New Vortex Initialization Scheme for the NCEP's HWRF Model

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Introduction

For better prediction of hurricane track and intensity, the hurricane should be well initialized in the model initial condition. Recently, many data assimilation methods deal with the tropical cyclone initialization as models increase their horizontal resolution and various observations are emerging continuously (Zhang et al. 2007). But, it is still not enough to analyze the hurricane initial structure for high resolution hurricane model's initial condition. In addition, the mass-wind imbalance issue often appears when the difference between observation and the model background is fairly large.

The Hurricane Weather Research and Forecasting (HWRF) model primarily developed by NOAA/NCEP/EMC has been used to forecast the track and intensity of tropical cyclones. It has a unique vortex initialization method that corrects the location, size and intensity of tropical cyclone based on hurricane information provided by National Hurricane Center prior to the data assimilation. The 6 h predicted vortex from previous cycle is used as the first guess, and we assume the vortex achieves the mass-wind balance during 6 hours model forecast. This method aims to keep the model balance during the vortex structure modification.

In this study, we have further developed the vortex initialization scheme for the HWRF model. The new vortex initialization scheme can afford to keep the model balance better than the operational one. And, the modified vortex is smoothly merged into the environments with vortex blending method, so that the only vortex changes in the background without large scale damage.

Characteristics of New Vortex Initialization

- Several scientific and technical differences from operational vortex initialization (Table 1)
- Vortex initialization on a pressure coordinates
  : Benefit on the gradient wind calculation (p can be ignored)
  : Good for horizontal filtering
  : Alleviate the topography effect for the relocation
- To keep model balance during intensity correction, geopotential is adjusted based on increment of wind change using the gradient wind balance
- To take advantage of the good track forecast skill of GFS, Vortex blending method is introduced instead of vortex replacement method.
  Inner core: HWRF disturbance, outer: GFS disturbance

Table 1. Difference from Operational TC initialization

Scientific difference	New Vortex Initialization
Size correction	Taking observed intensity into account during size correction → To better match of storm size Pressure recalculation after the wind structure correction → To better model balance
Intensity correction	Tangential wind adjustment after the geopotential correction → To better model balance
Moisture adjustment	Temperature and moisture calculation from the virtual temperat ure and humidity → To keep the humidity of cycled storm
Vortex blending	Inner core: HWRF disturbance, outer: GFS disturbance → To take advantage of the good track forecast skill of GFS
Vertical stretching	Vertical stretching during intensity correction → Warm core height increases when intensity increases
Technical difference	**New Vortex Initialization**
Initialization procedure	Simple and modularized structure → Flexible about various models
4x domain (Filtering purpose)	The resolution of 4x domain is identical to the parent domain → Smaller memory requirement

Design of the New Vortex Initialization Scheme

New Vortex Initialization Procedure

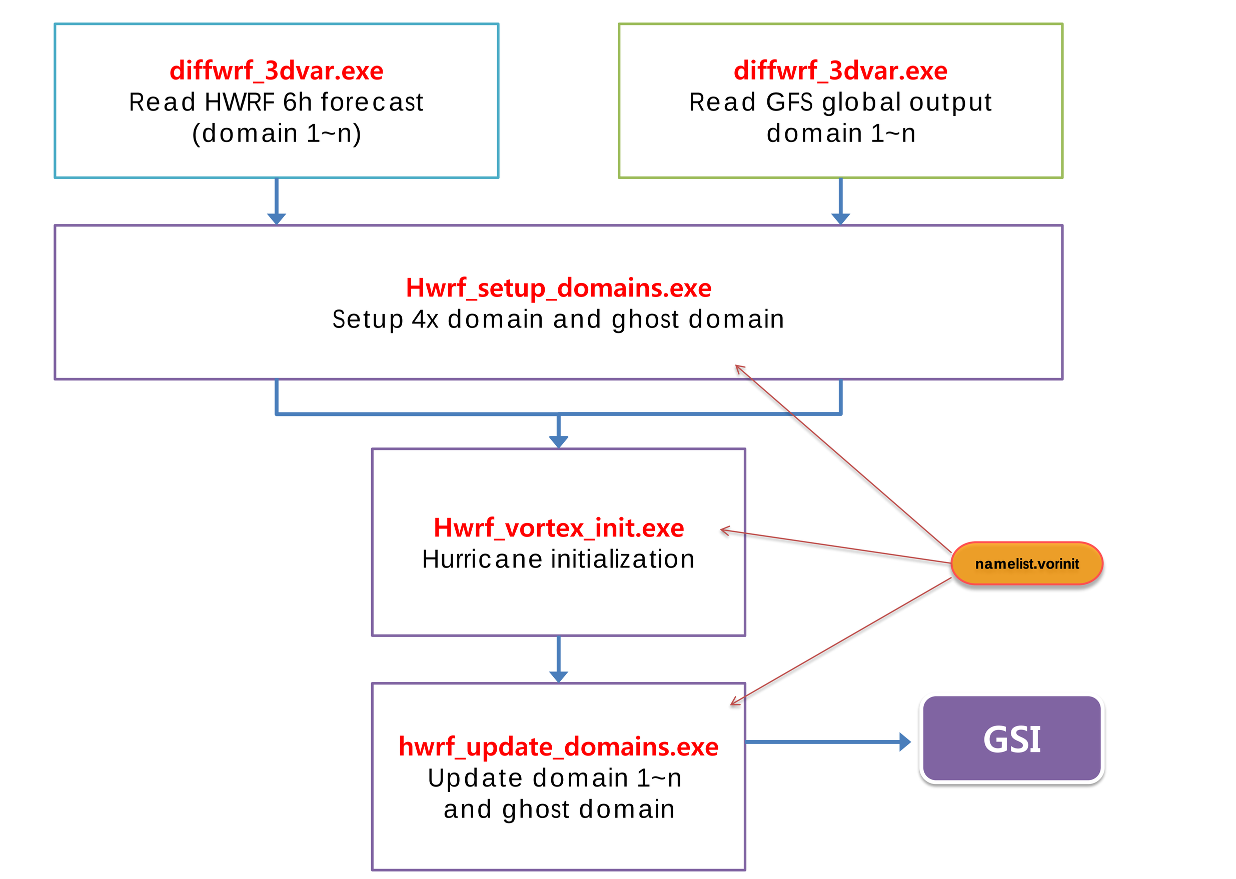


Fig 1. Diagram of the new vortex initialization procedure (n number of model domains assumed)

- Read model domains from both HWRF and GFS (vortex from HWRF)
- Read only GFS model domain, If it is a cold start (vortex from GFS)

Configuration of Domains for the initialization

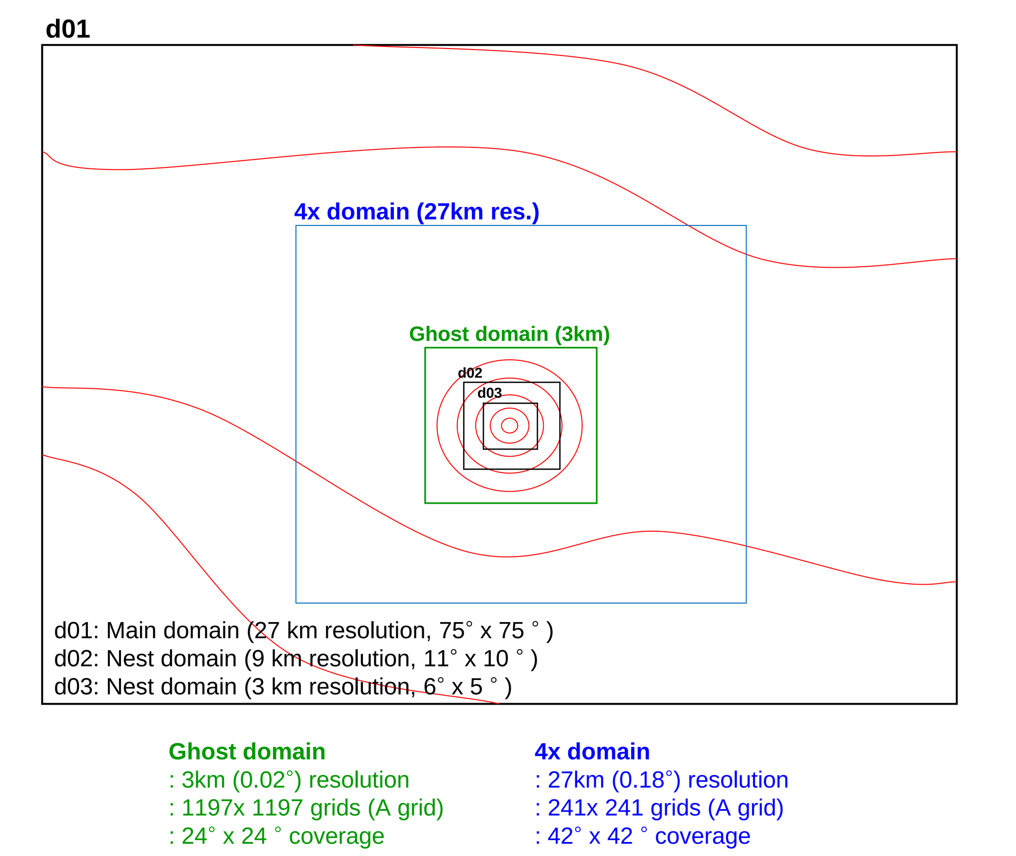


Fig 2. Model domains and two additional domains for the initialization

- d01-03: HWRF model domains
- Ghost domain: Vortex initialization domain, fully covering hurricane
- 4x domain: Domain for horizontal filtering

Vortex Structure Correction

Size correction

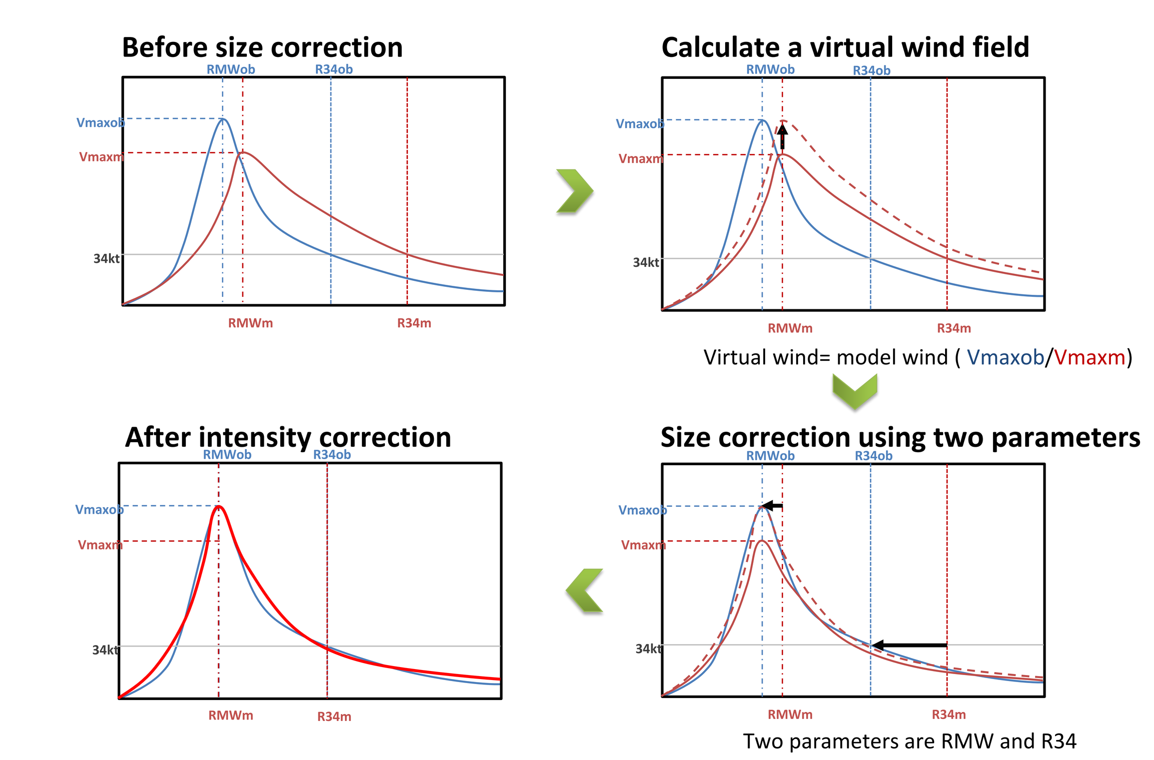


Fig 3. Diagram of size correction. Hurricane size after intensity correction matches observation

Pressure adjustment after size correction

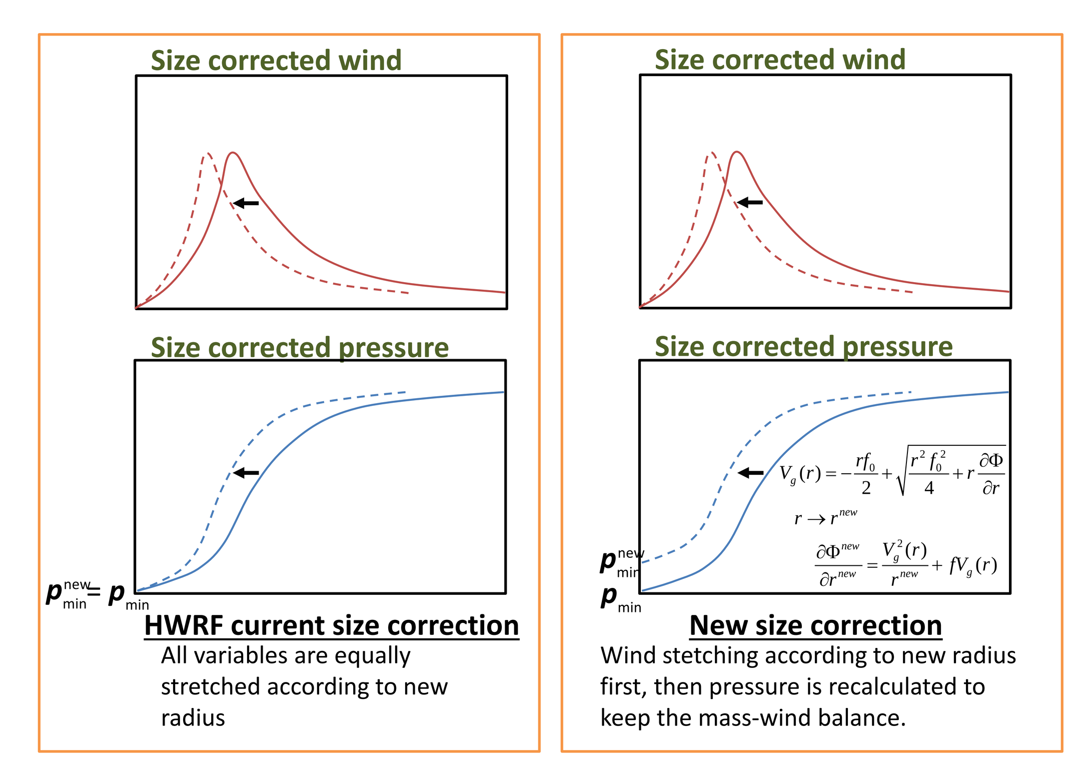


Fig 4. Diagram of pressure adjustment to keep the mass-wind balance

Intensity correction

1. Goepotential modification modification

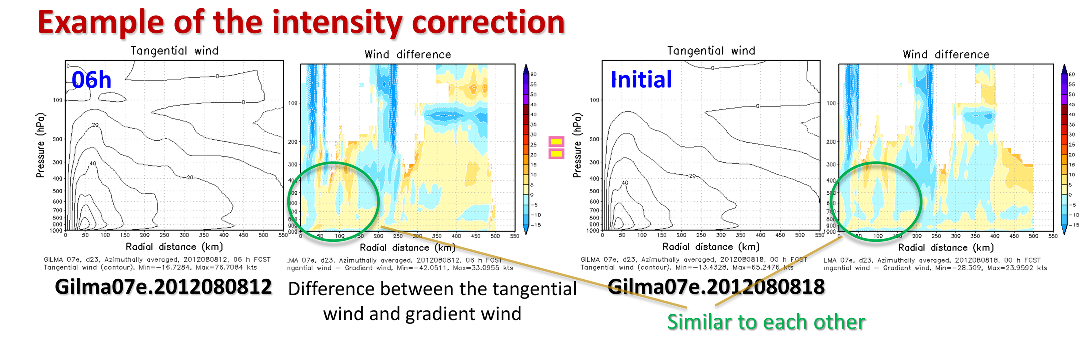
$$\Phi^{new} = \Gamma\Phi \qquad \Gamma = \frac{\Phi_b^{new}}{\Phi_b} = \frac{\int_\infty^r \left(\frac{\beta^2 V_t^2}{r} + f_0 \beta V_t\right) dr}{\int_\infty^r \left(\frac{V_t^2}{r} + f_0 V_t\right) dr}$$

β: Ratio of observed max. wind to model max. wind

2. wind modification

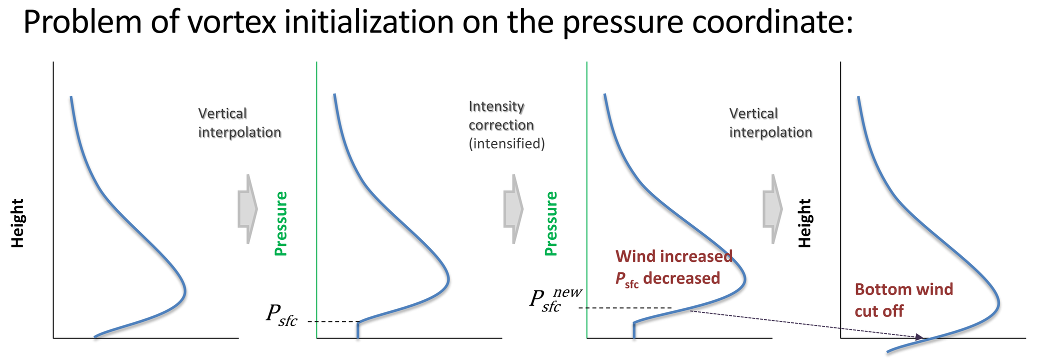
$$V_t^{new} = V_t \frac{V_g^{new}}{V_g} \qquad V_g^{new} = -\frac{rf_0}{2} + \sqrt{\frac{r^2 f_0^2}{4} + r\frac{\partial \Phi^{new}}{\partial r}} \qquad V_g = -\frac{rf_0}{2} + \sqrt{\frac{r^2 f_0^2}{4} + r\frac{\partial \Phi}{\partial r}}$$

Example of the intensity correction



Vertical stretching

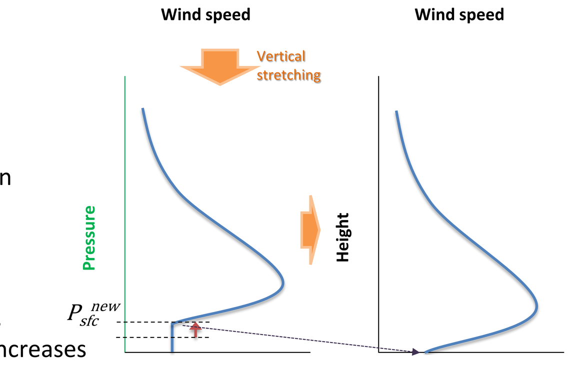
Problem of vortex initialization on the pressure coordinate:



Solution: Vertical stretching
: Wind at p_{sfc} is relocated to p_{sfc}^{new}
: When wind increases → Stretched up
: When wind decreases → Stretched down

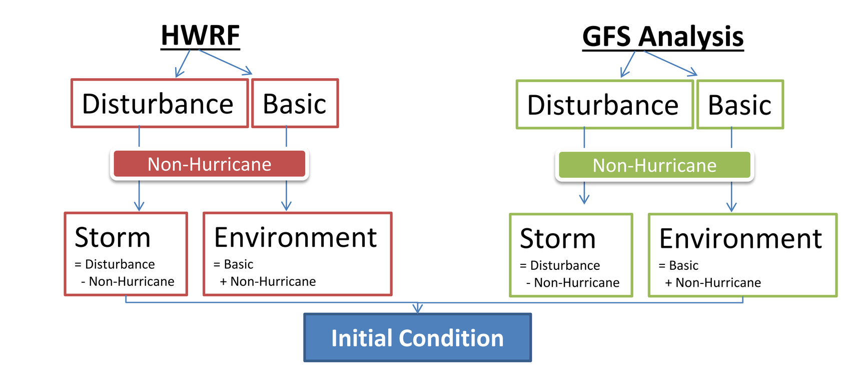
Benefit of the stretching

: If the first guess intensity is weaker than the observation, during the initialization,
: Warm core height rises as well as wind increases
- Favorable to the storm intensification

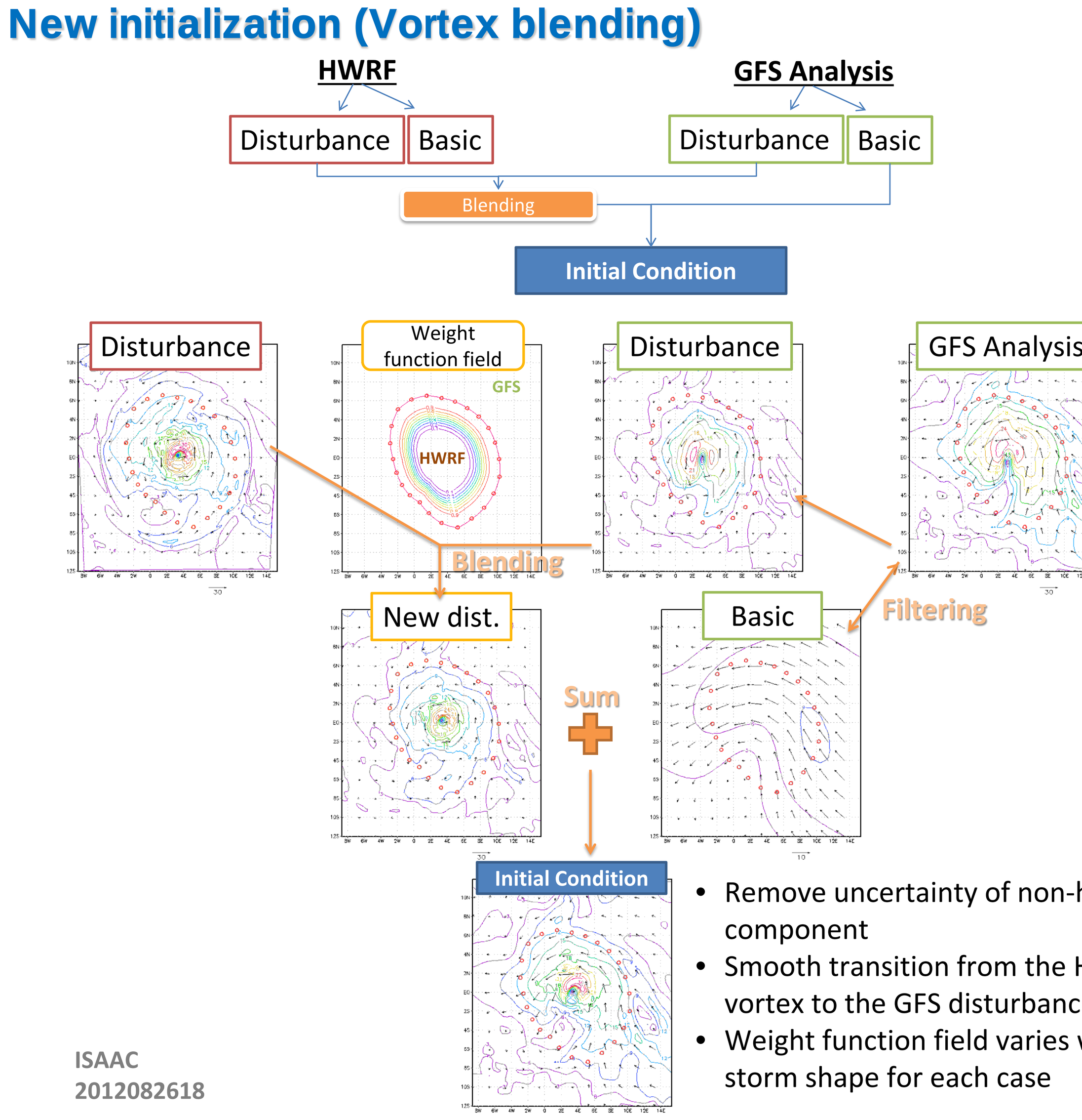


Vortex Blending

Operational initialization (Vortex replacement)



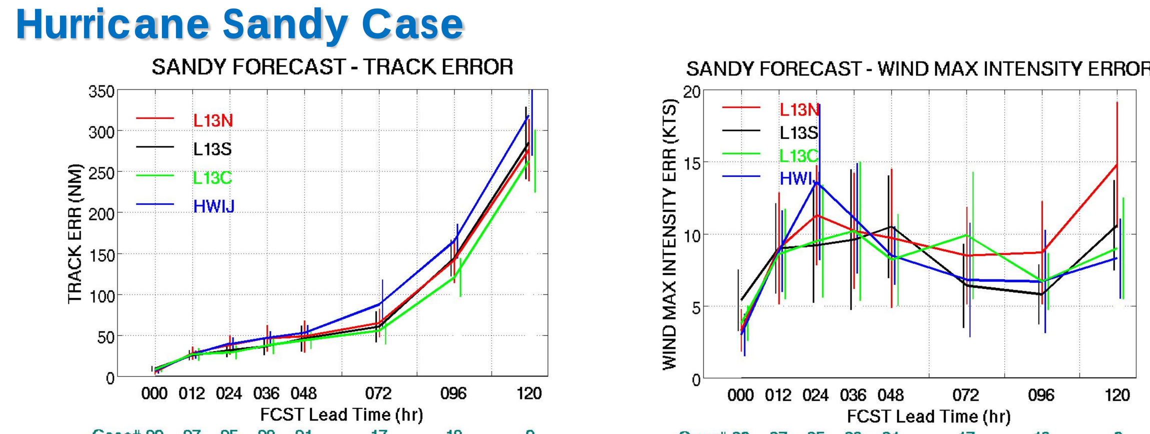
New initialization (Vortex blending)



- Remove uncertainty of non-hurricane component
- Smooth transition from the HWRF vortex to the GFS disturbance
- Weight function field varies with the storm shape for each case

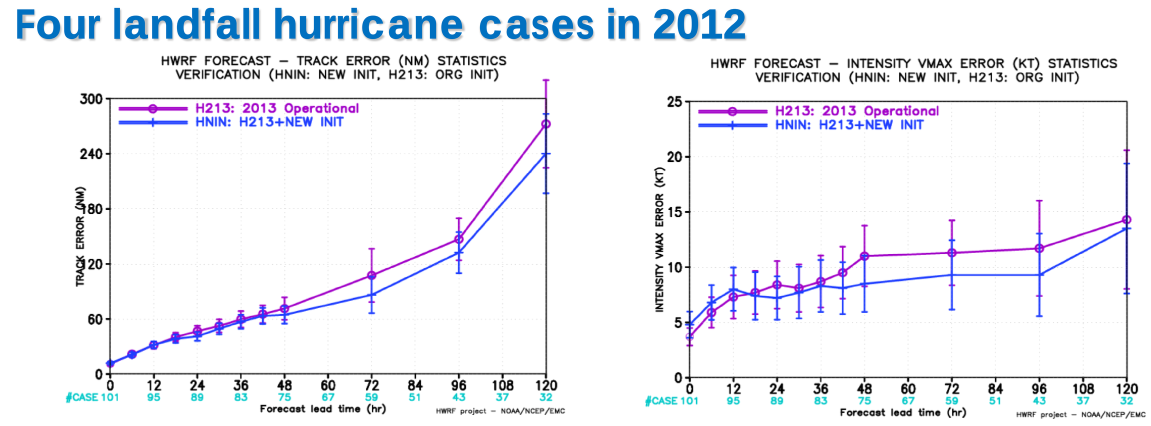
Results and Discussion

Hurricane Sandy Case



L13N: HWRF 2013 version , Pt=0.5hPa, Satellite, Operational initialization scheme
HWIJ: HWRF 2012 version, Pt=50hPa, No satellite, New initialization scheme
L13C: HWRF 2013 version, Pt=0.5hPa, Satellite, New initialization scheme
L13S: HWRF 2013 version , Pt=0.5hPa, Satellite, Iterative size and intensity correction

Four landfall hurricane cases in 2012



H213: HWRF 2013 version, Pt=50hPa, No satellite, Operational initialization scheme
HNIN: HWRF 2013 version, Pt=0.5hPa, Satellite, New initialization scheme

Discussion

- New initialization with HWRF 2013 outperforms others for both track and intensity forecast
- The number of cases is not big enough yet, more experiments will be performed later.