20 YEARS OF OPERATIONAL FORECASTING AT OCEANWEATHER

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1. INTRODUCTION

The rapid evolution of numerical wave prediction models over the past three decades has been closely linked with the desire to improve operational wave forecasting systems. For example, the P-T-B directional spectral wave model (Pierson et al., 1966), supported initially to develop new wave climate data for improved ship design, was implemented at the Fleet Numerical Oceanography (FNOC, now FNMOC) as arguably the first true spectral model to be used for wave forecasting in 1973 (Lazanoff and Stevenson 1975), well before the same model was applied to develop a Northern Hemisphere wave climate. By the time of the SWAMP wave model inter-comparison exercise (SWAMP, 1985) most of the models that participated were being used to make real time wave forecasts (e.g. MRI (Japan), NOWAMO (Norway), GONO (The Netherlands), BMO (UK), HYPA (Germany)). It is not widely appreciated that the main objective of the WAM Group during the 1980's was to develop a model to be implemented into the real time system of the ECMWF in time to be ready to assimilate satellite wave data from the ERS satellite scheduled for launch in the early 1990s. Subsequent to that landmark implementation (The WAM Group, 1988), WAM and later third generational wave models such as WAVEWATCH-3 (Tolman 1991) were quickly adopted by most major government numerical weather prediction centers (NWP) to make global wave forecasts.

There is an interesting contrast between weather forecasting and wave forecasting. The major part of the constituency for weather forecasts is the general public and while weather data are increasingly transmitted to the general public by the private weather industry or commercial divisions of national weather forecasting centers, the ultimate source of those forecasts are the NWP models operated by, and the model derivative forecast products generated at, the government centers. On the other hand, the overwhelming part of the constituency for wave forecasts is the commercial sector, including the shipping and offshore industries, and purveyors of their supporting service industries (e.g. supply boat operators) and of coastal operations such as dredging, cable laying and the like. Those users often require highly customized forecast services. For example, the shipping industry utilize strategic voyage planning and tactical seakeeping guidance, both of which require vessel specific wave response predictions, dedicated grid systems and communications systems, and yet, the needs may be transient. The needs of these users are often better met by the private sector for several reasons. First the wave model technology and operational system attributes may be specifically tailored to the application. In addition, such services may take advantage of on-site feedback and (often) proprietary measurements, communicated in ways often incompatible with standard Global Transmission System (GTS). The services may also be set-up quickly, optimized in a short period of time with user feedback, operated when needed and then terminated after the often-transient requirement is satisfied. Of utmost importance, however, is the ability of such systems to use wind forcing developed with expert interactive systems as opposed to NWP center systems which are invariably driven directly by the output of fully automated NWP models themselves.

This paper describes one such private sector marine wind and wave forecasting system operated by Oceanweather (OWI) since 1983. Because global, basin and regional scales are so closely linked in wave forecasting, the system has included and currently includes the continuous operation of a global wave model, whose output is used directly for the shipping industry, and as a source of boundary conditions for regional and coastal applications. We start with a brief history of the development of the system, including description of its underlying technology and performance (mainly by reference to published works) and description of a few specific applications. The main focus of the paper is the description and verification of the current high-resolution global wave model against the global in-situ and satellite database.

2. SYSTEM EVOLUTION

2.1 First Beginnings

OWI was founded in 1977 primarily to carry out research and development in the application of high-level wave hindcast technology to provide design data for the offshore industry and coastal engineering communities. In 1983, OWI was approached by a major oil company to adapt this high level technology in real time to produce a specialized wind and wave forecast for, at the time, the world's largest drilling ship, Discoverer Seven Seas (DSS). The vessel was to operate in Wilmington Canyon (about 100 nm southeast of Atlantic City, New Jersey) in water depths up to 2,286 meters. Warnings of exceedance of critical thresholds of significant wave height and vessel heave and heave acceleration were required to manage the drilling riser system and avert potential loss of the riser itself. The challenge was met by adapting OWI's ODGP model to the western two-thirds of the North Atlantic basin on a two-nest grid system. The finer mesh, which just covered the middle Atlantic coast to about 300 nm offshore, had grid spacing of 0.625 degrees latitude by 1.25 degrees longitude (OWI's current global wave model covers the entire global oceans with this grid resolution, a testament to increases in computing power over the past two decades). A VAX 11750 super-mini computer was required to allow OWI to issue 72-hour wave forecasts (twice daily). The most unique feature of the service, however, was the use of a team of meteorologists to modify the output from NOAA's LFM model (at that time the most skillful NWP model for this region). The goal of these modifications was to minimize systematic and random errors in surface mass and motion fields, especially in situations of strong wind forcing associated with US East Coast cyclogenesis, strong frontal passages and tropical cyclones. Since gridded data were not readily available at that time, a brute force but effective man-machine mix was adopted in which LFM surface pressure contour fields obtained by weather fax (12-hour intervals) were modified manually and digitized on a large digitizing tablet. The pressure fields were subsequently objectively transformed to hourly-average 20-m level wind fields using a calibrated PBL model and interpolated to 3-hourly intervals using an algorithm which preserved rapidly propagating wind field features. The forecast sea state and simplified wave spectra at the vessel location were transmitted to a computer onboard the vessel wherein heave acceleration and other vessel responses were calculated and displayed to the drilling supervisor.

A critical evaluation of the forecast system over the first 6-months of service against wave measurements acquired by a buoy moored near the vessel and recorded ship response showed excellent skill, particularly for the important potential threshold peak events. Error growth was surprisingly small. For example, at analysis time the mean and rms difference between issued significant wave height (HS) event peaks and measured peaks (for peaks greater than about 2 m) was less than 0.1 m and 0.7 m respectively at analysis time, 0.1 m and 0.9 m at 24-hour horizon and 0.1 m and 1.0 m at 48-hour horizon. These skill measures were nearly a factor two better than provided by alternative NWP wave model predictions available at the time. Comparisons of predicted and measured heave acceleration indicated good skill with slight mean overestimation of 2% at 24-hours and 5% at 48-hours. The service operated over the full 16 months of the drilling program, during which several deep water drilling records were broken with no mishaps (Reece, 1988).

2.2 Extension of Man-Machine Mix to New Regions

The man-machine mix operation was extended to the North Pacific/Bering Sea basins during the ice-free drilling seasons in 1983-1984 to support offshore exploratory drilling from a semi-submersible in the Navarin Basin of the Bering Sea. For a time, this operation overlapped the US east coast service, which created some difficulties because of the manpower burden to modify and digitize maps in two separate basins. At the same time the system was extended to include the offshore east coast of Canada and incorporated into the forecast system operated by MacLaren Plansearch Ltd. of Halifax to provide site-specific offshore rig forecast services. During this time, the forecast service was also extended to support the Canadian government sponsored Canadian Atlantic Storm Project (CASP) experiment conducted offshore Nova Scotia in winter, 1986 (Eid et al., 1987). For this application, a second fine mesh which covered the Scotian Shelf and Grand Banks was added and both the nominal system (ODGP-OPR) as described above and a parallel run driven by CMC NWP output (ODGP-CMC) were run in real time. When the analyses and forecasts were evaluated against the CASP wave measurements at deep-water sites, it was found that ODGP-OPR HS rms differences varied from 0.85 m at analysis time to 1.07 m at 48-hours, while for ODGP-CMC the errors ranged from 1.88 m to 1.97 m, generally confirming the strong influence of systematic wind errors in NWP output on accuracy of wave forecasts. The ODGP-OPR service continued to operate until the rig activity offshore Canada diminished to virtually nil by the late 1980s.

During the second half of the 1980s, additional implementations were added in the Beaufort Sea (in support of various US and Canadian drilling programs) and in the South Atlantic Ocean. As a part of many of the Beaufort Sea commissions, the forecast wind fields were transmitted to other private companies that operated ice movement forecasting systems. The source NWP data for the Beaufort services remained NOAA LFM products with continued modification of pressure and wind fields using the DSS man-machine mix approach. For the South Atlantic service, however, NOAA AVN products were used and a semi-automated but still VAX based procedure was introduced to allow the forecaster to modify the tracks and intensities of centers of action and fronts.

2.3 Path to Globalization

The globalization of the forecast system at OWI, beginning with the implementation of a full northern hemisphere (NH) system in 1988, was prompted by several important developments. First, NWP global models were being extended into the medium range (3-10 days) and their gridded output fields were becoming readily available in real time. Evaluation of these forecasts (e.g Kalnay et al., 1990, Walker and Davis, 1995) indicated that they possessed useful skill in predictions of surface weather systems beyond 5 days. Chen et al (1993) shows some examples of spectacular skill in medium range predictions of major marine storms such as the March 1993 "Storm of the Century" in the 5-8 day range. Second, increases in computer speed allowed ready extension of the wave model with reasonably high resolution to be run in the medium range. The OWI NH system was implemented on a 2.5 degree x 2.5 degree lat/long grid and later extended to a global grid of the same resolution in 1992. Third, the introduction of PC technology had immense impacts on the forecast generation process. At OWI, the efficiency and flexibility of the man-machine mix were revolutionized in the early 1990s with the introduction of an Interactive Kinematic Objective Analysis (IOKA) operated through a PC based graphical interface called Wind WorkStation (WWS) (Cox et al., 1995). WWS allowed the forecaster to implement the quality control and modification of wind fields to the same level of care and within the same amount of clock time as in the DSS operation but on a global basis and out to three times the forecast horizon of that operation.

PC technology and advances in digital satellite communications allowed the implementation of new graphical and user-friendly systems for the display and utilization of the forecast products in PC based (expert) decision support systems. For example, the Integrated Marine Decision Support System (IMDSS, but currently called VOSS for Vessel Optimization and Safety System) of Ocean Systems Inc., which receives OWI global model output twice daily, allows a vessel master to download the wave forecast including parametric representations of the directional wave spectrum at each grid point over an entire basin and use that data for optimization of voyage routes and for avoidance of heavy weather damage through onboard real time seakeeping analysis (Chen et al, 1998). The vessel motion prediction aspects of IMDSS have been extended to tow simulations and response of drillships and floating production systems.

2.4 Specialization in Regional Applications

Two notable examples of regional applications are CYCLOPS (Tropical Cyclone Operational Prediction System) and RIBS (Rapidly Installed Breakwater System) support. CYCLOPS was initially implemented in the South China Sea in 1995 (Corona et al. 1996) but is now available in all basins subject to tropical cyclones. CYCLOPS utilizes high-resolution grids (typical grid spacing 0.25 degrees) as regional nests of the global system. CYCLOPS also utilizes a proven primitive equation mesoscale vortex model (Thompson and Cardone, 1996) and a tropical analysts workstation (Cox and Cardone, 2000) to develop wind fields of maximum possible accuracy to drive the high-resolution wave model. Track error properties and multiple model runs are synthesized in a probabilistic approach to develop forecasts of critical wind speed and sea state thresholds to support decisions regarding shutdown and evacuations. CYCLOPS has been shown to provide significant economic benefits to users in avoidance of unnecessary shutdowns while reducing risk of dangerous helicopter evacuations of large populations of offshore workers.

The forecast system has been applied at intervals over the past four years to provide support for ocean trials conducted by the U.S. Army Waterways Experiment Station of RIBS. The trials are typically conducted in shallow water within site of the beach and require accurate sea state forecasts within critical thresholds. In one such trial, conducted near Cape Canaveral, Florida in May 1999, high quality wave measurements from both a NOAA buoy 37 km offshore and at the site of the RIBS trials were available for verification of the forecasts. It was found that by applying a tri-nested grid (global scale, regional scale and coastal scale models were adopted, the last on a grid of 2.775 km) skill scores were comparable to those achieved in deep water with the wind and wave forecast technology. The bias at the buoy over all horizons to 72 hours was quite stable and averaged +8 cm at the buoy and +12 cm at RIBS with scatter indices of 0.24 at the buoy and 0.28 at RIBS. Even at 48 hours the correlation coefficient between forecast and measured HS time histories was 0.91 at the buoy and 0.85 at RIBS.

3. PRESENT SYSTEM

Today, OWI runs its global wind and wave models twice daily to a forecast horizon of 15 days. Multiple regional high-resolution nested wave models are run up to four times daily with more frequent updates made during storm conditions as user's needs require. Dedicated regional and localized systems such as CYCLOPS and RIBS and customized response prediction are brought on-line on very short notice. Table 1 lists the current global and regional models being run operationally. Additional regional models setup and run for shorter-term projects are not described here. Figure 1 shows the general run stream of the OWI forecast that is further discussed below.

Table 1. Operational wave forecasts.

Model Domain	Resolution (degrees)	Time Horizon
Global	.625 x 1.25	3 Days
Global (Extended)	1.25 x 2.5	15 Days
U.S. East Coast Gulf of Mexico and Caribbean	.25	3 Days
South China Sea	.5	3 Days
North Sea	.125	3 Days
NE Atlantic and Western Mediterranean	.3125	3 Days
Florida East Coast	.025	3 Days
SW Caribbean	.125	3 Days

In contrast to other major operational centers, OWI applies an interactive approach in which a skilled marine meteorologist is presented with guidance from various sources and directly influences the forecast produced. Additional emphasis is placed on the location and strength of major tropical and extra-tropical systems that are the primary concern of most users. The Wind WorkStation (WWS) is the forecaster's primary interactive tool and allows for the display and modification of all available measured and model data. Measured and model data are continuously ingested and processed for use in the forecast system. The WWS displays available observations, all of which have been processed to a common reference level of 10 meters neutral. The forecaster uses the observations at analysis time and model guidance at forecast horizons to synthesize a continuous forecast of the marine surface wind field that retains the best characteristics of the available data. The WWS is primarily used on a matching grid to the wave model being applied. High-resolution applications get dedicated WWS setup and grid that allows the analyst to track features on smaller time and space scales as required for a particular application. For instance, in the RIBS experiment very high-resolution wind tower data was acquired that surrounds the Kennedy Spaceflight Center (KSC). Use of this data in a high-resolution implementation of the WWS led to very fine structure in the local winds.

Figure 1. Flowchart of operational forecast run stream.

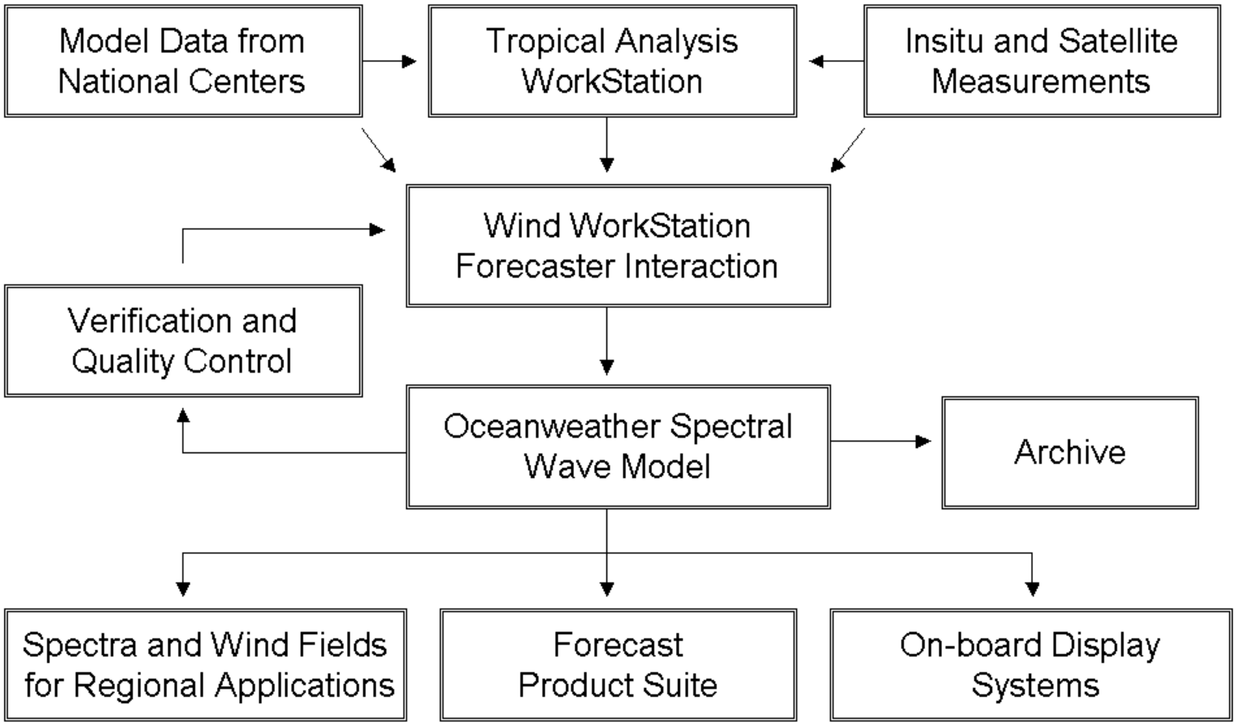
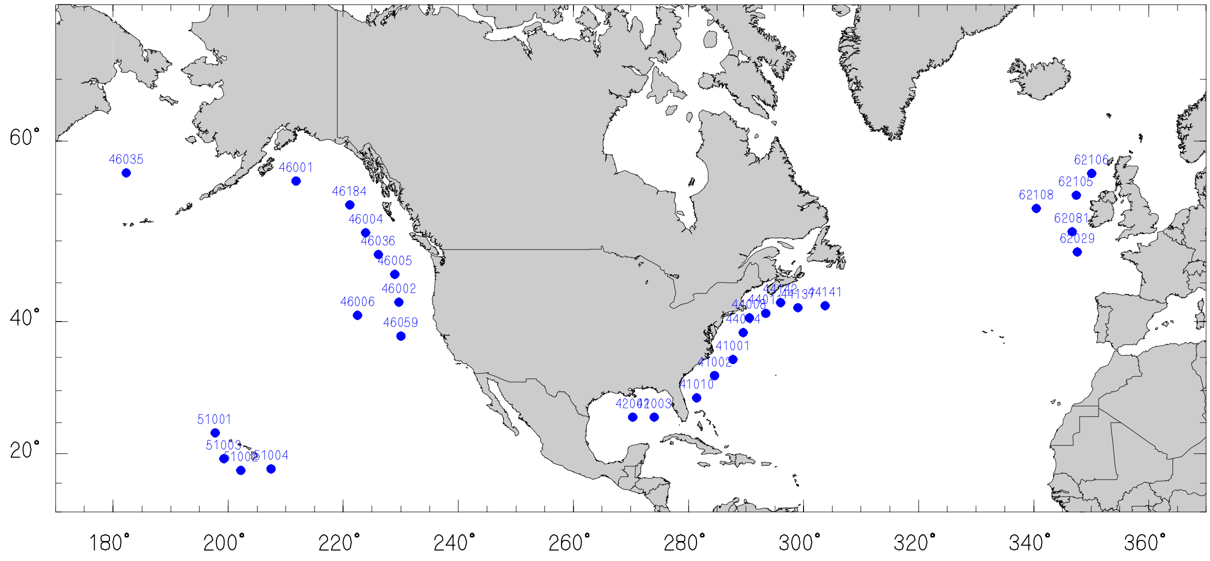


Figure 2. Location of insitu buoy and platform observations used in validation.



An advantage of the interactive approach to the generation of wind fields is in OWI's treatment of tropical systems. National centers such as the Tropical Prediction Center (TPC) and the Joint Typhoon Warning Center (JTWC) routinely issue forecasts of track, intensity and wind radii for tropical systems worldwide. These official forecasts are used in a dynamic tropical wind model (TC96), which results in wind fields that match the forecast track and intensity issued by the respective warning center. This methodology, described in Cox and Cardone (2000), has three main advantages: First, the wind model results in a more complete description of the tropical surface wind field than does simple bogussing or parametric estimates. Second, the wind and wave forecast issued matches the official forecast track/intensity. This avoids user-end confusion that would result if a prognostic tropical model that differs from the official track and intensity were applied. Third, using the official track forecast results in a known error structure as published by the respective warning center. This track and intensity error can be applied in a probabilistic sense as is done in OWI's CYCLOPS forecast.

All global and regional wave forecasts use the UNIWAVE spectral wave model (see Cardone el al. 1996). This model can be applied with second generation (2G, ODGP-2) or third generation (3G, OWI3G) physics (see Khandekar et al. 1994) and in either deep water or shallow water mode. All implementations of UNIWAVE use 24 directions (15 degree) and 23 frequency bands and share common propagation code. This model is applied from the global long-range forecast model (~140 km) down to regional applications of just a few kilometers without the need for "tuning" or other basin-specific modifications to the model. In all forecast applications the ODGP-2 physics are applied, which allow for increased resolution that would not be possible given OWI3G's more rigorous CPU requirements. Inter-comparison of 2nd and 3rd generation models (Cardone el al. 1996) has shown that 2G models may match or in cases surpass the performance of the more costly 3G models. Application of ODGP-2 results in the best balance given the time pressures of an operational forecast and the desire to run at the best possible resolution to order to capture storm peaks, coastal effects, wave blocking by island chains and other important features.

Once the forecaster has completed work on a forecast wind field the UNIWAVE spectral wave model is run and forecast wave output is produced. The forecaster can immediately verify the analysis portion of the forecast against available wave observations. Wave spectra from the GLOBAL model are applied at the boundaries of all regional wave model implementations. Products from the forecast output range from simple tables for fax/email to full directional spectra for on-board motion prediction modeling. Since 1994, wave output at analysis time has been displayed on OWI's web site (www.oceanweather.com) for the general use of the maritime community.

4. PERFORMANCE OF GLOBAL DURING THE WINTER OF 2001/2002

In November of 2001 the GLOBAL forecast model was upgraded from a resolution of 1.25° in latitude by 2.5° in longitude to .625° in latitude by 1.25° in longitude. The winter of 2001/2002 (December –February) represents the first real test of the new operational model and its performance when compared to insitu buoy/platform measurements in the Northern Hemisphere and against TOPEX altimeter measurements worldwide. The verification presented in this section is consistent with those presented by operational centers when comparing wave forecast models (Bidlot et al. 2002).

4.1 Measured Datasets

Figure 2 shows the 29 buoy and platform locations used in this evaluation. This dataset represents the deep-water locations that were reporting measurements during this period in which real-time verification was performed. Observations from the US buoys and Canadian buoys were obtained hourly from the National Data Buoy Center (NDBC) and Marine Environmental Data Service (MEDS) respectively. All other observations were obtained in real-time from GTS (Global Transmission System) intercepts. All wind data were adjusted for stability and height to a 10-meter reference level and all data were smoothed +/- 1 hour to reduce sampling variability. Wind and wave measurements from TOPEX were obtained from the NASA Physical Oceanography Distributed Active Center at the Jet Propulsion Laboratory/California Institute of Technology. Data was quality controlled and adjusted to make the data consistent with buoy wind and wave observations. Individual 1Hz data points were binned onto a 55km global grid using a 30-minute time window for use in the validation.

Figure 3. Timeseries comparison of wind speed (m/s), wind direction (deg), significant wave height (m), wave period (s) and wave direction (deg) for Buoy 46002 vs. forecast analysis.

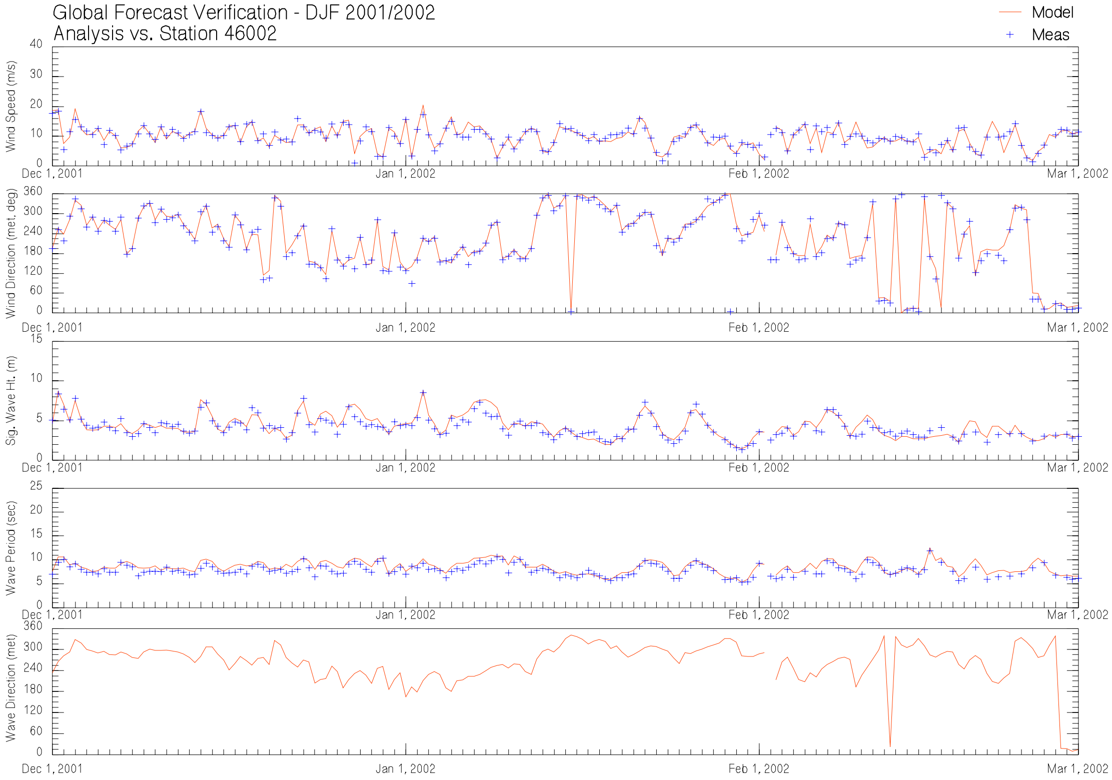


Figure 4. Timeseries comparison of significant wave height (m) for Buoy 46002 vs. analysis, day+1, day+2 and day+3 forecasts.

4.2 Insitu Comparisons

Figure 3 shows the 3-month timeseries and winds and waves at the Pacific buoy 46002 vs. the GLOBAL forecast analysis. The model winds track the buoy measurements due to the assimilation of the wind observations in the forecast methodology. The buoy waves, which are not assimilated, represent an independent verification and show that the forecast system produces a very skillful analysis in both wave height and period. Comparison of wave height at 46002 in the forecast horizon (Figure 4) shows very good skill at time horizons of 1 to 3 days. Most significant storm events were well forecasted; of the six events with wave heights greater than 7 meters within the forecasted period (Dec 13, 22nd and Jan 2,7,21 and 25th) only the short-lived January 2nd event is under predicted by more than a metre.

Table 2 summaries the comparison statistics for all the insitu locations as well as statistics for Hawaii, US East Coast and North Pacific regions. Observations from the Northeast Atlantic are not shown since there were only 41 comparison observations (vs. 600+ for the other regions), but are reflected in the overall statistics. Figure 5 shows the bias and scatter statistics for wind speed, wave height and wave period graphically. Wave heights have a small positive bias in the North Pacific and negative bias at the Hawaiian buoys. The US East Coast wave bias is near zero throughout the forecast period. Wave height scatter index (SI) predictably increases in forecast horizon. The US East Coast SI increases the fastest, which reflects the difficulty in predicting fast-moving intense cyclones as they develop off the coast. Storms in the Pacific, in comparison, evolve more slowly so the SI is lower at analysis time and increases more slowly. SI at analysis and forecast horizons is lowest at the swell dominated Hawaiian buoys, which indicates that the model does a good job in describing the analysis conditions correctly and propagating swells over vast regions. Wave period bias and SI are particularly well behaved in all basins. The largest bias is in the North Pacific, but all regions show very little increase in bias over the 5 day forecast horizon. The same is true for SI, which are very low at analysis time (.15 overall) and only increase to .20 overall by day 5.

Table 2. Summary statistics for insitu observations

Day	# Pts	Meas	Model	Bias	SI	CC
Wind Speed (m/s)						
0	3381	8.76	9.08	.32	.23	.86
1	3334	8.78	9.34	.57	.31	.76
2	3286	8.79	9.46	.67	.36	.67
3	3286	8.79	9.46	.67	.36	.67
4	3134	8.75	9.26	.51	.44	.45
5	3134	8.77	9.23	.46	.48	.33
Wave Height (m)						
0	3094	2.89	2.92	.03	.18	.94
1	3052	2.89	2.95	.06	.21	.92
2	3011	2.89	2.97	.08	.24	.89
3	3011	2.89	2.97	.08	.24	.89
4	2933	2.89	3.04	.16	.35	.77
5	2888	2.89	2.97	.09	.40	.69
Wave Period (s)						
0	3093	6.90	7.04	.14	.15	.85
1	3051	6.90	7.02	.12	.15	.85
2	3009	6.90	7.03	.13	.16	.83
3	3009	6.90	7.03	.13	.16	.83
4	2931	6.90	7.16	.26	.19	.76
5	2887	6.90	7.08	.17	.20	.70

Figure 5. Comparison of bias (top) and scatter index (bottom) for significant wave height (m, left), wind speed (m/s, middle) and wave period (s, right) for insitu data vs. forecast horizon in days.

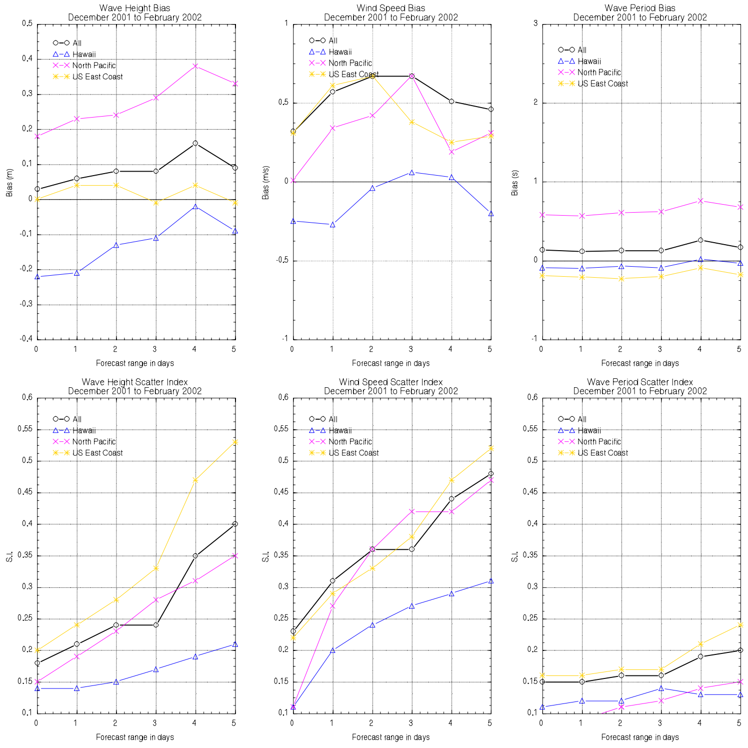
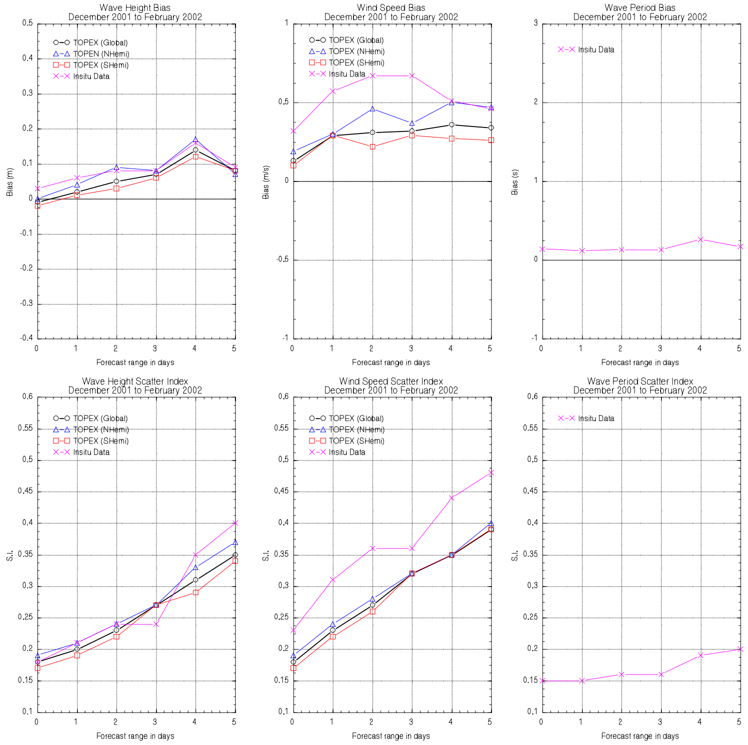


Figure 6. Comparison of bias (top) and scatter index (bottom) for significant wave height (m, left), wind speed (m/s, middle) and wave period (s, right) for TOPEX and insitu data vs. forecast horizon in days.



4.3 TOPEX Comparisons

Measurements from the TOPEX altimeter during this period provide a global view of the forecast skill. Summary statistics from global TOPEX comparisons are shown in Table 2 and graphically for bias and SI in Figure 6. The TOPEX data are further stratified by Northern Hemisphere (Winter) and Southern Hemisphere (Summer) for comparison. Overall, the statistics show excellent agreement in wave height and wind speed. The insitu data set, also plotted, shows that the buoy measurement evaluation of GLOBAL is consistent with the skill indicated globally by TOPEX. Wind speed bias and SI are larger against the insitu dataset primarily due to the inclusion of the Northeast Atlantic buoy/platform data, which were only available in real-time and not as quality controlled as the datasets obtained from NDBC and MEDS. The global coverage of TOPEX allows the spatial comparison of the bias and SI as shown in figure 7 and 8. Portions of the North Pacific and North Atlantic show some positive bias of .25 meters in select areas, but much of the Northern Hemisphere is near zero bias. In the Southern Hemisphere larger positive biases are found along the Antarctic ice edge, which is primarily due to ice tables that are updated no more frequently than monthly. There is an area of negative bias in the Eastern South Pacific (.25 meters) while the majority of the Indian, South Atlantic and Western South Pacific have near zero bias. Highest SI (Figure 8) primarily occurs at the coast and in smaller basins that cannot be fully resolved with the GLOBAL wave grid. The vast majority of the world’s oceans show very low SI’s ranging from .15 to .20. Overall the TOPEX comparisons indicate that the model performs well in all basins with little regional bias.

Table 3. Summary statistics for TOPEX observations.

Day	# Pts	Meas	Model	Bias	SI	CC
Wind Speed (m/s)						
0	43500	7.68	7.81	.13	.18	.91
1	42938	7.69	7.98	.29	.23	.88
2	42507	7.70	8.01	.31	.27	.84
3	41922	7.70	8.02	.32	.32	.78
4	41260	7.69	8.06	.36	.35	.71
5	40898	7.68	8.01	.34	.39	.63
Wave Height (m)						
0	43861	2.80	2.79	-.01	.18	.95
1	43298	2.81	2.83	.02	.20	.94
2	42869	2.82	2.87	.05	.23	.92
3	42293	2.28	2.89	.07	.27	.90
4	41621	2.83	2.96	.14	.31	.85
5	41231	2.82	2.89	.08	.35	.79

4.4 Forecast Reliability

A measurement of the reliability of the forecast can be found in quantile-quantile (Q-Q) plots showing the distribution of measured and modeled wave heights. Figure 9 shows Q-Q for both the insitu and TOPEX measurements vs. the model at analysis and day +2. The figure indicates that the analysis and forecast agree very well with the distribution of measured waves both at the buoy locations and globally in the TOPEX measurements. The highest percentiles (up to 99%) show a slight over-estimation of the model at the highest wave heights, this difference in less than .25 meters. The trend in the higher percentiles remains linear, which indicates that the forecast does a very good job at predicting the frequency and intensity of the stronger storm events.

Figure 7. Wave height bias (meters, analysis-Topex).

Comparison of Global Forecast Analysis and TOPEX Measurements
Mean Difference (meters) of Significant Wave Height for the period Dec 2001 to Feb 2002

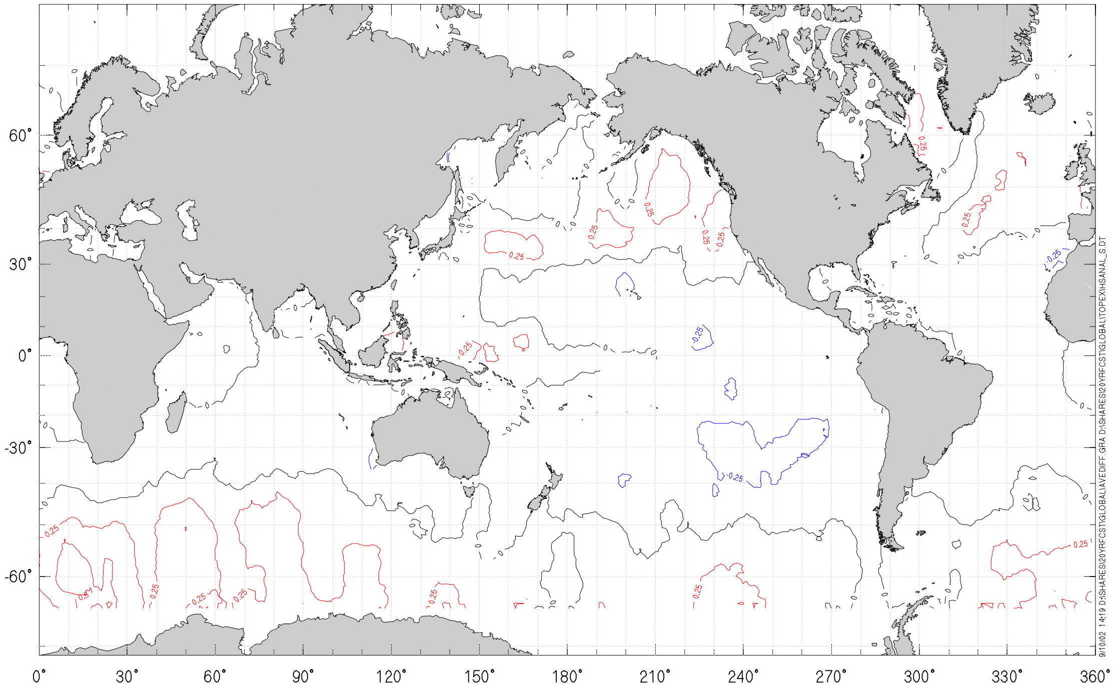


Figure 8. Wave height scatter index.

Comparison of Global Forecast Analysis and TOPEX Measurements
Scatter Index (StdDev/MeanMeas) of Significant Wave Height for the period Dec 2001 to Feb 2002

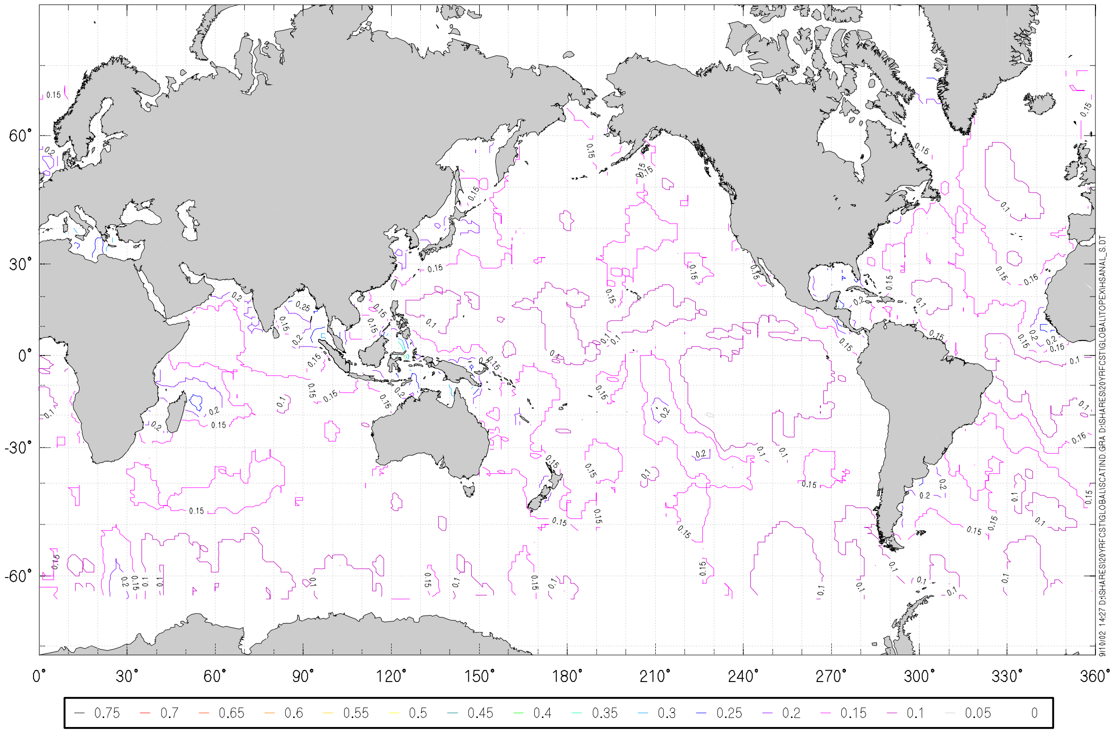
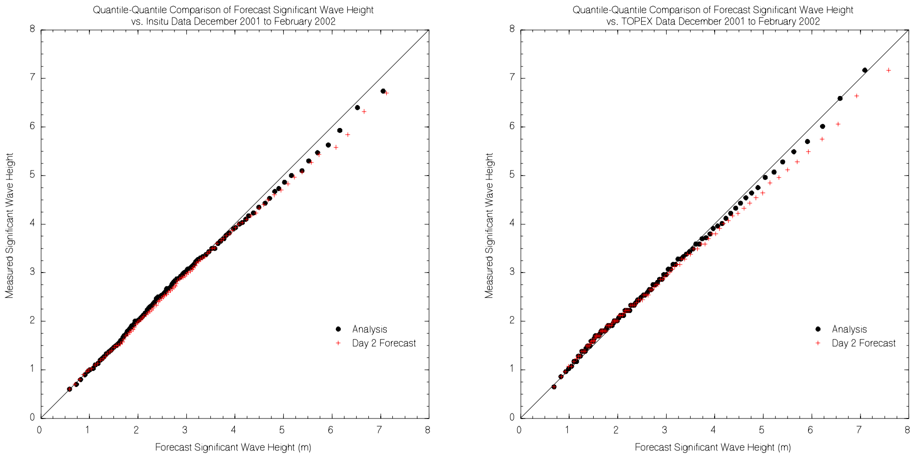


Figure 9. Quantile-quantile (1 to 99%) comparison of measured wave height (m) for insitu (left) and TOPEX (right) vs. forecast analysis (circles) and day+2 (crosses).



5. CONCLUSIONS

Since its inception in 1983, the operational forecast system has continued to evolve in response to user's needs, increasing computing power, and improved model guidance. The inclusion of interactive systems in the forecast run stream, with emphasis in strong tropical and extra tropical storms, has increased forecast skill. Long-term hindcast projects, such as the MSC50 (Swail and Cox 2000), continue to improve the forecast performance as new models, better application of data sources, and analysis techniques are incorporated in a forecast mode. For instance, the 3rd generation of the WWS, already being applied in hindcasting, is in process of being added to the forecast system. The operational system remains flexible and able to respond to individual needs in a short-time frame. This flexibility coupled with performance of the forecast system, particularly in storms, are the main reasons the system remains an important contribution to wave forecasting in the private sector.

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