SPECIFICATION OF HURRICANE WIND FIELDS FOR OCEAN WAVE PREDICTION[1]

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Abstract: A procedure to blend wind fields obtained from NCEP's operational AVN global atmospheric model and GFDL hurricane model for single and multiple tropical cyclones over the ocean has been developed. Blended wind fields are used in NWW3 wave model for predicting Western North Atlantic waves during the hurricane season of the year 2000. The resulting products, both winds and waves, are compared with data obtained from instruments on NDBC buoys. It shows that using blended wind fields provide more realistic wave fields over the areas within hurricane influence than just using AVN winds only.

INTRODUCTION

It is important to have a method to forecast hurricane generated ocean surface waves, since they greatly affect the safety and economic welfare of marine activities over the ocean and coastal areas. At NCEP, an improved third generation wave forecast model (NOAA WAVEWATCH III, NWW3) (Tolman, 1999) is used for operational global and regional wave forecasts. It uses input wind forecasts derived from the operational NCEP's aviation forecast model(AVN, see Kanamitsu et al. 1991, Caplan et al. 1997) to drive the wave model.

It is well known that the details of highly intense and rapidly varying nature of the wind field associated with a tropical cyclone is poorly resolved by a typical atmospheric model such as AVN. At present, the intrinsic spatial resolution of AVN model is about 1° latitude-longitude and, therefore, it is too coarse to resolve the wind field structure associated with

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a hurricane vortex in a realistic manner. As a result, predicted wave heights in areas under the influence of tropical storms can be unrealistic when AVN winds are used. Also, predicted directions and arriving times of swells in the coastal areas tend to be less adequate.

In order to provide a more accurate forecast of the storm track, intensity and wind distribution, NCEP uses a separate hurricane model during the hurricane season. This model, developed at the Geophysical Fluid Dynamics Laboratory (GFDL), is a multiply nested movable mesh model moving along the hurricane track. The model consists of three grid systems with horizontal resolutions ranging from 1° to 1/3° to 1/6° covering an area of 75° x 75 °, 11 ° x 11 ° and 5° x 5° in longitude-latitude, respectively. (Kurihara and Bender 1980, Kurihara et al. 1990, 1995 and 1998). The model, however, considers only one storm at a time. Thus when multiple storms exist simultaneously over the ocean region of concern (which happens quite frequently!), the storm that is not specifically considered in the hurricane model is dealt in the coarse outer mesh only. Therefore the GFDL model must be run separately for each storm that is developing over the Atlantic Ocean domain at the same time. Consequently, the combined effects of various wind fields associated with multiple storms on ocean waves cannot be adequately predicted by using the result of a single run of the GFDL model. Furthermore, since GFDL hurricane model uses a movable grid system, the domain does not necessarily always cover the entire wave model domain. The problem is how to incorporate the wind fields from the various runs of the GFDL model with the background wind field of the AVN, to produce the most realistic wave field.

A procedure to unify the wind field of AVN and GFDL for single and multiple storms has been developed. The resulting wind field is then used to predict hurricane associated wind waves over the North Atlantic Ocean. In what follows, the procedure of predicting hurricane winds and waves and the results of validation against observations are described.

SPECIFICATION OF HURRICANE WIND FIELD

During the period of this study, the operational GFDL hurricane model produces output data for the outer and innermost meshes 4 times per day at 6-h intervals up to 78 hours. The operational AVN model provides output 4 times per day at 3-h intervals up to 126 hours. The first step is to interpolate lowest level wind data from AVN and GFDL grids at the same projection hour onto the wave model domain (1/4° grid resolution) and adjust to 10 m height. Since GFDL hurricane model runs for each selected storm separately, discrepancies in the wind field features for the same storm from different model runs may occur if multiple storms co-exist. In order to resolve this problem, the concept of an area of influence (AOI) for each storm is introduced. Various definitions of AOI are considered and tested. It is found that the area that is determined based on the following procedure would provide the most realistic and consistent wind field structure:

(a) Determine the location of storm center based on the mean sea level pressure of the inner most grid.
(b) Determining a box area, which has the shortest distance from the hurricane eye to the 1015 MB isobar.
(c) Determining a box area extended from a maximum wind speed near the hurricane eye to four sides on which the wind speed decreases to 5.5 m/s or less.
(d) Forming a new box area with each side taken from the corresponding side of these two boxes which ever has smaller distance from the center.
(e) Define the area of storm influence (AOI) by restricting the new box area to be less or equal to a 12.5-degree longitude-latitude box.
(f) Replacing AVN winds in the AOI of each storm with GFDL winds.
(g) Use a weighted average procedure to smooth out winds in the vicinity of four boundaries of the box area
(h) Repeat the same process for all simultaneously existing storms
(i) Superimpose all AOIs over the AVN wind field in the wave model domain.

PROCEDURE FOR FORECASTING HURRICANE WIND-WAVES

The wave model used for the North Atlantic Hurricane wind-wave forecasting system (NAH) presently is identical to the Western North Atlantic wave model (WNA). A description of WNA model can be found in Chao, Burroughs and Tolman (1999). The hurricane generated wind-wave forecasting procedure for the NAH is as following:

(a) Initialize the NAH wave field at the official start of the hurricane season with output from the WNA.
(b) Search out the GFDL model output from each run cycle throughout the hurricane season.
(c) Use procedure developed in the previous section to derive blended winds.
(d) Obtain needed output spectra from the NWW3 global wave model to furnish boundary wave conditions of the NAH domain at each computational step.
(e) Use AVN winds to continue the NAH operations when no tropical storms/hurricanes exist during the hurricane season.

The system runs independently from the regular operational run of WNA that uses only AVN wind at all times.

PERFORMANCE EVALUATION

During September and October 2000, the procedures developed above were applied in a test mode. The system was run twice daily for the 0000Z and 1200Z UTC cycles. Most of storm tracks are either far away from buoys or storm strength is too weak to cause discernable wave height except Hurricane Gordon (officially named, September 14-18, 2000) and Helene (officially named, September 15-22, 2000). These two hurricanes swept o eastern Gulf of Mexico causing considerable high waves off the West Coast of Flo

Figure 1 shows the time series comparisons of the significant wave height, wind and wind direction between measurements at Buoy No. 42036 and the NAH m hindcasts. The buoy is located off the West Coast of Tampa, Florida (84.5° W, 28.5° N first peak in wave height in the figure appearing near the 17th and 18th of Sept corresponds to Hurricane Gordon, while the second peak near the 22nd correspon Hurricane Helene. In these graphs, only every 12-hr model output are plotted for cla Both NAH and WNA models have missed the occurrence time of observed peak height, but the former shows peak wave heights which are much closer to the measure than the later for both hurricanes. For Hurricane Gordon, the peak wave height of model is higher than that of WNA model, which is consistent with the predicted wind being used. For Hurricane Helene, however, the WNA model shows a higher peak height than that of NAH model even though differences in the wind speed given by models during this period of time is insignificant. This feature is mainly due to the diffe in the size of AVN and AVN-GFDL blended hurricane wind fields used respective WNA and NAH model, as will be explained in a later paragraph.

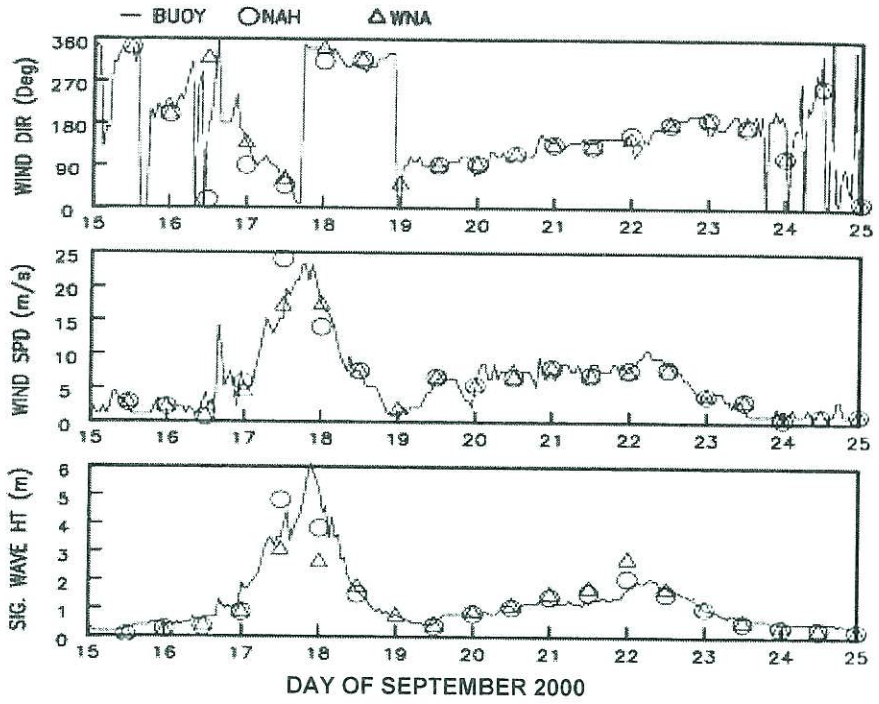

Fig. 1. Time series of predicted and observed wave height, wind speed and direction

Figure 2 depicts the difference between the AVN wind field (a) and the blended AVN and GFDL wind field (b) for Hurricane Gordon. Immediately noticeable are the differences in scale and intensity of the wind fields. The resulting wave fields are also substantially different as shown in Figure 3(a) and 3(b).

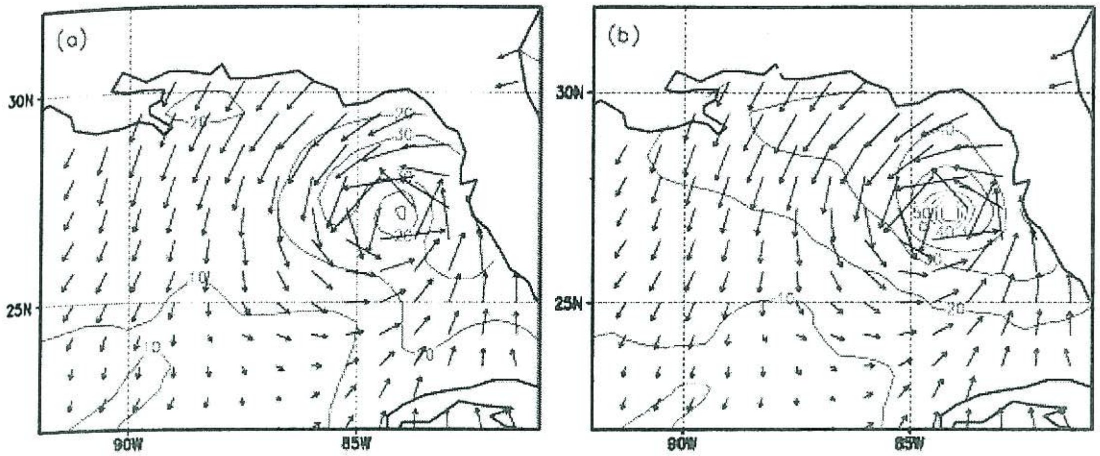

Fig. 2. Example of Hurricane Gordon wind field, valid at 2000/09/17 12Z. (a) AVN model; (b) AVN and GFDL winds blended

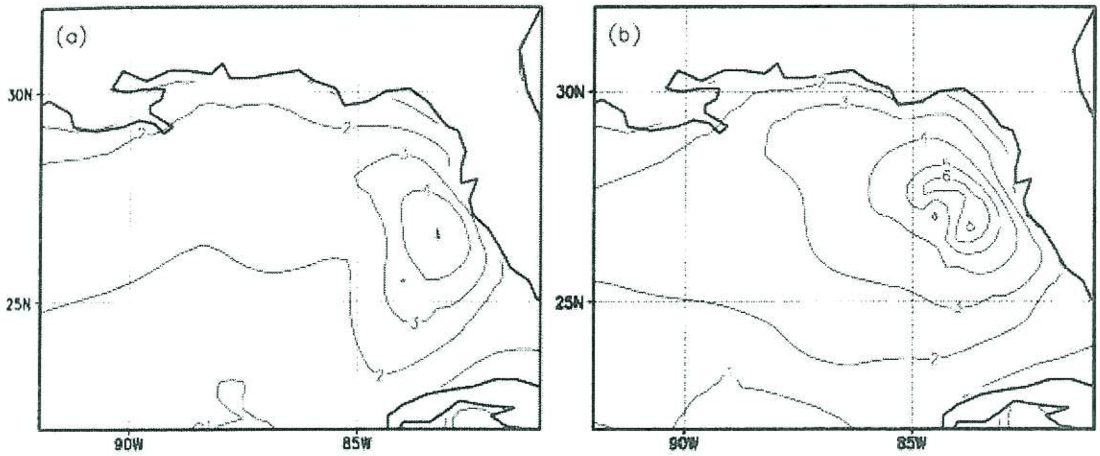

Fig. 3. Hurricane Gordon wave height field valid at 2000/09/17 12Z. Based on (a)AVN winds; (b) AVN and GFDL winds blended

Examples of wind fields associated with hurricane Helene is shown in Figures 4(a) and

4(b). Here, the intensity of AVN wind field is somewhat lower than the blended wind field, but covers a much larger area than the blended wind field. This results in a larger field of high waves by using the AVN wind field than by using the blended wind field as shown in Figures 5(a) and (b). The waves predicted at buoy 42036 by the WNA are higher than those predicted by the NAH, which are much closer to the observed waves. The difference is due to the difference in aerial coverage of the two wave fields generated by the different

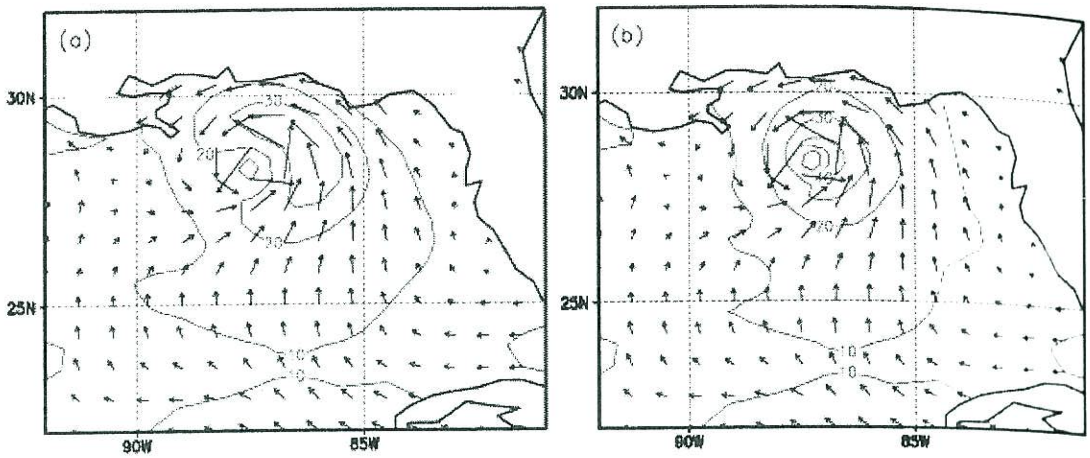

Fig. 4. Example of Hurricane Helene wind field valid at 2000/09/22 00Z. (a) AVN model; (b) AVN and GFDL winds blended

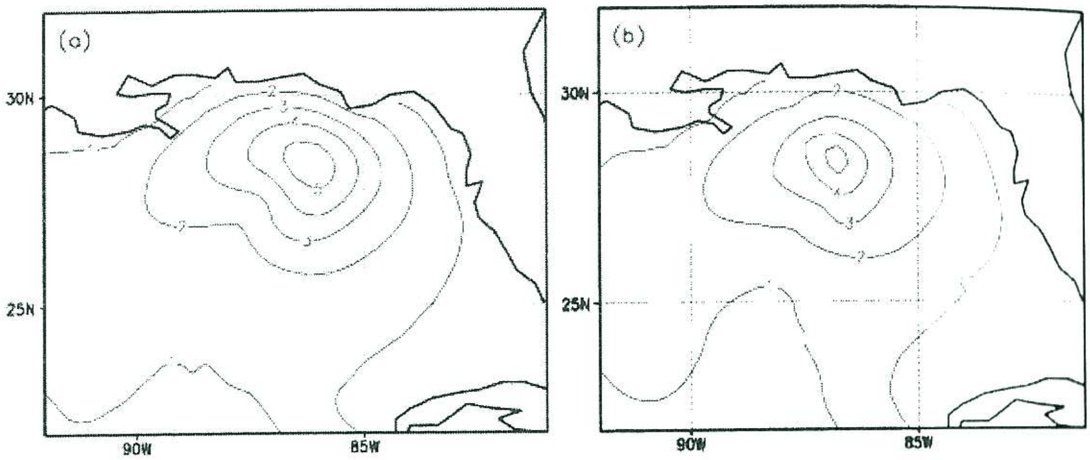

Fig. 5. Hurricane Helene wave height field valid at 2000/09/22 00Z. Based on (a) AVN winds; (b) AVN and GFDL winds blended

wind inputs.

An important aspect in forecasting hurricane-generated waves is on its ability to provide information regarding swell conditions in coastal areas while hurricane or hurricanes are still far offshore. Many accidents occurred near the beach where the weather is quite nice yet long and high swells generated by a hurricane several hundred miles away begin to arrive. Figures 6(a) and 6(b) show the wind field pattern of AVN and AVN-GFDL blended when hurricanes Isaac and Joyce co-exist during September 25 through October 1 in the far distance Atlantic Ocean from the East Coast. The blended wind field shows much higher intensity for both hurricanes which in turn results in much higher wave height and longer period waves as shown in Figures 7(b) and 8(b) in contrast to 7(a) and 8(a), respectively. Accordingly, waves predicted by NAH are expected to propagate to the East Coast area much faster than predicted by WNA. The inability of the WNA model to predict hurricane swell arrival times is well known among NCEP's operational forecasters . Although the year 2000 hurricane season provided us with insufficient cases to objectively establish this contention, operational forecasters at NCEP generally agree that the NAH swell dispersion patterns are far superior to the WNA patterns.

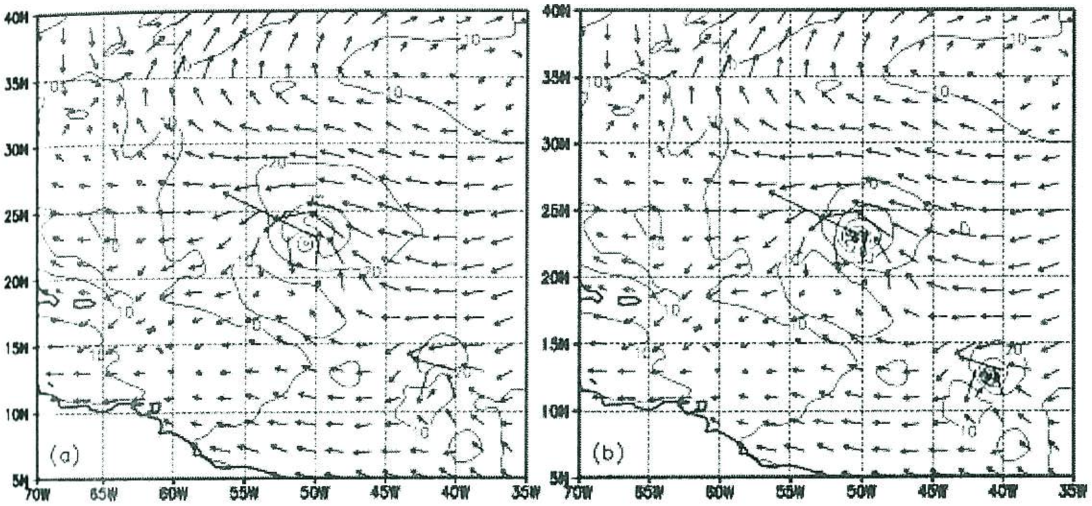

Fig. 6. Example of Hurricanes Isaac and Joyce wind fields valid at 2000/09/28 00Z. (a) AVN model; (b) AVN and GFDL winds blended

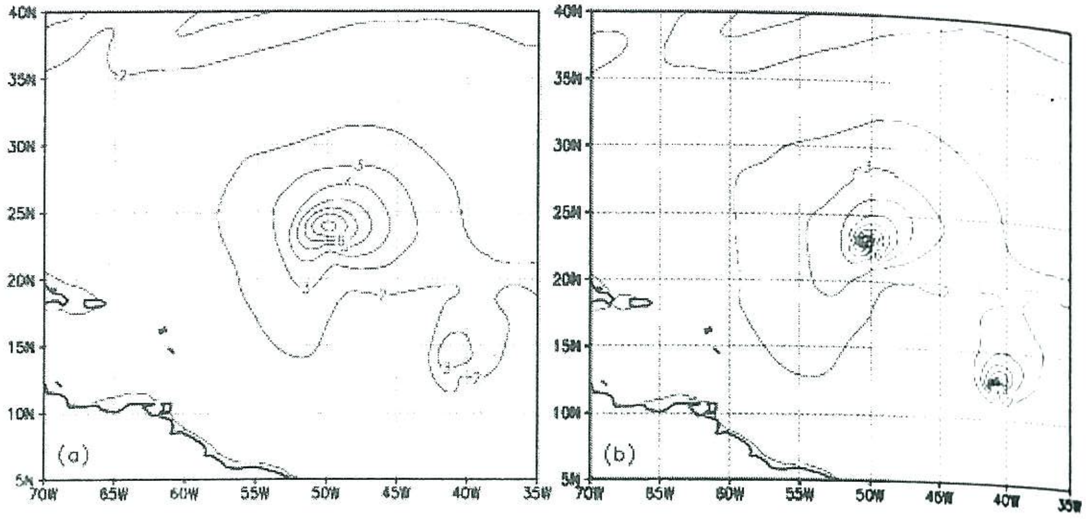

Fig. 7. Hurricanes Isaac and Joyce wave height fields valid at 2000/09/28 00Z. Based on (a) AVN winds; (b) AVN and GFDL winds blended

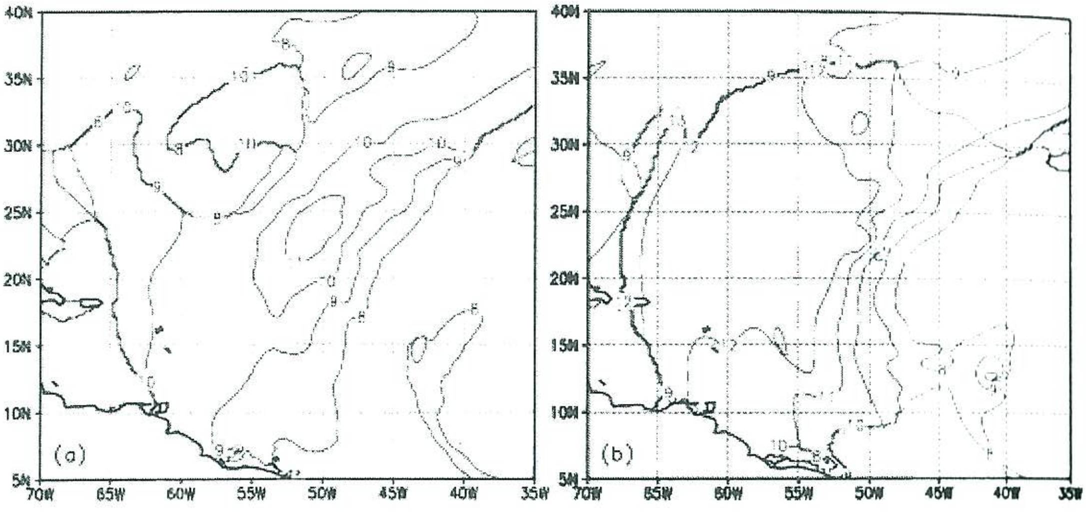

Fig. 8. Hurricanes Isaac and Joyce wave period fields valid at 2000/09/28 00Z. Based on (a) AVN winds; (b) AVN and GFDL winds blended

CONCLUDING REMARKS

An operational system, NAH, for forecasting North Atlantic Hurricane wind waves and swells using blended GFDL and AVN models winds has been developed and tested successfully during the year 2000 hurricane season. Results of the validation study show that the forecasting system provides more realistic hurricane wave predictions than predictions provided by the existing operational regional Western North Atlantic wave model (WNA) using solely AVN winds. The new system, in general, predicts much higher wave heights over the areas within hurricane influence and earlier arrival of longer and higher swells in the coastal areas. The system has officially become operational to provide forecasting guidance at the start of the 2001 hurricane season.

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