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Improvements in Deterministic and Probabilistic Tropical Cyclone Surface Wind Predictions

Principal Investigator: John A. Knaff, CIRA/Colorado State University
Co-Investigator: Mark DeMaria, NESDIS Office of Research and Applications

TPC Contacts: Miles B. Lawrence, James M. Gross and Chris A. Sisko

Background:

This proposal describes newly developed methods for improving deterministic and probabilistic surface wind predictions that will be evaluated in an operational setting. Improvements of deterministic predictions of tropical cyclone intensity will be accomplished by 1) the inclusion of predictors derived from aircraft and satellite data into the Statistical Hurricane Intensity Prediction Scheme (SHIPS), and 2) developing a neural network-based prediction method and comparing its performance with the standard multiple regression technique. To provide probabilistic surface wind speed predictions, a Monte Carlo model is being developed that combines the random errors/variability associated with track, intensity, and wind radii. Track and intensity errors are determined from the historical official track and intensity forecasts from the National Hurricane Center, the Central Pacific Hurricane Center, and the Joint Typhoon Warning Center. The variability in the radial distribution of the winds is determined from the error characteristics of a climatology and persistence wind radii prediction model.

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A. The SHIPS model – The U.S. Air Force Reserve flight level data for all Atlantic and east Pacific tropical cyclone cases from 1995-2002 was obtained and put into a common format. This data is being used as input to a variational analysis system, which combines data in 12-hour intervals in a storm-relative coordinate system to produce tangential and radial flight level winds in a cylindrical coordinate system. Because this analysis must run in a fully automatic mode when implemented in real time, considerable effort was put into development of data quality control. The quality control includes the following three steps:

1. Gross error checking: Data is tested to make sure it is physically reasonable (wind speeds between 0 and 250 kt, directions between 0 and 360^{o})

2. An objective method for determining whether data coverage is sufficient: The maximum data gaps in the radial and tangential directions are calculated, and compared with the pre-specified smoothing parameters of the objective analysis. If the gaps are too large, the case is flagged as containing insufficient observations. Much larger gaps are allowed in the tangential than the radial direction. The smoothing parameters are set so

that an analysis can be performed as long as there are at least two radial legs of data, separated by at least 160 degrees of azimuth.

3. Comparison of input data to a pre-analysis: If the data coverage is sufficient, a preliminary objective analysis is performed, and then interpolated back to the observation points. If the magnitude of the vector difference between the interpolated analysis wind and the original wind vector exceeds a specified amount, the data is flagged as being in error. After this step, the objective analysis is repeated with the bad data points removed. If more than 10% of the data points are flagged, an analysis is not performed. This method is a generalization of a "buddy check"

The analysis provides radial and tangential winds at 16 azimuths at 5 km radial intervals out to 200 km from the storm center. Data coverage is usually sufficient to estimate azimuthal wave numbers zero (the azimuthal mean) and one. The initial statistical prediction will be based upon the azimuthal mean tangential wind field.

The figure below shows radial profiles of the wave number zero tangential wind for hurricane Lili from Oct 1-3, 2002, obtained from the objective analysis program. Similar profiles are available for about 100 storms from 1995-2002. Cases from 2003 will also be added, once the aircraft data become available.

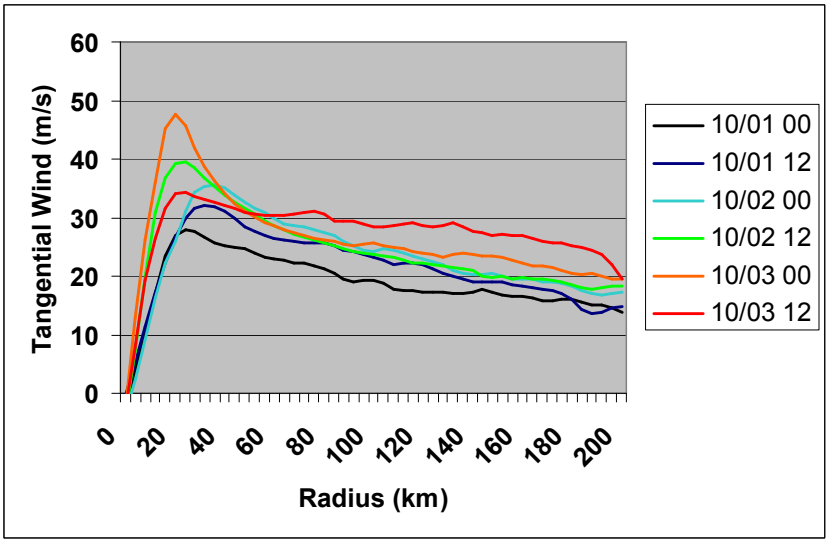

Figure 1. Sample radial profiles of mean tangential wind from Hurricane Lili 2002 generated by the variational objective analysis system.

The GOES infrared satellite images have also be azimuthally averaged, and interpolated to the same radial points as the radial wind points. This combined data set is the starting point for the updated version of SHIPS. The operational SHIPS forecasts will be used as the starting point, and then deviations from these forecasts will be predicting using the satellite and aircraft data as input. An empirical orthogonal function analysis will be

applied to the radial profiles of IR brightness temperatures and tangential wind to determine if this helps reduce the dimension of this input.

Work has also begun on a comparison of multiple regression and neural network methods. In cooperation with Dr. Charles Anderson of the Colorado State University Computer Science Department, a neural network version of SHIPS is being developed using the standard SHIPS input. This evaluation will provide guidance as to whether a more general prediction system is warranted. The neural network model is being developed from 1989-2002 data, and will be tested on independent cases from 2003.

B. Monte Carlo Model – The basic framework of the Monte Carlo model for the Atlantic basin was developed under previous funding from the "Insurance Friends of the National Hurricane Center". The first step of the JHT project was to implement this initial version on NCEP computing systems in cooperation with Jim Gross. This initial version of the code was implemented on the NCEP IBM in August of 2003, and was initiated automatically through the Automated Tropical Cyclone Forecast System (ATCF). Atlantic basin probabilities were generated in real time for the remainder of the 2003 Atlantic season, and gridded fields were generated in a form that can eventually be added to the National Weather Service National Digital Forecast Grid (NDFG), should NHC decide to make the probability product operational.

Plots of the Atlantic basin probabilities were generated in real time, and collected on a web site for further analysis (see http://aller.cira.colostate.edu/tcwinds/). Based upon the results from the 2003 season, the following modifications are being implemented:

1. To provide smoother results at the very low probabilities, the random number generator was replaced, because the original one appeared to have slightly periodic properties after a few hundred calls. Also, the MC code was modified to sample from the full range of error distributions, rather than the 1st through 99th percentiles at discrete 1% intervals.

2. During some of the landfall cases in 2003, the wind probabilities appeared too high when the storm was very far inland. This problem results from the fact that the basin-wide intensity distributions are randomly sampled, whether the storm is over the water over land. To correct this problem, the part of the code that includes serial correlation in the intensity random samples was generalized to include distance inland, in addition to the intensity at the previous forecast interval. This inclusion tends to lowers the intensities of the random samples when the storm is inland. In a related problem, the random intensity samples for some of the longer range forecasts of the two long lasting and intense storms in 2003 (Fabian and Isabel) also seemed unrealistically high. This problem results from the fact that the intensity distributions are not stratified by predicted intensity, since the there are not enough cases in the historical error samples to do this. As an alternate solution, the forecast intensity was added to the previous intensity forecast (for the serial correlation) and the distance to land in the part of the code that predicts the

expected intensity. This addition accounts for the fact that the intensity error distribution for forecasts of very high maximum winds has a different bias than those of lower winds.

In preparation for generalizing the code to the eastern, central and western Pacific, the ATCF forecasts and best tracks for these basins were obtained from NHC, the Central Pacific Hurricane Center (CPHC) and the Joint Typhoon Warning Center (JTWC). The code will include three basin options as follows. 1. Atlantic, 2. East/Central North Pacific, 3. Western North Pacific. The sample size for the Central Pacific is too small to develop meaningful error distributions, so it is combined with the East Pacific. In addition, the code was modified so that the forecast track can cross the dateline. For this purpose, a 0 to 360^{o} range of longitude was implemented, measured eastward from the Greenwich meridian. In addition, the wind radii perturbations are determined from the errors relative to a climatology and persistence wind radii model (radii-CLIPER). Versions of the radii-CLIPER model are being developed for these additional forecast basins.

JHT IT Requirements

No changes are expected in the IT requirements for this project, relative to the description provided in the original proposal.

Outlook for the remainder of year 1 (Feb 2004-July 2004):

M. DeMaria and J. Knaff will attend the March Interdepartmental Hurricane Conference to provide an update on this project. Further details of the work in the second half of year 1 are described below.

A. SHIPS model –The aircraft and IR datasets will be finalized and the statistical analysis will be performed. Depending on the outcome of the statistical tests, either a multiple regression or neural network method will be used for the model development. Once the model is developed and tested, coordination with JHT/TPC staff will begin to implement the new model for real time testing during the 2004 season. Access to the IR data should be straightforward, since this is already available on the NCEP IBM. However, the implementation of the variational analysis system will require greater coordination, since it will be necessary to tap into the Air Force Research flight level data stream. It is anticipated that CIRA project personnel will travel to TPC to implement this part of the code in July of 2004, in preparation for the main part of the hurricane season.

B. Monte Carlo model – Work will continue on development of the model for three ocean basins. Coordination with Jim Gross of NHC will be needed to update the Atlantic version already implemented on the NCEP IBM, and to add the runs for the East/Central Pacific. Coordination with JTWC through Buck Sampson and Ed Fukada will continue to begin implementation on their ATCF systems for tests during the 2004 season.