UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

Further Development and Applications of an Efficient and Configurable Vortex Initialization Technique

Brian D. McNoldy[1], Eric A. Hendricks[2], Eric D. Rappin[3], Sharanya J. Majumdar[1], David S. Nolan[1], and James D. Doyle[2]

1 – University of Miami / RSMAS 2 – Naval Research Laboratory, Monterey 3 – Western Kentucky University

1. Introduction

Tropical cyclones continue to pose a significant forecast challenge for numerical weather prediction models, and vortex initialization is one of the factors in improving forecast accuracy. In the most basic (yet still practical) approach, a synthetic or "bogus" hurricane-like vortex can be generated and inserted into a model's large-scale environment.

Kurihara et al. (1993) argued that the synthetic vortex should possess three properties to minimize dynamic adjustment and false spin-up/spin-down:

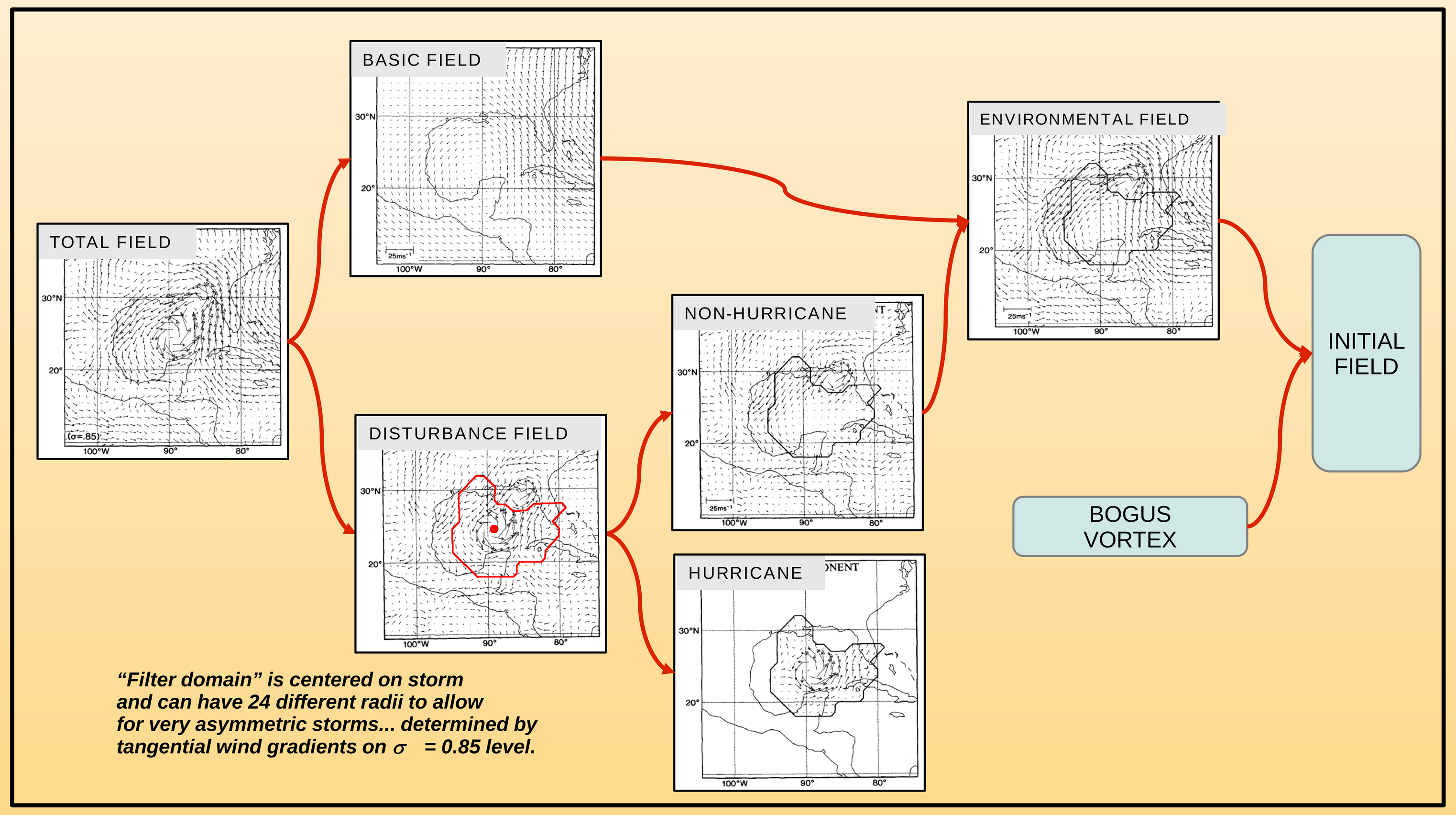
- *structural consistency*
- *resemblance to the "real storm"*
- *compatibility with the numerical model*

To ensure these qualities are enforced in the generation of tropical cyclone-like flows for model initialization, three general techniques, that work together or alone, have been developed: 1) data assimilation, 2) dynamic initialization, and 3) vortex bogusing.

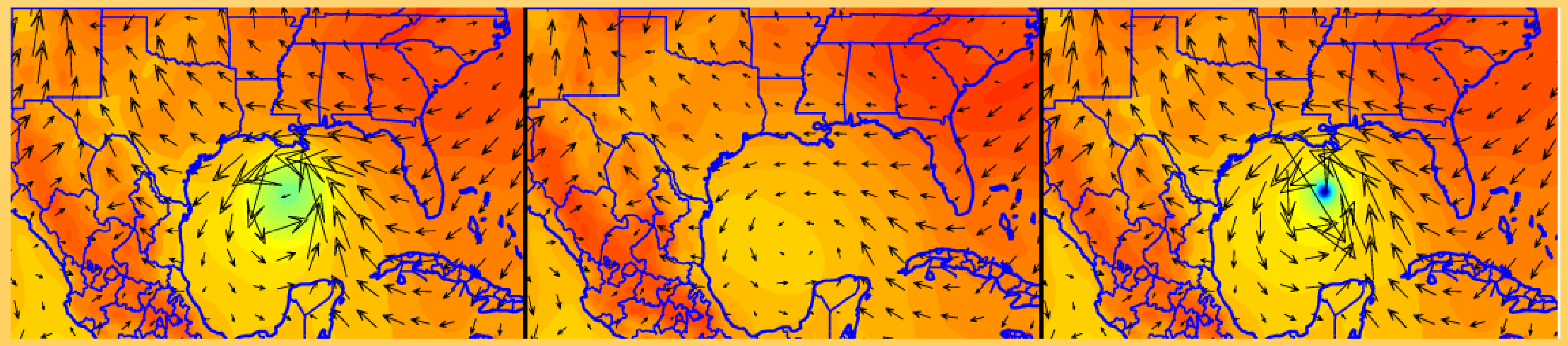
This methodology provides an efficient and portable vortex bogusing scheme with many configurable parameters. A more detailed description and results can be found in Rappin et al. (2013).

2. Vortex Removal & Addition

The vortex removal technique closely follows that designed by GFDL (Kurihara et al. 1993, Kurihara et al. 1995). The figure below shows a flow diagram of the process, beginning with a model's initial analysis. (Hurricane Florence 1988, from Kurihara et al. 1995).



In this framework, a moist, axisymmetric vortex is created and inserted into the model's background environment. The radial and vertical structure can be specified, and a secondary circulation can be generated. Below is an example of the "total", "environmental", and "initial" fields (wind vectors and perturbation hydrostatic pressure). (Hurricane Lili 2002, from Rappin et al. 2013).



3. Configurable Parameters

A primary advantage of this technique is that many of the parameters that control the vortex removal and addition processes are easily adjustable. In the current version of the code (in Matlab and Fortran 90), there are nearly two dozen parameters the user can change. Some options depend on other options being set, but examples include:

- Storm center location (model-based or best-track)
- Radial structure (Mod-Rankine or Willoughby dual-exponential)
- Vertical structure (Gaussian decay or Emanuel)
- Secondary circulation (Emanuel or none)
- Boundary layer flow scheme (Foster similarity or Gaussian decay)
- Boundary layer depth
- Boundary layer eddy diffusivity
- Radius of maximum wind
- Vortex depth
- Moisture enhancement
- Outflow temperature
- Radius of tropical storm winds
- Tangential wind decay exponent
- Gaussian decay rate constants

There are only 7 fields that the vortex removal/insertion alters: the 3D wind field, water vapor mixing ratio, dry air mass, geopotential, and temperature.

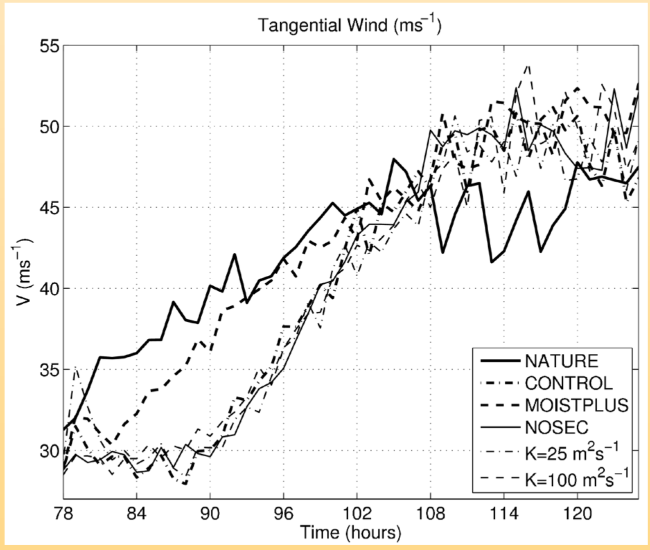
4. Previous Model Experiments

The simulations in this section use the WRF 3.1.1 model with 27/9/3km nested domains. Details on the various radiation, convection, microphysics, etc parameterizations and schemes can be found in Rappin et al. (2013).

Setup of experiments on Hurricane Bill 2009:

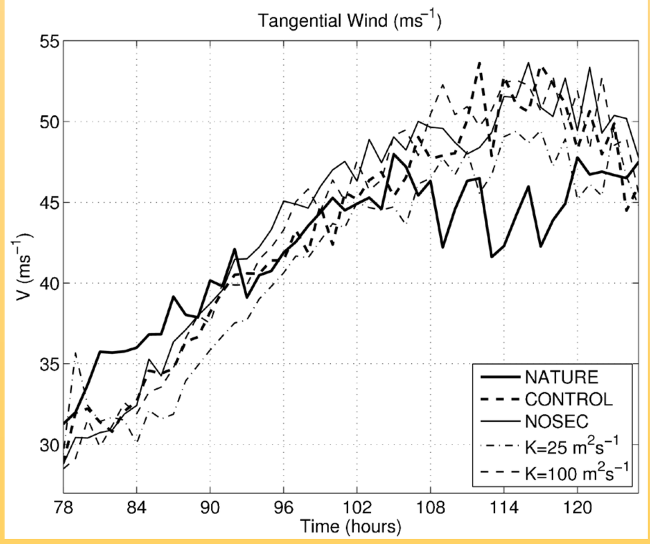
- Nature run (**NATURE**: no bogusing)
- Control run (***CONTROL**: default bogus vortex)*
- Initial moisture enhancement (***MOISTPLUS**: +10% RH at RMW)*
- Influence of initial unbalanced secondary circulation (***NOSEC**: U,W=0)*
- Varying eddy diffusivity value (***K25**: 0.45*CTRL, **K100**: 1.8*CTRL)*

In all cases, the track forecast was very similar, and is not shown. The intensity forecasts (azimuthally averaged maximum tangential wind at lowest model level ~ 100m) are shown here. All synthetic vortex initializations shown here were conducted at 78 h into the nature run.



The MOISTPLUS run is the only one that does not suffer from a significant initial adjustment period of vortex spin-down.

To further demonstrate the effect of enhanced moisture on initial adjustment, all experiments were rerun but with 15% higher RH in the inner core.

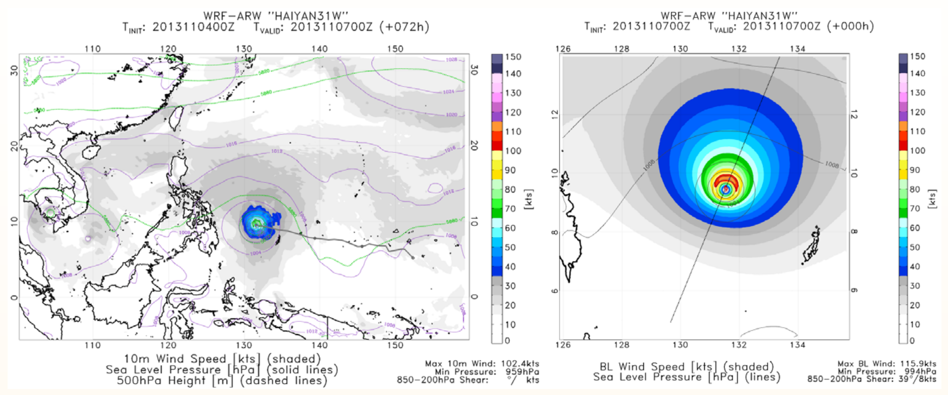


With inflated inner core moisture, regardless of secondary circulation and eddy diffusivity value, the adjustment time is greatly reduced.

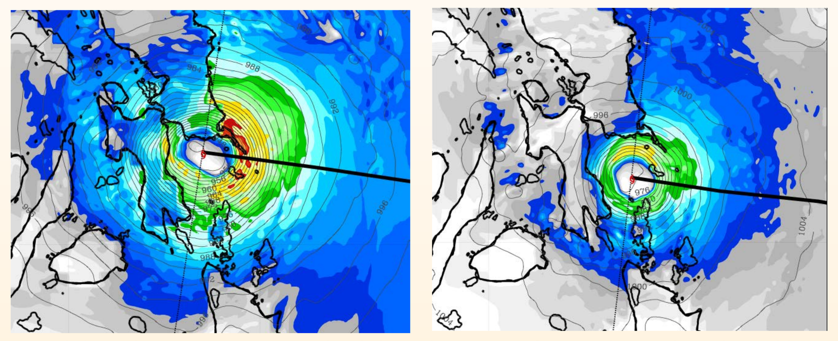
Funding from ONR grant N00014-08-1-0250 is gratefully acknowledged.

5. Ongoing Model Experiments

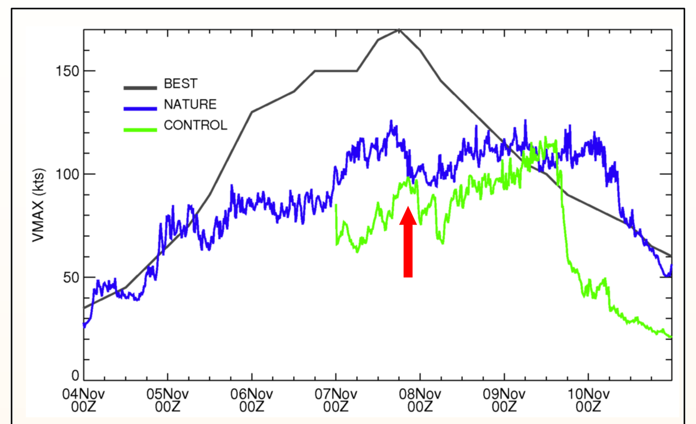
The structure and intensity evolution of Supertyphoon Haiyan (2013) in WRF and COAMPS-TC is being investigated. The WRF-ARW configuration utilizes v3.5.1 of the model, with 18/6/2km nested domains, and using the same microphysics, radiation, cumulus parameterization, boundary layer scheme, and ocean model as the WRF nature run described in Nolan et al. (2013).

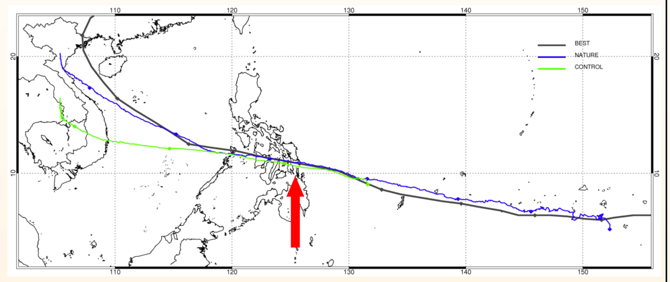


72h into "nature" run, the model's vortex is removed, and a specified synthetic vortex is added to the background flow. At this point, a new "control" run is initialized. Simulations with different idealized vortices will be run to find what degrades/improves the forecast.



At 90h into the "nature" run and 21h into the "control" run, the cyclone is making landfall in the Philippines. While the tracks are generally similar up to this point, the structure and intensity are not.

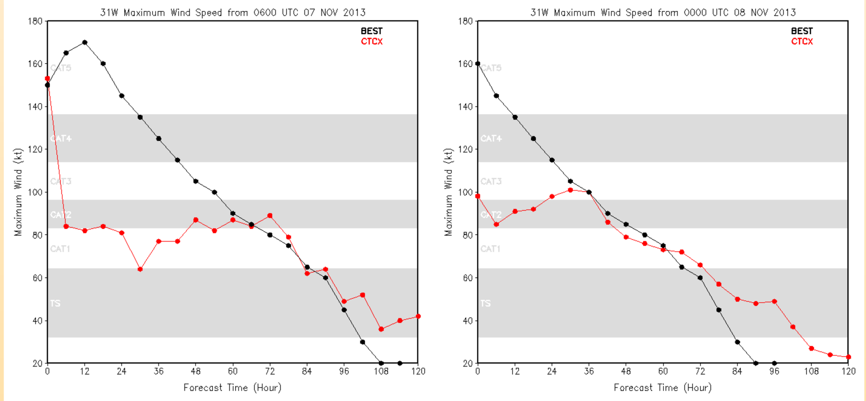




Intensity and track forecasts from the WRF "nature" and "control" runs . The JTWC best-track data for Haiyan are shown for reference, but future experiments will be evaluated against the nature run so comparisons are all done in model space. *The red arrows highlight the timing and location of the plots to the left.*

This case is particularly interesting for two reasons: Haiyan was a remarkably well-organized and intense typhoon with a major societal impact, and the COAMPS-TC operational model occasionally failed to initialize close to the "correct" intensity and/or suffered from a dramatic spin-down in the first few hours of each run (it should be noted that this issue is not unique to COAMPS-TC… other hurricane models suffer from similar problems).

Clearly, there are more robust metrics by which a model can be evaluated, but the maximum surface wind speed is widely used. To the right are two examples of the model's difficulties with initialization and spin-down.



Run initialized at very high intensity, but followed by an immediate 70kt spin-down adjustment.

Run under-initialized by approx 60kts.

6. Applications

The Fortran 90 version of the code runs *~150x faster* than the original Matlab version, and is more portable, so is therefore better suited for research as well as quasi-operational purposes. The code can be made available to the community upon request.

- Idealized simulations, sensitivity studies
- Test observing strategies in OSSEs
- Basic plug-and-play vortex in bogusing schemes
- A step in dynamic initialization schemes
- Ensemble of bogus vortices for data assimilation schemes

Emanuel, K. A., 1986: An air-sea interaction theory for tropical cyclones. Part I: Steady-state maintenance. *J. Atmos. Sci.*, **43**, 585-604.
Kurihara, Y., M. A. Bender, and R. J. Ross, 1993: An initialization scheme of hurricane models by vortex specification. *Mon. Wea. Rev.*, **121**, 2030-2045.
Kurihara, Y., M. A. Bender, R. E. Tuleya, and R. J. Ross, 1995: Improvements in the GFDL hurricane prediction system. *Mon. Wea. Rev.*, **123**, 2791-2801.
Nolan, D. S., R. Atlas, K. T. Bhatia, and L. R. Bucci, 2013: Development and validation of a hurricane nature run using the joint OSSE nature run and the WRF model. *J. Adv. Model. Earth Syst.*, **5**, 24pp.
Rappin, E. D., D. S. Nolan, and S. J. Majumdar, 2013: A highly configurable vortex initialization method for tropical cyclones. *Mon. Wea. Rev.*, **141**, 3556-3575.
Willoughby, H. E., R. W. R. Darling, and M. E. Rahn, 2006: Parametric representation of the primary hurricane vortex. Part II: A new family of sectionally continuous profiles. *Mon. Wea. Rev.*, **134**, 1102-1120.

30 March – 4 April 2014 . 31st Conference on Hurricanes and Tropical Meteorology . San Diego, California