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Improvements in Deterministic and Probabilistic
Tropical Cyclone Surface Wind Predictions

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I. BACKGROUND:

This proposal describes newly developed methods for improving deterministic and probabilistic surface wind predictions that will be evaluated in an operational setting.

The deterministic surface wind prediction improvements expand upon previous work with the Statistical Hurricane Intensity Prediction Scheme (SHIPS). A major limitation of SHIPS is that relies almost entirely on relationships between the storm environment conditions and intensity changes. Research results have shown that internal processes such as eyewall contraction and replacement can also have large impacts on hurricane intensity changes. Since theses processes can often be observed in aircraft reconnaissance observations and GOES imagery, a new component to the SHIPS model will be developed and evaluated where aircraft reconnaissance and GOES imagery will be utilized to better determine the inner core structure. Aircraft data are not currently used as SHIPS input, and the GOES 10.7 μm imagery is used in a rudimentary way that involves averages over large areas. The intensity forecast model with the inner core GOES and aircraft data will be a separate component that predicts deviations from the SHIPS prediction, and will be referred to as the GOES and Reconnaissance Intensity Prediction (GRIP) model. To account for nonlinear interactions between possible predictors, a neural network prediction method will be tested in addition to the multiple linear regression method that is currently used by SHIPS.

As part of the overall development of statistical tropical cyclone forecasting techniques, a new method for estimating the uncertainty associated with surface wind forecasts is proposed. The wind uncertainty estimate is obtained using a Monte Carlo Probability (MCP) model, where a large set of plausible tracks and intensities are determined by randomly sampling historical forecast errors distributions. Special procedures were developed to account for the effects of land, for the serial correlation between the track and intensity forecast errors, and for the relationships between intensity and wind structure. A prototype version of the MCP was developed for the Atlantic basin and provides fields of the probability of the surface wind exceeding specified wind thresholds over specified time intervals. In this proposal, the Atlantic MCP model will be generalized to include the East Pacific, Central Pacific, and West Pacific tropical cyclone basins. The code will also be generalized so that it can run as part of the Automated Tropical Cyclone Forecast (ATCF) system, and generate fields on the NWS National Digital Forecast Database grid system.

II. SECOND YEAR ACCOMPLISHMENTS

A. Improvements in Deterministic Surface Wind Predictions

This part of the project involves the testing of radial structure information from aircraft flight level wind data and GOES infrared observations as input to SHIPS (the GRIP model) and a comparison of a neural network technique with the multi-regression method currently used in SHIPS.

1.The GRIP Model

The dependent dataset for the GRIP model was described in the previous progress report for this project. An automated quality control and objective analysis system was developed for the aircraft data to provide radial profiles. In cooperation with Chris Sisko from TPC, the aircraft data was sent to the NCEP IBM in real time during the 2004 hurricane season. A script was written to run the analysis system on the IBM. However, there were some problems with the aircraft data stream to the IBM from TPC (some vortex messages were incorrectly being included in the flight level data processing, resulting in unreadable characters in the IBM files). These problems were eventually worked out during the season, but because the aircraft data stream was not completely reliable, it was decided not to put the 2004 GRIP intensity forecasts in the ATCF or provide them to the hurricane forecasters. However, all of the GRIP forecasts were run with the operational input and the final corrected set of aircraft observations that were collected in real time. It was found that some minor modifications were needed to the error checking routines with the real time data stream because these are available at either 30 or 60 second intervals, compared to the 10 second data used in the dependent data set. Because the operational data is sparser, the tolerances for the “buddy check” part of the quality control needed to be increased.

Because the 2004 season was very active, especially on the western side of the Atlantic basin where the reconnaissance aircraft typically fly, a large validation set was obtained. A total of 123 objective wind analyses and corresponding GOES profiles were available from the automated system for the GRIP model. Figure 1 shows an example from Hurricane Jeanne of the real time wind data (after the data was error checked and put into storm relative coordinates), the objectively analyzed wind field in the cylindrical coordinate system and an isotach plot.

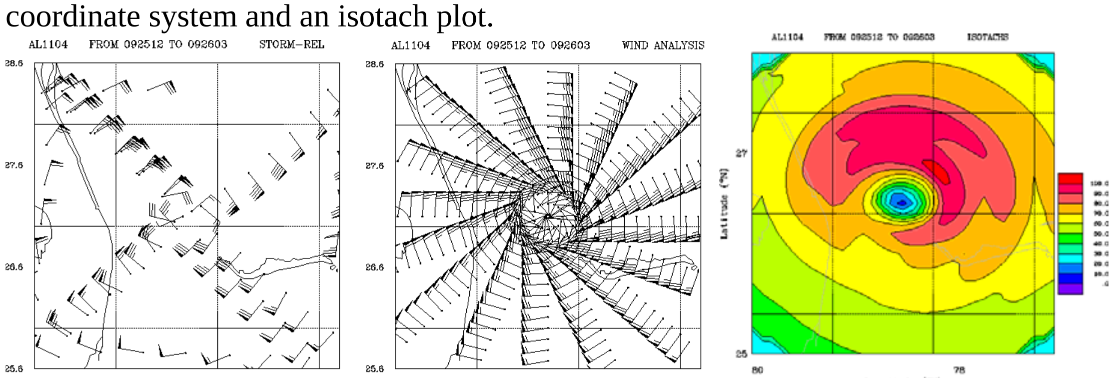

Figure 1. The aircraft flight level wind data in storm-relative coordinates (left), the objectively analyzed wind field (middle,) and the isotach field (right) generated as part of the input procedure for the GRIP intensity forecast for hurricane Jeanne at 0000 UTC on 26 September 2004.

The initial development of the GRIP model was described in previous progress reports. The original idea was to find the empirical orthogonal functions (EOFs) of the radial profiles of IR brightness temperature and azimuthally averaged tangential wind in the dependent data set (1995-2003), and then use the amplitudes of the EOFs (the principal components) as predictors of intensity change. The EOF analysis was performed and results showed that 99% of the variance of both the tangential wind and GOES IR profiles could be explained with just a few EOFs. In order to take advantage of the much larger dataset included in the SHIPS model, the dependent variable is actually the deviation from the SHIPS forecast. In real time the GRIP model provides a correction to the SHIPS forecast. For the dependent sample, it was found that three principal components (two for the tangential wind and one from the GOES profiles) were significantly correlated with the residual from the SHIPS model. For the dependent sample, the PC input reduces the SHIPS errors by a few percent. For comparison, an alternate formulation of the GRIP model was developed, where physically based parameters from the tangential wind and GOES profiles were used as input. From this analysis it was found that four parameters were correlated with intensity changes as follows: 1) The radially averaged tangential wind outside the radius of maximum wind, 2) the radial gradient of the tangential wind outside the radius of maximum wind, 3) the maximum tangential wind, 4) An eye brightness temperature parameter. With the physically based input, the GRIP forecasts improved the SHIPS forecasts by up to about 5%.

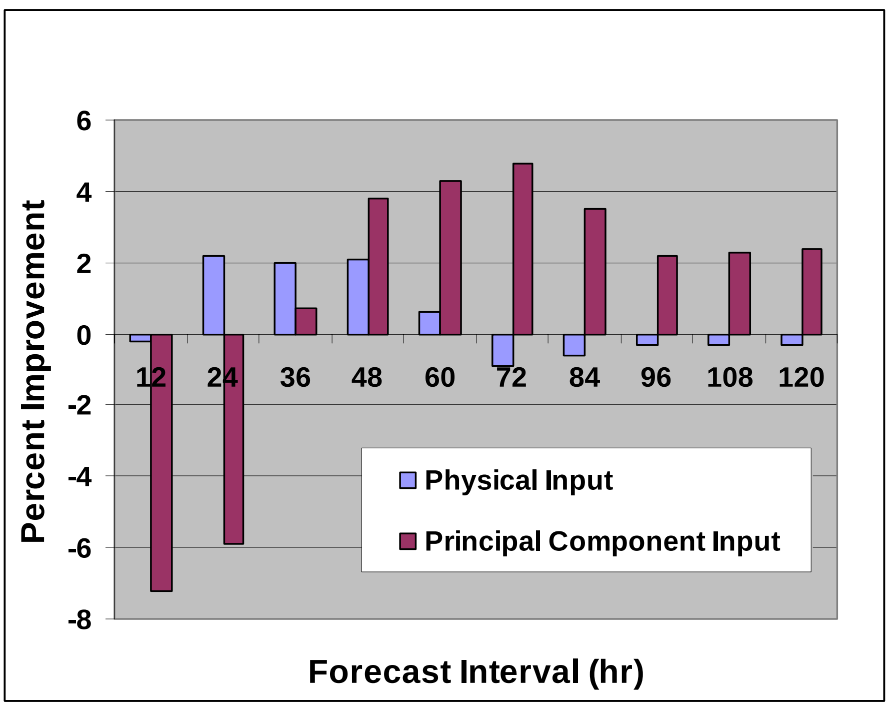

Figure 2. The percent improvement of the GRIP intensity forecasts relative to SHIPS for independent cases from the 2004 Atlantic hurricane season.

Both versions of the GRIP model (the EOF and physical parameter versions) were tested on the 123 independent cases (63 by 120 h) from the 2004 season. Figure 2 shows the percent improvement of the GRIP forecasts over the SHIPS forecasts. These results show that the physically based input resulted in a modest improvement in the 24-48 h time frame, without much degradation at other times. In contrast, the PC input degraded the short range forecasts, but provided larger improvements than the physical input for the longer range predictions. These results indicate that there is useful predictive information in the aircraft and GOES radial profiles.

The 2004 data will increase the developmental sample by about 15%. This data will be added and the GRIP model will be re-developed for the 2005 season. The results in Fig. 2 suggest that a combination of the PC and physically based input should be included in the prediction. A combined GRIP model will be developed and tested in real time during 2005.

2. The Neural Network Model

In cooperation with Dr. Charles Anderson from the CSU computer science department, a neural network (NN) version of the SHIPS model was developed using the dependent data from 1982-2003. The results from the dependent sample were quite encouraging, where 5 to 10% additional variance could be explained, relative to the regression model. A version of the neural network model was developed using a sample from the 1982-2002 season so it could be thoroughly tested on independent cases from 2003. The results from the independent tests on the 2003 data were quite disappointing, where the NN model actually increased the errors by several percent relative to the operational SHIPS forecasts. The NN model was re-derived with the 2003 cases added, and was tested on the first few forecasts from the 2004 season. Results again showed that the NN technique provided a better fit to the dependent data than the multiple regression method, but provided worse forecasts on independent cases. One final version of the NN model will be developed by Dr. Anderson, where the emphasis will be on techniques that help to reduce over-fitting. The revised NN model will be tested on the 2004 cases. If the results again are negative, this will confirm our tentative conclusion that the NN method has no advantage over the simpler multiple regression technique, given the sample size and uncertainties in the SHIPS database.

B. Improvements in Estimating Surface Wind Speed Probabilities

The basic Monte Carlo (MC) model code was developed during the first year of the project. The MC model provides estimates of the probability of 34, 50 and 64 kt winds, and versions were developed for the Atlantic, eastern and central North Pacific, and western North Pacific. The method includes uncertainties in the track, intensity and radii forecasts.

The MC code was implemented on the NCEP IBM by the start of the main part of the 2004 season, in cooperation with Jim Gross of TPC. The probabilities associated with all active storms in the entire northern hemisphere were generated on the NCEP IBM, and the output was put on a password protected web site at CIRA for evaluation by TPC and JTWC, as well as set of potential users selected by TPC. The products were provided on four slightly over-lapping areas to provide the cumulative probabilities for 0-12, 0-24, … 0-120 hours. These fields were animated on the web site, and were updated every six hours. In addition, the fields were archived for later use in training activities by TPC. Figure 3 shows examples of the 0-120 hour cumulative probabilities for the 34 kt winds for each of the four regions that were displayed on the real-time web site.

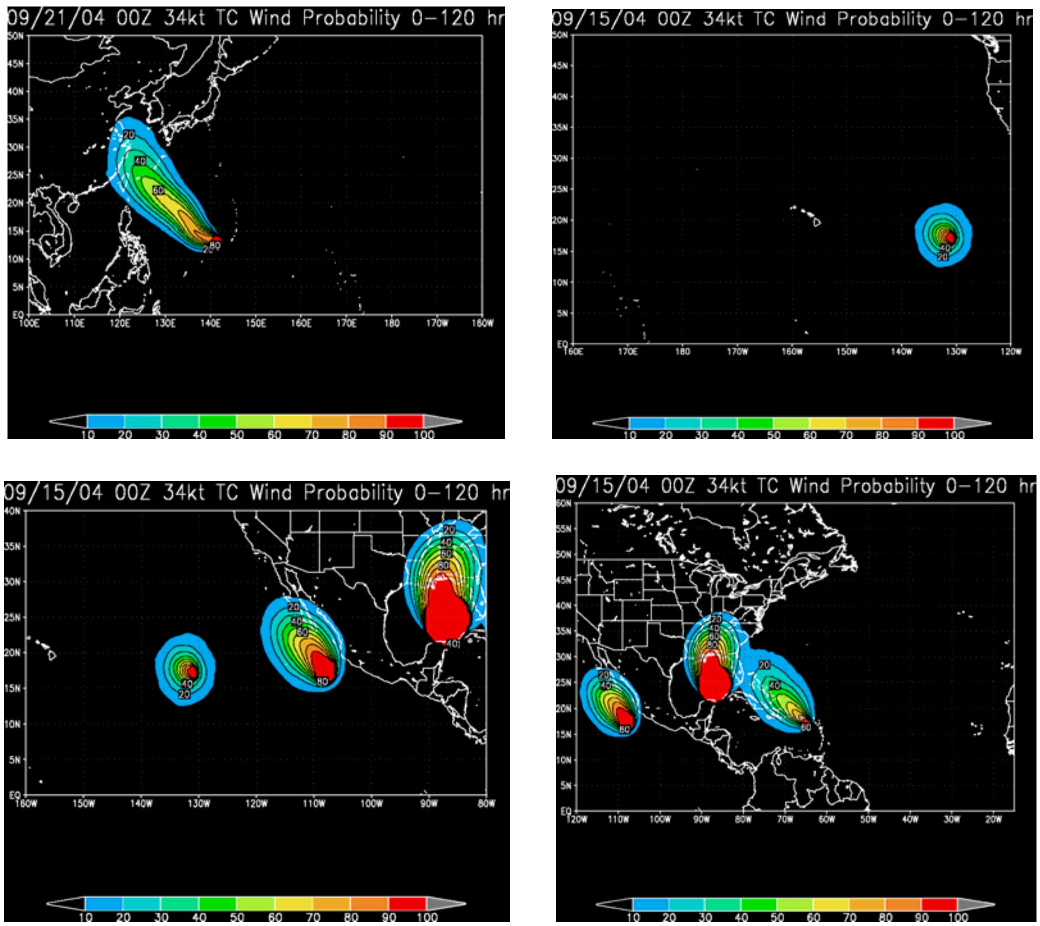

Figure 3. Examples of the 34 kt wind probability product for the western Pacific (upper left), Central Pacific (upper right), eastern Pacific (lower left) and Atlantic (lower right) from the 2004 hurricane season. The west Pacific example is from 00 UTC on 21 September 2004 and the other three areas are from 00 UTC on 15 September 2004.

Based upon feedback from the 2004 season, a few modifications will be made for 2005. A zero hour product, which shows the region initially inside the various wind thresholds, will be added to provide better continuity in the loops. In addition, the wind radii distributions were determined from the operational radii estimates from NHC and JTWC.

The operational radii represent the maximum radius in four quadrants relative to the storm center (NW, NE, SW, SE), but are used as the average radii in each quadrant. The archive of H*Wind analysis available from the Hurricane Research Division will be used to develop a factor to convert the maximum radii to average radii. Preliminary results indicate that a factor of about 0.8 will be applied, which will slightly reduce the area included in the probabilities and eliminate a possible source of bias. Coordination with TPC will continue during 2005 as they develop web-based and operational probability products based upon the MC model output.

III. Things not Completed/Pending Items

The GRIP model still needs to be evaluated in real time because this task was not completed during the 2004 season due to the unanticipated delay in establishing the aircraft data feed on the IBM. However, everything is in place for a test during 2005. Otherwise, the project is basically on schedule and results should be available to determine what to make operational after the project is completed. Some changes to the SHIPS, GRIP and MC model will be required because of the change in the NCEP computing environment (frost/snow being replaced by blue/white). These changes should be minor and will be coordinated with TPC.

IV. Things that did not succeed

The MC model and the GRIP show promise so far. However, the neural network technique does not perform as well as expected when applied to independent cases. One last test of that method will be performed before the 2005 season in collaboration with CSU Department of Computer Science, but if the results are the same as before, that part of the project will not be pursued further.