NOAA Joint Hurricane Testbed (JHT) Mid-Year Progress Report, Year 1

Date: Feb. 1, 2010
Project title: *Advanced Applications of the Monte Carlo Wind Probability Model*
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Project dates: Aug. 2009-Jul. 2011

1. Long-Term Objectives and Specific Plans to Achieve Them

Under previous JHT support a program for estimating the probability of occurrence of 34, 50, and 64 kt winds was developed by NESDIS and CIRA. A Monte Carlo (MC) method was utilized to combine the uncertainty in the tropical cyclone track, intensity and wind structure forecasts. The MC probability program has been run in NHC and CPHC operations since 2006.

In the current two-year project, four new applications of the MC model are under development. These include (1) Landfall timing and intensity distributions; (2) Methods for using the MC model to enhance WFO local products; (3) Probabilities integrated over coastal segments; (4) Automated guidance for issuing coastal watches and warnings.

The current project also includes four refinements to the MC model code. These include (1) A procedure to adjust the model time step for fast moving and small storms; (2) Modification of the azimuthal interpolation routine that occasionally leads to inconsistent probability values for 34, 50 and 64 kt winds; (3) Evaluation of the spatial interpolation method that sometimes results in inconsistencies between the gridded and text probabilities; (4) Evaluation of the underlying wind radii model utilized by the MC model.

The timeline for Year 1 of this project is provided in the Appendix.

2. Accomplishments

The accomplishments below are described for each of the four new applications and four code refinements.

<u>Application 1, landfall timing and intensity distributions.</u>

The MC model code was modified to create a new output file that includes the track, intensity and wind radii of all 1000 realizations at every time step. A separate post-processing routine is under development that calculates the landfall timing and intensity distributions for a set of user defined points. Because this application requires a forecaster to select points of interest along the coast, a prototype graphical user interface called Hurricane Landfall Probability Applications (HuLPA) was developed for demonstration of these capabilities. HuLPA is java-based, but a similar application could be developed in the ATCF framework. Figure 1 is a screen capture of the HuLPA application run on a

Windows system. Because of the use of java, the program also runs on Linux systems. The user selects from a set of storm cases (Hurricane Ike initialized at 00 UTC on 12 September 2008 in this example), and then the program displays the NHC forecast track and intensity. The user then selects the coast points of interest (Port Aransas to Morgan City in this case), and then the application of interest (landfall timing and intensity distribution in this example). The user can modify the selected points or forecast case and re-run the application.

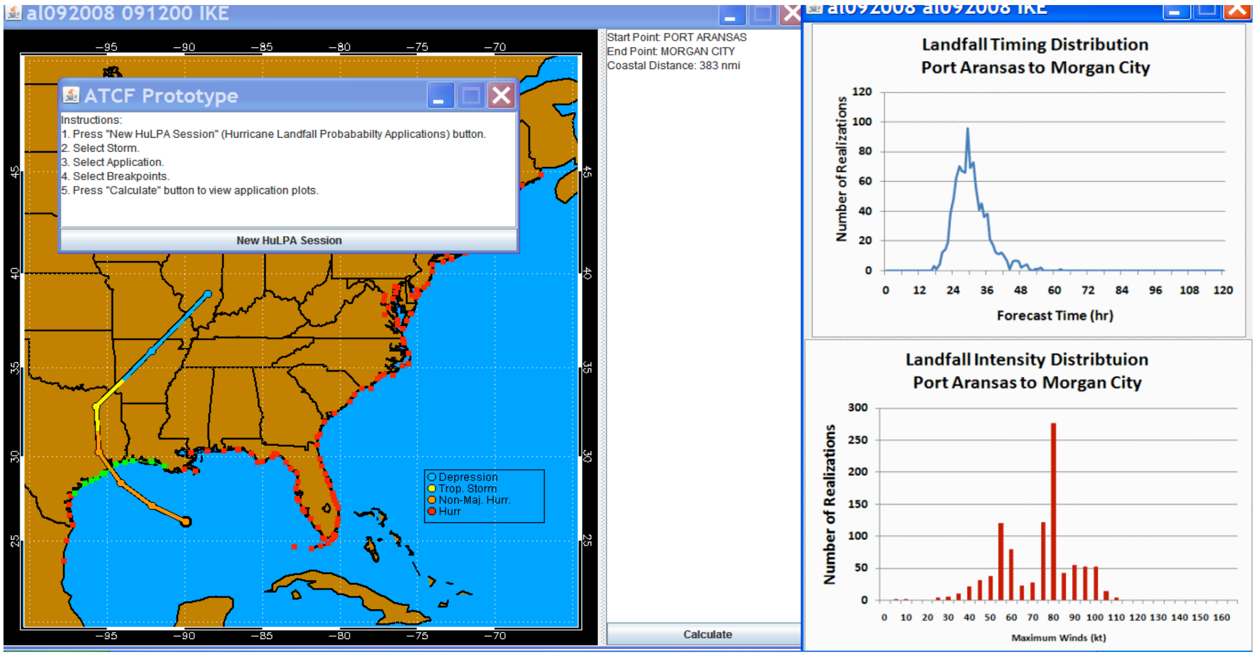

Figure 1. Screen capture of the HuLPA program for a case from Hurricane Ike (2008).

<u>Application 2. WFO local applications.</u>

In coordination with Pablo Santos from the Miami, FL WFO and Dave Sharp from the Melbourne, FL WFO, an extensive verification of the 12 h incremental probabilities was performed for coastal and inland points to help them refine their WFO applications. 400 forecast cases from 20 landfalling storms from the 2004-2008 hurricane seasons were run with the most current version of the MC model (the 2009 version). Figure 2 shows the tracks of the storms included in this study.

The probabilities of 34, 50 and 64 kt winds were determined from the MC model at a set of about 300 coastal points and a corresponding set of points 50 km inland. Figure 2 shows the coastal and inland points included in the verification. Using the NHC post-season best track, the probabilities were validated using the Threat Score (TS), Peirce Score (PS) and Relative Operating Characteristic (ROC) scores. It was found that the TS was the most useful for determining the optimal thresholds for the WFO applications. The TS score measures the percent overlap of the area within a specified probability threshold and the area that experienced those winds. It is not impacted by the large areas that have zero probabilities and no observed winds. Those large "null" areas are included in the PS and ROC scores, making them less useful. To further refine the WFO applications, the U.S coastline was stratified into three regions (Brownsville, TX to Mobile, AL, Mobile AL to the GA/SC border and the GA/SC border to Eastport, ME). Results showed that there is some advantage to using different probability thresholds for different regions, but the need for consistency of products between WFOs probably outweighs the benefit of variable thresholds. Results from this study were presented by Pablo Santos at the AMS 20th Conference on Probability and Statistics in the Atmospheric Sciences in January 2010.

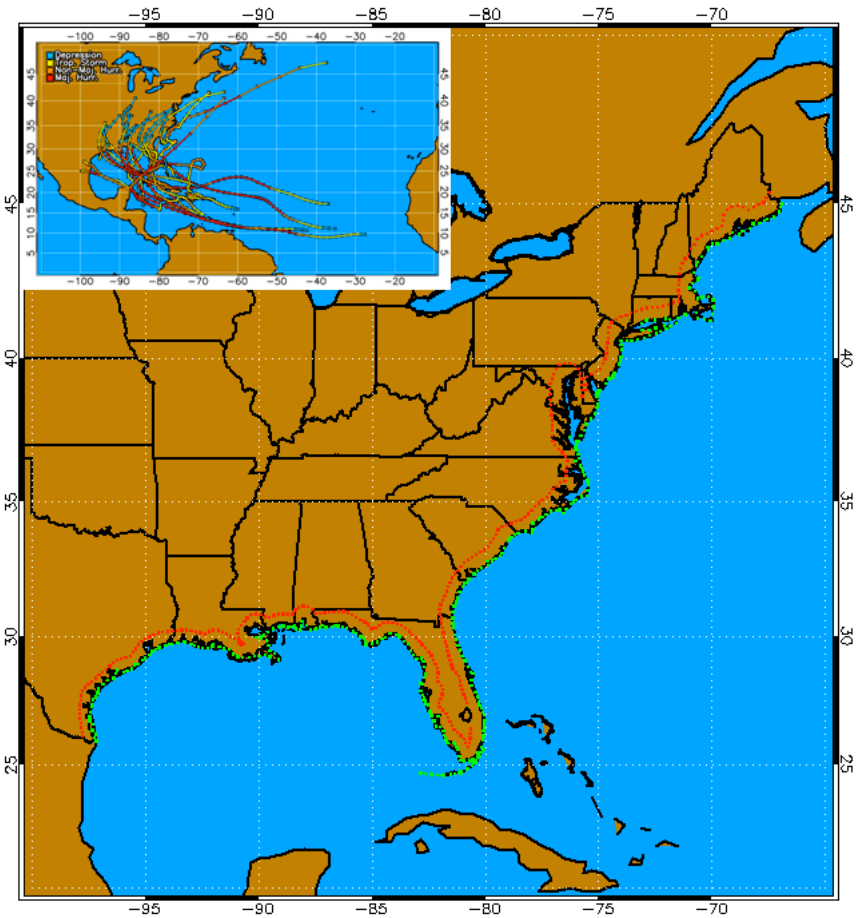

Figure 2. Tracks of storm cases used in this WFO verification study (insert) as well as coastal and inland points for which verification was conducted. Inland points (286) are in red and coastal points (343) in green. Inland points are about 50 km from the coast.

Application 3. Integrated probabilities

The HuLPA application described above is being adapted to include the ability to calculate probabilities integrated along the coastal points selected by the user.

Application 4. Automated watch/warning guidance

The HuLPA application described above is being adapted to include the ability to provide automated guidance on watches and warnings. Because this calculation does not required a user to select a section of coastline, this application could also be fully automated and run outside of HuLPA. Some experimentation is being performed to determine the impact of NHC's revised definitions of hurricane watches and warnings. However, because the new definitions are actually more consistent with what was done in operations the past few seasons than the previous definitions, the thresholds for raising and lowering warnings are probably reasonable since they were tuned to hurricane warnings from the past few years.

<u>Code refinement 1. Time step adjustment.</u>

The MC model code was modified to allow the underlying time step to be changed. The original version interpolated the tracks, intensities and wind radii to a 2 hr interval. A guideline for the time step value (in hr) is that it should be smaller than the wind radius (in nmi) divided by the translational speed (in kt). The current time step of two hours is valid for the average radius of hurricane winds (40 nmi) for storms moving at up to 20 kt, which is adequate in most cases. However, for very small or very fast moving storms, this time step is too large, and results in probability fields with a "centipede" appearance, especially for the early part of the forecast before the realizations spread out. An extreme example of this problem occurred for latter stages of Hurricane Gordon in 2006. For the 18 UTC model run on 19 September, Gordon was a smaller than average hurricane (average wind radii of 30 nmi) moving eastward at about 28 kt. The left side of Fig. 3 shows the 0-120 cumulative probabilities of 64 kt winds for this forecast using the 2 hr time step. With the revised code, the time step was reduced to 1 hr and the "centipede" appearance was greatly reduced (right side of Fig. 2). This example was run with much higher spatial resolution (0.1^o lat/lon) than the current operational model (0.5^o lat/lon grid) so the differences could be more readily seen.

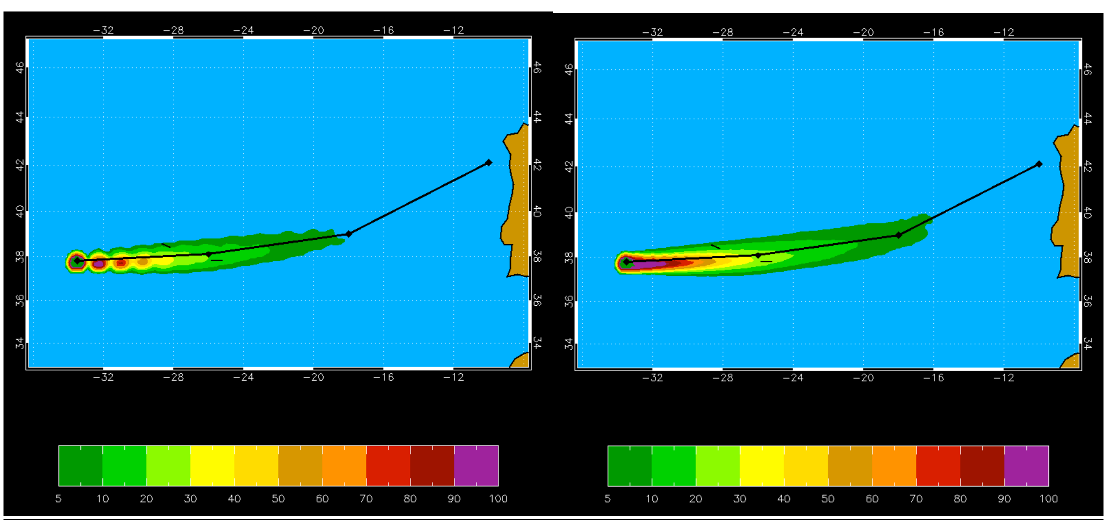

Figure 3. 0-120 hr cumulative 64 kt wind probabilities for Hurricane Gordon (2006) initialized on 19 Sept 2006 at 18 UTC. The left panel used the 2 hr time step of the current operational MC model and the right panel used a 1 hr time step.

Several other cases with larger and slower moving storms were tested, and the differences in the probability fields with the two time steps were much smaller than in the Hurricane Gordon case. Thus, the one hour time step is not always need. However, because of the code optimization, doubling the time step does not double the run time. For runs on a CIRA Linux workstation with moderate sized domains (201 by 161 grid points, 0.25^{o} resolution), the run time only increased by about 10% when the time step was reduced from 2 to 1 hr. Also, after coordination with the NHC and CPHC project focal points (Dan Brown and Rick Knabb), the landfall timing distributions should be to the nearest hour, which would require the 1 hr time step. Assuming the result that halving the time step only increases the run time by about 10%, the MC model should probably always use a 1 hr time step.

Code refinement 2. Azimuthal interpolation of wind radii

The wind radii in the MC model are determined from a simple climatology and persistence model. If used in its continuous form, the radii of each wind threshold (34, 50 and 64 kt) would be consistent. However, because the model includes a persistence component based on the 4 quadrant values from the NHC official forecast, the wind radii are azimuthally interpolated from the underlying vortex model evaluated in 4 quadrants. This interpolation works very well in most cases. However, in a few cases where the radii are zero in some quadrants for some wind thresholds but not for others, the interpolation can introduce inconsistency between the radii values. For example, the 34 kt radii can be smaller than the 50 kt radii for a small range of azimuth. The code is being modified to correct this problem by building additional consistency checks into the radii interpolation routine. A straightforward solution is to use azimuthal extrapolation rather than interpolation when a wind radii value is non-zero in one quadrant, but zero in the next quadrant.

Code refinement 3. Spatial interpolation of probabilities

The MC model is run on a large domain on a 0.5^{o} lat/lon grid and on a set of coastal points for text products. The large domain product is interpolated to a much finer grid for use in AWIPS and the National Digital Forecast Database (NDFD). In regions of large probability gradients, the interpolated gridded values do not agree perfectly with the corresponding coastal values calculated directly. Two approaches to solving this problem are being considered. First, it may be feasible to increase the resolution of the large domain run to 0.25^{o}. Tests will be run to determine if this change reduces the inconsistency of the interpolated and coastal probabilities to an acceptable level. If not, a more complex interpolation method will be investigated that includes the gridded and coastal values simultaneously.

Code refinement 4. Radii model evaluation

Because NHC does not forecast wind radii out to 120 h, the radii in the MC model are determined from a simple climatology and persistence wind radii model and its error distributions. This simple wind radii model is used because the radii must be constructed from a very small set of parameters (the storm position and maximum wind at each forecast time) for each realization. The wind radii model assumes a modified Rankine vortex structure. Although very simple by necessity, this wind model should reproduce the observed distribution of wind radii. In this part of the project, the wind model is evaluated and adjustments will be made if needed.

As a first step in this evaluation, a large sample of modeled 34 kt radii were compared to those estimated from observations. The observed radii were obtained from the Atlantic extended best track dataset for the period 1988-2008. These radii are from the NHC forecast advisories from 1988-2003 and from the NHC best track from 2004-2008 (best track radii are not available prior to 2004). This sample includes 20,139 non-zero 34 kt wind radii values. For comparison, the 34 kt wind radii from 5 runs of the MC model from the 2009 season were used. Each run includes 1000 realizations, and 4 values of 34 kt radii (one in each quadrant) for each realization. This results in a sample of 20,000 wind radii values, which includes 15,221 non-zero values at the 72 h forecast period. The 5 runs included 1 each from Ana, Danny and Erika and two from Bill and were chosen so that the intensity and latitude distributions of all the realizations at 72 hr roughly matches from the 1988-2008 sample of Atlantic cases.

Figure 4 shows the observed and modeled distributions of the 34 kt wind radii. The two distributions compare reasonably well, suggesting that the method for generating the wind radii in the MC model are reasonable in a statistical sense. This analysis will continue by examining the 50 and 64 kt radii distributions, the distributions at additional forecast times, and the distributions from the east Pacific and western Pacific basins. More than 5 MC model runs will be needed at the earlier times, because all 1000 realizations for each run start with the same radii at t=0.

3. Plans for the remainder of Year 1

During the 2nd half of the first year of the project, the timeline in Appendix will be followed. The work on the HuLPA program will continue so that it includes all of the proposed applications. If possible the HuLPA program can be tested in real time during the 2010 hurricane season. Work on the code refinements will also continue. Preliminary results will be presented in March 2010 at the Interdepartmental Hurricane Conference and a Year 2 proposal will be submitted.

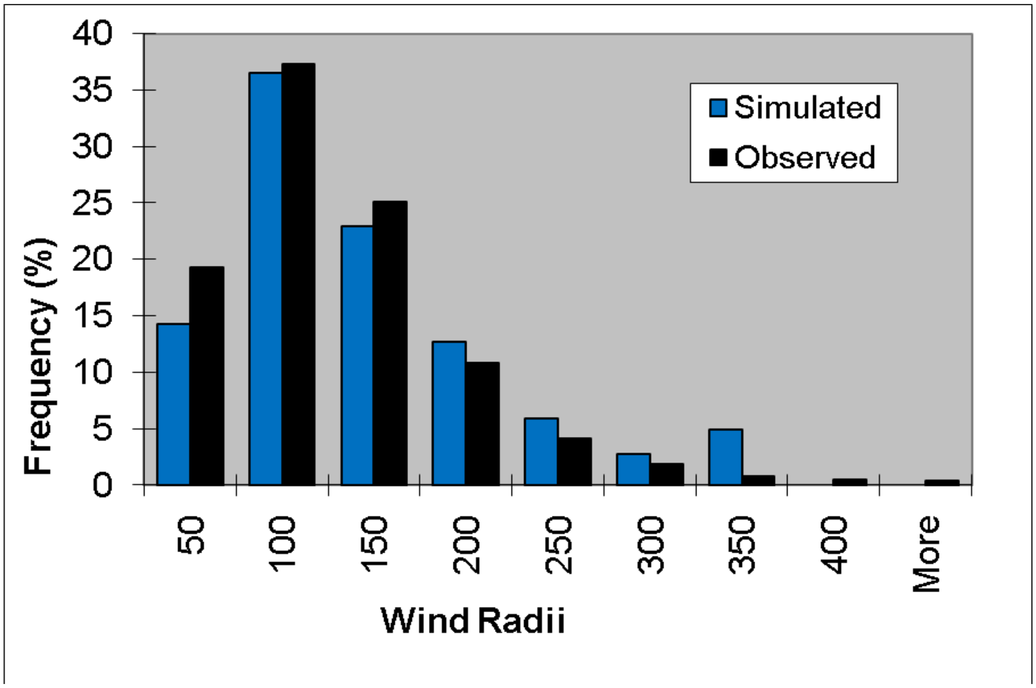

Figure 4. The distribution of Atlantic 34kt wind radii (nmi) from the combined NHC forecast advisory (1988-2003) and NHC best track (2004-2008) (black) and those from 5000 realizations from 5 runs of the MC model from 2009 (blue).

Appendix
Year 1 Project Timeline

Aug 3, 2009 - Project Begins
Oct 2009 - Completion of the incremental probability verification (application II) for the Miami WFO

Nov 2009 - Completion of the time step adjustment (code modification I)

Jan 2010 - Completion of the wind radii consistency (code modification II)

Mar 2010 - Addition of the landfall timing and intensity distribution calculation to the main MC model code (application I)

February 1, 2010 - Mid-year report due

Mar 2010 - Progress report at the Interdepartmental Hurricane Conference

April 1, 2010 – Year two renewal proposal due

May 2010 - Modification of the MC model code on the IBM and ATCF for include code upgrades I and II, and the output for application I (landfall probabilities)

Jun 2010 - Completion of the wind radii evaluation study (code modification IV)

Jul 2010 - Completion of the first version of application the watch/warning guidance (application IV)

Aug 3, 2010 –Year one ends/ year one progress report due