Bogussing of Tropical Cyclones in WRF Version 3.1

By

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## Introduction

We have taken a simple scheme for bogussing tropical cyclones written earlier for MM5 REGRID and have implemented it in WRF Version 3.1. In this version of the scheme one can either introduce a new vortex or remove an existing vortex. The input to the scheme is a single file containing fields on isobaric surfaces that has been produced by running the WPS metgrid.exe program. At present only one bogus storm can be inserted into a single domain though we are generalizing this to include multiple storms. Also the scheme only works on a single time period and must be run on a single processor. The output from the scheme is a single metgid-type file that contains the bogus storm. This file serves as an input file for the WRF program real.exe to produce the boundary and initial conditions files necessary for running the WRF model.

## Vortex Removal

The TC bogus scheme starts by searching for the vortex corresponding to the storm in the first guess-field. This is done by looking for the maximum relative vorticity in the pressure field nearest the surface (usually 1000hPa) within a prescribed radial distance from the Best Track location of the Tropical cyclone. We currently use 400 km as the search radius (Figure 1). The grid point where the maximum vorticity is located serves as the center of the vortex to be removed.

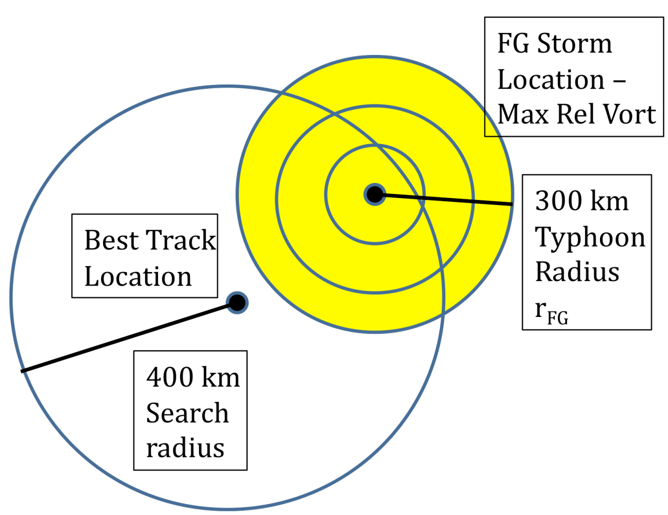


Figure 1

Once the vortex has been found we remove the first-guess vorticity and divergence within a 300 km radius of the first guess storm and re-calculate the velocity. This is done as follows.

For the vorticity we have the following relationships.

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

Where $\psi$ is the stream function for the non-divergent wind and $\zeta$ is the relative vorticity. To define the non-divergent wind associated with the first-guess storm, the vorticity is set to 0 outside a radius of 300 km. Then we define the Dirichlet boundary conditions stream function to be 0 and use Successive 0ver-Relaxation (SOR) method to solve equation 1 for the perturbation stream function on all pressure surfaces. The non-divergent wind is then calculated from the following relation.

$$v_\psi = \hat{k} \text{ x } \nabla\psi$$

Once the non-divergent wind is calculated it is subtracted from the first-guess U and V wind fields.

Removal of the divergent wind from the first-guess storm is similar. We use the relation

$$\nabla^2 \chi = \delta$$

where $\chi$ is the velocity potential and $\delta$ is the divergence computed from the horizontal winds. In this case the divergence is set to 0 outside a radius of 300km. The velocity potential is calculated from the following equation.

$$v_\chi = \nabla\chi$$

Once the divergent wind is calculated with the equation above it is subtracted from the first-guess U and V wind field.

Next we remove the geopotential height anomaly from the first-guess field. The equation $\nabla^2 \phi = \zeta_g \; f_0$ is solved for the perturbation height then the geostrophic wind is calculated by

$$v_g = \hat{k} \text{ x } \nabla\phi$$

$v_g$ is then subtracted from the first guess-field.

The temperature anomaly field due to the first guess-storm is calculated from the following equation.

$\partial\phi'/\partial\ln(p) = -RT'$ where R is the gas constant and p is the pressure.

After the temperature anomaly field is removed we remove the surface and sea–level pressure perturbations associated with the height anomalies from the surface and sea-level pressure fields. Finally we are left with only the background flow where the first-guess storm was originally located. At this point the user can exit the scheme and have the vortex removed from the metgrid file.

## TC Bogus Insertion

The profile of the bogus storm that is inserted is based on the following:

(1) Axis symmetry
(2) Radius of maximum wind which is an input parameter to the WRF namelist.input
(3) Mass and wind fields in nonlinear balance.
(4) Nearly saturated (w. r. t. water or ice) core. No eye on 45km grid.
(5) Maximum winds of the bogus storm are a user specified fraction of maximum winds observed. This is an input parameter in the WRF namelist.input.

The wind profile of the vortex is given by a Rankine vortex.

$$v = A(z)\,F(r)$$

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

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

where $v_m$ is the maximum tangential wind at the radius of maximum winds $r_m$. We have chosen $\alpha$ = -0.75. The amplitude and height dependencies are contained in A(z).

A(z) = scale factor * altitude factor
Surface – 850mb: 1.0
850 – 700mb: 0.95
700 – 500mb: 0.90
500 – 300mb: 0.7
300 – 200mb: 0.6
200 – top: 0.1

The relative humidity field is defined according to figure 2. Within the radius of maximum winds, the relative humidity is defined as nearly saturated. Outside twice the radius of maximum winds, the relative humidity is not affected. Between the two radii, a linearly weighted relative humidity is constructed.

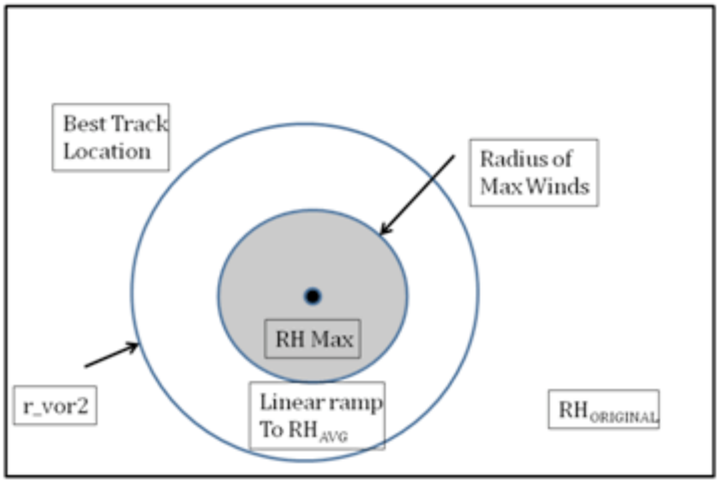

Figure 2

At this point the new bogus storm is defined and written to the output metgrid file.

## TC Bogus Options

As mentioned above the bogus options come into the scheme from the WRF namelist.input file. The following are the run-time options for the tc bogus scheme.

&tc

- `insert_bogus_storm`, logical T/F insert vortex
- `remove_storm`, logical T/F remove storm and stop
- `num_storm`, integer currently set to 1
- `latc_loc`, real, best track center latitude
- `lonc_loc`, real best track center longitude
- `vmax_meters_per_second`, real max wind speed
- `rmax`, real, radius of max wind speed (m)
- `vmax_ratio`, real, max speed scale factor

Hard-coded constants in source

- `r_vor`, bogus typhoon and first-guess typhoon size, 300 km
- `r_vor2`, "outside" first-guess influence, 4x r_vor
- `r_search`, how far to go to find first-guess vorticity max, 400 km
- `humidity_max`, 95%, below 400 mb
- `humidity_min`, 5%
- `alpha`, wind speed constant for Rankine vortex, set to -0.75

## Example Initialization

To test the scheme we used the Typhoon Sinlaku which took place in September 9 – 10 2008. We used 1 degree x 1 degree GFS data for the first-guess input. The following three figures show the results.

Figure 3 is the GFS control.

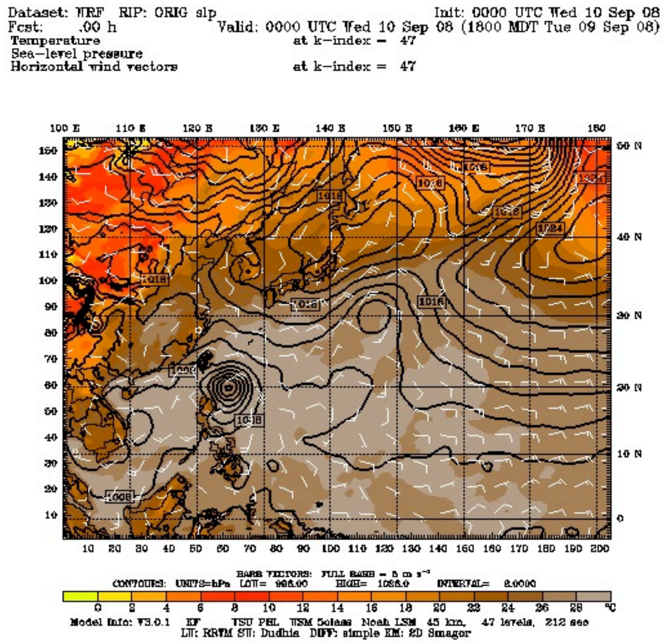


Figure 3

Figure 4 shows the vortex removed and figure 5 shows the new Rankine vortex inserted into the storm.

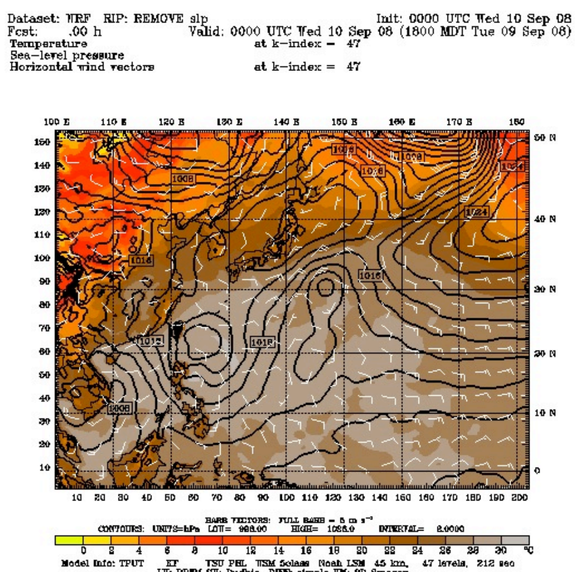


Figure 4

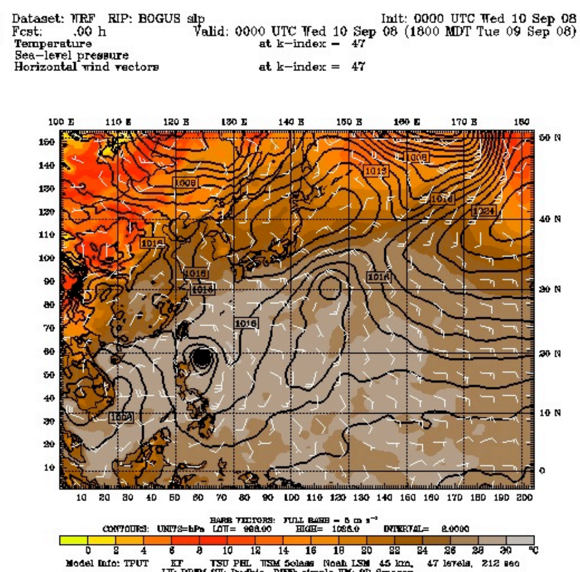


Figure 5

# Summary

A method to remove a vortex and add a bogus typhoon to the WPS package metgrid output has been ported from the MM5 system. We are looking at the impact of running the WRF Digital Filter to reduce the oscillations introduced with a bogus storm insertion.

Our future work includes the ability to add more than one storm to a domain. This ability is currently being tested. We also are working on a separate program which will allow the user to take either a WRF input file which is output from real.exe or a WRF model output file from a simulation and vertically interpolate the U, V, temperature, height and relative humidity fields to pressure surfaces. The output of this program will be a metgrid type file which the tc bogus scheme can read. We plan on having both of these abilities available in the next WRF release.