# Development of a Tropical Cyclone Bogussing Scheme for the MM5 system.

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## 1. INTRODUCTION

A simple scheme for bogussing tropical cyclones into the initial condition of MM5 is developed. The scheme is designed to be robust and provide a significant enhancement of initial tropical storm strength and positioning relative to what is available in the background gridded information obtained from global models, such as the National Center for Environmental Prediction (NCEP) Aviation (AVN) model or the Navy Operational Global Analysis and Prediction System (NOGAPS).

The scheme has two primary components: (1) Detection and extraction of tropical cyclone from the first-guess, and (2) Computation of bogus vortex and blending with modified background field.

The details of these two components are described in the subsequent sections. It is followed with the results an example, which highlights the changes in the initial fields and the subsequent impact on a 24-h simulation of hurricane Floyd.

## 2. REMOVAL OF VORTEX FROM FIRST GUESS

Because most of the first guess information that is available analyses with relatively coarse effective resolution, the vortices contained in these analyses are too broad and too weak. Initialization of a higher-resolution model from these analyses results in a storm that typically maintains its physical characteristics from the initial time. If the storm starts out with a radius of maximum wind (RMW) of, say, 200 km, the RMW tends to remain near this value for an extended period during the forecast until the model is able to produce a scale contraction and associated intensification of the vortex. This often requires 1-2 days of integration.

To improve the intensity prediction, it is necessary to insert an initial vortex that is closer to the observed storm intensity than is the vortex in the background. In order to do this, the erroneously large vortex in the background must be first removed. Otherwise, the initial state for MM5 would contain two vortices which may be at different spatial locations.

The first step of the removal process is to identify the vortex corresponding to the storm of interest in the first guess field (Fig 1a). This is accomplished by searching for the maximum vorticity on the analysis pressure-level nearest the surface within a prescribed radial distance (~400 km) from the Best Track location of the tropical cyclone. The point of maximum vorticity then serves as the center of the vortex to be removed. Because the first guess has a coarse grid increment, the vorticity field on the MM5 grid has no small-scale variations that might complicate locating the center.

There are various ways of removing the erroneous first guess vortex once it has been located. For example, Kurihara et al., (1993) uses a sophisticated filtering scheme. The approach we adopt is to modify the vorticity, geostrophic vorticity, and divergence, then solve for the change in the non-divergent stream function, geopotential and velocity potential and compute a modified velocity field.

The general approach to modifying the flow can be illustrated in the context of vortic-

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ity and non-divergent wind. The relationship between wind, stream function and vorticity is:

$$\nabla^2\psi = \zeta \qquad (1)$$

$$v_\psi = \hat{k} \times \nabla\psi \qquad (2)$$

where $\psi$ is the stream function for the non-divergent wind, $\zeta$ is the relative vorticity and $v_\psi$ is the non-divergent wind. To define the non-divergent wind associated with the first-guess storm, we set vorticity equal to zero outside a radius '$r_m$', specify $\psi$=0 on the lateral boundaries of the domain and solve (1) for a perturbation stream function $\psi$' on all pressure surfaces. From (2) $v_\psi$' is calculated and subtracted from the first-guess wind field.

Removal of the divergent wind and pressure anomalies associated with the first-guess storm follows (1) and (2), except in the case of divergence, (1) and (2) are replaced by

$$\nabla^2\chi = \delta \qquad (3)$$

$$v_\chi = \nabla\chi \qquad (4)$$

where $\chi$ is the velocity potential, $\delta$ the divergence and $v_\chi$ the velocity potential.

To remove the geopotential height anomaly (1) and (2) become:

$$\nabla^2\Phi = \zeta_g f_0 \qquad (5)$$

$$v_g = \hat{k} \times \nabla\Phi \qquad (6)$$

and we similarly set the geostrophic vorticity (subscript 'g') equal to zero outside r=$r_m$ and solve for a geopotential anomaly $\phi$' which will be subtracted from the first guess.

To remove the temperature anomaly field due to the first-guess storm, we use the hydrostatic relation:

$$\frac{\partial\Phi'}{\partial\ln(p)} = -RT' \qquad (7)$$

where R is the gas constant and p is the pressure. The temperature anomaly field is also removed, leaving a first-guess field with only a background flow where the first-guess storm was located (Fig. 1b). Although in the current version of the scheme the background flow is unmodified, deviations between the background steering flow and storm track could be identified at this stage. The bogus storm to be added to the background field is axisymmetric in the current version of the scheme and hence, will not affect the storm motion.

## 3. ADDITION OF BOGUS VORTEX

Because the input data to the bogussing scheme is limited, consisting mainly of storm location and estimated maximum winds, the specification of a three-dimensional vortex structure is arbitrary, to some extent. The need for rapid integration of the model initialization scheme precludes the use of sophisticated schemes such as developed by Zou et al. (1999) based on 4D-VAR. The bogus storm profile chosen here is based on the following assumptions:

(1) Axi-symmetry.
(2) Vorticity specified within 300 km of the bogus storm center.
(3) Radius of maximum wind (RMW) fixed (90 km on 45-km grid).
(4) Mass and wind fields in nonlinear balance.
(5) Nearly saturated (w.r.t. water or ice) core; no eye (on 45-km grid).
(6) Maximum winds of bogus storm are a pre-determined fraction of maximum winds observed.

The vortex wind profile is given by the

simple Rankine vortex:

$$v = A(z)F(r) \qquad (8)$$

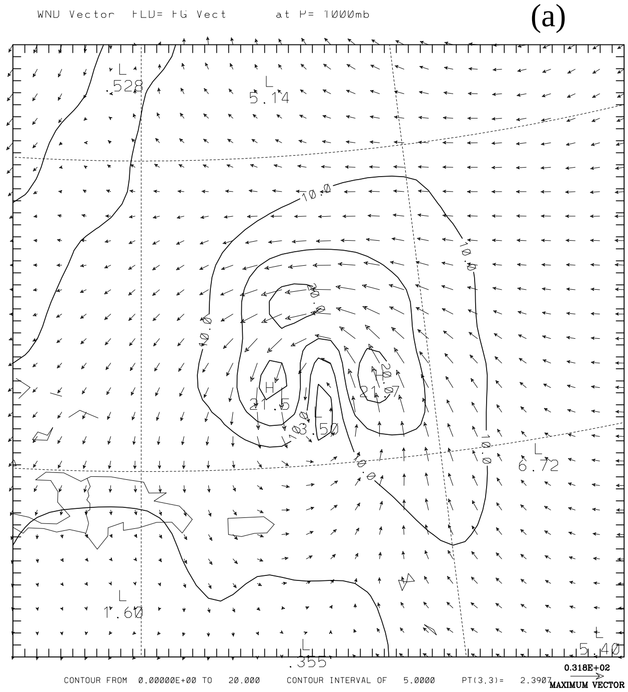
$$F(r) = \frac{v_m}{r_m} r \qquad (r \le r_m) \qquad (9)$$

$$F(r) = \frac{v_m}{r_m^{\alpha}} r^{\alpha} \qquad (r > r_m) \qquad (10)$$

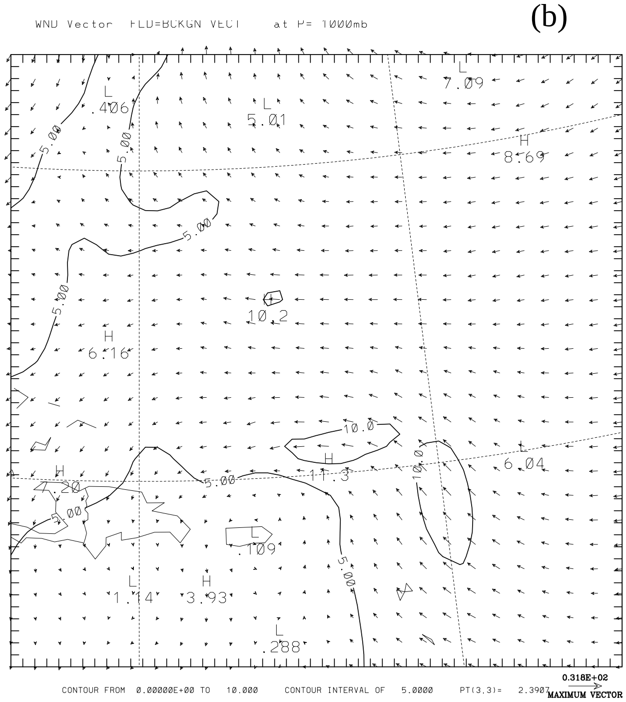
where $v_m$ is the maximum tangential wind at maximum radius, $r_m$. We choose $\alpha$ = -0.75. Other studies suggest slightly different values of $\alpha$ typically around -0.5. However, these profiles tend to be measured only within 150 km or so of the storm center. Such a profile yields velocities that are demonstrably too large at large radii (of order 500-1000 km) where the influence of the hurricane flow is often hard to deduce from the first guess disturbances. The choice of $\alpha$ = -0.75 is a compromise to yield an approximately correct functional relationship near the storm and reduce the influence of the storm at large radii. Fig. 1c shows the final wind field after the Rankine vortex has been added to the background field. The changes in the final field are mainly localized while keeping the far-fields unmodified. Possible future work would include more realistic wind profiles, based on the profiles produced by MM5 itself.

The amplitude and height dependence are contained in A(z). We assume that the maximum azimuthally averaged wind is 0.75V, where V is the reported maximum wind from the Best Track data. Because we specify a symmetric circulation, the maximum winds should be somewhat lower than the maximum wind reported, where significant asymmetries exist. The coefficient 0.75 is based on several MM5 simu lations of tropical cyclones of varying intensity with varying grid increments. The vertical weighting function is specified to be unity from the surface through 850 hPa, 0.95 at 700 hPa, 0.9 at 500 hPa, 0.7 at 300 hPa, 0.6 at 200 hPa and 0.1 at 100 hPa.

(a)




(b)



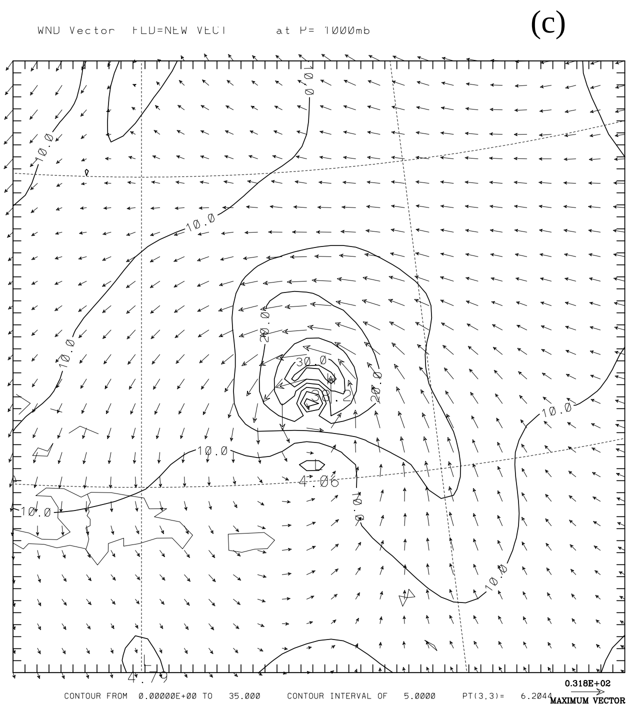


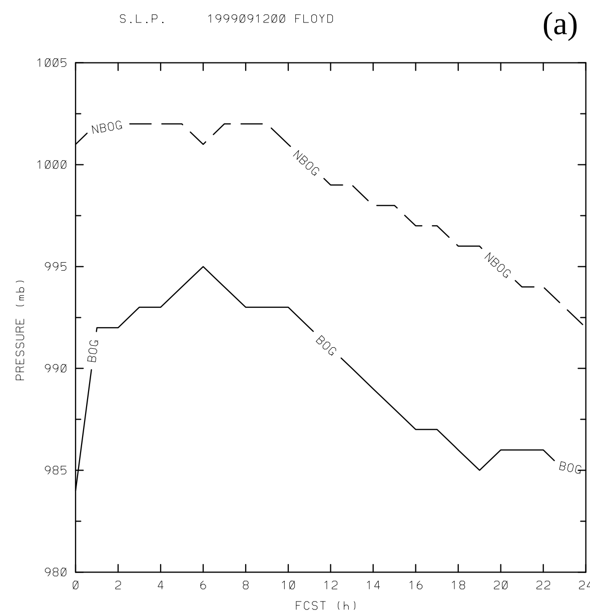

*Figure 1. 1000 hPa wind field (cint 5 ms$^{-1}$) of (a) first guess, (b) background, and (c) final field after bogussing hurricane floyd valid at 0000 UTC Sept 12 1999.*

**4. RESULTS**

An example of the effect of the bogussing on the model initial conditions and on the subsequent forecast is shown in Figs. 2 and 3. The example is hurricane Floyd, which formed in the Atlantic on Sept 7 1999. The MM5 model was initialized at 0000 UTC Sept 12, 1999, using initial conditions from the NCEP AVN model. Two forecasts were run, with (BOG) and without (NBOG) bogussing. The selected model physics (Grell 1994) were: the simple ice microphysics scheme, Grell cumulus scheme, and MRF pbl. The horizontal grid spacing was 45 km with 31 unequally-spaced levels in the vertical.

The maximum reported wind was 85 knots and Floyd had attained hurricane strength by Sept 12 1999. Using a RMW of 90 km, the BOG simulation reveals an initial adjustment in the first 30-60 min, followed at a steady period and thereafter a nearly constant intensification for a 24 h simulation (Fig 2a). The slight adjustment in the first 30-60 min may be due to the frictional effects in the planetary boundary layer which is not accounted for in the scheme and the prescribed nonlinear balance is disrupted. The near constant deepening suggests that the structure imposed is close to that preferred by MM5. The storm in BOG is about 7 hPa deeper than in NBOG with the maximum winds averaging about 34.6 ms$^{-1}$ as opposed to 21.9 ms$^{-1}$ during 24-h simulation (Fig. 2b). The deepening rate and the increase in maximum winds are in phase with one another in the BOG run.

The structures of the 24-h sea-level pressure fields from BOG and NBOG simulations are shown in Fig. 3. There is a greater degree of axial symmetry in the BOG storm, as well as more overall organization in the precipitation pattern. The maximum 1-h total precipitation at 24 h increased by 30% and is located at the storm center.



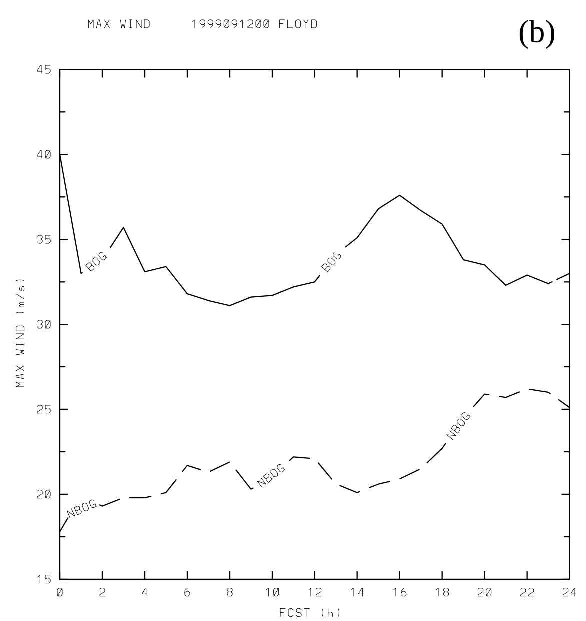



*Figure 2. Time Series of (a) deepening rate (mb $h^{-1}$) and (b) maximum wind ($ms^{-1}$) for the BOG (solid curve) and the NBOG (dashed curve) experiments.*

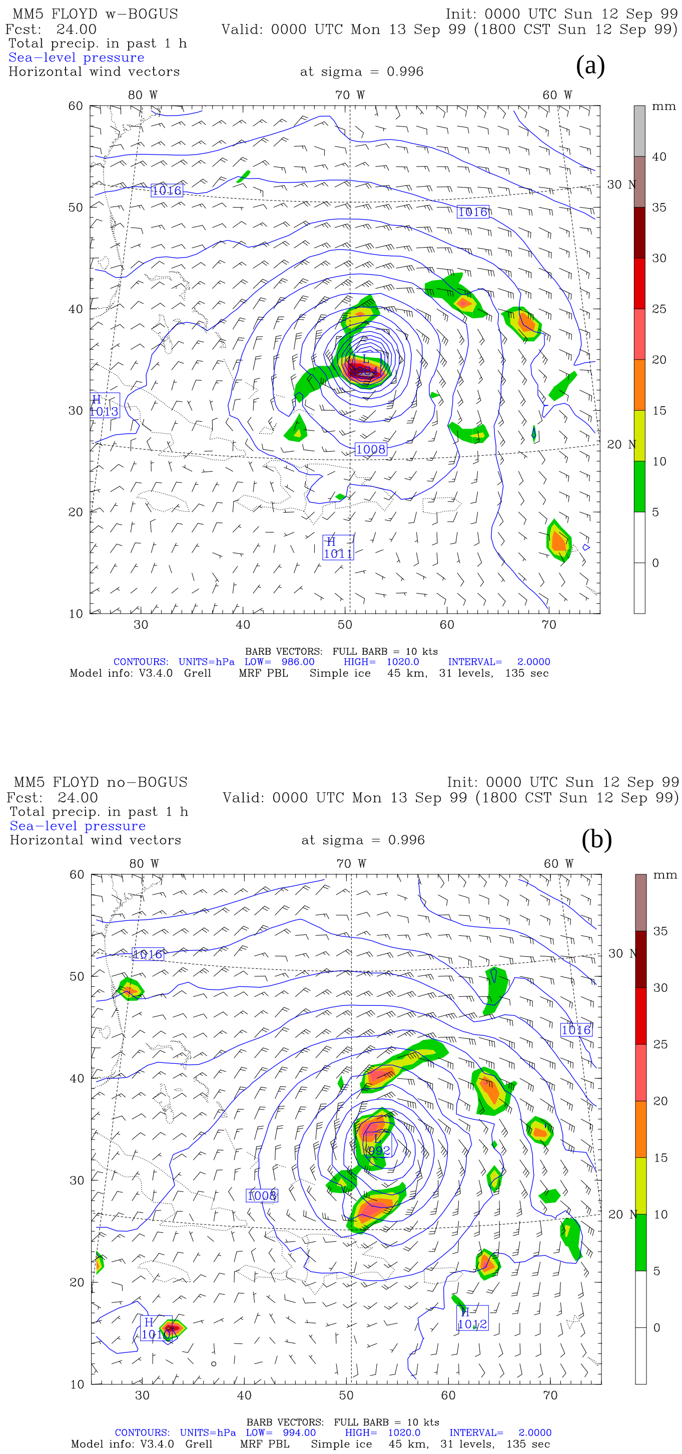



*Figure 3. Sea-level pressure (cint 2 hPa) with surface ($\sigma$=0.996) wind field: full barb=10 kt; flag=50 kt., and 1-h total precipitation (shaded) at 24 h for (a) with bogussing and (b) no bogussing, valid at 0000 UTC Sept 13 1999.*

## 5. CONCLUDING REMARKS

A simple tropical cyclone bogussing scheme has been implemented into the preprocessing software of the REGRID code of the MM5 modeling system, thereby allowing the specification of more realistic tropical cyclone intensity with a dynamically balanced structure in the initial condition. The scheme appears to improve significantly upon the intensity of tropical cyclones present in first guess fields from global models. The evolution of storm intensity during the first few hours of model integration does not appear to feature rapid adjustment as can occur if the initial conditions are not balanced or if the initial structure is not resolvable on the model grid.

The scheme consists of an extraction of any storm that may be present near (within 400 km) the observed storm in the first guess. The methodology for the extraction departs significantly from the filtering method used by the Geophysical Fluid Dynamics Laboratory (GFDL). In the present scheme a series of Poisson-type equations are solved to calculate nondivergent, irrotational and geostrophic wind fields with the vortex to be removed. Temperature anomalies are calculated from the hydrostatic equation.

The scheme is designed to improve the first guess conditions from which the MM5 initial conditions are derived. It is not intended for use with subsequent analysis packages because the imposed structure may be significantly distorted especially in the case of sparsely distributed observations. We are currently investigating methods of coupling the bogussing technique described in this report to more sophisticated initialization schemes wherein cycling of model forecasts and multivariate incorporation of observations is performed.

## REFERENCES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