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;
- Conclusion and Future Work.

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 ?

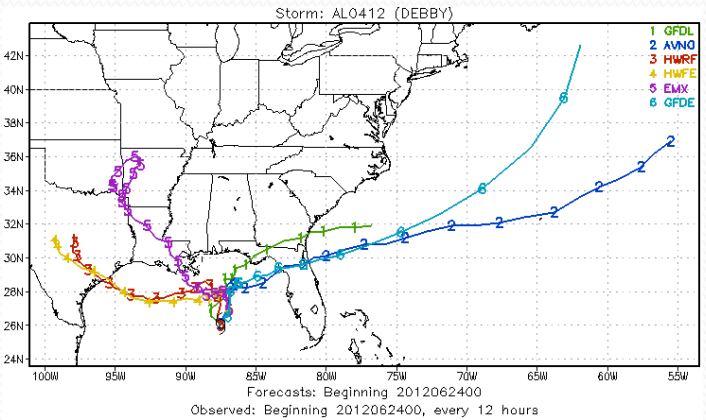
- *IC/BC uncertainties*: observational errors, poor data coverage, and errors in DA system;
- *Model uncertainties:* mis-representation of model dynamics/physics, impact of sub-grid scale features.

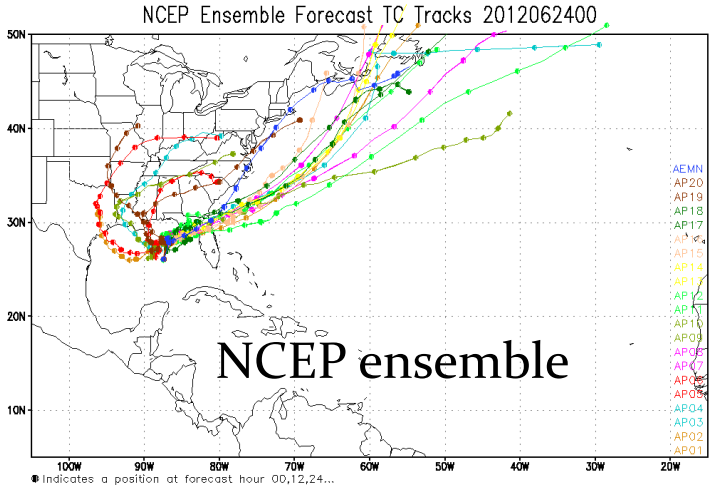
These uncertainties are inevitable. In a chaotic system like an atmospheric model, non linear errors will grow - sometimes rapidly. Eventually these growing errors cause the model forecast output to eventually become useless.

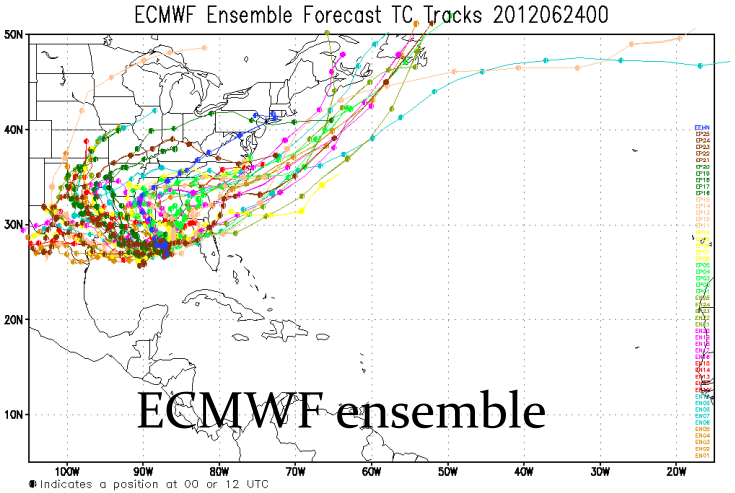
Track Prediction for Hurricane Debby, 20120624 00Z

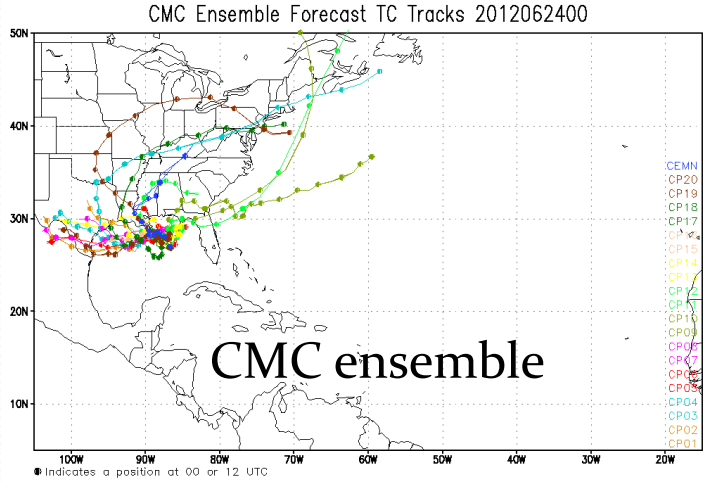
Large differences in predicted storm tracks due to:
1. multi-model dynamics;
2. multi-physics;
3. multi-initial analysis.

Multi-model





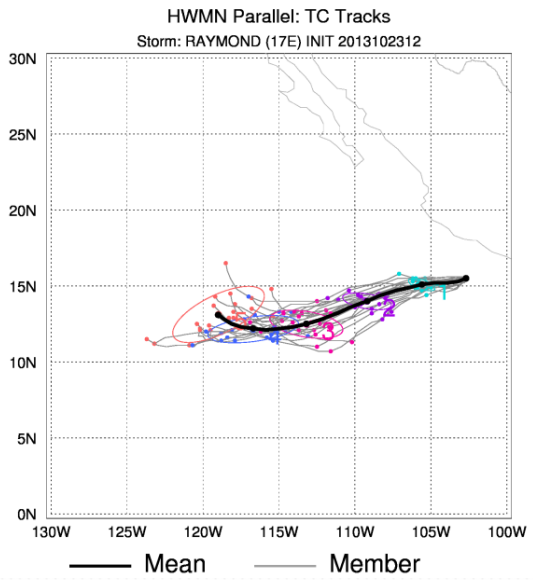


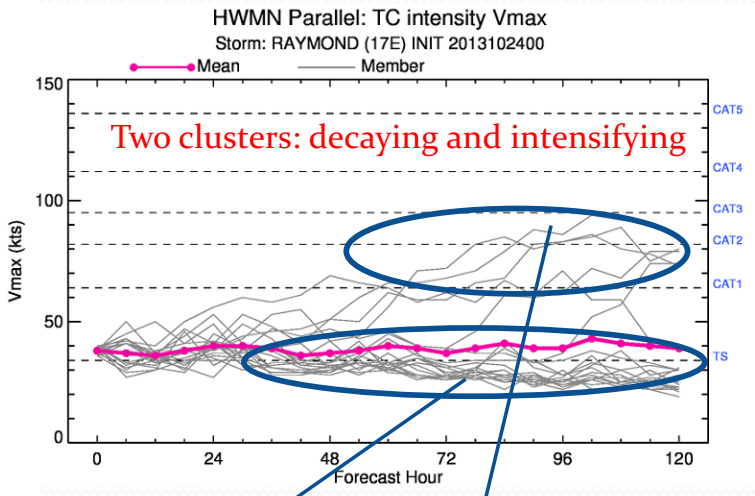


Prediction for Hurricane Raymond, 20131024 00Z

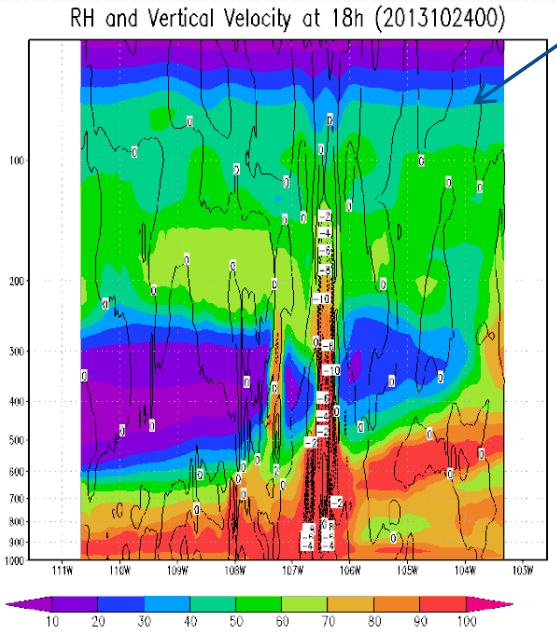
Large differences in predicted storm intensity due to sub-grid uncertainties in model physics: stochastically perturbed cumulus convection scheme in HWRF

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

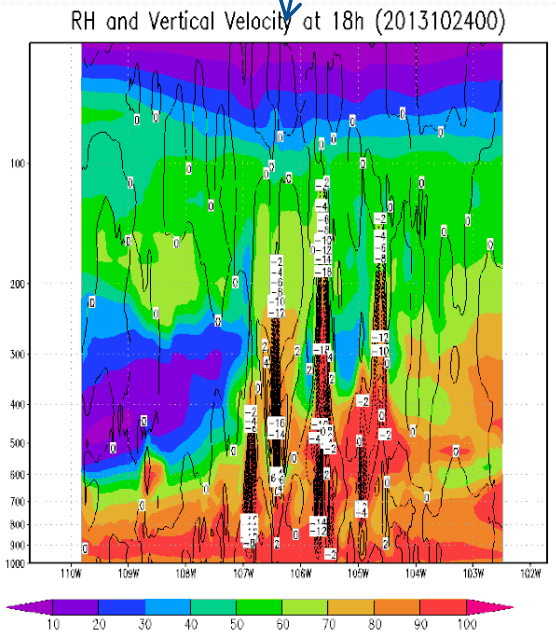




HW06



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:

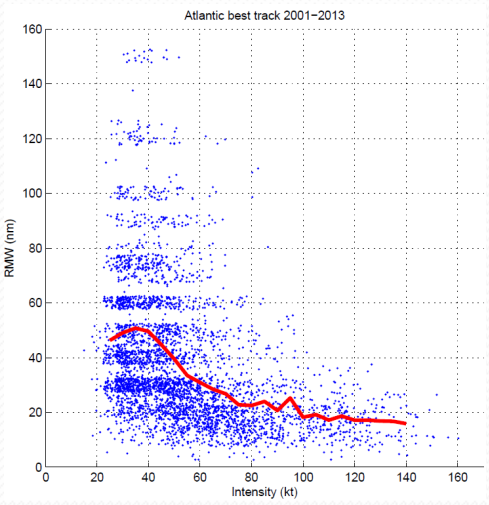
1. Uncertainties in initial storm position, intensity, and structure;
2. Uncertainties in large scale flows (ICs/BCs);
3. Multi-scale interactions among sub-grid scales, (~0-100m), convective clouds (~100-1000m), and the large-scale environment (~100-1000km)

2017 HWRF Ensemble Configuration

- Use 2017 operational deterministic HWRF model except for
  - Less horizontal resolution: 27/9/3km vs. 18/6/2km
  - Less vertical resolution: L43 vs. L75;
  - No GSI due to lack of GDAS data

- IC/BC Perturbations (large scale): 20 member GEFS.

- Model Physics Perturbations (vortex scale):
  - Stochastic Convective Trigger Perturbations 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;
  - Bug fixes to better represent the model physics uncertainties



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.

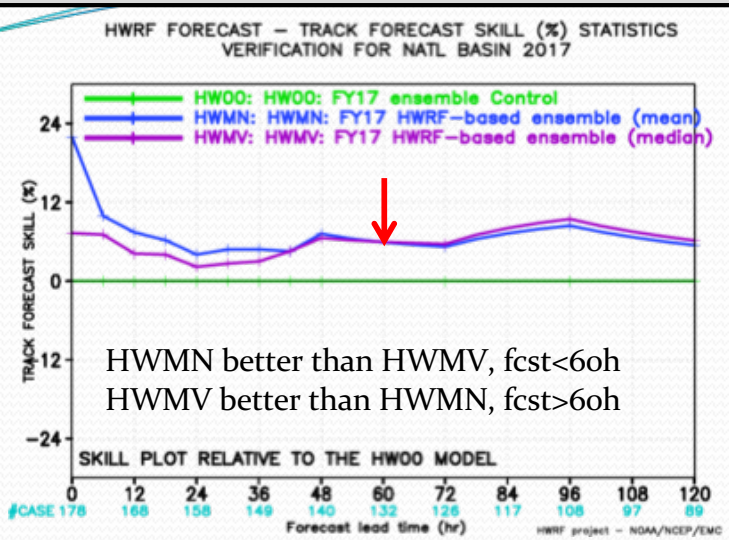
Methods Representing Ensemble Track/Intensity Forecasts

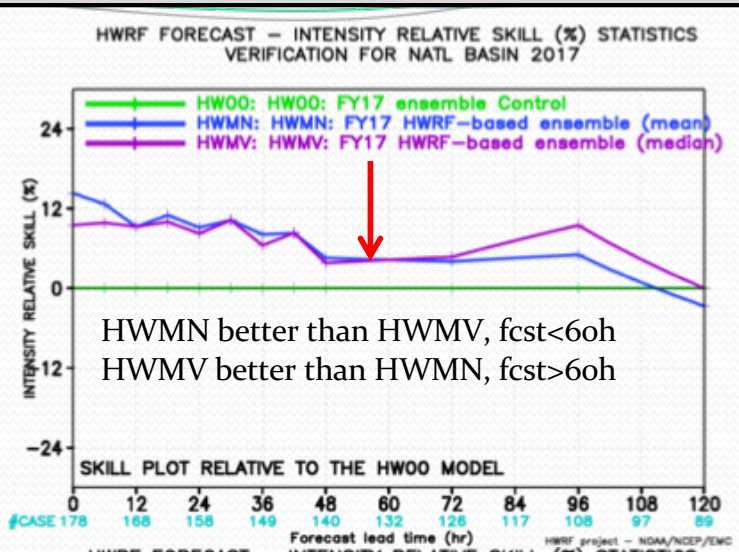
- Average over all ensemble members
- Select median Member in all ensemble members
- Combined the above two methods

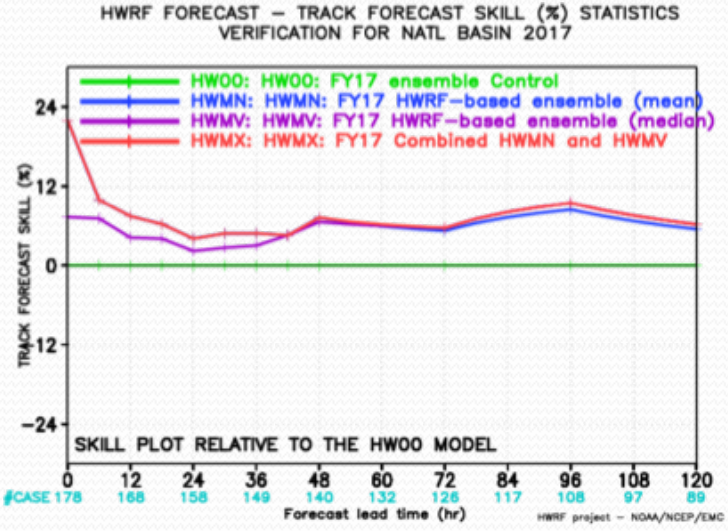
Control Experiments (Deterministic model)

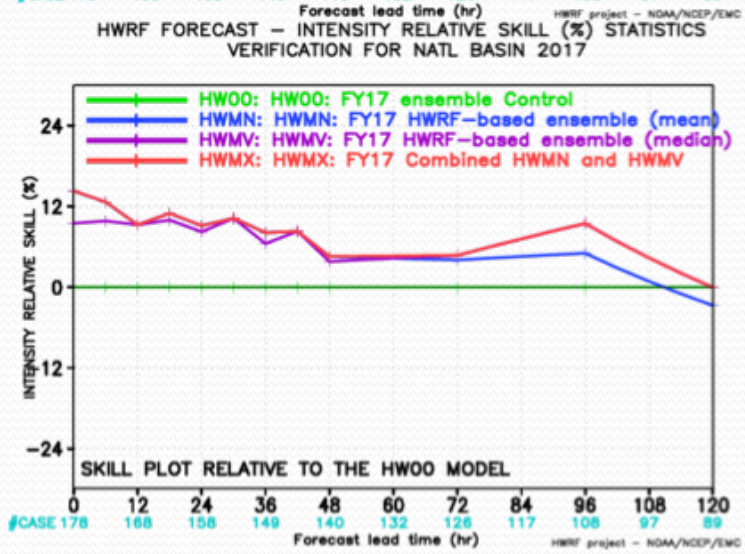
- HW00: Control run for HWRF-EPS, (un-perturbed)
- H217: FY17 operational HWRF at NCEP/EMC

Arithmetic ensemble mean vs. Median ensemble member



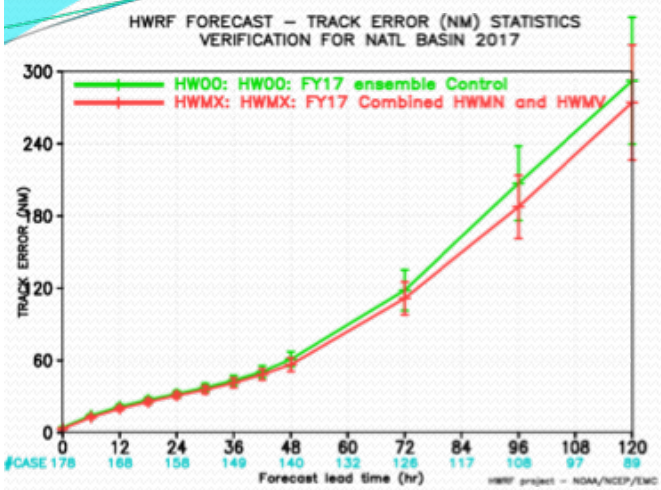


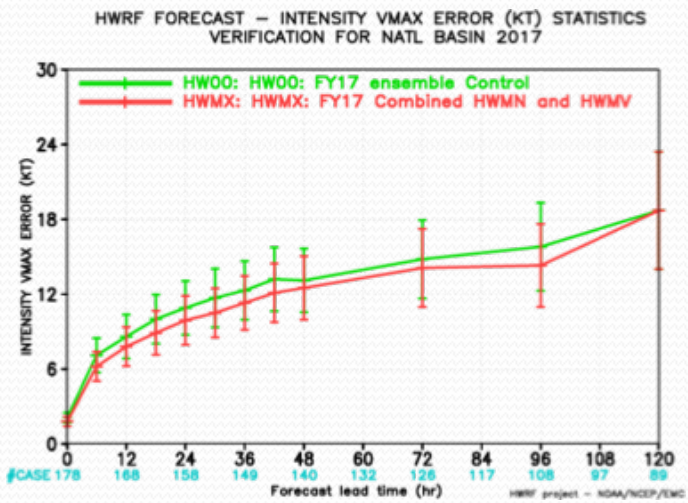


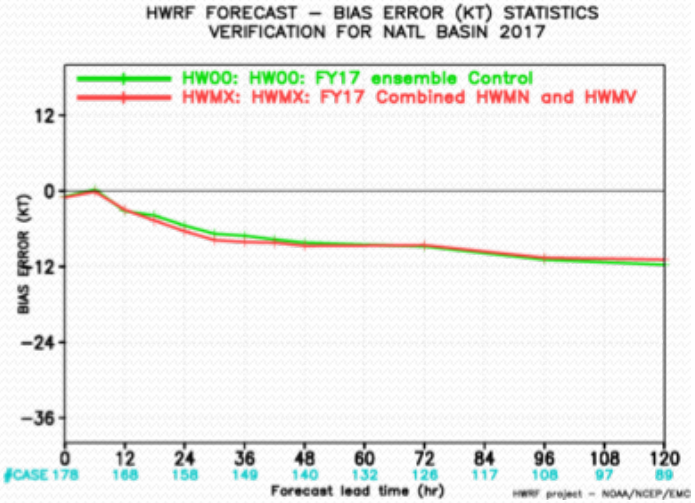


1. Arithmetic ensemble average method has higher forecast skills than median ensemble member before forecast hour 60;
2. Median ensemble member has higher forecast skills than arithmetic ensemble mean after forecast hour 60;
3. Combined HWMN and HWMV provides the improved forecast track/intensity forecast skills, ~4% additional improvements

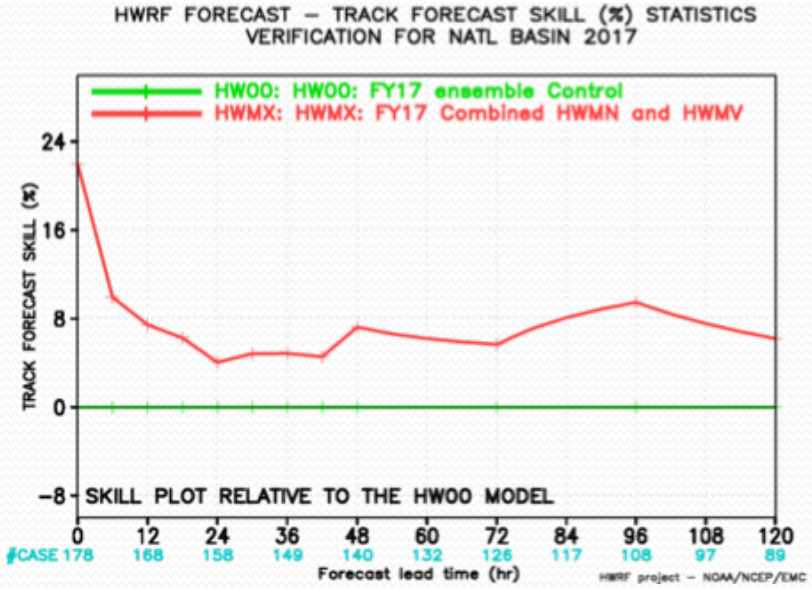
Verification: HWRF-EPS vs Deterministic HWRF
2017 Atlantic Storms

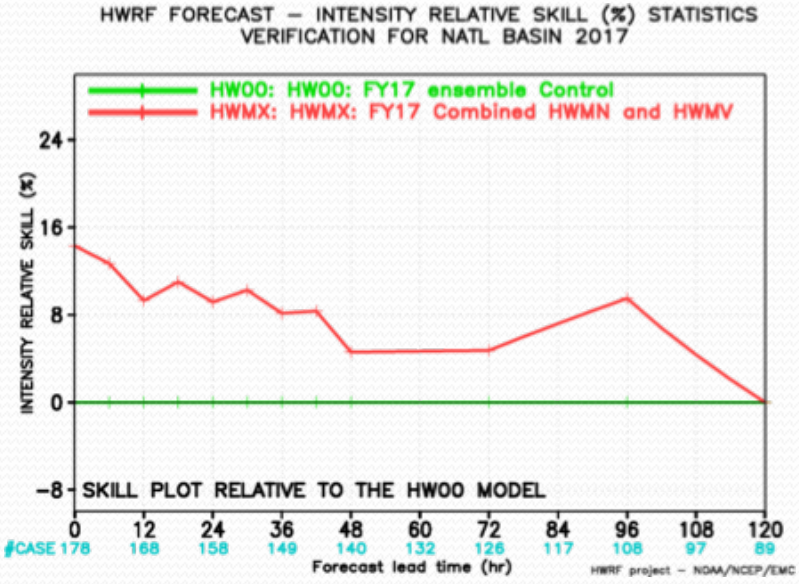






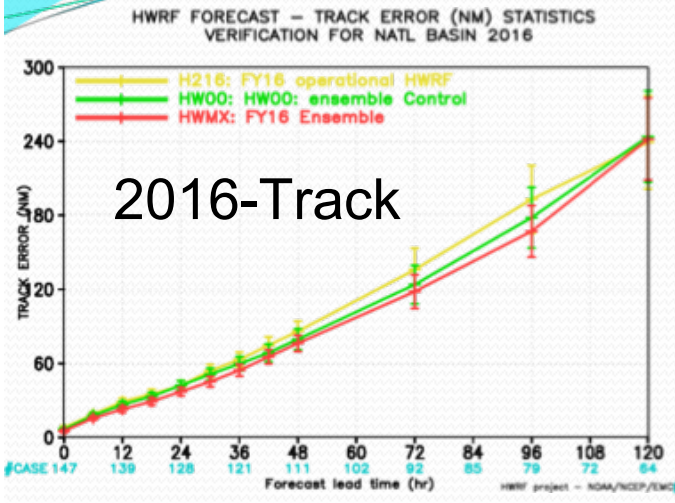
HWRF-EPS provides about 8% track and intensity forecast skill improvements in average over its deterministic system (HWoo)

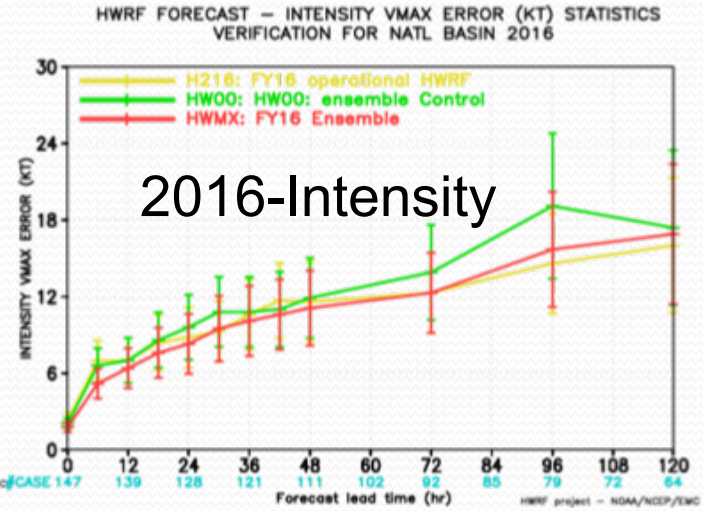


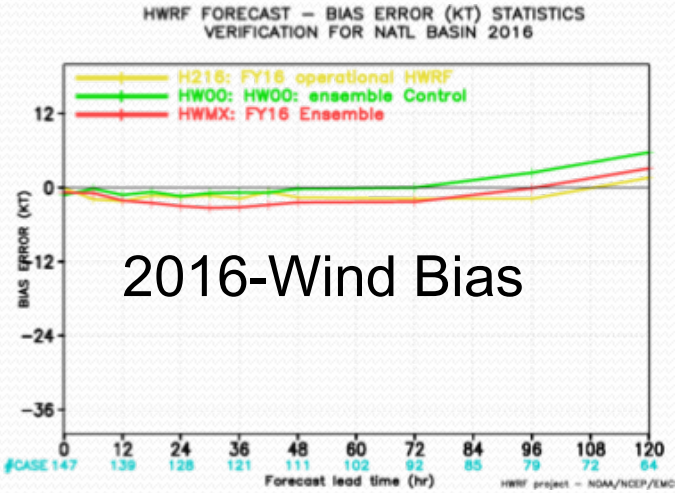


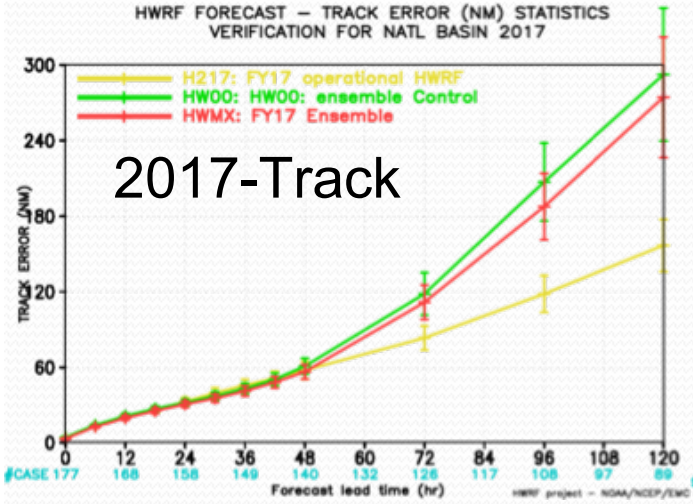
Verification: HWRF-EPS vs Operational HWRF

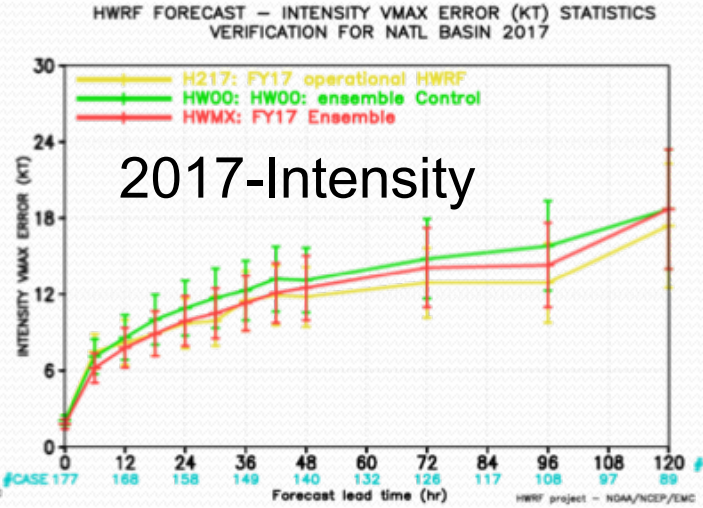
2017 Atlantic storms

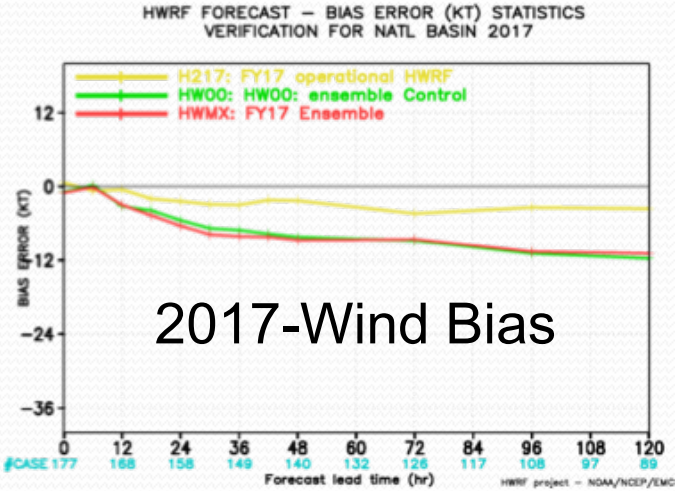






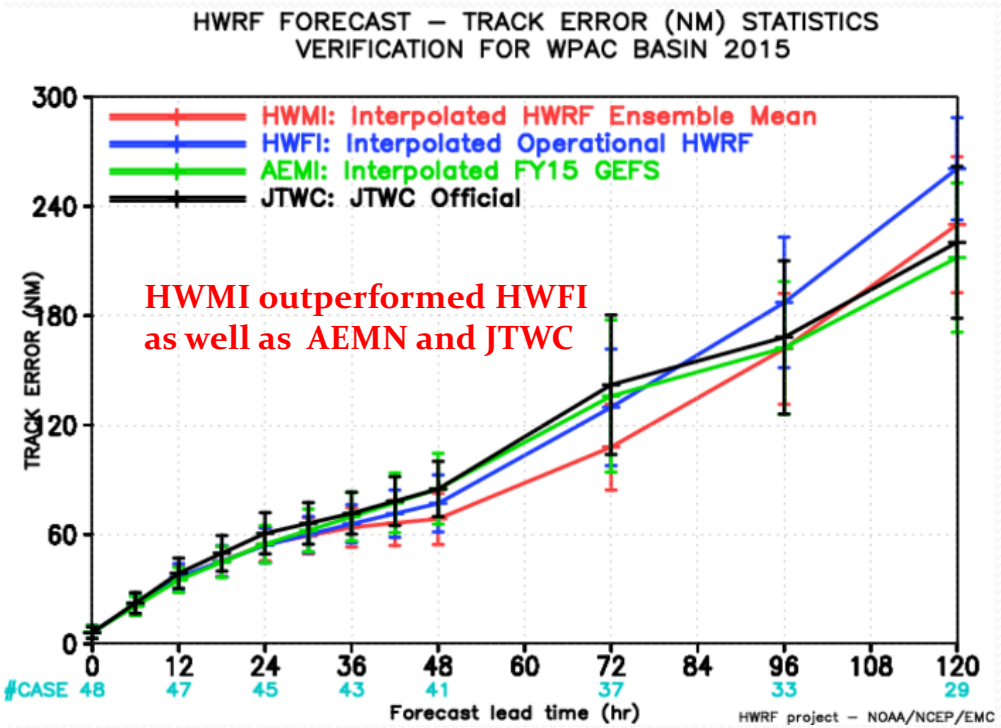


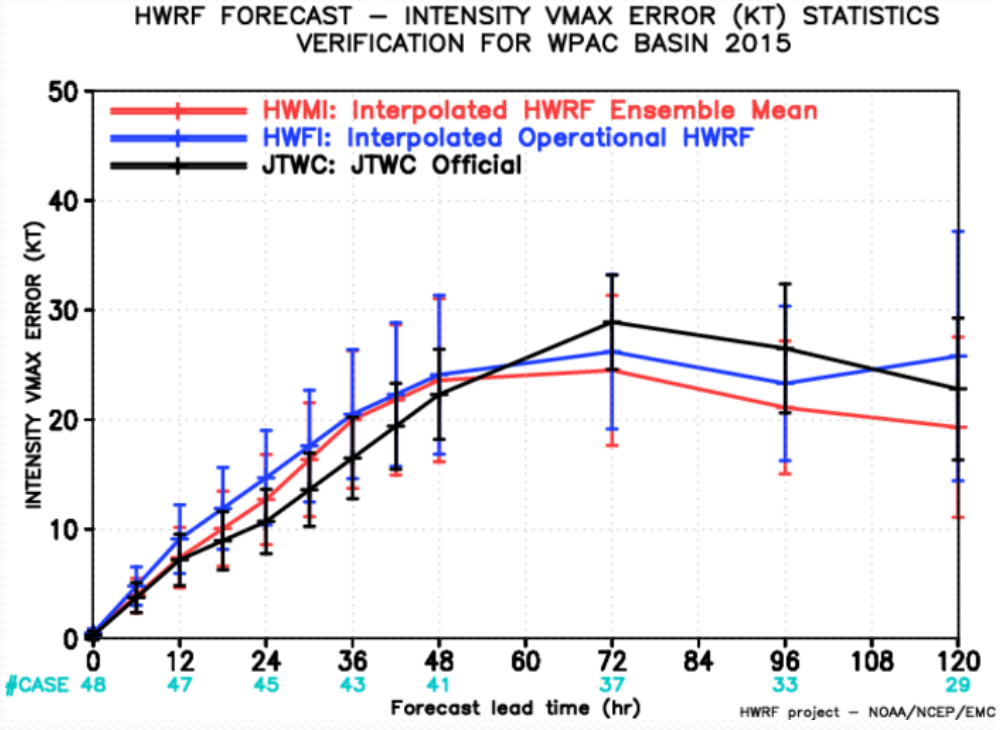




1. In the past years, HWRF EPS (Lores.)outperformed the deterministic operational model (Hires.), but this year, the results reversed;
2. As always, HWRF EPS produces better ensemble mean track/intensity forecasts than its own deterministic system;

Verification for 2015 WPAC Storms



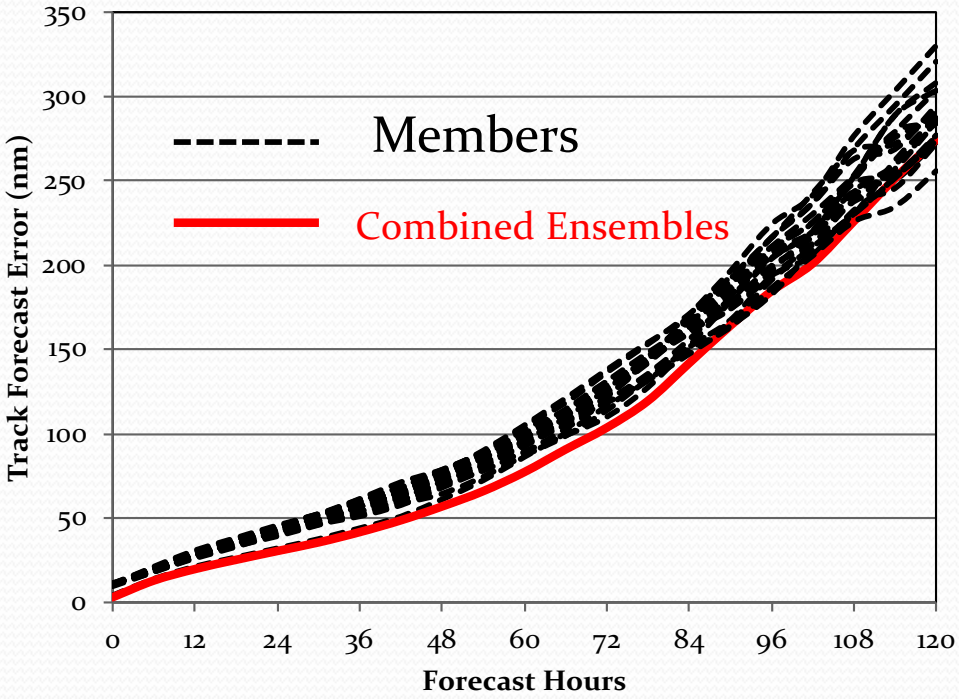


HWMI outperformed HWFI both JTWC after day 2

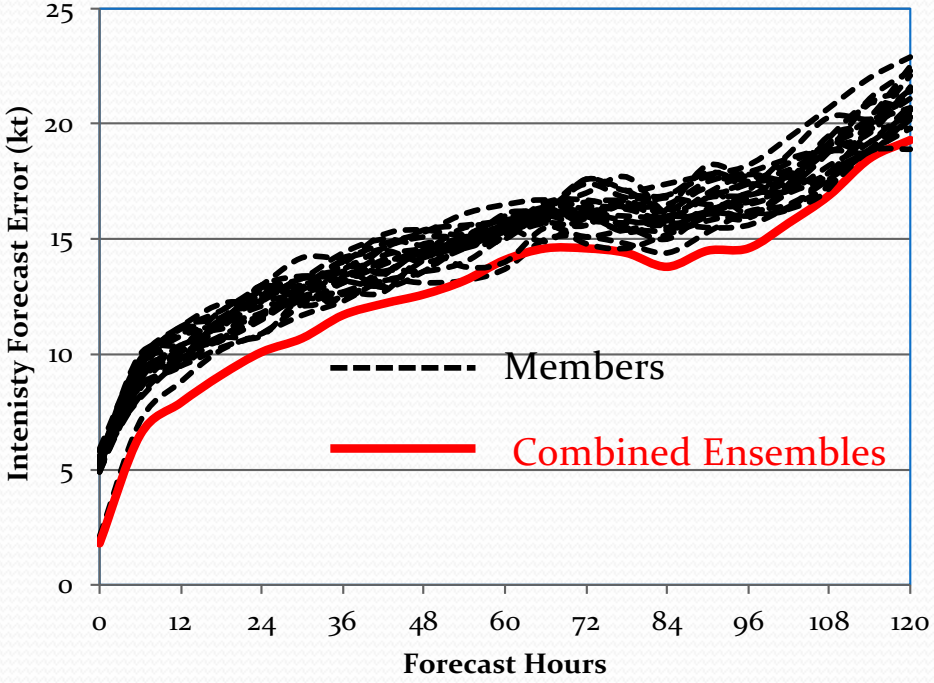
Verification Comparison

Individual ensemble members vs. Combined Ensembles

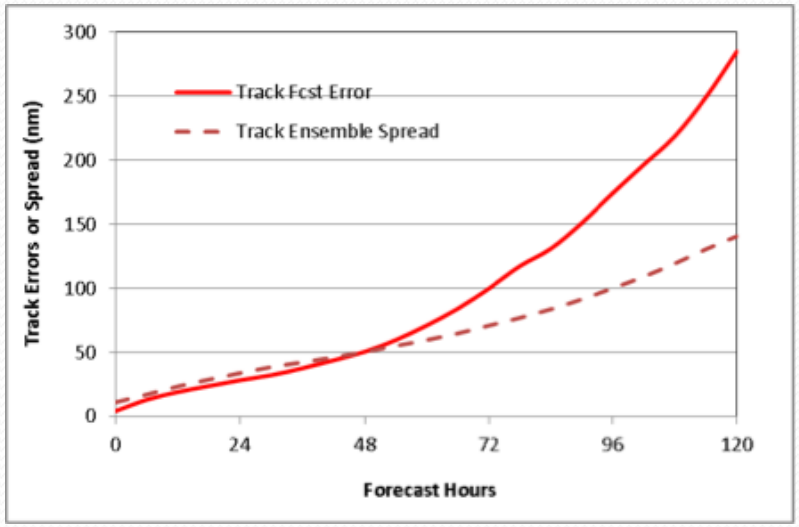
Track

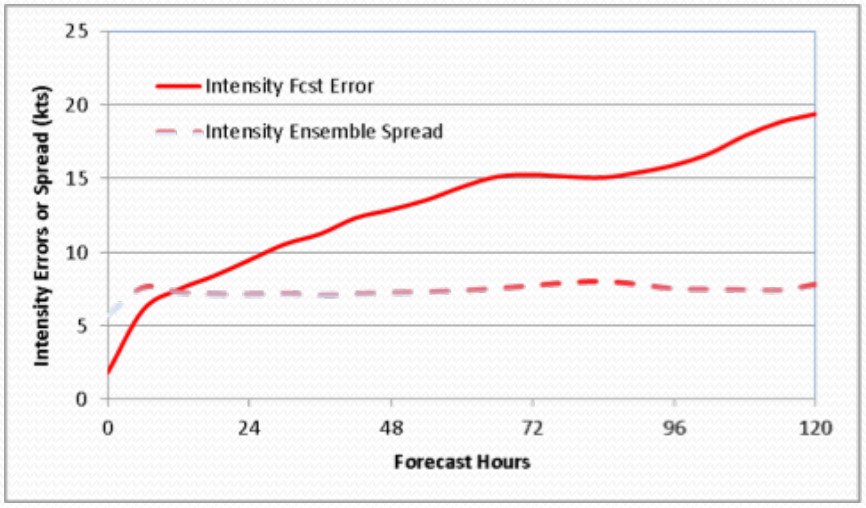


Intensity

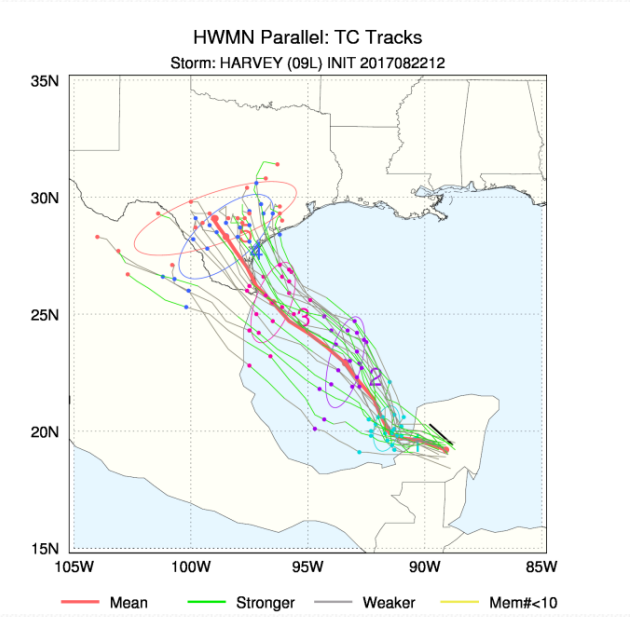


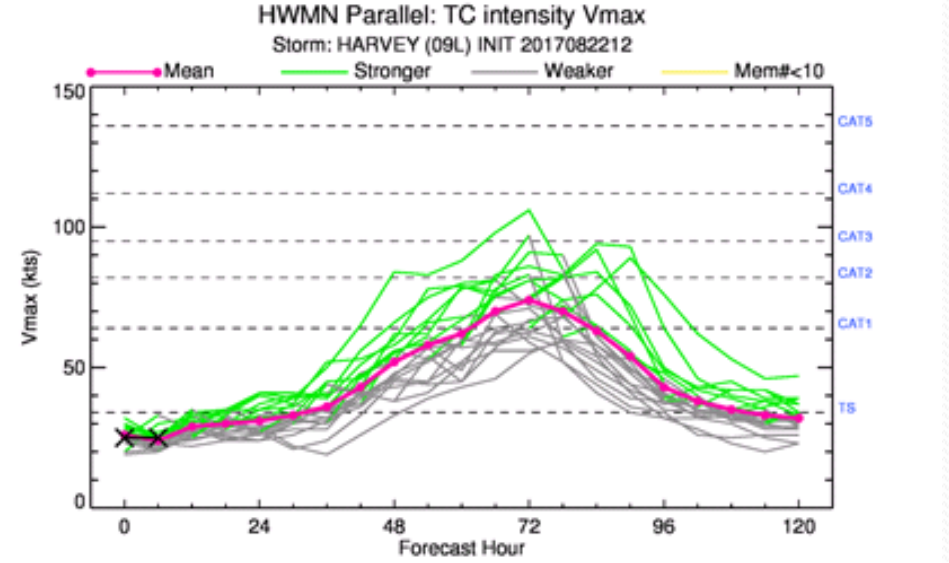
HWRF-EPS Ensemble Spread





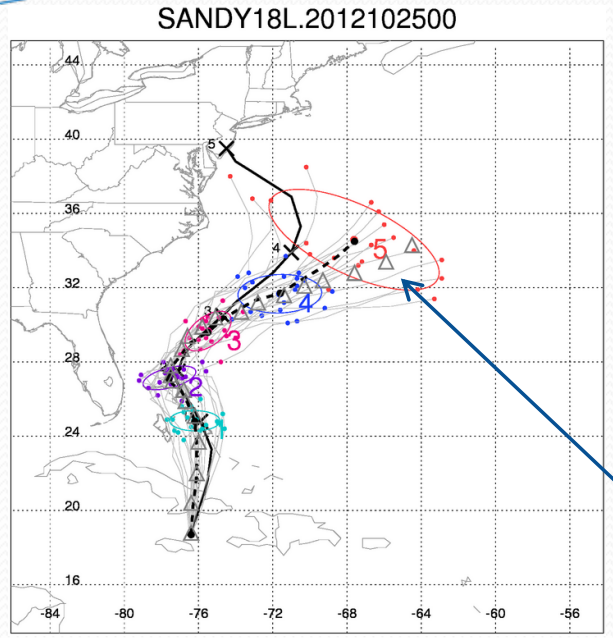
HWRF-EPS is under-dispersed in average.



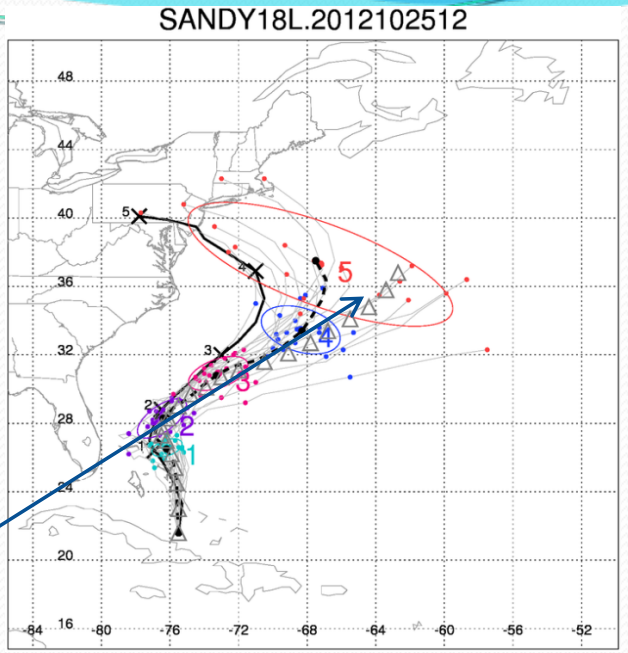


Track Probability Forecasts for Hurricane Sandy

Few members turned west

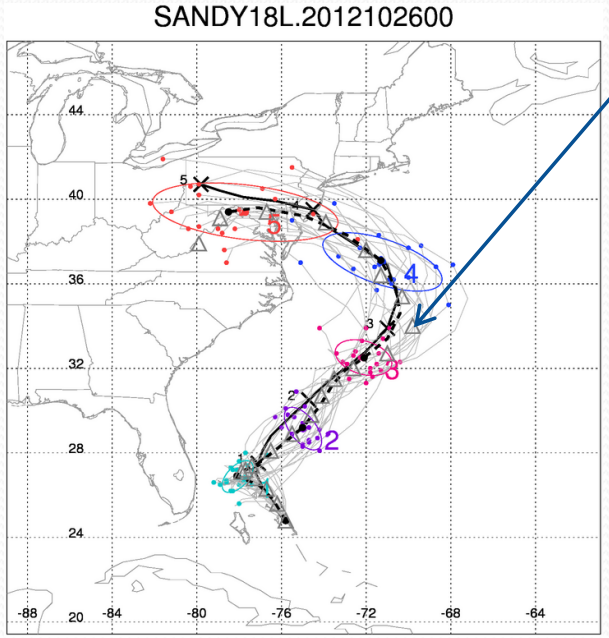


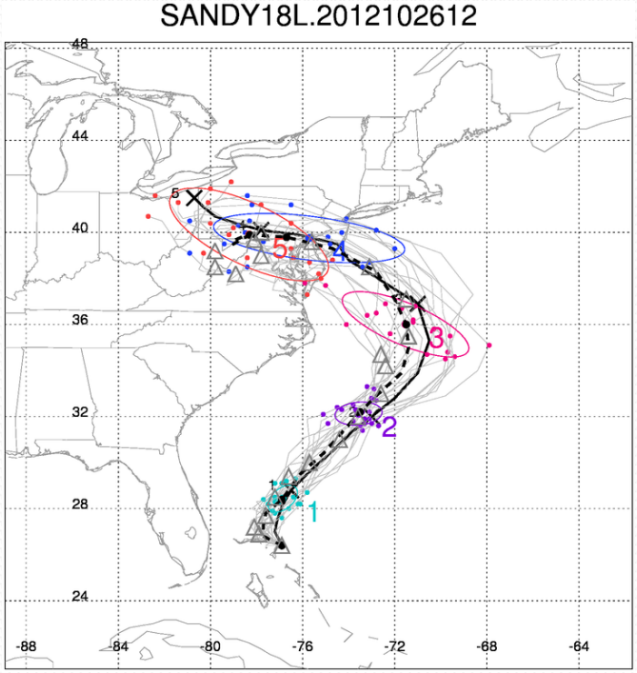
More members turned west



FY13

All members turned west





How to run HWRF based EPS

parm/hwrf_ensemble.conf

```
[config]
run_gsi=no                ; Turn off GSI
gfsinit_type=1        ; 1=grib2, 2=nemsio, 3=spectral, 4=highres grib2
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.py -f 00 01-20 2017 11L HISTORY

---- use 20 GEFS output as IC/BC
---- no GSI
---- Stochastic physics perturbations not supported in this release

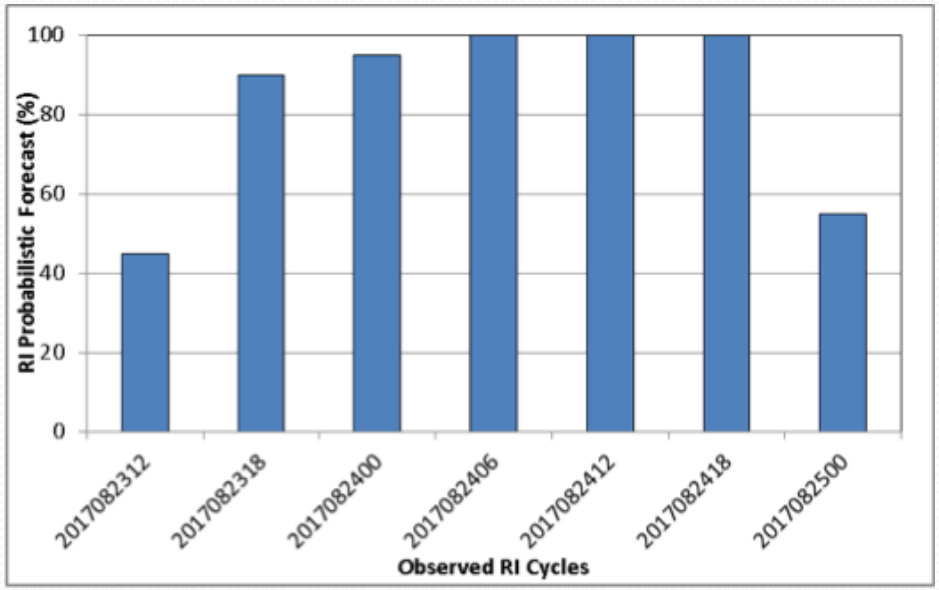
Probabilistic Forecast Products of HWRF based EPS

HWRF-EPS Rapid-Intensification Prediction

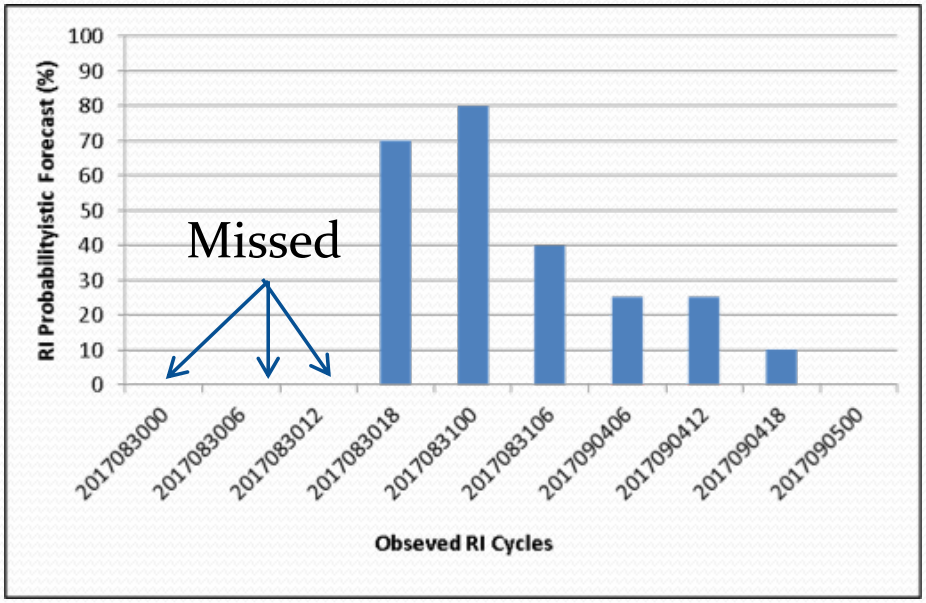
P=RI/ALL

RI: number of ensemble members that predicted storm Rapid Intensification;
All: Total number of ensemble members

Harvey 09L

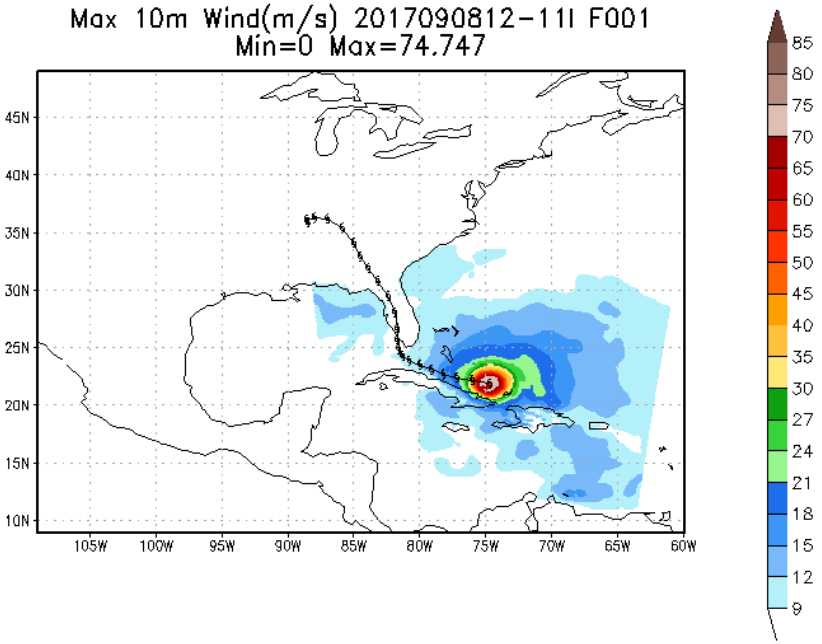


Irma 11L

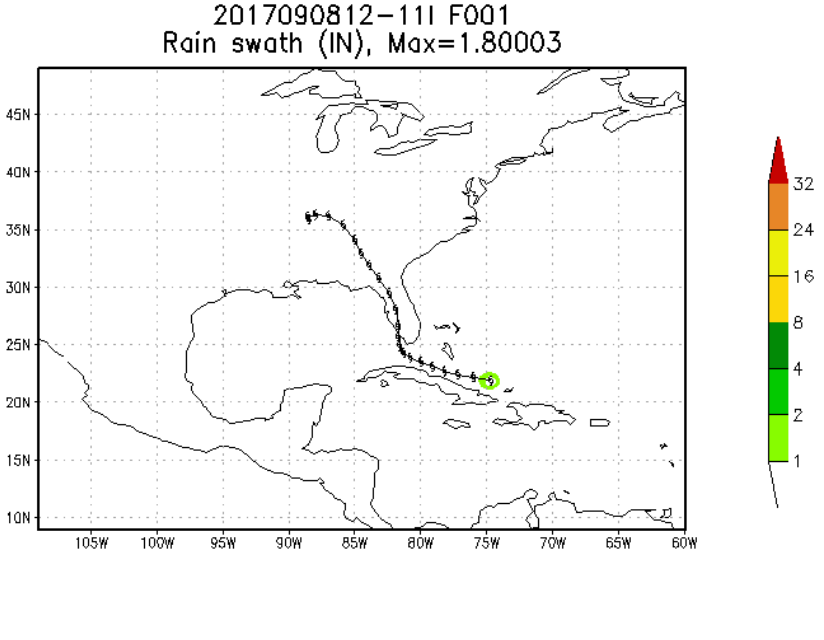


HWRF-EPS Probabilistic Prediction

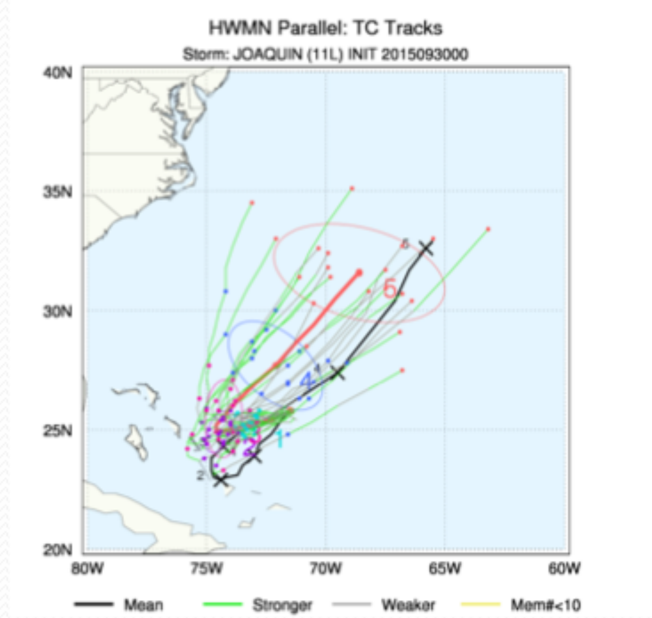
Wind Speed at 10m

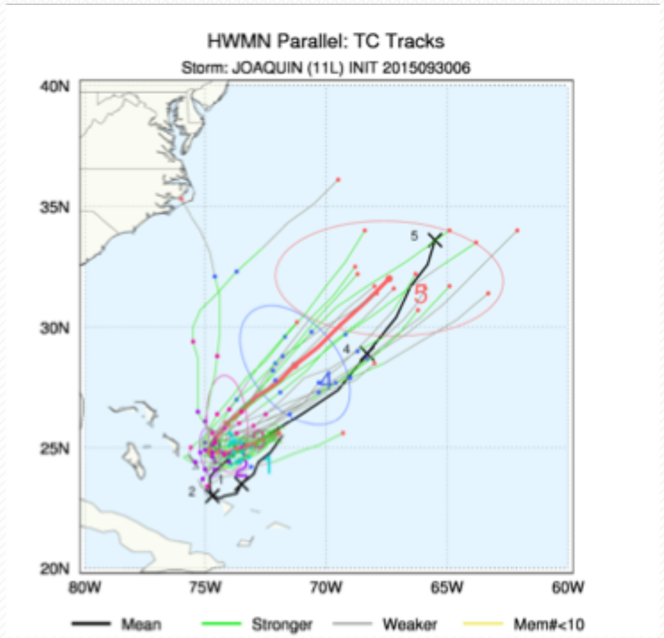


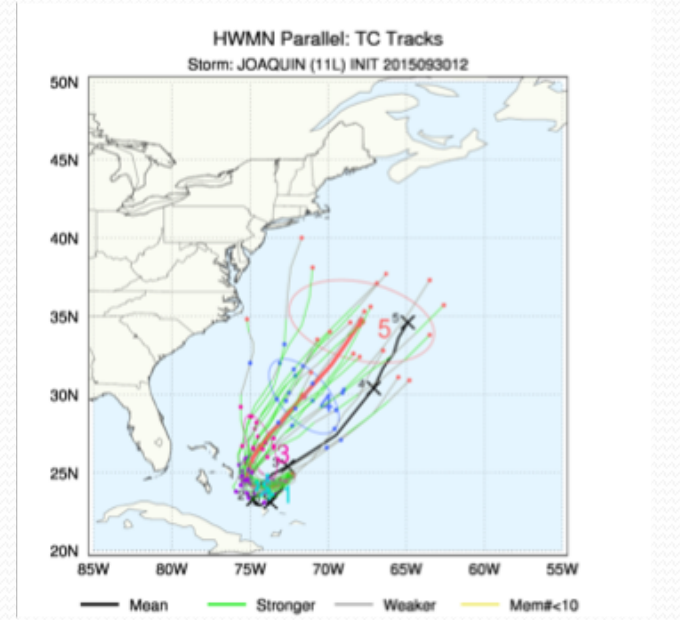
Rainfall Swath

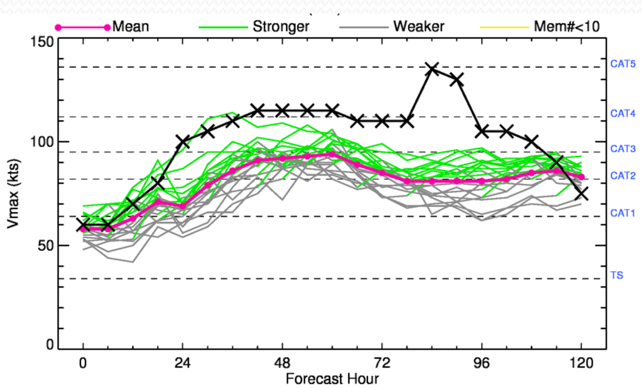


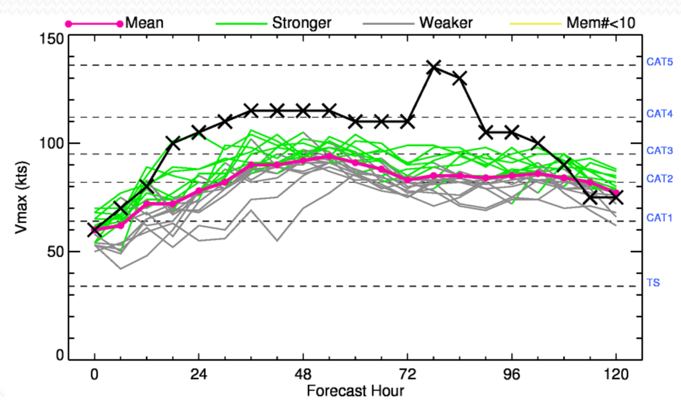
Sample HWRF-EPS Forecast
Joaquin 11L, 20150930

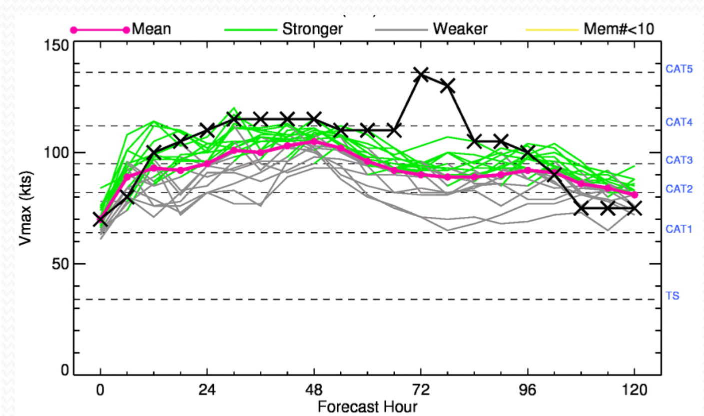










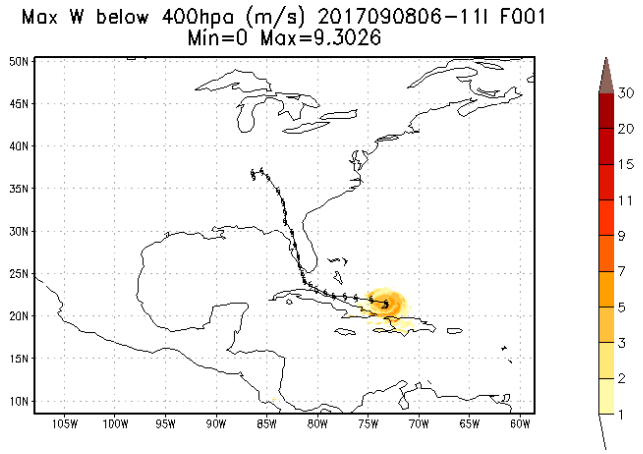


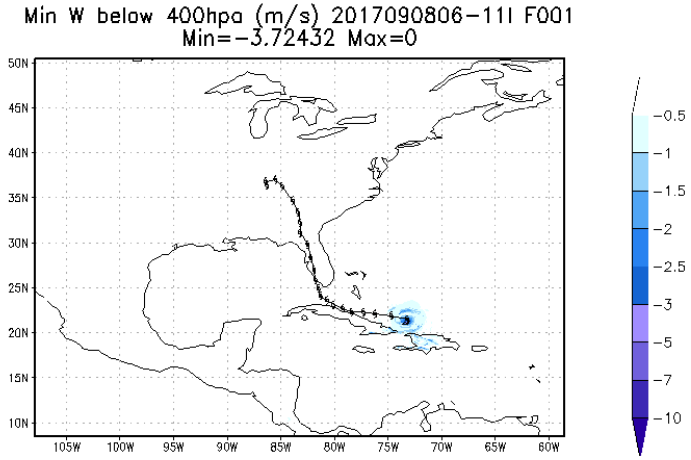
00Z

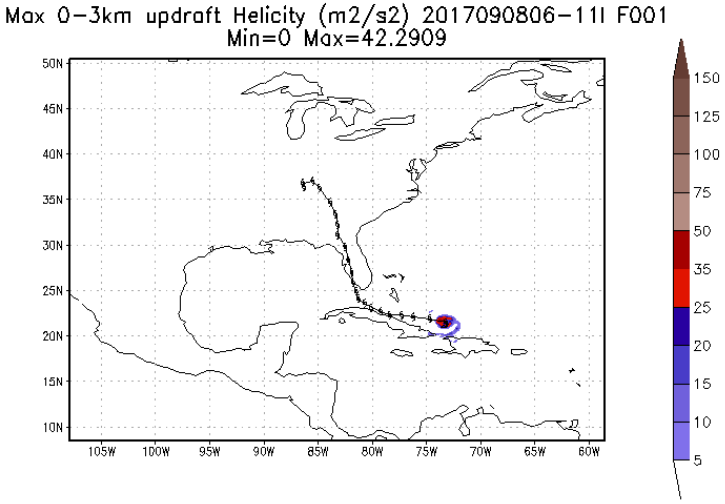
06Z

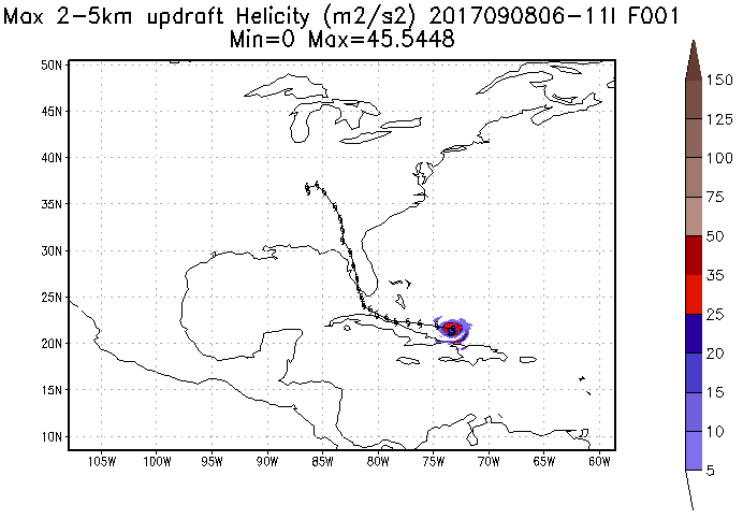
12Z

High frequency output of Max/Min Wind Speed and Updraft Helicity

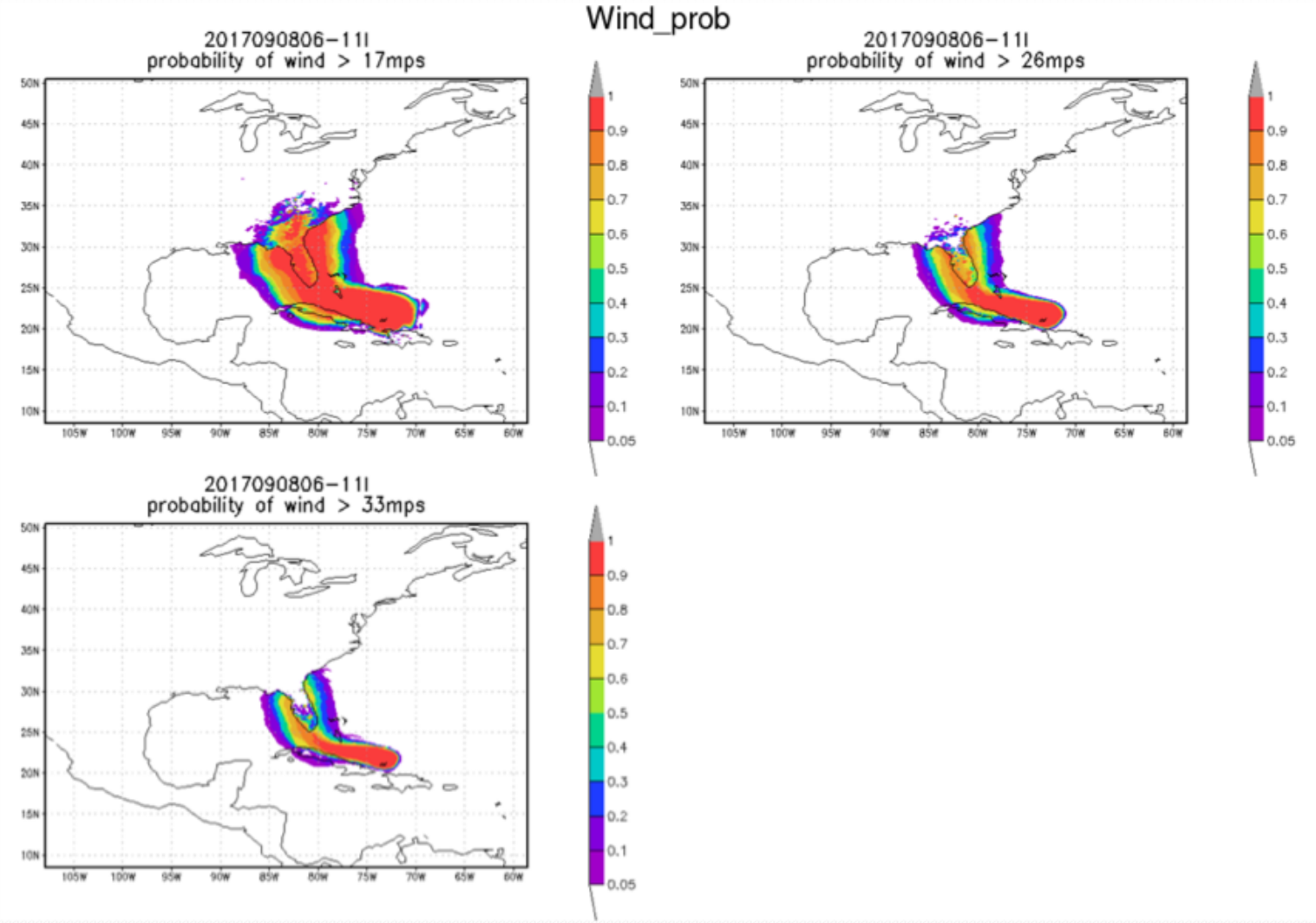




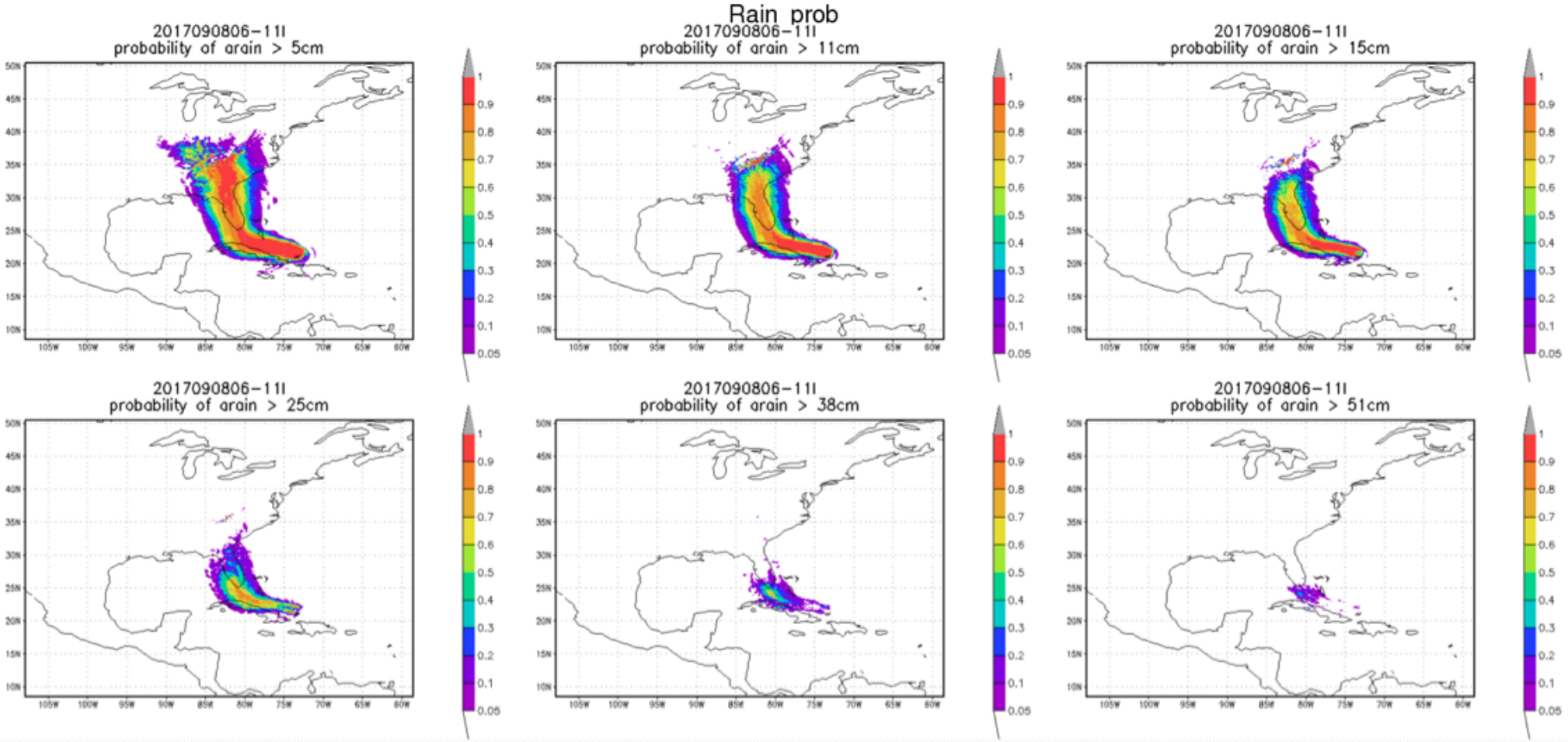




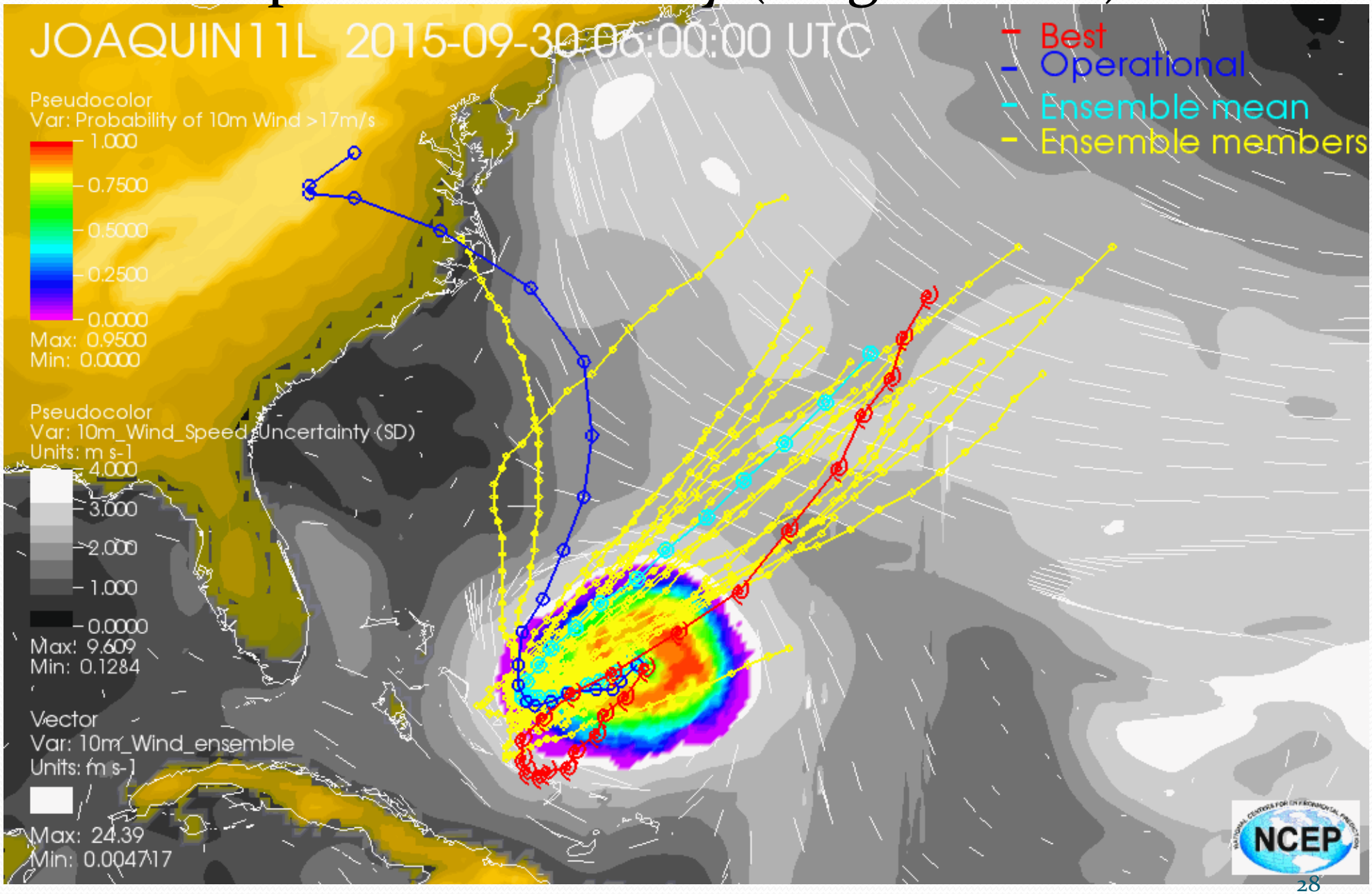
Wind Speed Probability at Various Thresholds



Rainfall Probability at various thresholds



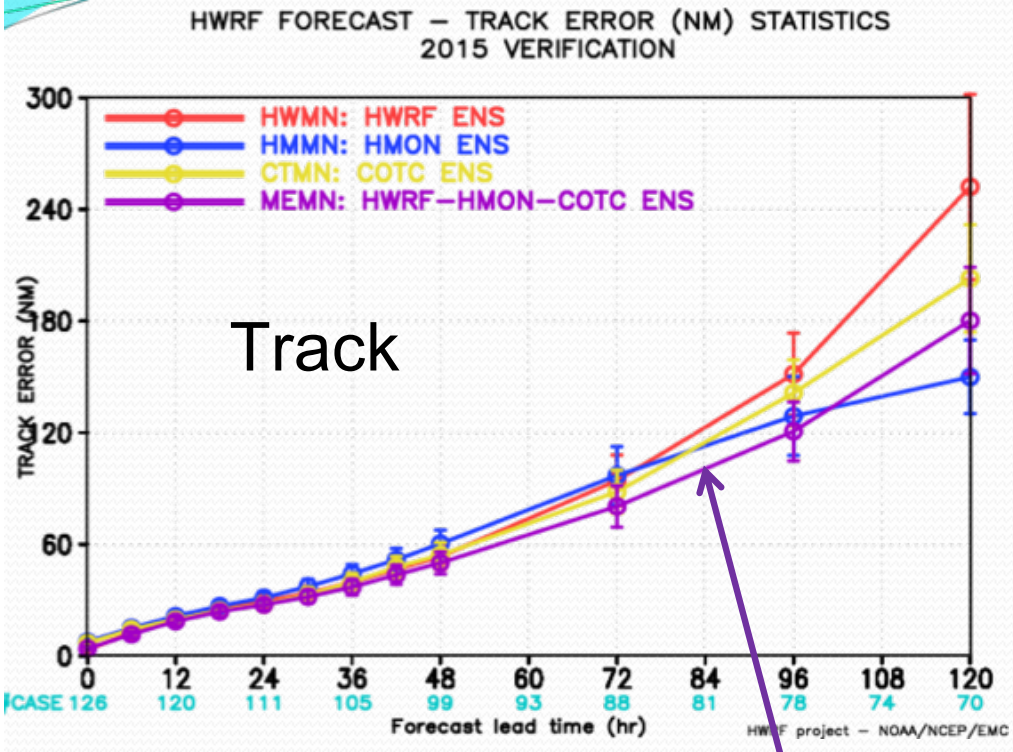
Wind Speed > 17m/s (color) and 10m Wind Speed uncertainty (Bright white)

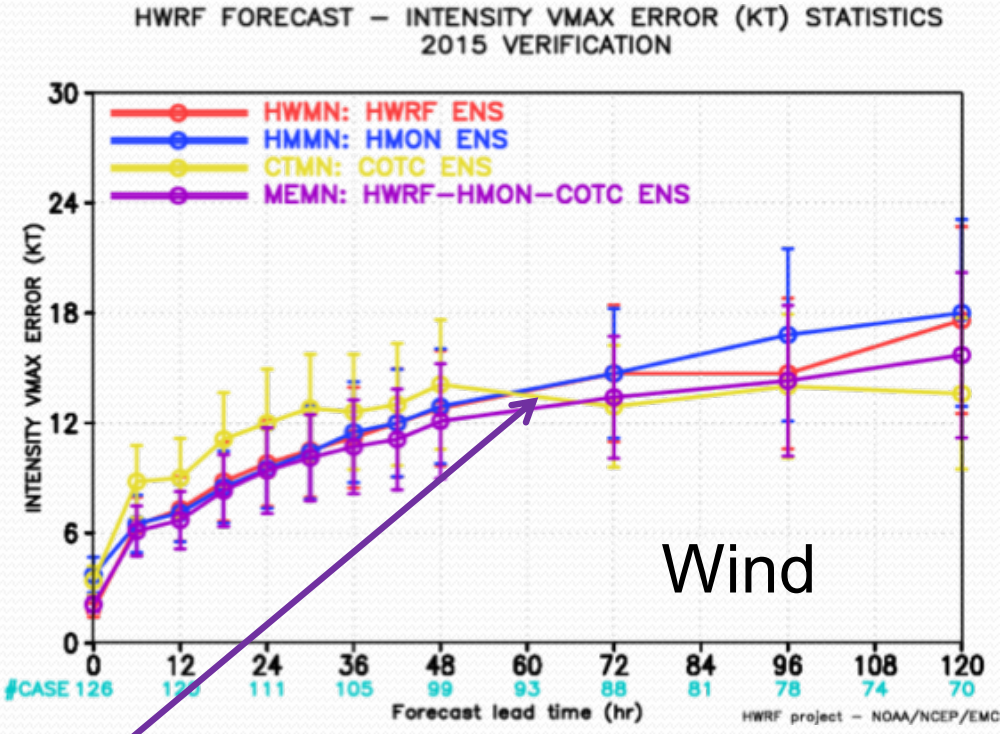


Combined Multi-Model EPS

- 20-member 3km HWRF ensembles driven by GEFS for IC/BC and stochastic convective and PBL perturbations
- 10-member 4km COAMPS-TC ensembles driven by IC/BC perturbations based on GFS analysis & tcvitals
- 10-member 3km HMON ensembles using various physics packages
- High-resolution probabilistic products provide forecast uncertainty in track, intensity, structure (size) and rainfall, along with ensemble mean products

Multi-Model EPS (HWMN+HMON+CTMN)





Combined Multi-Model Ensemble

Future Development for HWRF based Ensemble Prediction System

- Use higher resolution model (same as deterministic model);
- Include Data assimilation in Ensembles;
- Improve representation of HWRF model error and initial uncertainties, hence improve ensemble spread
- Develop more post-processed deterministic products
- Develop more probabilistic products, visualization of model variable uncertainty fields
- Continue HWRF EPS and Multi-model EPS real time demo
- Run 10 member HWRF-based EPS operationally in 2019

Real time HWRF-EPS website, 2015-2017:
http://www.emc.ncep.noaa.gov/HWRF/HWRFEPS/index.php