14C.2 **Hurricane Initialization in High Resolution Models**

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1. Introduction

The current operational 3-D hurricane forecast model at National Centers for Environmental Prediction (NCEP) uses vortex replacement strategy to initialize hurricanes (Kurihara, et al., 1995). The initialization consists of three major steps: 1) interpolate global analysis field from Global Forecast System (GFS) onto operational GFDL hurricane model grid; 2) remove the GFS vortex from the global analysis; 3) add a high resolution, model consistent vortex. The initialization can be summarized as follows:

Initial field = global analysis
 – globally analyzed NCEP vortex
 + specified GFDL vortex (1)

The specified vortex is defined as:

specified GFDL vortex =
 axi-symmetric vortex
 + asymmetric vortex (2)

The axi-symmetric vortex is generated from the time integration of the axi-symmetric version of the hurricane prediction model starting from a motionless initial condition. During the integration, the tangential wind component is gradually forced toward the target profile based on the observations from National Hurricane Center (TPC).

The asymmetric vortex is obtained from 12 hours earlier forecast valid at current time. The axi-symmetric part of the vortex was removed from the 12 hour forecasted hurricane component, only the asymmetric part was added to the final analysis.

A new method to obtain the specified vortex in high-resolution models is proposed here. The method can be described as follows: 1) separate high-resolution hurricane component from its environmental fields, 2) correct the intensity of the hurricane component based on the surface observations and its environmental fields, 3) insert the corrected hurricane component back to its environmental fields at observed location. The new fields are considered to be close to observations, and can be used either as an initial field in GFDL model or as a first guess in the hurricane WRF model.

In the following sections, we will give the procedures to obtain the new specified vortex (section 2), and present the test results of the new initialization (section 3). A brief discussion of the results is given in Section 4.

2. The New Initialization

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In the proposed new hurricane initialization, the specified GFDL vortex is replaced by the 6 hour (or background) GFDL forecasted hurricane component multiplied by a constant Beta. The initialization for hurricane wind can be summarized as follows:

Initial field = global analysis
 – globally analyzed NCEP vortex
 + (6 hours hurricane components) * Beta (3)

The 6 hour forecasted hurricane wind components contain both the symmetric and asymmetric parts of the vortex. The computation of Beta is discussed in Section 2.1.

Once the wind fields are obtained, the correction of the temperature field follows the GFDL model static balance procedure. Given the model wind fields, the surface pressure and temperature fields are calculated by solving the inverse balance equation in the sigma-coordinate (Kurihara *et al*., 1993). The correction of the moisture field is obtained based upon the assumption that the relative humidity is unchanged before and after the temperature correction.

2.1 Computation of Beta

Computation of Beta is based on TPC observed hurricane intensity and the model forecasted storm intensity. Let's denote the observed maximum surface wind as V_{obs}, the GFS environmental wind components as U and V (after hurricane component was removed), the GFDL hurricane components as u' and v'. Define two functions,

$$F = SQRT\left((U+u')^2+(V+v')^2\right)$$

And $$F^* = SQRT\left((U+\beta u')^2+(V+\beta v')^2\right) \quad (4)$$

Function F is the new initialized wind speed on GFDL model grids if Beta=1.0, and function F^* is the new initialized wind speed on GFDL grids if Beta = β.

To match the maximum initial surface wind in GFDL model to the observation, we need to find the constant β to satisfy the following equation at a particular model grid where F^* is at its maximum:

$$(U+\beta u')^2+(V+\beta v')^2=(V_{obs})^2 \quad (5)$$

For simplicity, we assume that the maximums of F and F^* are at the same grid (The assumption is valid since the environmental wind component U and V are smooth in the hurricane region and β is close to 1.0). To find β, we first find the grid where F is at its maximum. Denote the wind components at that grid as U_m, V_m, u_m' and v_m'. Substitute those values into equation (5), we have quadratic equation for β:

$$(u_m'^2 + v_m'^2)\,\beta^2 + 2(U_m u_m' + V_m v_m')\,\beta + (U_m^2 + V_m^2) - (V_{obs})^2 = 0$$

therefore β can be solved as,

$$\beta = (- (U_m u_m' + V_m v_m') + Q) / (u_m'^2 + v_m'^2) \quad (6)$$

where $Q = SQRT\,((u_m'^2 + v_m'^2)(V_{obs})^2 - (U_m v_m' - V_m u_m')^2)$

2.2 Correction to surface pressure

Let's assume the surface pressure for hurricane is an inverse exponential function of radius (Schloemer, 1954),

$$P = P_c + (P_\infty - P_c)\, exp(-r_m/r) \quad (7)$$

and the corresponding cyclostrophic wind (hurricane component wind) is

$$v_\tau = SQRT\,(\rho_0^{-1} (P_\infty - P_c)(r_m/r)\, exp(-r_m/r)) \quad (8)$$

where r_m is the radius of maximum wind, ρ_0 is the air density, P_c is the pressure at hurricane center and P_∞ is the pressure at large radius.

At $r=r_m$, the wind becomes

$$(v_\tau)_m = SQRT\,(\rho_0^{-1} e^{-1} (P_\infty - P_c)) \quad (9)$$

If we multiply $(v_\tau)_m$ by β ($(v_\tau)_m$ has linear relationship with u_m' and v_m'), we must also change P_c to satisfy equation (9). We can't change the surface pressure at a large radius (P_∞). Suppose the center pressure changed from P_c to P_c^* after multiply $(v_\tau)_m$ by β, i.e.,

$$\beta\,(v_\tau)_m = SQRT\,(\rho_0^{-1} e^{-1} (P_\infty - P_c^*)) \quad (10)$$

Solve for P_c^* from equations (9) and (10), we have

$$P_c^* = P_\infty - \beta^2 (P_\infty - P_c) \quad (11)$$

Replace P_c by P_c^* in equation (7), we have the new surface pressure,

$$P^* = P_c^* + (P_\infty - P_c^*)\, exp(-r_m/r)$$

And it can be rewritten in terms of the old surface pressure P as,

$$P^* = P - (P_c - P_c^*)(1 - exp(-r_m/r)) \quad (12)$$

where P^* is the new surface pressure, P is the old surface pressure. If we limit the surface pressure correction to the hurricane area only, equation (12) becomes,

$$P^* = P - (P_c - P_c^*)(1 - exp(-r_m/r))H(r) \quad (13)$$

where

$$H(r) = ((r_b - r)/r_b)^{**}0.5 \quad if\ r < r_b$$

$$H(r) = 0 \quad otherwise$$

where r_b is the average radius of the forecasted storm in 24 directions.

3. Simulation results

We have run two groups of tests. Table 1 and Table 2 show results using the 2001 operational GFDL model. The results in the second group using the upgraded 2003 operational GFDL model will be briefly discussed in Section 4.

Results from the 2001 assimilation show that both the intensity and track forecasts are better compared to those of the operational models. We have 25 runs for the life cycle of storm Felix. The simulation starts from 12Z Sept. 11, 2001 and ends at 00Z Sept. 18, 2001.

Table 1. Average Intensity Forecast Errors (Knots)

	00	12	24	36	48	72
GFDL	8.5	10.2	7.3	6.7	8.3	10.3
TEST	2.0	5.8	6.5	6.7	6.1	7.8
OFCL	1.6	6.8	11.8	14.6	16.0	17.4
#CASE	25	25	25	23	21	17

Table 2. Average Track Forecast Errors (NM)

	00	12	24	36	48	72
GFDL	6.4	27.1	48.1	70.4	91.0	157.3
TEST	18.2	26.2	31.0	42.4	64.3	114.0
OFCL	4.7	35.0	60.0	83.1	102.2	140.7
#CASE	25	25	25	23	21	17

4. Discussions

A significant upgrade was made in the 2003 operational GFDL hurricane model. The original deep convection scheme was replaced by the GFS SAS scheme. The boundary layer scheme was also upgraded. Those changes make GFDL model intensity forecasts from positive bias to large negative bias. The proposed initialization does not perform as well as those in the old tests. The intensity forecasts improved within the first 36 hours forecast, but the track forecasts become slightly worse. If a model has large negative bias in the intensity forecasts, we can expect that the upper level vortex structure will be significantly distorted after repeated uses of the new initializations.

5. References

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