JHT Final Report
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Improvements in Deterministic and Probabilistic
Tropical Cyclone Surface Wind Predictions

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I. Background

This purpose of this project is to develop new methods for improving deterministic and probabilistic surface wind predictions and to perform an evaluation in an operational setting. This was a two year project funded by the NOAA Joint Hurricane Testbed (JHT).

The deterministic surface wind prediction improvements expand on previous work with the Statistical Hurricane Intensity Prediction Scheme (SHIPS). A major limitation of SHIPS is that it relies almost entirely on relationships between the storm environment conditions and intensity changes. Research results have shown that internal processes such as eye wall 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 is being developed and evaluated where aircraft reconnaissance and GOES imagery are utilized to determine the inner core structure. Aircraft data are not currently used as input to the operational version of SHIPS, and the GOES 10.7 μm imagery is used only in a rudimentary way that involves averages over large areas. The intensity forecast model with the inner core GOES and aircraft data is a separate component that predicts deviations from the SHIPS prediction, and is referred to as the GOES and Reconnaissance Intensity Prediction (GRIP) model. To account for nonlinear interactions between possible predictors, a neural network prediction method was 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 was developed. 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 in the track and intensity forecast errors, and for the relationships between intensity and wind structure.

II. 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

In the first year of the project the emphasis was on the development of the object analysis system for the recon data, and assembling the dependent database. Considerable effort was put into the automating the objective analysis, which required the development of a fairly robust quality control system. The quality control system includes a gross error check, a method to determine whether data coverage is sufficient, and a pre-analysis to eliminate erroneous data. The final input to the GRIP model is the azimuthally averaged radial and tangential wind, and the GOES brightness temperature on a 4 km radial grid extending from the storm center to 200 km.

Also in the first year, an empirical orthogonal function (EOF) analysis was performed on the GOES and recon data in an attempt to reduce the dimension of the data for the regression against intensity change. Figure 1 shows the radial structure of the first few EOFs of the recon and GOES data. The results showed that most of the variability of the data is explained by these patterns.

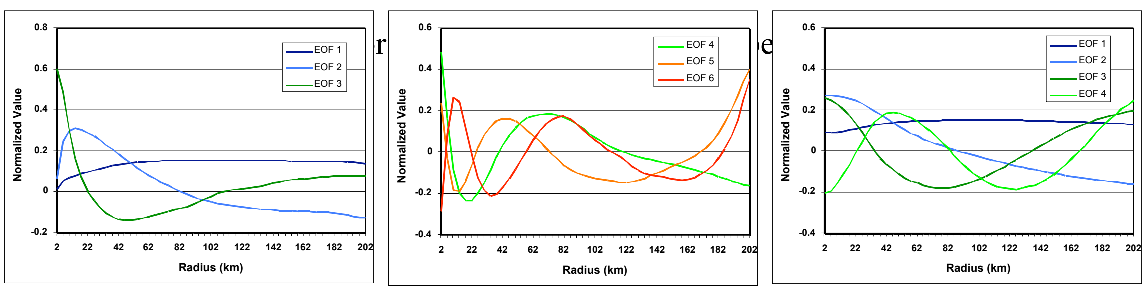

Figure 1. The first 6 EOFs (left and middle) from the aircraft data and the first 4 eigenvectors (right) from the GOES data. These EOFs explain 99% of the variability of the original data.

In the second year of the project, the GRIP model was developed from cases from the 1995-2003 hurricane seasons, and tested on independent cases from the 2004 season. Testing on independent cases continues during the 2005 season. Figure 2 shows an example of the aircraft reconnaissance data that is input to the automated objective analysis system, and the analyzed wind field. Several parameters from the wind field are used for the intensity prediction in combination with parameters from GOES imagery.

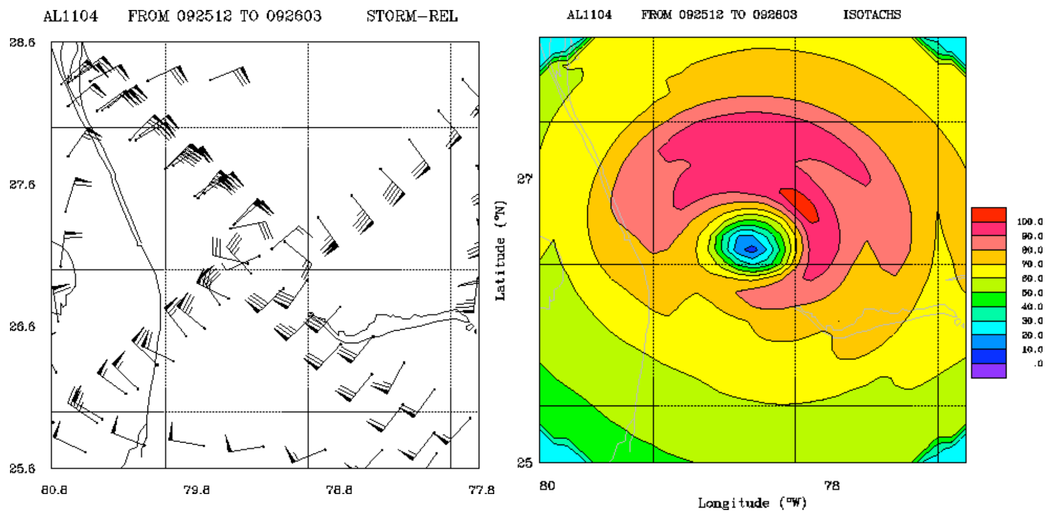

Figure 2. Aircraft flight level winds from hurricane Jeanne in storm relative coordinates from 25 September 2004 (left panel) and the objectively analyzed wind speed field (right panel).

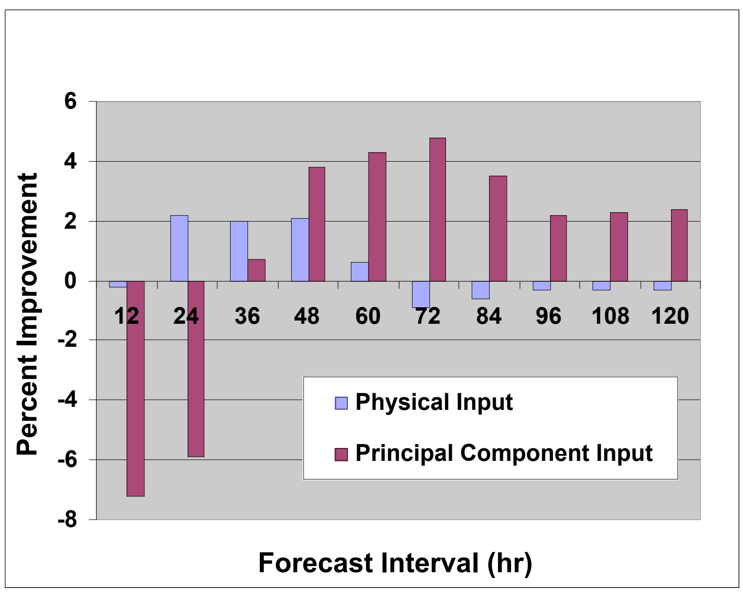

Figure 3. The improvement of the GRIP model relative to the SHIPS model for independent cases from the 2004 Atlantic hurricane season.

Two versions of the GRIP model were developed for comparison. One utilized physically based variables such as the average GOES brightness temperature and radius of maximum wind, and the other used the amplitudes of EOFs (principal components, PCs) of the radial profiles of the GOES and aircraft data. Figure 3 shows the improvements in the intensity forecasts with these two versions of the GRIP model from the independent cases from the 2004 hurricane season. The PC model had a negative impact in the short range, but a positive impact at later times. The physical model had a smaller negative impact, but also a smaller positive impact. Both versions of the model are being tested during the 2005 Atlantic season.

One aspect of the GRIP model development that was originally proposed but not accomplished was the real-time testing of the GRIP forecasts. In year one of the project, the establishment of a reliable aircraft database on the NCEP IBM was delayed due to other time commitments by TPC project personnel. In the second year, the transition from the old NCEP IBMs (frost/snow) to the new IBMs (blue/white) resulted in a down time of about 6 months for the GOES database required by the GRIP model. In fact, the GOES database was not made available on the new IBMs until after the 2005 hurricane season had already started. Neither TPC staff nor the project PIs had any direct control of the conversion of the GOES database. Thus, there was not adequate time in the off-season to implement and test the real time version of the GRIP model on the IBM.

Although the GRIP model forecasts were not run in real time, routines were set up to capture all of the real time input required to evaluate the model using operational input. The results from the 2005 season combined with the 2004 cases should provide TPC with an adequate sample to determine whether the GRIP model should be transitioned to operations. This evaluation will be performed after the 2005 hurricane season is over, and provided to TPC project personnel.

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 1982-2002. Dr. Anderson is an expert on computer learning techniques. The results from the dependent sample were quite encouraging, where 5 to 10% additional variance of the intensity changes could be explained, relative to the regression model. The NN model was tested on independent cases from the 2003 season. The results from the independent tests 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 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. Thus, we concluded that the NN technique does not provide an advantage over the linear regression method.

Although this part of the project is essentially completed, one final test of the NN model will be performed. Dr. Anderson plans to develop another NN model where the emphasis will be on techniques that help to reduce over-fitting. The revised NN model will be tested on the independent 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. If these results are positive, they will be presented to TPC for evaluation and possible operational implementation.

B. Improvements in Estimating Surface Wind Speed Probabilities

The basic Monte Carlo Probability (MCP) model code was developed during the first year of the project. The MCP model provides estimates of the probability of 34, 50 and 64 kt winds through five days, 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 track and intensity error distributions are determined from the NHC and JTWC official forecasts, and the corresponding radii distributions are determined from the errors of a simple climatology and persistence radii forecast model that was developed as part of this project. It was not possible to use the error distributions of the NHC or JTWC radii forecasts because they do not extend to five days.

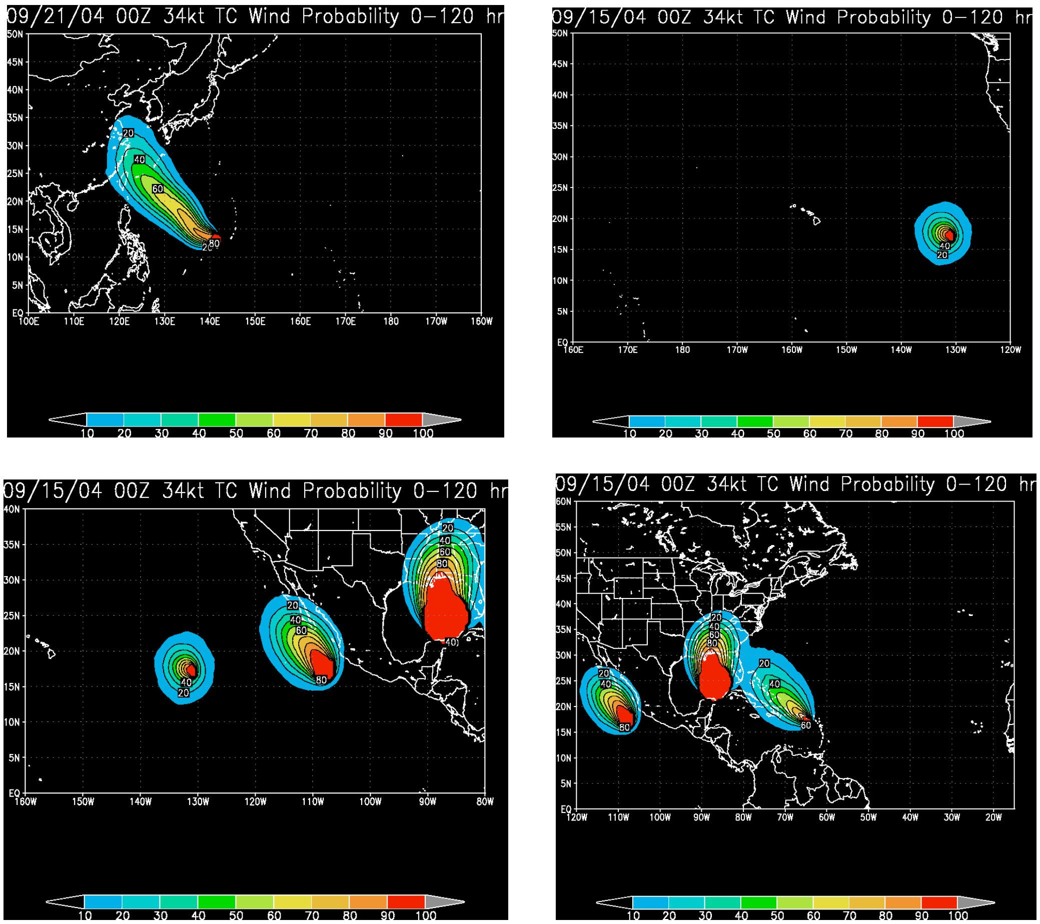

Figure 4. Examples of the 34 kt wind probability product for the western Pacific (upper left), Central Pacific (upper right), eastern Pacific (lower left) and Atlantic (lower right) from the 2004 hurricane season. The west Pacific example is from 00 UTC on 21 September 2004 and the other three areas are from 00 UTC on 15 September 2004.

The MCP 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 4 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.

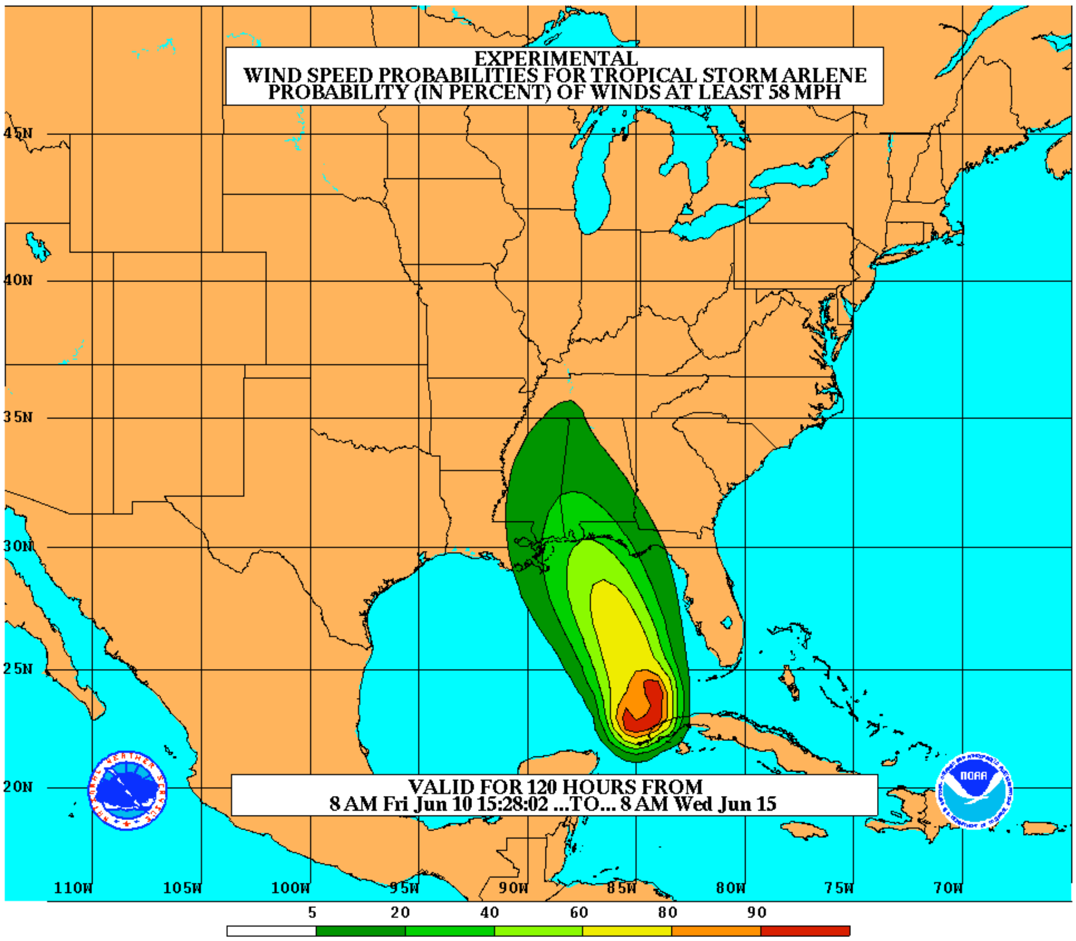

Figure 5. Example of the output of the Monte Carlo probability program for tropical storm Arlene from the 2005 Atlantic hurricane season.

Based upon feedback from the 2004 season, five modifications were made to the MC model for 2005. 1) A zero hour product, which shows the region initially inside the various wind thresholds, was added to provide better continuity in the loops. 2) The wind radii CLIPER model was developed from 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 was used to develop a factor to convert the maximum radii to average radii. 3) A method to account for cases where the perturbed track is over the water, but the original forecast track is over land was developed. Intensity persistence from the last forecast point over water is used along the perturbed track. This adjustment corrected a potential source of error for storms that move inland but remain close to the coast. 4) In response to a request from the NWS Weather Forecast Offices (WFOs), the code was generalized to provide incremental probabilities in addition to the cumulative probabilities. 5) The track and intensity error distributions were updated so that they are based upon the operational forecasts from the 2001-2004 seasons. To provide users with examples of the new MC model, a web site is being created that shows several cases from the 2004 hurricane season (see http://rammb.cira.colostate.edu/projects/tc_wind_prob/index.html).

The new MCP model was provided to TPC and was implemented on the NCEP IBM. The model is being run in real time during the 2005 season, and several experimental products are being generated and displayed on the TPC web site. A sample product from the TPC is shown in Fig. 5 below. The tests during the 2005 season will provide TPC with enough information to determine if the new products derived from the MCP model will become operational in 2006. So far, the feedback has been very positive.

III. Things not Completed/Pending Items

All aspects of the MCP model were completed. The only pending item for that part of the project is for TPC to make a final decision on operational implementation. The GRIP model results from 2004 were encouraging, but a little ambiguous, because the short term forecasts degraded slightly. The GRIP model will be evaluated after the 2005 season, which should provide TPC with enough information to make a decision on operational implementation.

IV. Things that did not succeed

The neural network technique did not perform as well as expected when applied to independent cases. As described above, one final test of the method will be performed with a method designed to minimize over-fitting, in collaboration with the CSU Computer Science Department. However, unless this last test is very positive, the neural network technique will not be implemented in operations. The real-time evaluation of the GRIP model was not possible, primarily due to delays related to the conversions of the NCEP IBM computer system.