EVALUATION OF A GLOBAL OCEAN WAVE MODEL
AT
THE NATIONAL METEOROLOGICAL CENTER[1]

H. S. Chen[2]

ABSTRACT

The Cycle 4 version of the WAM (Wave Model) model (hereafter referred to as WAM4) has been implemented at the National Meteorological Center (NMC), National Oceanic and Atmospheric Administration (NOAA) to replace the previously operational NOW (NOAA Ocean Wave) global spectral ocean wave model to make improved global wave forecasts and hindcasts. For the purposes of evaluation and comparison, the WAM4 was run daily, producing wave forecasts up to 72 hours, from October 1992 to January 1994. The significant wave heights, H_s, from WAM4 and NOW were compared with the NDBC (National Data Buoy Center) buoy data. During the periods of November 20-27 and December 20-27, 1993, the H_s from WAM4 and NOW were also compared with ERS-1 altimeter data. Also, for two storms which occurred on October 30 and November 19, 1993, respectively, the maximum H_s from WAM4 and NOW were compared with wave heights from the Sea State Analysis Charts. These comparisons indicate that the WAM4 consistently predicted more accurate waves than the NOW version. The CPU time for a 12-hour hindcast and 72-hour forecast run on the NMC Cray YMP computer is less than 720 seconds.

INTRODUCTION

Accurate understanding and prediction of wind waves is of considerable interest to marine forecasters, oceanographers, and ocean and coastal engineers. During the last five decades, the state-of-the-art in wind wave modeling and prediction has improved significantly from the empirical approaches of Sverdrup an Munk (1947) and Bretschneider (1958) (for example see the Shore Protection Manual 1984), to spectral approaches which include directionality using the radiative transport equation (e.g. SWAMP Group 1985). The models using spectral approaches are classified as first, second, and third generation (1G, 2G, and 3G) wave models, based primarily on their formulation of the source function dealing with nonlinear wave interactions. The 1G models completely neglect the nonlinear source function. The 2G models, such as the NOW model, use an over-simplified nonlinear source function. The 3G models, such as the WAM model (WAMDI Group 1988), include a parameterization of the exact nonlinear source function and, at present, are considered to be the most advanced directional wave spectral models. Although they are computationally complex and have achieved significant improvements in wind wave prediction, many uncertainties still remain. Wind waves result from air-sea interaction as well as several other physical processes; specifically, wave propagation, refraction, and source functions. The source functions include atmospheric generation.

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[1]OPC Contribution No. 98.

[2]NOAA/NWS/NMC21, 5200 Auth Rd, Camp Springs, MD 20746.

wave-wave interaction, wave-current interaction, and wave dissipation. Some of these physical processes can be described with adequate precision, but others, like atmospheric generation and wave dissipation, are still not completely understood and remain a challenge for the research community. Despite this incomplete understanding of the source functions, many wind wave models are being used not only for marine forecasts and rational engineering design, but also for understanding and verifying the mechanisms involved in wave evolution.

In 1990, an evaluation of the Cycle 2 version of the WAM (WAM2) was conducted on the Cyber 205 computer at NMC. Although the WAM2 produced more accurate wave predictions than the NOW, it took too much CPU time to be used operationally (Chen 1991). During the period of November 1991 through March 1992, we evaluated the Cycle 3 version of the WAM (WAM3) on the Cray YMP computer at NMC. The WAM3 not only produced more accurate results than the NOW, its CPU time was greatly reduced, making it suitable for use in operations (Chen 1993). In late 1992, the WAM4 was made available for evaluation on the Cray YMP computer at NMC. The major difference between the WAM3 and WAM4 is in the wave generation source function. In WAM3, the wave generation depends only on wind velocity and uses Snyder's empirical formulation (Snyder et al. 1981) with replacement of wind velocity by friction velocity based on Komen's scaling (Komen et al. 1984). In WAM4, the wave generation source function depends on both wind velocity and wave age, and uses Janssen's formulation based on a quasi-linear theory of wind-wave generation (Janssen 1989, 1991). In this regard, the WAM4 has improved parameterizations for the physical processes involved than the WAM3. The reader is referred to Hasselmann (1987), The WAMDI (1988), and Günther, et al (1992) for a detailed description of the WAM model. In this paper, the WAM4 implementation was described and quantitative measurements of the performances of the WAM4 and NOW waves were presented.

WAM4 Implementation

The WAM4 global model was run twice daily for the 0000 and 1200 UTC forecast cycles to predict global ocean wave spectra for 12-hour hindcasts and 72-hour forecasts. The NMC three-hourly analysis wind was used as input to the model for the hindcast and the NMC three-hourly aviation wind for the forecast. The computational grid covers the global ocean region from 67.5S to 77.5N and from 0E to 360E with a resolution of 2.5 degrees in both latitude and longitude. The wave spectrum was represented by 25 logarithmically-spaced frequencies with the ratio of frequency increment to its frequency being equal to 0.1 and the minimum frequency being $0.04177\,hz$. The wave directionality was resolved into 12 directions (i.e., 30 degrees per angular bin). The integration time step was 20 minutes for both propagation and source function terms. The calculations were conducted on one processor of the Cray YMP computer at NMC. The CPU time for a 12-hour hindcast and 72-hour forecast run was less than 750 seconds.

EVALUATION

Buoy Data

The WAM4 wave forecasts were compared with data from 28 moored deep-water buoys maintained primarily by NDBC. These buoy stations were 21001, 21004 and 22001 in the southern seaboard of Japan, 32302 in the western seaboard of Chile, 46001, 46002, 46003, 46004, 46005, and 46006 in the Gulf of Alaska and the western seaboard of Canada, 46035 in the Bering Sea, 51001, 51002, 51003 and 51004 near the Hawaiian Islands, 52009 near Guam

Island, 17001 near the Antarctic Circle, 41001, 41002, 41006, 44004, 44005, 44011, and 44014 in the eastern seaboard of the United States, 42001, 42002, and 42003 in the Gulf of Mexico, and 62108 in the western seaboard of Ireland.

Comparison of significant wave height, H_s, time series at the buoy stations indicated that the WAM4 waves generally agreed well with the buoy data, but often underestimated the extreme waves as mentioned in many similar studies (e.g. Chen 1993). Statistics of H_s from WAM4 were better than those from the NOW. Figure 1 shows their bias and root-mean-square error (RMSE) values for the 24-, 48-, and 72-hour forecasts calculated from the wave measurements at each of the buoys. In Figure 1, NOAA/WAM indicates the operational name for WAM4. Notably, even through the NOW model has implemented a data assimilation scheme using buoy and ERS-1 altimeter data, in contrast to WAM4 which does not yet contain a data assimilation procedure, the bias and RMSE of the most NOW forecasts were still inferior to the WAM4 forecasts. A data assimilation to improve the WAM4 will be done in the near future.

ERS-1 Altimeter Data

Statistics of H_s for the WAM4 and NOW models based on the ERS-1 altimeter data were calculated for the periods of November 20-27 and December 20-27, 1993. They are shown in Table 1. Overall, the WAM4 waves clearly outperform the NOW waves.

Table 1. Statistics on H_s of WAM4 and NOW,
based on ERS1 altimeter data.

Mo/Yr	Model	24h Forecast bias	24h Forecast RMSE	48h Forecast bias	48h Forecast RMSE	72h Forecast bias	72h Forecast RMSE
11/93	WAM4	0.47	0.77	0.40	0.70	0.31	0.66
	NOW	0.58	0.79	0.59	0.82	0.56	0.86
12/93	WAM4	0.24	0.75	0.17	0.65	0.18	0.63
	NOW	0.36	0.61	0.44	0.73	0.46	0.78

units are in meter.

Storm Cases

Maximum values of H_s from the WAM4 and NOW forecasts were compared during two storm events. One storm occurred at 0000 UTC October 30, 1993, near 170E, 50N in the north Pacific (Fig 2). This storm had winds of up to 40 knots which generated a maximum H_s of $36\,ft$ as shown in the Sea State Analysis Chart (Fig 2). The Chart was produced by NWS (National Weather Service) marine forecasters, using all available data from buoys, C-man stations, satillites, ship reports, model results, etc.. The maximum H_s from the NOW 48-hour forecast was $27\,ft$ (Fig 3) and the maximum H_s from the WAM4 48-hour forecast was $34.7\,ft$ (Fig 4). The NOW forecast produced an underestimate of $9\,ft$ compared with the Sea State Analysis; the WAM4 clearly was much closer to the analysis.

Another storm occurred at 0000 UTC November 19, 1993, near 50W and 50N in the northeast Atlantic. This storm generated a maximum H_s of 6 to $10\,m$, with a median value of $8\,m = 26.4\,ft$, according to the Sea State Ship Plot shown in Figure 5. The maximum H_s from the NOW 48-hour forecast was $15\,ft$ and that from the WAM4 48-hour forecast was $25.1\,ft$. The WAM4 forecast was again much closer to the ship report than the NOW.
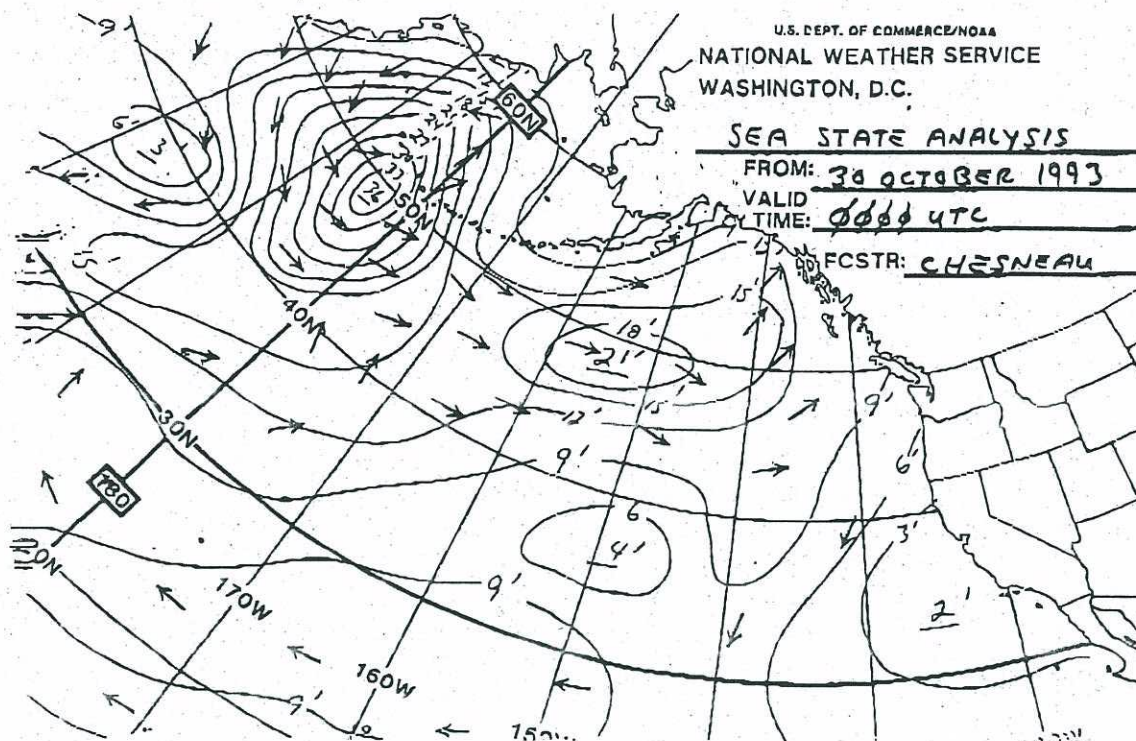
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COMPARISON OF SIGNIFICANT WAVE HEIGHT STATISTICS
FROM
NOAA/WAM AND NOW MODEL

Legend
— NOAA/WAM
—◯— NOW Model

Figure 1. Comparison of H_s statistics from WAM4 (NOAA/WAM) and NOW model.

Figure 2. Sea State Analysis Chart for the storm on 10/30/93.
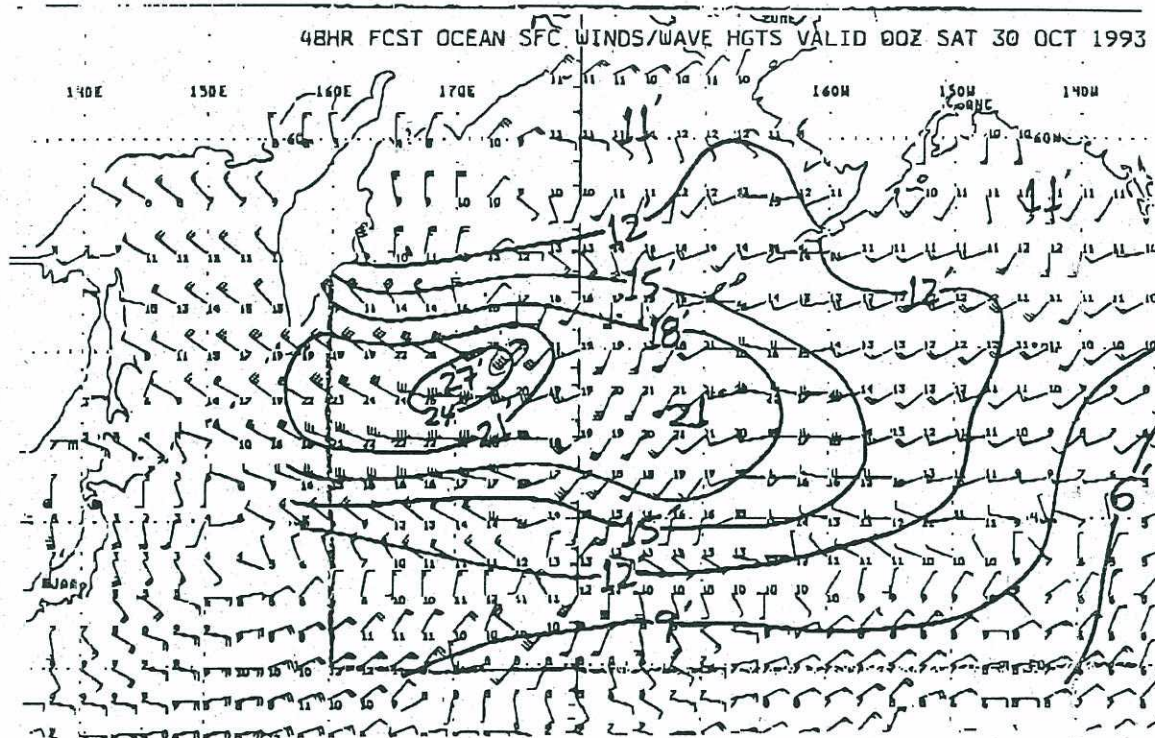
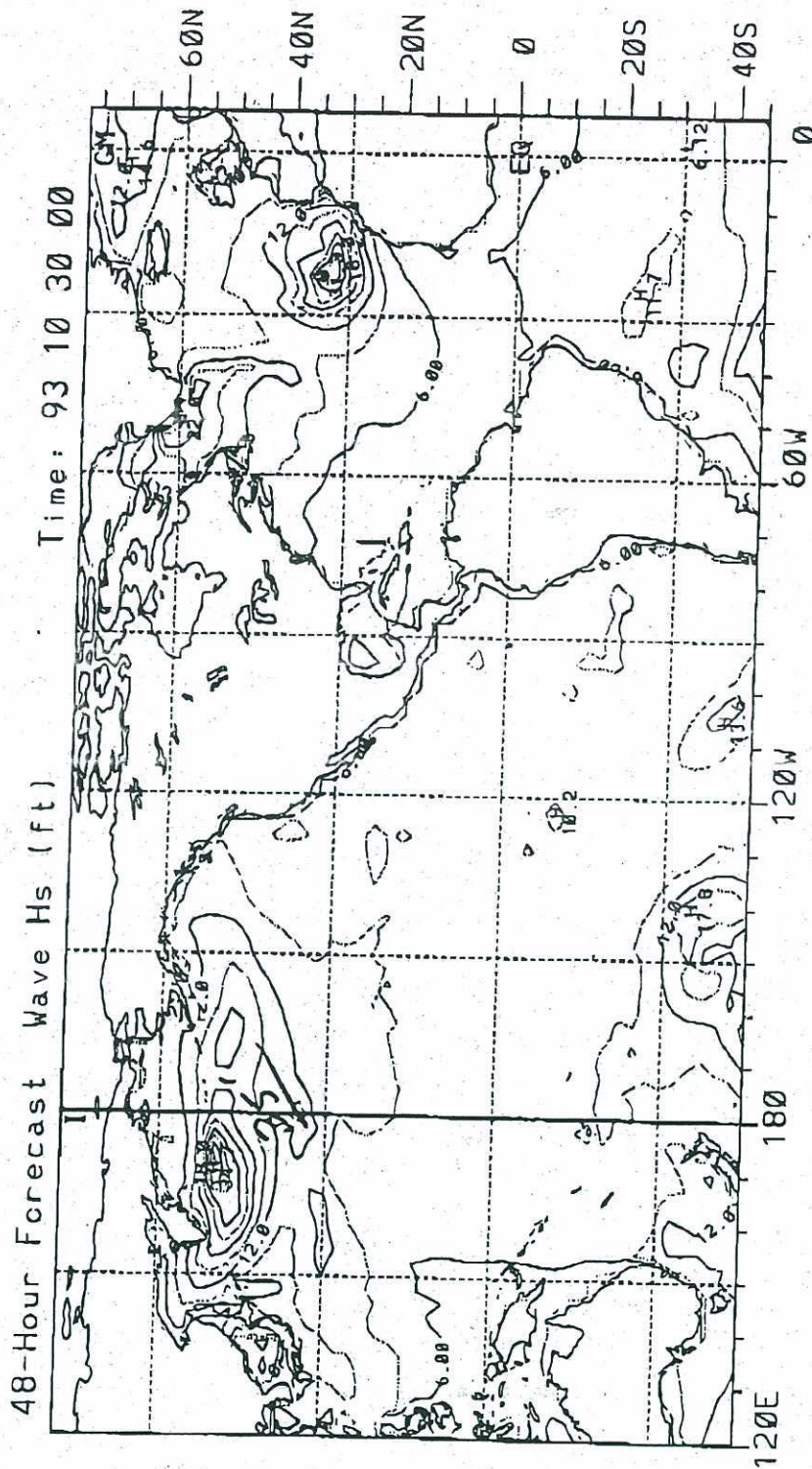Figure 3. NOW 48-hour forecast for the storm on 10/30/93.

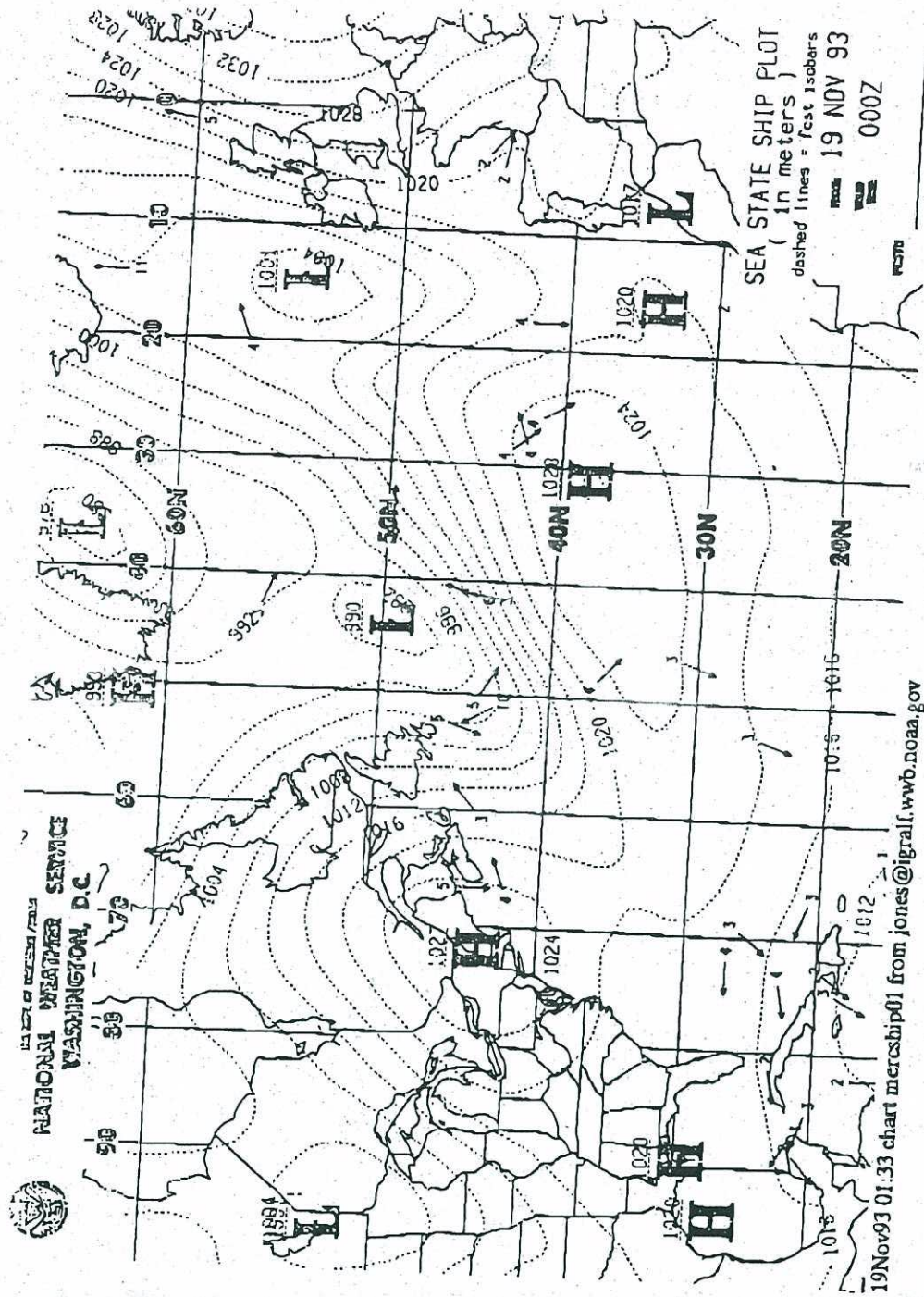Figure 4. WAM4 48-hour forecast for the storm on 10/30/93.

Figure 5. Sea State Ship Plot for the storm on 11/19/93.

Generally, in storm situations, the maximum H_s values from WAM4 were more accurate than those from the NOW. The NOW waves have a consistent tendency to under-forecast high waves, probably because the NOW model imposes artificial constraints on the calculated wave spectrum. Also, the NOW wave directional response to changing winds is too slow to be reliable.

CONCLUSION

Based on comparsions with buoy and ERS-1 altimeter data, H_s values forecasted by WAM4 had consistently smaller absolute bias and RMSE values than those produced by the NOW model. In storm conditions, the maximum H_s values forecasted by WAM4 were always closer to observations than those waves from the NOW.

Finally, the WAM4 global wave model has been operational at NMC since October 1994 and since that time, the model has been formally referred as the NOAA/WAM model.

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