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DYNAMICAL AND STATISTICAL PREDICTION OF MARINE GUIDANCE PRODUCTS*

by

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ABSTRACT

The Ocean Products Center (OPC) provides a variety of marine meteorological and oceanographic guidance products to the National Weather Service's (NWS) field forecast offices which have marine responsibilities. Some of the products are generated by applying additional dynamical and/or thermodynamical considerations to the output fields from the operational large scale numerical weather prediction (NWP) models of the National Meteorological Center (NMC). Some examples of such forecast fields are the ocean surface winds, global spectral ocean wave forecasts using a deep water model, and a regional shallow water spectral model for the Gulf of Mexico. Since the large scale NWP models are not capable of resolving coastal geometry adequately, a separate set of wind forecasts are produced at several coastal points that are considered critical by the NWS using a statistical approach based on the forecast fields of the nested grid model (NGM) This approach is also used to forecast wind fields over 12 regions on the Great Lakes. Wave forecasts on the Great Lakes are produced at 64 points using these regional winds in an empirical scheme. Statistical techniques are also use to produce guidance forecasts on fog and visibility over the high seas areas of the North Atlantic and North Pacific.

Introduction

NWS is responsible for providing forecasts and warnings to increase the safety of life and property, and for the of conduct marine operations in a safe and effective manner, in coastal, off shore, and high seas areas of the U.S. as well as over the Great Lakes. To support this responsibility of the NWS, NMC provides central guidance products from a suite of operational models and disseminates them to the field offices using various communication networks. This central guidance is then used by the field offices, with appropriate modifications to account for local conditions, to issue warnings and forecasts to the public. The public forecasts normally consist of wind, wave, and weather (small craft advisories, gale, storm, tropical cyclone, and hurricane storm surge warnings) information. Where and when appropriate, ice conditions are included in the forecasts of certain field offices. In addition, analyses of global and regional sea surface temperatures, frontal analyses of the Gulf Stream and Loop Current and the associated eddies are also provided to the public on a regular schedule. See [6] for a detailed description of the products produced by the OPC. A brief description is presented in this paper on the OPC models that provide forecasts of the ocean surface winds, coastal and Great Lakes winds, fog and visibility, and global and regional ocean waves.

Wind Forecasts

The marine wind forecast products consist of two distinctly different types. One is a global product that provides forecasts of winds at 10 m. above the ocean surface on a grid of 2.5 x 2.5 degrees latitude and longitude. This product is derived from the global operational Aviation (AVN) model through the use of a diagnostic boundary layer technique. The other is a local product that provides wind forecasts for selected locations along the coasts and the Great Lakes. This product is derived by applying statistical techniques to output fields from the operational NGM (see the special issue of Weather and Forecasting, Vol. 4, No. 3, 1989 for a collection of articles on NMC's numerical models).

The AVN model is a global spectral model with a horizontal wave number truncation of T-126. Its vertical coordinate is a sigma coordinate. The model has 18 unequal layers in the vertical between its top and bottom. The lowest sigma layer is 10 mb thick and, hence, the forecast winds are available at approximately 50 m above the sea level. To a good first approximation, this height can be considered to be in the constant flux layer and, therefore, a simple logarithmic profile fit is sufficient to obtain the winds at 10 m from the forecast level of 50 m. Stability of the atmospheric column above the ocean, as represented by the air-sea temperature difference, is taken into account in deriving the 10 m winds. The forecast fields are distributed to the field offices over the AFOS (an electronic communication system used by NWS for information exchange) in terms of wind barbs. The forecasts are also sent over the DIFAX, Honolulu FAX, Alaska FAX, and San Juan Fax systems with areal coverage appropriate to each region. Of all of these fax charts, only those on the DIFAX are available to the public through subscription. The fax charts combine both wind and wave information to save transmission time-one chart containing wind and wave height forecasts and another containing dominant wave period and direction. Fig.1 is an example of the DIFAX chart displaying wind forecasts using wind barbs (and also significant wave heights from the global deep water model to be discussed later) on a 2.5x2.5 degrees latitude/longitude grid. The OPC routinely performs a quantitative evalua-

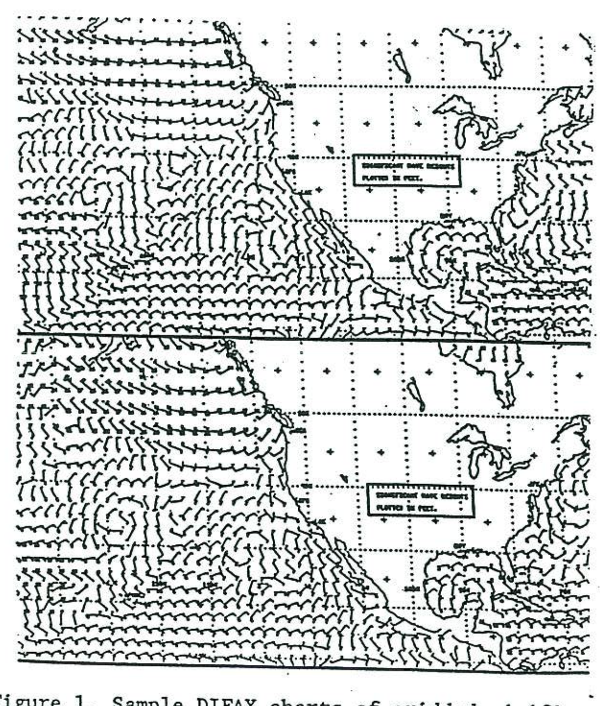

Figure 1. Sample DIFAX charts of gridded sigificant wave height (SWH) and winds barbs at two different time projections 12h apart.

tion of all its products on a monthly basis to monitor their performance and to identify the sources of errors so that remedial measures can be taken to improve the quality of the product. Fig. 2 shows an example of this quantitative evaluation in terms of biases and root mean square (rms) errors for the 24 h forecasts of the OPC model calculated by using the measurements from the off shore buoy network of the National Data Buoy Center (NDBC). Also shown for comparison are the biases and rms errors from the Navy model. The ocean surface wind forecasts, now being produced on a 2.5-degree lat./long. resolution, would soon be available on a 1-degree lat./long. resolution.

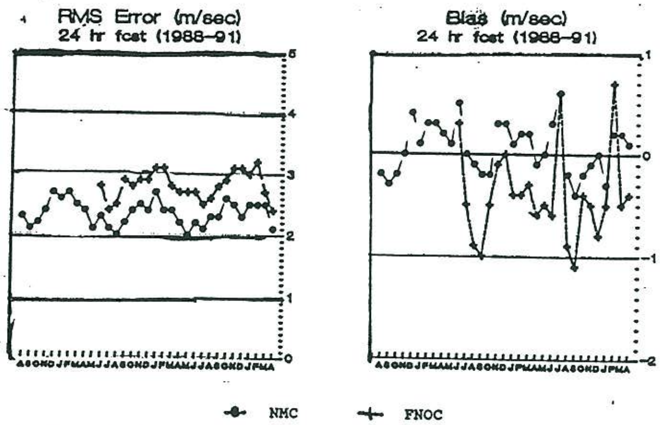

Figure 2. Bias and RMS errors for the 24h forecasts from NMC's and FNOC's marine surface winds.

The AVN model is a large scale global model. Hence, it is not able to adequately resolve the complex influences of the land-sea configuration and topography on the wind fields in the coastal regions. However, there are requirements for wind forecasts at several critical locations on the coasts (see Fig. 3) and over the Great

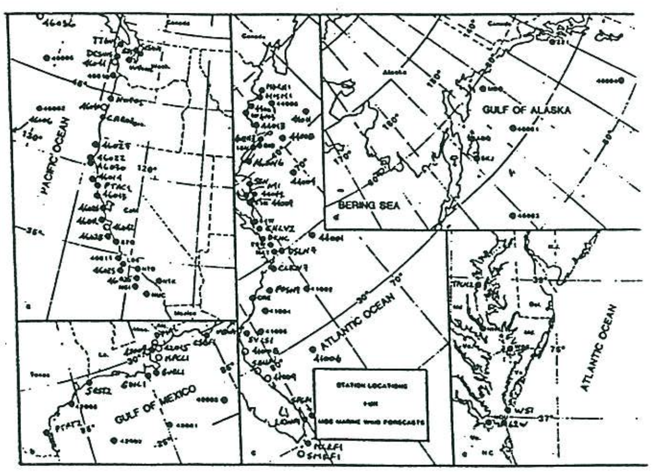

Figure 3. Coastal and offshore locations for the Coastal Wind Forecast System. a, West coast; b, Gulf of Mexico area; c, East coast; d, Alaska area; e, Chesapeake Bay. Open circles indicate stations that will be implemented in Phase 2. Arrows pointing outside boundaries with station ids show stations outside figure boundaries.

Lakes of the U.S. In order to meet these requirements, it is necessary to resort to a statistical approach that has the potential to permit local effects to be taken into account by relating model forecast variables to observations taken at specific points of interest. The method used to do this is called the Modified Perfect Prognosis (MPP) technique. This technique consists of using the Limited Area Finemesh (LFM) model's initialized and 6-hr projection data (predictors) as though they were perfectly analyzed and developing regression equations for the predictands- in this case, the U and V components of the wind. These equations are then applied to the forecast fields from the NGM model (see [2] for details). The forecasts are issued at 6 hr intervals out to 48 hrs in the form of a bulletin. On the Great Lakes, the forecasts are given over 12 regions instead of specific locations.

Fog and Visibility Forecasting

Fog and visibility are not direct forecast variables of weather prediction models but inferences on the occurrence of fog and the extent of visibility can be made using variables of the forecast model. A guidance product in this area is clearly needed since most of the accidents at sea occur under foggy conditions and poor visibility (< 3 km). Fog and visibility conditions depend on the sea surface temperature and profiles of air temperature, humidity, and wind speed in the marine boundary layer. The later quantities, in general, are not available with the required vertical resolution from any of the operational NWP models to make inferences on the occurrence of fog and the extent of visibility in a reliable manner. Hence, a statistical technique called the "perfect prog" technique is adopted to provide the guidance on fog as well as visibility. In this approach, all the data used for the predictands and predictors to develop the regression equations are the analyzed (for predictors) and the observed (for predictand) data taken, usually, at concurrent time. When the equations thus developed are used in a prediction mode, the required predictors are taken from a forecast model. The predictand data for fog and visibility were taken from ship observations and the predictor data from NMC's Global Data Assimilation System. A discriminant analysis technique was used to derive the forecast equations. The forecast system is applicable only over the high seas and during the warm season (April-September) when fog and visibility problems occur more frequently (see [3] for additional details). Fog and visibility forecasts, out to 72 h, for the North Atlantic and the North Pacific oceans are produced twice a day using the predictors from the AVN model. Fog and visibility problems are also important in the coastal regions, perhaps, even more so than on high seas. However, unfortunately, there are not sufficient observations available to derive statistically robust forecast equations in this domain. Alternative methods based on boundary layer diagnostic modelling are being considered for this purpose.

Ocean Wave Forecasts

Ocean waves are a hazard to navigation and recreational activities. Wave forecasts, on a global and regional basis, are essential to avoid, or at best minimize, loss of life and damage to property in various marine related activities and also to provide optimum ship routing to save time and fuel for commercial carriers. Ocean wave forecasting has evolved from the empirical methods developed by Sverdrup and Munk, in which the significant wave height is a function of the fetch and duration of the wind, to more sophisticated models based on the concepts of a random sea surface whose properties can only be predicted in terms of the evolution of the wave spectrum. In terms of the wave spectrum, the significant wave height is proportional to the square root of the total energy contained in the spectrum. Forecasting methods based on the wave spectrum solve a time dependent spectral wave energy equation in which the evolution of spectral energy density in a given frequency and directional band at a point is governed by processes such as generation, dissipation, propagation, and nonlinear interactions between different frequency components. In view of the computational complexities involved in spectral wave forecasting technique, a hierarchy of models - referred to as the first, second, and third generation or 1G, 2G, and 3G models- have evolved in practice. Since the most time consuming calculation is the one that involves the nonlinear interactions, the 1G models exclude them altogether, the 2G models represent them in a parameterized form, and the 3G models attempt to calculate them in a more explicit form. NMC provides guidance wave forecasts using 2G models for the global oceans and the Gulf of Mexico and empirical methods for the Great Lakes and the Chesapeake Bay.

The NOAA Ocean Wave (NOW) model is a global, deep water, spectral model that computes the two-dimensional wave spectrum E (f, d)- E is the energy density, f the frequency, and d the direction- on a 2.5 degree lat./long. grid. The domain of the global ocean extends from 72.5 S to 75.0 N; the precise north-south limits are determined by the polar sea ice edges which are provided to the model on a weekly basis. The model has 15 frequency bands (f) and 24 directional bands (d) at each grid point. The wind input to the model is from the global ocean surface wind forecasts discussed above. The nonlinear terms are parameterized according to SAIL II mechanism [5]. The wave energy is allowed to spread within ± 90 degrees of the wind direction using a cosine-cubed law. Dissipation in frequencies higher than the peak-energy frequency is controlled by the Pierson-Moskowitz spectrum for a fully developed sea. Energy is also dissipated when waves impinge on a coast or run against the prevailing wind. The forecasts are given out to 72 h in terms of significant wave height, peak-energy wave period, and its direction of propagation. Graphic products of the wave forecasts are sent out on the AFOS and the facsimile systems mentioned earlier. Fig. 4 is an example of a chart displaying

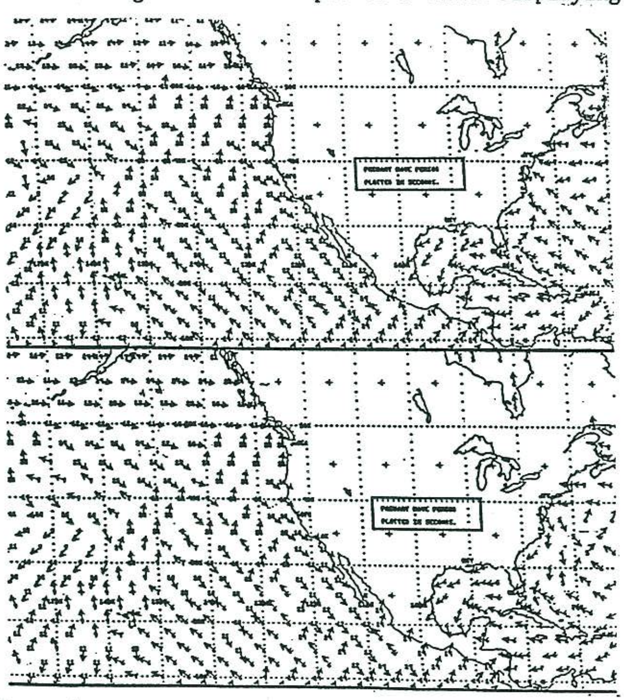

Figure 4. Sample DIFAX charts, showing gridded values of wave period and wave direction arrows.

dominant wave period and direction on the DIFAX. As indicated earlier, another chart with wind and wave height forecasts (Fig.1 in this case) is also sent on the fax circuit to provide complete information on the wind and wave conditions. Again, as in the case of wind forecasts, a routine evaluation of the wave forecasts is conducted on a monthly basis using the wave height measurements from the NDBC buoy network. The bias and rms errors for the NOW model and Navy's GSOWM model are shown in Fig. 5.

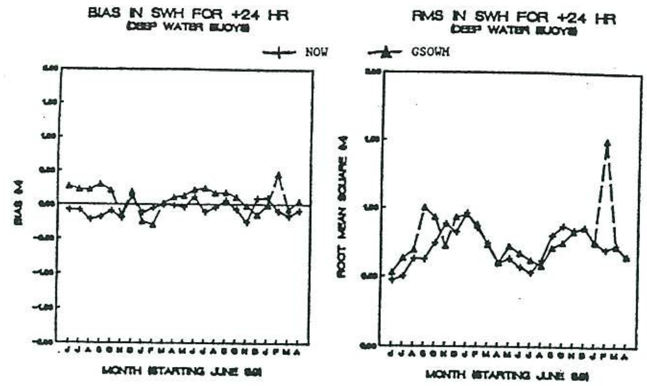

Figure 5. Bias and RMS errors for 24 h forecasts from the NOW and GSOWM model.

Since the NOW model is a global model, using a grid resolution of 2.5 degrees in latitude and longitude, it is incapable of resolving the influences of such features as coast line geometry, presence of islands and barriers, and mesoscale properties of the wind field on the wave spectrum for coastal and regional applications. The NOW is also a deep water model and, as such, it is incapable of taking into account the modifications to the wave spectrum produced by refraction and shoaling by bathymetry, and dissipation of wave energy by bottom friction. For these reasons, a shallow water spectral model developed by [5] was adapted to produce forecasts over the Gulf of Mexico (GMEX). In this model the parameterization of nonlinear interactions is based on the assumption that the interactions will transform the wind sea into a JONSWAP spectrum (conserving the total energy). The wave energy dissipation processes taken into account are whitecapping, bottom friction, and percolation. Computations on the Gulf of Mexico are performed on a horizontal grid of approximately 55 km in the east-west and north-south directions and forecasts are issued out to 48 h (see [6] for additional details). The wind fields used to run the model are again the ocean surface winds from the AVN model. Fig. 6 shows

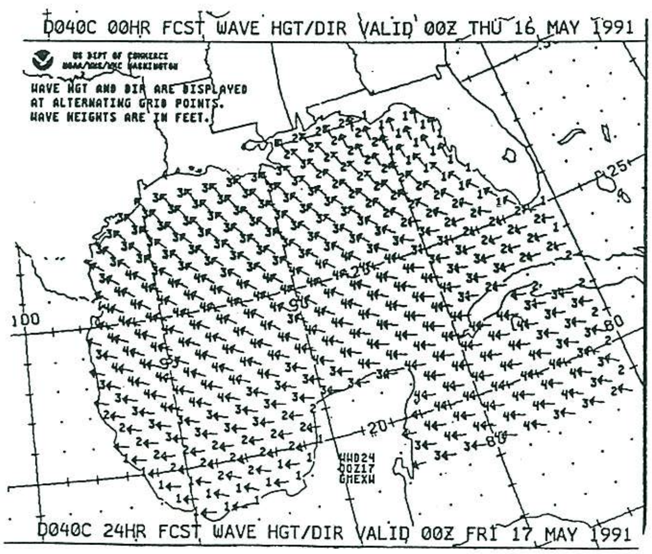

Figure 6. DIFAX display of Gulf of Mexico wave forecasts.

the DIFAX panel displaying the wave forecast products for the Gulf. Fig. 7 shows the results of monthly evaluation statistics for the GMEX model along with those from the global NOW and GSOWM models. It is clear that in most cases the regional model performs better than the global models in the Gulf.

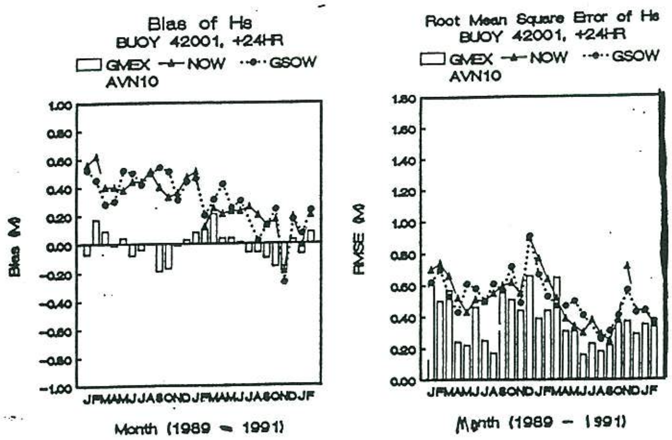

Figure 7. Bias and RMS errors for the 24 h wave forecasts from GMEX, NOW, and GSOWM model.

The global ocean model and the regional model cover most of the navigable water of the U.S. coast line. In practice, it is really necessary to implement shallow water models for application along the eastern and western seaboards of the U.S. to more accurately compute the modification of the deep water spectrum as it propagates and impinges on the coast. Work along these lines is in progress. There are other navigable water of the U.S. that are not covered by the NOW and GMEX models for which forecasts are needed. These are the Great Lakes and the Chesapeake Bay. As mentioned earlier, Great lakes wind forecasts are given over 12 regions by using statistical methods. These winds are then used to provide wave forecasts at 64 points on the lakes (see [4] for details) using a modified Sverdrup-Munk procedure. Over the Chesapeake Bay, wave forecasts, using the same procedure, are issued at 6 points. The winds at these points are obtained by interpolation from the NGM model.

Summary

A brief description of the methods used to derive guidance forecast products on ocean surface winds, coastal and Great Lakes winds, open ocean fog, and global and regional ocean waves has been presented. Some of the products are produced using deterministic dynamical procedures and others using statistical procedures. Work is continuing to improve the performance of the products. In particular, emphasis is being placed on increasing the horizontal resolution of the models to better resolve the regional mesoscale influences on the analysis and forecast fields.

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