_s$/RMSE of both the model wind speed and the wave height. It shows that the trend of increase in

$RMSE_s$ and decrease in IOA of the model wind as the season changes from winter to summer is comparable to that of the model wave. It suggests that errors in the wind prediction is a major factor that contributes to the error in the wave prediction.

Table 2

Month	IOA	RMSE (m/s)	$RMSE_s/RMSE$ (Wind)	(Wave)
3/87	.82	2.50	.43	.31
4/87	.79	1.83	.49	.52
5/87	.76	1.79	.63	.66
6/87	.73	1.73	.72	.89
7/87	.65	2.08	.89	.94
8/87	.61	2.02	.92	.96

4. SUMMARY AND CONCLUDING REMARKS

The performance of four wave forecast models - GSOWM, NOW, TDL and NROWM1 is evaluated. The model performances presented in this article concentrates solely on the the significant wave height forecasts and the concurrent measurements at three NDBC buoys in the Gulf of Mexico for the months from March 1987 through August 1987. Three major error statistics, i.e., the index of agreement, the root mean square error and the systematic error contained in a model are used as the evaluation standard. The results show that the NROWM1 performs best among the four models, perhaps because of its finer spatial and temporal resolutions.

There is an important question concerning the NROWM1, however. That is how well the model will perform with the hurricane winds? Since no major hurricane passed through the Gulf during the period in which data are archived, the question remains unanswered. There is an indication that the accuracy of the wind model deteriorates and underpredicts the wind speed during the warm seasons, which in turn produces a lower wave height than actually observed. The current NROWM1 system is inadequate for the low wind condition. Further improvement and modification of the system in these areas and further evaluation of the system based on a much longer period of measured data can raise the level of model performance.

References

Cardone, V.J., 1969: Specification of the wind field distribution in the marine boundary layer for wave forecasting. Report TR-69-1, Geophys. Sci. Lab., New York University.

Chin, H., 1985: An operational,global scale spectral ocean wave forecasting model. OCEAN-85 Conference Record, Vol. 2, 110-111.

Collins.,J.I., 1972: Prediction of shallow water spectra. J. Geophys. Res., 77, 2693-2707.

Duffy, D.G., and R. Atlas, 1984: Surface wind and wave height prediction for the QEII storm using SEASAT scatterometer data. Proceeding of Oceans, September 10-12, 1984, 183-188.

Golding, B.W., 1983: A wave prediction system for real-time sea state forecasting. Q.J.R. Meteorol. Soc., 109, 393-416.

Hasselmann, K., 1974: On the spectral dissipation of ocean waves due to whitecapping, Bdy.-Layer Met., 6, 107-127.

Hoke, J.E., 1984: Forecast results for NMC's new regional analysis and forecast system. 10th AMS Conference on Weather Forecasting and Analysis, 6 pp.

Pore, N.A., and W.S. Richardson, 1973: Weather service program in objective wind-wave and swell forecasting. NOAA/NWS/TDL unpublished manuscript.

Shemdin, O.H., Hsiao, S.V., Carlson, H.E., Hasselmann, K., and Schulze, K., 1980: Mechanisms of wave transformation in finite-depth water. J. Geophys. Res., 85,5012-5018.

Takacs, L., 1985: A two-step scheme for the advection equation with minimized dissipation and dispersion errors. Mon. Wea. Rév., 113, 1050-1065.

Thornton, E.B., 1977: Rederivation of the saturation range in the frequency spectrum of wind-generated gravity waves. J. Phys. Ocean, 7,137.

Willmott, C.J., 1982: Some comments on the evaluation of model performance. Bull. Amer. Metero. Soc., 63(11), 1309-1313.

Zambresky, L.F.,1987: The operational performance of the Fleet Numerical Oceanography Center Global spectral Ocean-Wave Model. Proceedings of the Symposium, Measuring Ocean Waves From Space, Johns Hopkins APL Technical Digest, 8(1), 33-36.