Joint Hurricane Testbed first year accomplishments and second year proposal

Project: Estimating tropical cyclone wind radii using an empirical inland wind decay model

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1. First year accomplishments (April 1, 2005 – April 1, 2006)

a. Modification of decay model for real-time use

Software routines were developed to extract the storm track, intensity, and wind radii information that are required to run the decay model from the ATCF database. These routines were successfully employed to generate the necessary model input files for several recent landfalling storms including Hurricanes Charlie (2004), Dennis (2005), Katrina (2005), Wilma (2005) and Rita (2005). Many of the modifications required to convert the decay model from an interactive to real-time model were implemented. Specifically, the model was modified so that it could be run off of the input files that are generated using the ATCF software extractions routines described above. The model was also modified so that the decay model coefficients are determined as a function of storm latitude along the forecast track following the methodology of DeMaria et al. (2005). Furthermore, the model was modified to account for changes in storm speed along the forecast track when estimating the left to right storm motion induced asymmetry (Kaplan and DeMaria 1995). When computing the storm motion, the fractional portion of the storm motion rather than the total storm motion was determined from the empirical relationship developed by Schwerdt et al. (1979). Code was also added to compute the 34,50, and 64 kt wind radii in each of the four quadrants at user specified forecast time intervals.

The decay model described above was utilized to obtain wind radii estimates for several recent major U.S landfalling hurricanes. These tests revealed some difficulties fitting the initial wind field of Hurricane Dennis (2005) which was a relatively small storm. To ameliorate this problem the vortex fitting algorithm employed by Knaff et al. (2006) was tested. Sensitivity tests showed that this algorithm provided a superior fit for the initial wind field of Hurricane Dennis (2005) when compared to that employed in Kaplan and DeMaria (1995). However, the formulation of the parametric model employed in the latter study provided a superior fit for the much larger Hurricane Rita (2005) suggesting that the parametric model formulations from both studies are needed to fit the spectrum of storm shapes that are observed. Thus, the decay model was modified so that the parametric model that provided the best fit to the wind radii was employed for any given storm.

b. Wind swath generation

Swaths of the maximum sustained wind were generated for major U.S. landfalling hurricanes Charlie (2004), Dennis (2005), Katrina (2005), Rita (2005), and Wilma (2005). The parametric wind models described in Kaplan and DeMaria (1995) and Knaff et al. (2006) were employed to generate the initial vortex. The parametric model described in Kaplan and DeMaria is given by:

$$V(r,\theta) = c_s[(\cos(\theta)] + V_x(r/r_m)\exp\{1/a[1 - r/r_x)^a]\} \quad (1)$$

where $\boldsymbol{r}$ is the radius from the storm center, $\boldsymbol{r_m}$ is the radius of maximum winds, θ is the angle measured counterclockwise from a line perpendicular and to the right of the direction of motion, $\boldsymbol{c_s}$ is the left/right asymmetry due to storm motion determined using the empirical relationship determined by Schwerdt et al. (1979), $\boldsymbol{V_x}$ is the symmetric part of the maximum sustained wind obtained after subtracting out the storm motion($\boldsymbol{c_s}$), and $\boldsymbol{a}$ is a parameter that provides an estimate of the shape of the wind field. The parametric model described in Knaff et al. (2006) is given by:

$$\begin{aligned} V(r,\theta) &= (v_x - c_s)\left(\frac{r_m}{r}\right)^a + c_s\cos(\theta - \theta_O) \quad \text{for} \quad r \geq r_m \\ V(r,\theta) &= (v_x - c_s)\left(\frac{r}{r_m}\right) + c_s\cos(\theta - \theta_O) \quad \text{for} \quad r < r_m \end{aligned} \quad (2)$$

where Θ_0 is the degree of rotation from the maximum wind located 90º to the right of the storm motion vector. Each of the parameters contained in (1) and (2) can be estimated from information contained in the official TPC/ NHC forecast advisory. The vortex shape (***a***) is determined by fitting the wind 64, 50, and 34 kt wind radii contained in the official NHC forecast advisory. Once the wind field prior to landfall has been determined from (1) and (2), it can be applied at every point to provide a swath of the maximum winds observed at any time during a storm's landfall.

Wind swaths were generated by employing both the official NHC forecast track and landfall intensity (hereafter referred to as "Official swaths") and the best track storm positions and the best track landfall intensity (hereafter referred to as "Best track swaths"). All wind swaths were generated for the last synoptic time for which an official NHC forecast was issued. After a storm made landfall, the decay model was then employed to decay the initial vortex wind field generated using (1) and (2) while the system remained over land. The decision to create both "Official" and "Best track" swaths was made both to demonstrate the sensitivity of the decay model to variations in the storm track and landfall intensity and to obtain a more accurate assessment of the skill of the decay model. Maximum wind swaths were generated for 5 major landfalling hurricanes from the past 2 hurricane seasons (Charlie (2004), Dennis (2005), Katrina (2005), Rita (2005), and Wilma (2005)). The maximum wind swath estimates were evaluated at all in-situ surface observation locations where wind observations were made continuously throughout a storm's lifetime. This was accomplished by first determining the decay model estimated maximum wind at each observation location at any time during the duration of the storm. Prior to performing evaluations of the surface wind observations and decay model maximum wind estimates, all surface in-situ wind data were converted to a maximum sustained 1-min wind at 10 m for open-water or open terrain exposure using the methodology described in Powell et al. (1996a) and Powell et al. (1996b). Evaluations were performed for the time period when the storm made landfall until the system became extra-tropical or dissipated.

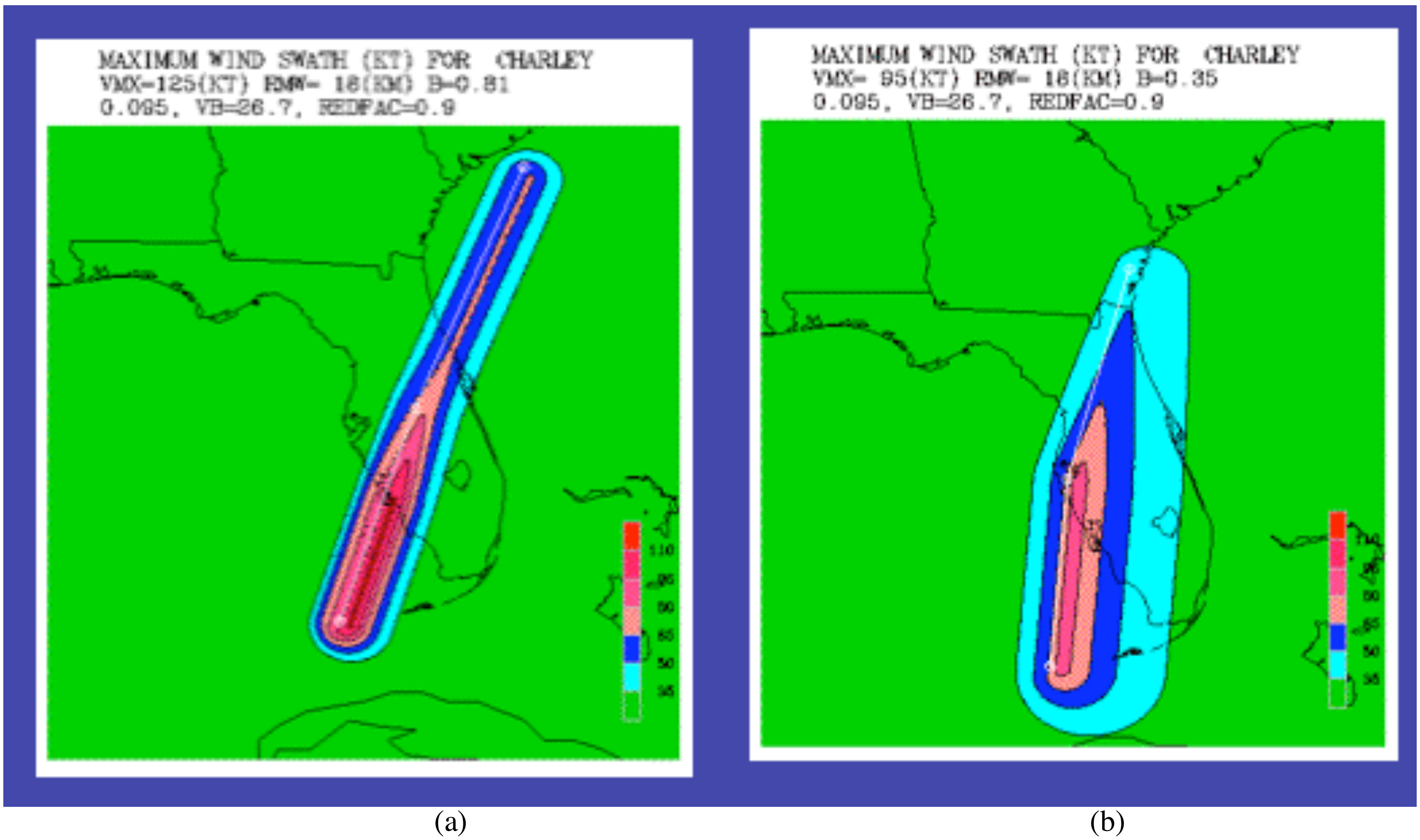
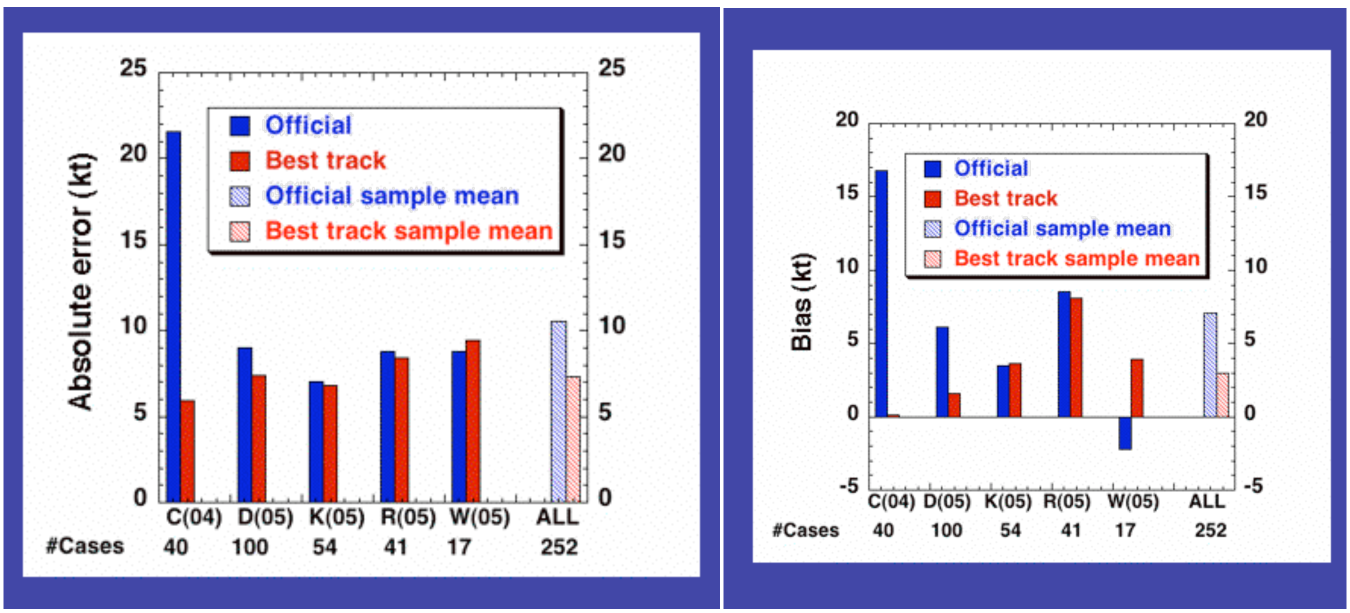


Fig. 1. "Best track"(a) and "Official"(b) decay model generated wind swaths for Hurricane Charlie at 1200 UTC on 12 August 2004. The storm track is shown in white.

Fig. 1. Shows an example of a "Best track" and "Official" wind swath generated for Hurricane Charlie (2004). The initial storm vortex employed to obtain the Charlie wind swaths was determined using storm size and shape information contained in the last NHC/TPC advisory issued prior to landfall. The figure indicates that the official track was further north resulting in a later "Official" landfall time for Charlie. The later landfall time coupled with the weaker than observed forecast landfall intensity resulted in some fairly larger errors for the official swath. Fig. 2 shows the errors and biases between the

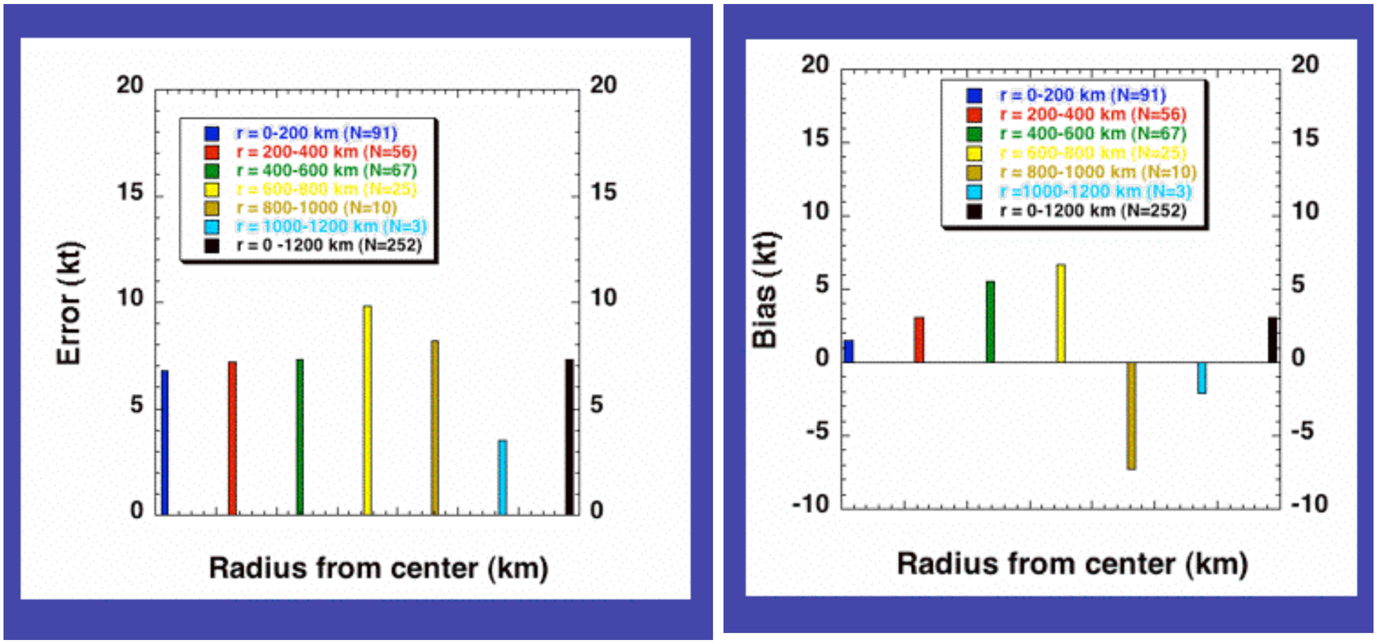
decay model and the in-situ observations for all 5 storms. The figure indicates that the model performed fairly well for these storms with an average mean absolute error of 7.3 kt and a mean bias of 3.0 kt (over-prediction of observed wind speeds) between the "Best track" swath and the observed wind estimates. The errors between the "Official" wind swath and the observed maximum sustained wind were higher with a mean absolute error of 10.5 kt and a mean bias of 7.1 kt. The figure indicates that this was due mainly to the large errors and high bias that were obtained for Charlie (2004). The relatively large "Official" swath errors obtained for Charlie resulted from the more northerly track, later landfall time, and weaker landfall intensity of the official NHC forecast track as was noted above. Although the best track landfall wind speed was higher than the official wind speed the later landfall time combined with the more northerly track resulted in less time for the storm to decay and thus on average higher winds at many of the inland observation locations.



(a) (b)

Fig. 2. The absolute error (a) and bias (b) between the in-situ wind observations and the "Best track" and "Official" wind swath maximum sustained wind estimates. Results are shown for Charlie(C), Dennis (D), Katrina (K), Rita(R), and Wilma (W) individually and for all 5 storms combined (ALL). The number of cases for each storm and for the entire sample are also shown at the bottom of the figure.

Figure 3 shows the variation of the absolute error and bias with radius for the "Best track" wind swaths. Although there does not appear to be a trend in the magnitudes of the absolute error as a function of radius, there is some tendency for an increasing positive bias from 200 and 800 km radius. The bias becomes negative beyond 800 km radius; however, the sample size is small at these radii so this finding may not have much significance.



(a) (b)

Fig. 3. The absolute error (a) and bias (b) between the in-situ wind observations and the "Best track" maximum sustained wind swath estimates as a function of radius from the storm center.

c. Wind radii estimation

Estimates of the 64, 50, and 34 kt wind radii in each of the four quadrants (NE, SE, SW, NW) were obtained from the gridded (5 km X 5 km) decay wind field for each of the 5 storms. This was accomplished by determining the maximum radius at which the various wind radii thresholds were observed in each quadrant at ~3 h after landfall. These wind radii were then compared to wind radii estimates obtained for the same time as the model estimates using the Hurricane Research Division's H*Wind analysis (Powell et al. 1996b). H*Wind is an objective analysis scheme that provides a means of analyzing all available data collected within a given time window in storm-relative coordinates. For the purpose of this study, the H*Wind analyses were performed using surface data from within ~3 h of the analysis time. A 3 h time window was employed since this ensured that only data collected when a storm was over land were employed in the analysis. The decision to estimate the wind radii at 3 h after landfall was made so that evaluations of the wind radii could be performed after a sufficient amount of storm decay had taken place and after sensitivity tests revealed that the data coverage was not sufficiently dense for analyses at later post-landfall times. Following the same methodology that was used previously when evaluating the wind swaths, wind radii estimates for each storm were obtained using both "Official" and "Best track" storm positions and "Official" and "Best track" landfall intensities. Also, the information required to generate the initial storm vortex that was decayed at landfall was obtained from the NHC official forecast

Figure 4 shows an example of the decay model wind radii estimates for Hurricane Charlie (2004) obtained using the "Best track" storm positions and landfall intensity and the storm structure information from the last NHC official advisory prior to landfall. Also, shown are the wind radii estimates from H*Wind. The figure indicate that the decay and H*Wind 64 kt and 50 kt wind radii are generally in good agreement although they do differ more significantly in the NW quadrant. The decay model estimates of the 34 kt wind radii are much larger than the H*Wind estimates. The relatively flat wind profiles at these wind speeds combined with the aforementioned decay model positive wind speed biases (see Fig. 3) could be the reason for these discrepancies. Fig. 5 shows the "Best track" wind radii estimates for Hurricane Katrina (2005). The figure shows that the 64 and 50 kt decay model wind radii estimates were in reasonably good agreement with those estimated from H*Wind; however, the decay model tended to underestimate the magnitude of the radii in the NE and SE quadrants. In contrast, the decay model overestimated the radius of 34 kt winds. To see the wind radii estimates for the other 3 storms and to examine the data coverage for all 5 storms consult Kaplan et al. 2006.

Fig. 6 shows the errors and the bias between the decay model wind radii and those obtained from H*Wind for the 5 storm sample. These statistics were obtained using both "Official" and "Best track" wind radii estimates. The figure indicates that the decay model 64 and 50 kt wind radii estimates were in reasonably good agreement with the H*Wind estimates particularly when the "best track" input were used. However, the decay model 34 kt wind radii were not in as good agreement with the H*wind estimates. This is likely the result of the flat wind field at the lower wind speeds and the positive bias in the decay model wind estimates at larger radii as noted previously. It is encouraging that the biases between the decay model and H*Wind wind radii are quite small for the 64 and 50 kt wind radii, although there is a significant positive bias in the 34 kt estimates.

When interpreting the results in Figs. 4-6 it is important to note that there are several sources of error in the wind radii estimates. First, the method for estimating the wind radii themselves is problematic since small shifts in the overall shape of the wind field can cause a significant difference in the wind radii for any given quadrant. For example, if the 64 kt winds are found due north of the storm (90º deg) but not west of due north the radii of 64 kt wind would be 0 nautical miles in the northwest quadrant whereas if 64 kt winds were observed at 90.5º deg north (northwest quadrant) the radii of 64 kt winds could be much different. Also, while the H*Wind radii are being used as ground truth for validation purposes, there are several factors that lead to uncertainties in these estimates. First, to obtain sufficient data coverage it was necessary to employ data from a 3 h time window on either side of the analysis center time. However, the observation times of these data are not necessarily symmetric about the analysis time meaning that for some quadrants the wind radii may be representative of a time earlier or later than the analysis time. Also, the data coverage may not be as good in some regions, thus reducing the accuracy of the wind radii estimates in some quadrants. In short, the difficulties of estimating wind radii over land should be kept in mind when interpreting the wind radii results. The aforementioned uncertainties in wind radii estimates are what prompted the authors to provide the wind swath error statistics in section 1b.

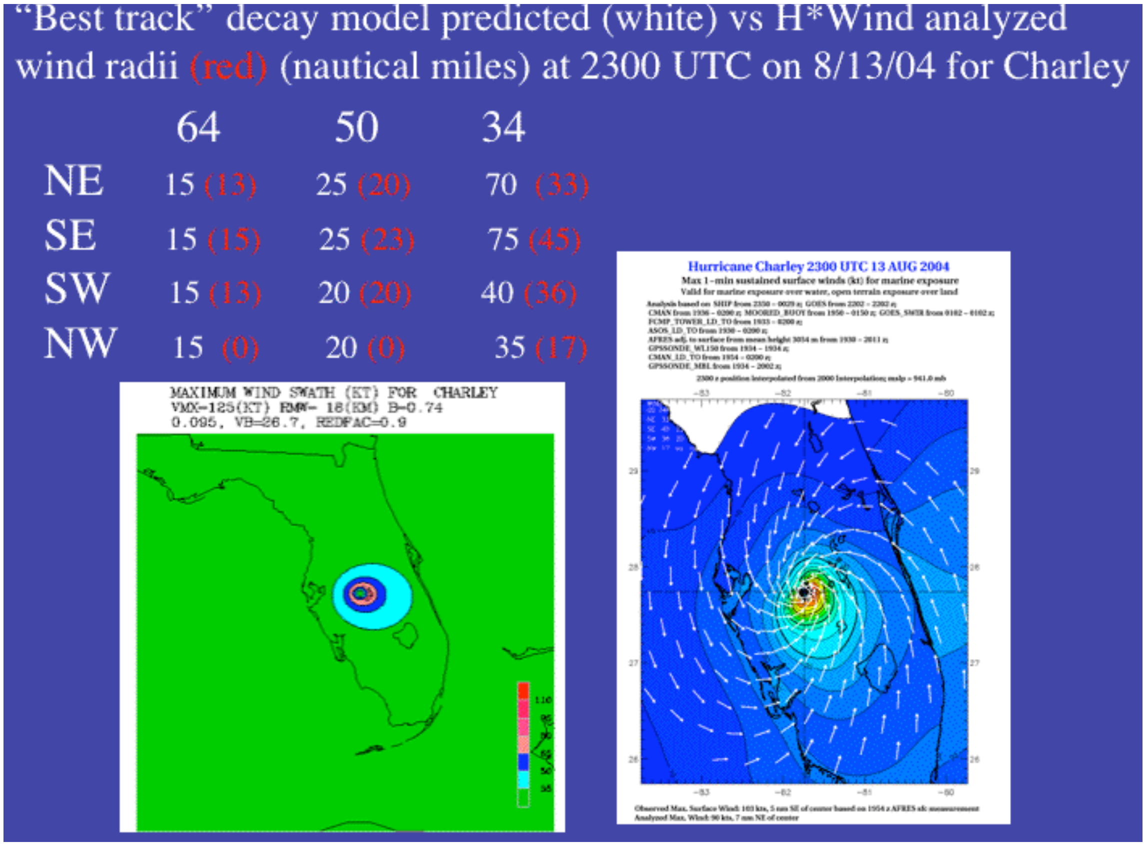


Fig. 4. " Best track" and H*Wind analyzed wind radii for Hurricane Charlie (2004).

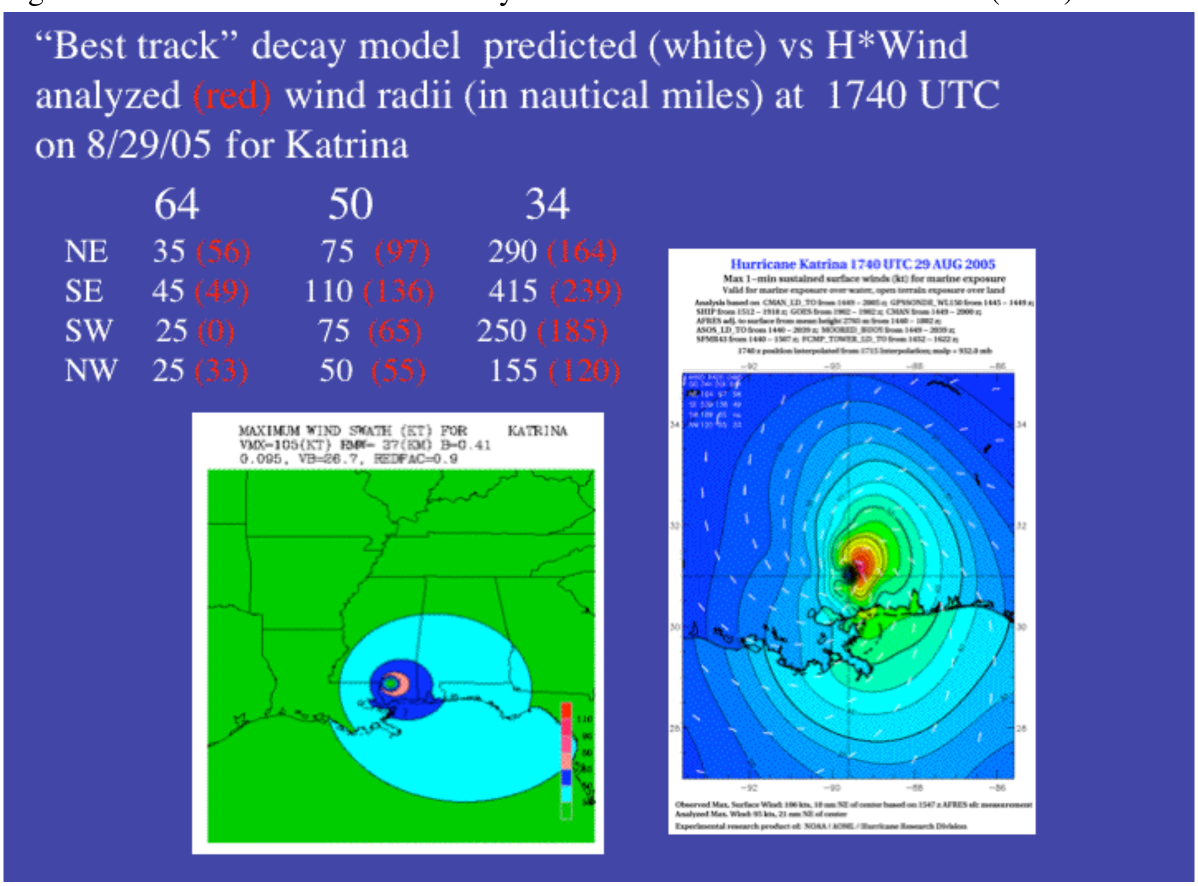
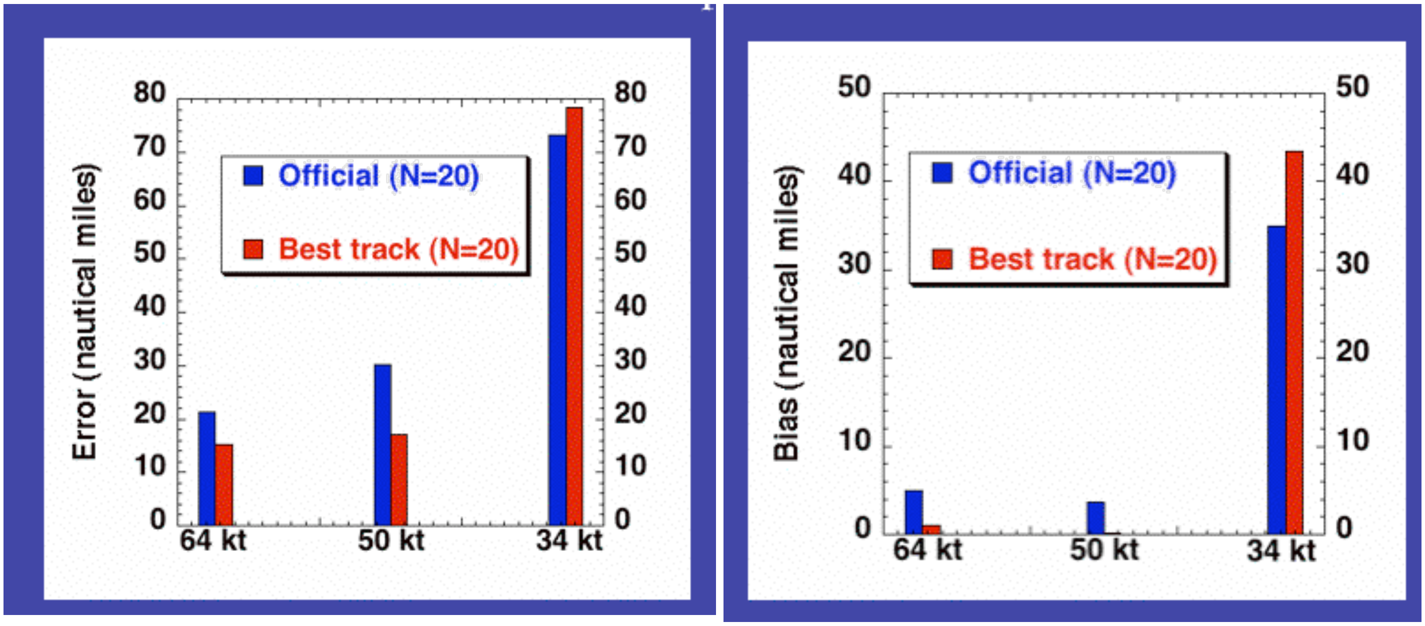


Fig. 5 Same as Fig. 4, except for Hurricane Katrina (2005).



(a) (b)

Fig. 6. Mean absolute error (a) and bias (b) between the decay model and H*Wind wind radii estimates.

2. Second year proposal (April 2006 - April 2007)

a. Work Plan

In year 2, the software routines that were developed to run the decay model in real-time during year 1 of the proposal will continue to be optimized based upon evaluations performed during the first year. One such required optimization is the modification of the decay model to account for storms that make multiple landfalls within the forecast period, since this scenario was not encountered when the model had been previously run interactively. After these optimizations have been made the decay model will be tested in real-time during the 2006 E. Pacific and Atlantic hurricane season. Finally, the decay model performance will be verified against verification data sets that have been collected during recent landfalling hurricanes. As part of that verification process, a new version of the decay model (DeMaria et al. 2006) will be evaluated to determine if it can be used to provide more accurate maximum wind radii estimates for landfalling tropical cyclones.

b. Timeline

April-August 2006	Optimize/update software developed in year 1 of proposal
Aug 1- Nov 2006	Test updated version of decay model in real-time and print out at TPC
Nov. 2006- March 2007	Evaluate year 2 performance of decay model and perform sensitivity tests to determine if the updated decay model can be used to provide improved wind radii estimates
Nov 2006- March 2007	Modify/update decay model based upon year 2 evaluations
March 2007	Present year 2 results at IHC
April 2007	Submit final report

c. Schedule and needs for expected travel

Fall/winter 2006	Mark DeMaria to Miami to help implement/evaluate the new version of the decay model
Spring 2007	PI travel to Interdepartmental Hurricane Conference

d. JHT staff requirements

We do not anticipate the need for any significant changes in the previously requested JHT staffing requirements. As noted previously, we will need access to the JHT computers so that the decay model can be run and or viewed at TPC/NHC. Finally, JHT staff may need to spend some time developing an N-AWIPS routine for plotting the maximum wind swath from a file that could be output from the decay model, if desired.

e. References

DeMaria, M., M. Mainelli, L.K. Shay, J. Knaff and J. Kaplan, 2005: Further improvements to the Statistical Hurricane Intensity Forecasting Scheme (SHIPS). *Wea. Forecasting*, **20**, 531-543.

_____, J.A. Knaff, and J. Kaplan, 2006: On the decay of tropical cyclone winds crossing narrow landmasses. J. Appl. Meteor*, in press*.

Kaplan, J., and M. DeMaria, 1995: A simple empirical model for predicting the decay of tropical cyclone winds after landfall. J. Appl. Meteor., **34**, 2499-2512.

________, J. Dunion, N. Carrasco, and M DeMaria, 2006: Estimating tropical cyclone wind radii using an empirical inland wind decay model. Minutes of the 60th Interdepartmental Hurricane Conference. [Available at http://www.ofcm.noaa.gov/ihc06/linking_file_ihc06.htm].

Knaff, J. A., C.R. Sampson, C.J. McAdie, M. DeMaria, T. P. Marchok and J. M. Gross: 2006: Improved statistical intensity forecast models. Statistical tropical cyclone wind radii prediction using climatology and persistence. Submitted to Wea. Forecasting.

Powell, M.D., and S.H. Houston, 1996a: Hurricane Andrew's landfall in South Florida. Part I: Standardizing measurements for documentation of surface wind fields. Wea. Forecasting, **11**, 304-328.

_____, and S.H. Houston, and T. A. Reinhold, 1996b: Hurricane Andrew's landfall in South Florida. Part II: Surface wind fields and potential real-time applications. Wea. Forecasting, **11**, 329-349.

Schwerdt, R.W., F.P. Ho, and R.R. Watkins, 1979, Meteorological criteria for standard project hurricane and probable maximum hurricane wind fields, Gulf and East coasts of the United States. pp 317. [Available from National Technical Information Service. U.S. Dept. of Commerce, Sills Bldg. 5285 Port Royal Road, Springfield, Va. 22161].

f. Budget

Decay			**Budget Year 2**	
			JHT	
			Requested	
			mm	Amount
Personnel				
AOML	Kaplan		2.0	15.7
CIMAS	Dunion		2.5	12.7
CIMAS	Carrasco		1.0	3.8
Subtotal				32.3
Fringe Benefits		NOAA		4.2
		CIMAS		5.7
Total Salaries and Fringe Benefits				42.3
Indirect Costs		NOAA		8.0
		CIMAS		5.8
Total Labor Costs				56.1
Equipment				0.0
Supplies				0.0
Travel				5.0
Other	Publications			0.0
	Computer Infrastructure (hardware/software)			6.0
Total				67.1

Salaries	56.1
Equipment	0.0
Comp/Communications	6.0
Travel	5.0
Other	0.0
Total	67.1

The proposed budget includes a request for two months of support for the PI and 2.5 months of support for the Co-Investigator (Jason Dunion) in year 2 to modify, implement, and evaluate the updated version of the decay model. The year 2 budget also includes 1 month of programmer support (Nicholas Carrasco) to implement the required software to run the decay model in real-time. The computing and communications costs are for maintaining and supporting computer hardware, software, and communications links (LAN) to TPC that meet NWS security specifications. The travel costs are to cover expenses for the presentation of JHT related results at the Interdepartmental Hurricane Conference (IHC) and to enable Dr. Mark DeMaria of NOAA/NESDIS to travel to Miami to help optimize the swath code that he originally developed.