Introduction to the HWRF-based Ensemble Prediction System

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Outline

- Introduction to ensemble prediction system (EPS)
  - What and why ensemble prediction
  - Approaches to ensemble prediction
  - Hurricane ensemble prediction
- HWRF-based EPS
  - Methodology;
  - Ensemble vs. Deterministic;
  - Multi-Model Ensemble System;
  - Statistical Characteristics of HWRF EPS;
- 2015 HWRF EPS Products

What is an Ensemble Forecast ?

An ensemble forecast is simply a collection of two or more forecasts verifying at the same time. Ensemble forecast aims to estimate the probability density function of forecast states

Why do we need ensemble forecast ?

Uncertainties, or weak noises, acting upon a numerical weather prediction (NWP) model system can have far-reaching consequences due to its chaotic and nonlinear nature (Lorenz, 1963, 1965).

What are the main source of uncertainties ?

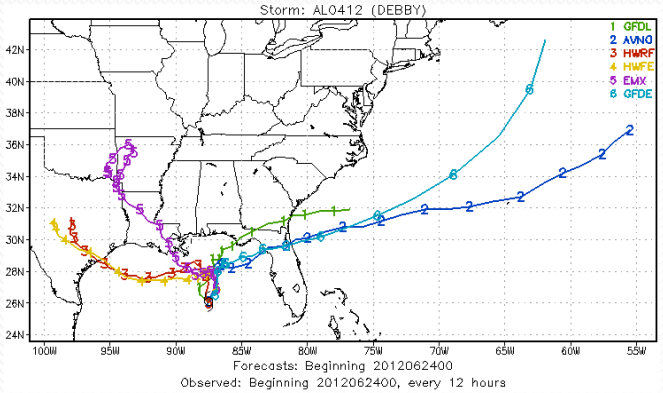
- *IC/BC uncertainties*: observational errors, poor data coverage, and errors in DA system;
- *Model uncertainties:* mis-representation of model dynamics/physics, impact of sub-grid scale features.

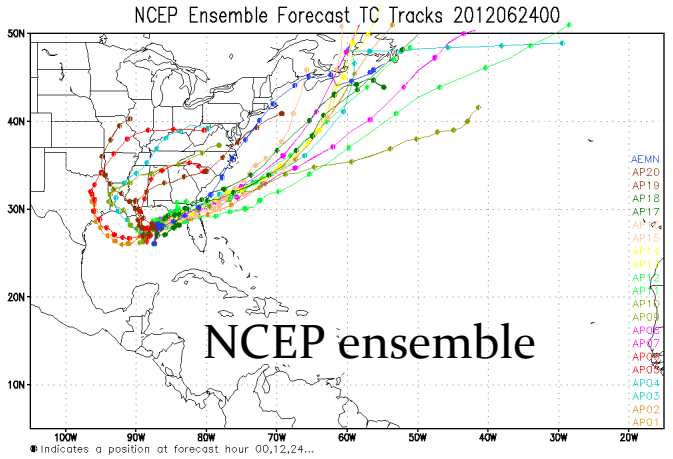
These uncertainties are inevitable. In a chaotic system like an atmospheric model, non linear errors will grow - sometimes rapidly. Eventually these growing errors cause the model forecast output to eventually become useless.

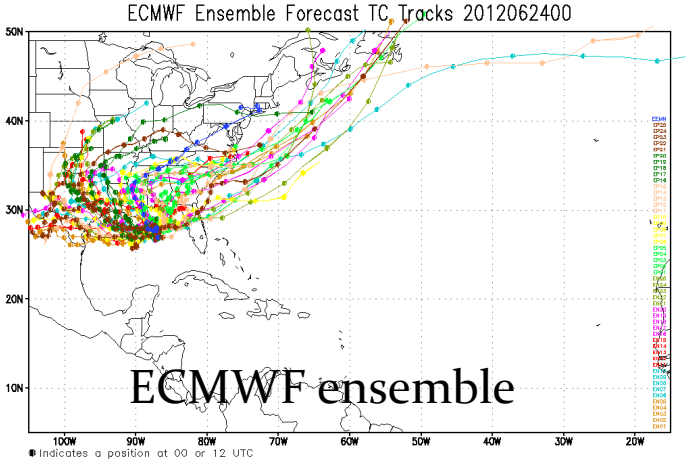
Track Prediction for Hurricane Debby, 20120624 00Z

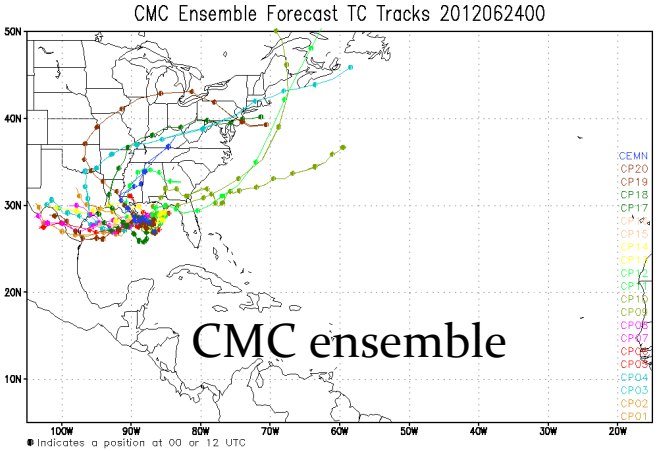
Large differences in predicted storm tracks due to:
1. multi-model dynamics;
2. multi-physics;
3. multi-initial analysis.

Multi-model





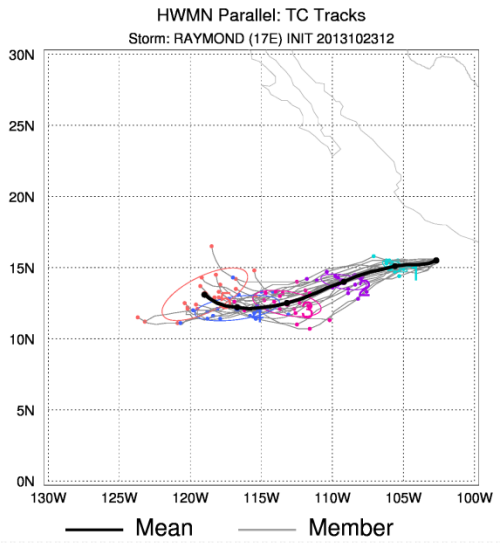


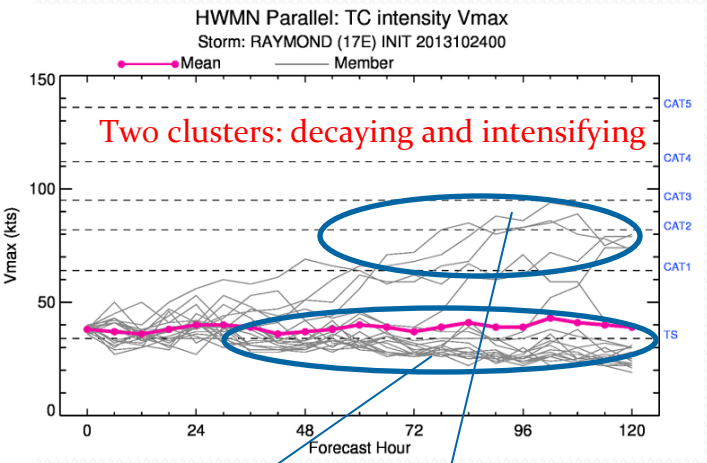


Prediction for Hurricane Raymond, 20131024 00Z

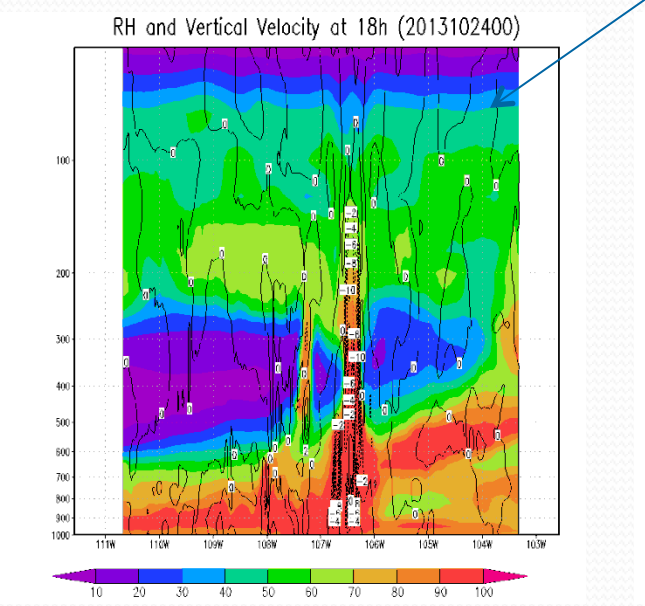
Large differences in predicted storm intensity due to sub-grid uncertainties in model physics: stochastically perturbed cumulus convection scheme in HWRF

Dry air at mid-level suppressed storm development in one member, while active convective cells overcome the dry air, storm intensified in anther member.

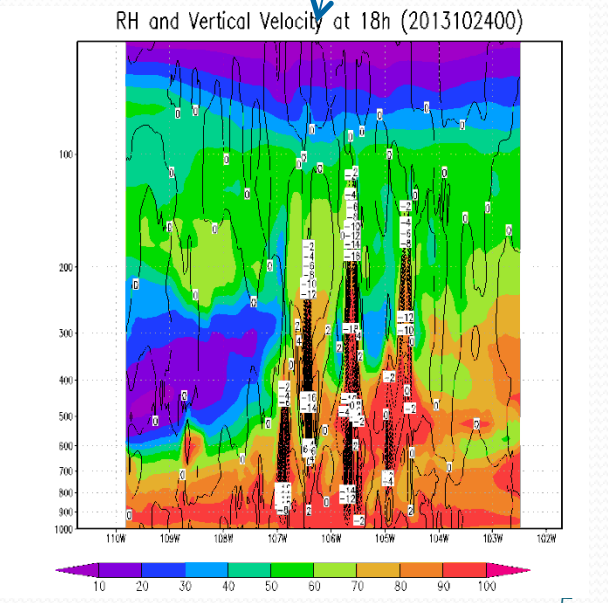




HW06



HW10



Approaches to Ensemble Prediction

- Monte Carlo Approach ---- not practically possible

  sample all sources of forecast error, perturb any input variable and any model parameter that is not perfectly known. Take into consideration as many sources as possible of forecast error.

- Reduced Sampling ----- limited resource

  Sample leading sources of forecast error. Rank error sources, prioritize, optimize sampling: growing components will dominate forecast error growth, important model physics, etc..

- Existing Methods
  - Initial uncertainties: SV-based ensemble (ECMWF), EnKF-based ensemble (MCS), BV-based ensemble (NCEP), ETKF-based ensemble (UKMet), ETR-based ensemble (NCEP), EOF-based ensemble (hurricane).
  - Model uncertainties: Multi-model ensemble; Single model with multi-physics.

- Desired Ensemble Perturbations

  Growing modes, Orthogonality, No bias, Mimic analysis errors and/or model errors.

HWRF-based Ensemble Prediction System

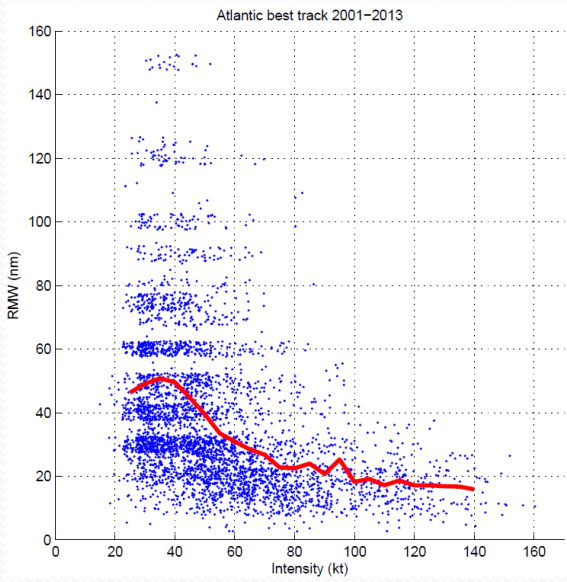
Considerations for Hurricane EPS:

1. Uncertainties in initial storm position, intensity, and structure;
2. Uncertainties in large scale flows (ICs/BCs);
3. Multi-scale interactions among sub-grid scales, (~0-100m), convective clouds (~100-1000m), and the large-scale environment (~100-1000km)

2015 HWRF ensemble Configuration

- Use 2015 operational deterministic HWRF model except for
  - Less horizontal resolution: 27/9/3km vs. 18/6/2km
  - Less vertical resolution: L43 vs. L61;
  - No GSI due to lack of GDAS data;
- IC/BC Perturbations (large scale): 20 member GEFS.

- Model Physics Perturbations (vortex scale):
  - Stochastic Convective Trigger in SAS: -50hPa to + 50hPa white noise ;
  - Stochastic boundary layer height perturbations in PBL scheme, -20% to +20%;
  - Stochastic Cd perturbation;
  - Stochastic initial wind speed and position (TCVital) perturbations considering best track uncertainty (Ryan Torn)



Convective Trigger Function Perturbation

- Convective Trigger function in Current HWRF Cumulus Parameterization Scheme (SAS: Simplified Arakawa-Schubert)

  P_{CSL}-P_{LFC} <= DP(w) Convection is triggered,

  P_{CSL}-P_{LFC} > DP(w) No sub-grid convection

  P_{CSL}: Parcel pressure at Convection Starting Level,

  P_{LFC}: Parcel pressure at Level of Free Convection

  DP(w): Convective Trigger, which is function of large scale vertical velocity w.

DP(w) is arbitrarily confined between 120hPa-180hPa

- Storm intensity (Max Wind Speed) is found very sensitive to the convective trigger function;
- Necessary to introduce fuzzy logic trigger to represent sub-grid features.

Run HWRF based EPS: parm/hwrf_ensemble.conf

```
[config]
run_gsi=no                ; Turn off GSI
use_spectral=no           ; Use GRIB2, GEFS has no spectral files;
run_ensemble_da=no  ; conflicts with forecast ensemble
is_forecast_ensemble=yes
archive=hpss:/NCEPDEV/emc-hwrf/1year/{ENV[USER]}/{SUBEXPT}/{ENS}/
    {out_prefix}.tar

[ensemble]
ensize=20         ; number of ensemble members (should match GEFS)
pertmethod=1 ; 1. Vmax pert. only, 2. new init. by Ryan
vmax_pert=3 ; m/s maximum perturbation in tcvitals
tcvitals_seed=auto ; automatically decide a seed from cycle and storm
```

Run HWRF based EPS:

parm/hwrf_ensemble.conf

```
[ungrib]
dataset = gefs                                  ; use GEFS data
subset_grib1 =
item = gep_2a                                   ; GEFS member 01-20
item2 = gep_2b
item_E00 = gec_2a                               ; GEFS member 0
item2_E00 = gec_2b
tbl = {PARMhwrf}/hwrf_Vtable_gefs2012    ; use GEFS Vtable

[wrf]
metgrid_soil_levels=4

[wrf_namelist]

physics.pert_sas=.true.                         ; Turn on SAS perturbation;
physics.pert_pbl=.true.                         ; Turn on PBL perturbation;
physics.pert_Cd=.true.                          ; Turn on Cd perturbation;
physics.ens_pblamp=0.2                          ; Max stochastic PBL perturbation (100%);
physics.ens_sasamp=50.0                         ; Max stochastic SAS perturbation (hPa);
physics.ens_Cdamp=0.2                           ; Max stochastic Cd perturbation.  (100%)
physics.ens_random_seed={ENS}
```

Run HWRF based EPS: (Using GFS input) parm/hwrf_ensemble.conf

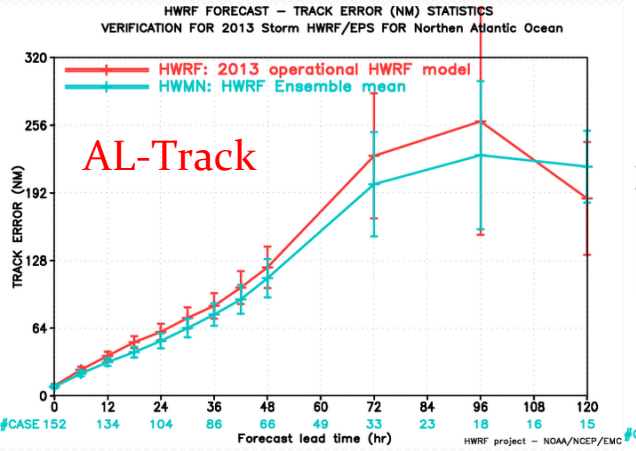
1. Specify GFS data path for parameter gefs in hwrf_input.conf;
2. Change file name convection from GEFS to GFS in hwrf_input.conf;
3. Include following section in configuration file:

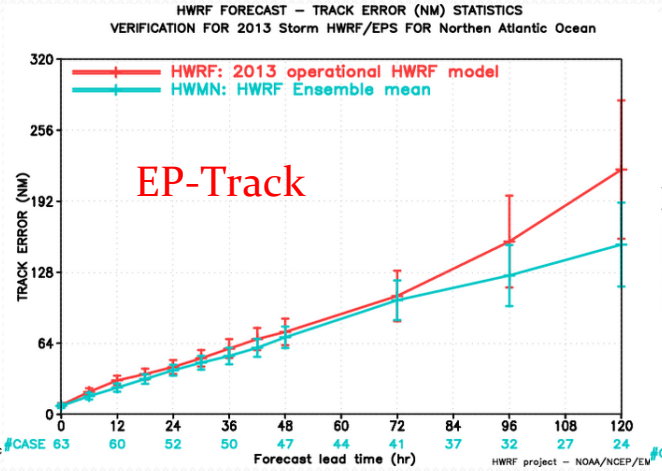
```
[ungrib]
dataset = gfs                                   ;; Dataset for hwrf.input to find files
subset_grib1 = {PARMhwrf}/hwrf_global_1x1_paramlist.foo
tbl = {PARMhwrf}/hwrf_Vtable_gfs2014            ;; The Vtable file for Geogrid
item2_optional=yes                              ;; Is the second GRIB file type optional?
item = gfs_gribA                                ;; item (grib file type) for the hwrf.input
item2 = gfs_gribB                               ;; second GRIB file item for hwrf.input
item_E00 = gfs_gribA
item2_E00 = gfs_gribB
tbl2011 = {PARMhwrf}/hwrf_Vtable_gfs2012
```

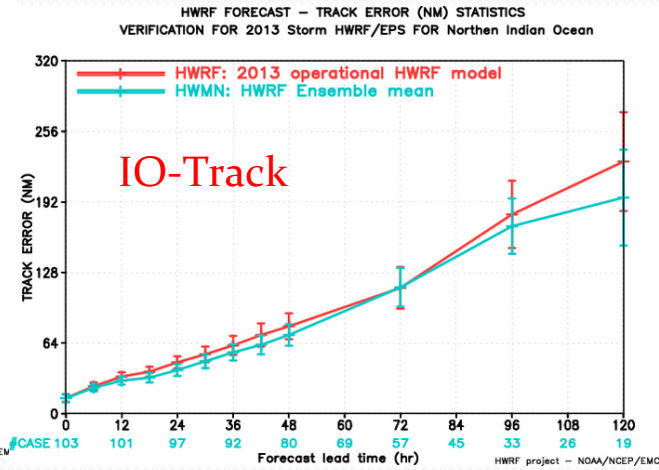
Run HWRF ensemble:

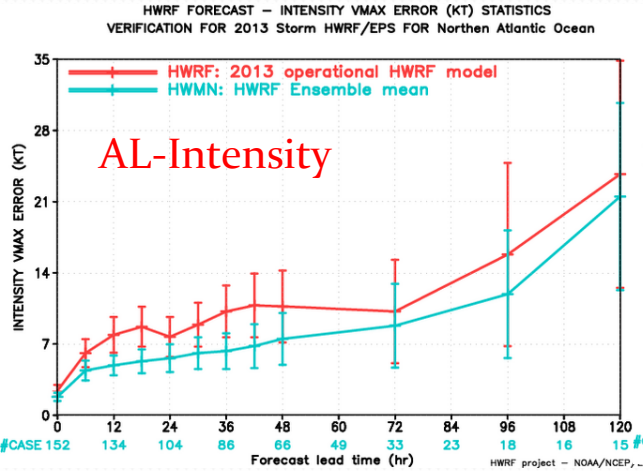
```
./run_hwrf.py -f 00-20 2015 11L ../parm/hwrf_ensemble.conf
```

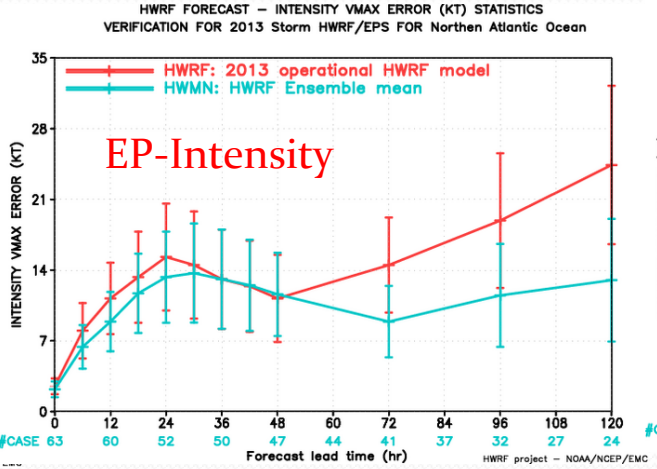
Verification for 2013 Storms

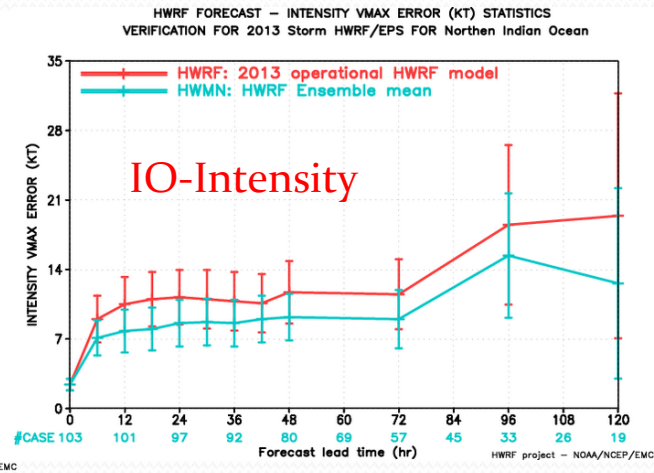






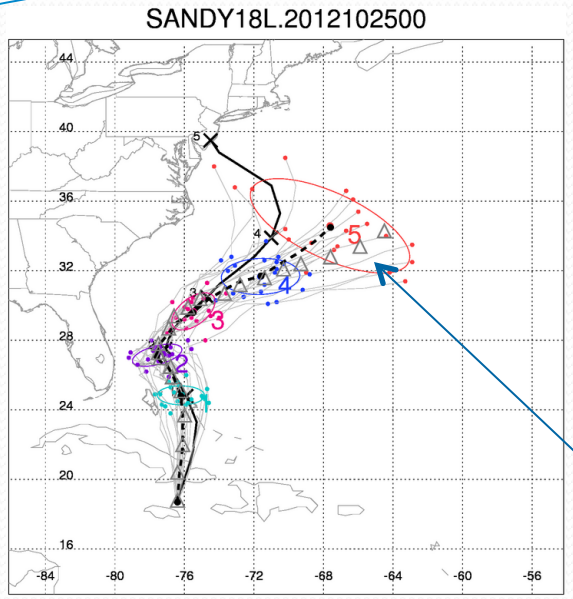




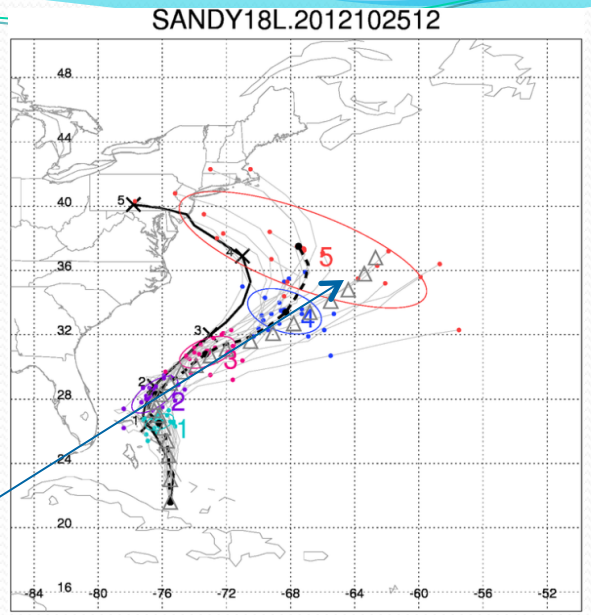


Track Probability Forecasts for Hurricane Sandy

Few members turned west

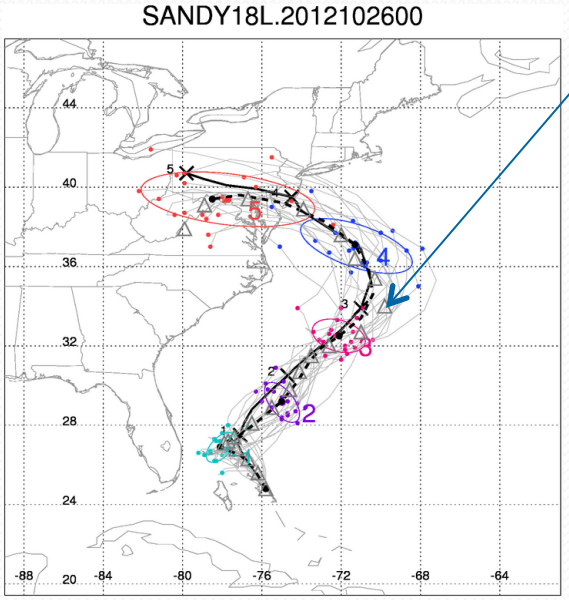


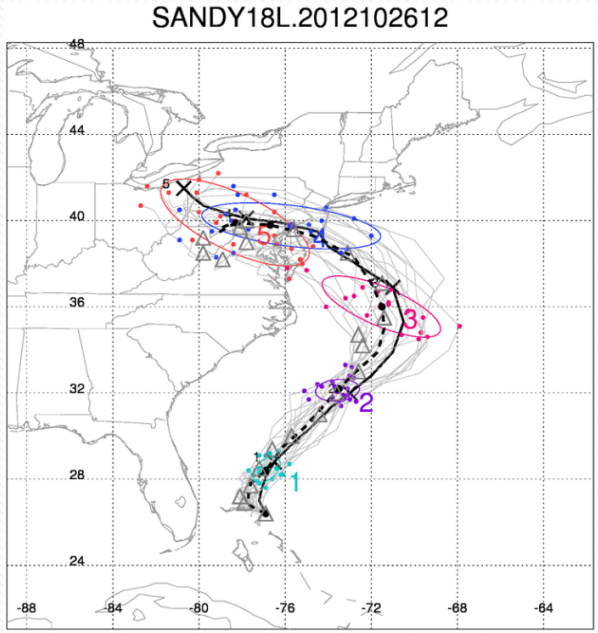
More members turned west



FY13

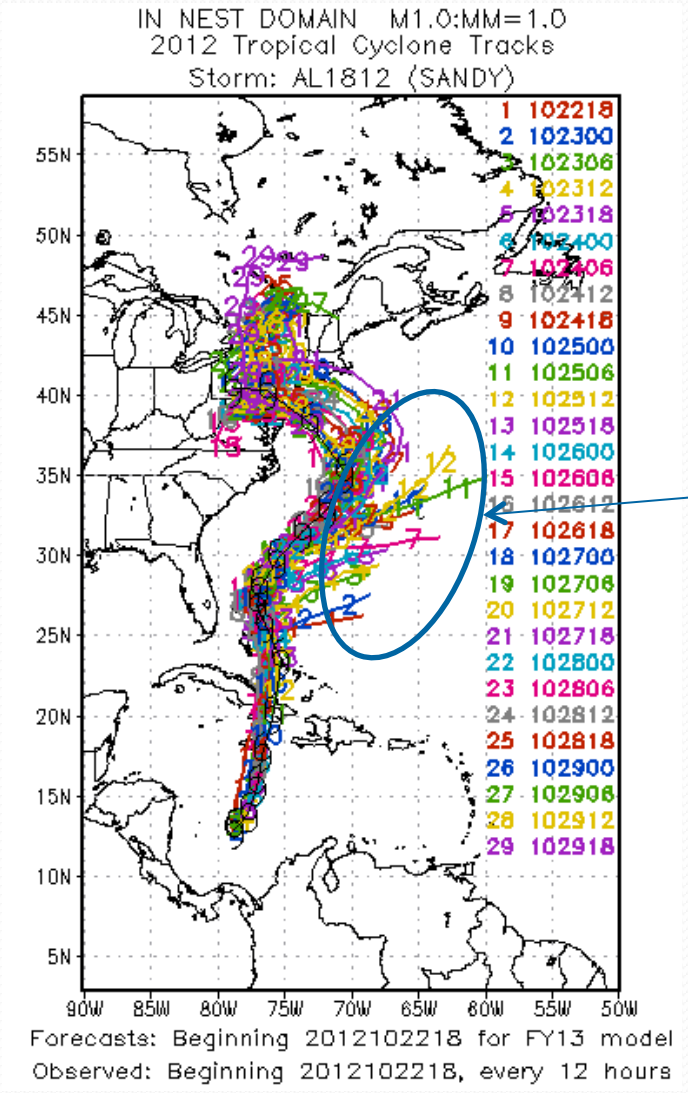
All members turned west



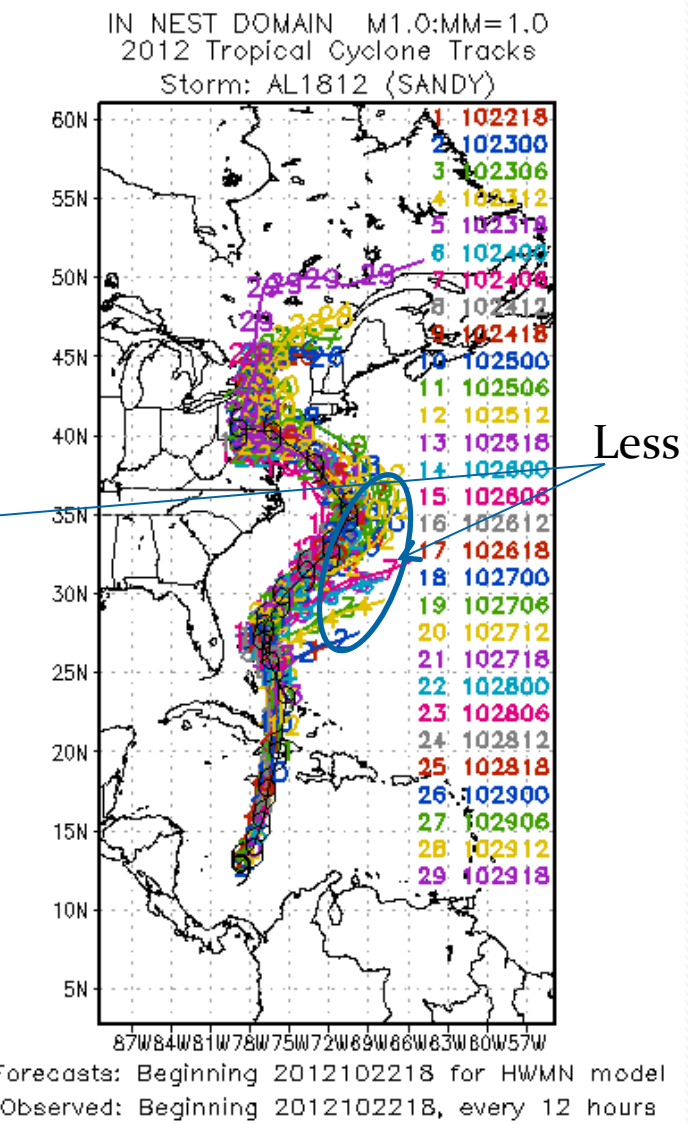


Spaghetti Plots Comparison for Track Forecasts Sandy, 2012

FY13



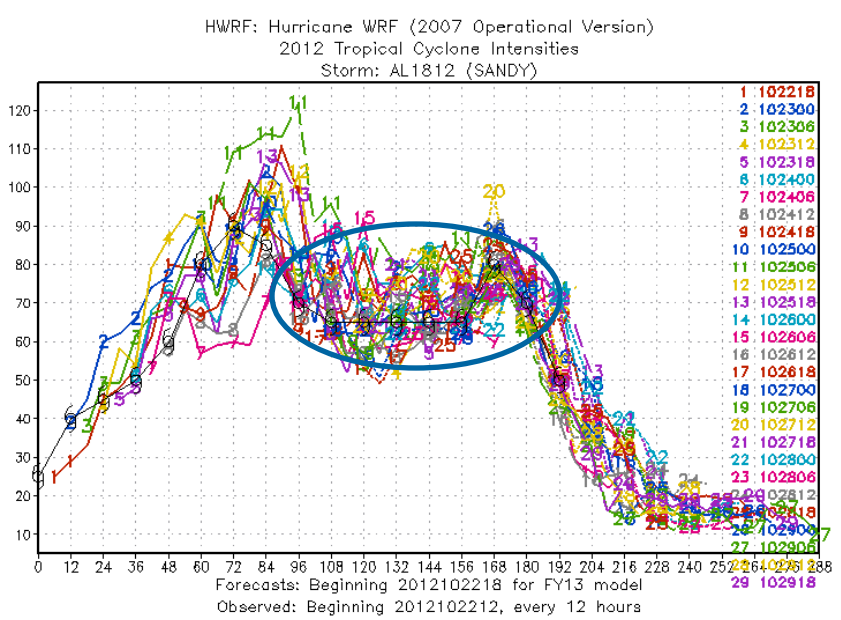
HWMN



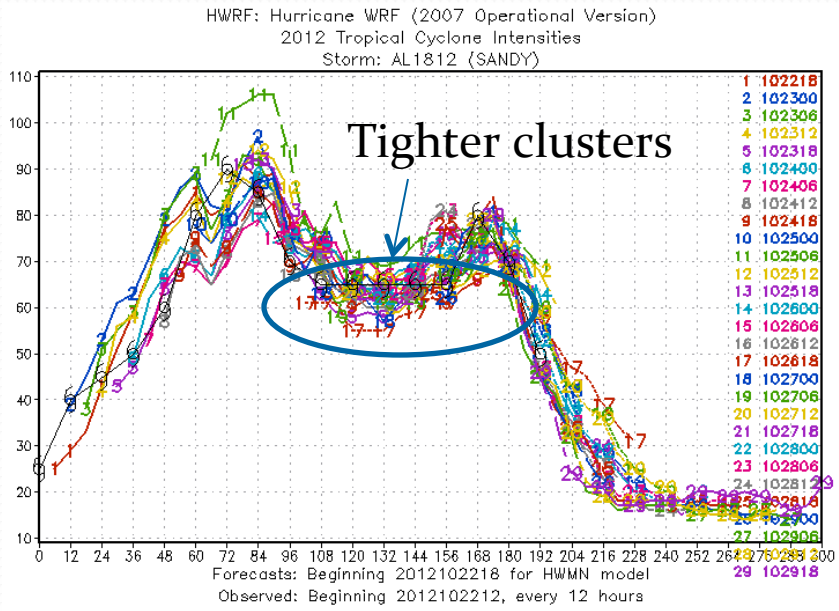
Less outliers

Spaghetti Plot Comparison for Intensity Forecasts Sandy, 2012

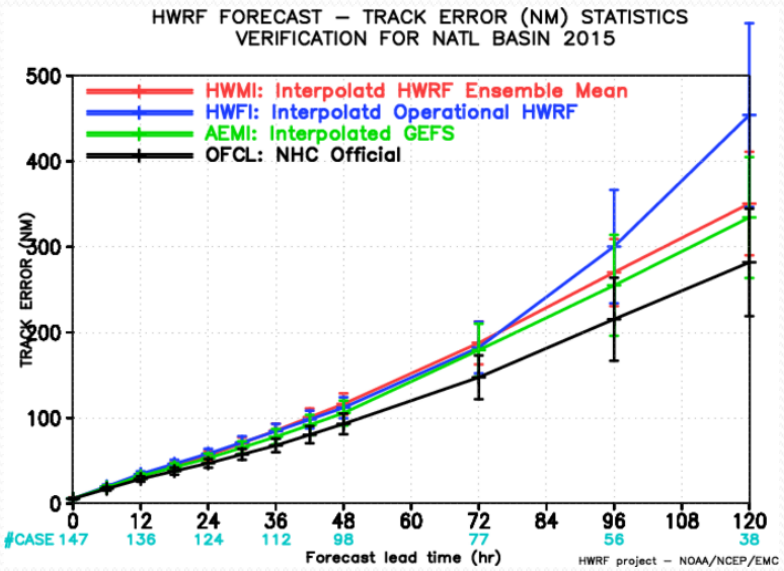
FY13

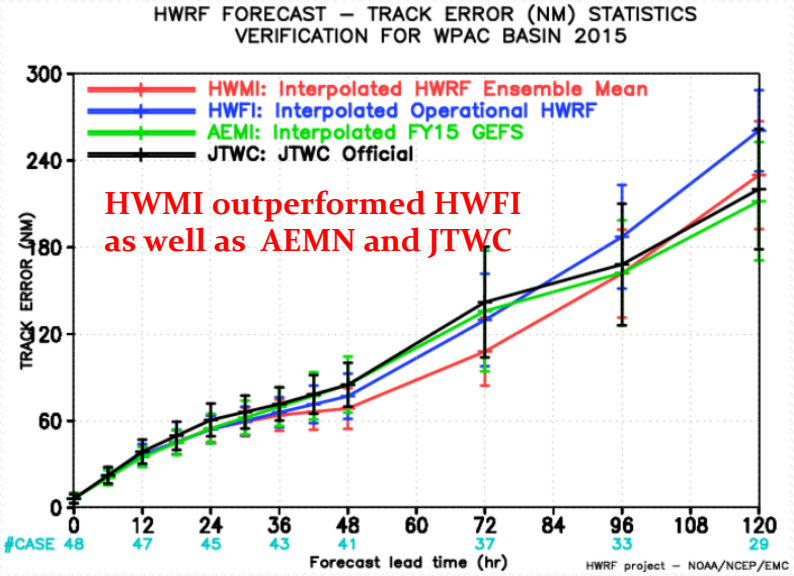


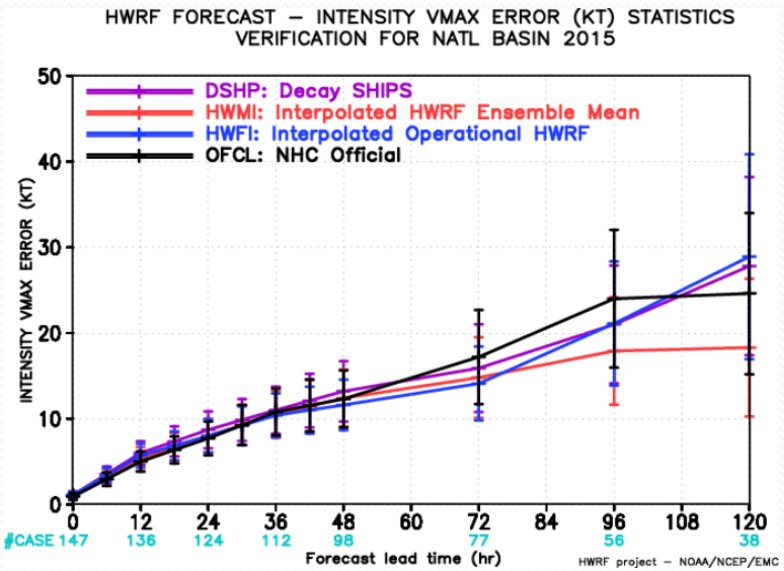
HWMN

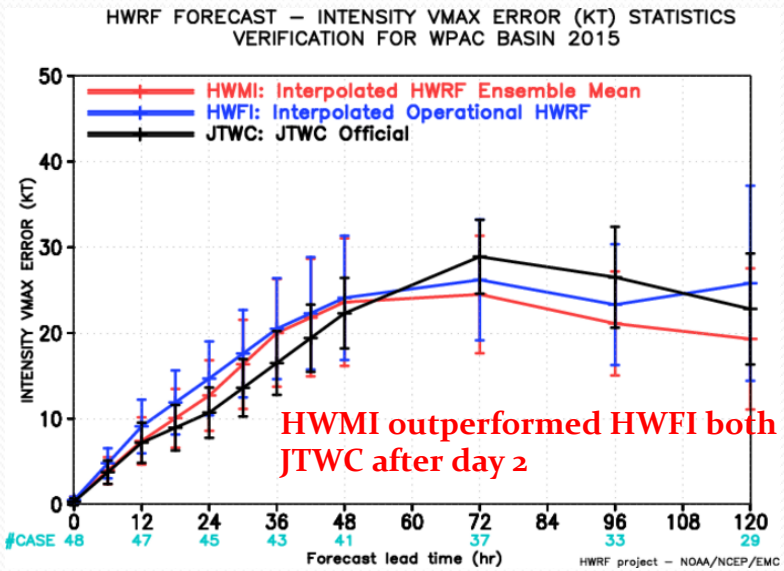


Verification for 2015 NATL/WPAC Storms



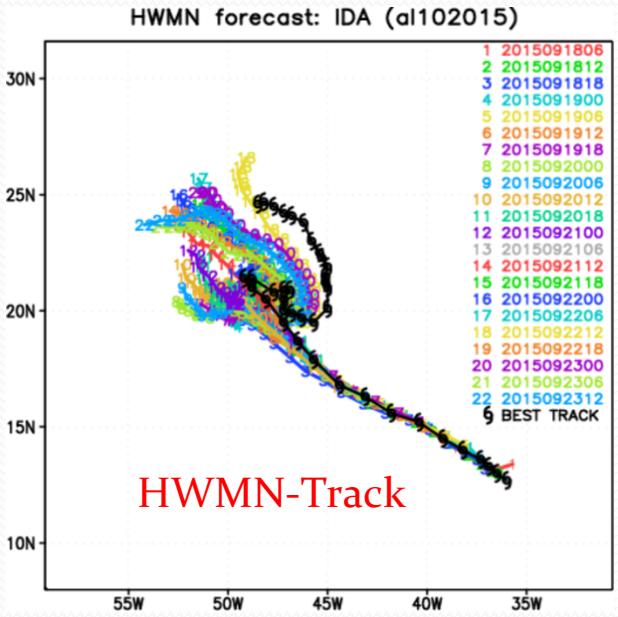


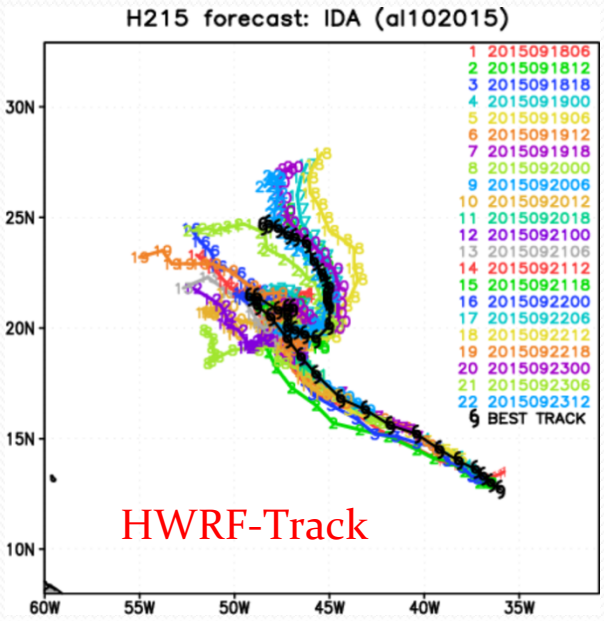


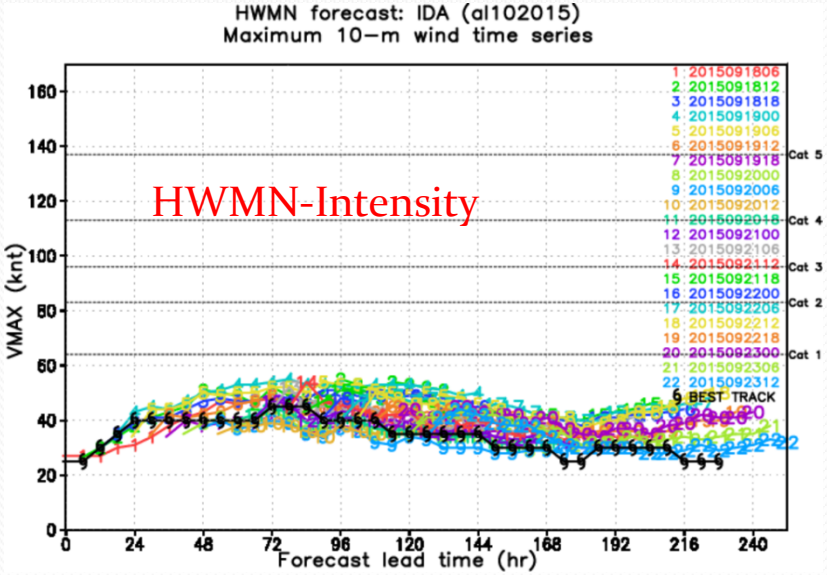


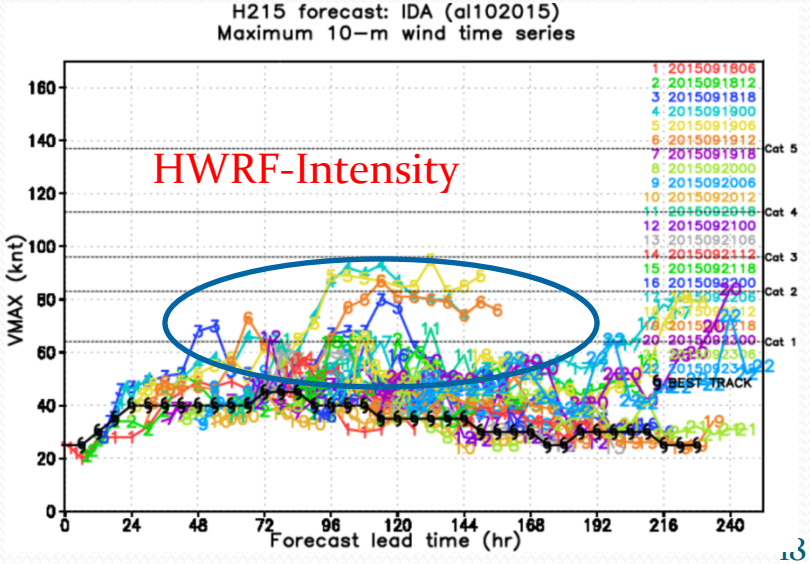
Deterministic vs Ensemble

IDA 10L, 2015



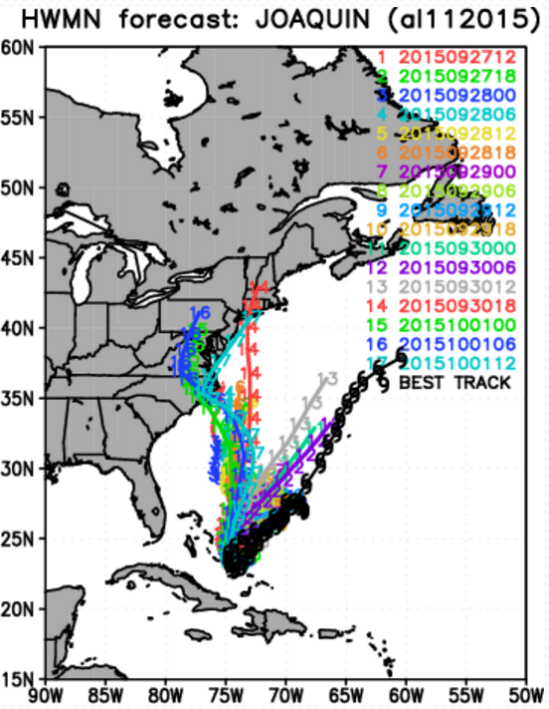




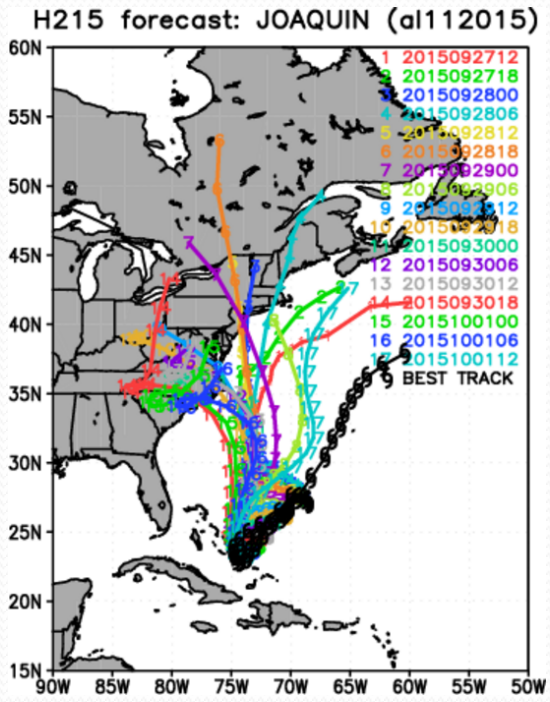


Deterministic vs Ensemble

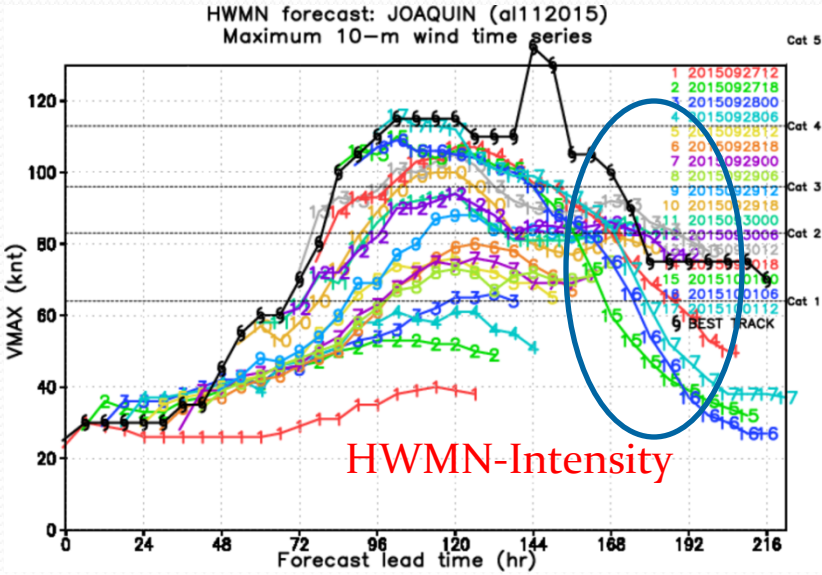
Joaquin 11L, 2015

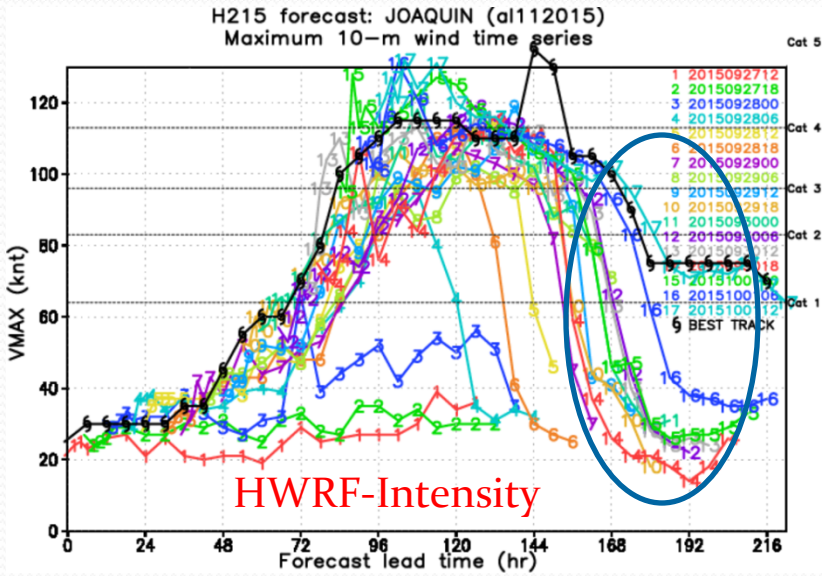


HWMN-Track



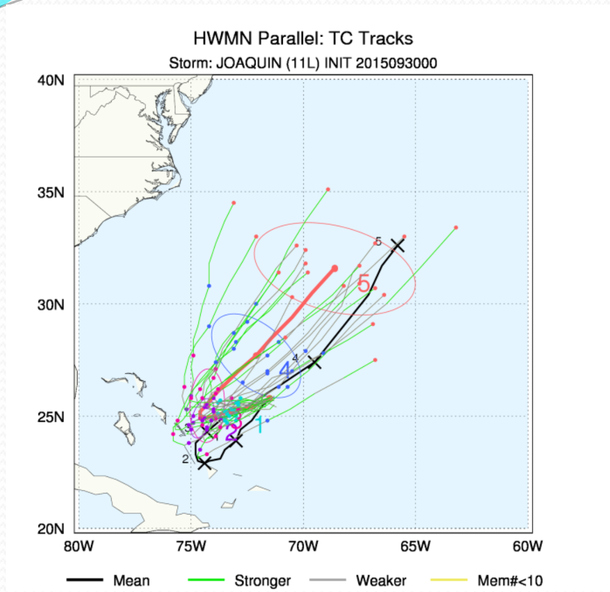
HWRF-Track

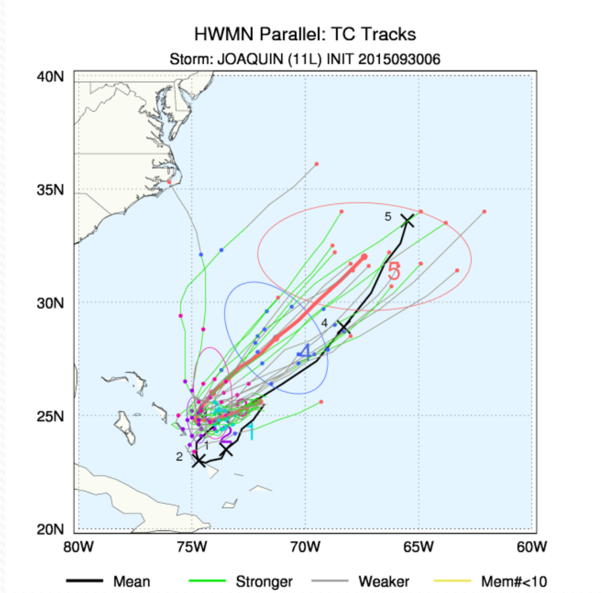


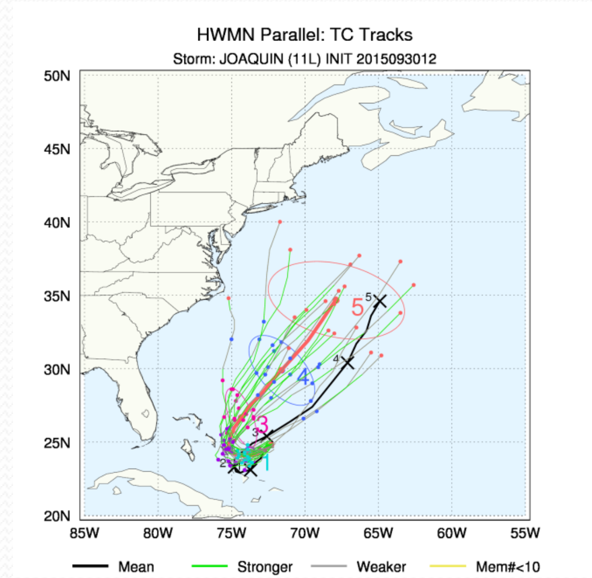


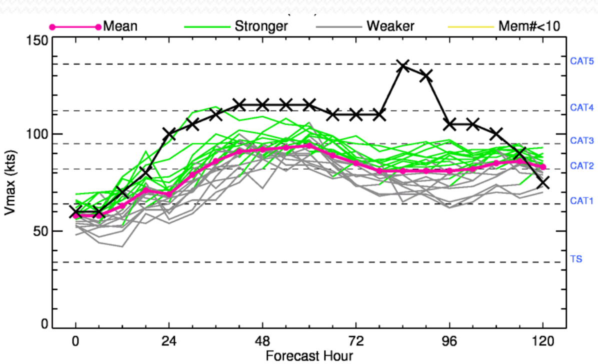
1. HWMI had better track forecasts than its deterministic version;
2. Higher resolution EPS needed to predict better in RI;
3. Ensemble has smaller intensity forecasts errors in later forecast hours

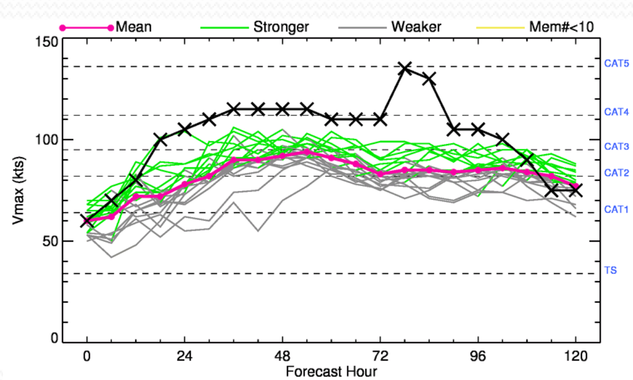
Sample HWRF-EPS Forecast
Joaquin 11L, 20150930

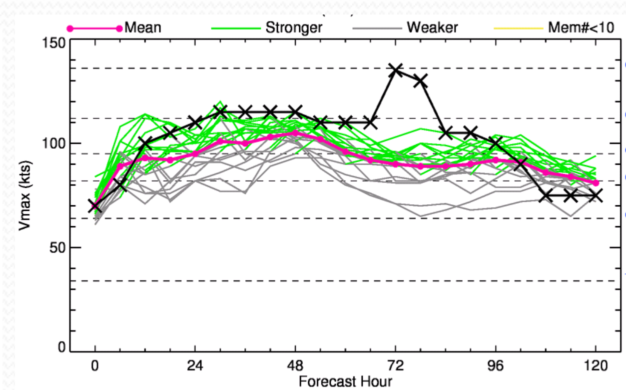










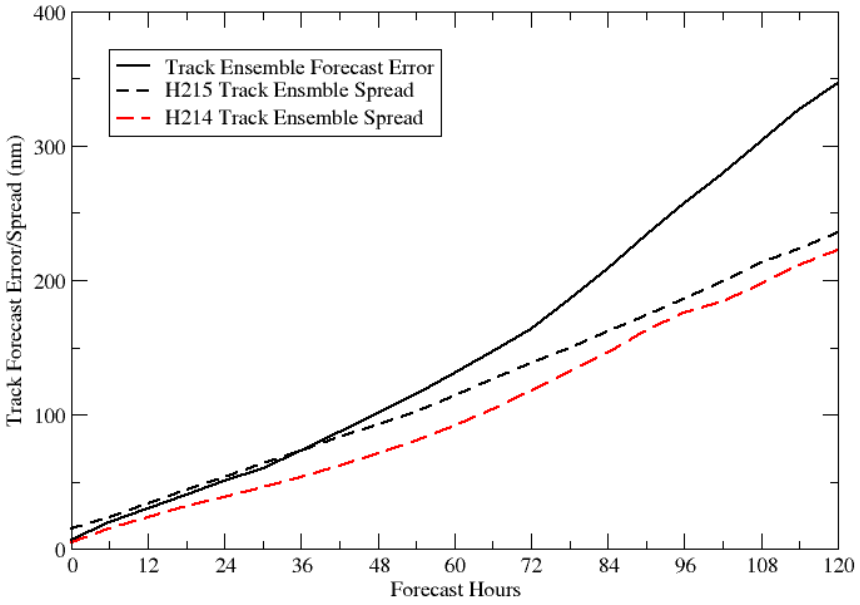


00Z 06Z 12Z

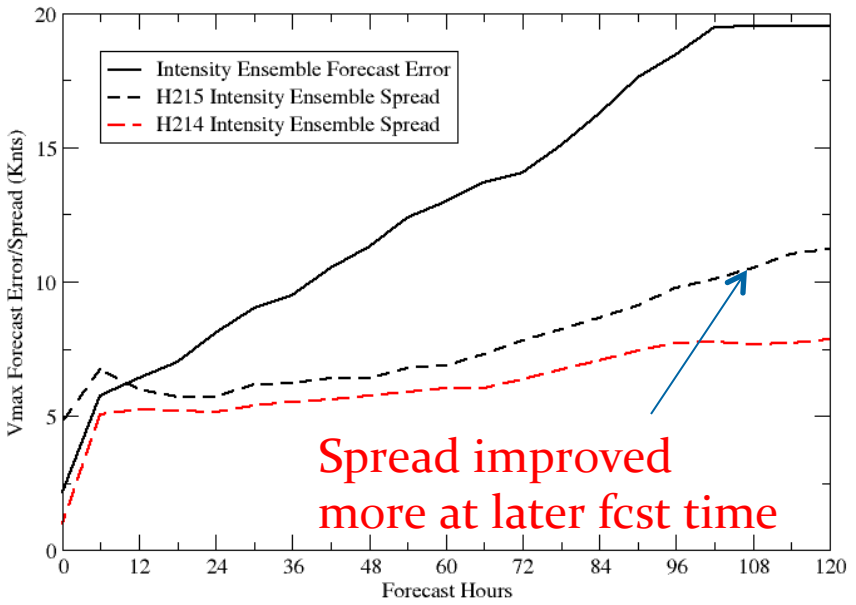
Forecast Errors vs Ensemble Spread

All 2015 AL Storms

Track



Intensity



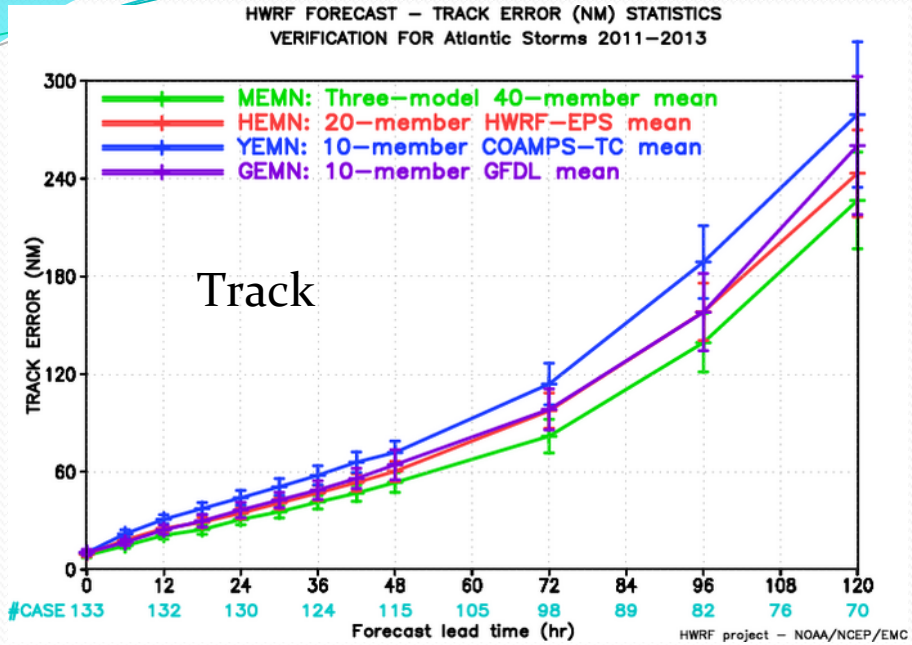
H215 ensemble spread is improved over H214, although still under-dispersion in terms of both track and intensity

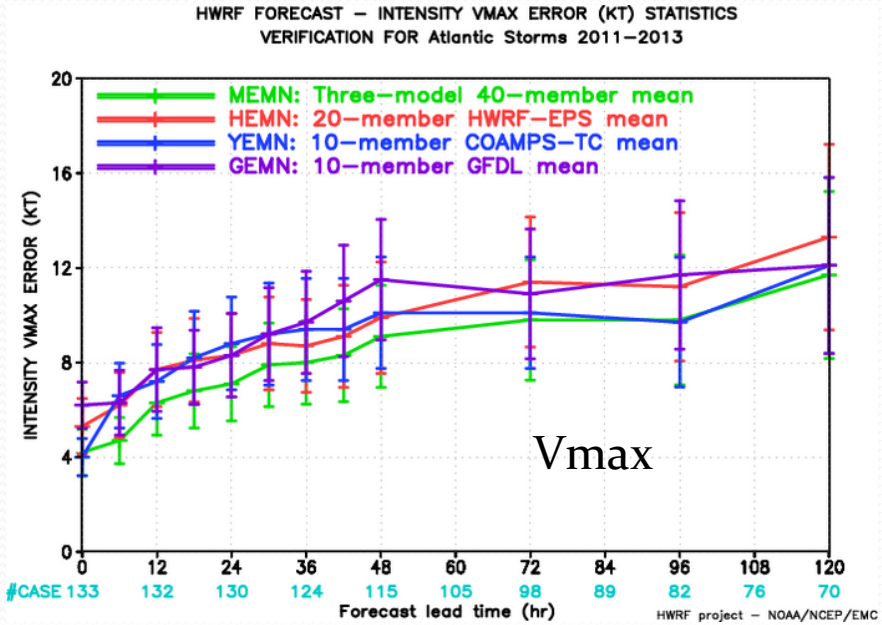
Combined Multi-Model EPS

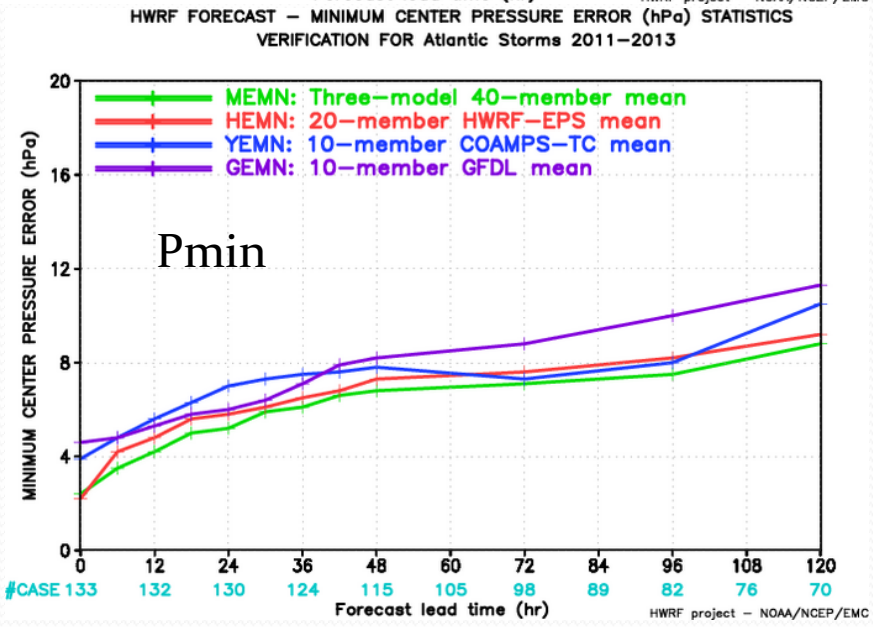
- 20-member 3km HWRF ensembles driven by GEFS for IC/BC and stochastic convective and PBL perturbations
- 10-member 3km COAMPS-TC ensembles driven by IC/BC perturbations based on GFS analysis & tcvitals
- 10-member 9km GFDL ensembles with vortex scale inner-core perturbations
- High-resolution probabilistic products provide forecast uncertainty in track, intensity, structure (size) and rainfall, along with ensemble mean products

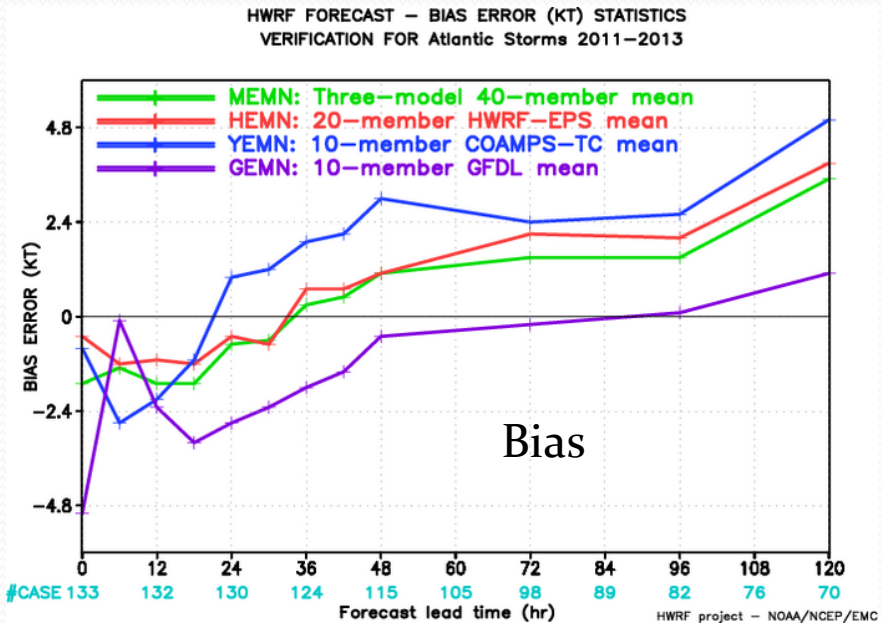
Multi-Model Ensemble Verification

(Retrospective runs 2011-2013)

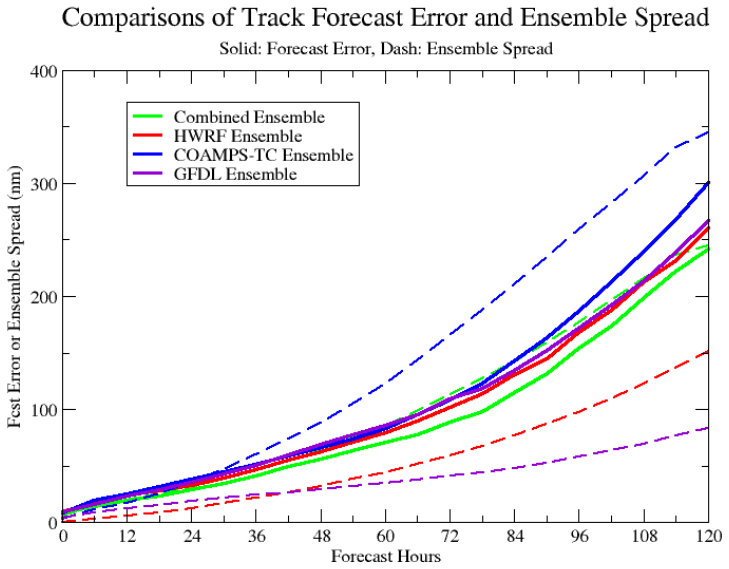


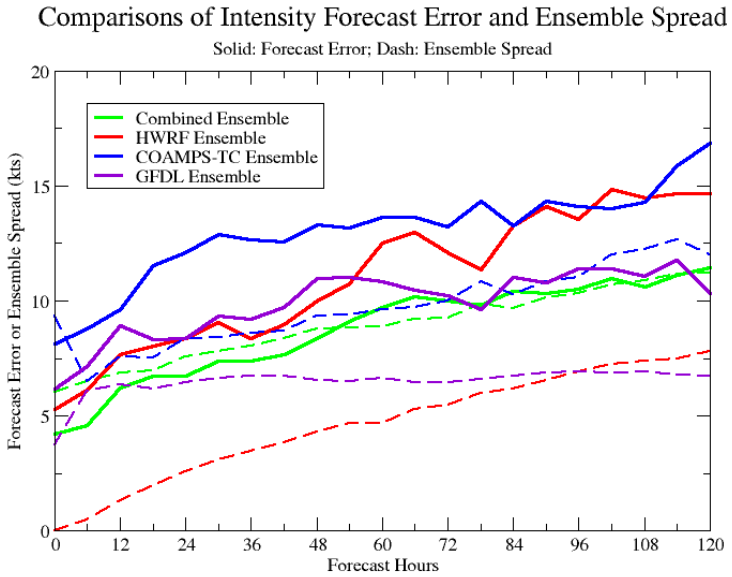






Ensemble Forecast Error vs. Ensemble Spread





Combined ensemble track forecasts have:

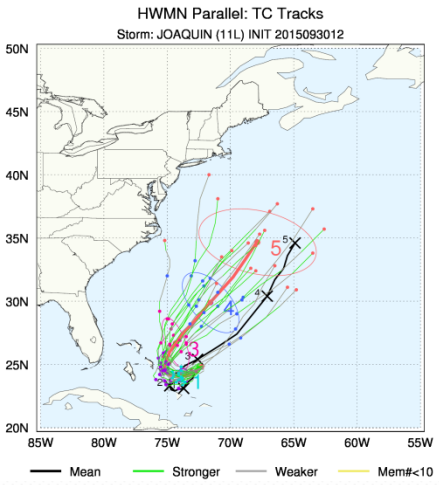
1. lowest track forecast errors;
2. adequate ensemble track spread.

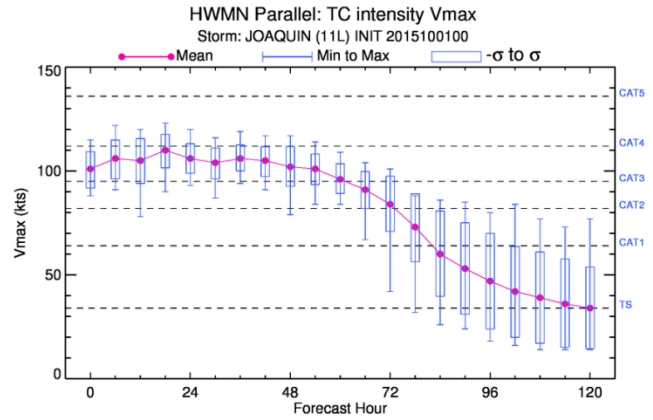
1. Even though HWRF ensemble spread has fast growth rate, it is much smaller than its forecast error because of zero spread at the initial time. This is corrected by adding intensity uncertainties at initial time now.

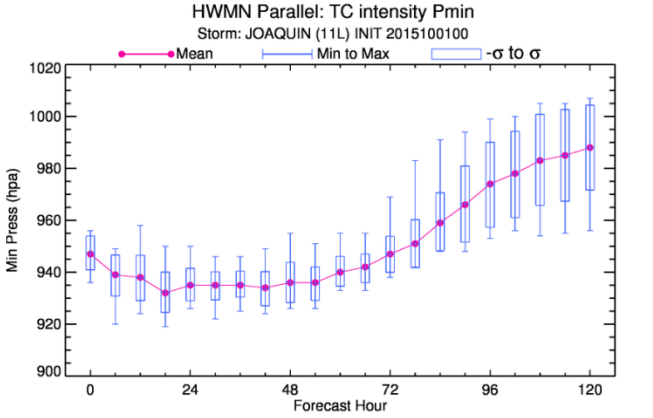
2. Combined forecast errors are close to the combined ensemble spread.

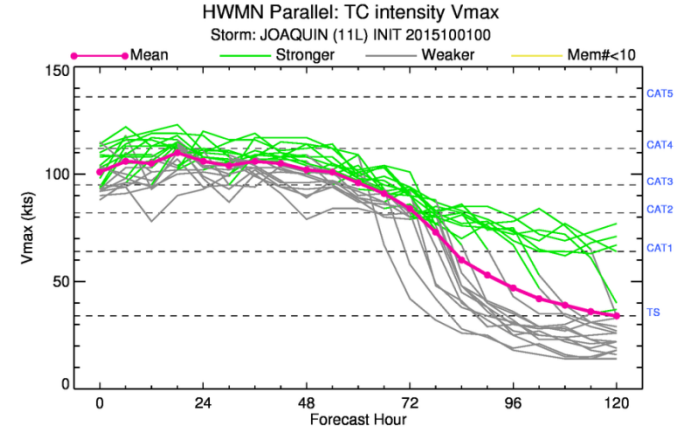
Probabilistic Forecast Products of 2015 HWRF based EPS

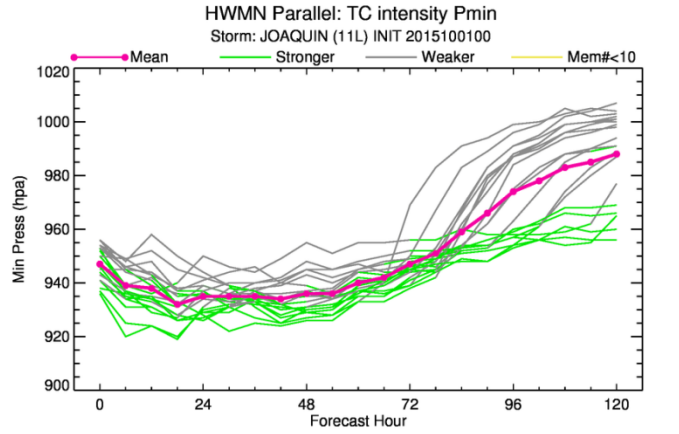
Individual Track/Intensity Forecasts of HWRF Based EPS



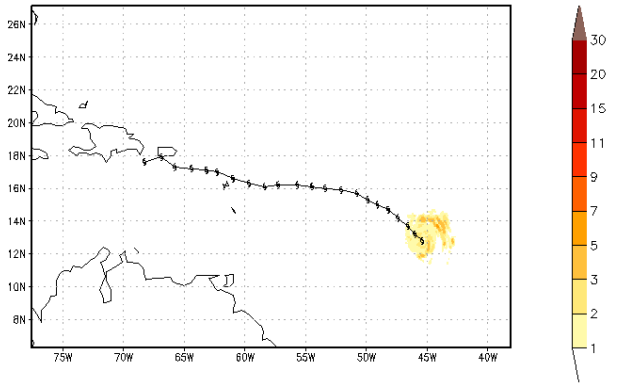




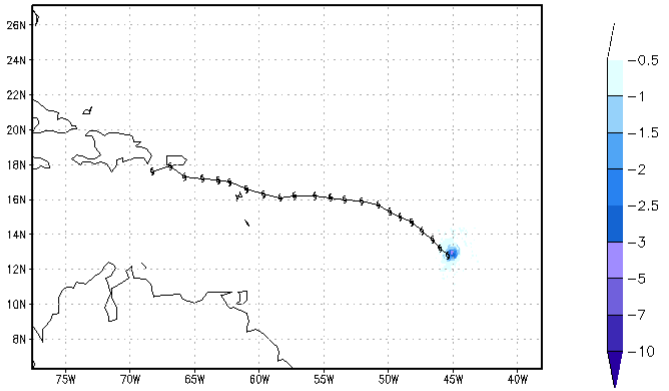




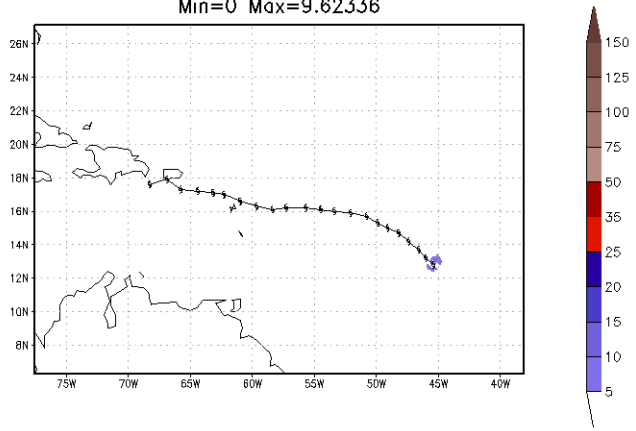
Max W below 400hpa (m/s) 2015082018-04I F001
Min=0 Max=6.35015



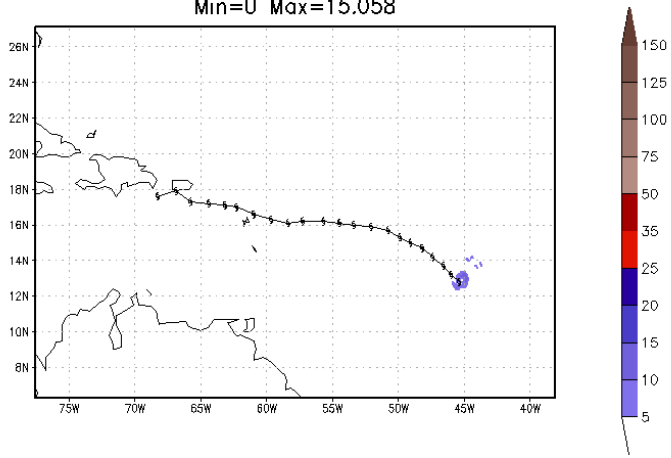
Min W below 400hpa (m/s) 2015082018-04I F001
Min=-4.21236 Max=0



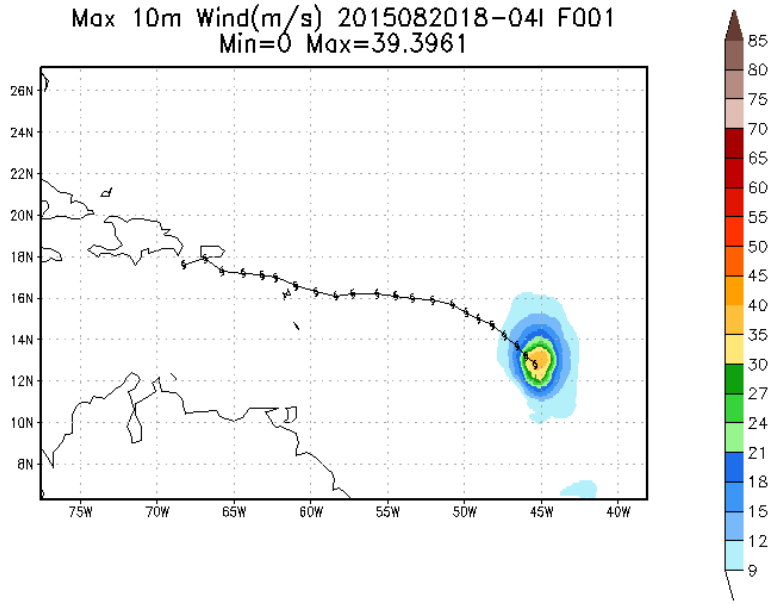
Max 0-3km updraft Helicity (m2/s2) 2015082018-04I F001
Min=0 Max=9.62336

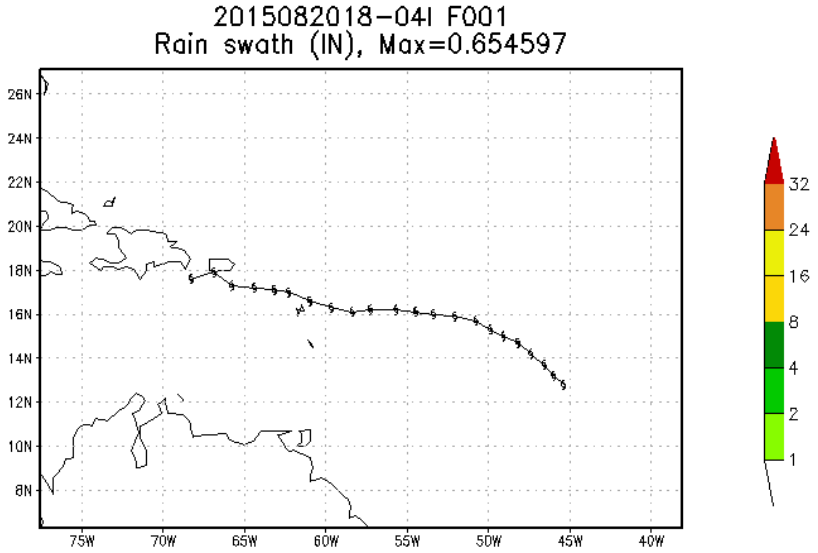


Max 2-5km updraft Helicity (m2/s2) 2015082018-04I F001
Min=0 Max=15.058

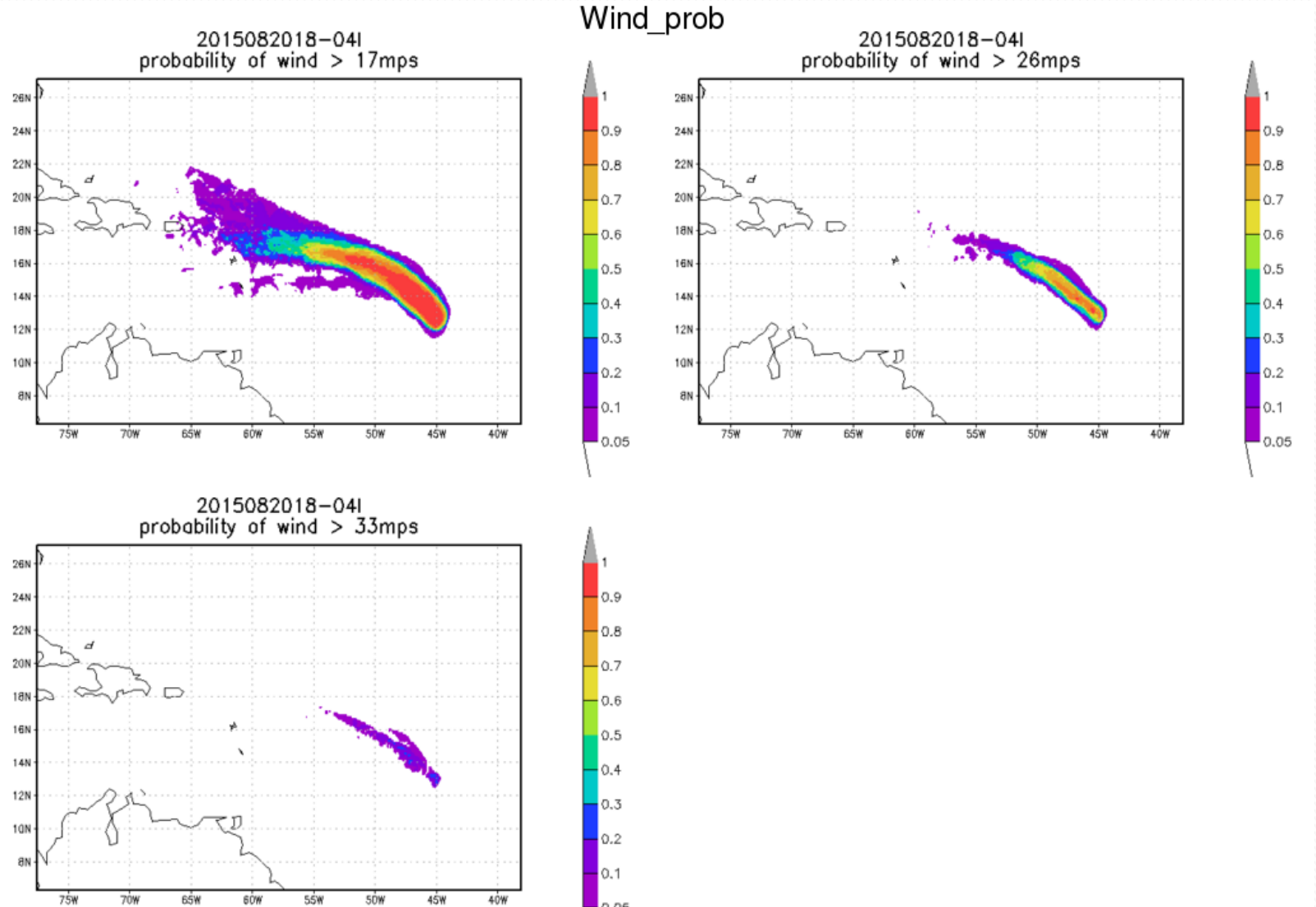


10m Wind Speed and Rain Swath

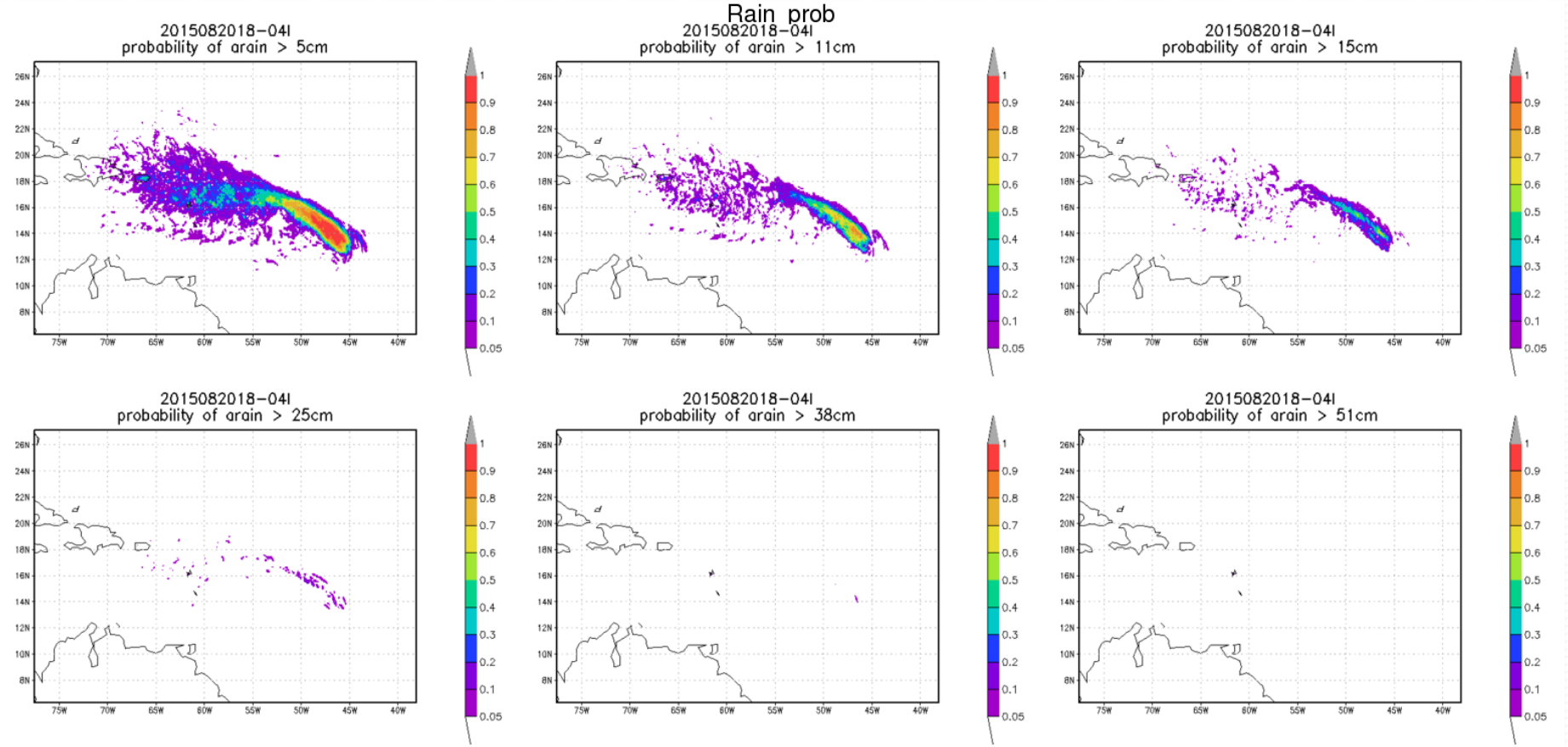




Wind Speed Probability at Various Thresholds



Rainfall Probability at various thresholds



Wind Speed > 17m/s (color) and 10m Wind Speed uncertainty (Bright white)